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White Paper

Beyond the Standards: Extending the Reach of Copper Cabling

By Paul Wachtel

Research Manager, Panduit Research and Development

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ABOUT THE AUTHOR:

Paul Wachtel

Research Manager
Panduit Research and Development

Paul Wachtel has been part of Panduit Research and Development for 18 years. He received a BSEE from Purdue University in 1997.

Executive Summary

Introduction

Twisted pair copper structured cabling has long been a reliable and affordable media to deploy Ethernet networks. This reliability has partially come from the aligned standardization of the cabling infrastructure and the applications they support (i.e., Category 6A cable supports 10GBASE-T Ethernet). One element of the alignment between cabling standardization and applications is a strict limit of 100 meters as the maximum cabling channel length. However, newer 22 AWG twisted pair cable designs are emerging in the market with claims that they enable 1000BASE-T at distances far beyond the 100-meter standard. This has raised concerns regarding the reliability of these claims.

While Panduit does not have insight into how cable manufacturers have validated claims for performance beyond 100 meters, in many cases it appears to have been through testing on some sampling of equipment. While this may appear to be a preferred manner to evaluate, it is subject to significant variability due to the unknown amount of margin built into the devices under test. Simple actions like using different devices that were not tested or upgrading firmware may suddenly cause the device to no longer function at extended lengths.

Along with extensive application testing, Panduit believes testing should follow a standards-based approach as much as possible to understand the extended-reach benefits of a 22 AWG Category 6 or 6A cable. While the standard defines a maximum cabling length of 100 meters, it also defines other cabling transmission characteristics that ensure a robust 1000BASE-T Ethernet link. This paper will provide guidance as to how far beyond 100 meters a cable can reach and still function reliably.

Results

Panduit completed testing in our lab environment, examining 22 AWG links of different lengths, each with a total of 10 meters of 24 AWG patch cords, as shown in [Figure 1](#).



Figure 1: 22 AWG link under test with a total of 10 meters of 24 AWG patch cords

The results are as follows:

- 1000BASE-T systems were designed to meet a minimally compliant Category 5 channel
- Critical parameters that limit system length are insertion loss and propagation delay skew
- Category 6 and higher standards offer additional margin to the Category 5 standard on critical parameters like insertion loss; it additionally provides lower noise due to superior NEXT and ACRF performance
- 22 AWG Category 6 and higher cables offer further insertion loss margin to the standard
- A 130-meter 22 AWG permanent link with 10 meters of 24 AWG patch (140-meter channel) can minimally meet the 1000BASE-T system requirements and support reliable communication between a diversity of networking equipment and endpoints

Conclusion

For extended reach, Panduit recommends a maximum 140-meter channel, including 130 meters of 22 AWG Category 6 link, plus 10 meters of 24 AWG patch cords. Panduit validated this recommendation both theoretically and experimentally.

Historical Gigabit Standards and Specifications

The IEEE-802.3ab standard was published in 1999. The standard defines gigabit Ethernet communication (1000BASE-T) over unshielded twisted pair (UTP) Category 5 copper cabling. Category 5 (later replaced by Category 5e) was the first twisted pair copper infrastructure capable of supporting both 10Mbps and 100Mbps Ethernet communication up to 100-meter lengths. With the publication of the IEEE-802.3ab standard, the installed base of Category 5 cabling could now support gigabit Ethernet communication.

To ensure robust 1000BASE-T communication, TIA/EIA-568-A specifies transmission parameters of the cabling channel. The transmission parameters, which are specified over a frequency range of 1 – 100 MHz, include insertion loss, propagation delay, delay skew, characteristic impedance, NEXT (near-end crosstalk), ACRF (attenuation to crosstalk ratio, far-end), PSACRF (power sum attenuation to crosstalk ratio, far-end), and return loss. According to section 40.7.2 in IEEE-802.3ab, compliance with the specified transmission parameters ensures reliable communication up to at least 100 meters.

In addition to specifying the transmission characteristics of the cabling channel, the IEEE-802.3ab standard also specifies the necessary electrical characteristics of the hardware to reliably transmit and receive communication over the link. Thanks to the thorough specifications defined in the IEEE-802.3ab and the ANSI/TIA/EIA-568-A standards, all compliant hardware and cabling channels can reliably interoperate, providing the market with a robust solution for 1000BASE-T communication. As a result, 1000BASE-T networks have been successfully deployed globally for over two decades.

Today, the ANSI/TIA-568.2 series and the ISO/IEC 11801 series of standards both define performance requirements for Category 5e (Class D) to Category 6A (Class EA) cabling at channel lengths up to 100 meters.

Critical Transmission Requirements and Benefits from Newer Categories

Comparing the Standards: Category 5 versus Category 6 and 6A

Newer cabling infrastructure standards such as Category 6 and Category 6A support Ethernet communication at speeds up to 10Gbps. The transmission characteristics of these cables are far improved over the original Category 5 requirements. **Figure 2**, **Figure 3**, **Figure 4**, and **Figure 5** show a comparison of the insertion loss, NEXT, ACRF, and return loss requirements for the various cabling categories over the 1000BASE-T frequency range of 1 – 100 MHz.

