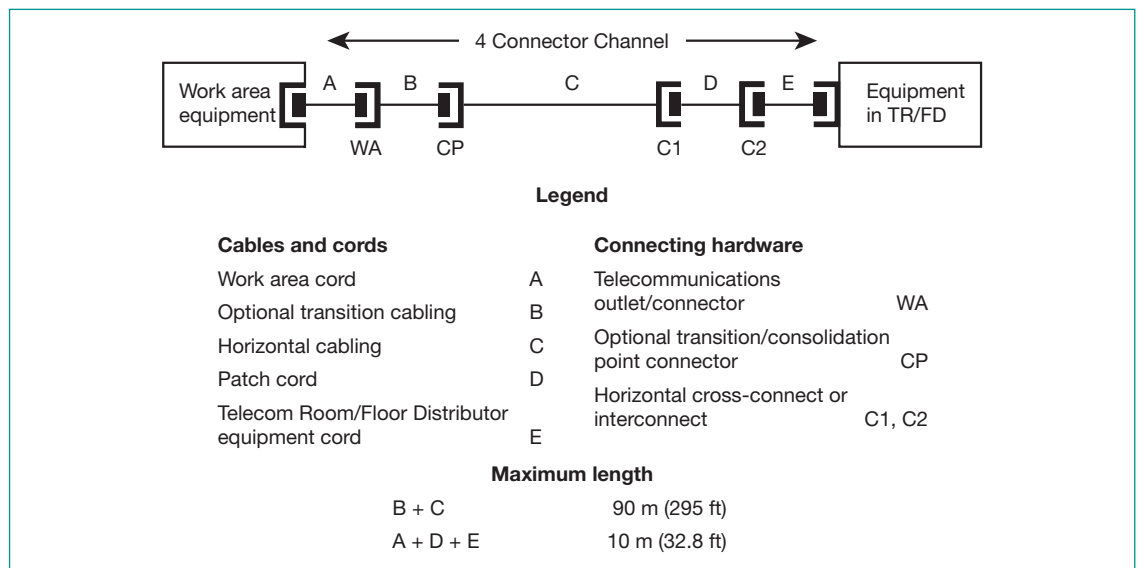


10 Gigabit UTP Cabling Performance Explained

Until the advent of the Category 5 systems and cabling standards, LAN performance was limited primarily by the building cabling and the ability of the LAN equipment to properly decode the signals that were distorted by the cabling. The improvement in performance seen with Category 5 at the time alleviated this issue. However as LAN speeds continued to increase, a similar issue emerged as equipment designers tackled the requirement to support gigabit speeds over the infrastructure, hence the move to Category 5e and 6 specifications. Now, as LAN speeds increase to 10 Gb/s and cable and connector technology inevitably improve, the LAN designer must account for the impact that all channel components and their installation, have on performance.

The SYSTIMAX[®] GigaSPEED[®] X10D Solution has been specifically engineered with enhanced cable and connector performance designed to support the emerging 10 Gb/s Ethernet requirements. Using patented technology and the scientific capabilities of SYSTIMAX Labs, the GigaSPEED X10D Solution exhibits far superior channel performance for legacy solutions and innovative engineering techniques to meet the specific demands 10 Gb/s brings to the physical layer. The GigaSPEED X10D Solution exceeds the draft IEEE requirements for 10GBASE-T over UTP and the proposed TIA/EIA Category 6A and ISO/IEC Class E_x channel performance specifications up to 500 MHz.

The cabling implementation used to define end-to-end performance is a 4-connector channel. This portion of the cabling system referred to as the Horizontal sub-system, (between the floor distributor and the work area) is the area where most debate over LAN and cabling performance occurs.



The data carrying capacity of a structured cabling system is affected by a number of impairments introduced into the channel by the system components and their surrounding environment. Several of the impairments that negatively impact the throughput of a structured cabling system are listed below.

- External Noise
- Delay and Delay Skew
- Insertion Loss/Attenuation
- Impedance Mismatch/Return Loss
- Crosstalk

These potential impairments can cause bit errors, which can reduce the overall throughput of a structured cabling system channel. Bit-Error-Rate (BER) is the ratio of the number of incorrectly received bits to the number of bits transmitted. The need to minimize bit errors in order to maximize throughput, is critical as high-speed, bandwidth intensive applications emerge. In data applications, higher BER results in slower network performance due to signal retransmissions. In video applications, higher BER results in choppy displays, missed frames and the creation of white speckles (snow). In each application area, higher BER results in unsatisfactory performance.

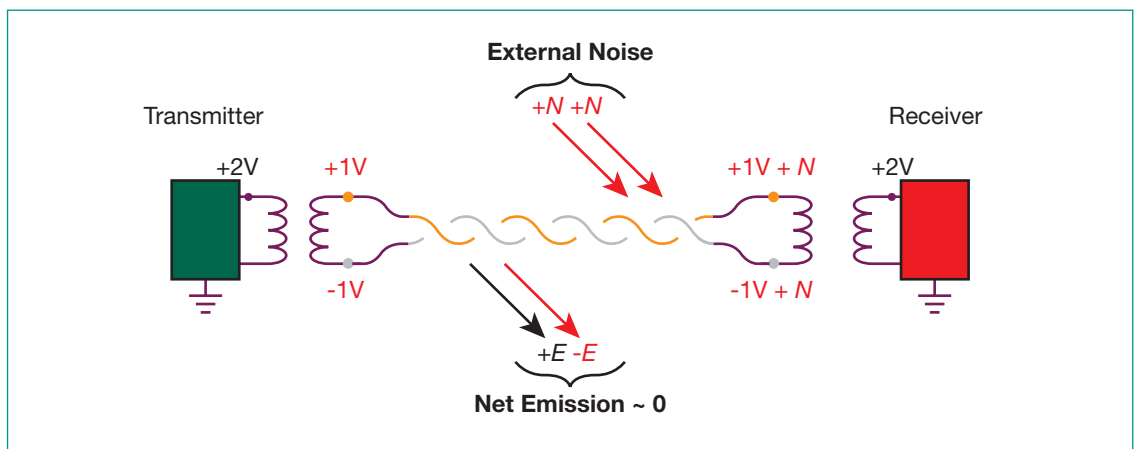
The key cabling parameters are Impedance, Channel Return Loss, Insertion loss and Crosstalk, and an understanding of these is essential in assessing this cabling system's full potential.

