White Paper

RISK OF TRANSMITTING HIGH-SPEED DATA IN AIRCRAFT USING MIL-DTL-38999 CONNECTOR SYSTEMS

Introduction

Connector manufacturers have responded to the need for higher bandwidth, controlled-impedance interconnects to support aerospace and defense applications using Ethernet at 10 gigabit per second (Gb/s), and other high-speed data protocols. There are now many options suitable for applications that offer a broad range of good-to-excellent signal integrity performance. However, design engineers are still choosing to use MIL-DTL-38999 open pin field connectors, hoping they can save money, combine more signals in one connector, and facilitate easier field repairs. These connectors are often shown to have insufficient electrical performance for newer, more demanding higher-speed data transmission requirements.

For design engineers who insist on using standard MIL-DTL-38999 connector system configurations, Gore provides test data showing possible signal degradation resulting from different pinouts and the effect that pin and ground assignments have on signal quality. Gore also evaluated two case studies where design engineers selected these connector systems for high-speed data with less than desirable results. Measurements for near-end crosstalk (NEXT) and return loss are also shown for various pinouts where signals may be positioned to improve crosstalk and return loss characteristics.

Data transmission from Ethernet and other protocols that use multi-level signaling to reach longer distances can be degraded by noise and reflections. Therefore, Gore compared these connectors for crosstalk and impedance control. Additionally, data links containing these connectors were characterized using a functional 10-Gb/s Ethernet test system capable of measuring bit errors and autonegotiation events.

Together, improving life

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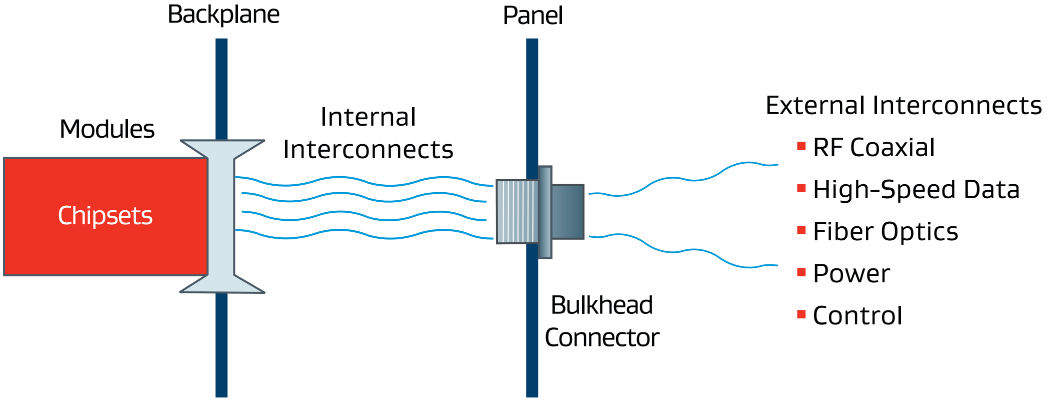
System Approach to Interconnect Design

Designing interconnects for high performance, and critical aerospace and defense applications must go beyond verifying individual cable performance to ensure they meet industry specifications. Due to environmental conditions such as temperature fluctuations, EMI potential, and surrounding high-speed signals, design engineers must consider substantial noise margin to ensure error-free performance in the application. Also, the effects of multiple connections in a given link must be factored into the design. Once a system is assembled, it can be difficult to troubleshoot issues with signal integrity, especially if transmission bit errors are intermittent and cannot be reproduced in a lab environment. Figure 1 shows how the individual components work together in a system. It identifies the potential issues around mechanical durability, electrical performance, and long-term reliability that design engineers should consider when designing a system.

Figure 1: Understanding System-level Interconnect Issues



Specifying a complete interconnect system can be a daunting task. With many choices, design engineers must compare data links based on performance, density, field reparability, design flexibility, predicted mating cycles, adaptability, and cost. When considering connectors based on minimum performance levels, they should be aware of all aspects of the system — including chipsets, backplane connectors, internal interconnects, and the number of bulkhead connectors or production breaks. Design engineers should also consider any future requirements that may be imposed on interconnect systems as technology advances to higher speeds. Choosing a connector system based exclusively on what is viewed on the outside of an enclosure can lead to significant problems. Prior to completing a design, connector systems should also be thoroughly tested in a way that is consistent with application use and potential upgrades. Thorough testing should include environmental and surrounding EMI conditions, the length between boxes, routing, and future scenarios for high data rate operation.

In addition, all other interconnect types and their potential interference with high-speed data links must be considered in the system design. These other lines, such as microwave/RF coaxial cables, fiber optics, power lines and low-frequency control lines, must all be included in the overall system design and sustainment plan. These types of signals are often mixed within a specified connector; thus, it is important to understand the critical effects that they may have on each other.

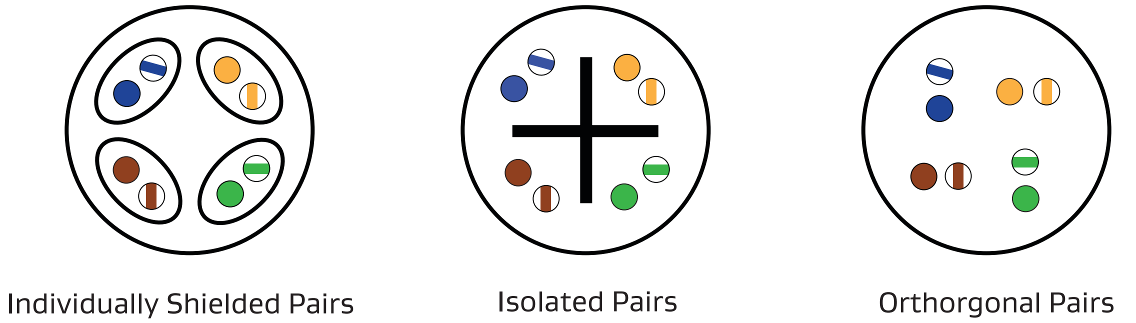
Inertia Using MIL-DTL-38999 Open Pin Field Connector Systems

Some design engineers avoid using newer, controlled-impedance aerospace high-speed connector systems due to perceived difficulty with field termination or higher cost. Many have tried carefully selecting pinout configurations that can still use standard cable assembly techniques at a familiar cost. They should determine the upfront and downstream costs based on this type of decision versus potential cost savings using alternative connector systems. The cost of finding an optimized pinout and then complete subsequent testing to ensure acceptable performance can outweigh the initial low-cost benefit. The length of uncontrolled impedance from a mated pair with standard 38999 connector systems can be up to 6 inches (152 millimeters) depending on jacket and shield preparation. These workmanship variables can be difficult to specify and control, especially with field installations. The risk of system performance degradation or failures due to data links inadequately performing should not be underestimated or ignored.

Basic 10-Gb/s Ethernet Connector System Designs

Improved connector systems developed for the aerospace industry use three basic design concepts to provide impedance control and reduced crosstalk (Figure 2).

Figure 2: Basic 10-Gb/s Ethernet Connector System Designs



Individually Shielded Pairs Design

The individually shielded pairs design includes a continuous shield around each pair that provides the highest degree of impedance control and crosstalk prevention. The Amphenol® OCS modular connector system is an example of this design type (Figure 3). Each pair is individually terminated into a shielded contact and installed into a specialized connector insert cavity designed to provide the correct alignment between the contacts upon mating. The shields of the contacts are connected around the pairs to form a 360-degree attachment that provides maximum crosstalk prevention. The pairs can be inserted into many configurations based on the number of high-speed links required.

Figure 3: Amphenol® OCS Connector System

Isolated Pairs Design

This design includes a ground plane cross member between the pairs to improve performance in MIL-DTIL-38999 open pin field connector systems The ground plane provides a reference plane within the connector interface that allows for impedance control and also reduces crosstalk between the pairs within the connector system.

Figure 4 shows the TE Connectivity® CeeLok FAS-X® connector system that contains a ground plane cross member hidden within the connector insert, which has limitations. For example, the shield of the cable is attached to the cross member; however, the ground plane element is not directly connected to the ground plane in the mating connector. This discontinuity reduces the isolating effects of the ground plane and disrupts the field lines at the contact interface, which is important especially at higher frequencies. The CeeLok FAS-X® connector system is limited to 4 pairs within a single MIL-DTL-38999 connector system.

Figure 4: TE Connectivity® CeeLok FAS-X® Connector System

Isolated Pairs Design (continued)

Another example of isolated pairs is the Glenair El Ochito® connector system (Figure 5). This design approach is slightly different because four pairs are integrated into an individually shielded multi-pin insert. There are still ground planes between the signal pairs; however, each set of four pairs can be installed into a MIL-DTL-38999 connector system with a size 8 opening. The cross member ground plane shows through the connector interface. Although the ground planes are visible, they are not directly connected to the ground plane in the mating connector, which limits overall performance. These connector systems provide very high-density constructions with the ability to combine dozens of signal pairs within a single 38999 shell.

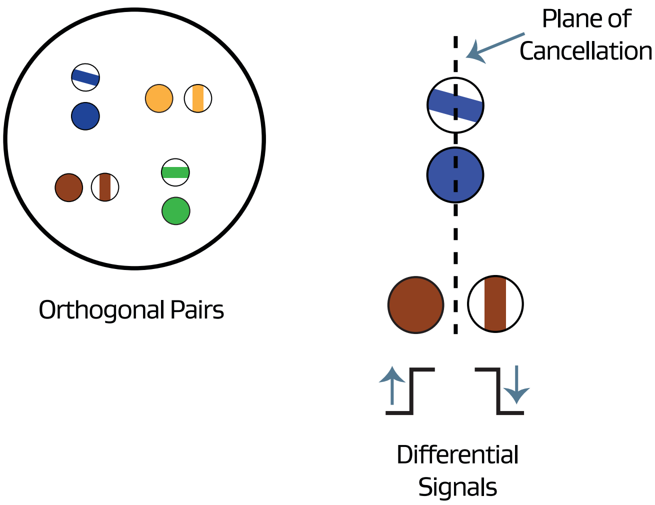
Figure 5: Glenair El Ochito® Connector System

Lastly, the ITT Cannon OctoGig™ Connector System also uses this design. It brings out the ground planes between sets of pairs to make electrical contact at the mating points; thus, addressing the concern around ground planes not providing continuity at the connector interface. While providing better crosstalk protection, this connector system can only handle four signal pairs within a given connector, which is similar to the CeeLok FAS-X® connector system. The unique ground plane contact mechanism allows these connectors to handle frequencies up to the same range as connector systems with individually shielded pair designs.

Orthogonal Pairs Design

The orthogonal pairs design used in these purpose-made connector systems depends on the effect of field cancellation that occurs with differential signals along an orthogonal plane with respect to the pairs (Figure 6). Crosstalk is reduced by rotating the contact positions 90 degrees on the adjacent contacts. However, this design does not address impedance control, which may mean that one leg from a pair could be imbalanced due to its close proximity to another pair, possibly impacting return loss slightly at higher frequencies. Since there are no internal shields or ground planes, this design is the closest to a standard connector for use in cable assembly techniques that facilitate easy field repair.

Figure 6: Differential Signals in Orthogonal Pairs Design



An example of this connector system design is the LEMO® 2B Series constructed with four pairs in two sizes with signal spacing depending on the application requirements (Figure 7). While not technically a MIL-DTL-38999 style design, these circular connector systems are frequently used for high-reliability aerospace applications.