As evidenced in **Figure 2**, the insertion loss over 100 meters of Category 6 or 6A cabling is significantly less than Category 5. With the lower loss provided by Category 6 or 6A cabling, 1000BASE-T links will realize higher signal strengths, adding margin to the signal-to-noise ratio (SNR) seen by the receiver.

Figure 3, **Figure 4**, and **Figure 5** highlight the improved NEXT, power sum attenuation to crosstalk ratio far-end (PSACRF), and return loss characteristics of Category 6 and 6A cabling compared to Category 5. Crosstalk between pairs and reflected energy all contribute to the total noise present at the receiver. The noise seen by the receiver due to the cabling will be dramatically reduced due to the

significant margin provided by Category 6 or 6A cabling compared to the 1000BASE-T requirements. As a result, the signal-to-noise ratio (SNR) will be enhanced even further due to the superior transmission characteristics of Category 6/6A cabling.

To summarize:

- Category 6 and 6A standards offer significant improvements in insertion loss versus the Category 5 standard
- Category 6 and 6A standards offer noise reduction versus the Category 5 standard across all relevant parameters such as NEXT, ACRF, and return loss

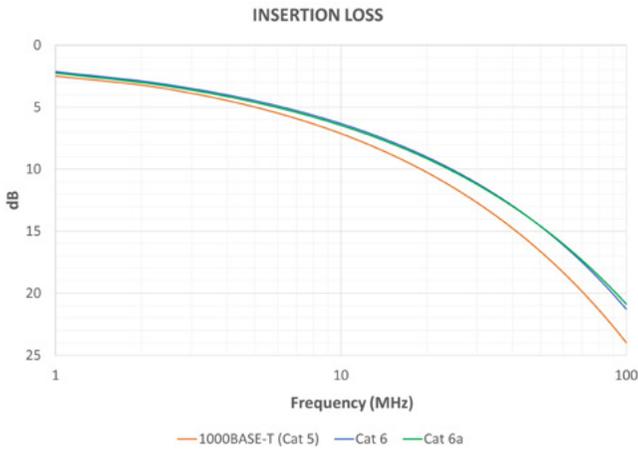


Figure 2: Insertion loss comparison between the 1000BASE-T specification and the Category 6 and 6A standards

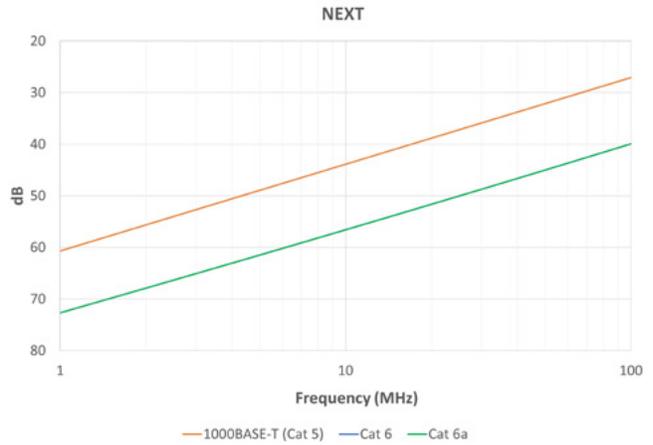


Figure 3: NEXT comparison between the 1000BASE-T specification and the Category 6 and 6A standards

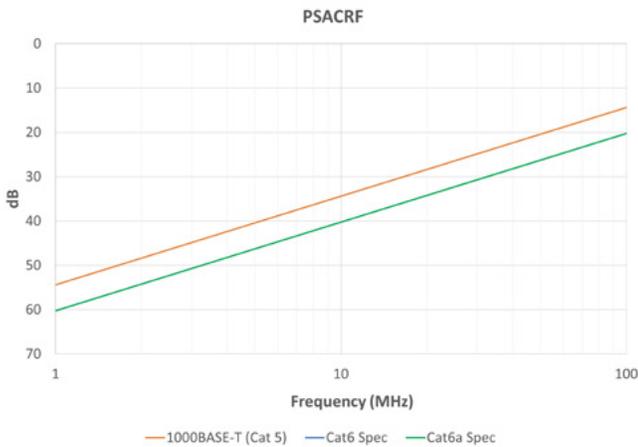


Figure 4: PSACRF comparison between the 1000BASE-T specification and the Category 6 and 6A standards

