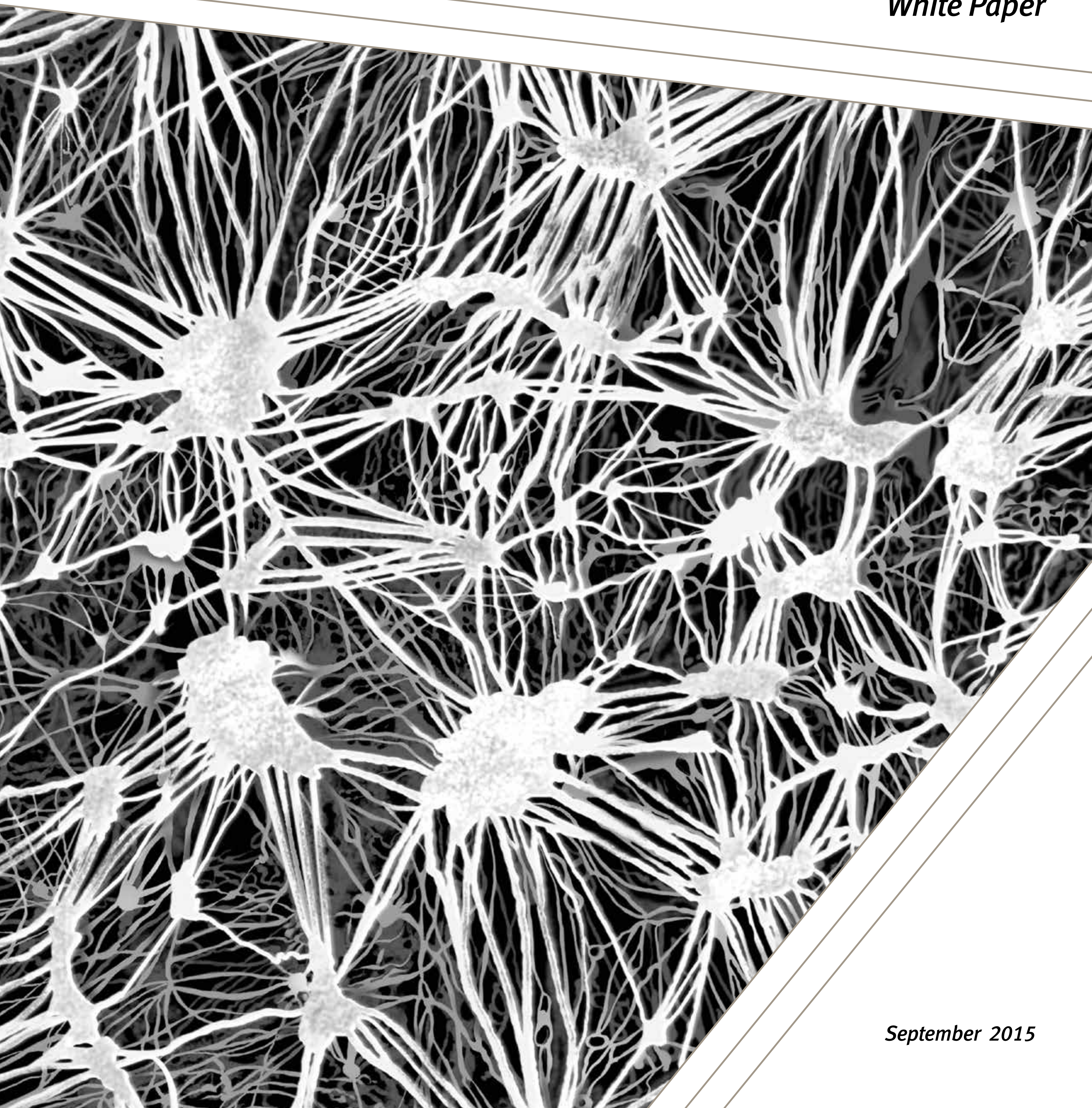
Selecting the Right Ethernet Cables to Increase High-Speed Data Transmission in Civil Aircraft

White Paper



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Abstract:

Selecting the right high-speed cables that enable systems to transfer data effectively is frequently overlooked during the design process. With the rapid advancements in modern avionics and in-flight entertainment, a cable that operates adequately today may not operate effectively with devices developed in the future. Therefore, it is essential to identify all of the potential issues that can affect the electrical and mechanical performance of the cable system. Careful consideration should be given to unique cable materials restrictions, regulatory requirements, and space constraints during the initial design process. In addition, thorough testing should be performed to ensure the cable system will perform reliably in specific applications.

