infrastructure for a connected world

Cabling Infrastructure for HDBaseT Applications

WHITE PAPER

The Growth of AV and its Involvement with Structured Cabling

Before HDBaseT™, AV professionals were challenged to find a cost-effective way to deliver quality video content over a longer distance, for a reasonable price. To deliver to the market, there were tradeoffs on quality, distance, cost, and complexity of a project. When the HDBaseT protocol was introduced to the market in 2010, it introduced the delivery of quality AV signals over a long distance, over a single category cable.

As a result, HDBaseT technologies have taken hold in the AV market, gaining popularity among AV professionals in several market segments. Used in nearly 70% of all commercial installations, HDBaseT has become the standard for video extension. Its effectiveness in delivering a standards-based approach for interoperability, its performance in delivering high quality resolutions over 100-meter distances, and its ability to drive signal convergence (HDBaseT 5-play) have made it a great asset to the AV market.

Today, the challenges AV professionals face are the same challenges they have faced before: higher quality content over long distances, while still seeking reasonable prices.

The Growth of AV and its Involvement with Structured Cabling (continued)

To keep up with customer demand, the HDBaseT™ Alliance is working with Valens, the developers of HDBaseT technology for the AV market, to develop new chipsets designed for the next generation of video distribution. These not-so-far-in-the-future chipsets will be able to send fully uncompressed 4K 60Hz 4:4:4 video content over a 100-meter length of Category cable. In addition, these technologies will continue to support USB 2.0, enhanced audio, and 1Gb Ethernet control, while maintaining backwards compatibility. (Source: Valens)

With bandwidth on these signals eclipsing 18Gb, the category cabling infrastructure plays an even more essential part of the overall system. As resolution transitions from 1080p to 4K – and soon to 8K – the technical demands of sending zero latency audio and video packets with low bit error rate and minimal dropped packets mean that a just “good enough” cable installation is not going to cut it. Untwisting cable pairs too much at the jack, using non-compliant products, selecting the wrong category levels for an application – these missteps will manifest as missing pixels, audio not synced to its video, screens that black out periodically, and other issues that will be very apparent to the end user.

The demand for a better understanding of cabling’s involvement in an HDBaseT system is growing across the AV ecosystem: installers need to answer questions about the right cable to pull; consultants want to specify the right cable; and end users need to appropriately plan infrastructure that will last well into the future.

This paper will seek to answer the above questions through comparison of different cable types in both category and construction. The goal is to provide adequate evidence to deliver a recommendation for the appropriate cabling infrastructure for HDBaseT systems of today and the future.

What Makes HDBaseT Different than Ethernet?

Like all systems communicating over twisted pair copper cabling infrastructure, the performance of HDBaseT links is largely determined by the signal-to-noise ratio (SNR) achieved over the bandwidth provided by the communication channel.

The cabling infrastructure impacts both the signal and noise levels seen by the HDBaseT receivers. The insertion loss of the channel directly impacts the received signal power. Internal crosstalk between pairs within the cabling channel significantly influences the received noise power.

In Ethernet applications such as 10GBASE-T, communication takes place bi-directionally over each twisted pair, which requires both Tx and Rx on each twisted pair at each end of the channel. With this arrangement, transmitters can interfere with receivers at each end of the channel. Transmitters at one end of the channel will interfere with receivers at the same end of the channel due to the inherent near end crosstalk (NEXT) and reflected energy (ECHO) that occurs in the cabling channel. Interference with receivers at the opposite end of the channel is due to the inherent far end crosstalk (FEXT) that occurs in the cabling channel. These impairments – NEXT, FEXT, and ECHO – all contribute to the received noise power in traditional bi-directional BASE-T communication. This is illustrated in Figure 1.

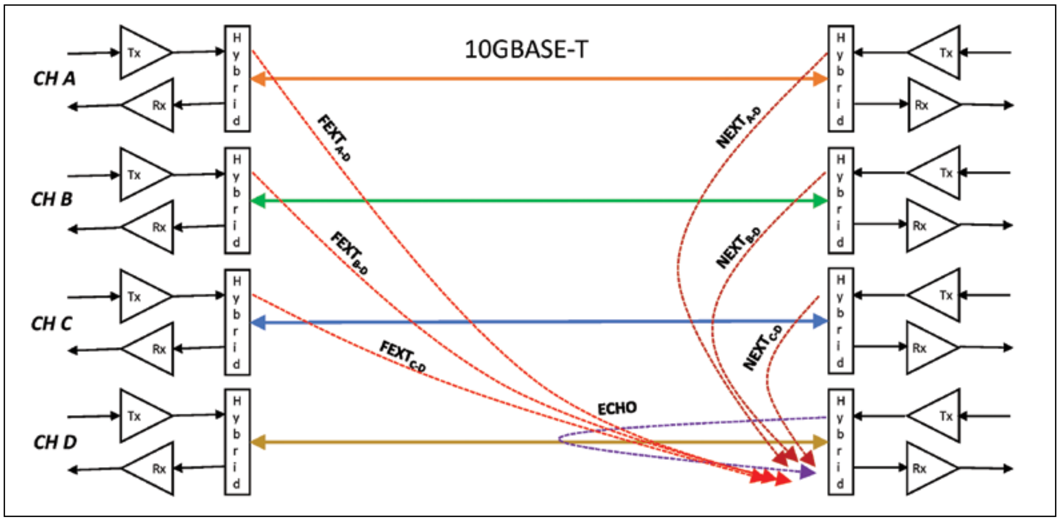

Figure 1: 10GBASE-T Noise Impairments from Cabling Channel

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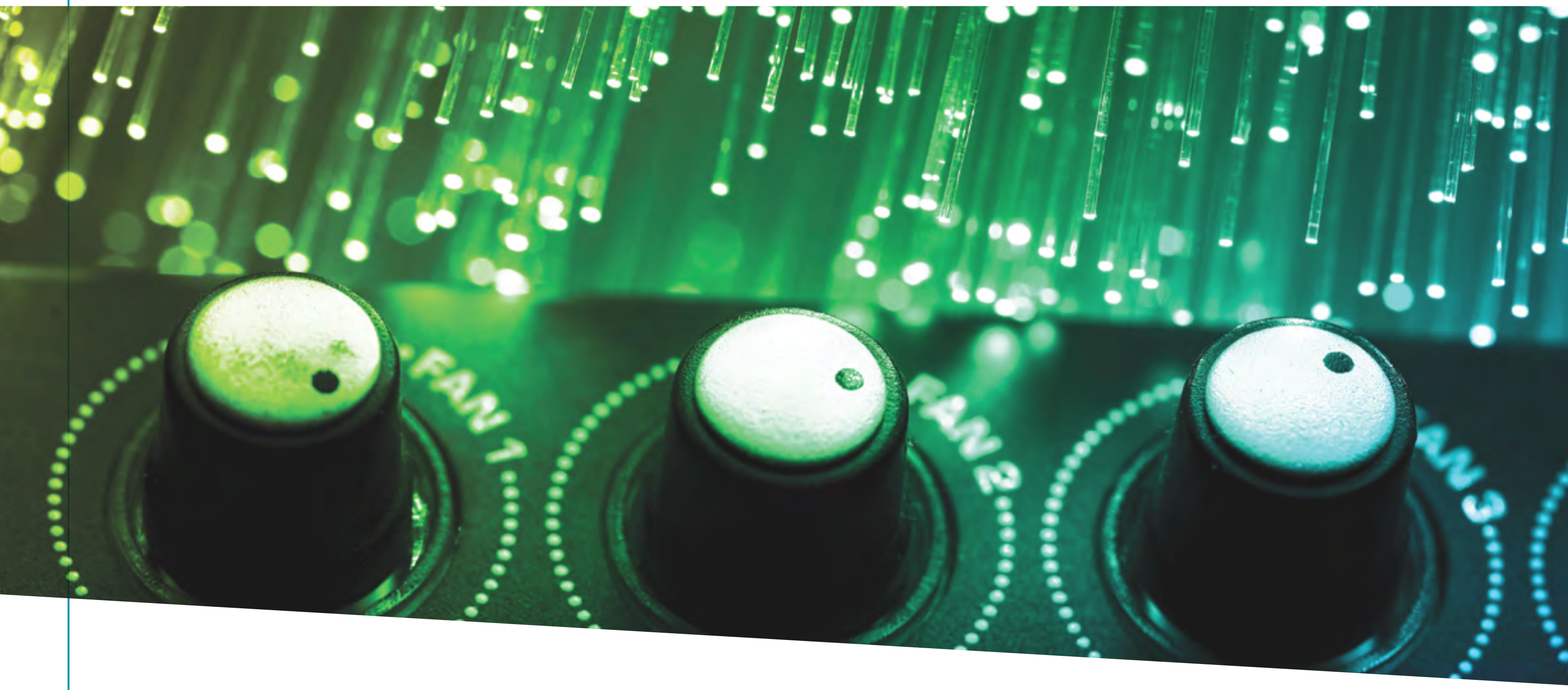


The nature of HDBaseT communication is unique compared to traditional BASE-T applications in that high-speed communication occurs in only one direction from source to display. With this arrangement, artifacts such as NEXT and ECHO have virtually no impact on the high-speed communication and only FEXT will significantly contribute to the received noise power. Figure 2 illustrates the single direction of communication signals in HDBaseT, and how FEXT is the only impact on the received noise power.