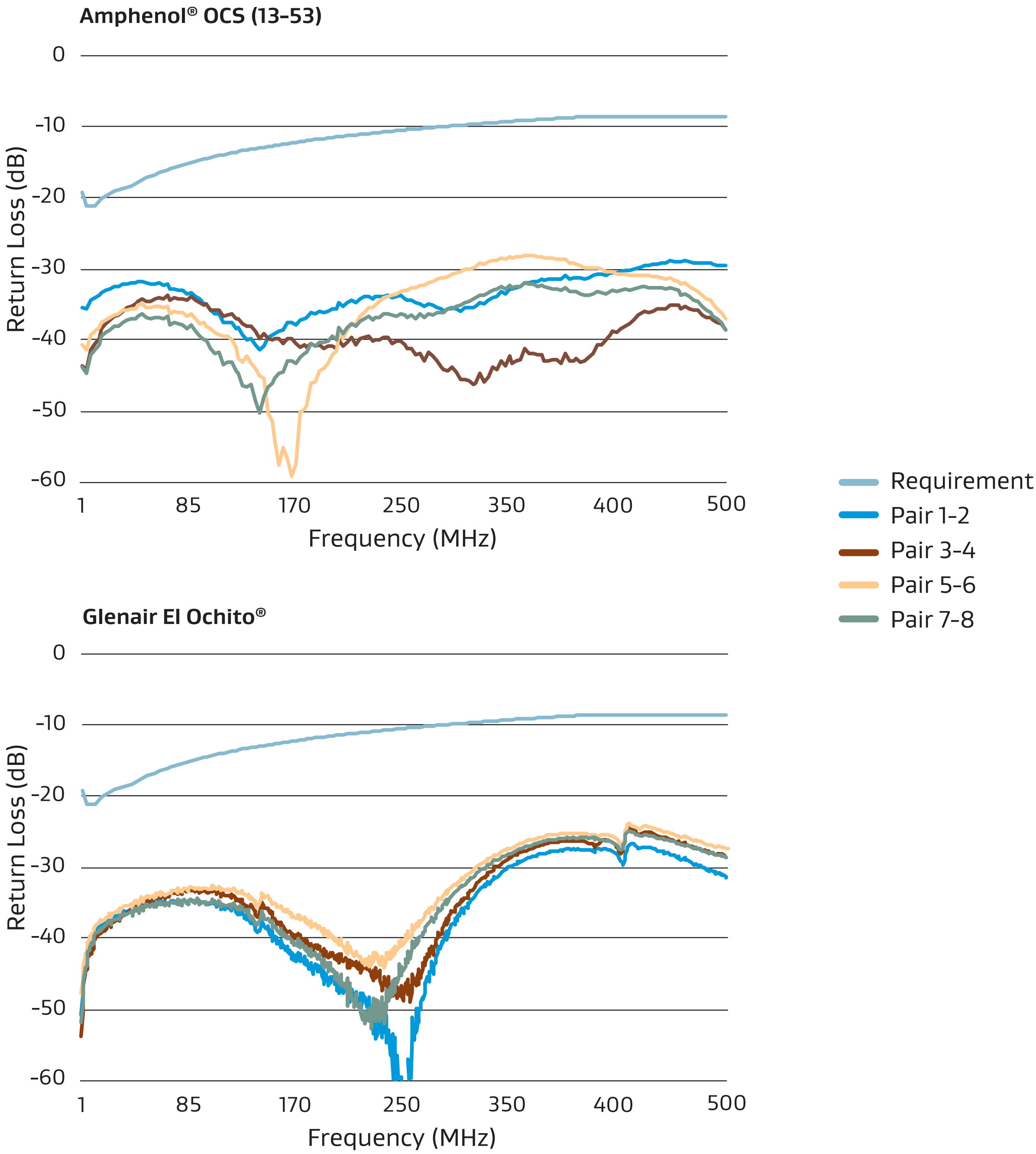
Figure 7: LEMO® 2B Series Connector System

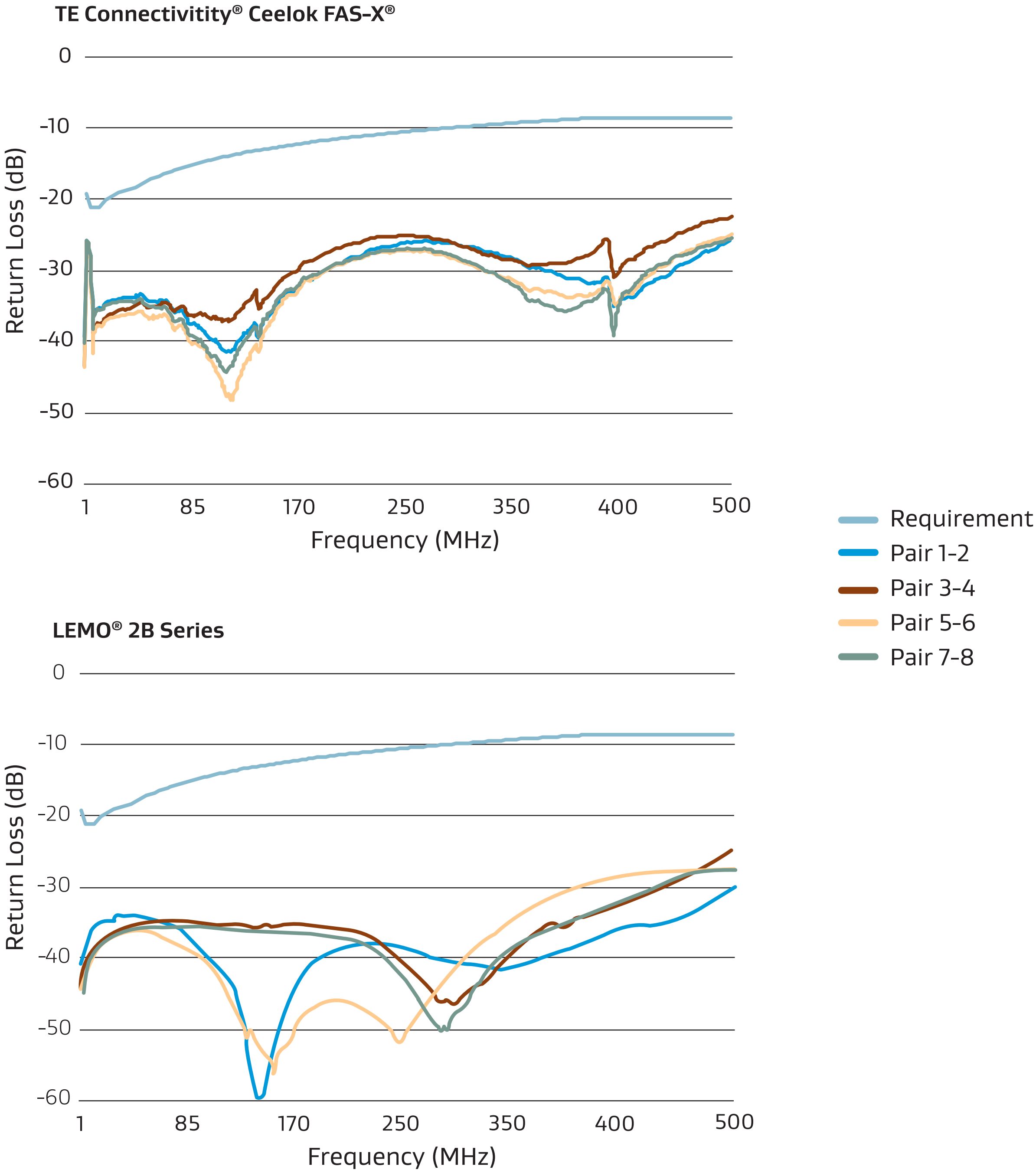
Electrical Performance Comparison

These basic connector system designs do a reasonably good job of establishing acceptable impedance control to maintain low return loss. Figure 8 shows that the values are well below the limits specified in the ANSI/TIA 568-C industry standard. Impedance control is achieved by controlling the geometry of the ground plane positions and contact locations.

The individual performance of these designs may vary at higher frequencies. For example, better performance at frequencies below 500 MHz does not translate to better performance above 1 GHz. In general, connector systems that have better impedance control and good grounding continuity will continue to perform above 1 GHz than connector systems primarily designed to handle 10-Gb/s Ethernet. It is important to understand specific data rates and required bandwidth before choosing a connector system. Connector systems performing at the highest bandwidth should also be used if system upgrades are anticipated to avoid replacing an inadequate wiring scheme and additional cost during retrofits.

Figure 8: Return Loss Comparison of Ethernet Cables

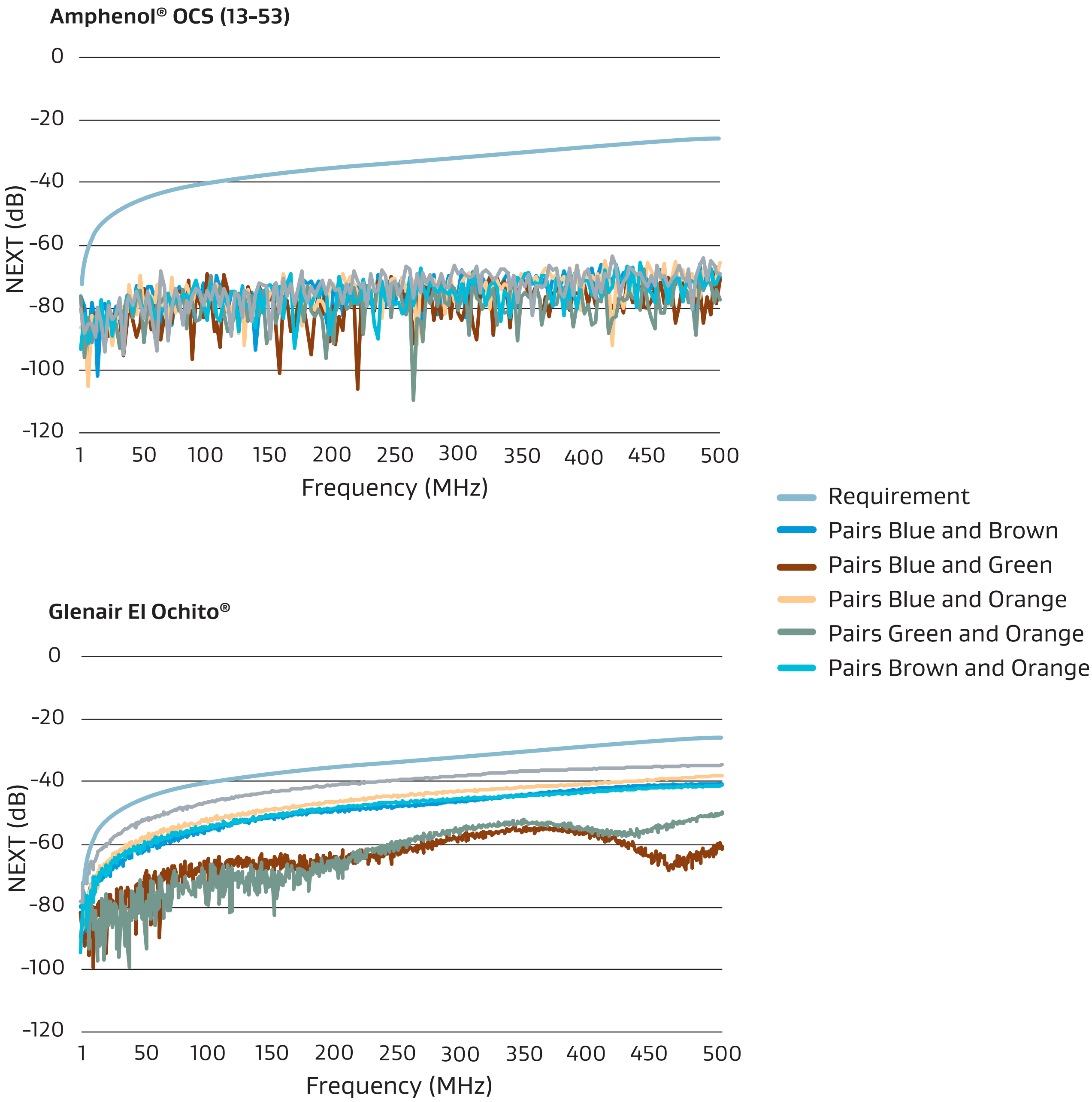




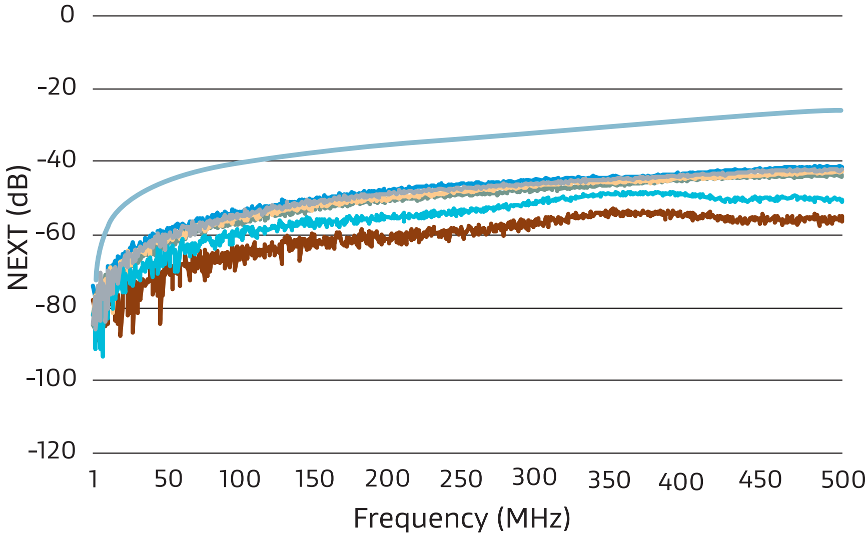
Furthermore, results indicated a considerable difference in crosstalk performance between these connector system designs (Figure 9). The Amphenol® OCS connector system using an individually shielded pair design showed decidedly lower crosstalk due to its 360-degree shield and continuous connection through the interface compared to the other designs. The TE Connectivity® CeeLok FAS-X® and LEMO® 2B Series connector system designs provide the next best level of crosstalk protection. Results showed similar performance at frequencies up to 500 MHz, indicating the orthogonal pairs design is just as effective as using an internal ground plane in the isolated pairs design. In contrast, results for the Glenair El Ochito® connector system showed higher levels of crosstalk, mostly due to the reduced spacing between the pairs in the isolated pairs design.

