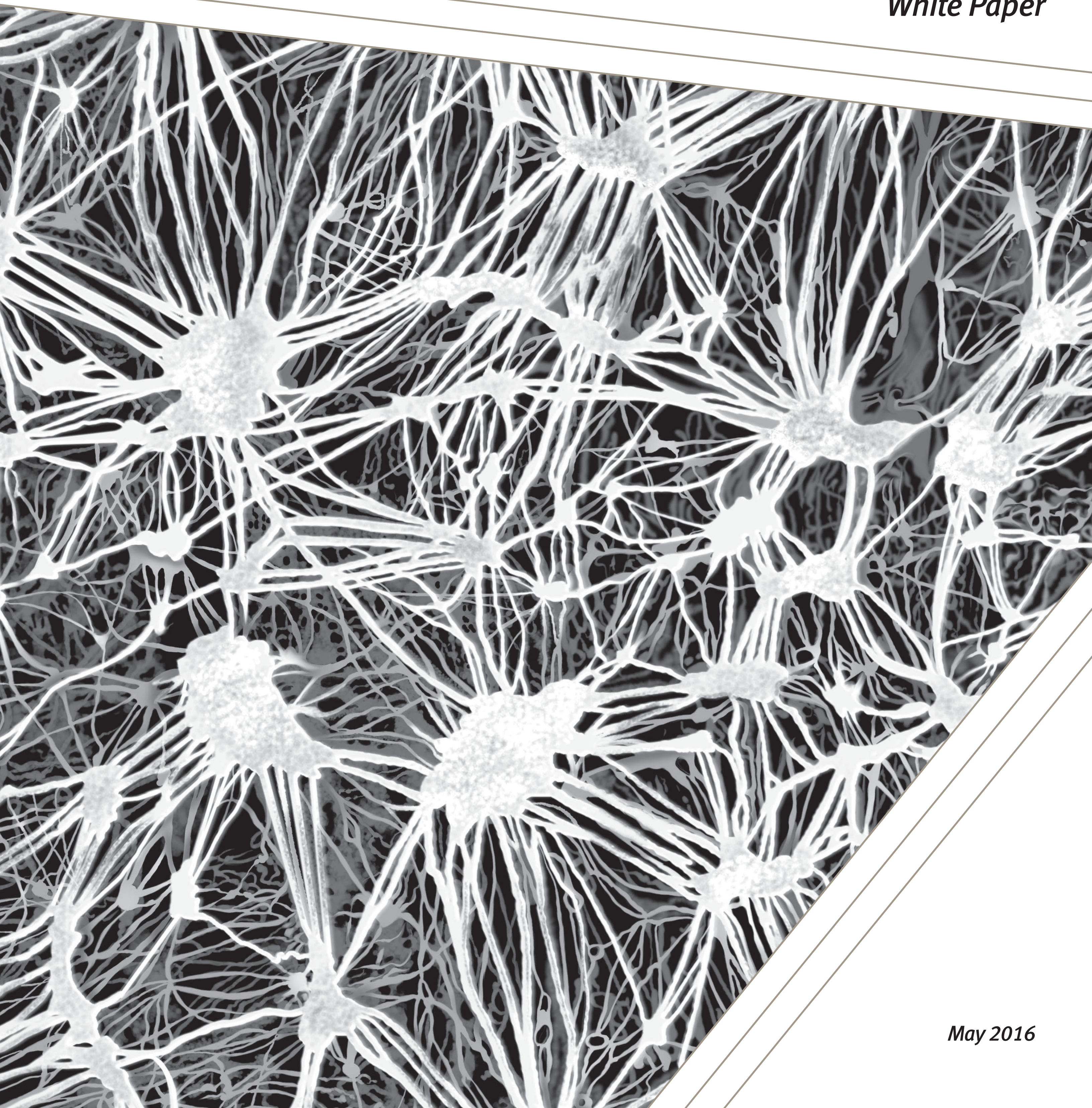
Designing the Right Ethernet Interconnect to Increase High-Speed Data Transmission in Military Aircraft

White Paper



May 2016

Abstract:
Designing the right high-speed Interconnect that enables systems to transfer data effectively is frequently overlooked during the design process. With the rapid advancements in modern avionics, data interconnects that operate adequately today may not operate effectively with devices developed in the future. Therefore, careful consideration should be given to connector designs and electrical performance as well as connector-cable interactions during the initial design process. In addition, thorough testing should be performed to ensure the data interconnect will perform reliably now and in the future to reduce life-cycle costs.

W. L. Gore & Associates (Gore) evaluated the designs and electrical characteristics of several leading high-speed connector systems to assist designers in selecting the best option for a specific application. In addition, they evaluated the electrical performance of their Ethernet Cat6a cable terminated with these leading high-speed connectors. This testing showed the importance of designing the right Ethernet Interconnect that delivers excellent mechanical and electrical performance for high-speed data transmission in challenging aerospace conditions to ensure mission-critical success.

Designing the Right Ethernet Interconnect to Increase High-Speed Data Transmission in Military Aircraft

Contents

Introduction

The demand for high-speed interconnects in military aircraft continues to grow at a rapid pace as new and advanced capabilities are implemented in modern avionics (Figure 1). However, standard commercial connectors and cables do not function adequately in electronic systems that operate in challenging aerospace environments. Therefore, connectors and cables must combine robustness with reliable electrical performance to withstand the challenges of modern avionics and military applications. Although more durable cables exist today to meet these requirements, few connectors are available that provide reliable mechanical and electrical performance. In the past, designers could position the contacts strategically in standard MIL-DTL-38999 connectors to achieve passable signal integrity. However, this approach is not effective for new electronic systems with interconnects that require greater bandwidth.

Furthermore, selecting the right high-speed connectors with cables that enable systems to transfer data effectively is often overlooked during the design process. With the rapid advancements in modern avionics, data interconnects that operate adequately today may not operate effectively with devices developed in the future. Therefore, designers must also carefully consider connector-cable interactions and perform thorough testing to ensure the data interconnect will perform reliably in applications now and in the future to reduce life-cycle costs.

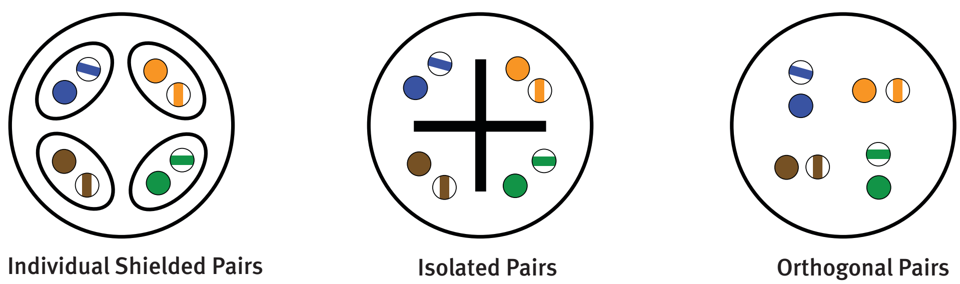
Figure 1: Connectors and Cables in Military Aircraft

Key Design Types

Ethernet interconnects operating at 1 Gigabit per second (Gb/s) or above have become the preferred protocol for new system architectures due to their widespread commercial use. However, they should comply with industry standards, such as the Telecommunications Industry Association (TIA) 568-C.2 to meet future requirements and ensure high-speed data transmission up to 10 Gb/s. As a result, connector manufacturers are designing a new pin and socket configuration with four distinct contact pairs that deliver sufficient signal integrity to handle these higher data rates. These pairs can be configured as a stand-alone connector or multi-pin modular insert with several groups of pairs that can be inserted into a larger circular or rectangular housing. In addition to handling Ethernet data up to 10 Gb/s, this new configuration is also compatible with other high-speed protocols such as Fibre Channel, Rapid I/O, USB or HDMI. Figure 2 shows several types of connector designs using this new pin and socket configuration that provide designers with suitable options when considering electrical performance, ease of termination and costs.

1. ***Individual Shielded Pairs***. Each pair of contacts is individually shielded to control the impedance through the interface and prevent crosstalk between the pairs.
2. ***Isolated Pairs***. An internal metal cross isolates each pair of contacts by dividing them into four quadrants to control impedance and reduce crosstalk.
3. ***Orthogonal Pairs***. Pairs are effectively decoupled without shields by positioning the contacts orthogonally to each other using the connector pin-field geometry.

Figure 2: Types of Connector Designs



There are inherent differences between these connector designs. For example, the Orthogonal Pairs design is suitable for most Ethernet interconnects. However, there may be issues with crosstalk for protocols with higher data rates or if the links are daisy-chained through several connectors in the signal path. The Isolated Pairs design includes a common metal plane that provides shielding within the connector. However, these planes are not connected directly through the mated connector interface, which may limit the impact on crosstalk performance. The Individual Shielded Pairs design delivers the highest electrical performance regarding impedance control and in preventing crosstalk.