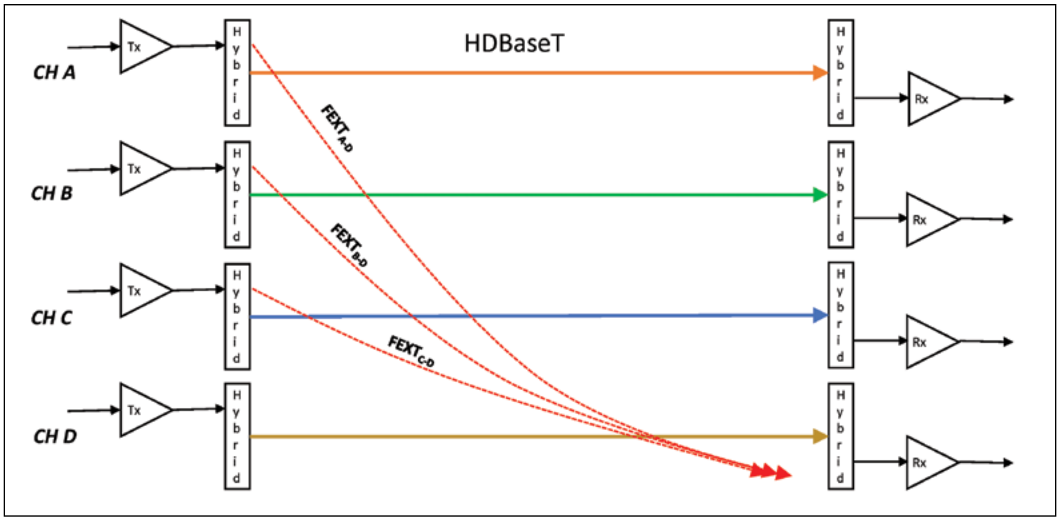


Figure 2: HDBaseT Noise Impairments from Cabling Channel

The SNR seen by HDBaseT receivers will largely be dictated by the insertion loss and FEXT of the cabling channel. These parameters will vary depending on the category, construction, and length of the cabling channel.

Impact of Cable Construction on HDBaseT Performance

Due to the differences in HDBaseT and BASE-T protocols, the cable type that installers choose for their data and communications network might not perform the best for HDBaseT applications. Engineers in Panduit's Enterprise Applied Research Lab (EARL) set out to test many different cable constructions and cable categories to determine which cable characteristics are most important for HDBaseT applications.

Category 5e vs. Category 6 vs. Category 6A

In every respect, Category 6A cables are superior to Category 5e and Category 6 in Ethernet applications. With respect to BASE-T, Category 6A cables enable 10x the amount of data to be sent over the cabling infrastructure. Category 6A cables are designed to minimize the effects of alien crosstalk that occur at higher frequencies. Category 6A cables also have larger copper diameters to achieve 10GBASE-T transmission. This reduces resistance and generates less heat in PoE applications which is a fundamental feature of HDBaseT hardware. Therefore, we went into testing with the expectation that Category 6A cable performance would be superior to Category 6 and Category 5e.

Unshielded vs. Shielded

The addition of shielding in cable construction has two primary purposes: it mitigates the effect of EMI and it minimizes crosstalk between pairs when individual pairs are shielded. The negative impact of EMI on HDBaseT applications can be immediately observed by the end user. If the interfering noise is strong enough, HDBaseT communication can be so negatively impacted that the video signal will be distorted or lost. Those lost or distorted video frames seen by the end user can't be corrected after the disruption to the link occurs. In this sense, HDBaseT transmission is more sensitive to EMI than traditional BASE-T applications. In setting up our testing, we tested both shielded and unshielded cables to determine if unshielded cabling could adequately tolerate low-level EMI commonly found in a typical enterprise AV environment. Common sources of EMI are lighting fixtures, cordless phones, walkie-talkies, and motors in paper shredders, cordless drills, etc. When HDBaseT is installed in areas where sources of EMI are present, whatever cabling is used must mitigate the effects of EMI.

The effect of shielded cables on crosstalk is addressed later in this paper.

Pair Twist

Delay Skew

Pair twist is another construction characteristic that impacts the delay skew of a channel which can influence HDBaseT performance. Delay skew is the time difference between the fastest and slowest propagation delay of the pairs. The difference in twist rates of the pairs in a cable is the leading contributor to delay skew. Pairs with tight twists are physically longer in length than pairs with a loose twist. Therefore, a signal will take more time to travel down pairs with tight twists than those with loose twists. In general, as the difference in twist rates between the pairs increases, so does the delay skew. Figure 3 shows a common twisted pair cable, with a central crossweb to separate the pairs. Each pair has a different cable twist rate.

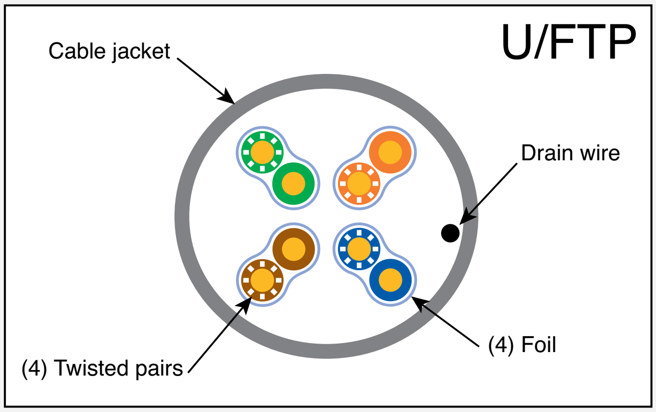
Figure 3: Cable Twist Rates Impact Delay Skew

Crosstalk

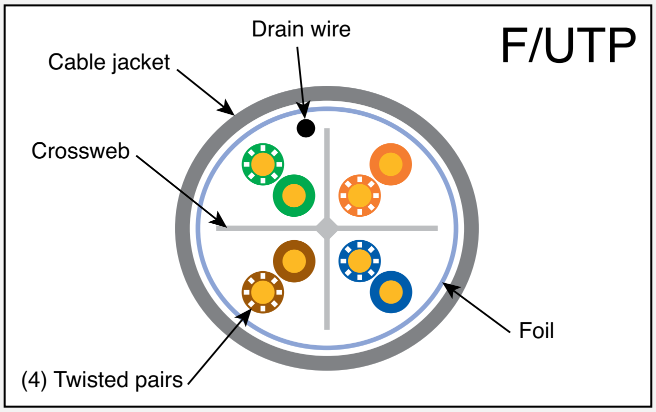
The reason that pairs are twisted at different rates is to minimize crosstalk between the pairs. As bandwidth requirements on cables extend to higher frequencies, the twist rate differences between pairs become bigger. Category 6A cables, which are designed to provide 500MHz of bandwidth, will typically require larger twist rate deltas between pairs than Category 5e cables which provide only 100MHz of bandwidth. Subsequently, Category 6A cables will inherently result in larger delay skews than lower category cables.

Another option to minimize crosstalk is to provide shielding between the pairs, as is common in foiled twisted pair (FTP) cables. FTP cables allow for the twist rates to be more alike, thus improving delay skew. Because of this, we went into testing expecting U/FTP cables to outperform F/UTP cables in HDBaseT applications.

U/FTP and F/UTP Shielded Cables



U/FTP: Unshielded with individual Foiled Twisted Pairs



F/UTP: Foil screen around Unshielded Twisted Pairs

U/FTP and **F/UTP** are both shielded cables but are constructed differently. U/FTP has an unshielded jacket, with each individual pair wrapped in foil. F/UTP has a foil screen around the entire cable and each individual pair is not covered. F/UTP does have a crossweb to increase distance between the cable pairs.

Testing the Hypothesis

Setup and Measurements

To understand how HDBaseT performance is impacted by the cabling channel, testing was performed across an extensive set of cabling channels of various lengths (40m, 70m, 100m), cable Category (5e, 6, 6A), and cable construction (UTP, F/UTP). Figure 4 shows the generic channel configuration used for each test with two connectors, two five-meter patch cords at each end, and the appropriate length of horizontal cable. In all cases, the channel components were of the same category and construction (UTP, or F/UTP with shielded connectors).