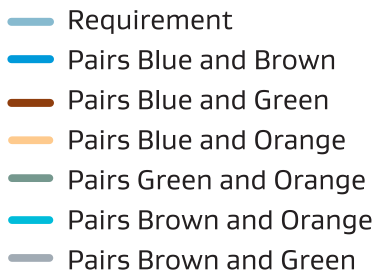
Electrical Performance Comparison (continued)

Figure 9: Crosstalk Comparison of Ethernet Cables

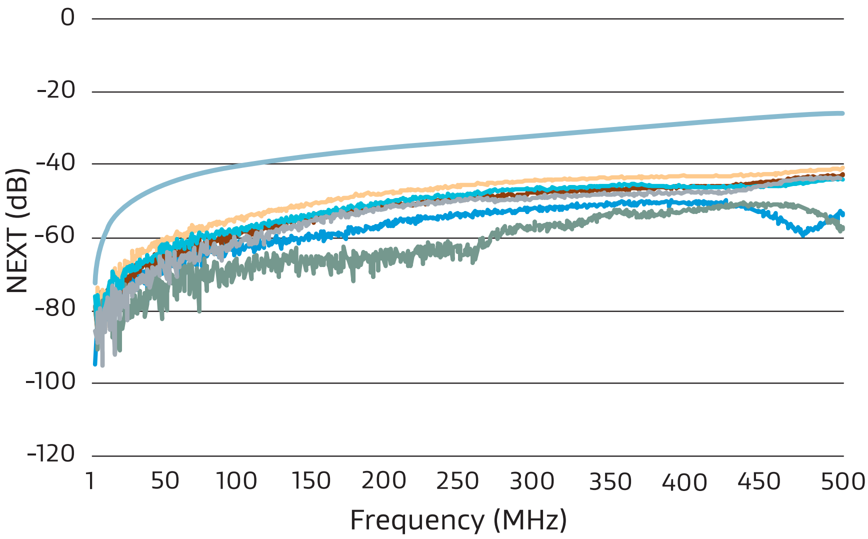


TE Connectivitity® Ceelok FAS-X®





LEMO® 2B Series

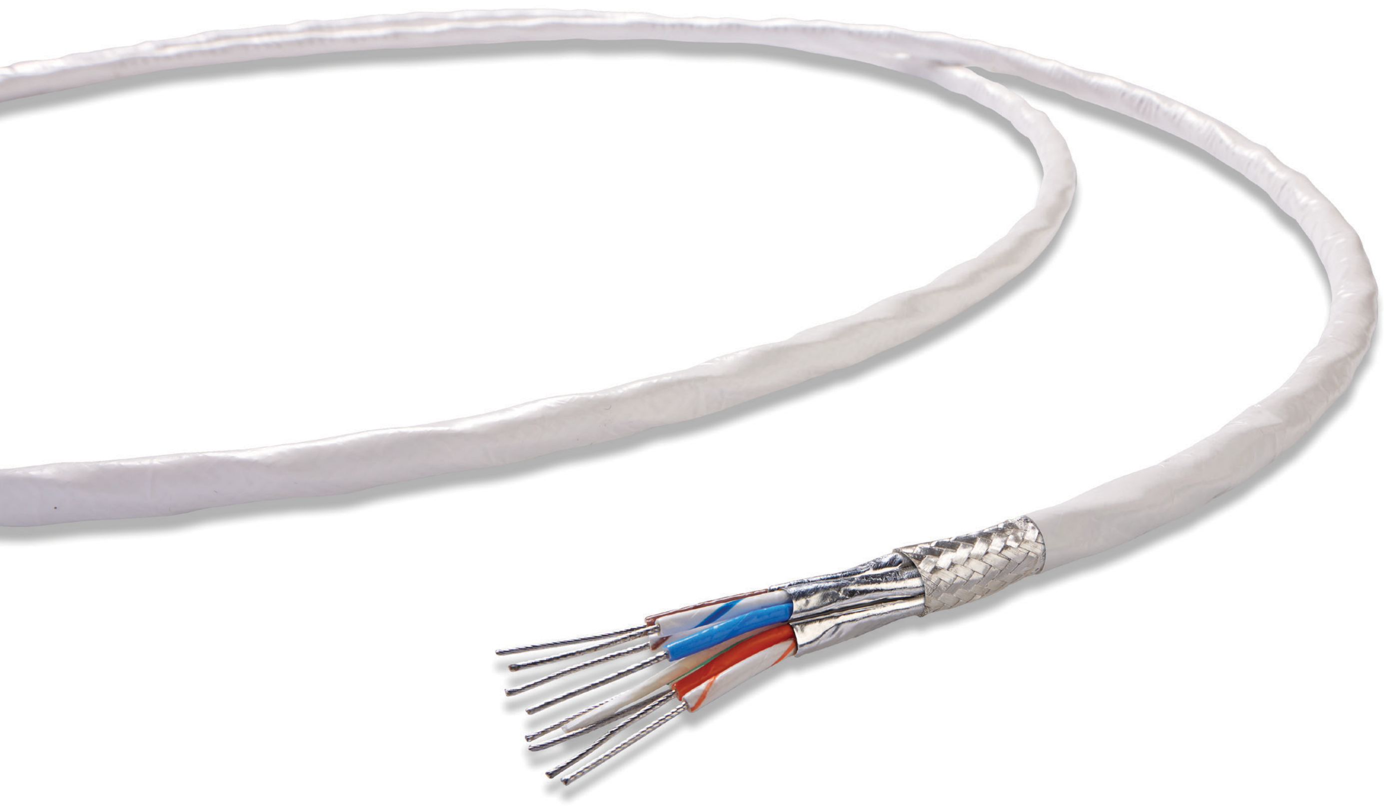


Overall, Gore's testing indicated that there are performance differences between these types of connector system designs. However, they all provide an acceptable level of performance for 10-GbE BASE-T data transmission, even when several connectors are included in the link. Therefore, choosing a connector system depends on the density requirement, field reparability concerns, ease of termination, cost, and tooling requirements. Just as important, any connector system should be thoroughly tested in the system environment prior to making a final commitment for application use.

MIL-DTL-38999 Open Pin Field Connector System Design

Despite the many excellent choices for connector systems delivering higher performance, design engineers continue to use MIL-DTL-38999 open pin field connector systems for high-speed data transmission in aerospace and defense applications. They must be aware of issues that can occur when using these types of interfaces for signals that can contain harmonics beyond 1 GHz, which can drastically impact system performance. As a result, design engineers must consider everything that may affect the connection, including:

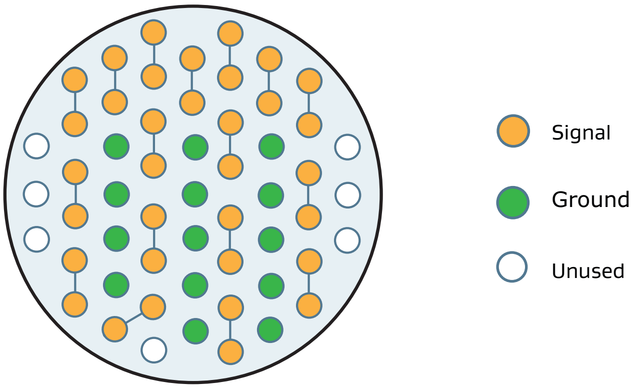
- Signal contact size
- Signal spacing between pairs
- Distance between differential pairs
- Locations of differential signals and associated ground
- Cable preparation
  - Length of impedance discontinuities before entering the connector
  - Spacing between differential signal pairs inside the backshell
  - Added shielding or twisting to increase coupling within the individual pairs.



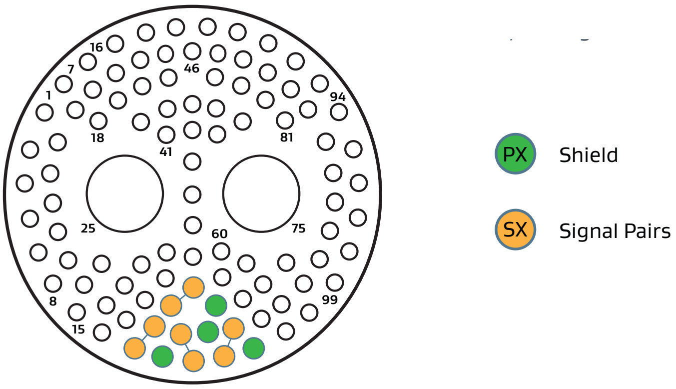
Gore evaluated two scenarios specified for high-speed data applications based on actual case studies to determine the effects of MIL-DTL-38999 open pin field connector systems on signal transmission. Figure 10 shows the pinout and insert configurations used in the case studies.

Figure 10: MIL-DTL-38999 Open Pin Field Connector System Configurations

Case Study 1: Video (16 Differential Pairs)



Case Study 2: Ethernet (4 Differential Pairs)



Spacing Between Legs of a Differential Pair

When open pin field contacts are used to carry differential signals, the characteristic impedance through the interface is determined by the spacing between the pins, pin size, wire diameter, and dielectric material used in the insert. If standard 38999 inserts are used, the spacing between pins and the size of the pins can be selected from a limited range of options. Design engineers typically do not consider the impact of spacing between pins when selecting an insert or contact arrangement. Usually, the connector type is chosen, and the pins for a differential pair will be positioned next to each other to achieve some degree of close coupling between the pair. In addition, the material used in a 38999 insert may not be clearly specified and typically has a relatively high dielectric constant. As a result, the characteristic impedance is generally not well defined unless it is actually measured in the pinout configuration being used. Often it becomes a “take what you get” situation because the connectors may have already been selected prior to analyzing the impact on electrical performance.

Case Study 1: MIL-DTL-38999 Open Pin Field Connector System

Designers selected a MIL-DTL-38999 open pin field connector system based primarily on mechanical needs; thus, the connector system was not optimized. This application required 16 high-speed pairs, so the pinout could not be optimized with many signal pairs adjacent to one another. As a result, this connector scheme was not able to achieve the desired data rates without transmission errors, and the data rates were reduced to the level accommodated by this configuration.

The following parameters were used to complete the case study:

- Insert: Size 21
- Pin Arrangement: 21-4
- Contact Size: 20
- Average Pin Diameter with Crimp Zones: 0.075 in (1.9 mm)
- Spacing between Pair Contacts: 0.125 in (3.18 mm)

Reflections and Return Loss

Testing was conducted using a TDR (Time Domain Reflectometer) to measure the characteristic impedance through the connector system interface. Measurements were recorded on one pair with the shield connection directly adjacent to the pairs. Measurements were then recorded on another pair with the shield pin some distance away from the pair (Figure 11). Results showed that there is some difference in TDR traces depending on where the shield pin is located. However, there is little difference in return loss at frequencies up to 1 GHz (Figure 12). Based on these results, the location of the ground pin for shield termination in this particular connector system pinout with respect to the pins for the differential pair seems to have little effect on impedance discontinuity or return loss.

Figure 11: Characteristics Impedance Traces through Connector System Interface Comparison

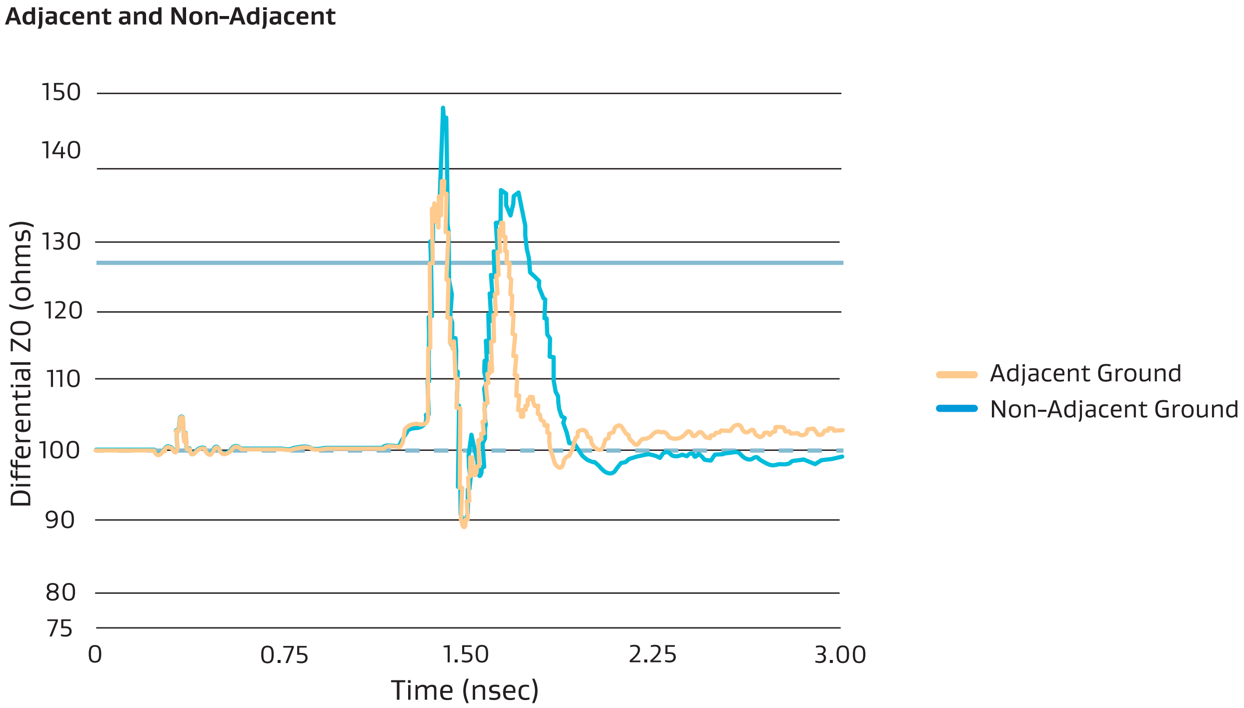
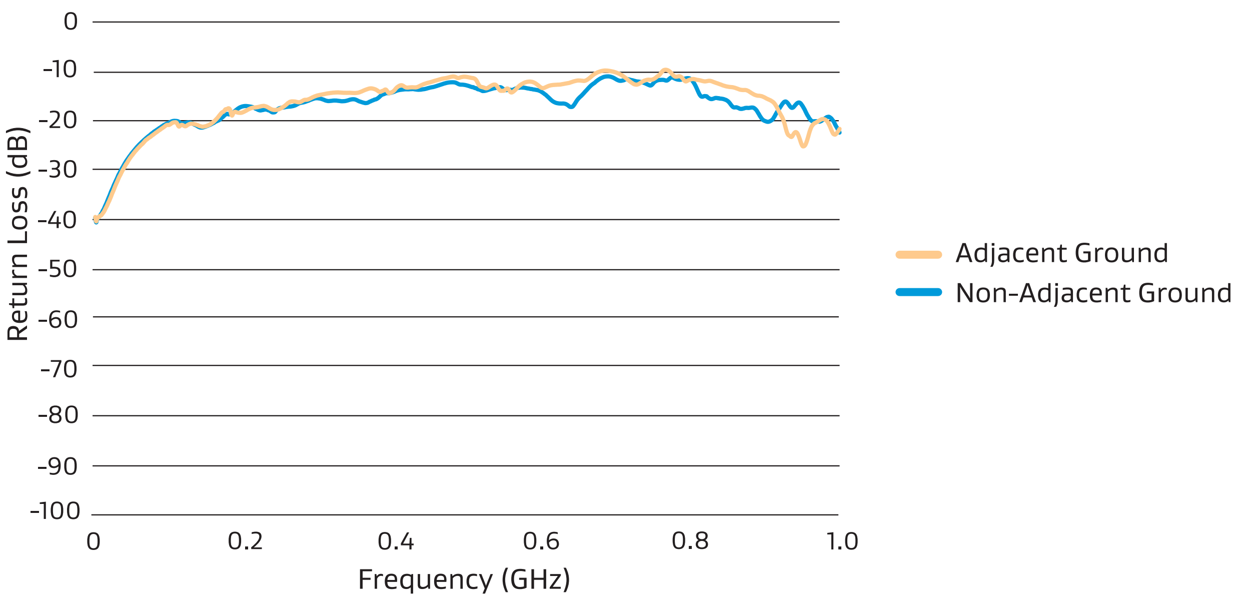