Each design varies in complexity with the components and termination process. The Orthogonal Pairs design is the simplest because the connectors require few additional parts and use a standard termination process. In contrast, the connectors that use the Isolated Pairs design require more additional parts due to the shielding and may require small pins to maintain the 100-ohm impedance control. Also, the termination process is relatively straightforward but may require crimping smaller pins using special tools. Lastly, the Individual Shielded Pairs design is the most complex because the connectors require many additional parts and termination steps. As a result, designers should carefully consider potential cost implications and overall time to terminate using these design types when selecting the right connector for a specific application.

Selecting the Connector System

Selecting a high-speed connector system for an Ethernet interconnect should include the following criteria:

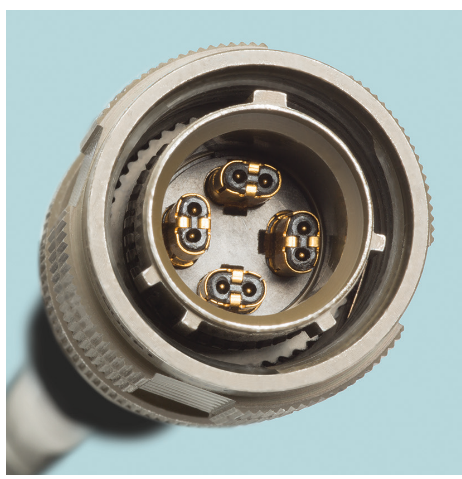
- Size of the internal components
- Number of connectors in the entire link
- Distance between connectors
- Ease and consistency of termination
- Noise margin availability
- Electrical performance of connector with selected cable

Gore's engineers evaluated the designs of several leading high-speed connector systems to assist designers in selecting the best option for a specific application.

Amphenol® Oval Contact System (13-53)

The OCS modular connector includes four oval inserts throughout the interface (Figure 3). Each oval insert contains two mating pins that are individually shielded to provide very low crosstalk and excellent impedance control for transmitting high-speed signals up to 10 Gb/s per pair. This connector can be inserted into a standard MIL-DTL-38999 multi-pin housing with cavities specifically designed to fit oval inserts. For Ethernet protocol, the OCS connector can fit four of these inserts into a size 13 shell; however, many other configurations are also available.

Figure 3: Amphenol® OCS



Amphenol® µ-Com Connector System

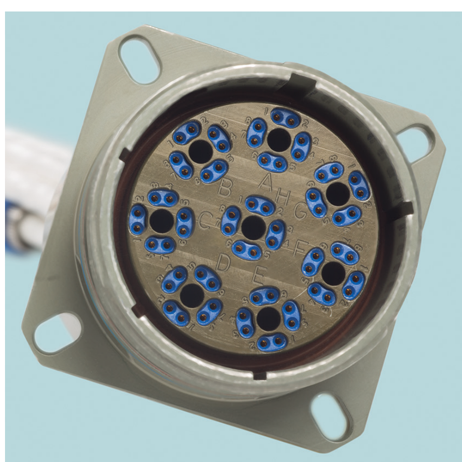
Using the Isolated Pairs design, the µ-Com micro connector, 10 Gb+ Series, features a controlled impedance interface with four isolated pairs (Figure 4). Male and female cable connectors include crimp or solder contacts. This connector also offers either a twist-locking mechanism or a push-pull release for easy attachment to the mating connector. In addition, a printed circuit board mount jack is also available.

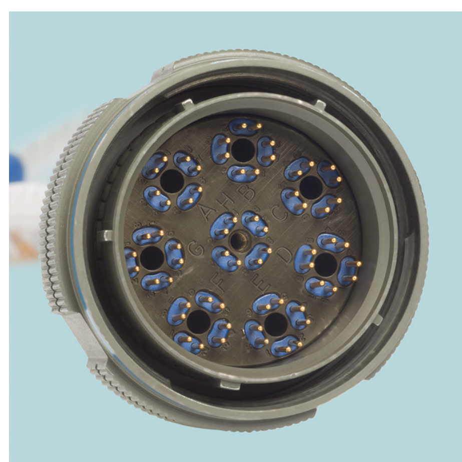
Figure 4: Amphenol® µ-Com Connector

Carlisle Octax® Connector System

This fully-integrated connector system includes eight contacts with four isolated shielded pairs to minimize impedance discontinuities and crosstalk (Figure 5). Fabricating the housing insert from metal provides the shielding between pairs. The connector is also available as a modular four-pair insert that fits in many standard connector platforms. This design utilizes standard M39029 size 22D contacts that are easy to repair in the field. In addition, custom configurations are available for various system design applications.

Figure 5: Carlisle Octax® — 8-Link Connector (Size 25)





Glenair El Ochito® Connector System

This multi-pin controlled impedance connector is designed to fit into a standard MIL-DTL-38999 size 8 contact opening (Figure 6). The connector is compatible with twinaxial cables and includes eight mini contacts divided into four quadrants that are shielded to minimize crosstalk between channels. The El Ochito® is the most compact Cat6a contact system available for 38999 series connectors.

Figure 6: Glenair El Ochito® — Multi-pin Insert (size 8) Connector

LEMO® 2B Series Connector System

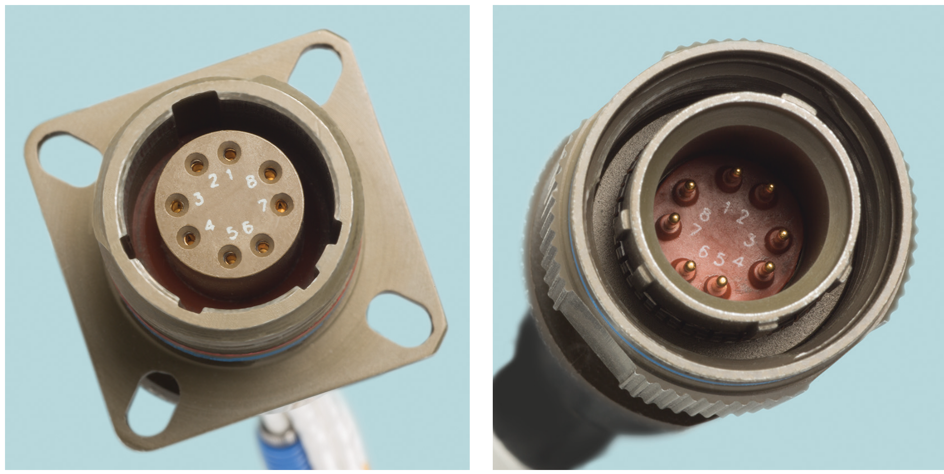
The Multipole Cat6a connector is part of the 2B Series designed for Ethernet applications operating at 10 Gb/s (Figure 7). In this design, four pairs of pins are decoupled by positioning them orthogonally to minimize crosstalk through the mated interface. The connector system features a shielded push-pull backshell for easy mating. In addition, the Multipole Cat6a connector can handle wire sizes up to 22 AWG for longer transmission lengths.

Figure 7: LEMO® 2B Series — Multipole Cat6a Connector

TE Connectivity® CeeLok FAS-X® Connector System

The FAS-X® connector design includes an internal metal cross that divides the connector into four shielded zones to minimize crosstalk and control impedance through the interface (Figure 8). This insert fits into a standard MIL-DTL-38999 shell for Ethernet Cat6a protocol and uses standard M39029 size 22D contacts for easier assembly with standard tools.

Figure 8: TE Connectivity® CeeLok FAS-X® Connector



Physical Characteristics

Table 1 shows a general comparison of the physical characteristics of leading high-speed connector systems.

Table 1: Comparison of High-Speed Connector Systems

Connector System	Mating Pin Diameter (in)	Wire Size (AWG)	Max. Cable Diameter (in)	Attach method	Design Type	Contact Type[1]
Amphenol® OCS 13-53	0.015	24-26	› 0.300	Solder	Individual Shielded Pairs	Custom
Amphenol® µ-Com	0.016	24-26	0.275	Crimp Solder	Individual Shielded Pairs	Custom
Carlisle Octax®	0.030	24-26	0.300	Crimp	Individual Shielded Pairs	M39029 22D
Glenair El Ochito®	0.015	26-30	0.220	Crimp	Isolated Pairs	Custom
LEMO® 2B Series	0.022	22-26	0.275	Crimp	Orthogonal Pairs	Custom
TE Connectivity® CeeLok FAS-X®	0.030	24-26	› 0.300	Crimp	Isolated Pairs	M39029 22D

[1] For more information, download termination instructions at www.gore.com/ethernet-cable-connectors