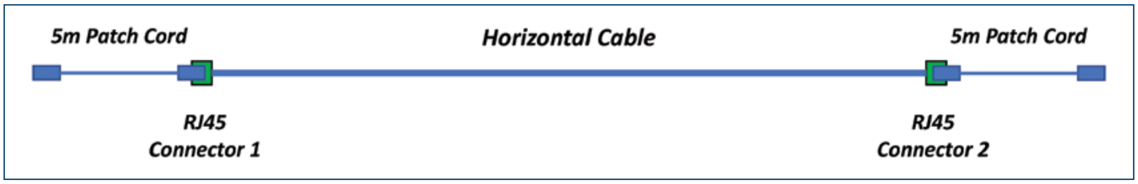


Figure 4: Representative Channel Configuration

The internal performance parameters of all cabling channels used during the testing were measured with a Fluke Networks DSX-5000 CableAnalyzer™ handheld field tester. Since HDBaseT applications can utilize a maximum bandwidth approaching 500MHz, the following parameters were measured up to 500MHz for all channels regardless of category:

- Insertion Loss (IL)
- Return Loss (RL)
- Near End Crosstalk (NEXT)
- Power Sum Near End Crosstalk (PSNEXT)
- Far End Attenuation to Crosstalk Ratio (ACR-F)
- Power Sum Far End Attenuation to Crosstalk Ratio (PSACR-F)
- Propagation delay
- Delay skew
- Transverse Conversion Loss (TCL)
- Equal Level Transverse Conversion Transmitted Loss (ELTCTL)

The signal-to-noise ratio presented to the HDBaseT receiver on each pair can be calculated from these measurements made on the various cabling channels, along with the transmitter power spectral density defined by the HDBaseT standard.

The performance of the HDBaseT link across all the different cabling channels was measured per the test setup as shown in Figure 5. Measurements of the HDBaseT performance were made with a PC connected directly to the HDBaseT hardware via USB. Software running on the PC captured relevant metrics directly from the HDBaseT integrated circuits (IC) inside the transmitter (Tx) and receiver (Rx) hardware units in real time with live video traffic.

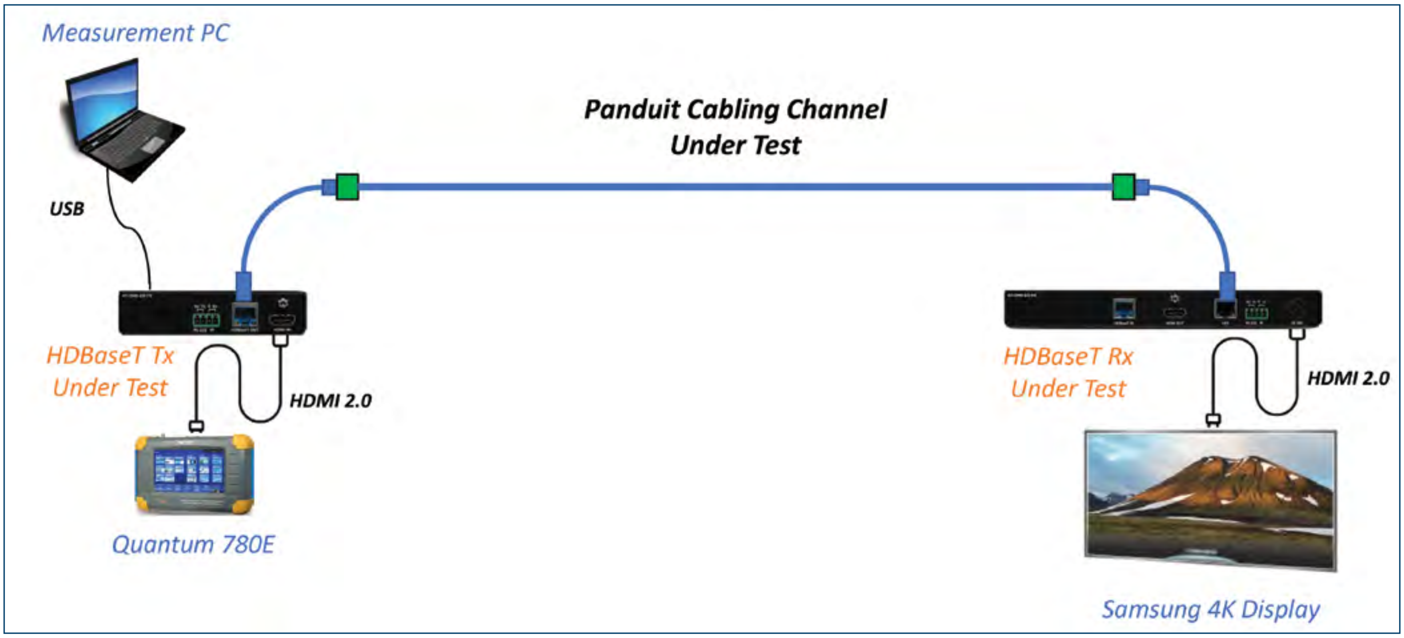


Figure 5: HDBaseT Performance Test Setup

The video source for all tests originated from the HDMI output of a Teledyne Lecroy quantumdata™ 780E Video Generator/Analyzer and connected to an Atlona HDBaseT Tx under test via a four-meter Panduit HDMI 2.0 cable. For each test, the video content sourced by the 780E was a pseudorandom stream configured in one of three resolutions as outlined in Table 1.

	Resolution		Frame Rate	Color Space		Bit Depth	Content
Video Mode 1	720p	1280 x 720	30 Hz	YCbCR	4:4:4	8 bit	Pseudo Random
Video Mode 2	1080p	1920 x 1080	60 Hz	YCbCR	4:4:4	8 bit	Pseudo Random
Video Mode 3	4K	3840 x 2160	60 Hz	YCbCR	4:2:0	8 bit	Pseudo Random

Table 1: Quantum 780E Video Modes

Data was captured in real time at an interval of approximately 1 second. Although the measurement PC was connected directly to the Tx unit, the cabling channel under test connecting the Tx and Rx units allowed the software to access data directly from the IC in the Rx unit. The real time data collected from the Tx and Rx ICs in the HDBaseT hardware was stored in log files on the measurement PC. The most relevant parameters captured for assessing the performance of the HDBaseT application are the Rx MSE (mean-square error), and the HDBaseT packet retransmission rate.

Rx MSE

Receive mean-square error (Rx MSE) is a measurement of how accurately the signal detected by the receiver matches the signal sent by the transmitter. The smaller the mean-square error, the more accurate the detection and the more robust the communication link between the Tx and Rx. In HDBaseT systems communicating over twisted pair cabling, there are four Tx and Rx pairs communicating over the four twisted pairs of the cable. To ensure successful HDBaseT transmission, accurate detection must occur on all four Rx lanes. If the detection error on any of the four lanes is too large, the entire HDBaseT link is compromised. The Rx MSE for each Rx is monitored and captured by the software as follows.

Rx MSE Ch A = Pair 12

Rx MSE Ch B = Pair 36

Rx MSE Ch C = Pair 45

Rx MSE Ch D = Pair 78

HDBaseT Packet Retransmission Rate

The HDBaseT 2.0 specification introduced a mechanism for retransmission of HDBaseT packets if an errored packet was detected by the Rx hardware. Each HDBaseT packet contains a unique Packet ID field and upon detecting an errored packet, the Rx hardware sends a request back to the Tx hardware to retransmit the bad packet identified by its Packet ID. This retransmission mechanism also implements provisions to ensure the retransmitted packet is successfully detected error free by the Rx. By implementing buffers in the Tx and Rx path, the additional latency introduced by the retransmission mechanism can be tolerated. The size of these buffers ultimately limits the maximum amount of retransmission requests that can be accommodated by the HDBaseT link.

The testing software captures in real time the number of HDBaseT packets transmitted as well as the number of retransmission requests sent by the Rx. In addition, the number of successfully retransmitted packets is collected. Together these numbers produce a retransmission rate. As long as the retransmission rate is low enough, there will be no interruption or distortion in the video display seen by the viewers.

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Test Results

Analyzing the HDBaseT measurements across the different cabling channels highlights the relationship between the SNR and the HDBaseT communication. Figure 6 shows the measured Rx MSE from two different families of Atlona HDBaseT hardware when linked with a variety of cabling channels. The plot shows the worst Rx MSE and SNR measured on each of the four pairs of a given cabling channel. It is clear that those channels which provide a higher SNR result in lower levels of Rx MSE indicating more robust HDBaseT communication.