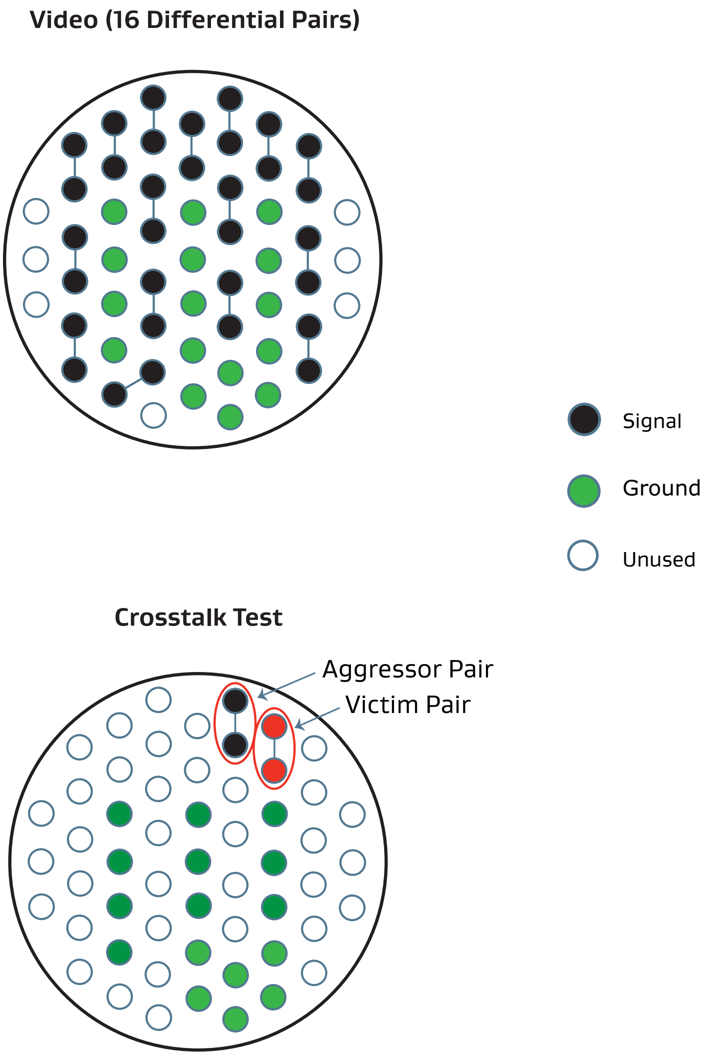
Figure 12: Return Loss for Adjacent and Non-Adjacent Shield Connections



Near-End Crosstalk (NEXT)

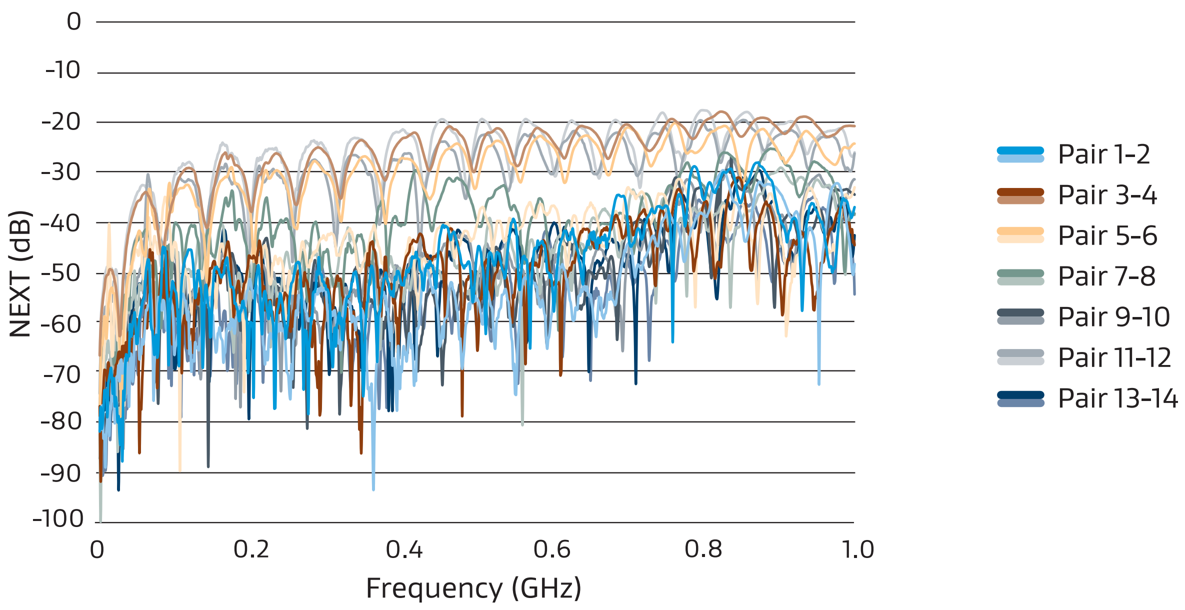
Crosstalk is typically the most severe limiting factor in the performance of an open pin field arrangement. As a worst-case scenario, crosstalk typically occurs as NEXT, where low-level receiving signals are being detected adjacent to full-strength transmitted signals being driven. As a result, Gore measured NEXT performance for signal degradation due to the connector system. Figure 13 shows the original pinout along with the aggressor/victim arrangement for a typical crosstalk test.

Figure 13: Original Pinout with Aggressor and Victim Arrangement



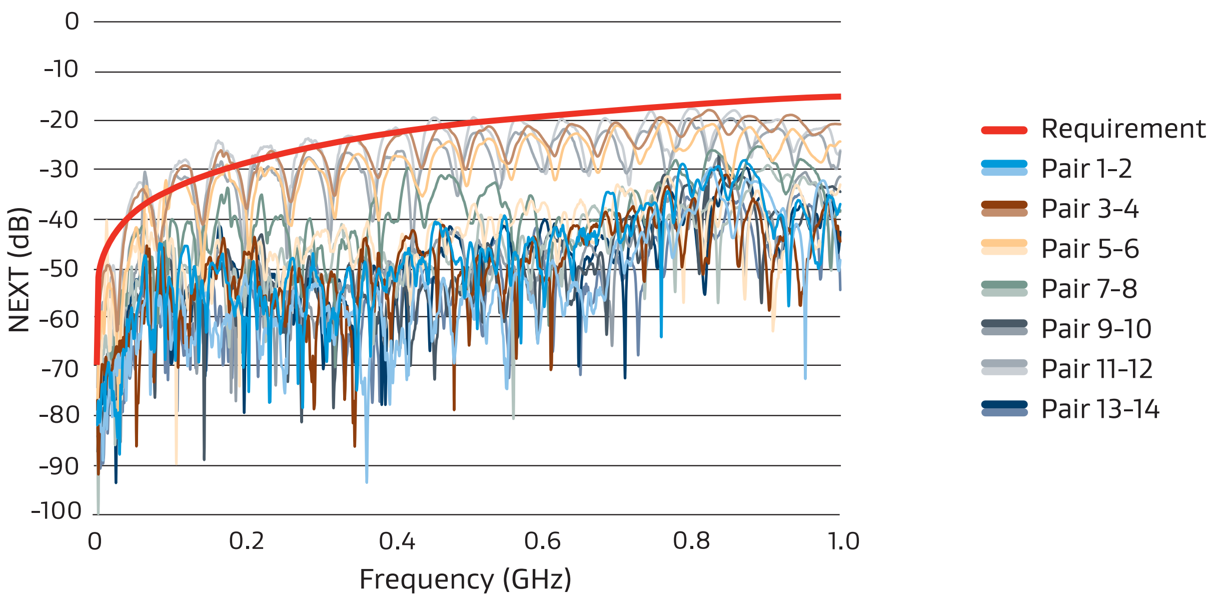
Gore applied an aggressor signal to each signal pair in the connector system and measured crosstalk for 15 victim pairs. The results yielded 15 crosstalk measurements in the frequency domain for each aggressor pair (Figure 14).

Figure 14: Crosstalk Performance between Victim and Other Pairs (15 Interactions)



If crosstalk limit lines are added based on Cat6a requirements for 10-Gb/s Ethernet data transmission, results clearly show that some interactions exceed the allowable crosstalk levels for reliable data transmission (Figure 15).

Figure 15: Crosstalk Limit Lines Performance between Victim and Other Pairs (15 Interactions)



Near-End Crosstalk (NEXT) (continued)

Gore reviewed ways to optimize the pinout with MIL-DTL-38999 open pin field configurations for optimized electrical performance to determine if they can be used for high-speed data transmission by comparing crosstalk arrangements generated with various pinouts. Gore measured typical crosstalk waveforms for two sets of lines — including one set adjacent to each other and another set of pairs that are separated. Figure 16 shows that there is a clear, measurable difference between these lines; however, it would be hard to assign a specific number to the crosstalk value based on these results. Figure 17 compares crosstalk performance between two other sets of pairs to show the difficulty in RF plots. The results show the curves are different, though it would be difficult to evaluate which one is better or worse. Therefore, Gore used a different technique to measure crosstalk in the time domain.

