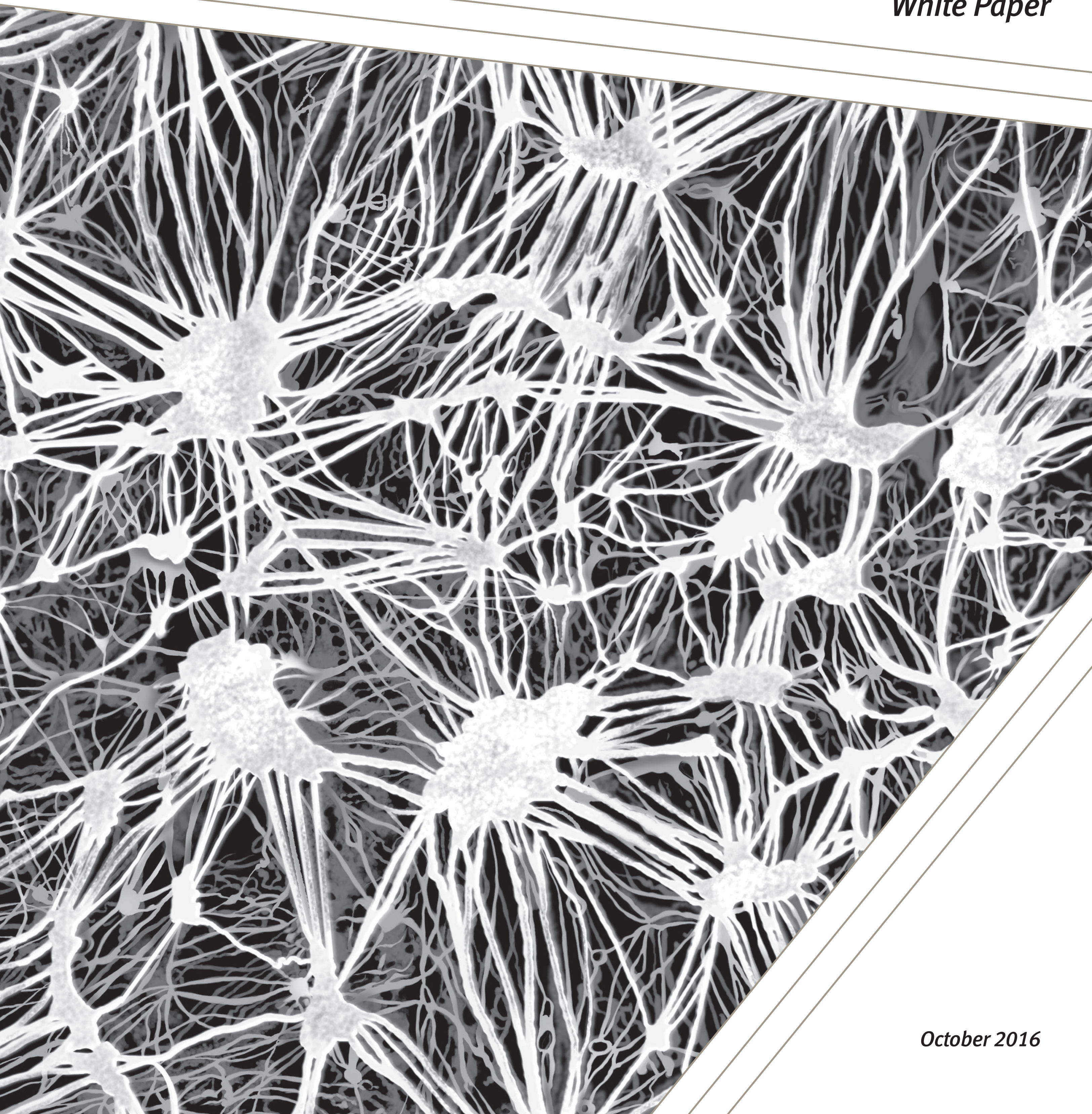
Installing the Right Ethernet Interconnect to Ensure Reliable Performance in Aircraft

White Paper



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Today's aerospace industry is demanding faster digital networks with increased performance in new and updated aircraft. As a result, more high-speed data interconnects and components need to be installed in the same or less space within an airframe to meet these requirements. Therefore, careful consideration should be given to space constraints, minimum bend radius (MBR) restrictions, signal integrity requirements, and cable handling practices during the initial design process. In addition, thorough testing should be performed to ensure the data interconnect can withstand complex routing in tight spaces and perform reliably after installation in specific applications.

W. L. Gore & Associates (Gore) evaluated the durability and electrical performance of several Ethernet Cat6a cables before and after routing, all with similar specifications. Gore also evaluated the electrical performance of the same cables at various lengths terminated with a leading high-speed connector system (i.e., daisy chaining). This testing showed the importance of installing the right Ethernet interconnect that delivers reliable electrical and mechanical performance for high-speed data transmission in real-world conditions to ensure mission-critical success.

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Introduction

With the increasing requirements for data gathering by manned and unmanned aircraft, system designers now have to install data processing networks with more capacity and higher speeds aboard aircraft. However, more devices mean less space and more complex routing of cables between the devices.

Further complicating the process is that cables carrying higher speeds are more susceptible to degradation during handling and routing. Therefore, typical installation practices may not be sufficient when trying to route more cables into an existing airframe to achieve higher speeds.

In addition, installers may need to navigate these cables through various aircraft bulkheads before reaching the targeted system receiver. Likewise, bulkhead connectors are often required when installing electronic retrofits in airframe upgrades. As a result, links within an aircraft may have to be interrupted by many connectors within the signal path, which can further compromise their electrical performance. Therefore, designers should carefully consider both connector types and connector-cable termination procedures, which may vary according to cable type even for the same connector.

The result may be that high-speed data links incorporating approved connectors and cables may not perform as expected during and after installation. Thus, qualifying an Ethernet interconnect in a stress-free lab environment does not ensure it will perform reliably in real-world conditions. Also, subtle issues with signal integrity are particularly hard to find and troubleshoot in an airframe. Therefore, components are typically swapped out (i.e., swaptronics) until the problem resolves itself, which can be very time-consuming and costly.

The impact of cables failing can be significant if left undetected during or after installation, including increased maintenance and downtime, replacement costs, and additional testing to requalify interconnects — not to mention the safety risks to passengers and crew and impact to the mission due to compromised system performance.