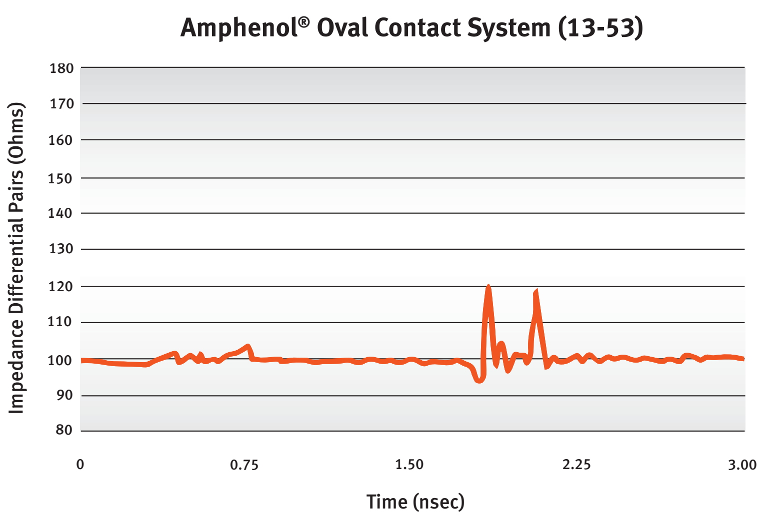
Electrical Performance

Connectors must ensure reliable electrical contact with minimal impedance discontinuity to maintain consistent signal integrity through the interface. Therefore, Gore's engineers evaluated the electrical characteristics of leading high-speed connectors to determine their overall performance, including Time Domain Reflectometry (TDR) analysis, return loss, insertion loss and crosstalk. They used optimal test interfaces by connecting coaxial cables directly to the signal contacts. These precision coaxial cables were terminated with SMA connectors for a direct interface to a Vector Network Analyzer (VNA). This type of setup allows the test to focus on the connector interface without relying on software gating techniques, which may be more difficult to interpret.

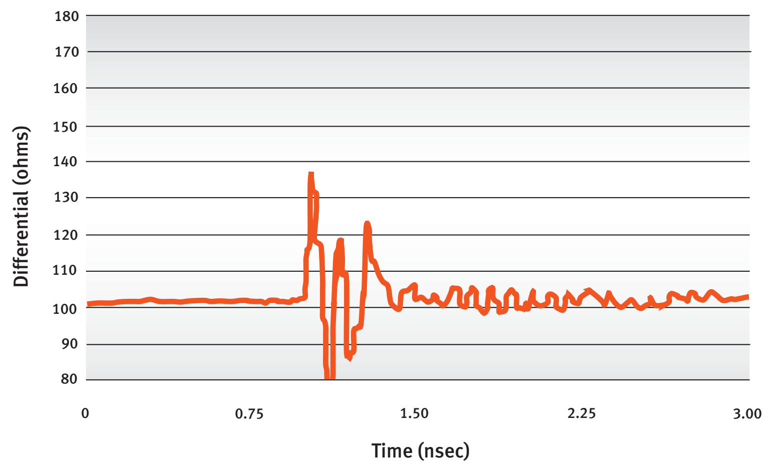
TDR Comparison

Using a TDR, a pulse (rise time equals 35 psec), or specifically, a positive edge transition is transmitted down the signal line. Reflections from the transmission line are then measured with a sampling oscilloscope. The size or height of these reflections determines the quality of the signal path. In other words, the smaller the reflections, the better the connector performance. Figure 9 shows typical traces seen with this measurement.

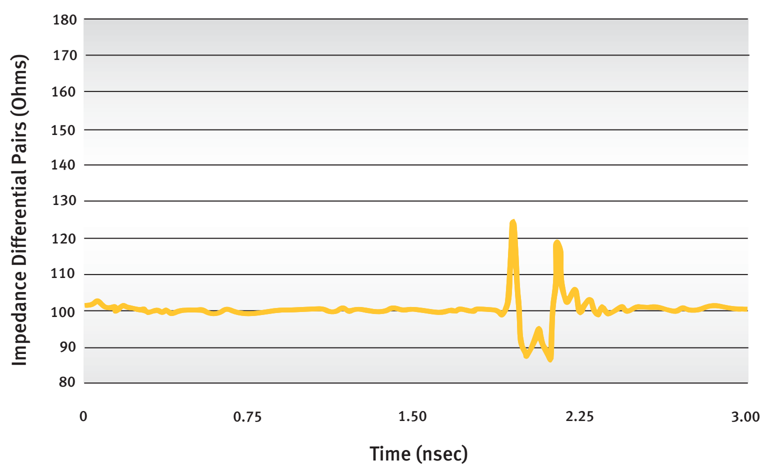
Figure 9: Impedance Comparison of High-Speed Connectors



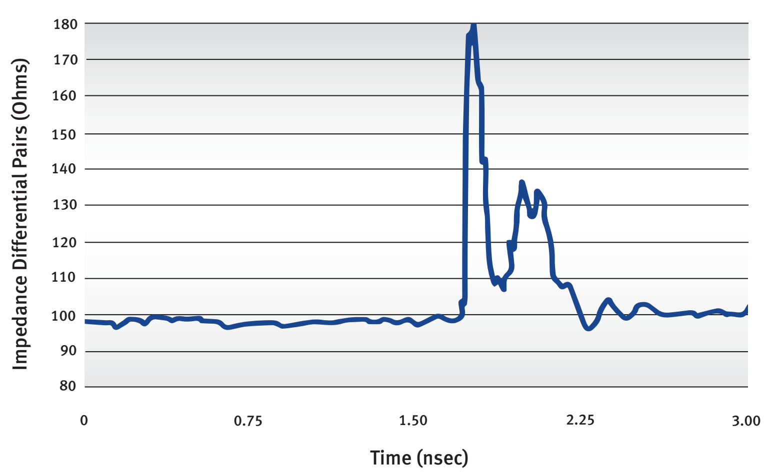
Amphenol® µ-Com Connector System



Glenair El Ochito® Connector System



TE Connectivity® CeeLok FAS-X® Connector System

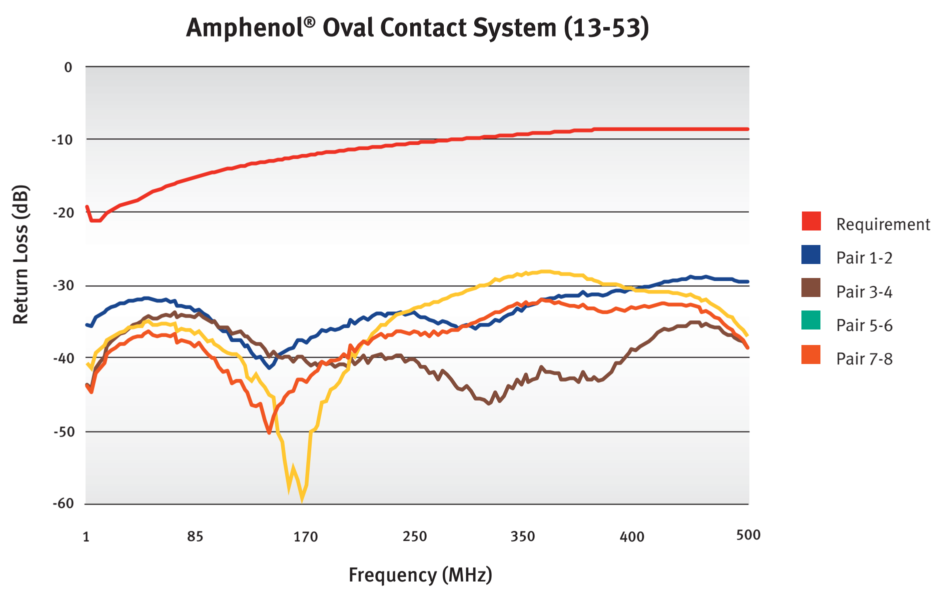


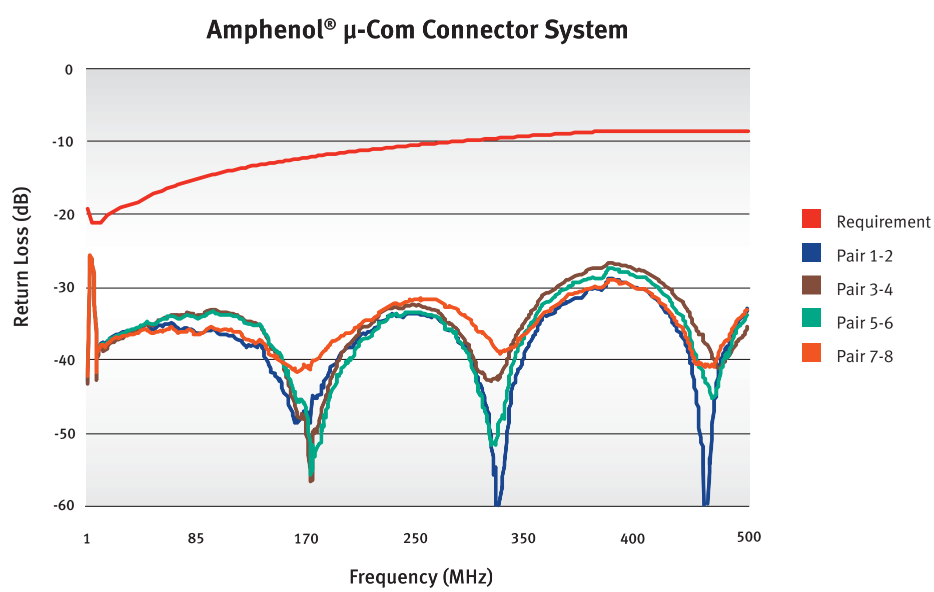
Return Loss Comparison

This testing provides the most direct measurement of controlled impedance. Gore compared the typical return loss of each connector system. In general, return loss should not exceed -15 dB through 500 MHz for reliable data transmission at 10 Gb/s. Otherwise, there may be issues with performance when using these connector systems at higher frequencies. Also, return loss is a significant concern when multiple connectors exist in a link, especially if there are shorter distances between connectors.

