# Testing 10 Gb/s Performance of Category 6 and 6A Structured Copper Cabling Systems within the Unified Physical Infrastructure$^{SM}$ (UPI)

WHITE PAPER

## Introduction

With the ratification of the IEEE 802.3an 10GBASE-T copper standard, end users now have more media options for deploying 10 Gigabit Ethernet (10-GbE) solutions in their network. The standard describes the line-encoding scheme and digital signal processing (DSP) technology required at the silicon level to achieve 10 Gigabits per second (Gb/s), and follows that with electrical requirements for achieving 10 Gb/s data rates over 100m of balanced twisted-pair copper cabling at frequencies up to 500 MHz.

Through these new media, network managers and other IT professionals are finding the implementation of 10 Gb/s more feasible and attractive than ever as part of a Unified Physical Infrastructure℠ (UPI)-based solution. One of the key questions surrounding any innovative technology is how to verify its performance under field conditions. With 10GBASE-T technologies, users specifically are wondering how to determine whether their structured cabling system is reliably achieving the advertised 10 Gb/s performance.

Any discussion of performance testing over this new standard must address the measurement of alien crosstalk (AXT), which is the measure of signal coupling between adjacent channels. This effect is observed over twisted copper pairs only at very high data rates, and is at the center of the IEEE 10GBASE-T standard for signaling performance across copper twisted-pair cabling installations. DSP technologies built into physical layer transceivers and switches are used to manage other forms of electrical interference across the network; unfortunately, they have a limited ability to suppress alien crosstalk because the noise is external to the cabling link.

This white paper reviews the methods and strategies that can be used to certify 10 Gb/s performance over both Category 6 and 6A structured cabling systems to improve network performance over high-speed data transport systems. It describes the two-stage process of testing for both internal channel and between-channel (i.e., “alien crosstalk”) parameters at swept frequencies up to 500 MHz for both systems.

## 10GBASE-T Cabling Standards

At the request of IEEE, TIA/EIA currently is developing two documents that specify 10GBASE-T electrical performance levels:

- TIA/EIA-568-B.2-10 (in draft), to cover both UTP and STP Category 6A cabling systems; and,
- TSB-155 (just completed), which extends TIA/EIA-568-B.2-1, to assess installed UTP and STP Category 6 systems to support 10GBASE-T.

The TIA/EIA-568-B.2-10 draft standard defines an entirely new cabling category, Augmented Category 6 (i.e., Category 6A), and establishes internal and external electrical requirements for channels, permanent links, and components. Category 6A cabling and components are specifically designed to drastically reduce alien crosstalk and to extend usable bandwidth up to 500 MHz. While IEEE 802.3an recognizes that Category 6 cabling systems may support 10 Gigabit Ethernet over limited distances, only Category 6A copper cabling systems will be able to reliably support 10 Gb/s data rates for distances up to 100m.

The TIA/EIA TSB-155 is a guidance document that extends an existing standard, TIA/EIA-568-B.2-1. The document outlines methods to assess the ability of Category 6 channel and permanent links to meet the extended frequencies (250-500 MHz) and additional AXT requirements necessary to support 10GBASE-T operations. Maximum channel-supported distances range from 37-100m over Category 6 UTP and STP cables, depending on such factors as the number and arrangement of channels in the installation across which 10 Gb/s is run, the types of cables and patch cords, and connectors used across channels.

The key similarity of these documents is that they both define channel and permanent link electrical limits and alien crosstalk test methods.

## Testing Stage 1: Internal Channel Parameters

10GBASE-T performance is achieved over copper by using a full-duplex transmission over each of the four twisted pairs. Therefore, the first stage of verifying 10 Gb/s performance over Category 6A and Category 6 structured cabling systems is to test internal channel parameters of all links at swept frequencies up to 500 MHz. These links must meet channel length, configuration, and performance requirements defined in TIA/EIA-568B.2-1 and draft TIA/EIA-568B.2-10 standards, and TSB-155.