Figure 16: Crosstalk Performance for Adjacent Pair and Isolated Pair

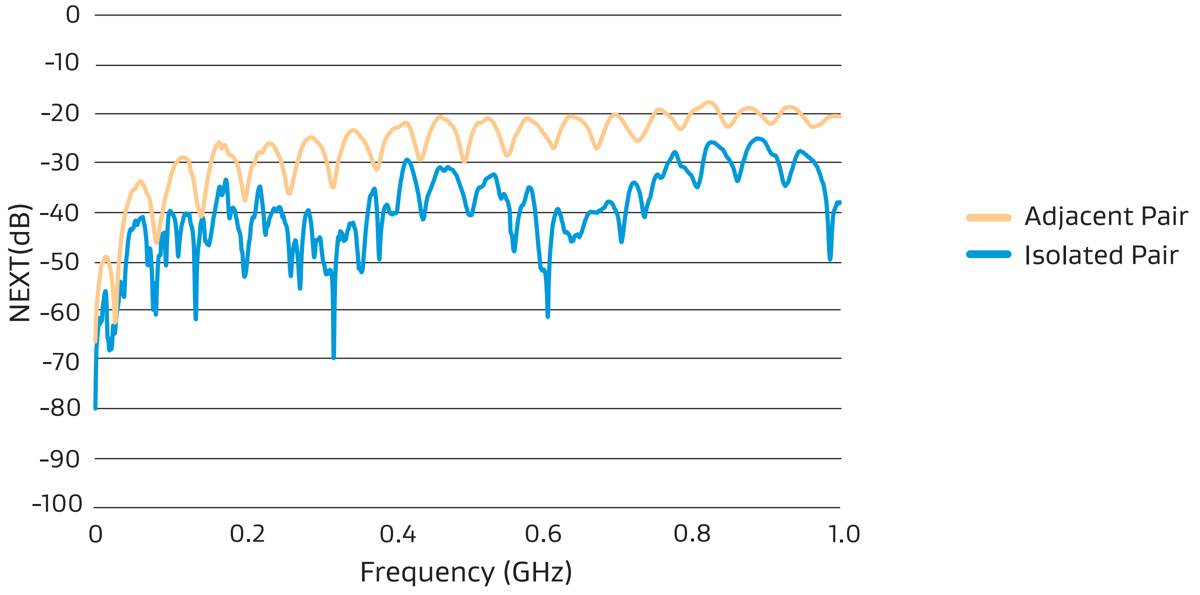
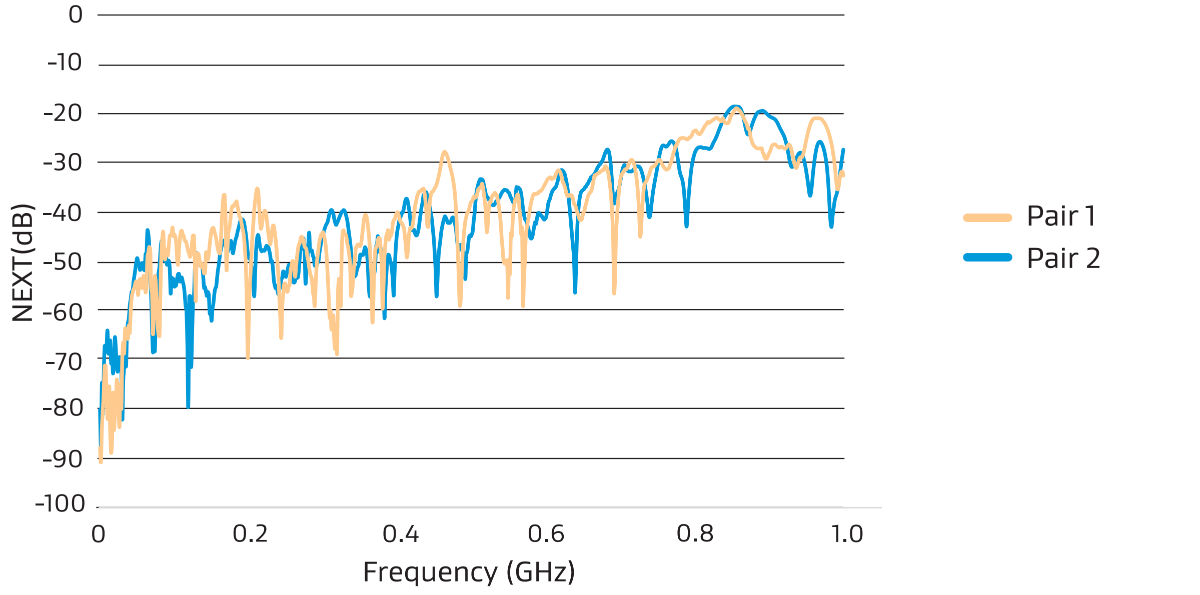
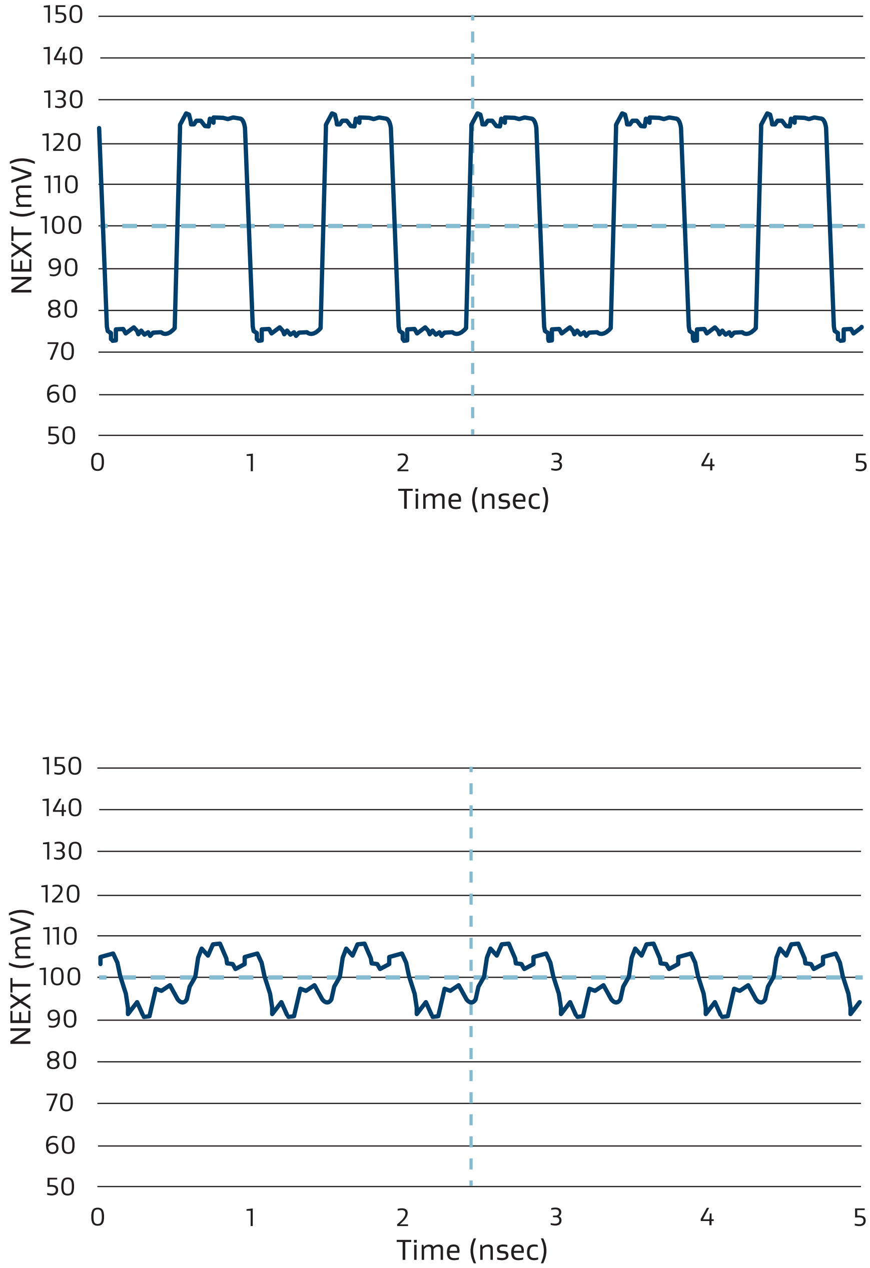


Figure 17: Crosstalk Performance for 2 Sets of Pairs



It is easier to work in the time domain to get a single value describing NEXT. Figure 18 shows an aggressor square wave signal with 100 picoseconds (psec) rise time on one pair while a second pair is monitored for crosstalk. By measuring the peak-to-peak voltage levels of crosstalk, a single value is obtained representing NEXT as a percentage of the input signal. Using this methodology generates a crosstalk mapping that shows the relative crosstalk on all pairs in the connector system when one pair is driven.

Figure 18: Crosstalk Performance in the Time Domain



Near-End Crosstalk (NEXT) (continued)

Figure 19 indicates the dark red circles exhibit high crosstalk, and the light red circles exhibit low crosstalk. Values are shown in percentages, as described. Note that the signals next to the aggressor line show an excess of crosstalk at 10 percent, which is quite significant and may actually be as high as the signal being received into the connector system.

Figure 19: Aggressor Signal at CY

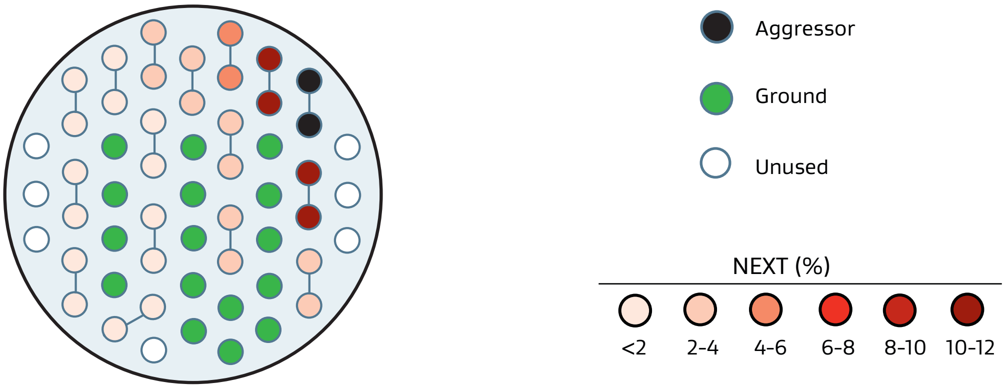


Figure 20 shows how pairs surrounding an aggressor pair can have edge-coupled crosstalk at about the same level as pairs that are directly adjacent.

Figure 20: Aggressor Signal at ZA

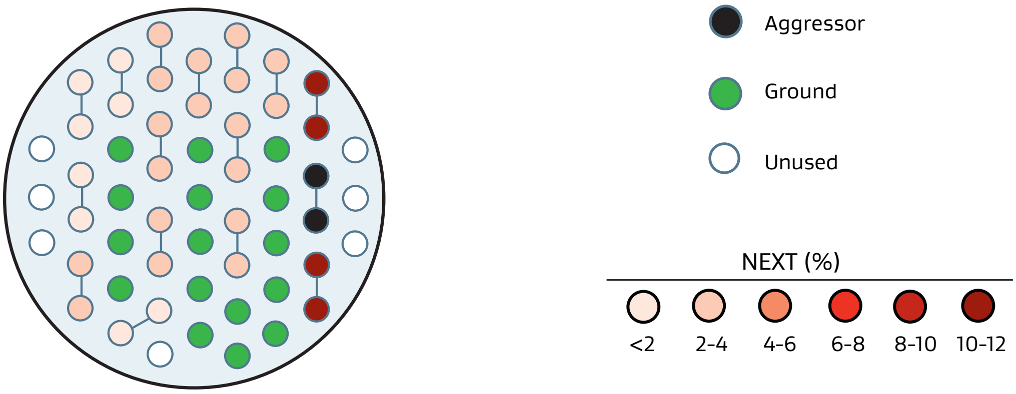
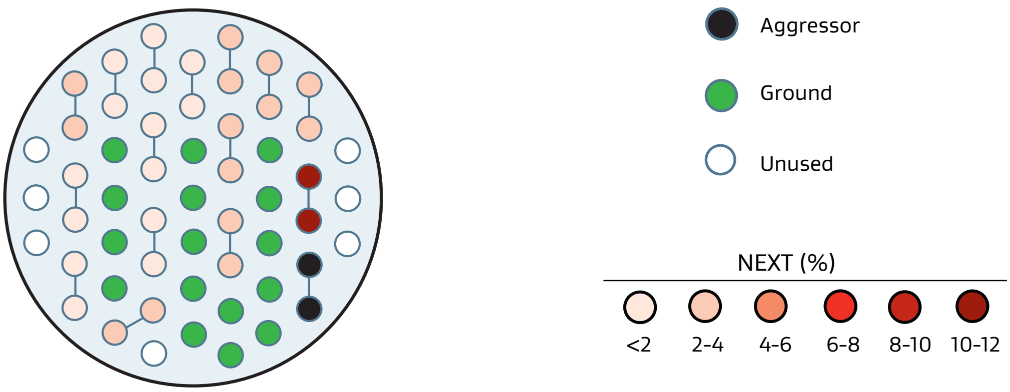


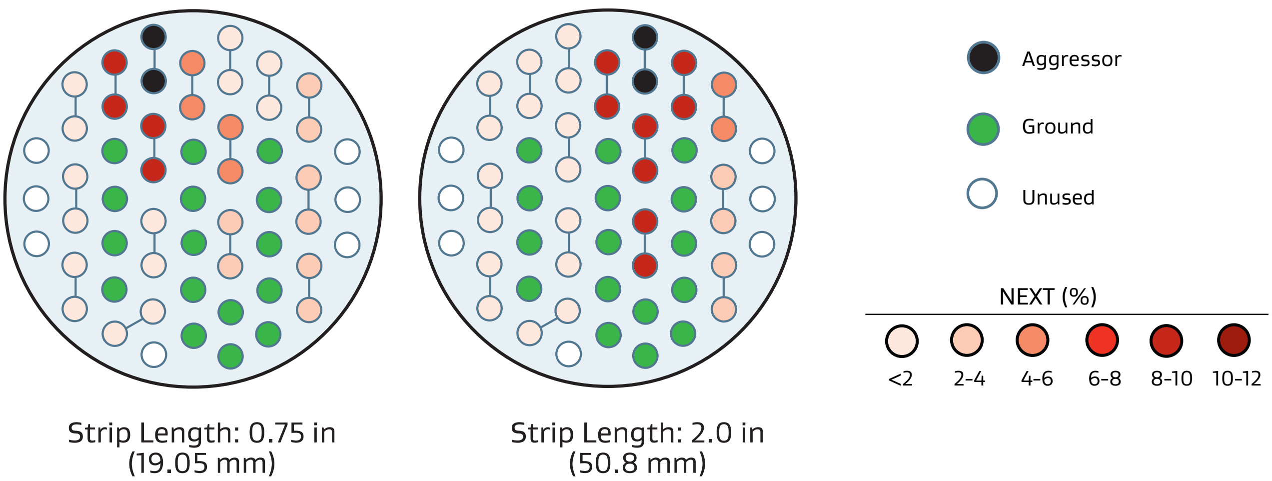
Figure 21 shows how adding separation and including ground pins between pairs can reduce crosstalk; however, it does not maintain it below 6 percent. Adding ground pins can take up significant connector real estate and with additional termination time for a cable assembly.