External Noise

Noise is coupled into the channel via external electrical and magnetic fields located in the vicinity of the channel. A non-direct discharge of Electro Static Discharge (ESD) or an Electrical Fast Transient (EFT) event is an example of an external noise source. With the GigaSPEED X10D cabling system, this is overcome by the products having excellent balance.

Balance is the degree to which the signal on one wire of a pair is equal in amplitude, but opposite in phase on the other wire of that same pair. Each signal is measured relative to earth ground. Assuming that the signal is applied in a perfectly balanced manner, the average voltage is zero. However, the balance can be disturbed. Main causes for this balance disruption are the connectors in the link.

Balanced Channel



When the channel is not well balanced (for example, the shielding of cables degrades balance), there is a voltage present between the pairs that will be added to the transmitted signal as common mode noise, thus increasing the occurrence of bit errors. The system will depend then on the Common Mode Rejection (CMR) of the receiver to get rid of any effects. Furthermore, unbalance increases emissions and degrades immunity.

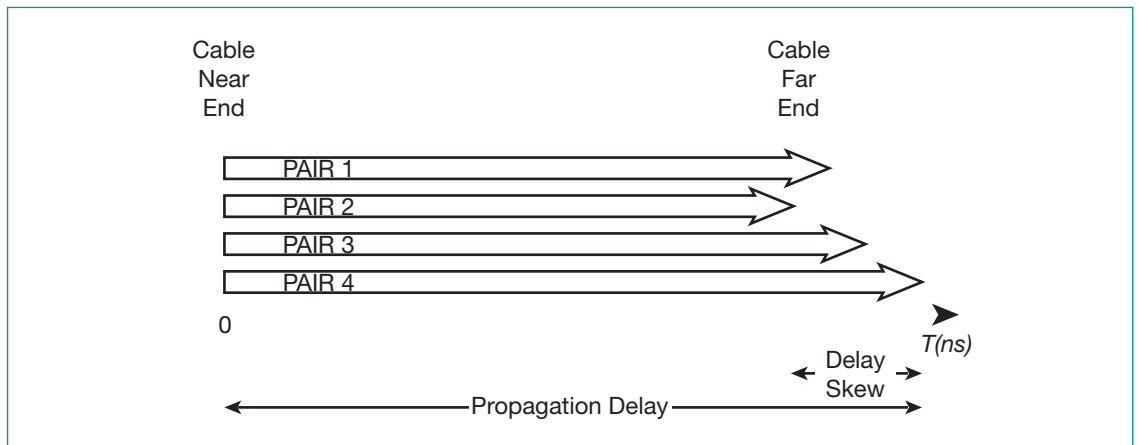
In LAN environments, the use of balanced transmission with well balanced electronics and cables eliminates the need for shielding the pairs as a measure against external interference and radiated emission, without the extra concerns of earthing and bonding. Since grounding and earthing requirements differ from one country to another, the only truly 'portable' and 'open' cabling system is the UTP cabling system.

Delay and Delay Skew

A signal travelling from end-to-end of a cabling channel is delayed in time by an amount equal to the length of cable divided by the velocity of propagation for that transmission medium. This delay is called Propagation Delay. For practical cables, the velocity of propagation depends on the properties of dielectric materials surrounding the conductors. The cable propagation delay is characterized by the worst case pair.

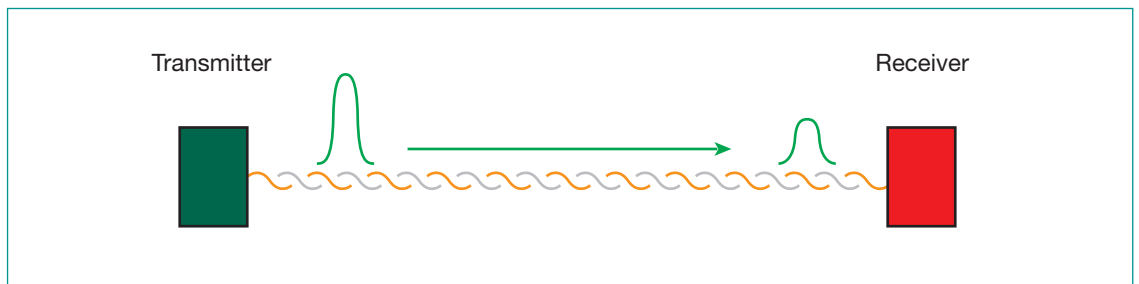
Delay Skew is the difference in propagation delay between any two pairs within the same cable sheath. This parameter is length dependent and it is possible for a shorter length to pass when it fails at 100 meters. Variations in twist rates, coupled with the dielectric composition of the pairs determine skew, which is expressed in seconds.

Minimizing delay skew is critical for applications that require signals to be transmitted over multiple twisted-pairs and arrive at the receiver end of a channel at the same time.



SYSTEMAX GigaSPEED X10D channels have excellent margin for propagation delay and delay skew.

Insertion loss/Attenuation



Insertion loss, also known as attenuation, is the loss or diminishing of a signal when it passes through a transmission medium. Loss occurs in any type of transmission medium. The effect of insertion loss is important because this primarily determines the maximum distance that two devices can be separated.

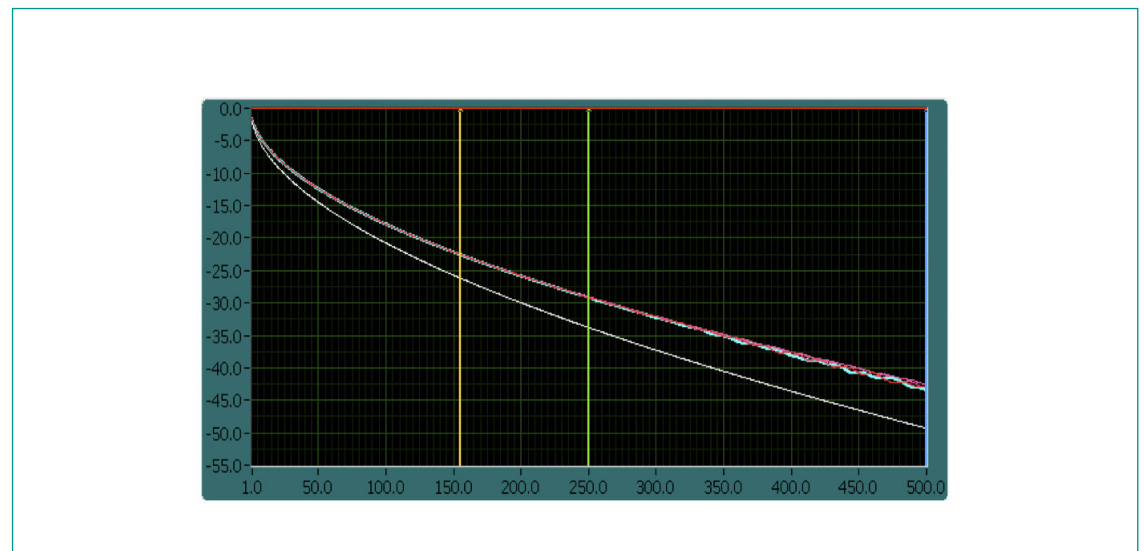
Insertion loss in copper wire is caused by two factors:

- Copper loss, which is unavoidable and similar for all 100 Ohm twisted pairs. This cannot increase significantly because of the limitations on size of insulated wire to be inserted into an RJ45 connector. Hence dramatic increases in attenuation would only be achievable with adoption of a new connector - not wanted by most users.
- Dielectric loss, or dissipation, due to the insulation and jacketing materials used on the conductors and the cable. Minimizing the dissipation loss of the insulating and jacketing materials is important to minimize the cable's attenuation. The dissipation factor is a relative measurement of a material's loss.

Insertion loss is usually expressed in dB per unit length (e.g., dB/1,000 feet) and is a measure of how much a signal is weakened or reduced in amplitude as it travels down a cable.

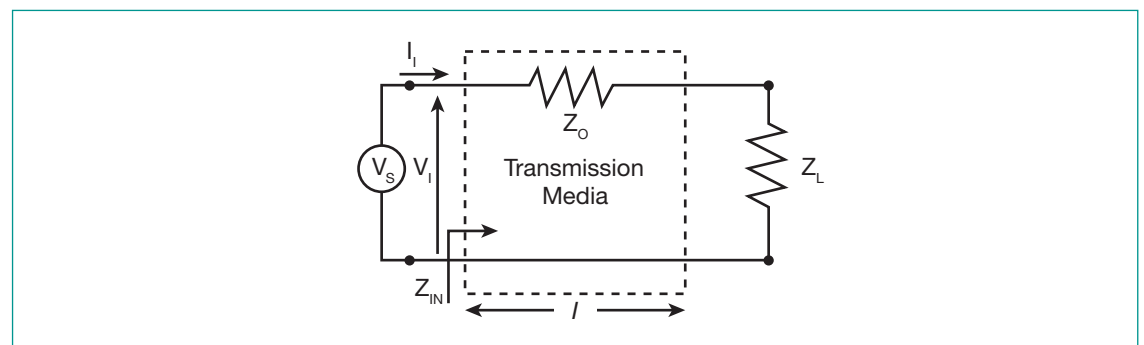
Insertion loss is a key parameter in deciding the available bandwidth used for 10GBASE-T, and the excellent insertion loss of the GigaSPEED X10D Solution is shown in Graph 1.

Graph 1: Typical Insertion Loss Performance of the GigaSPEED X10D Solution vs ISO Class E_a Limits



Impedance Mismatch/Return Loss

Characteristic Impedance corresponds to the input impedance of a uniform transmission line of infinite length:

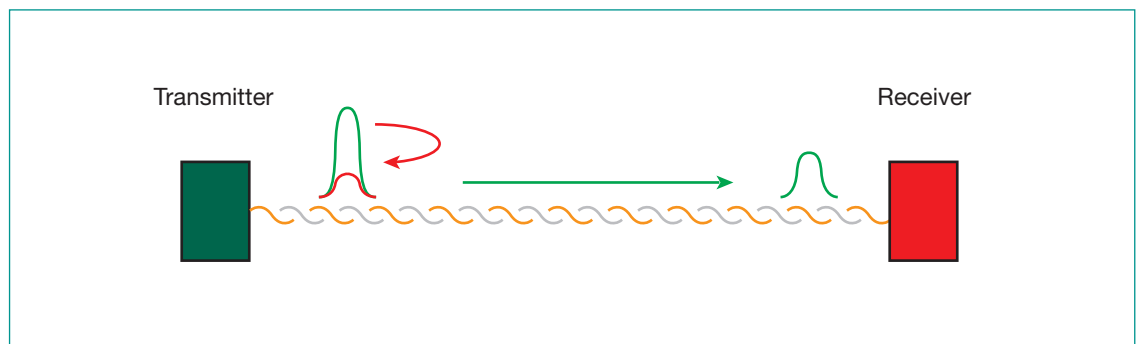


It also corresponds to the input impedance of a transmission line of finite length that is terminated in its own characteristic impedance. It is a function of cable construction and the frequency of the applied signal and is unrelated to length. At very high frequencies, the characteristic impedance tends to a fixed value that is resistive. For example, twisted-pair telephone cables have an impedance of 100 ohms above 1MHz.

Maximum power is transferred from the source to the load when the load impedance Z_L is equal to the transmission line characteristic impedance Z_0 . Expressed differently, all the energy is transmitted and none of the energy is reflected back at the cable termination. When the terminating or load impedance is different than the characteristic impedance, the signal traveling to the cable is partially reflected at the cable/load junction. The power of the reflected signal is called the Return Loss (R) in dB.

When the geometry of the cable varies along the length, so does its impedance. This fluctuation in impedance also causes reflections.