Cable Design Types

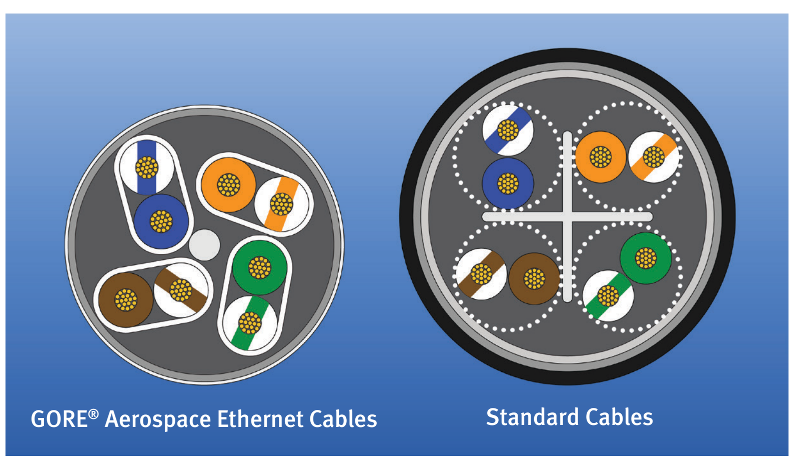
Ethernet Cat6a cables are the current industry standard to achieve high-speed network data transmission. This specification was developed to guarantee acceptable data transmission for carrying Ethernet signals at 1 Gigabit per second (Gb/s) and 10 Gb/s up to 100 meters. The standard Ethernet cable design consists of four 100-ohm unshielded twisted pairs to provide a controlled impedance path that is suitable for carrying signals at these high data rates. In addition, this design includes a cross-shaped spacer to separate the unshielded pairs in the cable to reduce crosstalk between the pairs to an acceptable level.

Typical cables designed to carry Ethernet signals in aerospace environments have a similar design that includes four unshielded pairs with a spacer; however, an overall shield is added to improve EMI performance(Figure 1). These enhanced cables also use high-temperature insulations and silverplated conductors to survive harsh aerospace environments. Unfortunately, this type of insulation and additional shielding often makes the cables more rigid and harder to bend during routing.

Gore has developed an alternative aerospace-qualified Cat6a cable design that includes individual shields over each pair (Figure 1). Adding a shield over each individual pair typically means increasing the insulation dramatically over each wire to meet the industry standard and maintain the 100-ohm nominal impedance. However, Gore's expanded polytetrafluoroethylene (ePTFE) primary insulation has a low dielectric constant of 1.3 allowing the shields to be applied without significantly increasing the insulation thickness. As a result, the size of each individually shielded pair in Gore's design is approximately the same size as an unshielded pair in the standard design. Furthermore, since each pair is shielded to reduce crosstalk, Gore's design does not require a cross-shaped spacer to separate the pairs physically. Also, new thin-wall insulation technology reduces the thickness of the outer jacket without compromising electrical and mechanical integrity.

The result is an Ethernet Cat6a cable design with individually shielded pairs that provides lower crosstalk compared to the standard design with unshielded pairs. Gore's Ethernet Cat6a cables are also 24 percent smaller and 25 percent lighter with greater flexibility and a tighter bend radius making routing easier in small spaces compared to the typical aerospace Ethernet cable design.

Figure 1: Design Comparison of Ethernet Cat6a Cables



Routing Challenges

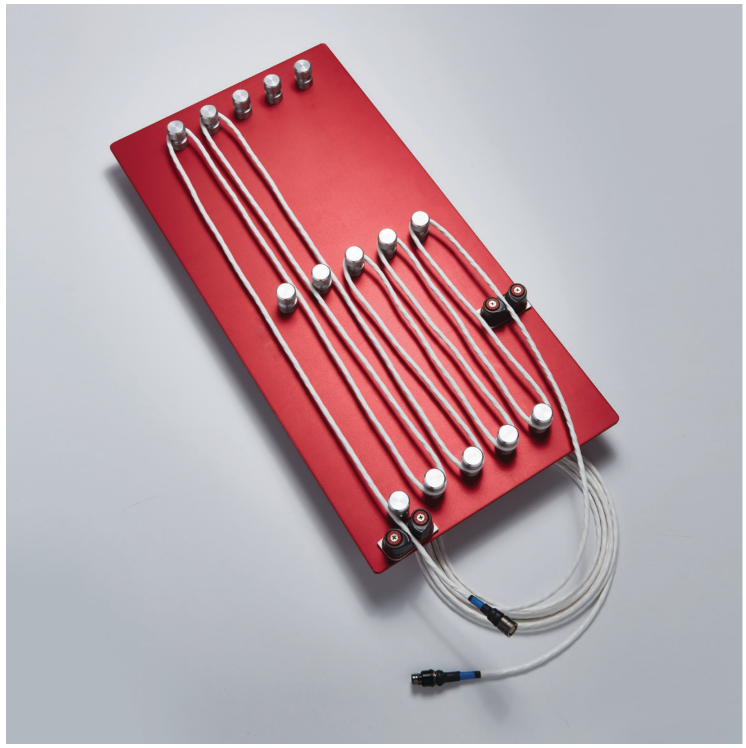
Routing cables successfully in aircraft is an ongoing challenge for engineers when designing wire harnesses, cable clamping, and overall bundle routing methods. And the need for more electrical actuators and sensors have further complicated the design process over the past few years. Also, routing high-speed data cables often include severely bending cables and jamming more wire bundles into confined areas of an existing airframe. Installers must be careful not to put too much stress on the cables when handling, bending, routing or tying cable bundles. Figure 2 shows the complexity of routing standard cables in an electronic system.

Figure 2: Cable Installation in Aircraft

In addition, high-speed cable specifications often include a larger MBR requirement that is difficult to meet and often violated to satisfy the dense packaging of aircraft avionics. Furthermore, actual data measuring electrical performance as cables are bent beyond the MBR during initial routing has not been adequately documented.