W. L. Gore & Associates evaluated the durability and electrical performance of several Ethernet cables for Cat6a protocol, all with similar specifications. This testing showed the importance of selecting the right Ethernet cables that deliver reliable signal integrity for high-speed data transmission in challenging aerospace environments.

Selecting the Right Ethernet Cables to Increase High-Speed Data Transmission in Civil Aircraft

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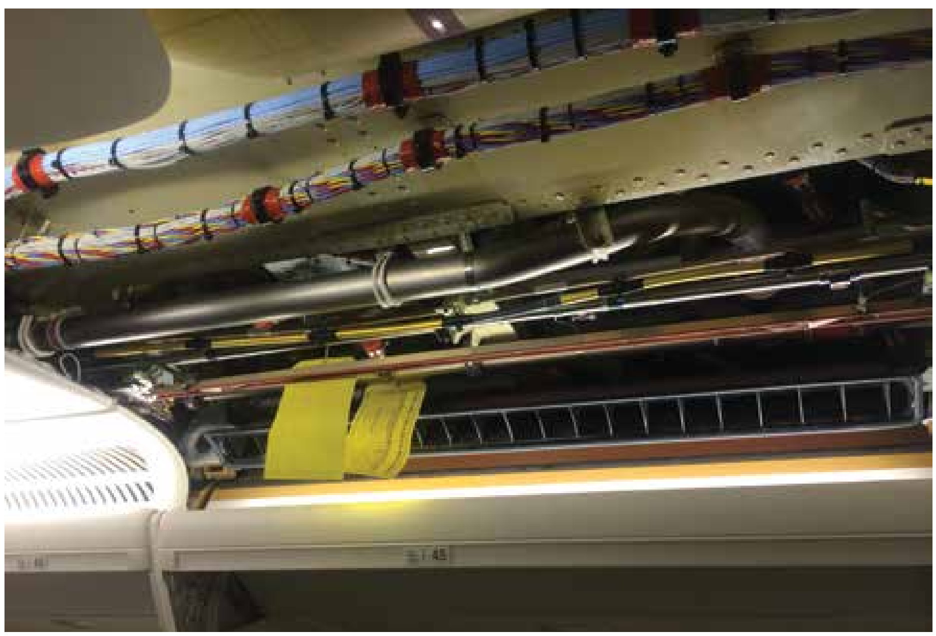
Introduction

Electronic systems used in today's civil aircraft, such as enhanced video processors, databus, and in-flight entertainment (IFE) systems, have increased in both quantity and functionality (Figure 1). It is challenging to connect all of the devices successfully and ensure adequate signal integrity to handle their high data rates, particularly in wireless IFE and content-loading systems. In addition, electronic systems must operate in harsh environments without interfering with each other. Regulatory requirements, materials restrictions, and space constraints further complicate the design process for aircraft.

Selecting the right high-speed cables that enable systems to transfer data effectively is frequently overlooked during the design process. With the rapid advancements in modern avionics and IFE systems, a cable that operates adequately today may not operate effectively with devices developed in the future. Cable reliability is based on both durability and signal integrity, and the ideal cable system should be designed to ensure system performance and last the life of the aircraft.

Figure 1: Wireless IFE in Civil Aircraft



Key Design Issues

The requirements for new electronic systems in aircraft are making the current protocols for bussing signals obsolete, such as ARINC 429 and 100base-T Ethernet. As data rates have increased, new protocols have been developed such as Fibre Channel and Ethernet, providing several options for designers. Ethernet cables operating at 1 Gigabit per second (Gb/s) or above have become the preferred protocol for new system interconnects due to their widespread commercial use. Data packets containing frames from other standard protocols, such as Fibre Channel, can be easily integrated into Ethernet IP packets, providing a seamless transition between technologies. Many aircraft designers are now specifying links that can handle data rates up to 10 Gb/s to ensure that cables installed on aircraft today will not need to be replaced as newer devices are installed in the future.