**Channel Test Configuration**

TIA/EIA specifies a 100m (328 ft) test channel configuration to be used to verify 1000BASE-T and 10GBASE-T channel performance. A channel may include up to 90m (295 ft) of installed horizontal cable (Figure 1, C + D), an additional up to 10m (33 ft) total of patch cord in the Telecommunications Room and equipment cord at the work area outlet (Figure 1, A + B + E), a telecommunications outlet/connector, an optional transition/consolidation connector, and two connections in the telecommunications room (see Figure 1). TIA/EIA-568-B.2 recommends (and ISO 11801 requires) that the consolidation point be located at least 5m (16.4 ft) from the telecommunications room to reduce the effect on near end crosstalk (NEXT) loss and return loss of multiple connections in close proximity.

TSB-155 states that 10GBASE-T should operate over channel lengths up to 37m over Category 6 cabling; channel length may be extended up to 55m depending on the alien crosstalk environment, and beyond 55m with AXT mitigation techniques (including the use of shielded cabling).

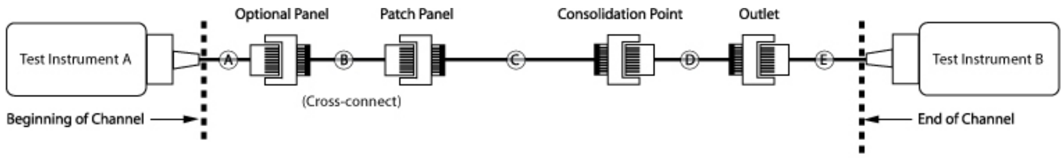


**Figure 1. Channel Configuration under TIA/EIA 568-B.2 Standards**

**Internal Channel Parameters**

Internal channel testing for both Category 6 and 6A cabling systems includes measuring at swept frequencies up to 500 MHz for familiar electrical parameters of propagation delay, delay skew, insertion loss, return loss, near-end crosstalk (NEXT) and its Power Sum (PSNEXT), and attenuation-to-crosstalk ratio at the far end (ACRF) and its Power Sum (PSACRF). The internal channel parameters for 1000BASE-T and 10GBASE-T cabling installations are shown in Table 1.

The most relevant of these parameters to a discussion of 10GBASE-T performance are return loss, NEXT, and ACRF, all of which are shown on Figure 2. Data rates of 10 Gb/s are achieved via full-duplex transmission, and these internal electrical parameters interfere with the required signal-to-noise ratio under full duplex conditions.

Return loss is a measure of the signal that is reflected back to the transmitter due to any impedance mismatches in the cabling link or channel; under full-duplex transmission, signals can be distorted (and reflection generated) at both transmitting and receiving ends. NEXT and ACRF measure signal coupling between twisted pairs within the same cable at the near and far end, respectively, of the full-duplex link or channel. ACRF also accounts for the attenuation factor that occurs as the signal is transmitted across the channel. NEXT, ACRF, and return loss can be suppressed with DSP technologies, unlike alien crosstalk. Note that ACRF and PSACRF are referred to as equal level far end crosstalk (ELFEXT) and its Power Sum (PS ELFEXT) in TIA/EIA-568B.2-1.