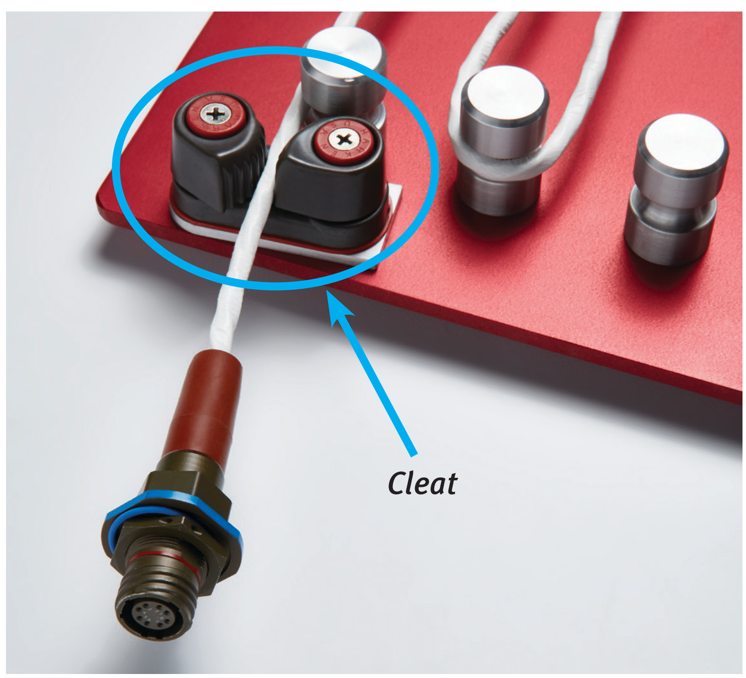
Therefore, Gore designed a test simulator that replicates the conditions a cable assembly experiences while being routed through an airframe to evaluate the effects of severe bending on their electrical performance at high frequencies (Figure 3). The simulator includes 15 mandrels with each mandrel set to a 0.5-inch bend radius that replicates MBR conditions an assembly encounters to ensure it is evaluated under the worst-case scenario without kinks in the cable. The mandrels are fixed at certain locations on the simulator allowing for more precise comparisons between various assemblies under controlled bending situations. Also, the mandrels are positioned on the simulator to provide consistent or variable distances between bends.

Figure 3: Test Simulator



The simulator also includes two cable cleats located at the cable entry and exit points on the board (Figure 4). During the routing process, the cable is inserted into each cleat to hold it tightly under tension and without crushing it to avoid adversely impacting test results.

Figure 4: Cable Cleat on Test Simulator



Results of Gore's testing are in accordance with qualifying Ethernet interconnects at 10-GbE as defined in Telecommunications Industry Associate (TIA) 568-C.2. This standard characterizes cable assembly performance up to 500 Megahertz (MHz). New and future requirements are expected to be even more stringent. Therefore, future testing should be performed at higher frequencies because signal integrity degradation will be worse at higher frequencies due to these routing and installation challenges.

Electrical Performance — Before Routing

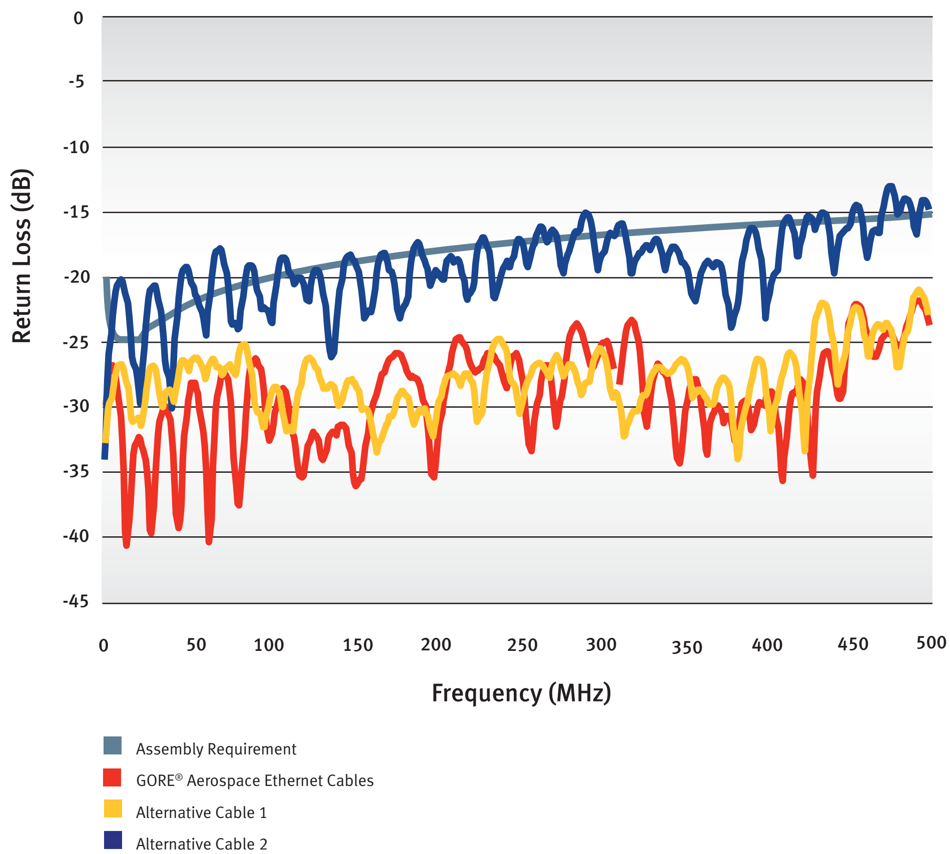
Return Loss and Crosstalk Comparison

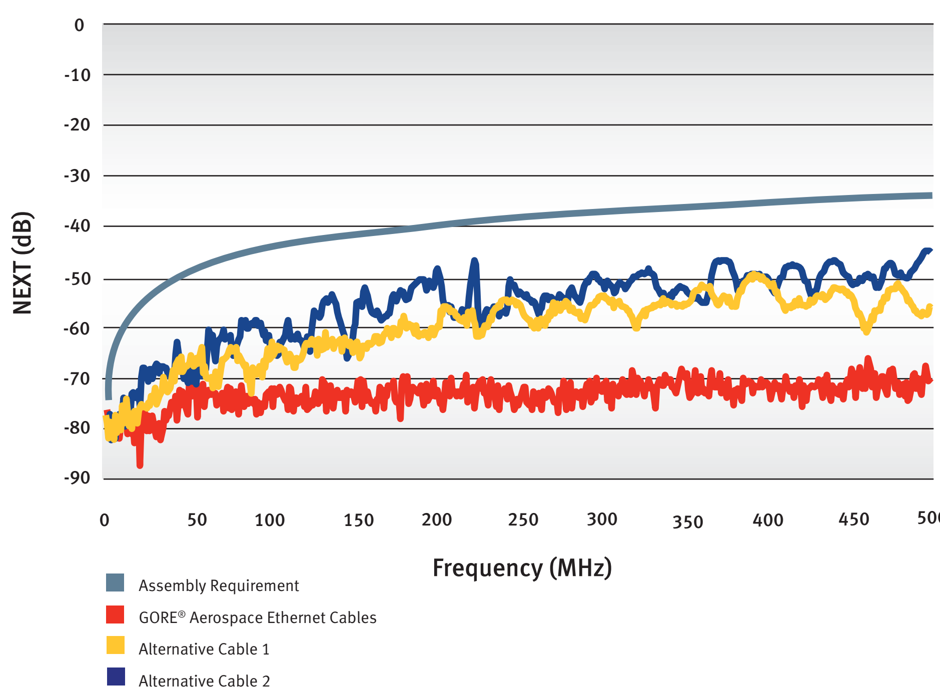
Gore compared their Cat6a Ethernet cables with leading alternative cables, all with similar specifications and without connectors. Testing was performed for return loss and near-end crosstalk (NEXT) before routing to measure performance when brand new. Using a Vector Network Analyzer (VNA), the results were recorded over the range of 1-500 MHz and served as a baseline to evaluate any performance change after being routed through the simulator.