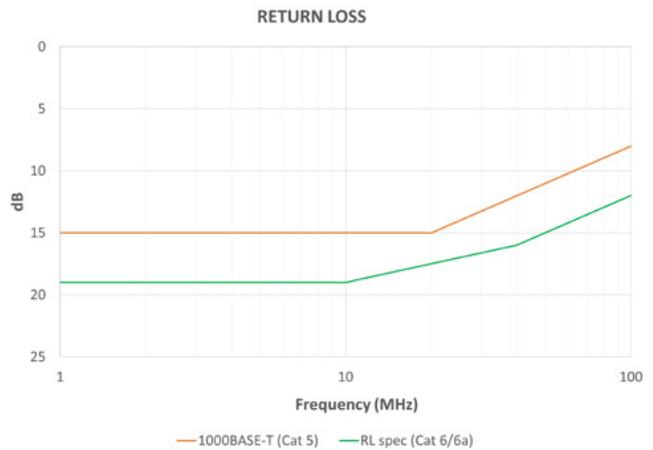
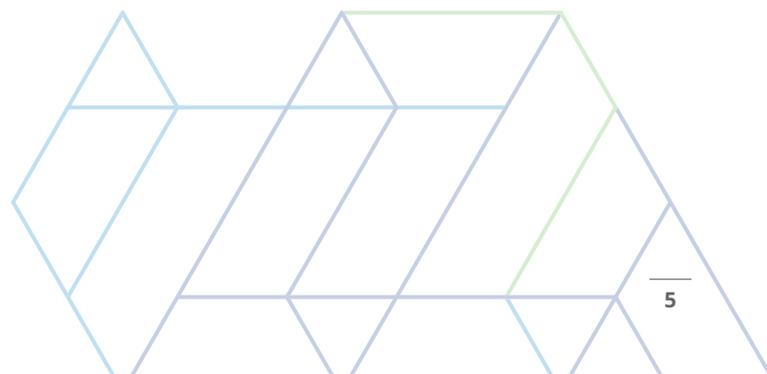


Figure 5: Return Loss comparison between the 1000BASE-T specification and the Category 6 and 6A standards



Signal-to-Noise Ratio Benefits: Category 5 versus Category 6 and 6A

The SNR is a critical parameter for data transmission as it serves as a metric to determine if the receiver can distinguish the signal from the noise. The method used to determine the SNR benefit of Category 6 and 6A versus Category 5 is as follows:

- Determine the power spectral density (PSD) of a 1000BASE-T transmitter (will be the same whether a Category 5, 6, or 6A cable is used)
- Determine the PSD for the total noise created by a Category 5 cabling channel
- Determine the PSD for the total noise created by a Category 6 or 6A cabling channel
- Determine the PSD of the received signal resulting from a 1000BASE-T transmitter communicating over both a Category 5 and Category 6 channel

Figure 6 shows a comparison of the PSD of the received signal and the total noise resulting from a 100-meter standard-compliant Category 5 channel, and the received signal and the total noise resulting from a 100-meter standard compliant Category 6 channel. The resulting SNR improvement of 5.9 dB can be calculated from the PSD values.

This total SNR improvement of 5.9 dB is a direct result of:

- The higher Rx (reception) signal power due to the lower insertion loss of Category 6 and 6A cables
- The lower total noise due to the improvement in NEXT, ACRF, and Return Loss

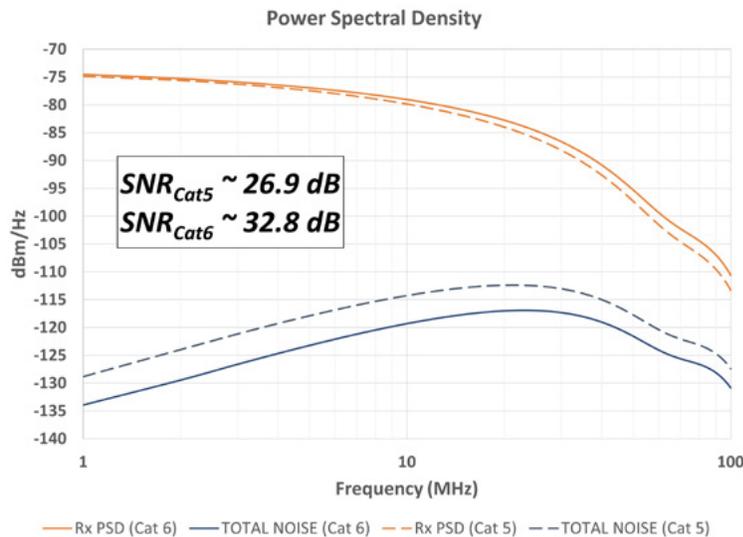


Figure 6: PSD of the noise for a Category 5 cabling channel, PSD of the noise for a Category 6 cabling channel, and the resulting PSD of the received 1000BASE-T signal transmitted over a Category 5 and Category 6 or 6A cabling system.

Caution Around only Using Signal-to-Noise Ratio

The SNR margin provided by Category 6 channels, shown in **Figure 6**, can be leveraged to provide extended channel lengths for 1000BASE-T links. The insertion loss of longer length channels will increase, but due to the lower total noise characteristics of Category 6 channels, the overall SNR can be as good or better than a Category 5 channel. **Figure 7** illustrates a theoretical maximum insertion loss of a Category 6 channel that will result in an equivalent Category 5 SNR of 26.5 dB. Naturally, 22 AWG horizontal cabling will be the most efficient solution to fully maximize the extended reach due to the lower insertion loss and DC resistance compared to traditional 23 or 24 AWG cabling.

SNR is not the only insertion loss-related factor impacting the receiver. As shown in **Figure 2** above, the insertion loss of the cabling channel varies directly with frequency. As frequency increases, the insertion loss increases. All 1000BASE-T receivers must compensate for this variation by employing digital signal processing (DSP) methods to equalize the frequency dependent nature of the cabling losses. Compliant receivers will be able to equalize the losses up to and including the 1000BASE-T IL limit. While SNR performance can be acceptable with Category 6 insertion losses beyond the 1000BASE-T limit, not all hardware will be able to adequately equalize these additional losses.