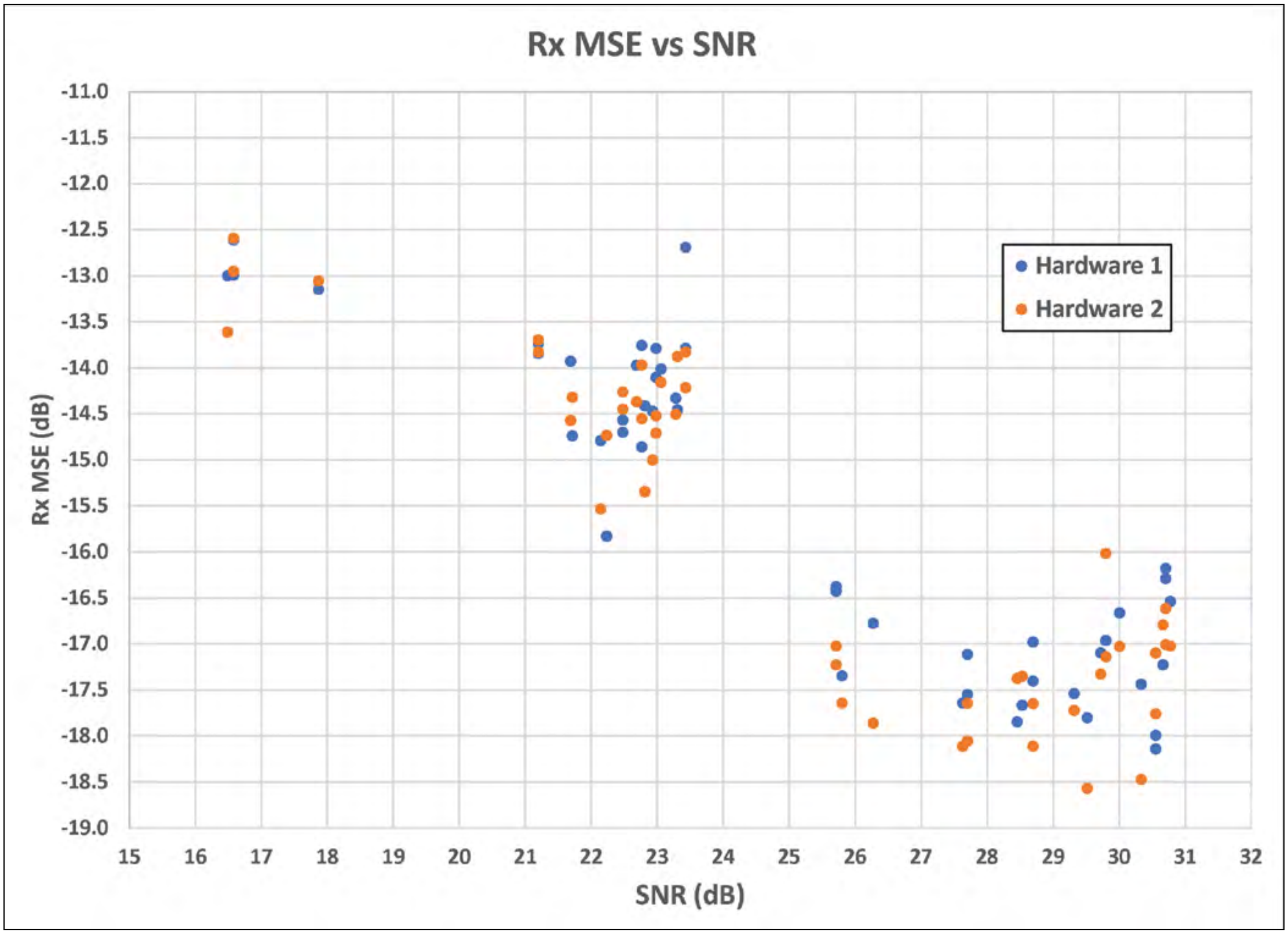


Figure 6: Rx MSE vs SNR

Figure 7 shows the retransmission rate measured on the two families of HDBaseT hardware as a function of the SNR provided by the various cabling channels tested. Higher SNR levels result in lower retransmission rates which ultimately drops to zero when the SNR rises above a threshold of approximately 24 to 25dB.

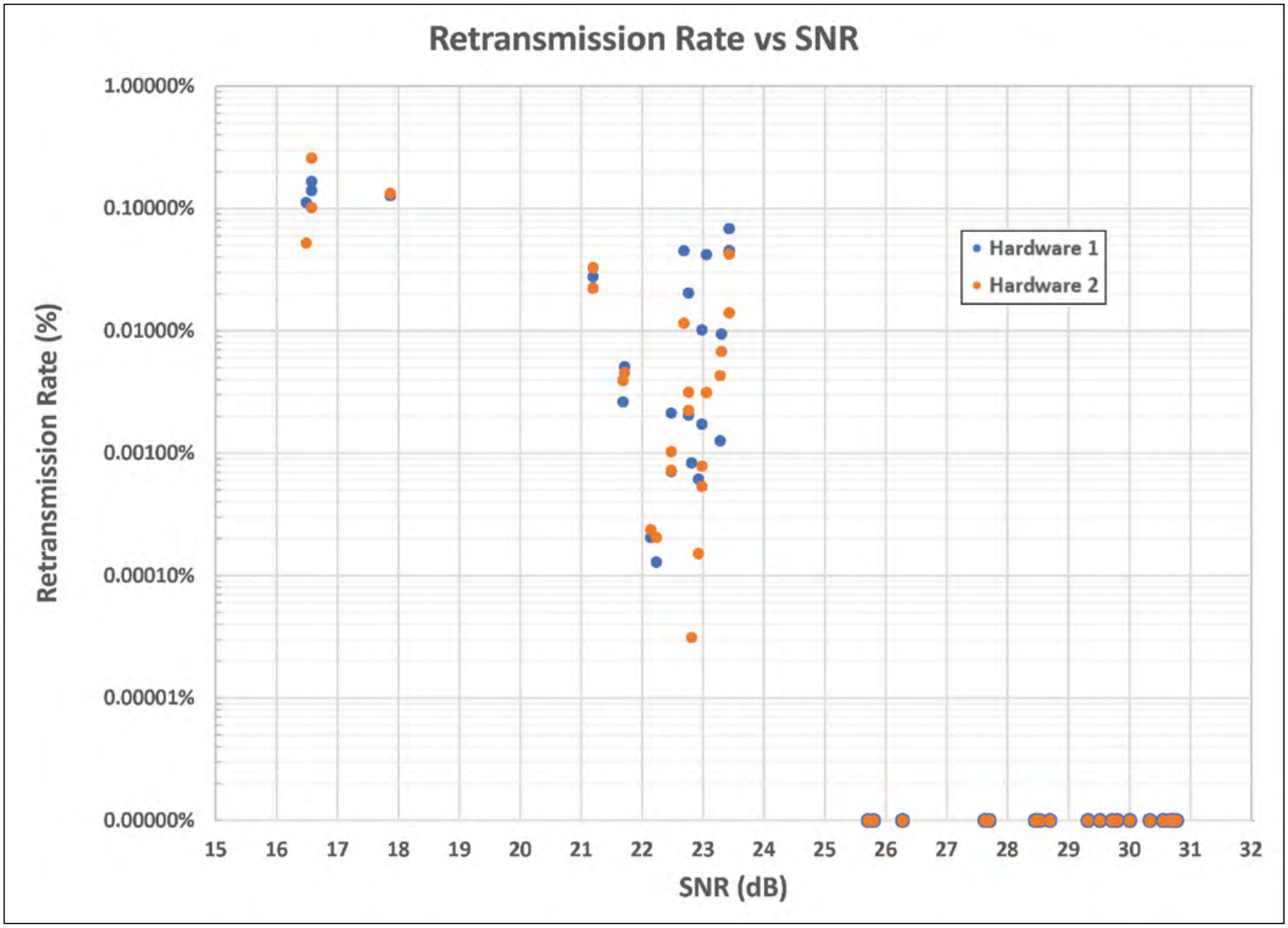
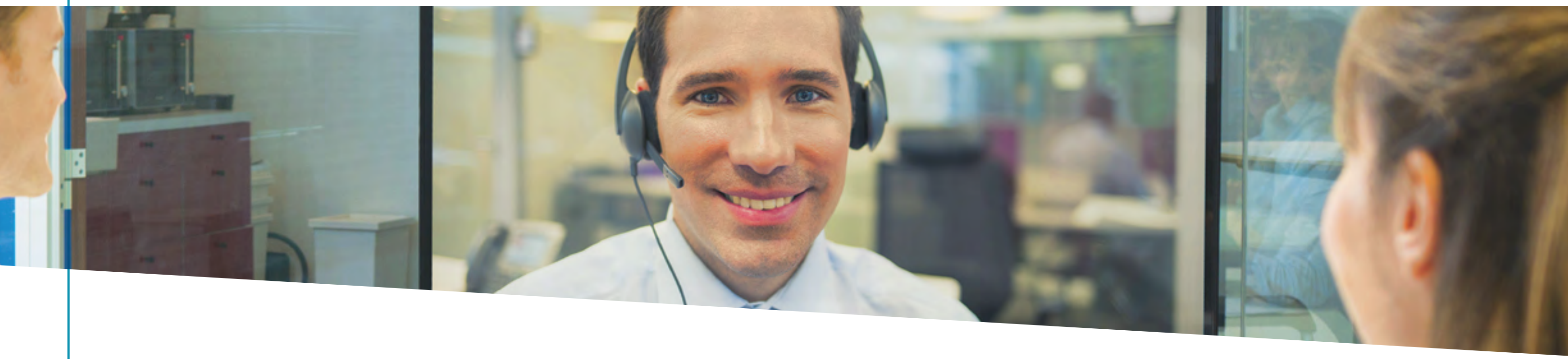


Figure 7: Packet Retransmission Rate vs SNR

In figures 6 and 7, variation in performance can be seen at a given SNR. This indicates that there are likely additional factors that impact the measured Rx MSE and packet retransmission rate. Further analysis of the data has shown the delay skew of the cabling channel can impact HDBaseT performance. With differences in twisting rates between the four pairs of the cable, the time it takes for a signal to propagate from one end of the channel to the other is different on each pair. The difference between the fastest and slowest propagation times of all four pairs defines the worst-case delay skew of a given channel. Figure 8 plots the Rx MSE as a function of delay skew as measured across the range of cabling channels tested with the two families of HDBaseT hardware.