Typically, there are four traces for each cable when measuring return loss, and six traces for each cable when measuring crosstalk. Results from Gore's testing displays the highest value from each trace across the frequency range to interpret the results easier while also ensuring that the worst-case results are recorded for each pair or interaction between any two pairs.

Even before routing through the simulator, Alternative Cable 2 exceeded the specification limit significantly for return loss (Figure 5). However, results indicated that return loss and crosstalk are considerably less with GORE® Aerospace Ethernet Cables due to the unique shielding over each individually twisted pair. These cables demonstrate better impedance control and lower crosstalk between the pairs.

Figure 5: Return Loss and Crosstalk Comparison of Ethernet Cat6a Cables BEFORE Routing





Electrical Performance — After Routing

Testing was performed using the same cables without connectors to evaluate the changes in high-frequency electrical performance after being routed. Each cable was routed around seven mandrels through the simulator to mimic typical bending practices during routing and installation.

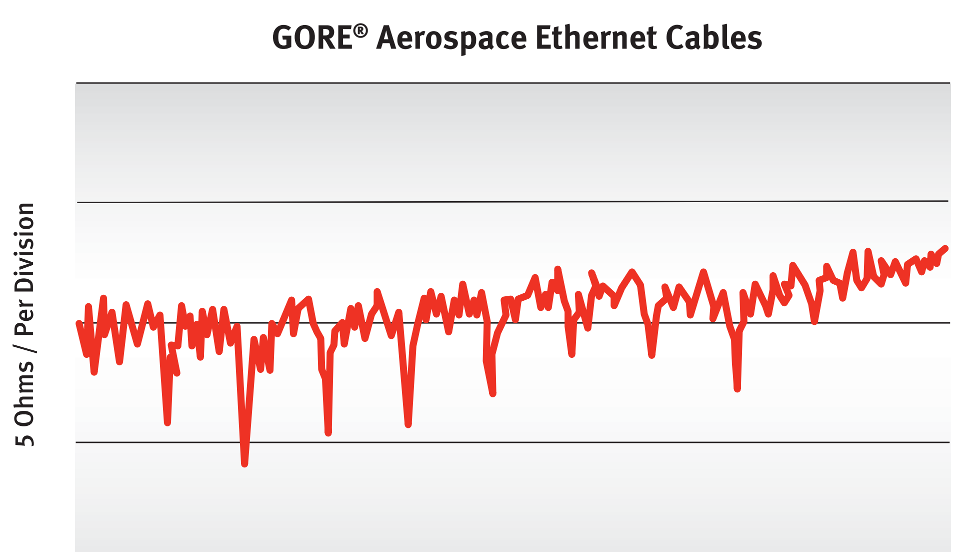
Time Domain Reflectometer (TDR) results were recorded for each cable type to evaluate the effects of bending on characteristic impedance. Return loss and crosstalk results were recorded over a range of 1-500 MHz to show the worst-case points at each frequency.

TDR Comparison

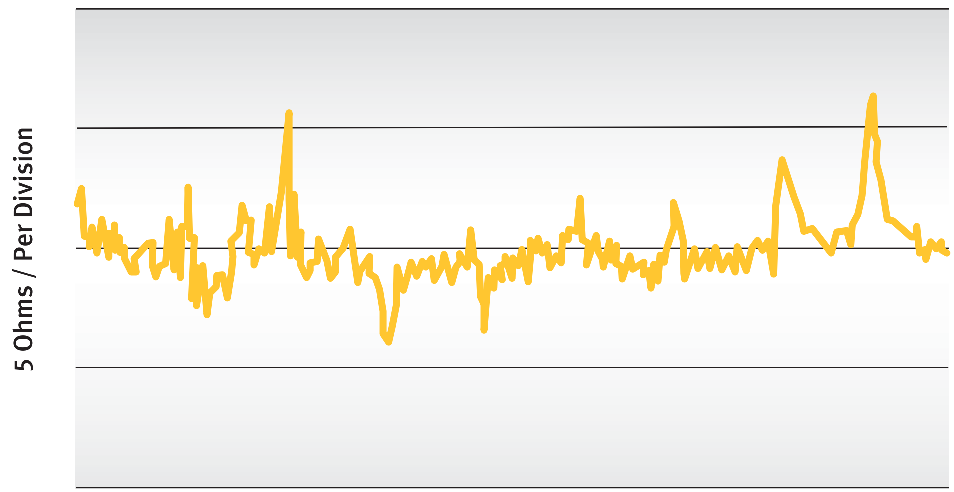
Bending high-speed data cables beyond their MBR during routing can often cause disruption in impedance in the specific bend area. Therefore, impedance was measured across the routing area (approximately 2 meters in length) of each cable. When using a TDR, a pulse (rise time equals 35 psec), or specifically, 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 interconnect performance.

The results demonstrated that impedance discontinuities at the cable bends were capacitive for GORE® Aerospace Ethernet Cables with shielded pairs (Figure 6). In contrast, the results for the leading alternative cables with unshielded pairs showed both inductive spikes and capacitive dips in impedance control. The inductive spikes may also indicate the pairs separated at times while being bent, which may adversely impact return loss and crosstalk performance.