Figure 21: Aggressor Signal at bG



Gore also tested the effects of cable strip length on crosstalk in pairs with very similar arrangements. The strip length of the aggressor pair was stripped back 2.0 in (50.8 mm), and the wires lost their twisting and shielding (Figure 22). However, the cable with a strip length of 0.75 in (19.05 mm) maintained twisting and shielding as close as possible, maintaining the ability to be prepped, and allowed for pins to be inserted into the connector. This mapping shows that crosstalk can be reduced slightly with the cable strip length approach, though, not as beneficial as expected. Due to the nature of cable preparation and stripping operations, these strip lengths can vary between cable assemblies leading to unexpected problems with crosstalk, which may be difficult to troubleshoot.

Figure 22: Crosstalk Comparison between Pairs

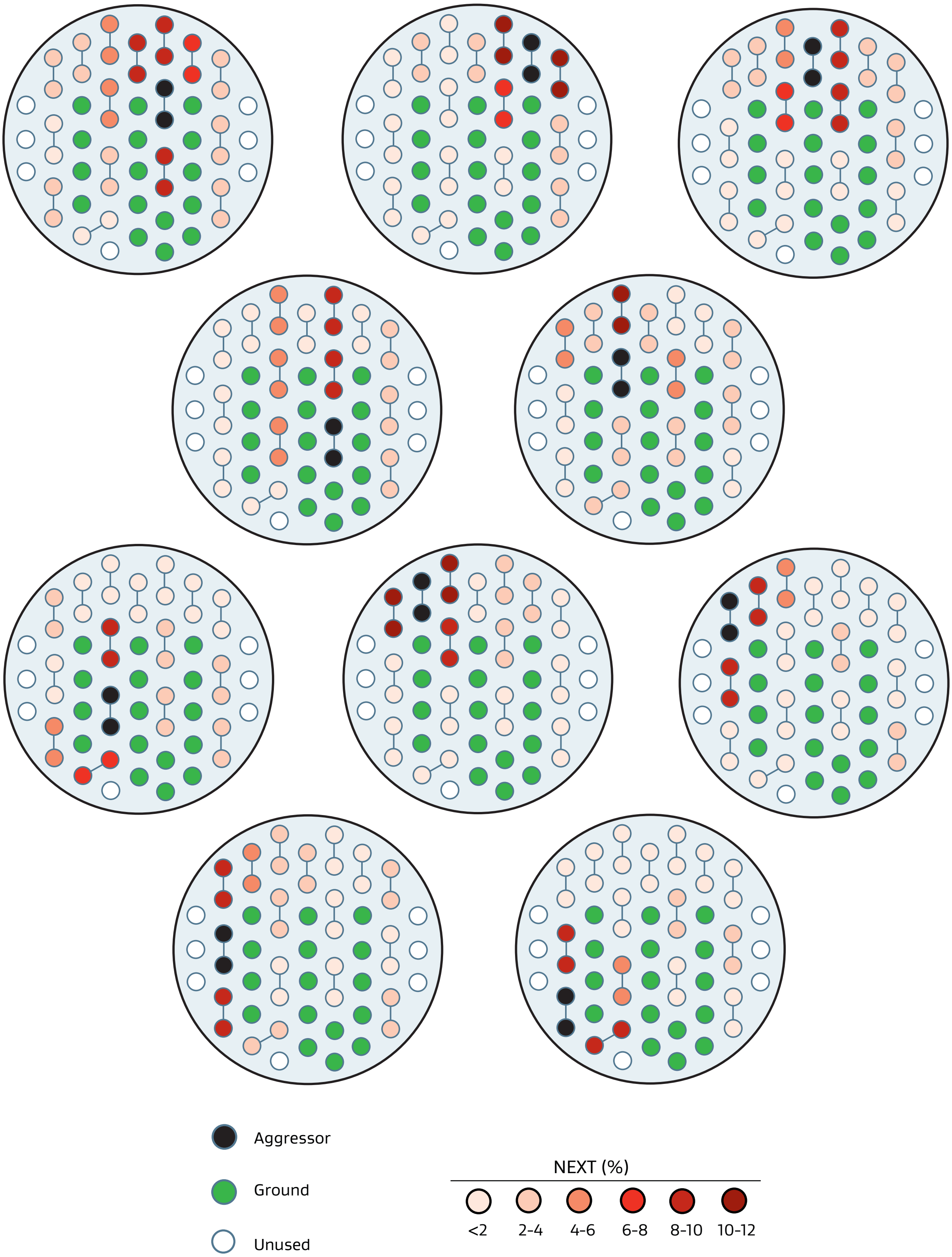


Crosstalk mappings of the remaining victims in the MIL-DTL-38999 open pin field connector system are shown in Figure 23. Based on these results, Gore concluded the following:

- Values up to 12 percent are indicated when the single adjacent line is driven, which could be additive when multiple lines are driven
- Crosstalk for TIA standards was always violated when pairs of signal contacts in connector systems are positioned adjacent to contacts from other signal pairs. The spacing rule depends on pin array; however, maintaining a minimum of two contact spaces between signal pairs will help reduce crosstalk. Maintaining this spacing will not always ensure that crosstalk will be held below acceptable levels for many protocols.
- Adding space between signal contacts has the biggest impact on reducing crosstalk between signal pairs
- Adding ground positions between signal pairs has some impact on reducing crosstalk
- Distance between contact positions for signal pairs and associated ground contact has limited impact on crosstalk
- Results are not always consistent within a connector system due to jacket/shielding trim lengths, maintaining twists, and wire routing within the connector backshell

Near-End Crosstalk (NEXT) (continued)

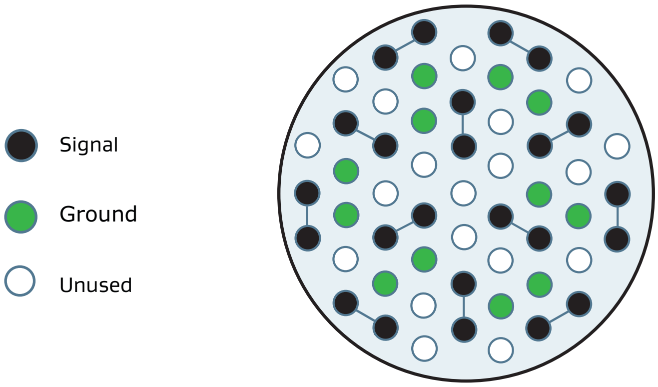
Figure 23: Crosstalk Mapping for Remaining Victims in the MIL-DTL-38999 Open Pin Field Connector System



Design Optimization

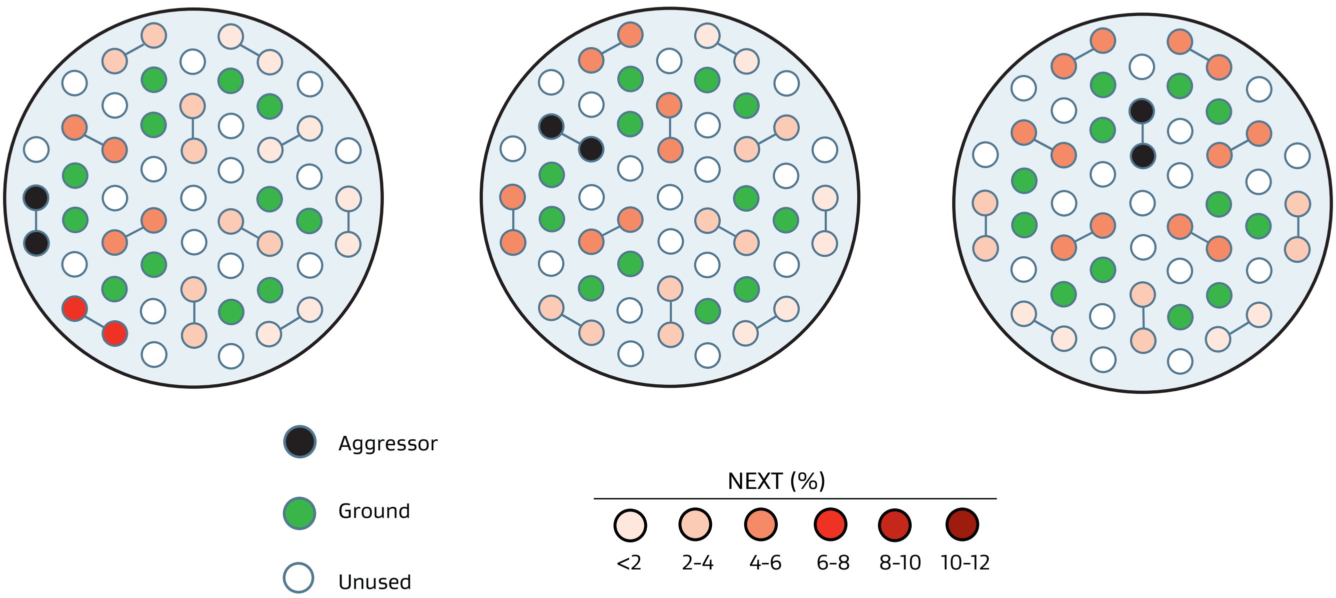
After reviewing the data from the original pin configuration, Gore developed a pinout configuration that separates adjacent pairs in the connector system to minimize crosstalk (Figure 24). This approach enables the highest signal density while preventing any signal pairs from being adjacent to each other in the connector system.

Figure 24: Optimized MIL-DTL-38999 Open Pin Field, Size 21 Connector System



Gore tested this configuration by positioning the contacts, as shown in Figure 25. However, results for only three contacts are shown due to the symmetry with the insert pattern. Crosstalk can be controlled to less than 8 percent, which is a significant improvement over the previous pinout; however, it can still be too high for many aerospace and defense applications. In addition, this improvement reduces density with 12 signal pairs versus 16 signal pairs in the original configuration. Since 16 pairs were needed, this pinout pattern would not have worked for this case study.

Figure 25: Crosstalk Performance with Optimized Contact Pinout



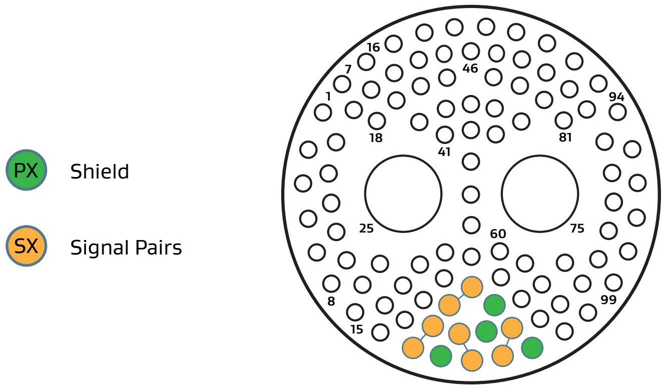
Case Study 2: SAE AS6129 Connector System with Ethernet Option

Gore selected a MIL-DTL-38999 open pin field connector system based primarily on mechanical needs; thus, the connector system was not optimized. The following parameters were used to complete the case study:

- Insert: Size 25
- Pin Arrangement: 25-7
- Contact Size: 22D
- Average Pin Diameter with Crimp Zones: 0.06 in (1.52 mm)
- Typical Spacing between Pair Contacts: 0.12 in (3.04 mm)

This size 25 connector system was specifically designed to carry a variety of signal types that are common when trying to minimize connector count and maximize capabilities. The designers of the SAE AS6129 standard assigned a pin configuration for 4 Ethernet pairs designed to carry 1-Gb/s Ethernet GBASE T (Figure 26).

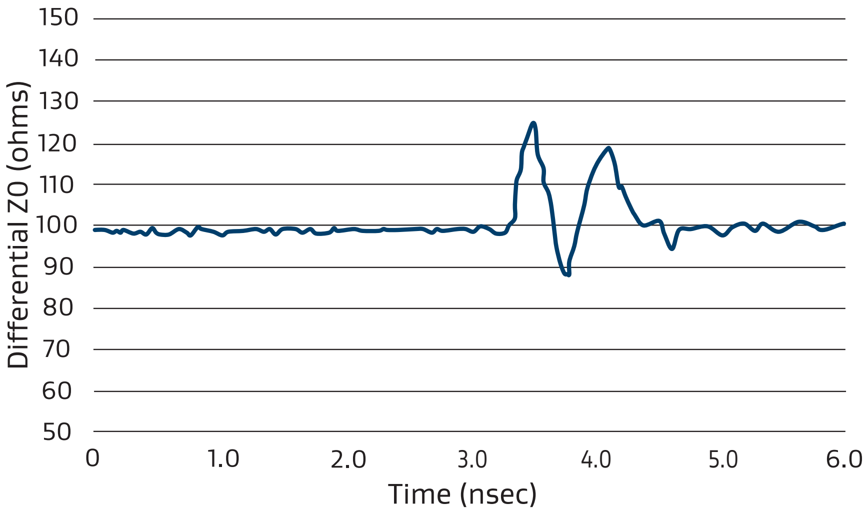
Figure 26: Pin Configuration Defined in SAE AS6129



Reflections and Return Loss

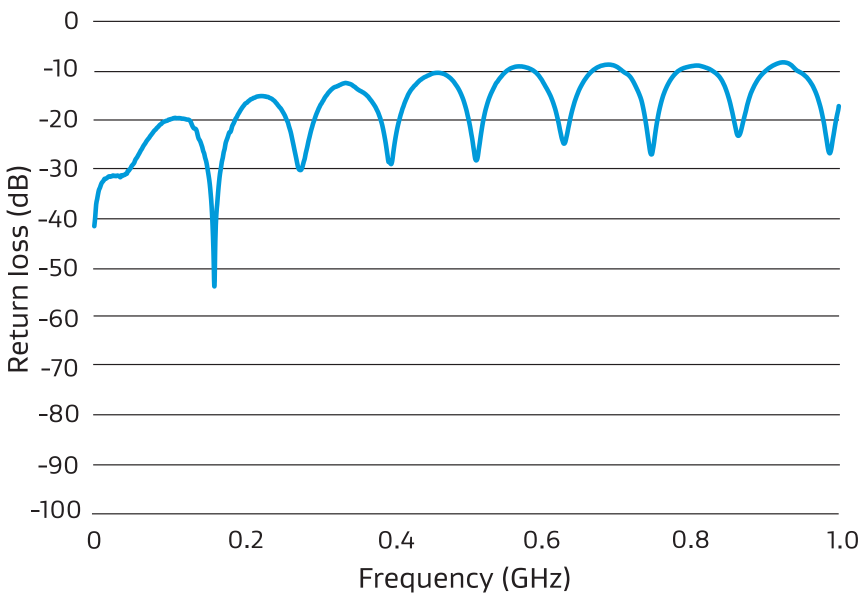
Testing was conducted using a TDR to measure the characteristic impedance through the interface. Measurements were recorded on one pair with the shield connection directly adjacent to the pairs. Measurements were then recorded on another pair with the shield pin some distance away from the pair. Results show less impedance discontinuity because the pins closer together enabled impedance through the connector closer to 100 ohms differential, though there are still significant reflections from this mated pair (Figure 27). Since the geometry is similar for all four pairs in the configuration, the impedance traces were approximately the same. This improved impedance match is also reflected in return loss performance.