While Figure 8 shows a trend of degraded Rx MSE with increasing delay skew, there are instances of channels with similar delay skew but significantly different Rx MSE performance. This is due to the interdependent relationship between SNR, delay skew, and HDBaseT performance. For example, HDBaseT performance can be dictated by a channel's poor SNR regardless of how low the delay skew may be. Conversely, very good SNR channels may also dictate the HDBaseT performance regardless of how high the delay skew may be, provided it does not exceed the maximum limit of 42 ns. The SNR of the channels tested ranged between 16dB and 31dB. Focusing on the channels with moderate SNR shows the impact of delay skew on HDBaseT performance more clearly. Figure 9 shows the trend of degraded Rx MSE with increasing delay skew for channels with an SNR between 22 and 29dB.

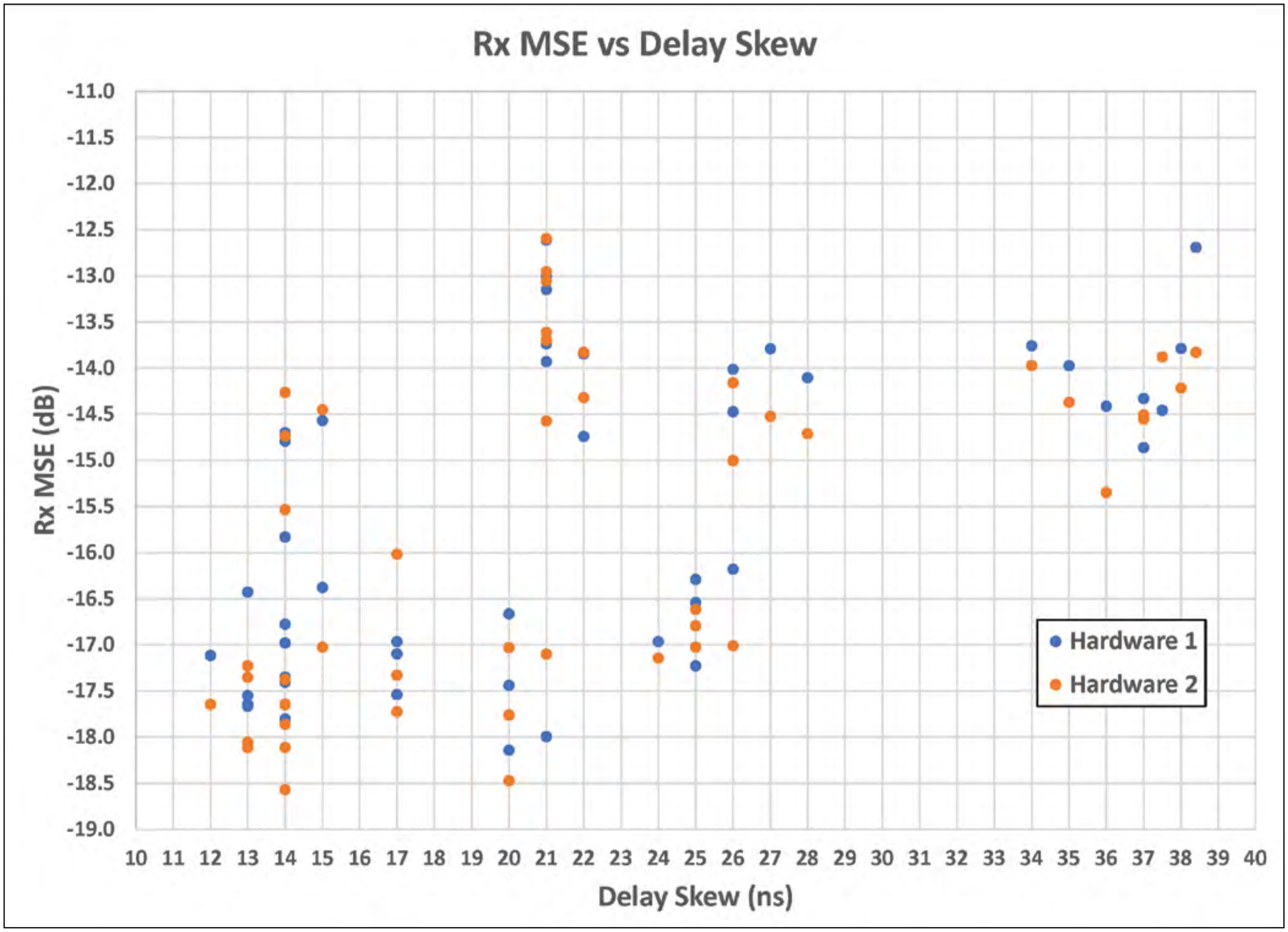


Figure 8: Rx MSE vs Delay Skew

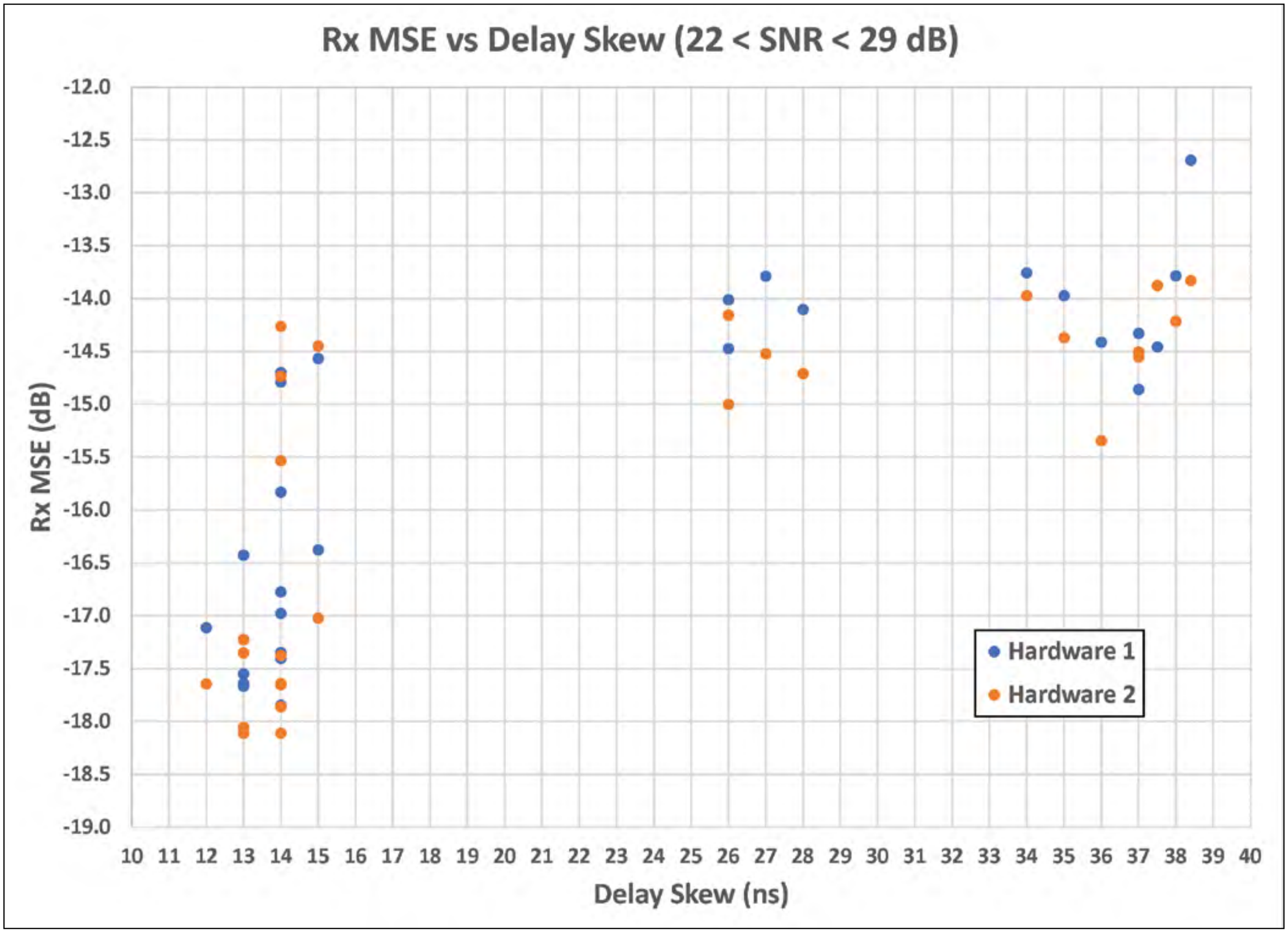


Figure 9: Rx MSE vs Delay Skew for Channels with SNR between 22 and 29 dB

Studying the HDBaseT performance over a range of cabling channels with known measured performance characteristics has shown that the most robust HDBaseT performance is achieved with a high SNR channel with low delay skew. The SNR is determined by the ratio of the received signal power to the received noise power. Cabling channels with low insertion loss and low internal FEXT will produce the desired SNR for HDBaseT communication.