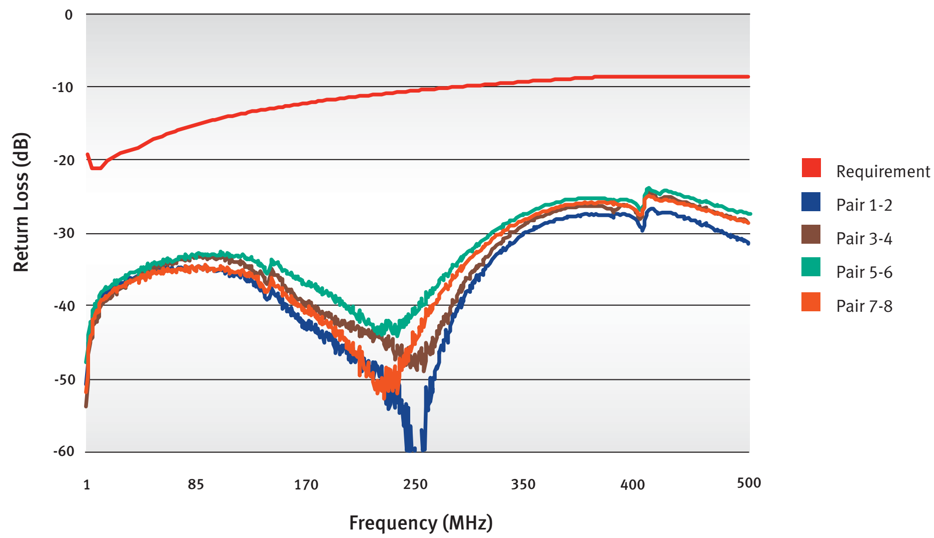
Results showed that the return loss traces correlate directly to the reflection measurements from the TDR testing. Therefore, the connectors with the least reflections had the best return loss (Figure 10).

Figure 10: Return Loss Comparison of High-Speed Connectors

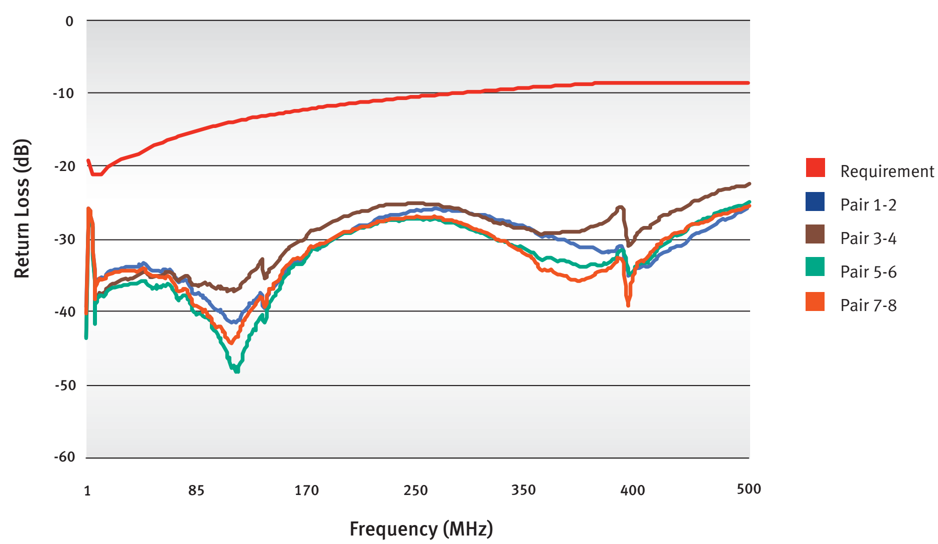




Glenair El Ochito® Connector System



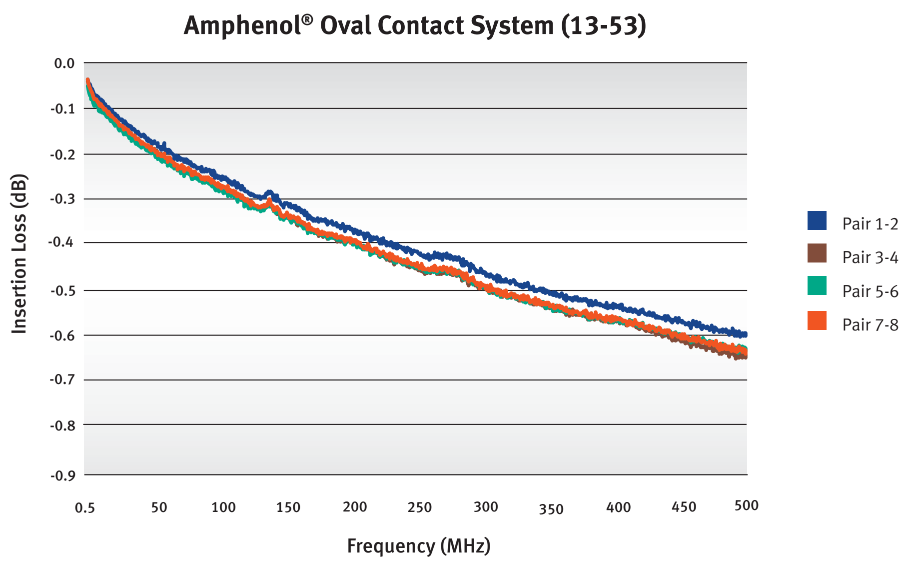
TE Connectivity® CeeLok FAS-X® Connector System

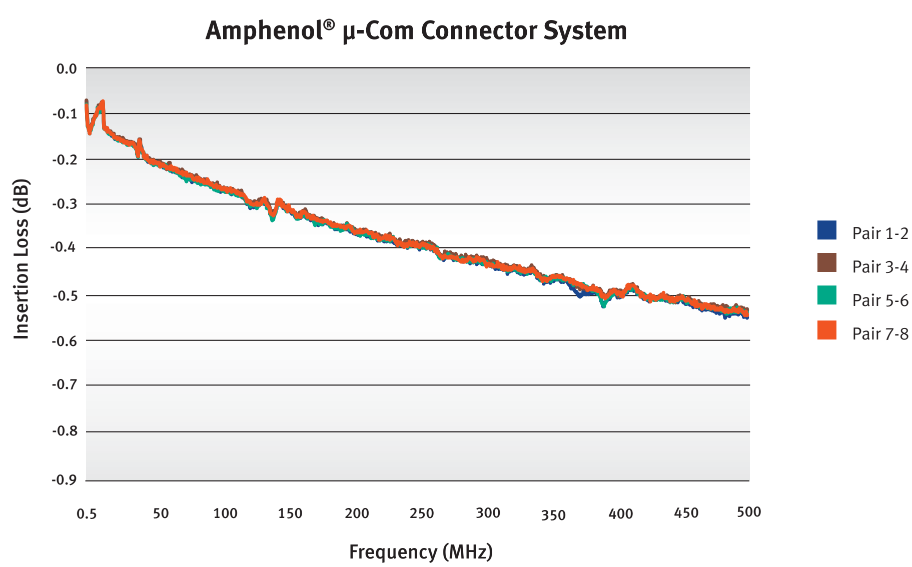


Insertion Loss Comparison

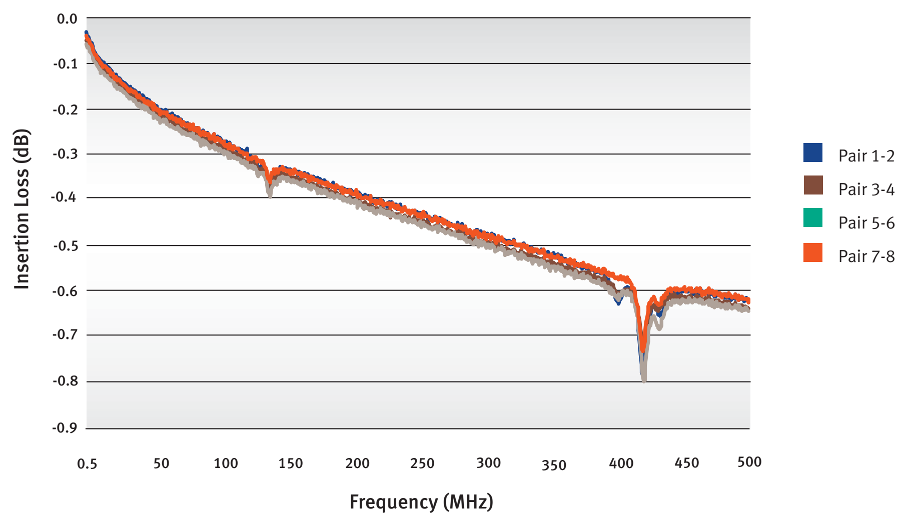
Testing for insertion loss provides useful information regarding the impact of reflections on signal integrity, and the potential to inject spikes into the frequency response of an assembly. Gore compared insertion loss for each connector system up to 500 MHz (Figure 11). These plots include additional loss from approximately one meter of coaxial cable in the test fixtures.