**Table 1. TIA/EIA Internal Channel Test Limits Over Category 6 and 6A Cabling**

| Parameter | Category 6 (568-B.2-1) | Category 6 (TSB-155) | Category 6A (568-B.2-10) |
|---|---|---|---|
| Data Rate | 1000BASE-T | 10GBASE-T | 10GBASE-T |
| Frequency Range | 1-250 MHz | 1-500 MHz | 1-500 MHz |
| Length | 100m | 37m* | 100m |
| Propagation Delay | 548 ns @ 100 MHz<br>546 ns @ 250 MHz | 548 ns @ 100 MHz<br>546 ns @ 250 MHz<br>Not specified @ 500 MHz | 538 ns @ 100 MHz<br>536 ns @ 250 MHz<br>536 ns @ 500 MHz |
| Delay Skew | 50 ns | 50 ns | 50 ns |
| Insertion Loss | 21.3 dB @ 100 MHz<br>35.9 dB @ 250 MHz | 21.3 dB @ 100 MHz<br>35.9 dB @ 250 MHz<br>53.4 dB @ 500 MHz | 20.9 dB @ 100 MHz<br>33.9 dB @ 250 MHz<br>49.3 dB @ 500 MHz |
| Return Loss | 18.6 dB @ 100 MHz<br>8.0 dB @ 250 MHz | 12.0 dB @ 100 MHz<br>8.0 dB @ 250 MHz<br>6.0 dB @ 500 MHz | 12.0 dB @ 100 MHz<br>8.0 dB @ 250 MHz<br>6.0 dB @ 500 MHz |
| NEXT | 39.9 dB @ 100 MHz<br>33.1 dB @ 250 MHz | 39.9 dB @ 100 MHz<br>33.1 dB @ 250 MHz<br>22.0 dB @ 500 MHz | 39.9 dB @ 100 MHz<br>33.1 dB @ 250 MHz<br>26.1 dB @ 500 MHz |
| PSNEXT | 37.1 dB @ 100 MHz<br>30.2 dB @ 250 MHz | 37.1 dB @ 100 MHz<br>30.2 dB @ 250 MHz<br>20.4 dB @ 500 MHz | 37.1 dB @ 100 MHz<br>30.2 dB @ 250 MHz<br>23.2 dB @ 500 MHz |
| ACRF (ELFEXT) | 23.3 dB @ 100 MHz<br>15.3 dB @ 250 MHz | 23.3 dB @ 100 MHz<br>15.3 dB @ 250 MHz<br>9.3 dB @ 500 MHz | 23.3 dB @ 100 MHz<br>15.3 dB @ 250 MHz<br>9.3 dB @ 500 MHz |
| PSACRF (PSELFEXT) | 20.2 dB @ 100 MHz<br>12.3 dB @ 250 MHz | 20.2 dB @ 100 MHz<br>12.3 dB @ 250 MHz<br>6.3 dB @ 500 MHz | 20.2 dB @ 100 MHz<br>12.3 dB @ 250 MHz<br>6.3 dB @ 500 MHz |

*TSB-155 states that 10GBASE-T should operate over channel lengths up to 37m over Category 6 cabling; channel length may be extended up to 55m depending on the alien crosstalk environment, and beyond 55m with AXT mitigation techniques.

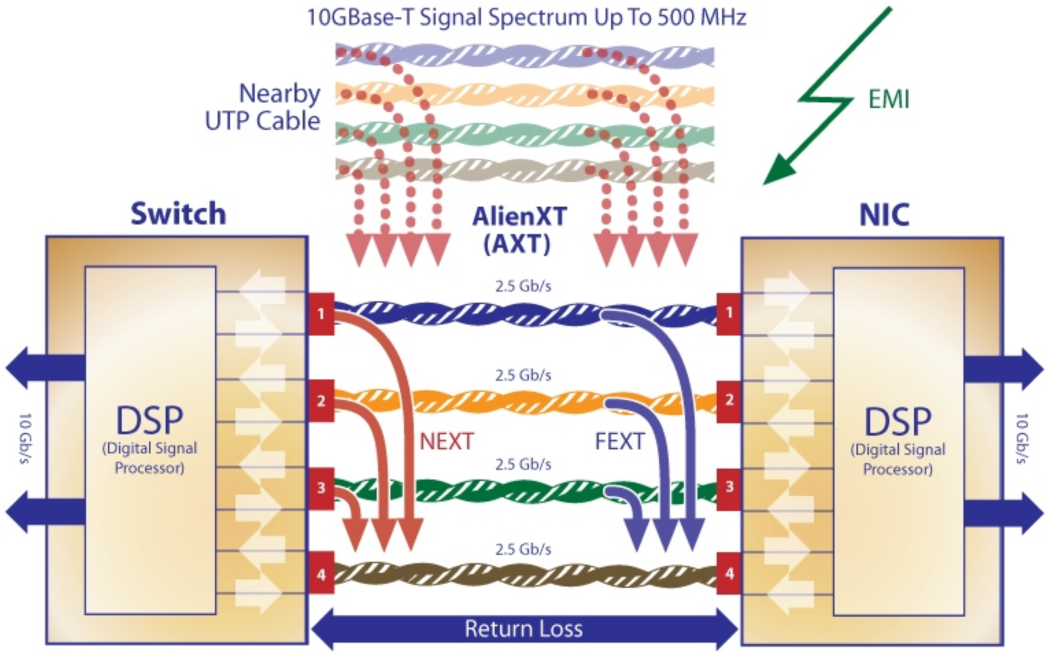


**Figure 2. Key Electrical Parameters to be Tested to Verify 10 Gb/s Performance**

## Testing Stage 2: PSANEXT and PSAACRF (PSELFEXT)

The second (and far less familiar) stage of certifying 10 Gb/s performance over twisted-pair copper is to measure between-channel alien crosstalk (AXT) parameters. Like internal channel crosstalk measurements, AXT is measured both at the near end (ANEXT) and at the far end (AACRF).