Another important factor that can impact the noise power seen by the HDBaseT receiver, and ultimately degrade the SNR, is electromagnetic interference (EMI) from external sources. The impact of EMI on HDBaseT performance was tested by Panduit Labs in an anechoic chamber that blocks EMI according to the test setup shown in Figure 10.

Similar to the HDBaseT performance test setup in Figure 4, the HDBaseT performance metrics of Rx MSE and packet retransmissions were monitored in real time while the cabling channel under test was exposed to electromagnetic interference. Of the UTP channels tested, the Category 6A UTP channels presented the highest SNR performance and therefore the highest likelihood of acceptable HDBaseT performance in the presence of EMI. The interfering noise from EMI was calibrated to a level of 3 V/m which represents the appropriate amplitude for commercial buildings and enterprise settings, which are typical for HDBaseT installations. The frequency of interference was tested at 200MHz, 300MHz, and 400MHz. Figure 11 shows the HDBaseT performance as a function of channel length in the presence of the electromagnetic interference.

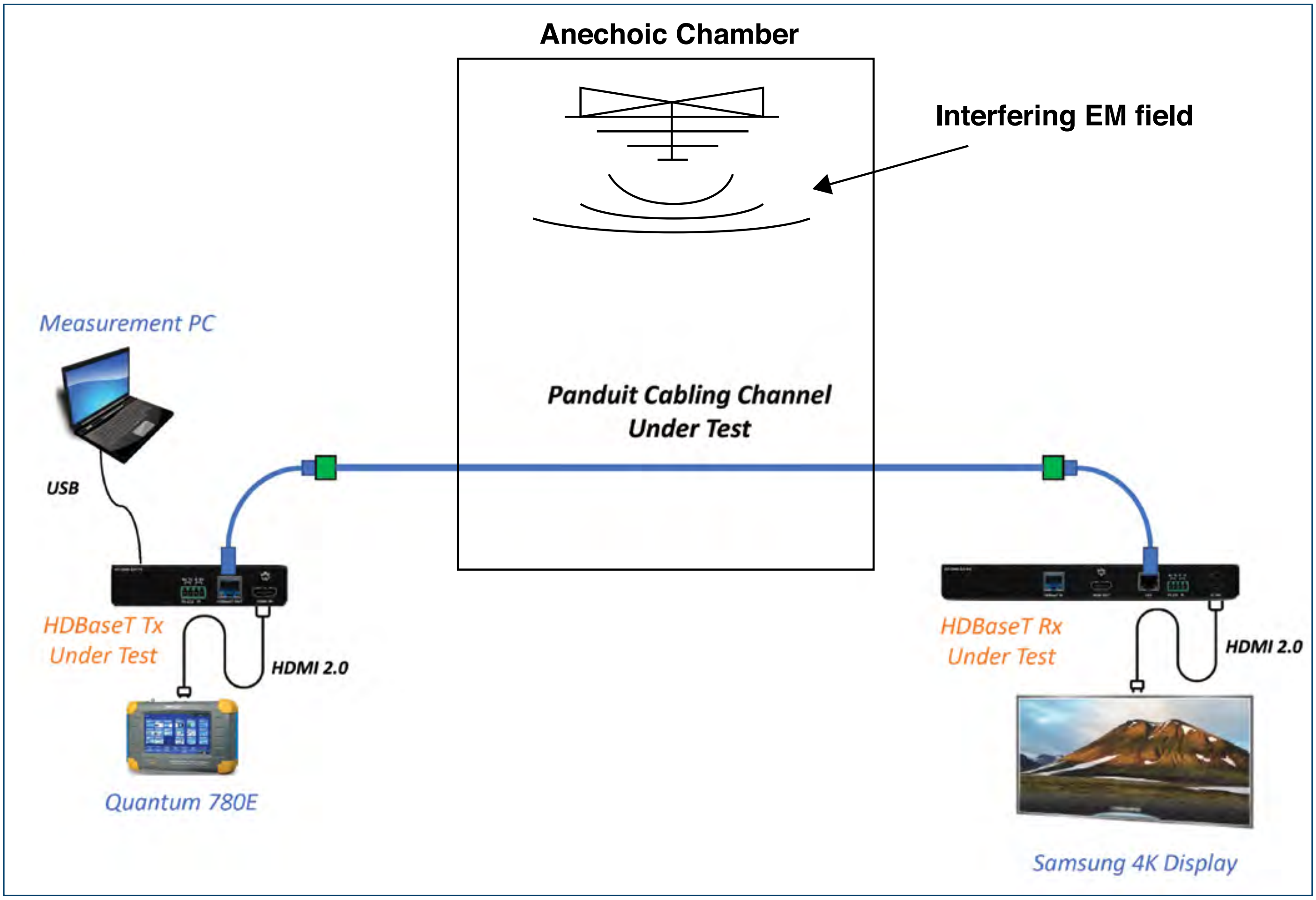


Figure 10: Electromagnetic Interference Test Setup

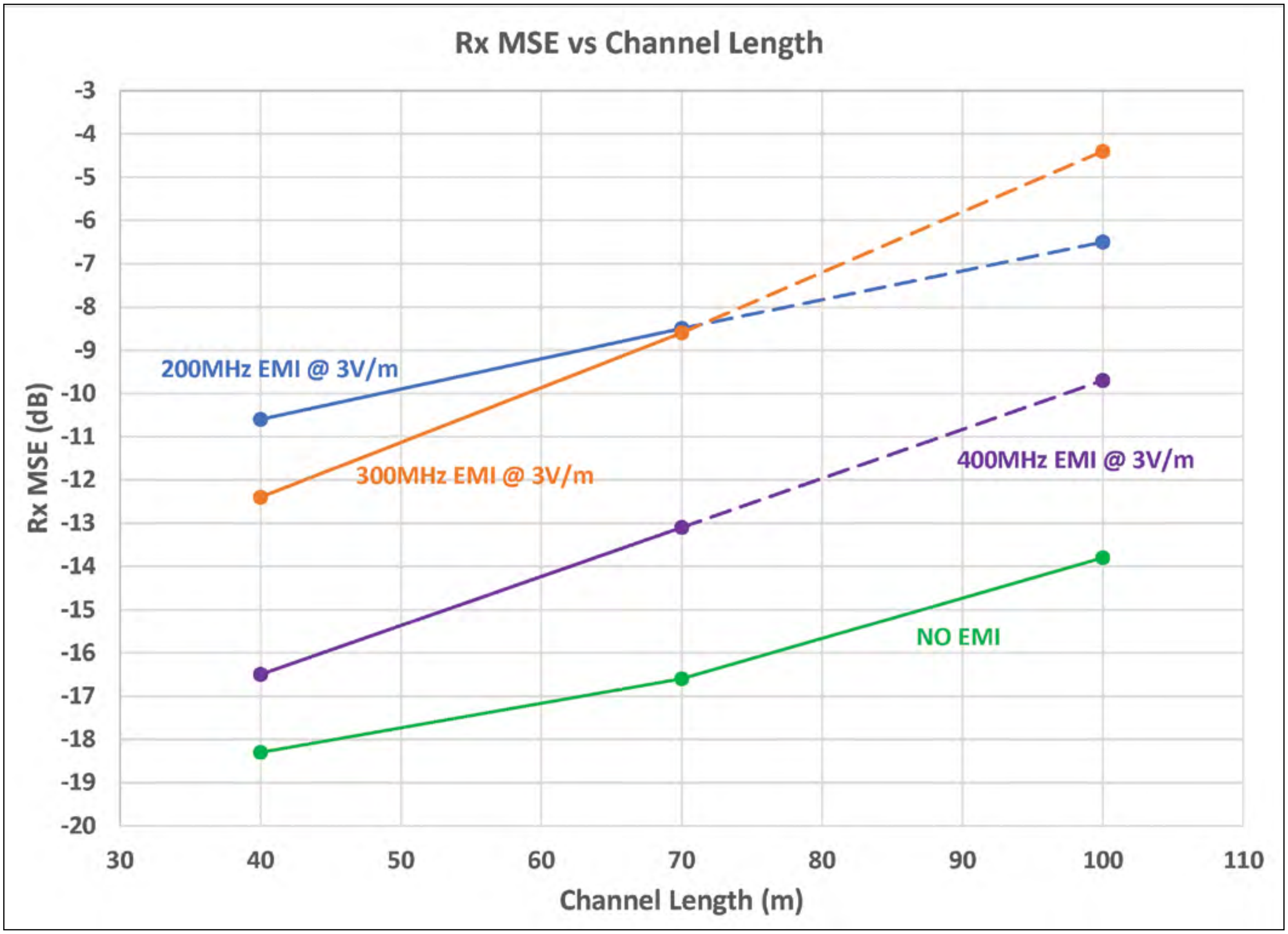


Figure 11: Rx MSE Performance in the Presence of EMI

The data shows that EMI causes a significant degradation to HDBaseT performance due to the additional noise and degraded SNR of UTP channels. At 100m channel lengths, the plotted Rx MSE are estimates, as the EMI caused the HDBaseT link to drop and data could not be collected by the measurement PC. When the