Figure 11: Insertion Loss Comparison of High-Speed Connectors

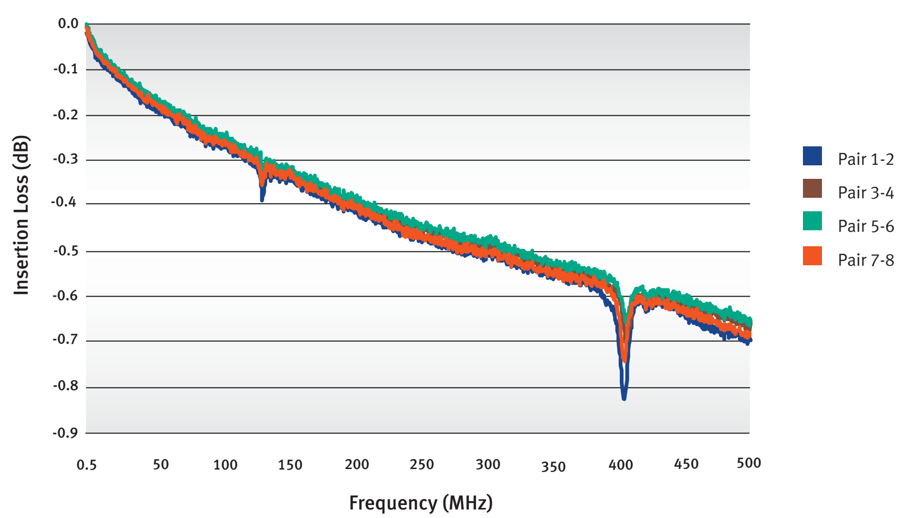




Glenair El Ochito® Connector System



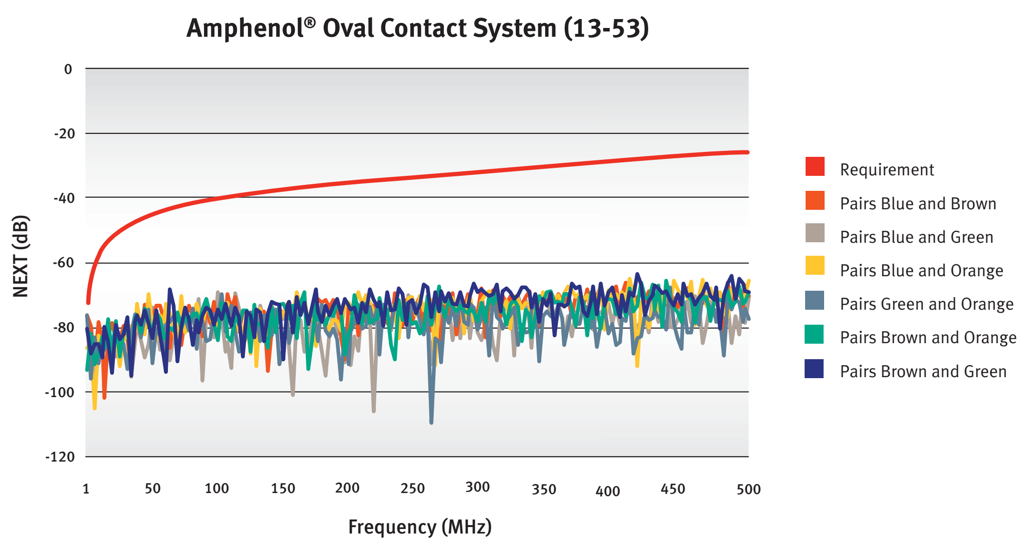
TE Connectivity® CeeLok FAS-X® Connector System

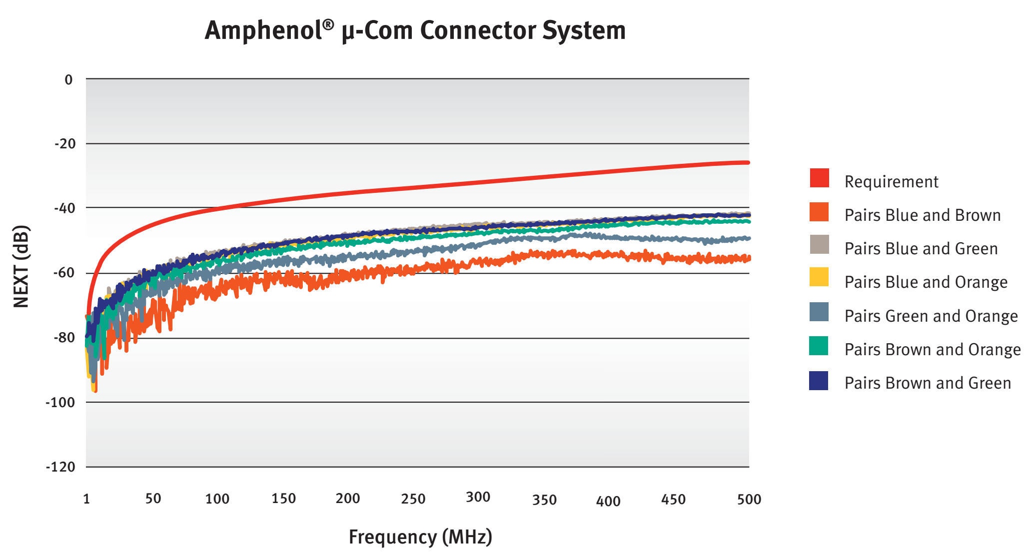


Crosstalk Comparison

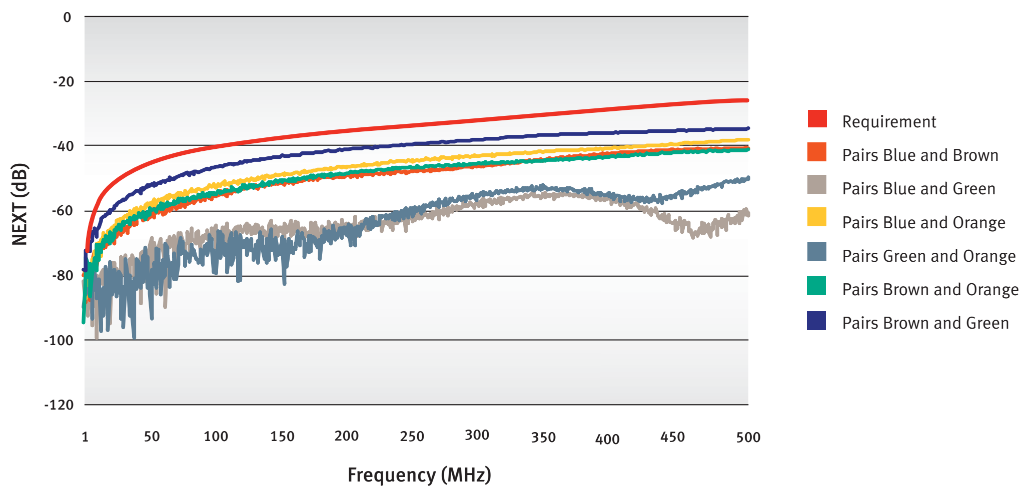
Gore compared crosstalk performance for each connector system. Using the coaxial cable leads minimizes any crosstalk from the test fixtures to provide an accurate measurement between pairs within the connector system (Figure 12). This testing demonstrates the advantage of using the Individual Shielded Pairs design. Results showed that crosstalk from the individually shielded contact is in the noise floor of the test equipment while the other connector designs showed much higher crosstalk levels that begin to approach the acceptance limits of the industry requirement.