The 10GBASE-T standards identify separate laboratory and field testing procedures for both Category 6 and 6A systems. Using a network analyzer in a lab environment is the most accurate method of measuring AXT, as laboratory testing procedures are able to simulate worst-case alien crosstalk scenario for any given cabling installation, and cables in the field should never be bundled any tighter than in a lab test.

### Testing Twisted Pairs in the Lab

In the laboratory, both TIA-EIA-568-B.2-10 and TSB-155 require that alien crosstalk be measured in a 6-around-1 cabling configuration in order to take into account the worst-case effect on a center "target" cable with six "disturber" cables tightly bundled around it (see Figure 3). This configuration assumes that cables not in direct contact with the center cable will generate much lower levels of alien crosstalk, and therefore the crosstalk contributions of these cables is insignificant.

Also, cables should be bundled (with cable ties or reusable hook and loop ties) every 8 inches except for the last 3.3 feet from each end. Worst-case maximum and minimum channel-length configurations should be tested in order to determine the worst case for different crosstalk parameters:

- Long channels (90m permanent link, 10m patch cords, 5m between consolidation point and outlet)
- Short channels (15m permanent link, 4m patch cords, 5m between consolidation point and outlet)

A total of 96 measurements are taken for each “target” cable tested in this configuration: each disturber cable contains four twisted pairs, each of which contribute a crosstalk amount to the four twisted pairs in the target cable, and these 16 crosstalk measurements must be taken for all six “disturber” cables.

To best assess the combined impact of each six-around-one channel tested, both TIA/EIA-568-B.2-10 and TSB-155 specify that overall alien crosstalk noise be measured as the calculated Power Sums of all external cabling pairs on the target pair at swept frequencies to 500 MHz. Specifically, the parameters are Power Sum Alien Near-End Crosstalk (PSANEXT); and Power Sum Alien Attenuation to Crosstalk Ratio at the Far-End (PSAACRF), which is the term used in both standards for the Power Sum of alien crosstalk at the far end.

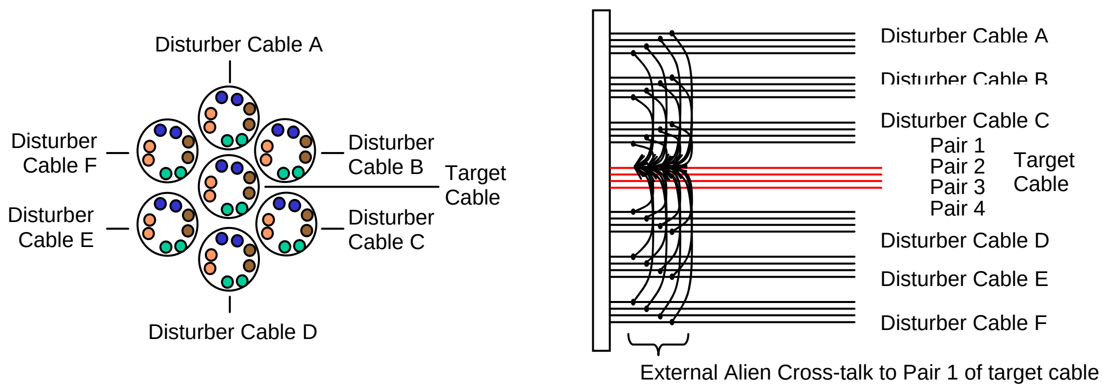


**Figure 3. Example 6-Around-1 Testing Configuration.** The left diagram shows a cross-sectional view of 6-around-1 configuration, and the right figure shows how alien crosstalk is measured in this tightly bound group.

**Testing Twisted Pairs in the Field**

While testing for alien crosstalk in a lab environment is fairly straightforward, field-certifying 10 Gb/s performance over twisted-pair cabling presents a challenge in terms of complexity and time. For one thing, the 6-around-1 test configuration is not useful for field testing, because the position of cable bundles in the field can change, and the percentage of installed cables that happen to lie in an exact 6-around-1 geometry is very small.