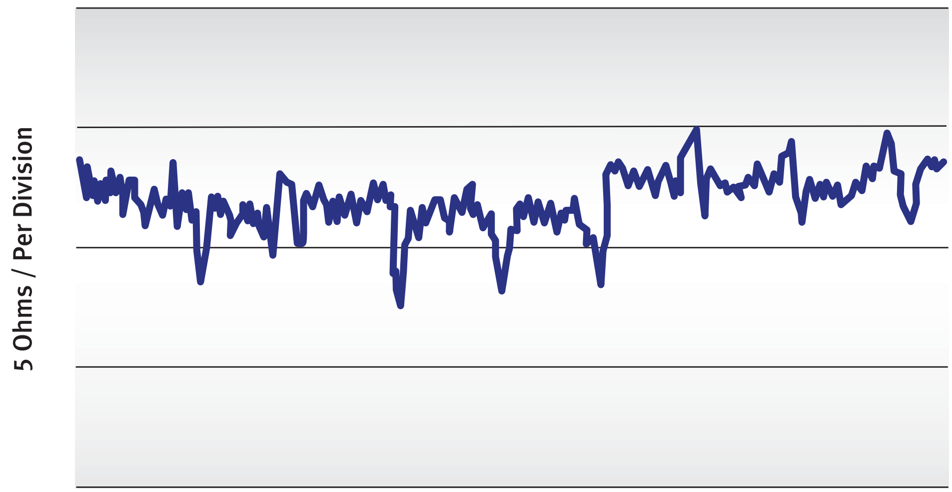
Figure 6: Impedance Comparison of Ethernet Cat6a Cables AFTER Routing



Alternate Cable 1



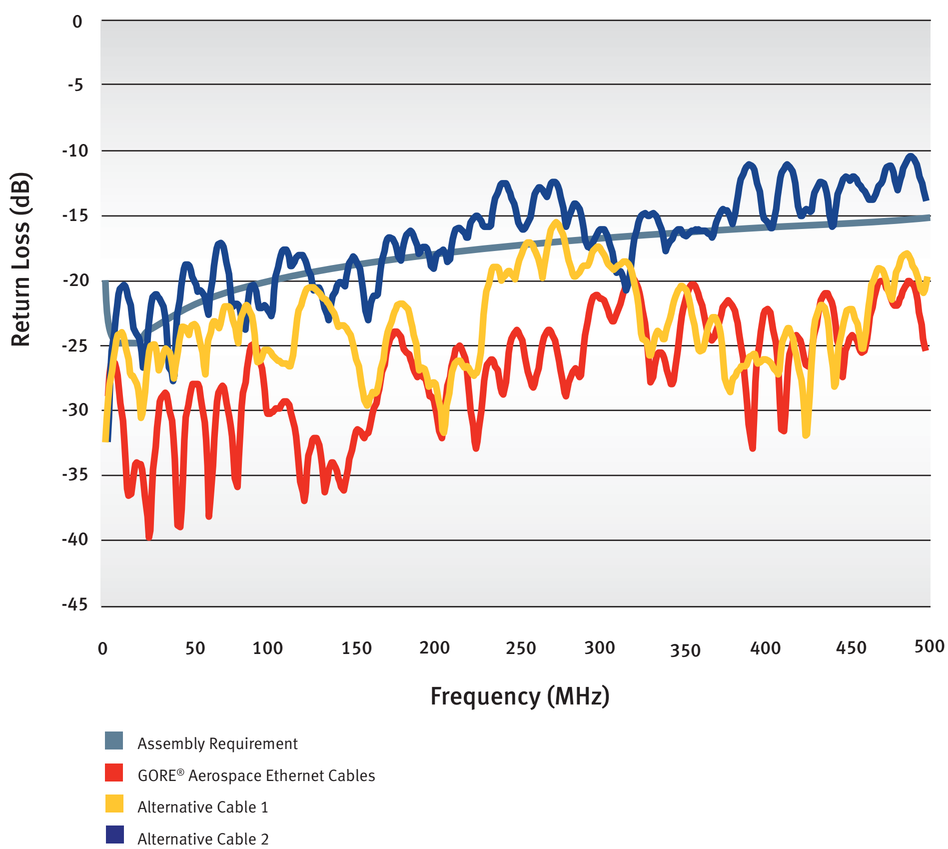
Alternate Cable 2



Return Loss Comparison

The results indicated that Alternative Cable 1 exceeded the specification limit slightly after being routed through the simulator (Figure 7). Also, results were much worse for Alternative Cable 2, which was expected since it exceeded the specification limit even before being routed through the simulator. In comparison, GORE® Aerospace Ethernet Cables maintained sufficient margin below the specification limit and provided consistent impedance control at higher frequencies, indicating reliable high-speed data transmission at 10 Gb/s.

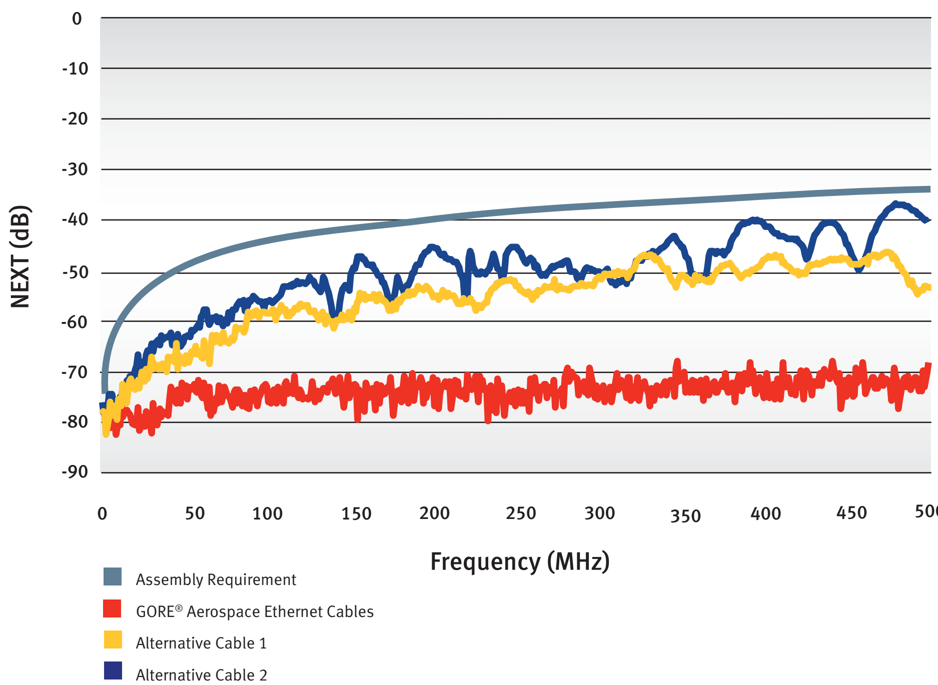
Figure 7: Return Loss Comparison of Ethernet Cat6a Cables AFTER Routing



Crosstalk Comparison

Results for the leading alternative cables showed reduced crosstalk margin by 2 and 7 dB respectively after being routed through the simulator (Figure 8). However, GORE® Aerospace Ethernet Cables maintained a consistent margin of 20 dB, providing lower crosstalk before and after routing compared to the alternative cables.