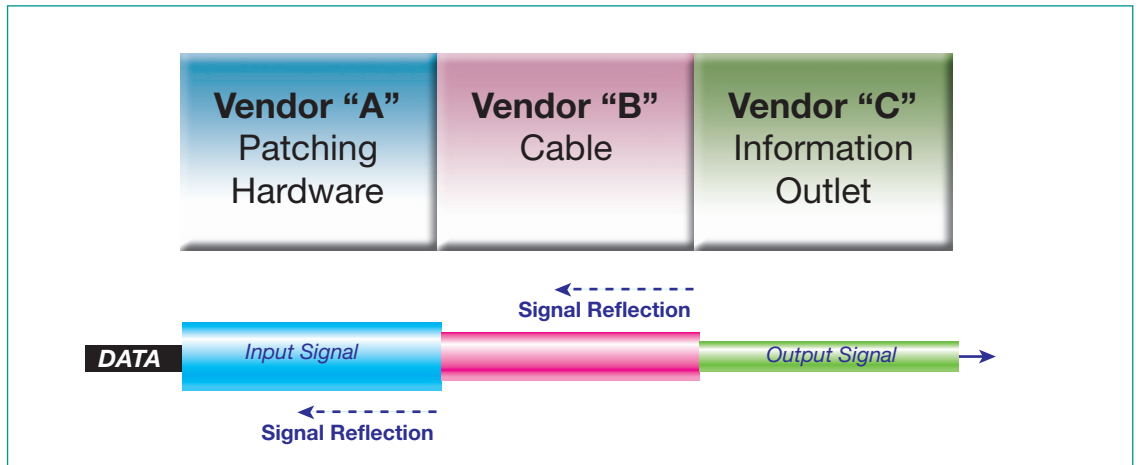
The Channel Return Loss (RL) is a measure of the consistency of the impedance down the length of not just the cable, but also the connections and the patch cables. The parameters that affect channel uniformity include the average separation distance between the two conductors of a pair, the twist uniformity of the pair and cross-sectional uniformity of the insulated cores themselves. These parameters are very much measures of the quality of manufacturing of the cables, connectors and patch cords. Even small variations in these parameters will significantly degrade RL performance.



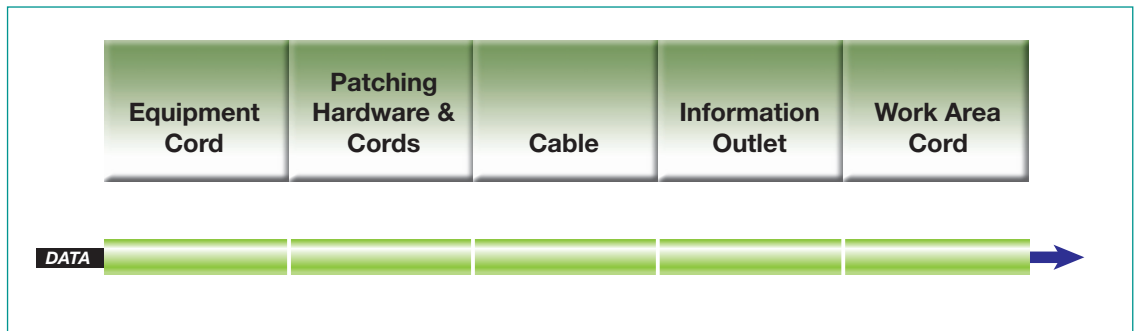
The reason why RL is of concern is that the variation in impedance down the channel causes a form of noise at the receiver. It is therefore important to control the allowable non-uniformity's to ensure that their effect is small compared to other sources of noise, such as crosstalk. Return loss is important for bi-directional transmission schemes (dual duplex) where one pair is used to transmit and receive at the same time. Note that a transmission scheme can be full duplex without being dual duplex (e.g. transmit on one pair, receive on another pair).

Minimizing impedance mismatch within a channel becomes important when attempting to support an application such as 1000BASE-TX or 10GBASE-T that employ a hybrid function in the interface circuitry. The hybrid function is used to achieve full-duplex (bi-directional) transmission of data information. The hybrid circuitry presents four pairs of terminals so arranged that a signal entering at one terminal pair will divide and emerge from the two adjacent pairs but will be unable to reach the opposite terminal pair. It is critical that the hybrid and channel impedance match otherwise echoes, representing transmitted energy that is reflected back, will be generated and appear as noise at the receiving circuitry. Echo cancellation circuitry is incorporated into the 1000BASE-TX and 10GBASE-T interface circuitry in order to significantly reduce echoes resulting from the hybrid function.

A channel composed of cable and connectors with different or mismatched impedance is going to have a poor Return Loss, caused by all the reflections originated at the connection.



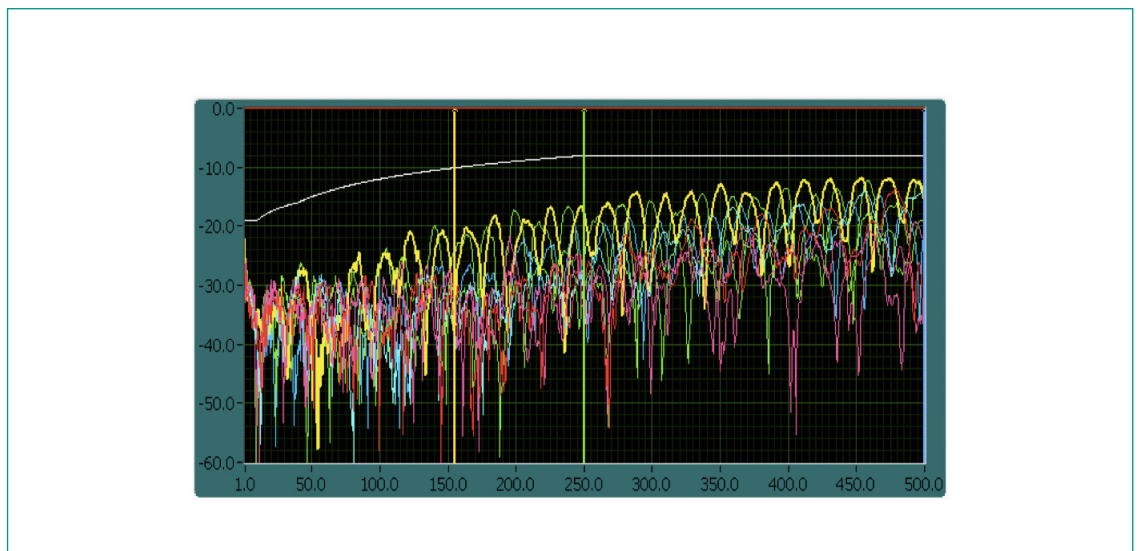
In the SYSTIMAX GigaSPEED X10D Solution, all the termination hardware, equipment and work area cords are designed to match the impedance of the cable, providing a "tuned" channel that ensures optimum performance.