This point is nuanced, but it should be noted that later in this paper, Panduit recommends meeting both the signal strength requirements and the SNR requirements.

Systems transmitting over Category 6 and 6A cabling can meet the SNR requirements of 1000BASE-T at longer reaches. However, the frequency-dependent variation caused by increasing IL may be excessive. Therefore, the theoretical IL limit in **Figure 7** can be used within engineering solutions to further extend the reach of a system but will cause issues between different types of equipment depending on the equalization capabilities.



Figure 7: Theoretical maximum Category 6 insertion loss limit for 1000BASE-T links

Propagation Delay

IL-related factors are not the only cabling aspects that influence reliable 1000BASE-T communication. Propagation delay and delay skew are two additional important transmission characteristics dictated by the cabling channel.

- Propagation delay refers to the amount of time required for a signal to be received after it has been transmitted
- Delay skew refers to the difference in propagation delay between each of the twisted pairs

Absolute propagation delay is not as critical in modern BASE-T networks as it was in the past. In legacy Ethernet networks such as 10BASE2, the propagation delay requirement ensured the round-trip delay was adequate for effective collision detection. These legacy networks connected multiple devices to the same cable and required collision detection as all devices were allowed to transmit over a shared cable. Today's wired BASE-T networks deploy point-to-point connections between switches and endpoints, making collisions extremely rare and collision detection unnecessary. Therefore, propagation delay is not as critical in today's 1000BASE-T networks.

However, delay skew is still an important parameter to meet. As the data sent across the channel splits over the four twisted pairs in the cabling channel, it is important that the difference in delay between any two pairs (skew) is constrained to ensure that the data on the four pairs can be properly reassembled at the far-end receiver. If the delay skew is too long, the receiver will not be able to properly reassemble the data. Delay skew is controlled by the insulating materials and twist rates of the cable. **Table 1** details the associated specifications for 1000BASE-T communication as well as for Category 6/6A cabling channels.

Table 1: Propagation Delay and Delay Skew Standard Requirements for Category 5, 6, and 6A channels

| PARAMETER | 1000BASE-T (Category 5) | Category 6 | Category 6A |
|-----------------------------|----------------------------|------------|-------------|
| Propagation Delay (Channel) | 570 ns | 555 ns | 555 ns |
| Delay Skew (Channel) | 50 ns | 50 ns | 50 ns |

This analysis shows that extended reach over a Category 6 or 6A cable, particularly a 22 AWG cable, is theoretically possible due to the improvements in the categories themselves and the benefits of using large gauge conductors. However, experimental validation using actual devices is also needed.

Experimental Validation of Reliable Extended Reach

Test Method

Since there is no standard currently that defines 1000BASE-T operation beyond 100 meters, Panduit conducted extensive application and channel testing to understand and quantify a reliable extended channel length that can support 1000BASE-T Ethernet.

To see the impact of all relevant factors on extended reach communication, Panduit performed a series of application tests. A test channel was constructed to test 1000BASE-T links between a diverse selection of networking equipment. The channel was built, per **Figure 8**, with 10 meters of

24 AWG patch cable, two Category 6 connectors, and 190 meters of 22 AWG Category 6 horizontal cable to create a 200-meter transmission channel. The networking equipment used in the test employed different BASE-T PHY chipsets to capture the diversity of technology and implementation found in real world deployments. Test equipment included legacy 10/100/1000BASE-T chipsets, as well as more modern 10GBASE-T and NGBASE-T chipsets.

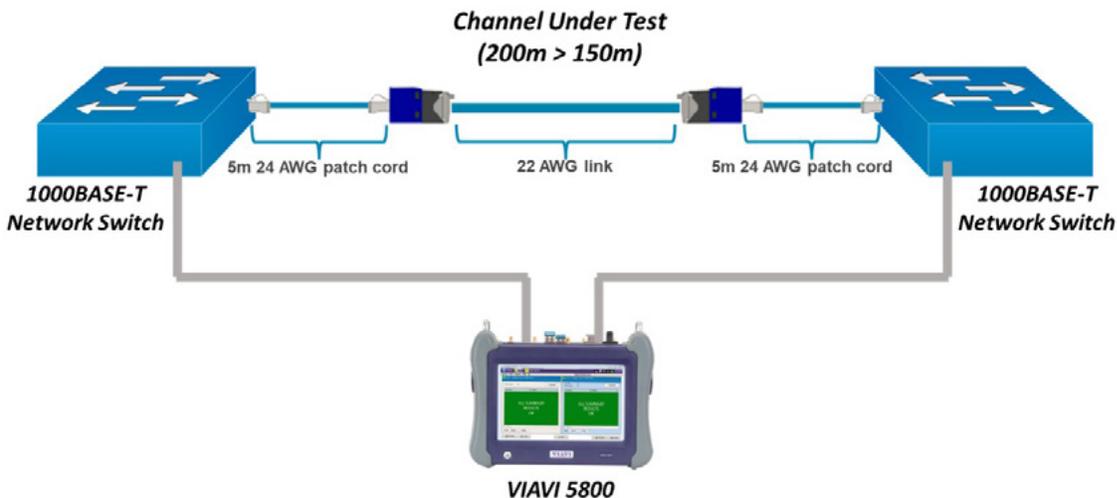


Figure 8: Test Channel Configuration

A Viavi 5800 network tester, running the Enhanced RFC 2544 test, captured link performance. This industry benchmark test captures key performance indicators such as throughput, latency, frame loss, and others in a reliable and repeatable manner.