Figure 8: Crosstalk Comparison of Ethernet Cat6a Cables AFTER Routing



Electrical Performance — Multiple Connectors

Testing was also performed on the same cables at various lengths terminated with multiple TE Connectivity® CeeLok FAS-X® connectors[1] (i.e., daisy chaining) to evaluate return loss and crosstalk (Figure 9). Again, results were recorded over a range of 1-500 MHz.

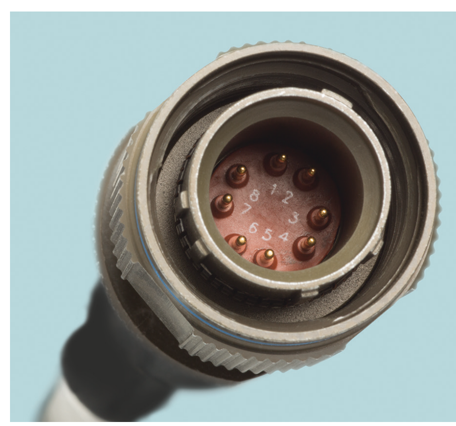


Figure 9: Gore's Cat6a Cable Terminated with TE Connectivity® CeeLok FAS-X® Connector System

Gore terminated their 10-meter Cat6a cable with a connector at each end to form a direct connection link. Then, Gore assembled cables at 2, 3, and 5 meters (totaling 10 meters) terminated with multiple connectors to form a daisy chain link and serve as a baseline for performance. The performance was recorded to compare both links. The cable assembly and test process were repeated using the alternative cables, and performance was recorded.

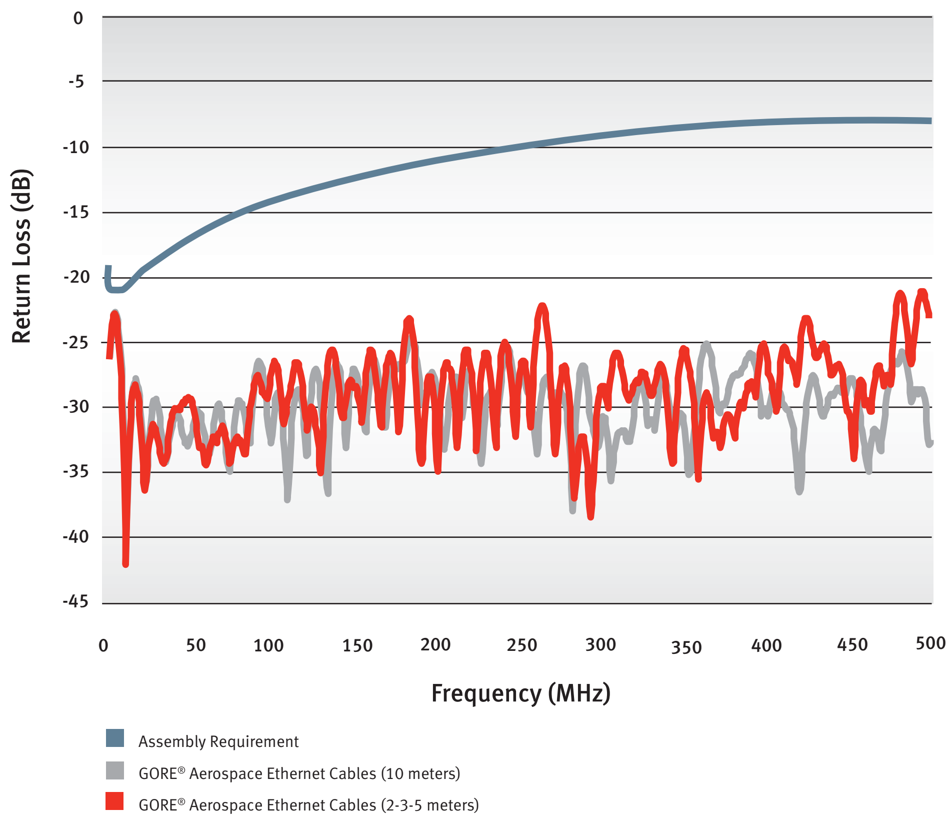
[1] For more information, download the white paper, *Designing the Right Ethernet Cables to Increase High-Speed Data Transmission in Military Aircraft* at gore.com/militaryinterconnects.

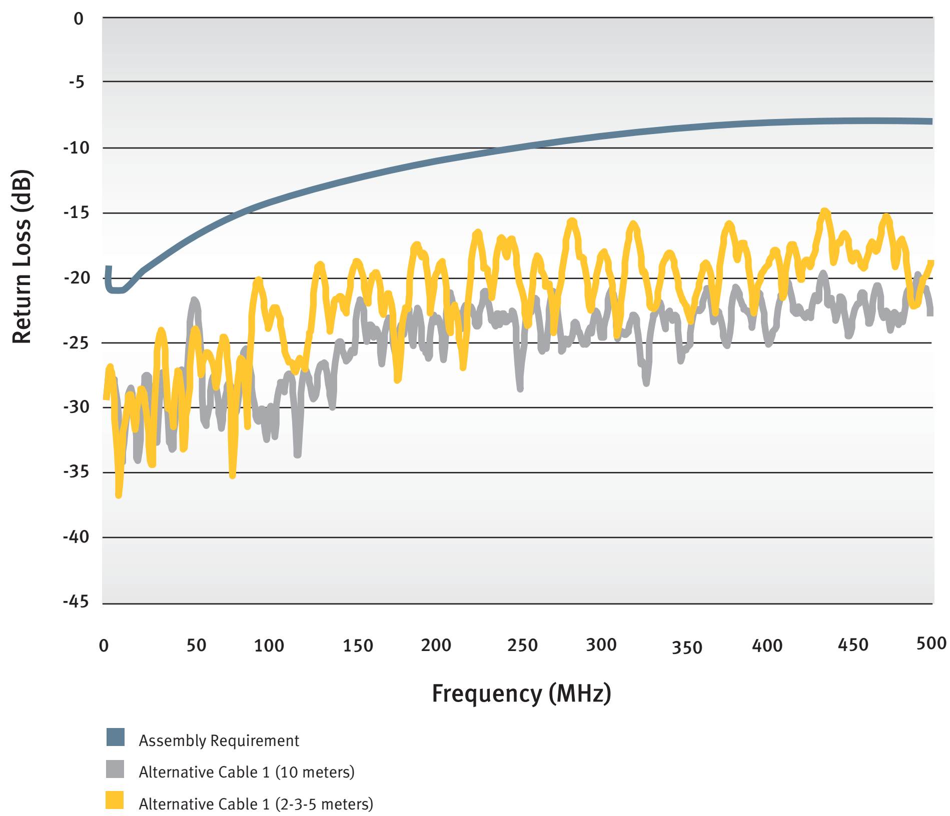
Return Loss Comparison

The results demonstrated only a slight change in performance for GORE® Aerospace Ethernet Cables due to the individually shielded pairs, indicating the connectors in both links had minimal impact on return loss (Figure 10). The discontinuity from the connector and the portion of the connector where the pairs are coupled is reduced because shielding is maintained next to the connector pins.