Channel return loss is dominated by the following:

- very low frequencies: cable impedance > 100 Ohms
- mid band frequencies: cable/cord impedance mismatches
- high frequencies: connector return loss (cable SRL negligible)

Graph 2: Typical Return Loss Performance of the GigaSPEED X10D Solution vs ISO Class E_A Limits



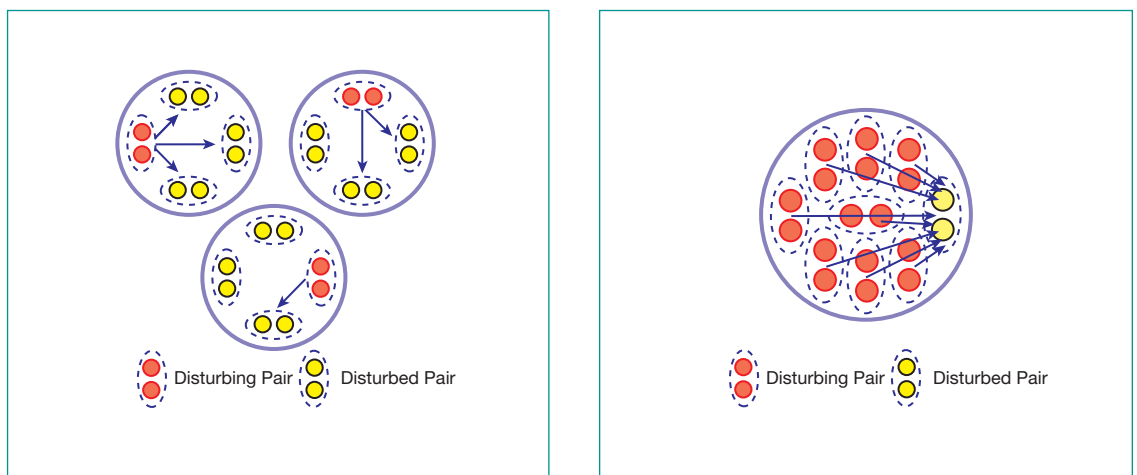
Crosstalk

Crosstalk is probably the most important characteristic of cabling for the high-speed data applications. It is the undesired energy appearing in one signal path as a result of coupling from other signal paths. The induced signals can be significant enough to corrupt data and cause errors.

Measurement Methodology for Crosstalk

Two methods of referring to crosstalk are common on the market today - Pair-to-Pair and Power Sum methods.

The pair-to-pair method requires that the crosstalk be measured for each pair combination in a cable. Specifically, for a 4-pair cable, the crosstalk is measured for a total of six pair combinations. The 'worst pair-to-pair crosstalk' is the crosstalk value for whichever of the six readings is the worst. The reason why the pair-to-pair method was selected for 4-pair cables is that, for LAN applications at the time, typically only two pairs (one pair combination) were used for data transmission. It should be noted that the active or used pairs are not the same for different applications such as 10BASE-T, Token Ring and TPPMD. Thus, although only one pair combination is important for any one application, the important combination changes with the application.



Pair-to-Pair Measurement and Power Sum Measurement

In situations where applications are sharing the same cable sheath or a Parallel Transmission Scheme is employed such as for 10GBASE-T, it uses the complete pair structure within the same cable. For instance, to run a gigabit network over their 4-pair cabling channels, simply specifying crosstalk on a pair-to-pair basis would not be adequate. Although the crosstalk coupling for each pair combination could meet the relevant category specifications on a pair-to-pair basis, the TOTAL crosstalk coupling onto one pair from all the other pairs could be excessive and cause loss of data integrity. By changing the measurement method to Power Sum, one is assured that the total crosstalk in a cable with all pairs in use does not exceed the crosstalk found in a cable with only two pairs in use. This is important to ensure that performance is not compromised.

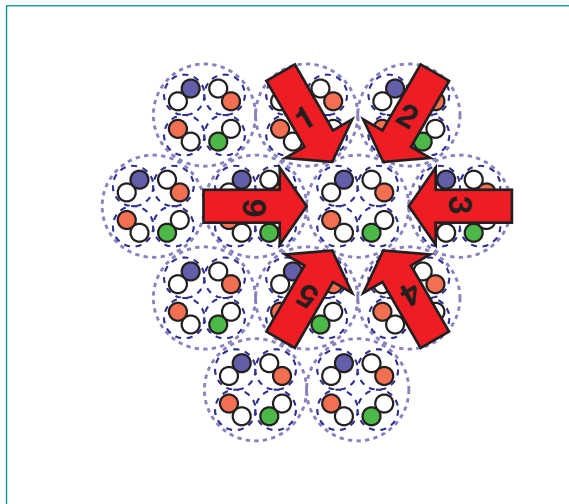
The Power Sum crosstalk calculation of a cable is usually 3-6 dB worse than its pair-to-pair crosstalk performance. However it should be noted that it is a different measurement method and users should ensure that the cabling vendor specifies both, as compliance to one cannot be assumed from compliance to the other.

It should also be mentioned under this section that testing from both ends of the cable is also required to fully understand the performance of any channel, because most systems have a transmitter and receiver at both ends. Crosstalk results at one end of the cable may vary from the results at the other end.

In crosstalk measurement, a higher numerical value (measured in dBs) is preferred to lower values. The higher value implies that lower level noise is transferred into the adjacent pair. Crosstalk is frequency dependent, meaning that the crosstalk becomes lower (i.e. more noise is transferred) as the frequency increases.