Standard Ethernet cables and connectors used in controlled network environments do not necessarily address all of the electrical and mechanical requirements for aircraft applications. For example, many of these cables cannot withstand the challenging environments of aerospace, such as extreme temperature changes or exposure to harsh contaminants. In addition, cables need to be smaller and more flexible, yet durable for easier routing in tight spaces to prevent damage.

Electrical Considerations

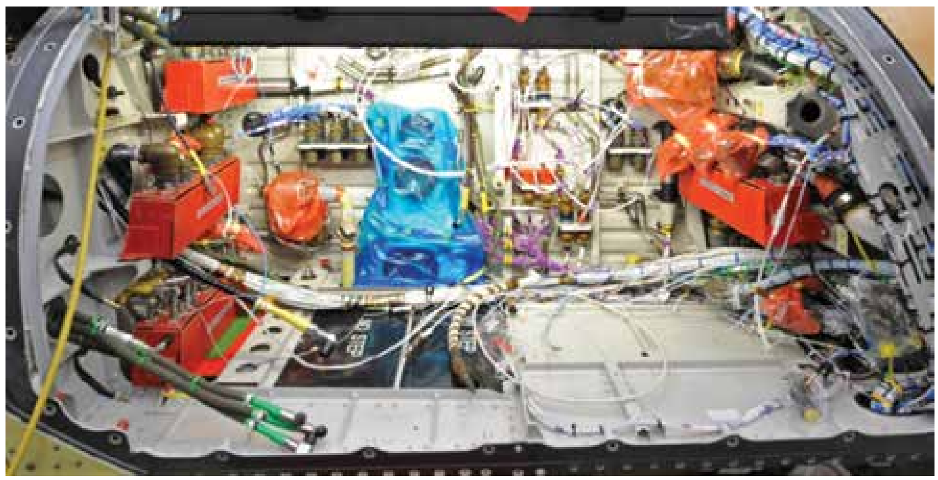
The Telecommunications Industry Association (TIA) 568-C.2 and other standards define electrical performance requirements for Ethernet cables that include frequency-based specifications for maximum insertion loss, return loss, and crosstalk. The requirements for Cat6 are adequate for data rates up to 1 Gb/s, and specify cable performance for frequencies up to 250 MHz. As data rates have continued to increase, the standard now defines Cat6a requirements for data rates at 10 Gb/s with a higher frequency range up to 500 MHz to ensure accurate data transmission.

Unlike most commercial Ethernet applications, aircraft typically have more equipment that radiates electromagnetic interference (EMI). For example, various antennas on an aircraft can generate high field strengths, which may disrupt data signals. Sensors on aircraft may also be affected by noise emanating from the data lines or power supplies. Due to the tight space constraints in an aircraft, interconnects are more susceptible to alien crosstalk (i.e., crosstalk between cables rather than within a cable). It is difficult to determine how the cables will be bundled in the aircraft during installation or maintenance. As a result, enhanced shielding around the cables is necessary to ensure that EMI and alien crosstalk are not an issue.

Mechanical Considerations

Aircraft are exposed to mechanical stress such as vibration, acceleration loads, flex life, and potential damage during installation. For example, severe bending in tight areas, tie-wraps, and clamps can cause permanent damage to cables and materials, resulting in signal reflections and other losses in the cable. Friction caused by cable vibration can result in jacket abrasion. Damaged insulation can eventually lead to failures when exposed to mechanical stress. Therefore, the materials used in cables need to provide durable protection to withstand these types of challenging environments (Figure 2).

Figure 2: Typical Cable Installation in an Airframe



Environmental Considerations

Environmental stress results from the physical area in which the cables are used. For example, high temperatures can cause materials to become very soft, and low temperatures can cause materials to become brittle and crack. Radiation can damage both the primary insulation and jacket materials, depending on the type and dosage level. Harsh contaminants such as hydraulic and de-icing fluids, cleaning solutions, and water can also damage insulation and jacket materials. In addition, cables must be non-flammable and comply with industry standards for smoke and toxicity. Environmental stress can significantly shorten the life of a cable, so these issues must be taken into consideration when designing a cable system.

Designing the Cable System

Once the key design issues have been identified that may impact cable performance, the next step is to design a cable system that will withstand all of the factors of the intended environment. This process involves selecting the right materials for cable construction, selecting the appropriate connectors, and ensuring that sufficient testing has been completed to verify that the cable will be fit for use in the application.