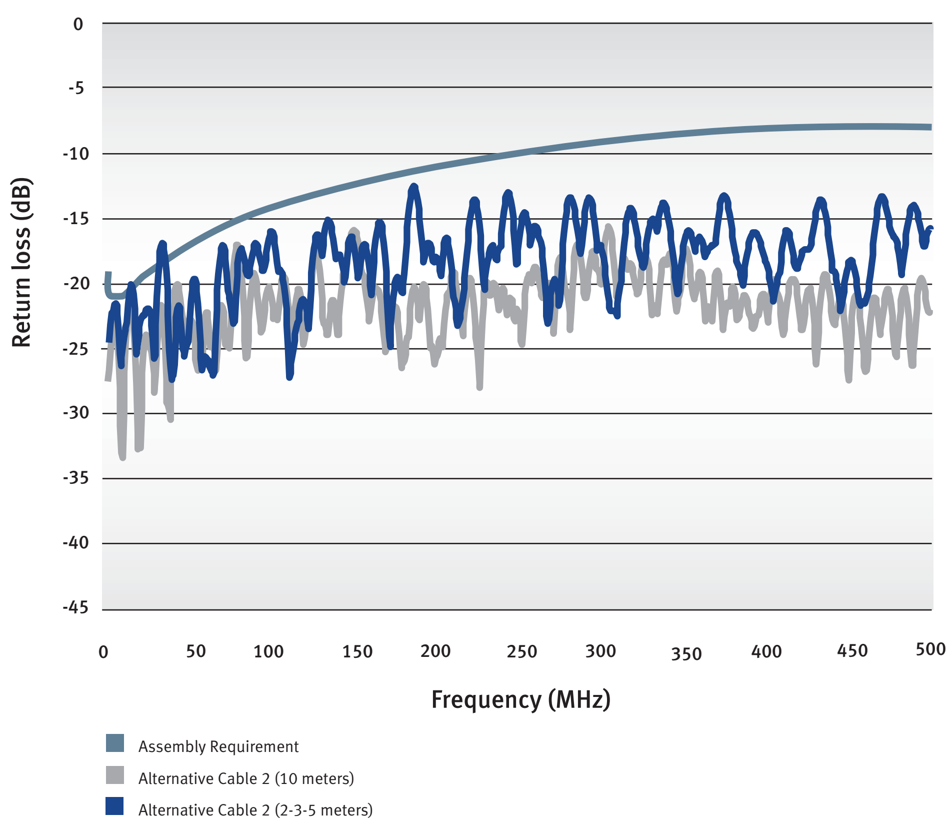
However, return loss increased significantly for the leading alternative cables using the same connectors in a daisy chain link due to the unshielded pairs. In fact, Alternative Cable 2 exceeded the specification limit at approximately 30 MHz.

Figure 10: Return Loss Comparison of Ethernet Cat6a Interconnects (Direct Connection vs. Daisy Chain)





Return Loss (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
0
50
100
150
200
250
300
350
400
450
500
Frequency (MHz)
Assembly Requirement
Alternative Cable 1 (10 meters)
Alternative Cable 1 (2-3-5 meters)