HDBaseT link dropped during the testing, the picture displayed on the 4K display was lost and did not return until the EMI noise was removed. As expected, testing with shielded channels that were properly terminated showed no impact from EMI. Rx MSE measurements were unchanged at all channel lengths with or without the presence of EMI.

Given the way EMI affects the application and the observable impact to the end user, shielded infrastructure is recommended to ensure uninterrupted video transmission.

The SNR performance and delay skew characteristics of various shielded infrastructure channels are compared in Figure 12 and Figure 13. The U/FTP shielded construction with individually shielded pairs produces the highest SNR and the lowest delay skew compared to F/UTP constructions.

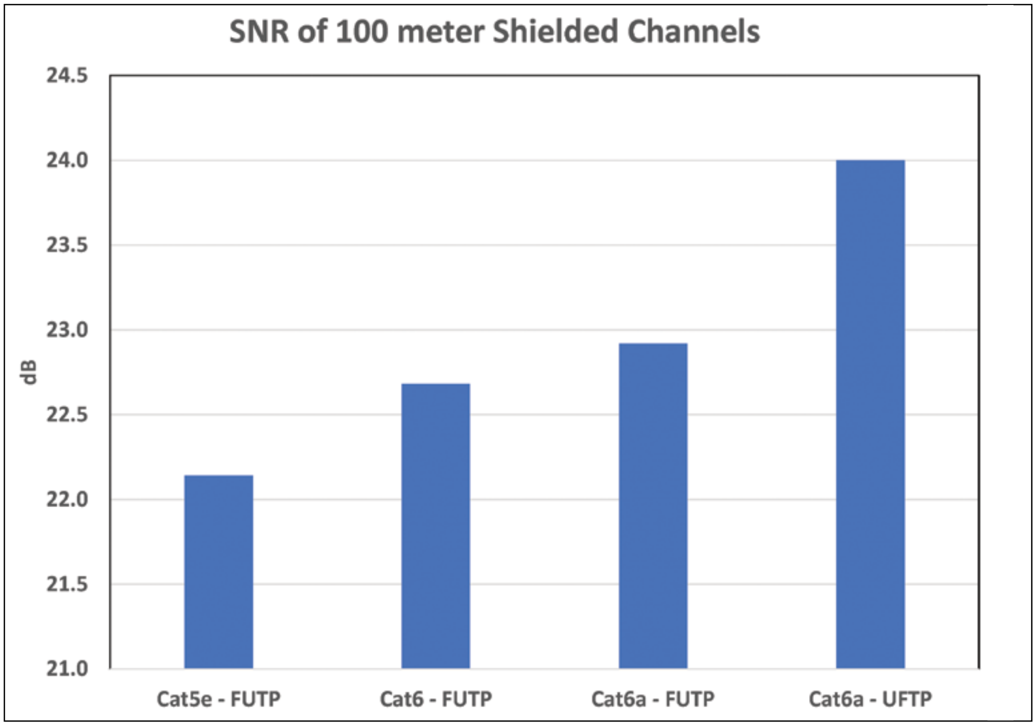


Figure 12: SNR of Shielded Cabling Channels

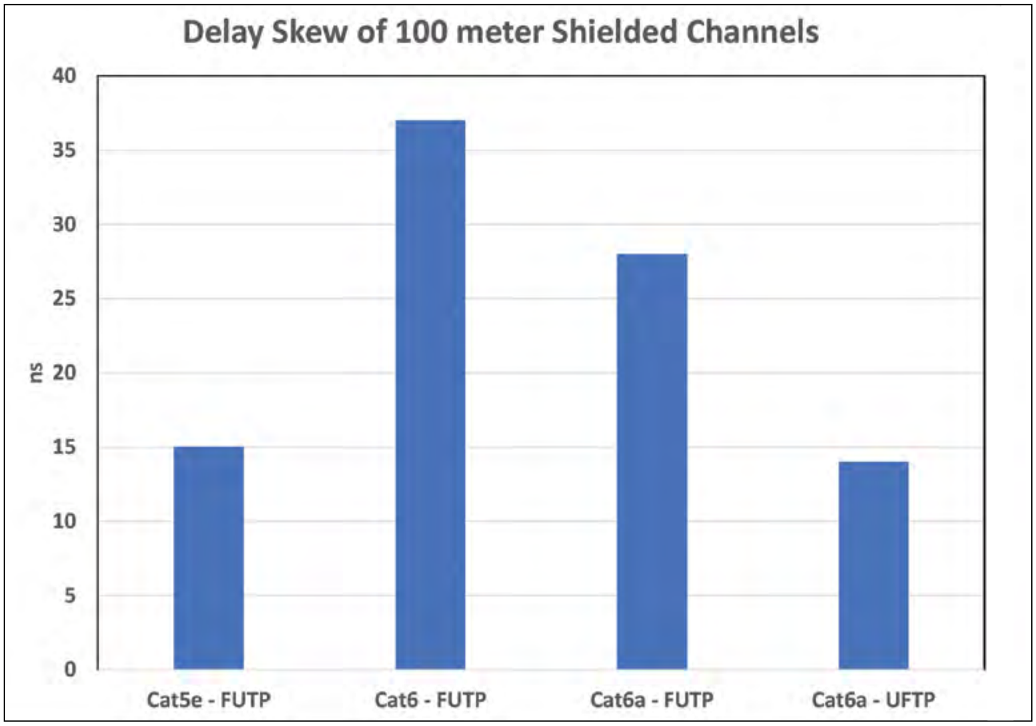


Figure 13: Delay Skew of Shielded Cabling Channels

The corresponding HDBaseT performance measured with these shielded infrastructure channels confirms the importance of SNR and delay skew in the cabling infrastructure. Figure 14 illustrates the Rx MSE measured on two families of HDBaseT hardware over 100 meters of shielded infrastructure. The packet retransmission rate measured over these same shielded cabling channels is shown in Figure 14. It is clear from these results that both SNR and delay skew are impactful on the overall HDBaseT performance. The Cat 6A U/FTP channel has both the best delay skew and SNR performance of all shielded channels and clearly provides the most robust HDBaseT performance of all channels tested.