Near End Crosstalk, Far End Crosstalk and Alien Crosstalk

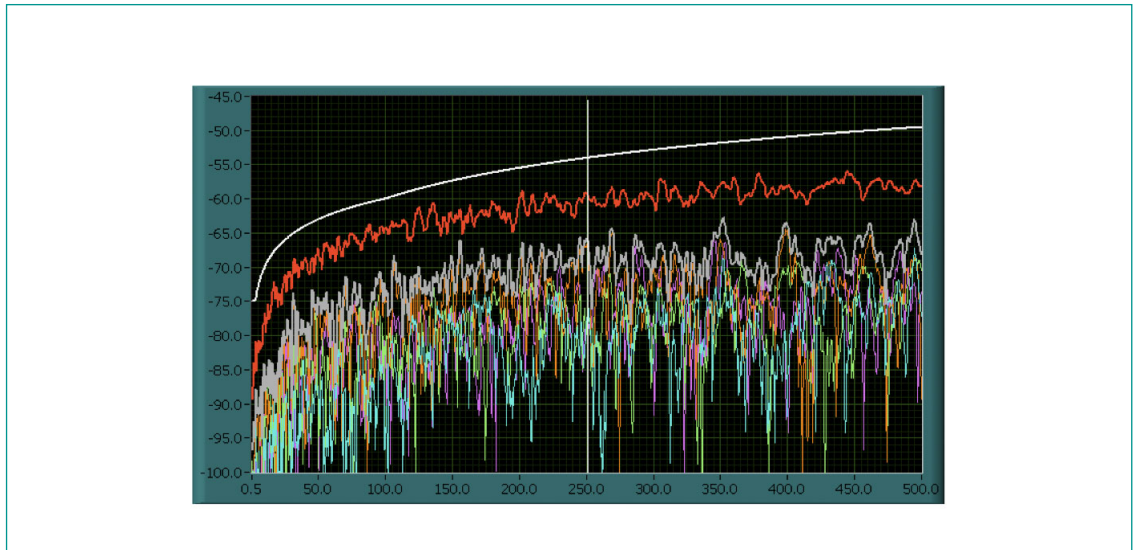
When LANs first started using UTP cabling systems as a transmission medium, the noise that limited their use originated from sources external to the cabling system as well as from signals on other pairs within the same cable. The external noise sources have been significantly reduced through better cable and equipment design, compliance with government emission standards and improved cable installation procedures. One form of external noise that is referred to is Alien Crosstalk. This is the noise picked up from other signals running in adjacent cables, generating Alien Crosstalk. The manner and care with which cabling is implemented are significant factors in the performance of installed cabling systems. Installation and cable management precautions should include the elimination of cable stress as caused by tension, sharp bends and tightly bunched cables.



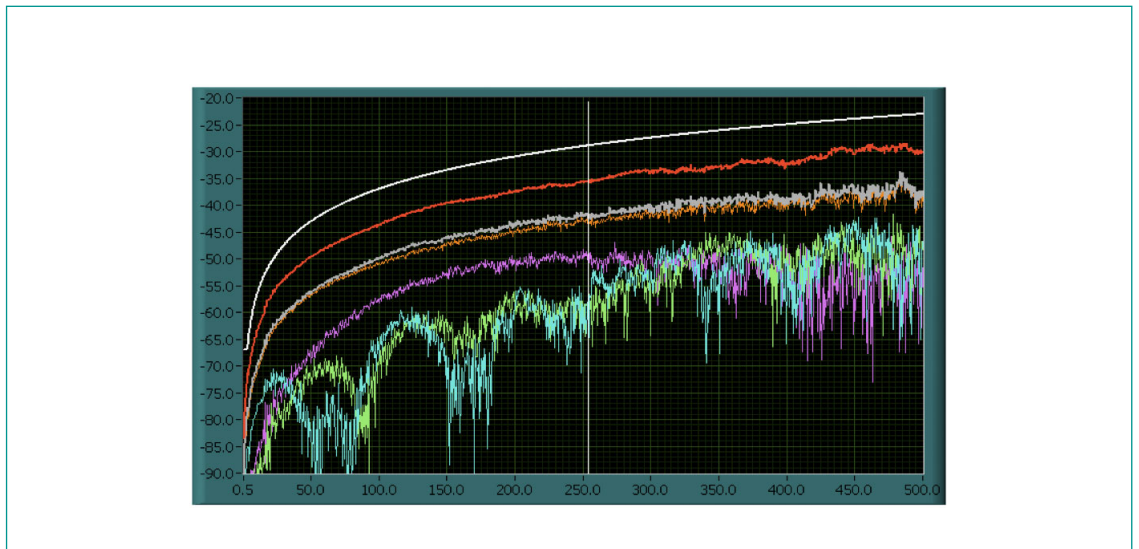
From a standards perspective, Alien Crosstalk measurements in the field are not straightforward and procedures are still under development. The realistic test configuration is to do a Power Sum computation of the Alien Crosstalk noise from 24 pairs of 6 cables surrounding a pair in the cable under test, known as the 6-around-1 configuration.

One of the main benefits of the GigaSPEED X10D Solution is substantial reduction in Alien Crosstalk, enabling the potential channel capacity required for 10GBASE-T. Using a 6-around-1 test configuration, the following test graphs for PSANEXT and PSAELFEXT show the excellent performance of the GigaSPEED X10D Solutions.

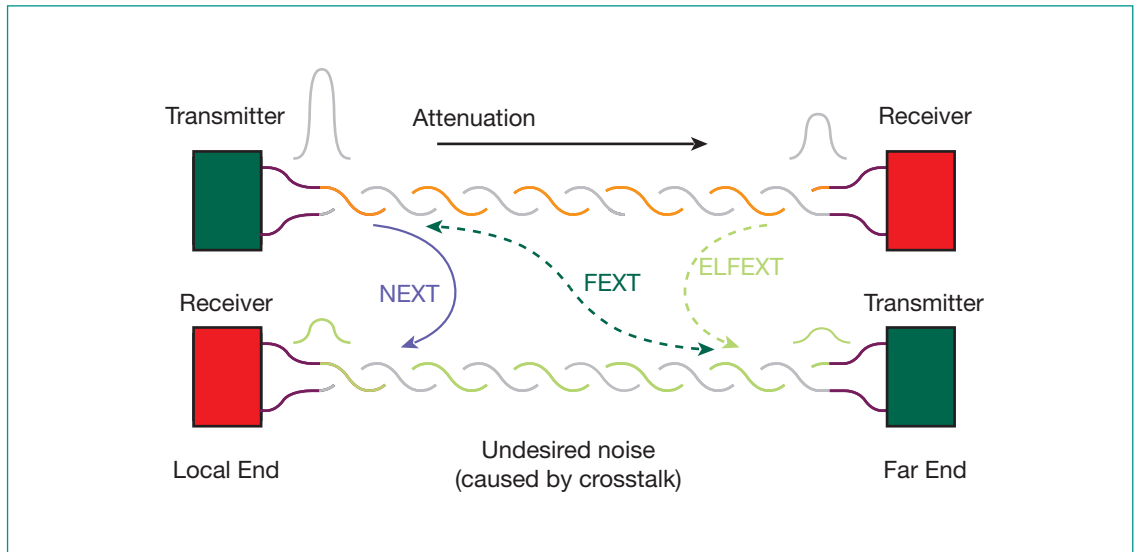
Graph 3: Typical PSANEXT Performance of the GigaSPEED X10D Solution vs ISO Class E_A Limits



Graph 4: Typical PSAELFEXT Performance of the GigaSPEED X10D Solution vs ISO Class E_A Limits



Other forms of crosstalk are also present within the cable and connecting hardware themselves.