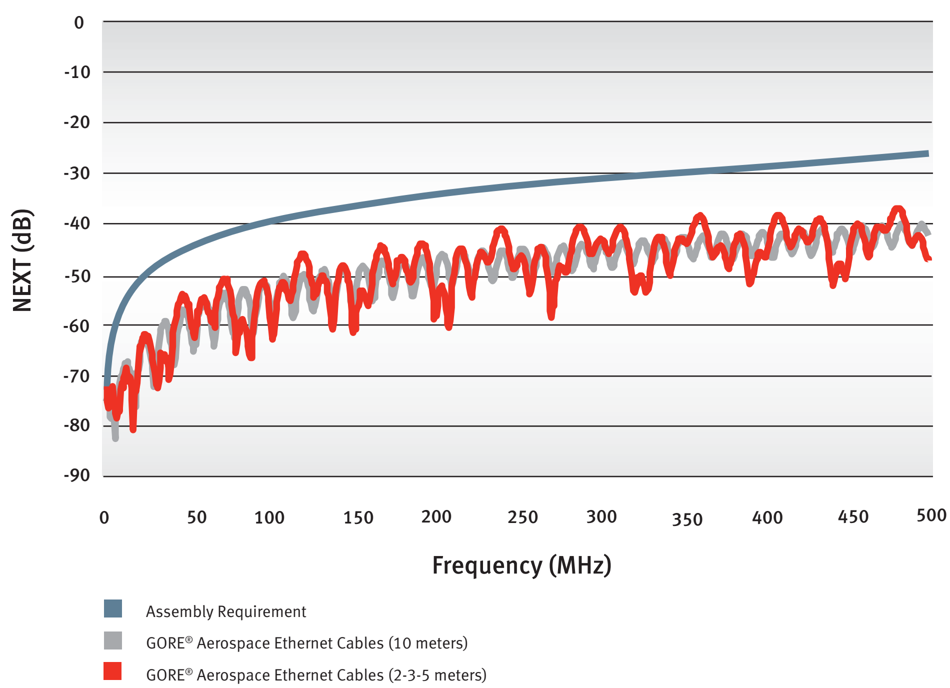


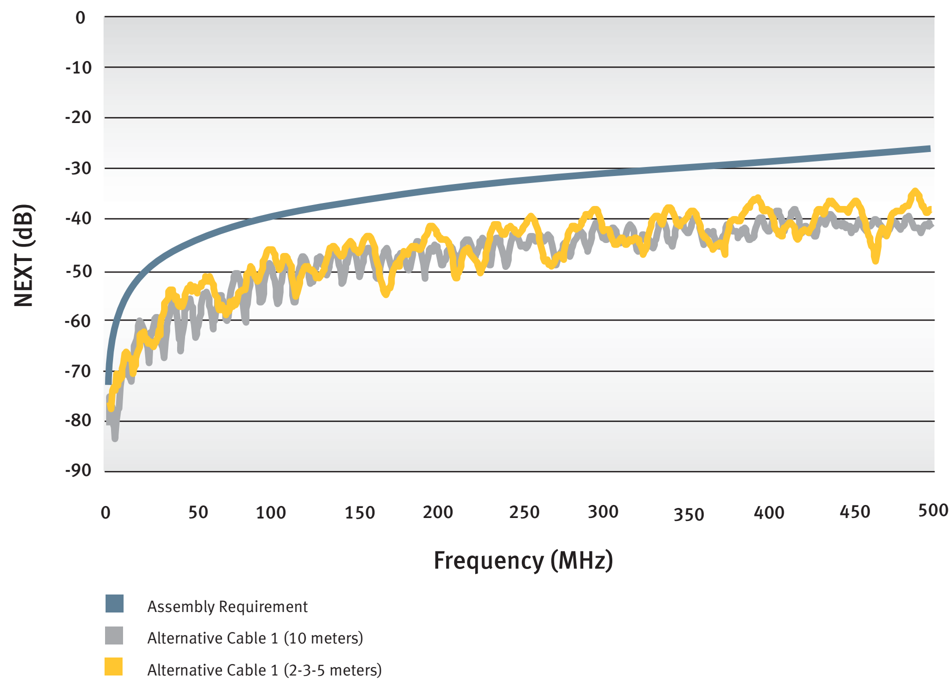
Return loss (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
0
50
100
150
200
250
300
350
400
450
500
Frequency (MHz)
Assembly Requirement
Alternative Cable 2 (10 meters)
Alternative Cable 2 (2-3-5 meters)

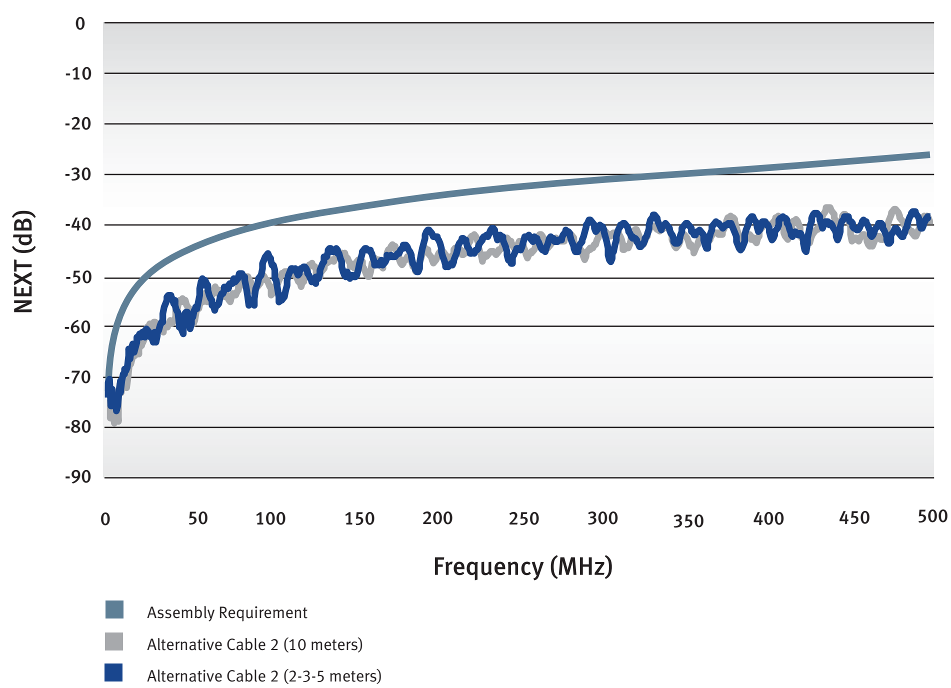
Crosstalk Comparison

Multiple connectors in a daisy chain link have less of an impact on crosstalk performance due to the selected connector with isolated pairs. However, results indicated that GORE® Aerospace Ethernet Cables maintained lower crosstalk compared to the alternative cables (Figure 11). In addition, these cables have a lower starting point for crosstalk due to the individually shielded pairs, which means that any increase in performance still maintains excellent shielding effectiveness.

Figure 11: Crosstalk Comparison of Ethernet Cat6a Interconnects (Direct Connection vs. Daisy Chain)




0
-10
-20
-30
-40
-50
-60
-70
-80
-90
NEXT (dB)
0
50
100
150
200
250
300
350
400
450
500
Frequency (MHz)
Assembly Requirement
Alternative Cable 1 (10 meters)
Alternative Cable 1 (2-3-5 meters)


0
-10
-20
-30
-40
-50
-60
-70
-80
-90
NEXT (dB)
0
50
100
150
200
250
300
350
400
450
500
Frequency (MHz)
Assembly Requirement
Alternative Cable 2 (10 meters)
Alternative Cable 2 (2-3-5 meters)

Conclusion

While industry standards adequately define high-frequency electrical requirements for Ethernet Cat6a protocol, testing in a lab environment does not guarantee that qualified interconnects will perform reliably in real-world conditions. Many cables on the market today fail during the complexities of installation because they are stiff and difficult to route in confined spaces, which can compromise the entire system in the aircraft. In addition, a specific connector and cable type that has shielded or unshielded pairs attached to the contacts can affect the overall performance of the entire interconnect. Electrical performance can also vary with different cable and connector types that are daisy chained in a link, which can dramatically affect signal quality when bent during routing in tight areas. If left undetected, the impact can be substantial with increased maintenance and downtime, replacements costs, additional retesting to verify every component, and more importantly, a severe risk to passengers and crew or the mission. Therefore, designers should carefully consider these harsh aerospace environments for their specific application and the potential impact on signal quality with selected interconnects.

As a result, Gore developed the test simulator to demonstrate the importance of testing interconnects in real-world conditions. Their testing[2] showed that performance significantly degrades because cables get damaged during routing or when terminated with multiple high-speed connectors in a daisy chain link, compromising the signal quality. However, Gore's testing proved that GORE® Aerospace Ethernet Cables delivered excellent signal integrity even after severe bending during routing compared to leading alternative cables. The unique construction of these cables is smaller and lighter weight, yet highly durable for greater mechanical strength and superior shielding effectiveness.

Selecting an interconnect with a durable construction that has been tested to survive real-world conditions is the key to ensuring reliability before and after installation. GORE® Aerospace Ethernet Cables deliver exceptional performance before and after installation, reduce maintenance and downtime, and reduce total costs over time.

[2]For more information, watch the video at gore.com/militaryinterconnects

Application Notes

CeeLok FAS-X is a registered trademark of TE Connectivity.

W. L. Gore & Associates

gore.com