Cable Selection — Materials and Construction

Selecting the right materials for cable insulation and jacketing is critical when designing a cable system. The materials used in cables for avionics and IFE systems must be upgraded for harsh aerospace environments. In general, upgraded materials, such as fluoropolymers, improve electrical performance in harsh conditions (Table 1). However, testing should be completed to ensure cables will perform reliably in specific applications, particularly for characteristics such as skew, shielding effectiveness, crosstalk, and loss.

Table 1: Typical Aerospace Cable Materials

Cable Component	Standard Cable Materials	Aircraft Cable Materials	Application Benefits
Signal conductor	Tin-plated or bare copper Solid conductor	Silver-plated copper Stranded conductors Alloy conductors	Corrosion protection Durable and flexible Higher strength
Primary dielectric	Polyethylene	Polytetrafluoroethylene (PTFE) Fluorinated ethylene propylene (FEP) Expanded PTFE (ePTFE)	Higher temperature resistance Non-flammable
Film shielding	Aluminized polyester	Aluminized polyimide	Higher temperature resistance Non-flammable/non-toxic Low outgassing
Braided shields	Tin-plated or bare copper	Silver-plated copper	Higher temperature resistance Corrosion protection
Outer jackets	Polyurethane Polyvinyl chloride (PVC)	Fluoropolymers Engineered fluoropolymers	Higher temperature resistance Abrasion resistance Non-flammable/non-toxic UV resistance Solvent resistance

While using standard fluoropolymers in outer jackets provide many advantages, this type of material can increase the size, weight, and rigidity of cables. As a result, cables are more difficult to route through bulkheads and existing openings, and they can be exposed to crushing, abrasion, and potential cut-through during installation. In addition, the weight of cables can decrease fuel efficiency in aircraft.

W. L. Gore & Associates (Gore) has developed proprietary technologies that allow PTFE to be engineered so it can withstand the challenges of modern avionics and civil applications (Table 2). For example, new thin-wall technology reduces the thickness of the outer jacket without compromising voltage breakdown or cut-through resistance. Due to the low dielectric constant, Gore's expanded PTFE primary insulation allows the twisted pairs to be individually shielded within the same space as unshielded twisted pairs using standard insulation. *Shielded twisted pairs do not require separators to prevent crosstalk, further reducing size, weight, and termination complexity (Figure 3).* The design also includes a silver-plated braided shield over each bundle of four pairs for increased shielding effectiveness (Figure 4).

Table 2: Enhanced Properties of Gore's Materials

Cable Component	**Aircraft Cable Materials**	**Application Benefits**
Primary dielectric	Expanded PTFE (ePTFE)	Higher temperature resistance Improved electrical performance Smaller cable bundles Lighter weight Non-flammable
Outer jackets	Engineered fluoropolymers	Higher temperature resistance Smaller cable bundles Lighter weight Abrasion resistance Cut-through resistance Solvent resistance Non-flammable/non-toxic UV resistance