Test Results

The testing was conducted first at 200 meters and then reduced incrementally by removing horizontal cable length. While some equipment began linking at certain lengths, Panduit wanted to find the case where all equipment was able to link and have robust “error-free” communication. Enhanced RFC 2544 testing was also done on the networking equipment under test to ensure that there was no throughput degradation and zero frame loss at a given length.

- 200 meters: 1000BASE-T links could not be established across all variants of network hardware
- 140 meters: All equipment could successfully negotiate a 1000BASE-T link and communicate reliably with no throughput degradation and zero frame loss

Therefore, application testing experimentally showed that 140-meter channels (130 meters of 22 AWG Category 6 plus 10 meters of Category 6 24 AWG patch cords) can reliably run 1000BASE-T.



Transmission Measurements of the 140-meter Channel

Measurements of the critical transmission characteristics of the 140-meter channel (130-meter 22 AWG Category 6 cable with 10 meters of 24 AWG Category 6 patch cords) are shown in **Figure 9**, **Figure 10**, **Figure 11**, and **Figure 12**. These graphs compare both the actual 1000BASE-T specification and the theoretical specification derived from the improved performance of Category 6 and 6A cables.

What can be seen is that:

- NEXT, PSACRF, and Return Loss (**Figure 10**, **Figure 11**, and **Figure 12**) all far exceed the 1000BASE-T specification
- Insertion loss (**Figure 9**) minimally fails the 1000BASE-T insertion loss limit by 1.8 dB at 100 MHz but far exceeds the theoretical Category 6 limit

Therefore, Panduit is confident that 140-meter channels (130-meter 22 AWG Category 6 permanent link with 10 meters of 24 AWG Category 6 patch) will provide a robust SNR and an insertion loss profile that can be equalized by compliant 1000BASE-T receivers.

Because of the marginal performance to the 1000BASE-T standard at 140 meters, there is risk for channel lengths beyond 140 meters, as not all receivers will be able to equalize the excessive losses.

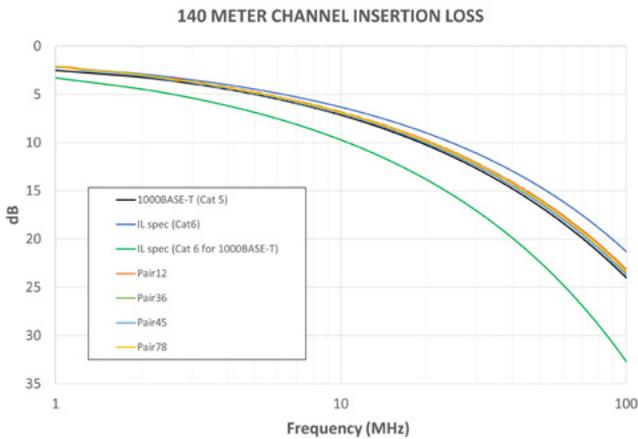


Figure 9: 140-meter channel insertion loss (130-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)

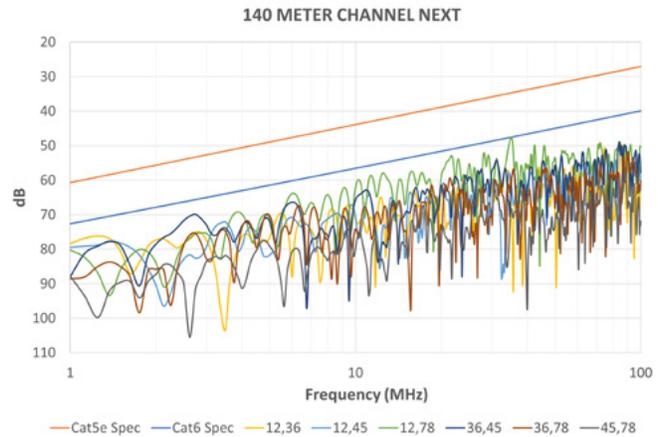


Figure 10: 140-meter channel NEXT (130-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)

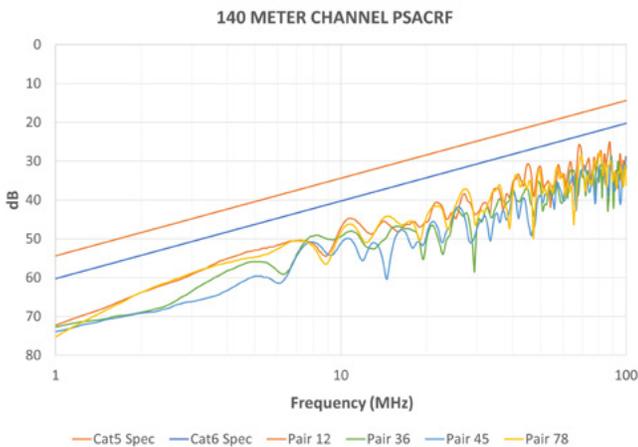


Figure 11: 140-meter channel PSACRF (130-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)