In field testing, for each target and disturber cable pair tested, the operator must plug in both ends of adjacent cables to a hand-held field tester, run the test to measure ANEXT and AACRF, download the results to calculate PSANEXT and PSAACRF, and then repeat for all cables to be tested in a given bundle. The field test equipment used to certify both Category 6A and 6 cabling installations must meet the accuracy requirements for Level IIIe field testers (i.e., Fluke Networks DTX-1800 series cable analyzer or equivalent).

Work conducted by *PANDUIT* Laboratories to test 10GBASE-T installations using hand-held equipment conservatively estimated that it takes approximately 15 minutes under optimal field conditions to measure 96 pair-to-pair ANEXT and AACRF crosstalk combinations between one target cable and six disturbing cables and calculate PSANEXT and PSAACRF. Therefore, for a 24-cable bundle, the time to test one target link against all 23 disturber cables would be approximately 60 minutes under optimal conditions.

Labor costs can climb due to any extra time required to correctly identify the cables to be tested. Even with well-labeled cabling, it takes time for field technicians to identify the right cables to be tested in bundles of 12 to 24, and poorly-labeled cabling adds to the potential for human error.

Clearly, for installations comprised of hundreds or thousands of links, testing every cable in every bundle is an unacceptable strain on time and budget. In general, only links in the same cable bundle are expected to contribute a measurable amount of alien crosstalk, so testing of links in nearby bundles is not required for 10 Gb/s certification. For practical field certification efforts, the key is to develop a test strategy that (1) limits the number of links in a bundle to be tested, and (2) focuses those tests on links most likely to be the weakest-performing.

(1) Limiting the number of links to be tested reduces the amount of time spent testing while evaluating only worst-case links. For example, Fluke Networks recommends sampling either 1% of the total number of links in a cabling installation, or five links, whichever is greater. Table 2 lists estimated times to test cabling systems of various sizes under this strategy.

(2) The signal-to-noise ratio due to alien crosstalk interference is least favorable for the longest links; the signal has endured the greatest amount of attenuation and therefore arrives weakest at the end of the link. Also, near-end alien crosstalk loss occurs within the first 20-40m of the cabling link. Therefore, for testing, select the longest links in the installation as well as shorter links with the shortest distance between connectors. These are considered the links most likely to have the highest AXT levels as measured by the PSANEXT and PSACCRF parameters. If these worst-case links pass, then one can conclude with a high level of confidence that other, less challenged links will also pass and very likely with better margins. Recall that all links should have passed the in-channel performance requirements tested from 1-500 MHz. The in-channel tests verify that the component performance is high and the workmanship of the installation has been properly executed.

**Table 2. Estimated Times to Certify Category 6 or 6A Cabling Installation**

| Number of Links in Installation | Stage 1: Internal Channel Test Time (hrs) | Stage 2: Between Channel | | | Overall Time to Certify (hrs) |
|---|---|---|---|---|---|
| | | Target Links | Bundle Size | Test Time (hrs) | |
| 100 | 1 | 5 | 12 | 2.5 | 3.5 |
| | | 5 | 24 | 5 | 6 |
| 750 | 5.5 | 8 | 12 | 4 | 9.5 |
| | | 8 | 24 | 8 | 13.5 |
| 1000 | 11 | 10 | 12 | 5 | 16 |
| | | 10 | 24 | 10 | 21 |

TIA/EIA-568-B.2-10 and TSB-155 suggest channel and permanent link configurations for field testing of alien crosstalk (see Figures 4 and 5), while allowing that other testing configurations may provide acceptable results. Structured cabling manufacturers also may identify workable field test configurations and methods in their warranty materials.