Figure 12: Crosstalk Comparison of High-Speed Connectors





Glenair El Ochito® Connector System



TE Connectivity® CeeLok FAS-X® Connector System

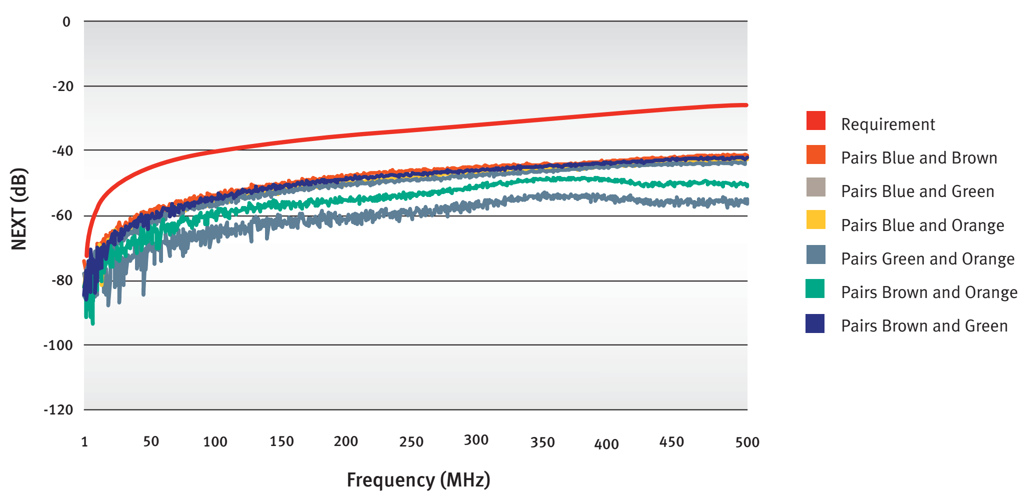


Table 2 provides an overall comparison of electrical performance results for leading high-speed connector systems based on Gore's testing.

Table 2: Performance Results for High-Speed Connector Systems[2]

Connector System	Impedance (Ohms)			Return Loss (-dB)		Insertion Loss (-dB)		NEXT		
	Nom.	Min.	Max.	500 MHz	1000 MHz	500 MHz	1000 MHz	10 MHz	100 MHz	500 MHz
Amphenol® OCS 13-53	100	90	130	-26	-23	0.5	0.7	-78	-68	-56
Amphenol® µ-Com	100	55	150	-28	-18	0.75	1.3	-66	-53	-42
Carlisle Octax®	75	52	160	-28	-16	0.5	1.2	-64	-45	-30
Glenair El Ochito®	80	73	131	-25	-16	0.7	1.2	-64	-44	-34
LEMO® 2B Series	90	60	130	-30	-16	0.5	1.2	-68	-52	-36
TE Connectivity® CeeLok FAS-X®	115	96	224	-25	-16	0.8	1.2	-66	-49	-40

Connector-Cable Performance

Selecting the right Ethernet cables[3] with connectors is frequently overlooked during the initial design process. Designers must also carefully consider connector-cable interactions to ensure data is transferred effectively. For example, a specific connector with a cable type that has shielded or unshielded pairs attached to the contacts can affect the overall performance of the entire assembly. In addition, the position of the wires inside the insert can greatly influence impedance control and crosstalk. Therefore, designers should perform thorough testing of the entire interconnect at its full length with all of the connectors to ensure the cable system will perform reliably in real-world conditions. Individual connector and cable components that comply with Cat6a requirements do not necessarily ensure that cable-connector combinations will also be compliant.

Gore's engineers evaluated the electrical performance of GORE® Aerospace Ethernet Cables for Cat6a protocol terminated with leading high-speed connectors[4]. They used a 10-meter cable assembly with plug and receptacle connectors based on specific part numbers. The connectors were mated to the test leads that are attached to the VNA. Then, the connectors were terminated with shielded microwave coaxial cables for each primary and SMA connectors. They measured return loss, insertion loss and crosstalk at 1 MHz to 500 MHz, and performance was recorded.

[2] Download electrical data for other high-speed connector systems at www.gore.com/ethernet-cable-connectors

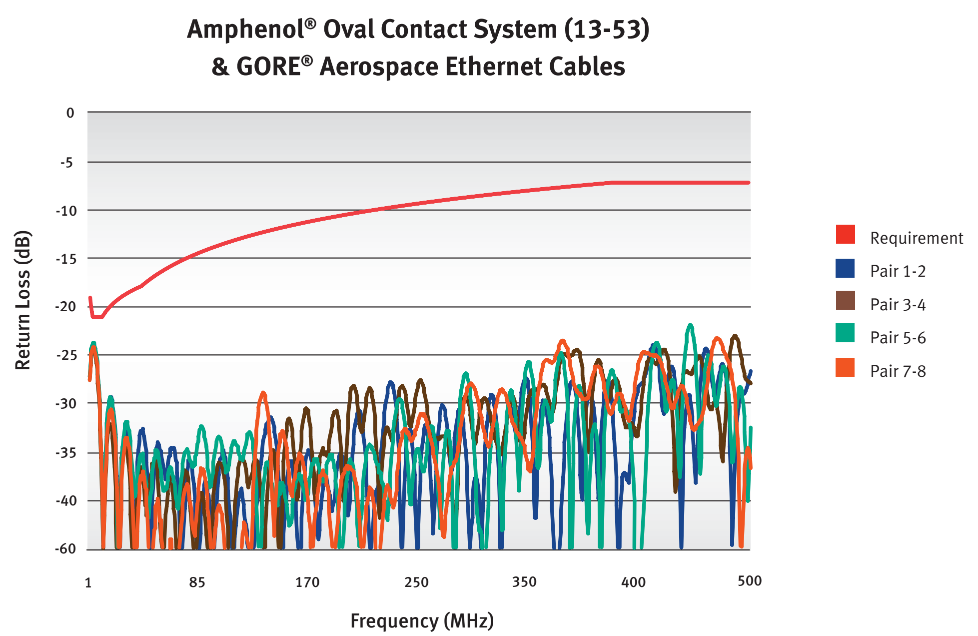
[3] For more information, download the white paper, *Selecting the Right Ethernet Cables to Increase High-Speed Data Transmission in Military Aircraft* at www.gore.com/ethernet-cables-military

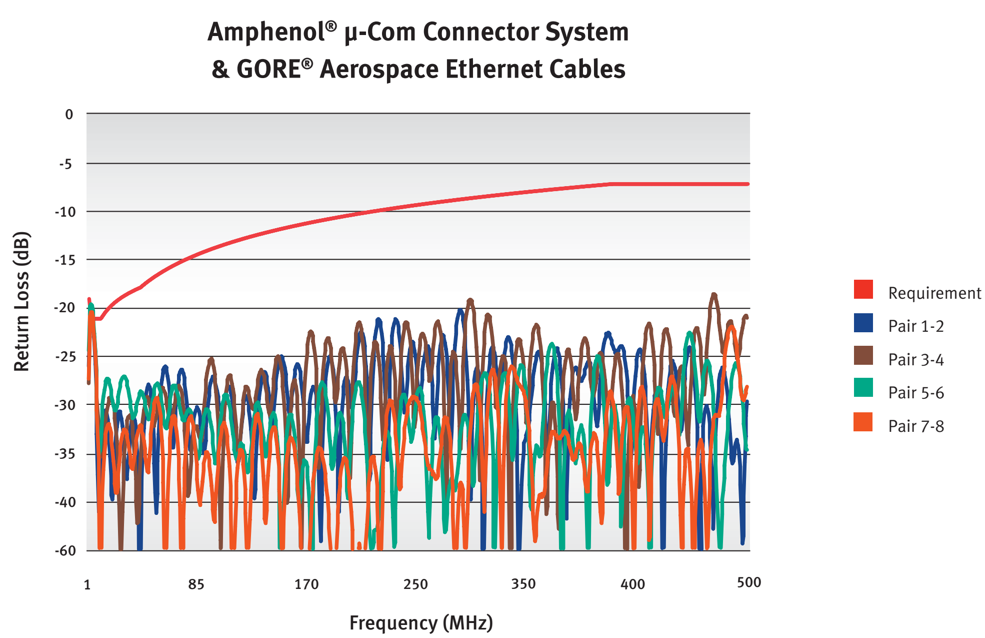
[4] Download termination instructions and electrical data for all high-speed connector-cable assemblies at www.gore.com/ethernet-cable-connectors

Return Loss Comparison

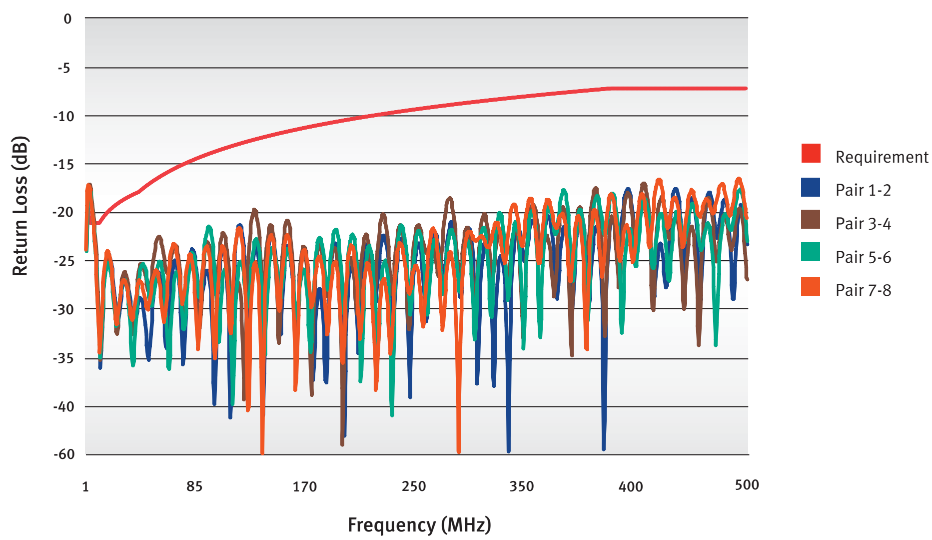
The test results showed that these Ethernet interconnects provided consistent impedance control at higher frequencies indicating reliable high-speed data transmission at 10 Gb/s (Figure 13).