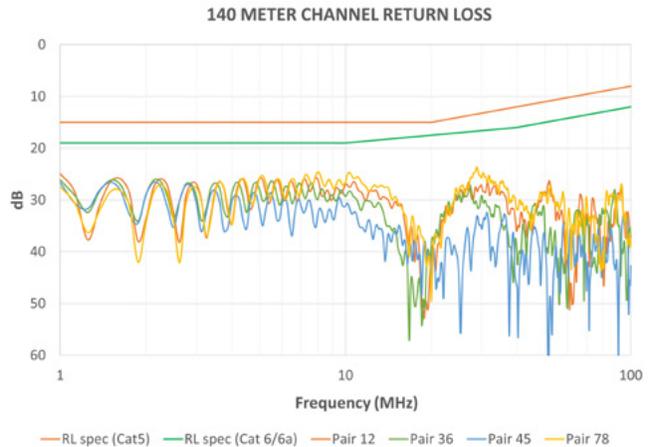


Figure 12: 140-meter channel Return Loss (130-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)

Propagation Delay and Delay Skew Measurements of the 140-meter Channel

Figure 13 shows five of the six pair combinations well within the 50 nanosecond (ns) delay skew limit defined in the standard. The delay skew between the tightest twist (Pair 4,5) and the loosest twist (Pair 7,8) is marginally beyond the limit by 3 ns.

Panduit is confident that due to the strong overall performance of the cable and based on the extensive application testing, this 140-meter channel will support 1000BASE-T.

However, the marginal performance is another reason to be cautious about performance beyond 140 meters as delay skew performance will worsen as channels get longer.

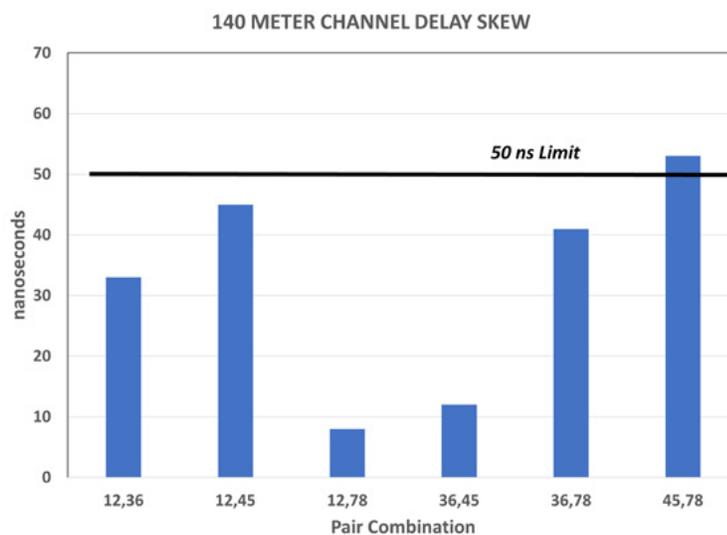
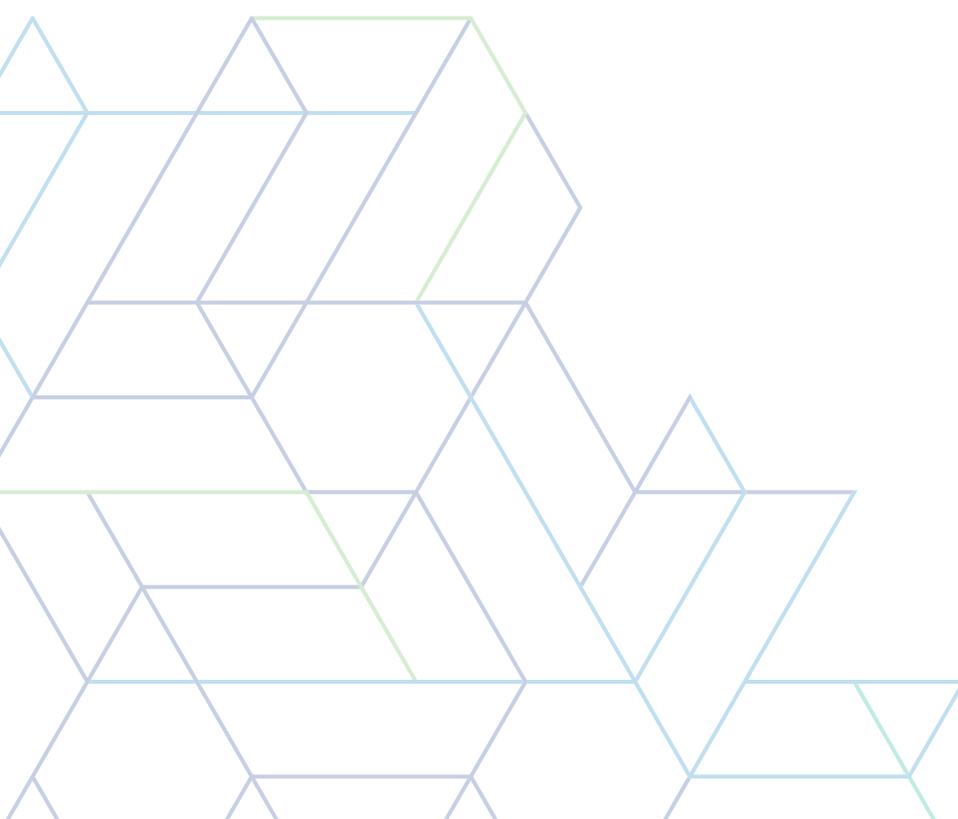