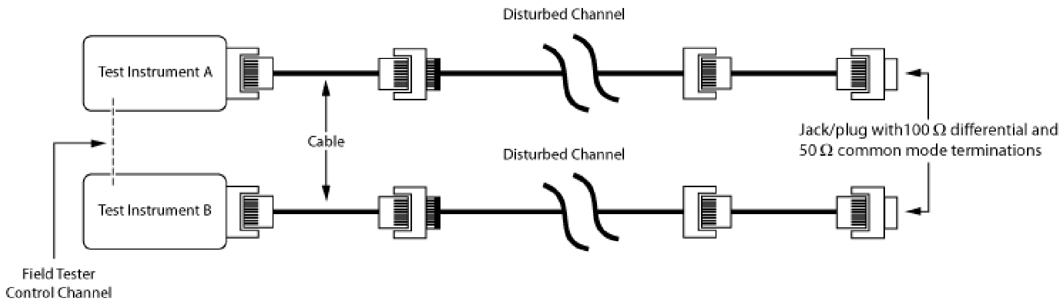


**Figure 4. TIA/EIA Recommended Configuration for Field Testing of ANEXT**

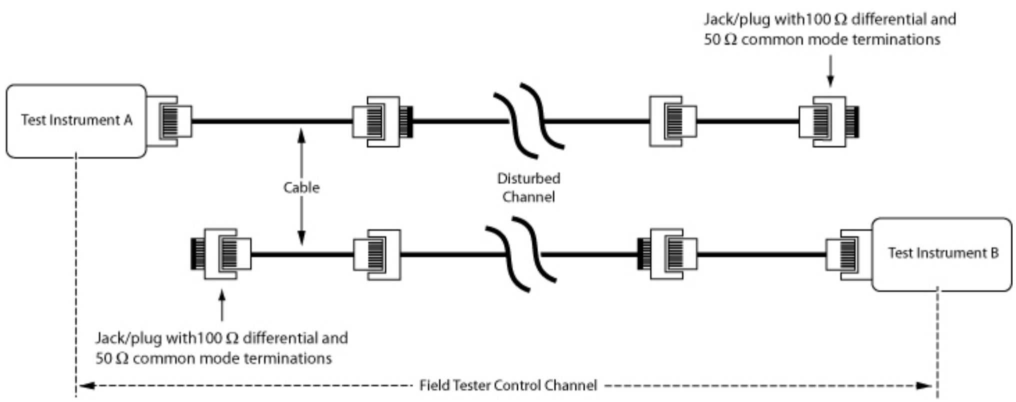


**Figure 5. TIA/EIA Recommended Configuration for Field Testing of AACRF**

**AXT Mitigation Techniques for Category 6 Systems**

Traditionally, Category 6 cabling has been specified and tested up to 250 MHz. These systems only achieve 10GBASE-T compliance over channel lengths when the cabling meets internal as well as alien crosstalk specifications up to 500 MHz, as defined in the TSB-155 guidance document.

From a testing strategy perspective, TSB-155 provides the following special considerations to verify 10GBASE-T performance over Category 6 cabling:

- Only test links that are intended to support 10GBASE-T;
- Test disturber links that are terminated adjacent to target links on patch panels or other connecting hardware;
- Consider testing multiple cabling channels or permanent links located close to each other;
- Calculate and monitor PSANEXT and PSAACRF levels until all likely disturber cables across a specific cabling topology have been measured.

Based on field-testing measurements, if a Category 6 cabling system does not meet the electrical requirements for supporting 10GBASE-T applications, TSB-155 provides guidelines designed to mitigate the alien crosstalk between the target pair and the disturbing pairs of Category 6 channels and permanent links. Annex B of TSB-155 outlines the following mitigation actions most appropriate for individual situations:

- Use Category 6 shielded or Category 6A patch cords;
- Replace Category 6 connectors with Category 6A connectors;
- Use non-adjacent patch panel positions;
- Separate equipment cords and patch cords;
- Unbundle or more loosely bundle the horizontal cabling; and
- Reconfigure the cross-connect as an interconnect.

## PANDUIT Products Help Reduce AXT

Another way to mitigate alien crosstalk is to use cabling products designed to be robust against its effects. Because 10GBASE-T transceivers cannot detect and compensate for noise from adjacent channels, Category 6A cabling and connectivity products are specifically designed to suppress this effect within a structured cabling system in order to ensure reliable 10 Gb/s data rates. All *PANDUIT TX6™ 10GIG*™ UTP and Shielded Copper cables, jacks, and patch cords are factory tested for key internal parameters to 500 MHz so that each component contributes to optimal 10 Gb/s channel performance (*TX6000*™ and *TX6500*™ Category 6 cable is factory tested to 250 MHz).

**UTP Cabling Systems**

With Category 6A UTP cabling, such as the *PANDUIT TX6™ 10GIG*™ UTP Copper Cabling System, *PANDUIT* Laboratories designed innovative features to reduce alien crosstalk into both the cable, such as increased separation between cables and tighter twist rates; and the connectors, such as crosstalk suppression within the printed circuit boards. These enhancements help installations comply with 10GBASE-T standard PSANEXT and PSAACRF specifications for achieving a reach of 100m.