Figure 13: Return Loss of Ethernet Interconnects

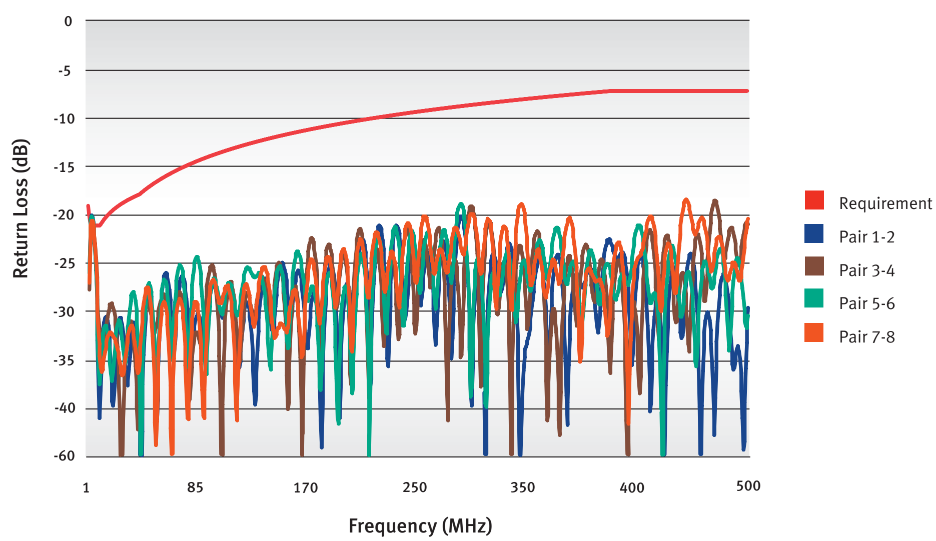




Glenair El Ochito® Connector System & GORE® Aerospace Ethernet Cables



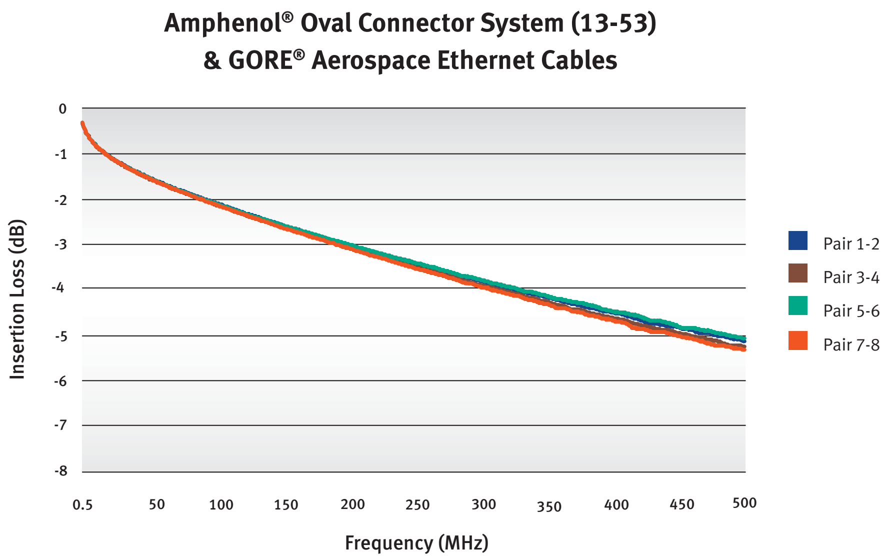
TE Connectivity® CeeLok FAS-X® Connector System & GORE® Aerospace Ethernet Cables

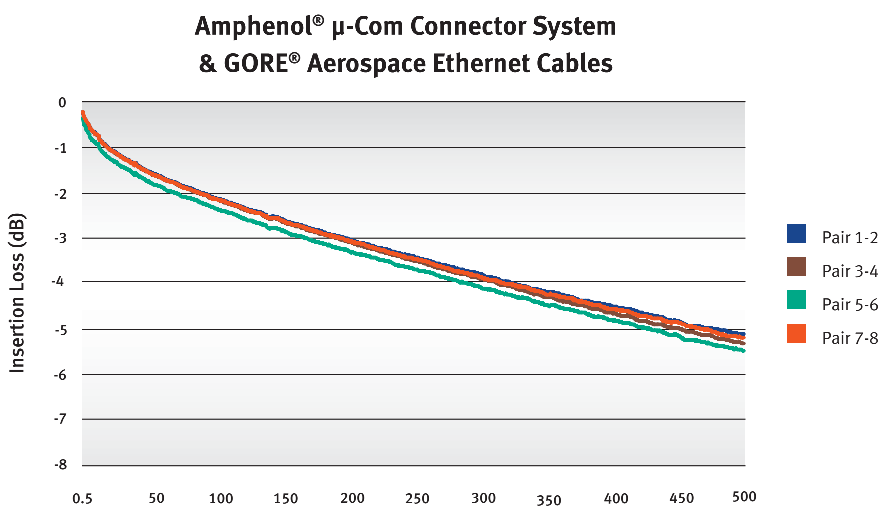


Insertion Loss Comparison

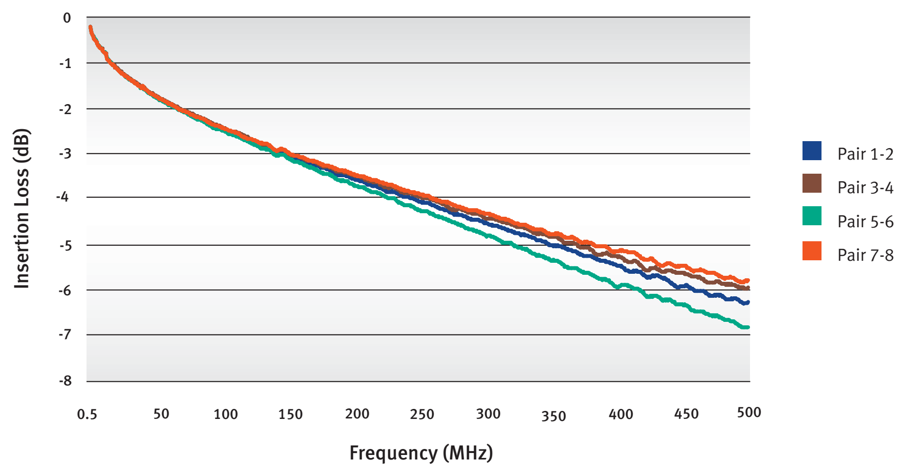
In addition, results showed that these Ethernet interconnects successfully maintained low insertion loss up to 500 MHz providing stable and accurate system performance (Figure 14).