Figure 13: 140-meter channel Delay Skew (130-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)



Power over Ethernet on Extended Reach

Supporting Power over Ethernet (PoE) applications as defined in the IEEE 802.3af, 802.3at, and 802.3bt standards is an important requirement for any modern deployment of BASE-T infrastructure. As channel lengths extend beyond 100 meters, it must be confirmed that cabling PoE requirements are met. The key parameters are:

- Channel DC resistance – the resistance of the channel twisted pair between the transmitter and receiver
- Channel DC resistance unbalance – the difference in resistance between the individual conductors of the twisted pair (i.e., the difference in resistance of wire 1 versus wire 2 in pair 1,2)
- Channel DC pair-to-pair resistance unbalance – the difference between the DC resistance between each of the twisted pairs

Measurements of the 140-meter test channel during Panduit testing (as shown in [Figure 8](#)) are shown in [Figure 14](#), [Figure 15](#), and [Figure 16](#).

As can be seen in the test results, the 140-meter channel will support PoE transmission with no problems.

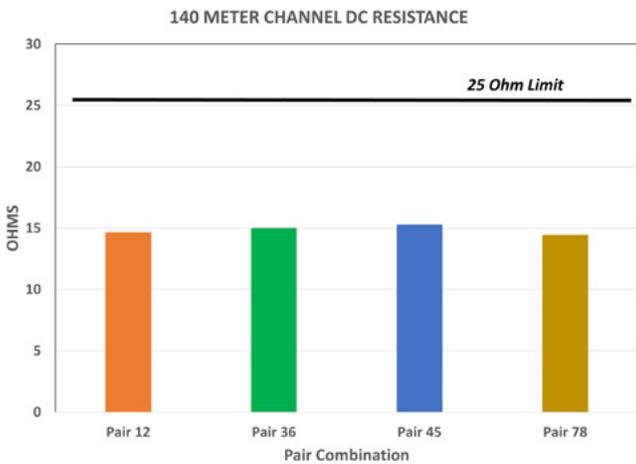


Figure 14: 140-meter channel DC resistance (130-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)

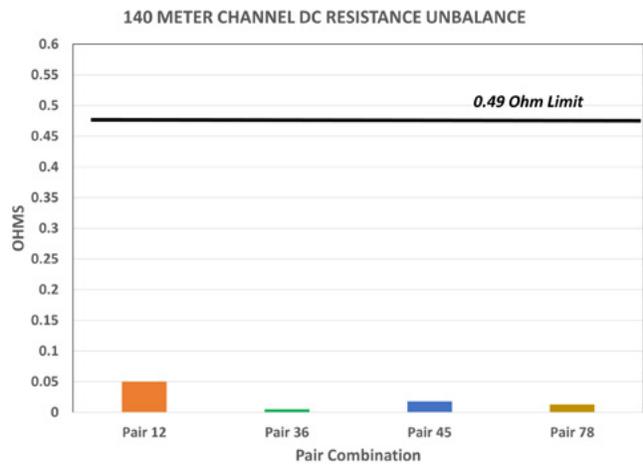


Figure 15: 140-meter channel resistance unbalance (130-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)

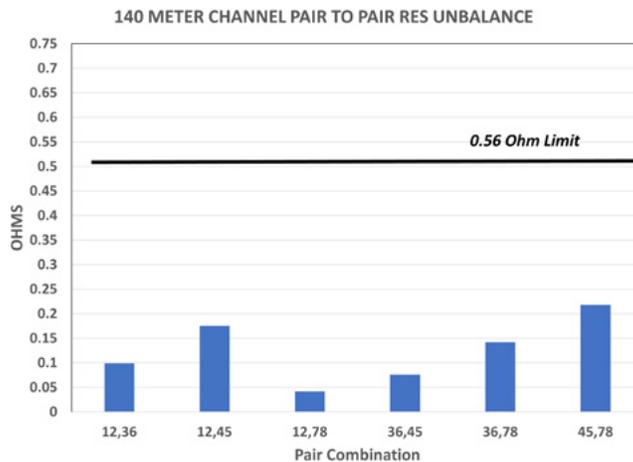


Figure 16: 140-meter channel pair-to-pair resistance unbalance (130-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)

200-meter Channel Problems

Within the industry, claims are being made that 1000BASE-T communication can be extended as far as 200 meters over 22 AWG cabling. This claim is problematic and can create issues for people attempting to install it. The two key parameters of channel insertion loss and delay skew are shown in **Figure 17** and **Figure 18**.