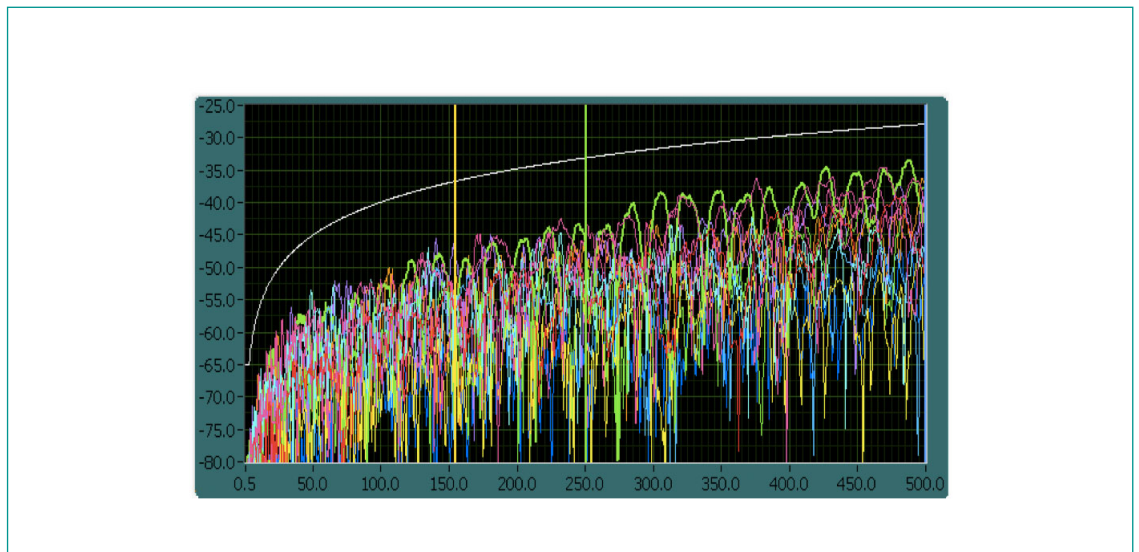


Near End Crosstalk (NEXT) refers to the undesired coupling of signals from the transmit pair onto the receive pair on the same (=near) end. NEXT isolation is expressed in dB and is a measure of how well the pairs in a cable are isolated from each other.

Pair-to-Pair NEXT

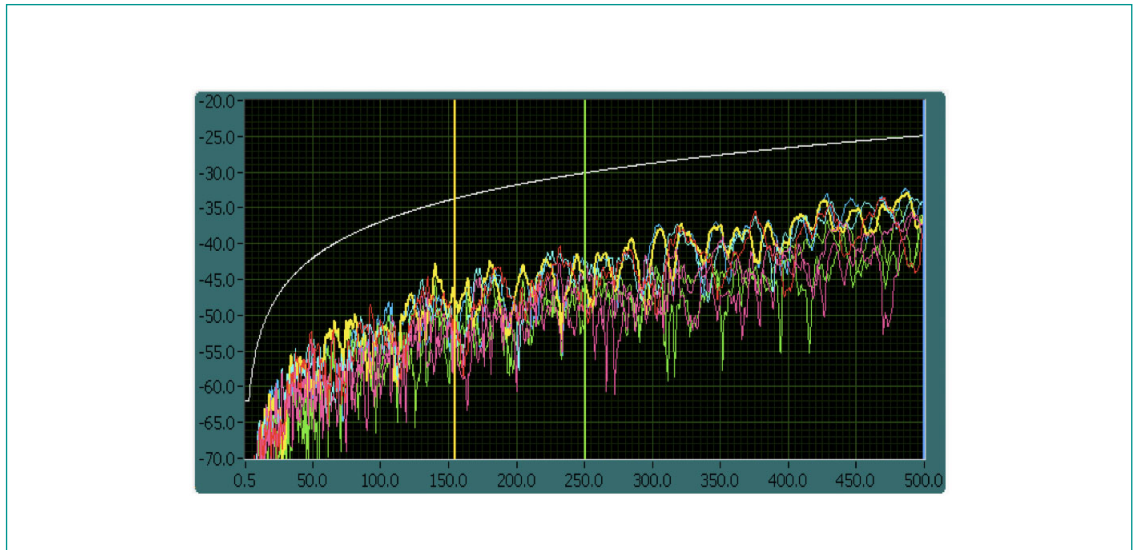
The pair-to-pair method is good for small pair-count cables (ie. 4-pair or less) and is the usual way of measuring NEXT. The measurement assumes one disturbing pair and determines the amount of signal coupled into other pairs in the cable.

Graph 5: Typical Pair-to-Pair NEXT Performance of the GigaSPEED X10D Solution vs ISO Class E_A Limits



Power Sum NEXT (PSNEXT) refers to the undesired coupling of signals from all other pairs into one pair. Basically Power Sum is a more stringent specification.

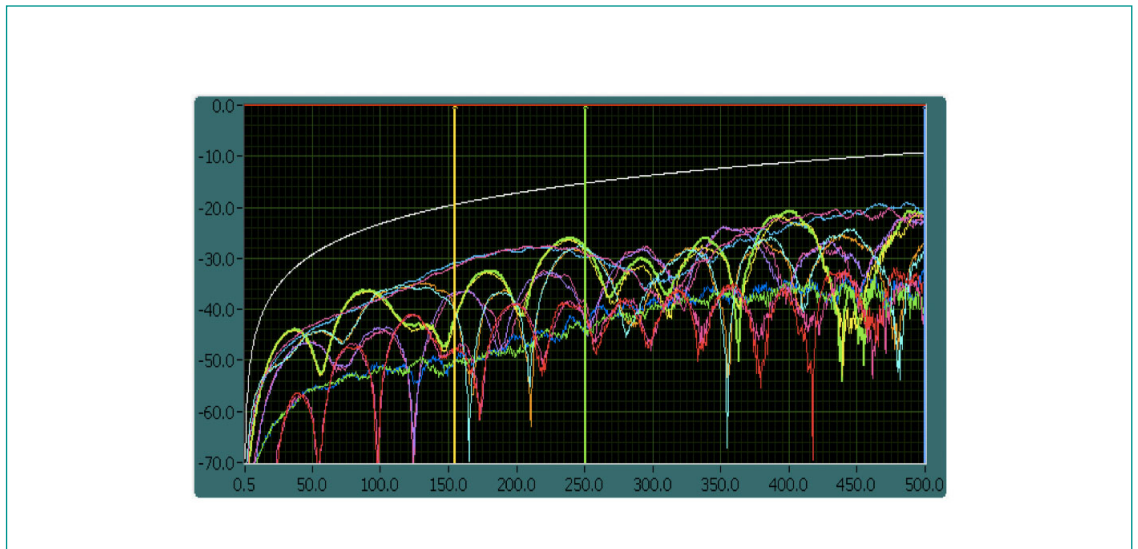
Graph 6: Typical PSNEXT Performance of the GigaSPEED X10D Solution vs ISO Class E_A Limits