Figure 3: Comparison of Ethernet Cat6a Cable Designs

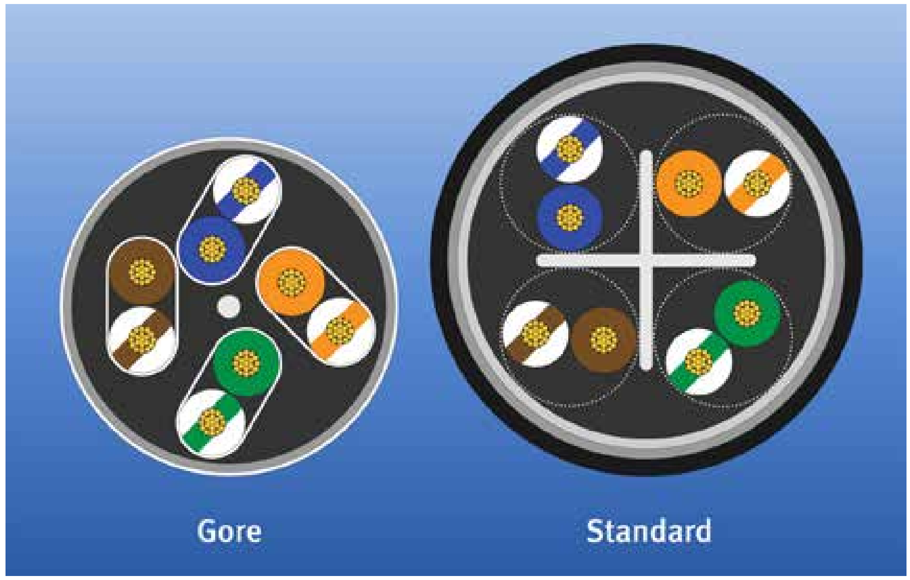
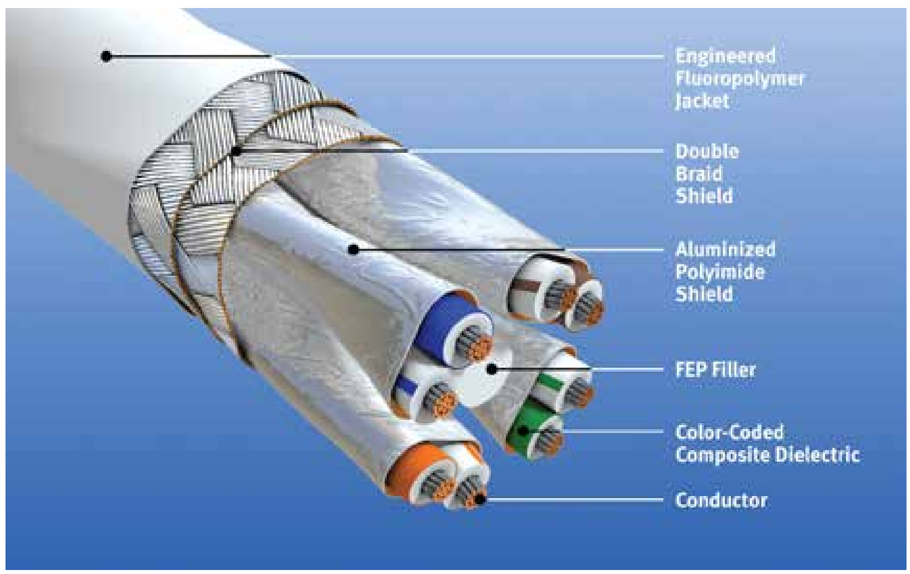


Figure 4: Construction of GORE® Ethernet Cables



Conductor Selection

Selecting a signal conductor can be the most important factor when designing high data rate cables. In many airborne applications, there is a minimum conductor requirement such as size 22 AWG or 24 AWG. *Smaller conductors can provide significant size and weight savings without impacting data transmission performance, particularly for interconnects up to 50 meters.* Smaller cables are also easier to terminate and compatible with a broader range of controlled impedance connectors. In addition, alloy conductors can provide additional durability when used with smaller cables.

Table 3 shows a general comparison of various conductor sizes for GORE® Ethernet Cables. Gore's engineered fluoropolymer materials enable this cable (26 AWG) to fit into Glenair® El Ochito® Size 8 Contacts (Figure 5). The overall cable diameter is 5.6 millimeters (0.220 inches).

Table 3: Comparison of GORE® Ethernet Cables (4 pairs)

Property	**24 AWG (19/36)**	**26 AWG (19/38)**	**28 AWG (19/40)**
Conductor diameter [mm (in)]	0.6 (0.024)	0.5 (0.020)	0.4 (0.016)
Cable diameter [mm (in)]	6.6 (0.260)	5.6 (0.220)	4.8 (0.190)
Nominal weight [g/m (lb/1000 ft)]	61 (41)	46 (31)	—
Maximum length [m (ft)]	80 (260)	65 (210)	50 (160)

Figure 5: GORE® Ethernet Cables with Glenair® El Ochito® Connector

Connector Selection

Designers must also carefully consider connectors and cable-connector interactions. Connectors must be compliant with existing standards such as MIL-DTL-38999 or ARINC 600 rack and panel connectors. Therefore, manufacturers are now offering specialized multi-pin controlled impedance contacts for use with 38999 connectors (Figure 6). These contacts can handle one or more twinaxial cables with low crosstalk through the interface.