Figure 27: Characteristics Impedance Traces through Connector Interface



Because the relative positions of the signals and shields within each pair are essentially the same, results also indicated little difference in return loss performance between all four pairs (Figure 28). These values fail to meet the Cat6a wiring borderline for the ANSI/TIA 568-C industry standard, which means that the connection will likely be out of specification when using this pinout and could be worse depending on termination techniques

Figure 28: Return Loss Performance



Near-End Crosstalk (NEXT)

Using the same methodology as the previous case study for measuring crosstalk, Gore evaluated performance between all four pairs for this configuration. The results shown in Figure 29 are clearly unacceptable for most aerospace and defense applications. While figures 30 and 31 show a more optimized contact configuration with reduced crosstalk, it can still exceed 6 percent, which may still be unacceptable for many applications.

Figure 29: Crosstalk Performance for SAE AS6129 Standard Pin Configuration

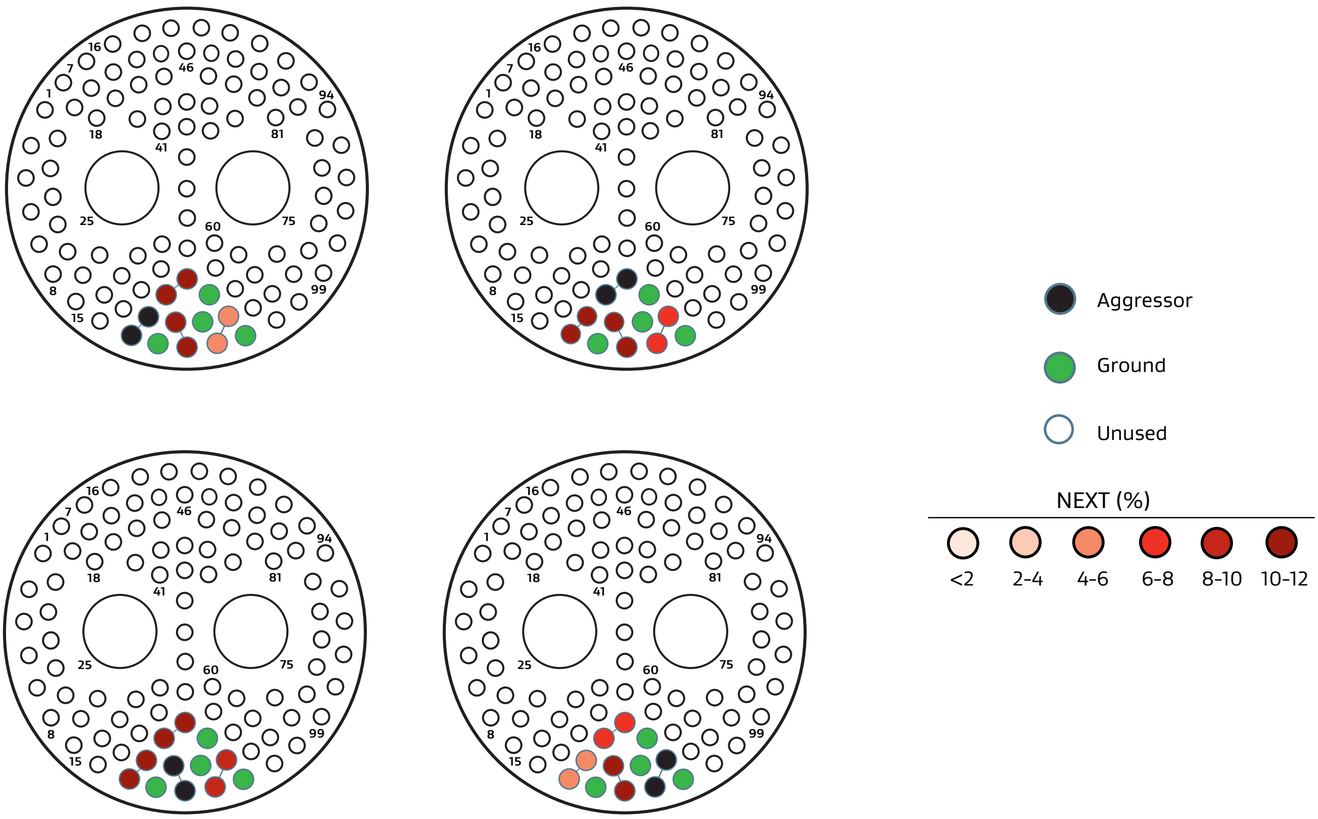


Figure 30: SAE AS6129, Size 25 Optimized Pinout Configuration

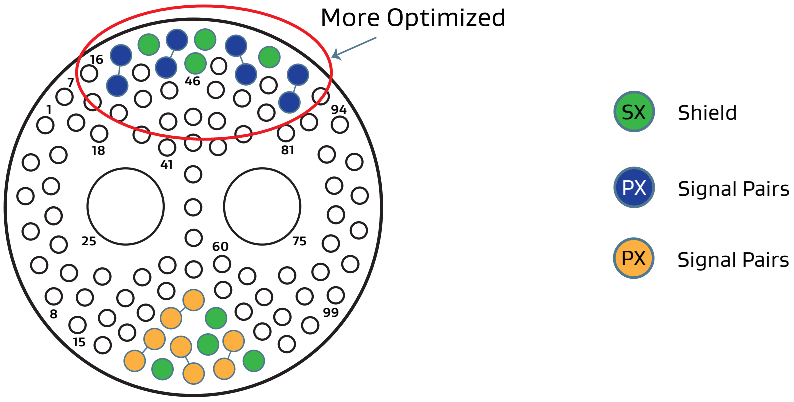
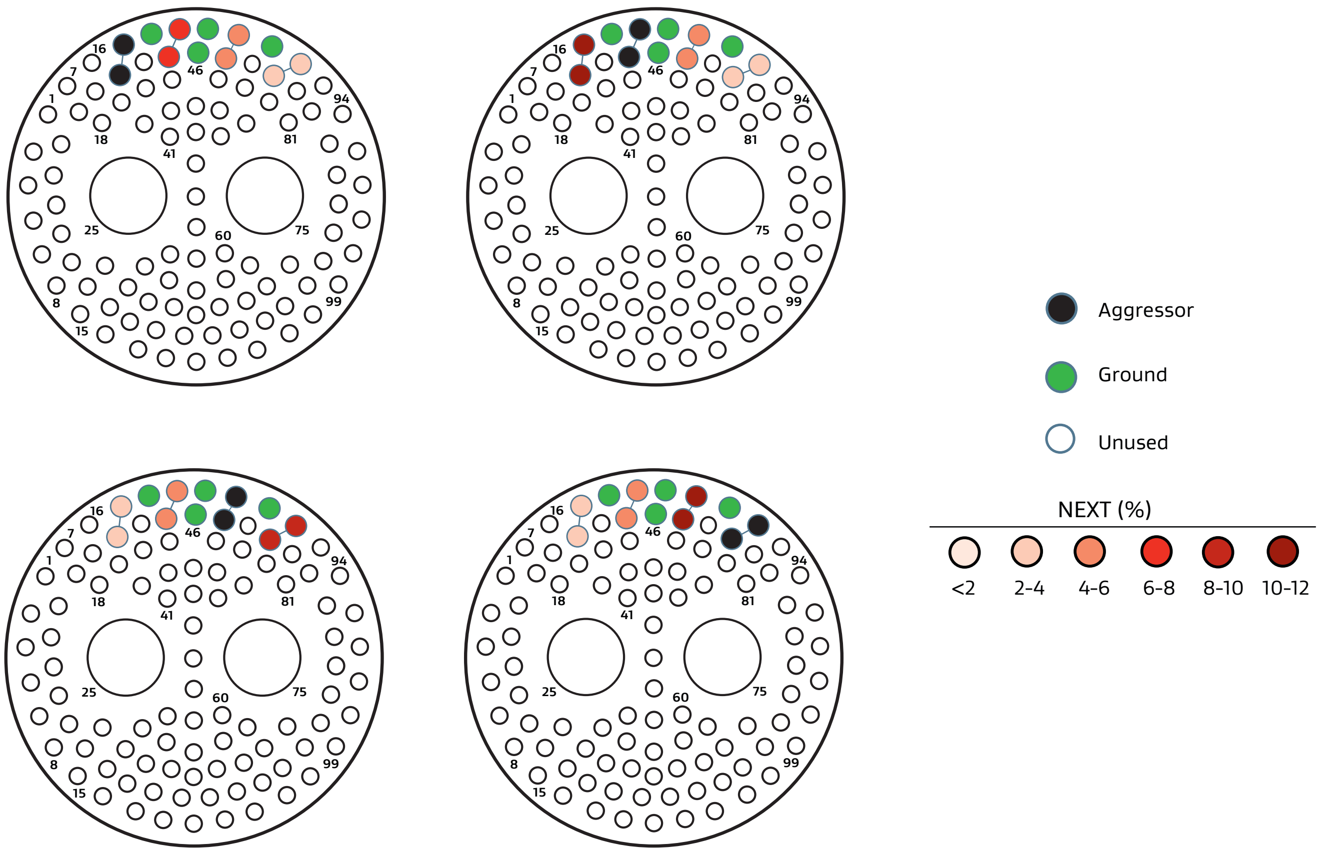


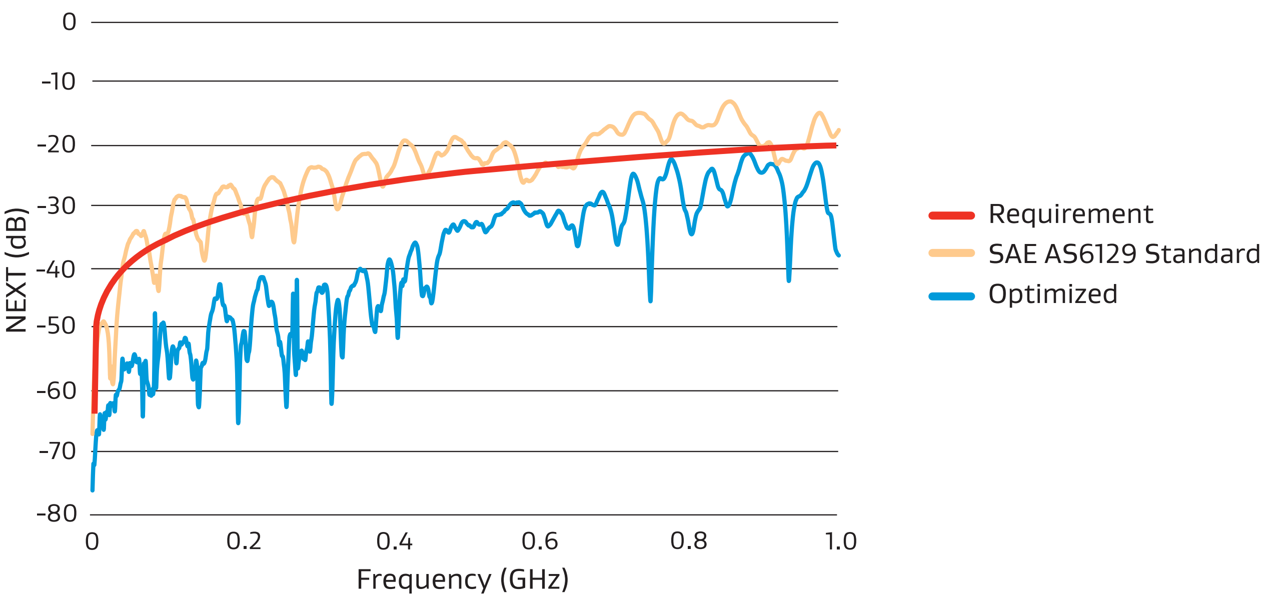
Figure 31: Crosstalk Performance for SAE AS6129, Size 25 Optimized Pinout Configuration



Near-End Crosstalk (NEXT) (continued)

Results in the frequency domain for the SAE AS6129, Size 25 connector system between standard and optimized pinouts, along with the crosstalk limit line for TIA 568-C Ethernet Cat6a requirement are shown in Figure 32.