**Shielded Cabling Systems**

Category 6A shielded and UTP cabling systems have comparable electrical performance for internal noise and crosstalk within a channel (see Figure 6). However, more importantly, the foil screens on (properly installed and bonded) Category 6A shielded cabling prevent signal coupling between cables to reduce alien crosstalk well below IEEE 802.3an specifications for PSANEXT (see Figure 7) and PSAACRF. This impact is similar whether the cable is comprised of individual shields around each pair, as in U/FTP and S/STP cables, or of a single foil around all pairs, as in F/UTP cables. Performance is generally at least 20 dB better than Category 6A UTP systems, leaving more headroom for 10 Gb/s applications and eliminating the need for cumbersome and time-consuming AXT field-testing. The foil shields also act as a barrier to prevent coupling of EMI/RFI from the environment (i.e., cell phones, radios, wireless access points) onto twisted-pair bundles.

The steps of bonding shielded cable to connectivity components and of properly designing and installing the power cabling system are essential to ensure proper performance. 10GBASE-T applications are very sensitive to noise, so potential differences in electrical grounds can result in a ground loop and cause bit-error-rates high enough to affect 10-GbE traffic. The *PANDUIT TX6™ 10GIG*™ Shielded Copper Cabling System has been designed for consistent seamless bonding when used with the *PANDUIT STRUCTUREDGROUND*™ Grounding Solutions. The components essentially are self-grounding with minimal additional cost. (UTP cabling systems are not bonded together and do not form an electrical loop, so the possibility of forming a ground loop does not exist.)

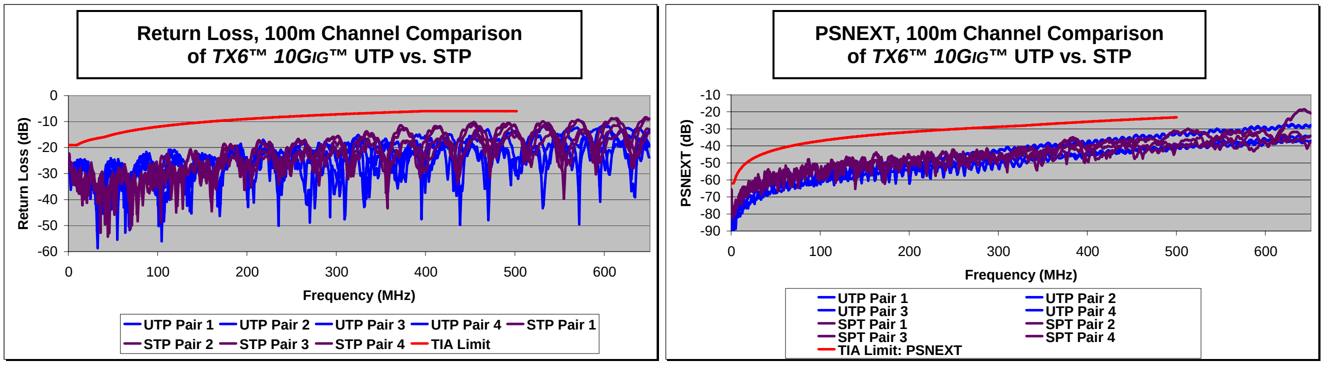


**Figure 6. Performance of *TX6™ 10GIG™* Category 6A Cabling for Internal Parameters of Channel Return Loss and Power Sum Near-End Crosstalk**