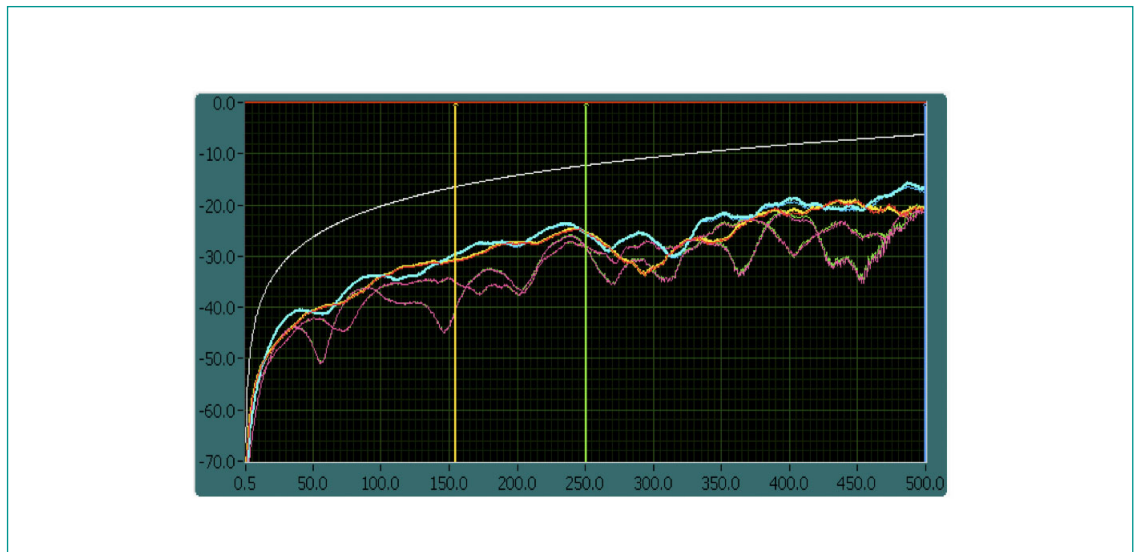
Far End Crosstalk (FEXT) refers to the undesired coupling of signals from the transmit pair onto the receive pair at the other (=far) end. FEXT isolation is also expressed in dB. For the newer high end applications this is now an important parameter.

Equal Level Far End Crosstalk (ELFEXT) is the same as FEXT, except that the coupled signal at the remote end is relative to the attenuated signal at the remote end on the pair the signal was applied to at the local end.

Graph 7: Typical Pair-to-Pair ELFEXT Performance of the GigaSPEED X10D Solution vs ISO Class E_A Limits



Power Sum Equal Level Far End Crosstalk (PSELFEXT) is the sum of the ELFEXT power from all other pairs in the cable. This measurement is applicable for parallel transmission schemes when more than two pairs in the cable are used to transmit in each direction (e.g. 1000BASE-T).

Graph 8: Typical PSELFEXT Performance of the GigaSPEED X10D Solution vs ISO Class E_A Limits

Historically, crosstalk was attributed primarily to cables, but as LAN speeds increased and the cables improved, other channel components started to contribute to the crosstalk. The cumulative effect became known as Composite Crosstalk and the primary channel components that contribute to this are the cords, connecting hardware and cable. Crosstalk values can also be affected by the installation practices, especially the length of equipment, patch and work area cords and the amount of untwist of pairs within the cables. Connector crosstalk can be quite a problem, unless compensated for in the design of the connector. The crosstalk can also increase through any mismatches between the patch cords, connectors and horizontal cable. This is most noticeable on short links. Again if this is not accounted for in the design of all the components that make up the channel, a channel containing apparently standards compliant components may fail tests once installed.

Improving Crosstalk Cancellation in Plugs and Jacks

In order to achieve Category 6A/Class E_A performance when mating modular jacks and plugs, jacks need to be designed with crosstalk cancellation techniques to compensate for the crosstalk exhibited by the plug. So how can the performance of this “weak link” be improved?

The answer is found in the “perfect match” of backward compatible plugs and jacks. Overcoming the hurdles in the mating of plugs and jacks can lead to consistent performance for Category 6A connections. The first hurdle is in overcoming the variability in performance found in the plugs. As the key difficulty lies in the termination of cable pairs inside the plug, SYSTIMAX Labs introduced in the GigaSPEED X10D GS10E plugs, a termination design that reduces variability to a negligible level. As soon as the cordage enters the plug from the rear, pairs are controlled and the untwisting of pairs and nesting of conductors required in conventional plugs is thus avoided. The second hurdle is in improving the mating performance of the jack. To take the performance of the jack to new levels while maintaining backward compatibility with existing plugs, SYSTIMAX Labs incorporated into its GigaSPEED X10D jacks additional crosstalk cancellation techniques unique in the industry.

The net result of the improved crosstalk performance in cable and connecting hardware is the optimum channel performance of an installed channel.

Summary

As LAN speeds continue to increase the transmission capability of a cabling system is reliant upon superior performance of not just the cable, but all the components in the LAN channel.

Manufacturers of end-to-end cabling systems (rather than manufacturers of individual components) have a significant advantage when it comes to end-to-end channel performance. It should be clear in this case that improved reliability and higher levels of performance is achieved by complimentary designs of cables, jacks and plugs. Similar considerations apply to the inter-relationship of other cabling system components and only careful evaluation of the relative strengths and weaknesses of every component in the cabling channel allows for the necessary fine tuning.

The improvement in insertion loss and dramatic reduction in all types of crosstalk exhibited by the GigaSPEED X10D Solution, exceeds the draft IEEE requirements for 10GBASE-T over UTP and the proposed TIA/EIA Category 6A and ISO/IEC Class E_h channel performance specifications up to 500 MHz.

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