Figure 32: Worst-Case Crosstalk Comparison for Standard and Optimized Pinout Configurations

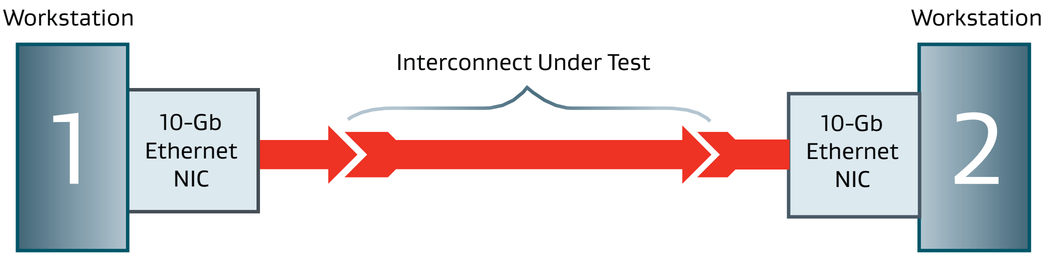


Ultimately, Gore's testing proved that MIL-DTL-38999 open pin field connector systems might not be suitable for high-speed data transmission. By using non-impedance controlled interfaces, reflections can impact return loss, which can be particularly deleterious when using multiple connector systems in the signal path. Both case studies show that the electrical performance of these connector systems can be improved by positioning the contacts to minimize crosstalk. However, performance improvement is limited and can be affected adversely by cable assembly techniques or other signals in the connector system. This optimization technique can be useful in situations where the connector systems are already defined, or field reparability issues may not permit the use of controlled-impedance contacts. Moreover, the use of MIL-DTL-38999 open pin field connector systems for high-speed data transmission will always reduce margin. These issues create an additional burden on design engineers to verify successful operation by testing the links in the environment that they will be used.

Verification of 10-Gb/s Ethernet Cable Assembly Performance

Gore developed a test bed capable of running Ethernet signals between 2 workstations at speeds up to 10 Gb/s (Figure 33). Each network interface card (NIC) has two bi-directional Ethernet ports. Gore also created software to allow control of each port in each direction. The duration of the test can be specified along with a naming convention to identify data associated with the link. Data rates of 1 and 10 Gb/s are available to be programmed into the test system.

Figure 33: 10-Gb/s Ethernet Verification Test System



The data is monitored at each end of the link tracking retries, packet drops, and packet errors to see how various transmission lines affect the performance of the link. The system also detects when the cable assembly degrades the signals enough to cause autonegotiation to 1 Gb/s or even 100 Mb/s, which allows for comparisons in network performance between different physical interconnects.

To create a baseline, Gore inserted Ethernet cable assemblies without connector systems between the 2 ports to determine specific lengths that could handle high-speed data transmission at 10 Gb/s with no errors or autonegotiation. Results confirmed that the Ethernet Cat6a cable assemblies could suitably transmit signals up to 328 feet (100 meters). The Cat6a version of GORE® Ethernet Cables performed reliably with no errors or packet drops (Table 1). In contrast, the alternative aerospace-grade Ethernet cable assembly autonegotiated to 1 Gb/s, possibly due to excessive loss or crosstalk.

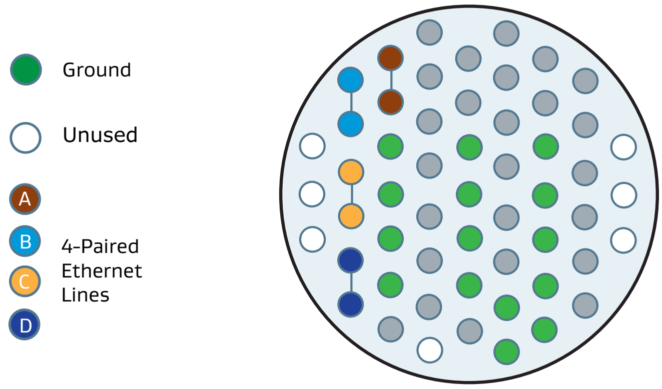
Gore also tested Ethernet Cat6a cable assemblies reported to work up to 164 ft (50 m) for 10 GBASE-T data transmission. Results confirmed that these cables could transmit error-free data using the test system at these lengths.

Table 1: Electrical Performance at Various Lengths for Ethernet Cat6/6a Cable Assemblies

Cable Type	Protocol	Length ft (m)	Additional Connector / Cable	Speed Gb/s	Results
GORE® Ethernet Cables	Cat6a	328 (100)	None	10	No errors / packet drops
Alternative Cables	Cat6a	328 (100)	None	1	Autonegotiation down
Commercial Cables	Cat6	166 (50.5)	None	10	No errors / packet drops
Commercial Cables	Cat6	166 (50.5)	None	1	Autonegotiation down

Next, Gore tested Ethernet cables terminated with MIL-DTL-38999 non-optimized connector systems to determine signal degradation at 10 Gb/s. The signals were launched from the ports on the NICs. The cable assemblies were then routed through 2 sets of connector systems with the pin configuration shown in Figure 34.

Figure 34: MIL-DTL-38999, Size 21 Non-Optimized Pinout Video Configuration



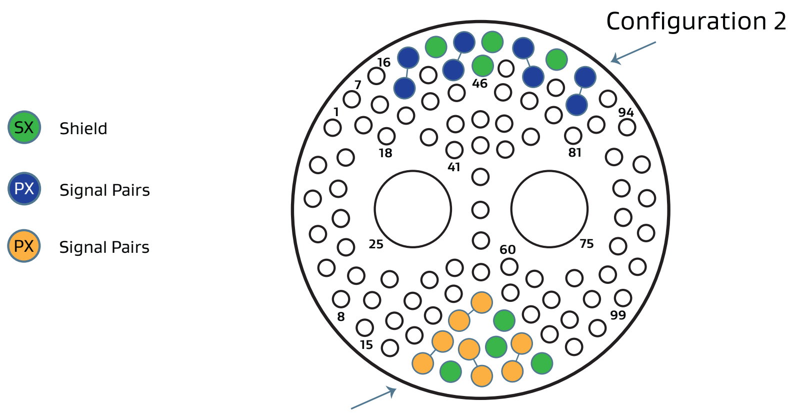
Results indicated that the MIL-DTL-38999 non-optimized connector systems could reduce the use length of the link by approximately 19.7 ft (6 m), which can be attributed to increased crosstalk, reflections, and signal loss (Table 2). In this case, some degradation in network performance was noticed with packet drops before autonegotiating down to 1 Gb/s. Therefore, these non-optimized connector systems combined with other environmental effects could prove problematic, and in general, should not be recommended for high-speed data transmission at 10 Gb/s.

Table 2: Electrical Performance MIL-DTL-38999, Size 21 Non-Optimized Pinout Video Configuration

Cable Type	Protocol	Length ft (m)	Additional Connector / Cable	Speed Gb/s	Results
Commercial Cables	Cat6a	160 (48.8)	Video	10	Autonegotiation down
Commercial Cables	Cat6a	156 (47.5)	Video	10	No errors / packet drops
Commercial Cables	Cat6a	140 (42.7)	Video	10	No errors or packet drops

In addition, Gore tested Ethernet cables terminated with the SAE AS6129 connector system using different pinout configurations. Configuration 1 shows the sub-optimized pinout specified in the standard (Figure 35). This configuration was expected to show the most performance degradation due to the signals positioned closer together with closer interactions between the pairs. On the other hand, Configuration 2 shows at least one shield pin in between each signal pair.

Figure 35: SAE AS6129 Optimized Pinout Configuration



Results showed that the overall use length for SAE AS6129 sub-optimized pinout configuration 1 was reduced by approximately 6.6 ft (2 m) compared to the optimized pin configuration (Table 3). With better pinout optimization, the cable assemblies achieved more length, which can be helpful if there are issues with a link, and the connector systems cannot be changed. By changing the pinout configuration, an additional margin can be achieved but only up to a certain limit. Therefore, it is recommended to avoid this type of issue by using connector systems that are purposefully designed for high-speed data connectivity.

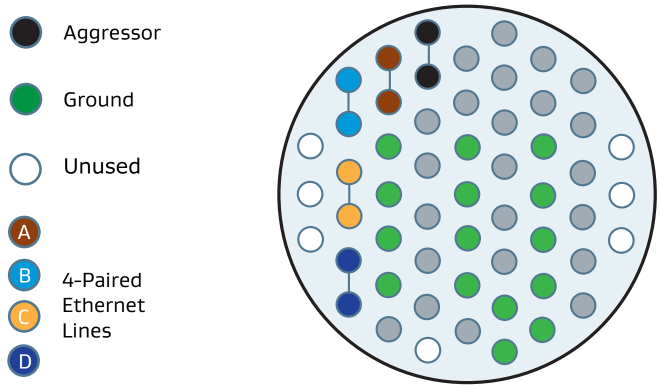
Table 3: Electrical Performance for SAE AS6129 Optimized Pinout Configuration

Cable Type	Protocol	Length ft (m)	Additional Connector / Cable	Speed Gb/s	Results
Commercial Cables	Cat6a	149 (45.5) 141 (43.1) 134 (40.7)	Configuration 1	10 10 10	Autonegotiation down Some errors / packet drops No errors or packet drops
Alternative Cables	Cat6a	156 (47.5) 148 (45.1) 140 (42.7)	Configuration 2	10 10 10	Autonegotiation down No errors / packet drops No errors or packet drops

Noise Effects from External Signaling on Ethernet Network Performance

When running high-speed signals through MIL-DTL-38999 connector systems, there would often be other signals transmitted through the same connector system on different pins. Therefore, Gore applied an external signal to 2 adjacent pins within the same connector system to determine the effects the external signal may have on transmitting Ethernet data at 10-Gb/s (Figure 36). In this case, the aggressor signal was a 1 GHz square wave with 50 psec rise time. The voltage level was varied to determine which level may impact data transmission.

Figure 36: External Noise Test Setup for MIL-DTL-38999, Size 21 Non-Optimized Pinout Configuration



The test was initiated by running 10 Gb/s signals through 2 connector system interfaces. The length of the Ethernet cable was approximately 32.8 ft (10 m). During the initial startup, the link ran successfully with no errors or packet drops. However, results indicated packet drops and errors as the voltage level of the aggressor signal was gradually increased to 500 mV. Results also showed that increasing the voltage level to just above 550 mV caused the link to fail. Even though there was no autonegotiation at first, the link still failed and did not come back until the external noise was removed.

Gore's testing validates a real concern when using MIL-DTL-38999 connector systems in a mixed-signal array. The accumulation of noise from other signals can significantly affect network performance and cause the link to fail. Aerospace connector systems specifically designed for high data rate transmission are much less susceptible to these issues because the shielding in these connector systems helps to reduce the effects of noise from adjacent signals. Also, since they may not have pins to carry adjacent signals, designers will be less inclined to mix signal types within a connector.

Conclusion

Thorough testing revealed that using MIL-DTL-38999 open pin field connector systems for 10-Gb/s Ethernet data transmission can be risky without carefully analyzing the effects of impedance discontinuities and crosstalk. These risks can be somewhat mitigated by choosing an optimized pinout configuration; however, Gore's testing proved that performance with these connectors could be limited and unpredictable. If design engineers must use this interconnect method, it is essential to use adequate cable assembly preparation and practices to minimize discontinuities going into and out of the connector system. In addition, proper testing and analysis should also include the effects of materials used in the connector web, since they are part of the dielectric and can vary between manufacturers.

Furthermore, characterization and qualification of MIL-DTL-38999 open pin field connector systems should not be based on testing in a lab environment. Instead, testing in real-world scenarios can better determine if the interconnect will operate reliably in the intended application. External conditions such as noise, EMI, and ground loops are typically present only when testing interconnects in the specific application, but may not be evident in a lab environment. Design engineers should also provide adequate margin to ensure successful operation of the links. They should perform frequency domain testing of signal lines to ensure there are no resonances or excessive loss that can occur where there are multiple impedance discontinuities. Multiple connections within a link to handle production breaks can be particularly problematic. Troubleshooting signal integrity issues in the field are nearly impossible, with the potential of losing vital data that must be gathered for critical missions. The defense sector has been saddled with "no-fault found" where issues are discovered in the field but cannot be replicated back on the ground. Design engineers should avoid taking unnecessary signal integrity risks for high data rate protocols and requirements that continue to increase with next-generation avionics.

Ultimately, testing and analyzing signal integrity costs can outweigh the benefits of using lower-cost MIL-DTL-38999 open pin field connector systems for high-speed data transmission. A variety of alternative connector system options exist on the market today that can achieve the required density and performance necessary for most aerospace applications. In turn, Design engineers can develop a reliable high-speed interconnect solution with enough bandwidth that can be replicated on future systems and upgrades.

When specifying a complete high-speed interconnect system, designers should be aware of all aspects of the system, consider other interconnect types, plan for future requirements, and thoroughly test connector systems in real-world conditions to ensure optimal performance.

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