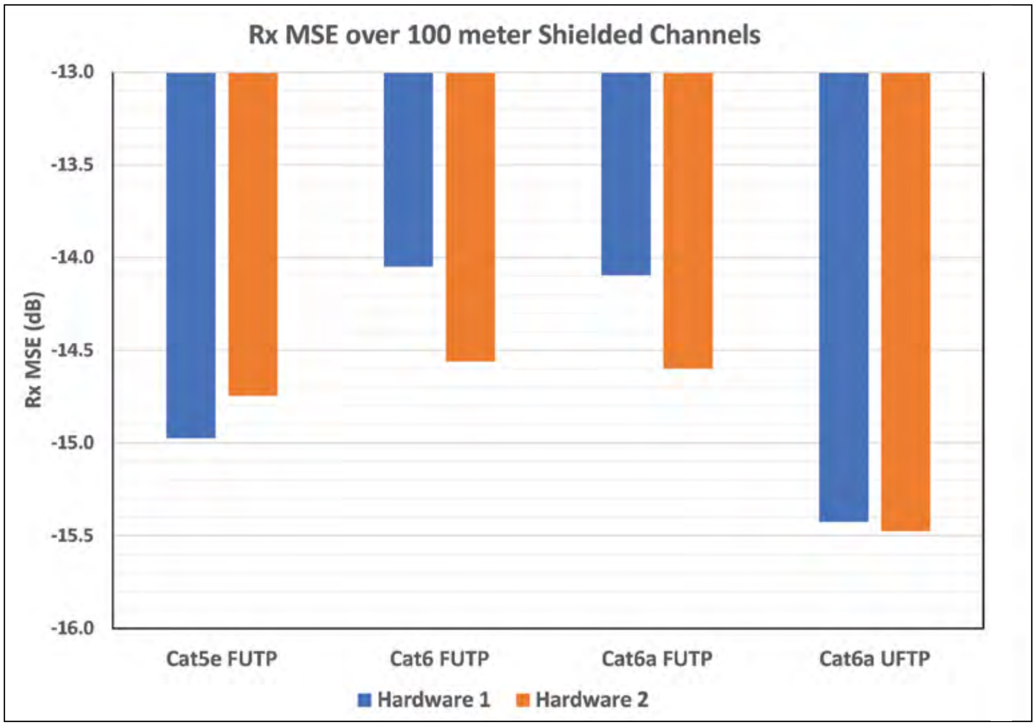


Figure 14: Rx MSE Measured over 100m Shielded Channels

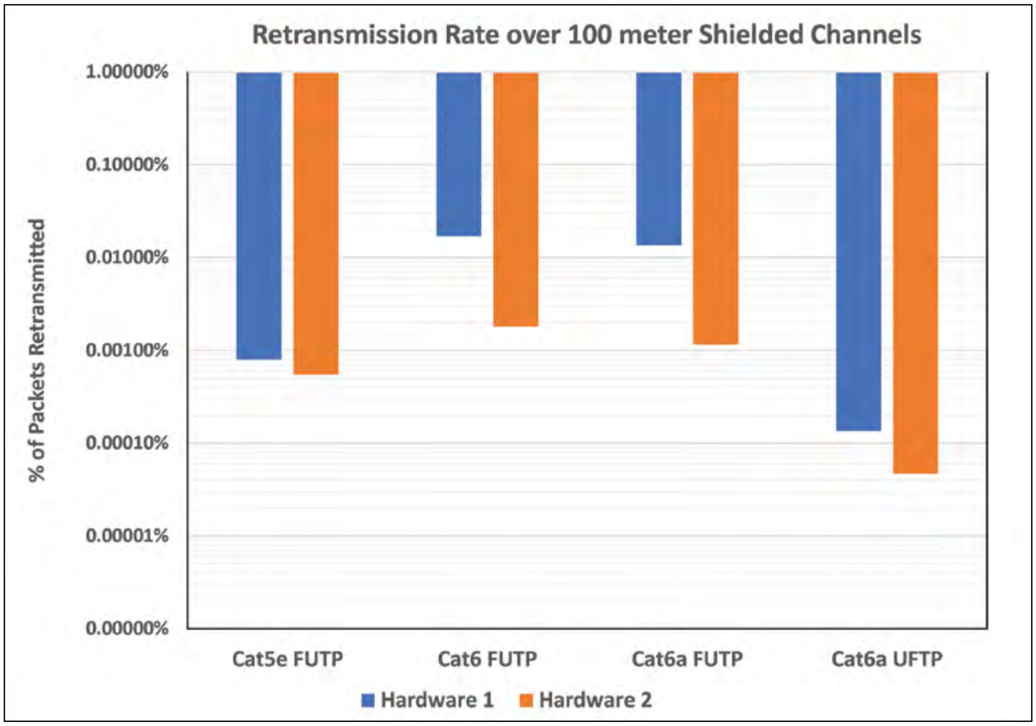


Figure 15: Retransmission Rate Measured over 100m Shielded Channels

With the emergence of the HDBaseT 3.0 standard, which will enable the transmission of fully uncompressed 4K@60Hz 4:4:4 up to 100 meters, the performance of the cabling infrastructure will be even more critical. HDBaseT 3.0 compliant hardware will be transmitting at faster clock rates which requires greater bandwidth from the cabling infrastructure. The specified and tested bandwidth of Category 6A channels provides the proper future-proofed infrastructure for the next generation hardware.

With Category 6A U/FTP infrastructure, the most robust performance is achieved with today's HDBaseT hardware and is ready for tomorrow's next generation of hardware.

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Conclusion and Recommendation

Though several other AV transmission technologies have begun to penetrate the market, HDBaseT remains one of the most widely used AV transmission protocols in the field. Its effectiveness in delivering a standards-based approach for interoperability, its performance in delivering high-quality resolutions over 100-meter distances, and its ability to drive signal convergence (HDBaseT 5-play) make it a great choice for several applications. With advancements in HDBaseT signal technology, we now understand the increased criticality that cabling infrastructure has with transmission.

As discussed, there are differences between HDBaseT and traditional Ethernet BASE-T transmission. When selecting a cable, there are a few key cable and performance characteristics to keep in mind:

- Signal to noise ratio (SNR)
- Receive mean-square error (MSE)
- Delay skew

These characteristics are interdependent, and with the right combination of low insertion loss and delay skew, high signal to noise ratio, and low receive mean-square error, high fidelity HDBaseT performance will exist.

Table 2 shows relative performance of different cable types compared to important transmission performance characteristics. The summary data shown is of cable at 100-meter channel lengths. It is important to note that all shielded cables successfully transmitted HDBaseT signals.

	Cat. 5e F/UTP	Cat. 6 F/UTP	Cat. 6A F/UTP	Cat. 6A U/FTP
Channel SNR	22.33 dB	22.75 dB	22.99 dB	24.00 dB
Delay Skew	14 ns	36 ns	27 ns	14 ns
Rx MSE	-14.86 dB	-14.40 dB	-14.35 dB	-15.45 dB
Retransmission Rate	0.00067%	0.01066%	0.00739%	0.00008%
Relative Performance	Good	Good	Better	Best

Table 2: Performance metrics of various cables.
Relative performance is a compilation of the performance characteristics shown and other factors.

Unshielded vs. Shielded

Data shows that EMI causes a significant degradation to HDBaseT performance due to the additional noise and degraded SNR of UTP channels. At 100m channel lengths across multiple categories of cable, the EMI caused the HDBaseT link to drop and the picture displayed was lost. As resolutions, color depths, and refresh rates continue to increase, a cabling channel's ability to resist interference from outside sources will be more important.

Category 6A F/UTP vs. Category 6A U/FTP

Both Category 6A F/UTP and U/FTP cables successfully transmitted HDBaseT signal across 100-meter channels while being subjected to electromagnetic interference. However, when reviewing the data, several metrics give the edge to the U/FTP cable type. From a cable characteristic, the delay skew of the U/FTP cable is half that of the F/UTP cable. Performance wise, the U/FTP cable provides better channel SNR, better RX MSE, and a better (lower) re-transmission rate. In addition to its performance capability, next generations of HDBaseT products are expected to require a U/FTP cable to pass higher bandwidth signal.

A Note on Category 5e

Though data shows that a shielded Category 5e channel performs surprisingly well, it is not suited for many applications in the future. First, Category 5e performance is only specified and guaranteed up to 100 MHz, which many standards, including HDBaseT, are far beyond. Secondly, as new technologies are introduced to the market, such as HDBaseT 3.0, they will carry a higher bandwidth requirement than Category 5e to have full function for both distance and feature set.

Because of these findings, Panduit recommends Category 6A U/FTP cabling for HDBaseT applications.

Panduit has the right Category 6A U/FTP cable with the right flammability rating for wherever you may be in the world.

Region	Flame Rating	Part Number
North America	Plenum (CMP)	**PUFP6X04BU-UG**
North America	Riser (CMR)	**PUFR6X04BU-UG**
European Union	EuroClass Dca	**PUFL6X04WH-HED**
European Union	EuroClass Cca	**PUFY6X04WH-HED**
Rest of Europe, Middle East and Asia Pacific	LSZH-1	**PUFL6X04WH-HED**
Latin America	Riser (CMR)	**PUFR6X04BU-HED**

Some additional points to consider when planning your next AV installation:

- Some AV equipment manufacturers require the use of shielded cables to qualify for their warranty; Category 6A U/FTP cables will satisfy this requirement
- Shielded cables are only as good as the installation; an improperly grounded shielded cable will likely perform worse than an unshielded cable
- Panduit's plenum and riser Category 6A U/FTP cables carry UL's Limited Power (LP) rating; LP-rated cable can simplify electrical inspections that are required by the NEC for Power over Ethernet applications over 60W

Please reach out to your Panduit sales representative to assist you in choosing the right infrastructure for all your enterprise, data center, and AV applications.

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Since 1955, Panduit's culture of curiosity and passion for problem solving have enabled more meaningful connections between companies' business goals and their marketplace success. Panduit creates leading-edge physical, electrical, and network infrastructure solutions for enterprise-wide environments, from the data center to the telecom room, from the desktop to the plant floor. Headquartered in Tinley Park, IL, USA and operating in 112 global locations, Panduit's proven reputation for quality and technology leadership, coupled with a robust partner ecosystem, help support, sustain, and empower business growth in a connected world.

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