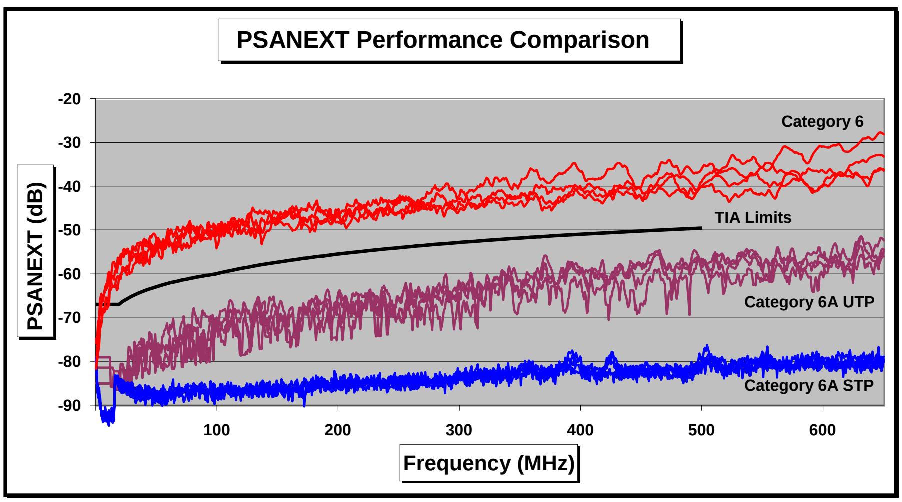


**Figure 7. Performance Comparison of Category 6 and 6A Cabling Types for PSANEXT over 100 m**

## Conclusion

10GBASE-T is an exciting, emerging technology that will provide end users cost-effective media to achieve 10 Gb/s data rates. The technology offers benefits of higher bandwidth and scalability at lower cost than existing 10 Gb/s connectivity solutions, but also presents new challenges for field testing.

Methods for verifying the performance of 10GBASE-T installations are complicated by the need to account for crosstalk between adjacent cables, as opposed to crosstalk within the same cable. As a consequence, field testing methods are becoming more sophisticated and time consuming. Available field testing equipment is limited as testing technology catches up to advances in speed and bandwidth. Also, the time involved to test for AXT in the field is so great that it is only practical to test a percentage of links for this electrical parameter (i.e., some or all of the estimated worst-case links, depending on time and resources).

One option available to customers is to install a shielded cabling solution, which prevents signal coupling between adjacent cables and eliminates the need for field testing of AXT. The other option is to install an unshielded solution, which would involve lower installation costs and fewer associated bonding and grounding requirements.

For unshielded solutions, laboratory testing for AXT is an accurate way to measure 10 Gb/s system performance because it tests links under worst-case (i.e., 6-around-1) conditions. If unshielded links pass laboratory tests, it can be assumed that the links will operate at 10 Gb/s in the field. All *PANDUIT* 10 Gb/s copper cabling systems comply with 10GBASE-T performance standards over a 4-connector channel up to 100m for Category 6A cabling. *PANDUIT* Category 6 copper cabling systems are capable of operating at 10 Gb/s up to 37m.

Because *PANDUIT* Laboratories tests 10 Gb/s copper cabling systems to comply with worst-case alien crosstalk requirements, and because field testing for AXT is onerous, *PANDUIT* does not require field alien crosstalk (ANEXT and AACRF) testing of its 10 Gb/s solutions in order for a system to be eligible for a performance-based system warranty. To qualify, each cabling system must be installed and independently verified by a *PANDUIT* Certified Installer (PCI) to the following specifications:

- For *PANDUIT TX6™ 10GIG™* UTP and Shielded Copper Cabling Systems, each channel must be tested at swept frequencies up to 500 MHz for internal channel performance parameters as defined in IEEE 802.3an and TIA/EIA-568B.2-10.
- For *PANDUIT TX6000™* and *TX6500™* Category 6 cabling solutions, each channel must be tested (and existing channels re-tested) at swept frequencies up to 500 MHz for internal channel performance parameters as defined in IEEE 802.3an and TSB-155.

For customers who feel that field testing is necessary to verify the 10 Gb/s performance of their structured cabling system, it is recommended that testing be carried out since methods for testing AXT in the field are accurate and effective.

## About *PANDUIT*

*PANDUIT* is a world-class developer and provider of leading-edge solutions that help customers optimize the physical infrastructure through simplification, increased agility and operational efficiency. *PANDUIT's* Unified Physical Infrastructure (UPI) based solutions give Enterprises the capabilities to connect, manage and automate communications, computing, power, control and security systems for a smarter, unified business foundation. *PANDUIT* provides flexible, end-to-end solutions tailored by application and industry to drive performance, operational and financial advantages. *PANDUIT's* global manufacturing, logistics, and e-commerce capabilities along with a global network of distribution partners help customers reduce supply chain risk. Strong technology relationships with industry leading systems vendors and an engaged partner ecosystem of consultants, integrators and contractors together with its global staff and unmatched service and support make *PANDUIT* a valuable and trusted partner.

www.panduit.com · cs@panduit.com · 800-777-3300