Figure 14: Insertion Loss of Ethernet Interconnects

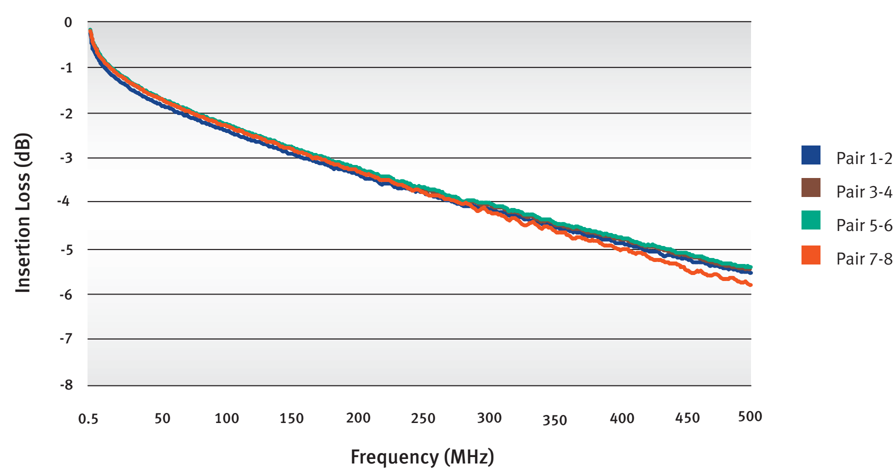




Glenair El Ochito® Connector System & GORE® Aerospace Ethernet Cables



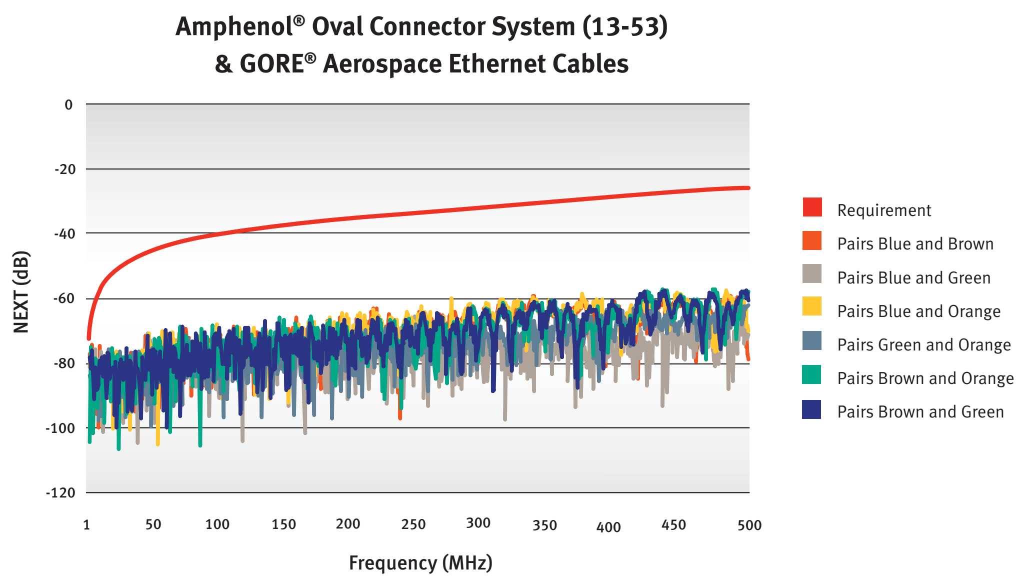
TE Connectivity® CeeLok FAS-X® Connector System & GORE® Aerospace Ethernet Cables

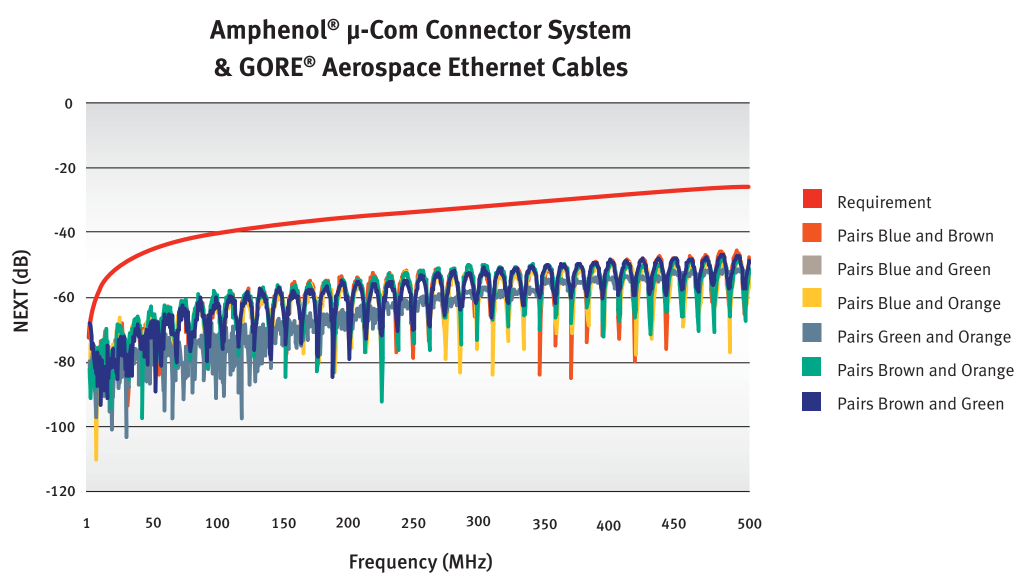


Crosstalk Comparison

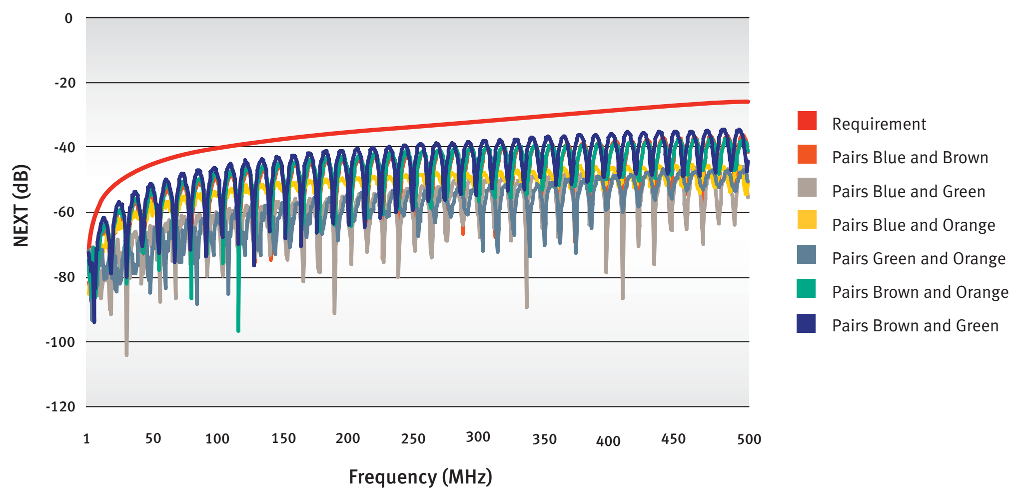
Likewise, these connector-cable combinations also reduced crosstalk up to 500 MHz indicating reliable signal integrity (Figure 15). The shielding over each individual twisted pair in GORE® Aerospace Ethernet Cables also increases shielding effectiveness for better noise immunity and reduced EMI emissions.

Figure 15: Near-End Crosstalk (NEXT) of Ethernet Interconnects

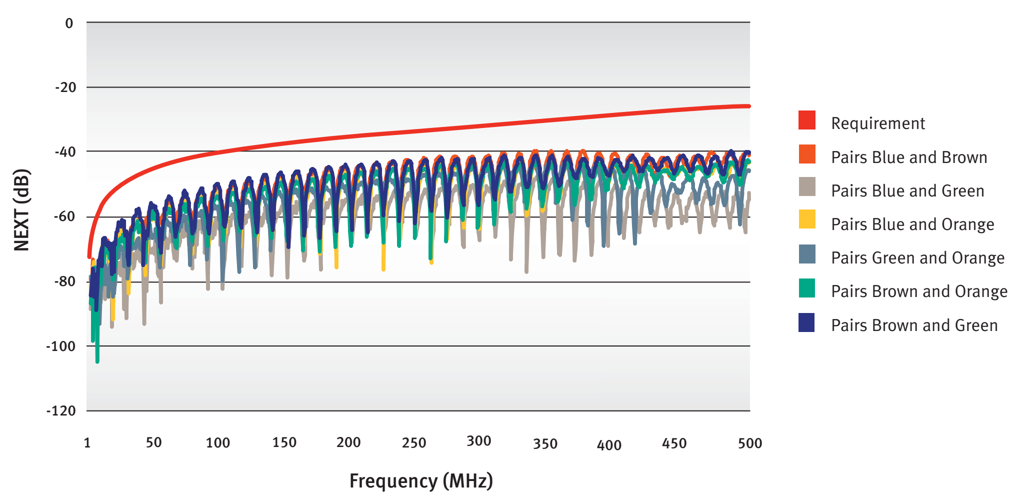




Glenair El Ochito® Connector System & GORE® Aerospace Ethernet Cables



TE Connectivity® CeeLok FAS-X® Connector System & GORE® Aerospace Ethernet Cables



Conclusion

As the demand for faster digital networks with increased performance continues to grow in the aerospace industry, Ethernet interconnects need to deliver high-speed data transmission while providing durable protection in challenging environments. However, few connectors exist that provide reliable electrical and mechanical performance. As a result, connector manufacturers are designing a variety of suitable Ethernet connectors that deliver sufficient signal integrity to handle higher data rates up to 10 Gb/s. Therefore, designers should carefully consider electrical and mechanical performance, ease of termination and total cost when selecting the right Ethernet connector during the initial design process.

In addition, designers should also give careful consideration to connector-cable compatibility during the initial design process, and perform thorough testing to ensure the entire interconnect will perform reliably in specific applications. Gore's testing showed that GORE® Aerospace Ethernet Cables terminated with leading high-speed connectors delivered dependable signal integrity with consistent impedance control, low insertion loss and minimal crosstalk. These connector-cable combinations meet and exceed electrical and mechanical requirements with a margin for Cat6a protocol providing reliable high-speed data transmission up to 10 Gb/s for up to 80 meters. Regardless of the connector system, the farther away the electrical margin from the specification limit will ultimately ensure a more tolerant, reliable and serviceable electronic system.

Gore's testing demonstrates the importance of designing the right Ethernet Interconnect that delivers excellent mechanical and electrical performance for high-speed data transmission in challenging aerospace conditions to ensure mission-critical success.

Application Notes

Designing the Right Ethernet Interconnect to Increase High-Speed Data Transmission in Military Aircraft

W. L. Gore & Associates

gore.com

Creative Technologies Worldwide