The results are as follows:

- The 200-meter channel grossly fails the 1000BASE-T insertion loss requirements
- The 200-meter channel grossly fails the 1000BASE-T delay skew requirements

As was noted in the prior sections, Panduit testers were not able to get the channel to link up at 200 meters with all equipment when using the Viavi 5800 network tester running the Enhanced RFC 2544.

Hence, while it may be possible to get a link to work depending on the type of equipment deployed, channels that exceed 140 meters have significant risk in terms of being able to create a reliable link.

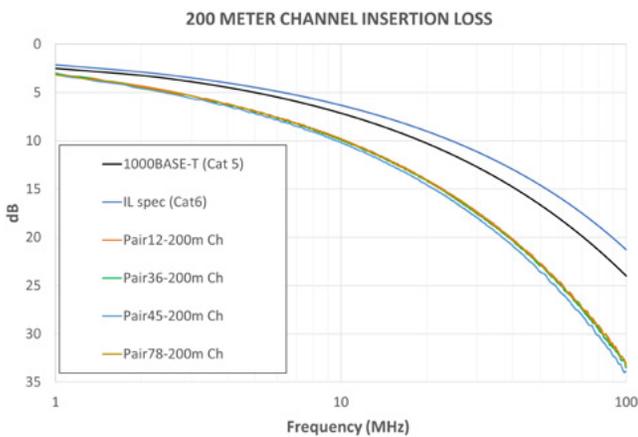


Figure 17: 200-meter channel insertion loss (190-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)

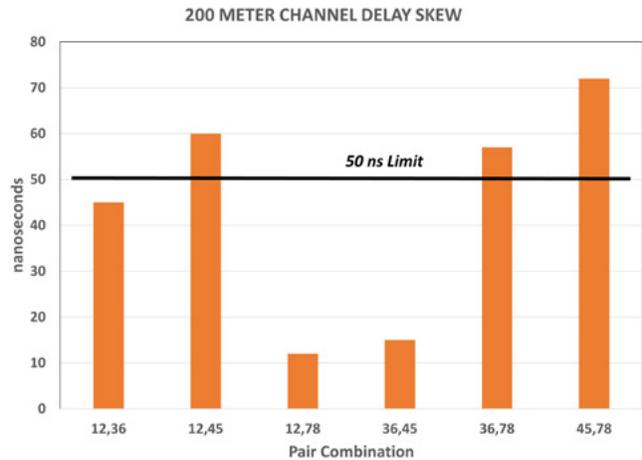


Figure 18: 200-meter channel delay skew (190-meter 22 AWG Category 6 cable, plus 10 meters of 24 AWG Category 6 patch cords)



Conclusion

Panduit has performed both theoretical and experimental validation that a 140-meter multi-connector channel is the maximum length to reliably transmit 1000BASE-T.

- The 140-meter channel was made of a 130-meter 22 AWG Category 6 cable and 10 meters of 24 AWG Category 6 patch cords
- The 140-meter channel was the maximum length where Enhanced RFC 2544 testing with all networking equipment had no throughput degradation and zero frame loss
- The 140-meter channel was also validated by assessing the transmission characteristics versus the 1000BASE-T channel requirements; the 140-meter channel was at about the limit for insertion loss and delay skew, but because of noise improvements with Category 6 and Category 6A cable, it can function at 140 meters
- Channels longer than 140 meters show issues across all tests and cannot reliably pass 1000BASE-T signals without case-by-case engineering evaluation

Therefore, Panduit offers the Panduit Certification Plus Warranty for 1000BASE-T performance on channels up to 140 meters in length, provided the channel meets the parameters outlined in this paper (130 meters of 22 AWG Category 6 or Category 6A cable, plus 10 meters of 24 AWG patch cords), and the channel is installed as outlined in the warranty.

Testing has confirmed additional channel configurations, as outlined in Figure 18.

| Application | Channel Configuration | Maximum Channel Distance @ 20°C Operating Temperature |
|---|---|---|
| 10 Mbps and PoE IEEE 802.3bt (90 Watt) | Direct Attach (plug to plug) | 240 meters |
| 10 Mbps and PoE IEEE 802.3bt (90 Watt) | 2- or 4-connector with maximum 10 meters of Category 6 UTP 24AWG stranded patch cords | 230 meters |
| 100 Mbps and PoE IEEE 802.3bt (90 Watt) | Direct Attach (plug to plug) | 150 meters |
| 100 Mbps and PoE IEEE 802.3bt (90 Watt) | 2- or 4-connector with maximum 10 meters of Category 6 UTP 24AWG stranded patch cords | 140 meters |
| 1 Gbps and PoE IEEE 802.3bt (90 Watt) | Direct Attach (plug to plug) | 150 meters |
| 1 Gbps and PoE IEEE 802.3bt (90 Watt) | 2- or 4-connector with maximum 10 meters of Category 6 UTP 24AWG stranded patch cords | 140 meters |

Longer lengths will be engineered solutions.

*Maximum distance is subject to change based on manufacturer's equipment and other environmental conditions

*Maximum length will be derated when used at higher temperatures

Refer to Panduit technical specifications for other channel configurations and operating temperatures.

Figure 18: Additional channel configurations result in additional reach scenarios.



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