Figure 6: Examples of Specialized Connector Contacts

Amphenol® OCS Connector — 38999 Compatible Differential Pair Inserts

Carlisle Octax® Connector System — 8-Link Connector (Size 25)

Glenair® El Ochito® Connector — Multi-Pin Insert (Size 8)

TE Connectivity CeeLok FAS-X Connector — Single-Link Connector (Size 11)

Selecting a connector for an Ethernet interconnect should include the following criteria:

- Number of connectors in the entire interconnect
- Distance between connectors
- Ease and consistency of termination
- Noise margin availability

Even if designers consider the above criteria, it is possible that interconnects designed with qualified cables and connectors will not deliver the level of performance required for specific applications. The newer connectors designed specifically for higher frequencies can significantly improve performance at 10 Gb/s; however, limited data exists to show the impact of various cable and connector combinations. In addition, multiple connectors in a data link may have an aggregate effect on characteristics such as reflections, crosstalk, and EMI. Therefore, it is important to test the entire interconnect at its full length with all of the connectors.

Electrical Testing

Automated testers can be used to measure electrical performance of a cable assembly for compliance with TIA-568 specifications. However, specific connectors such as type RJ-45 must be attached to the cable for these systems, which can degrade performance. *Therefore, a Vector Network Analyzer (VNA) should be used to provide the most accurate performance measurement of a cable assembly for qualification purposes.* Even with a VNA, proper adapters and cable preparation methods must be used to minimize the impact of connecting to the tester.

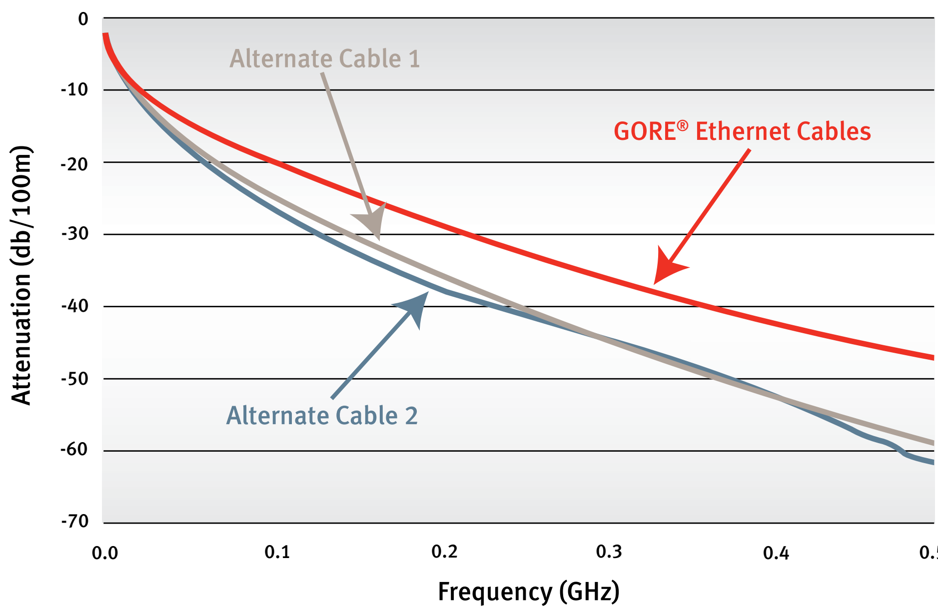
Testing for electrical performance includes insertion loss, return loss, and various forms of crosstalk. With proper adapters attached to the tester, insertion loss and return loss measurements are fairly straightforward. However, testing for accurate crosstalk measurements can be more difficult. Cables must demonstrate measured crosstalk at a low level to pass the test, which means carefully controlling the positions of the individual pairs in the area where the cable geometry and shielding have been disrupted. Current specifications limit the allowable crosstalk at low frequencies to less than -70dB, which approaches the noise floor of some test equipment. Achieving this level of sensitivity requires separation of all test leads and possibly a screened room to prevent noise from affecting the measurements.

Reliable Signal Integrity

Gore's engineers evaluated the durability and electrical performance of Ethernet cables. They compared several alternative cables with GORE® Ethernet Cables for Cat6a protocol, all with similar specifications. They connected the cables to a VNA to measure signal attenuation and crosstalk at 1 MHz to 500 MHz over a length of 100 meters.

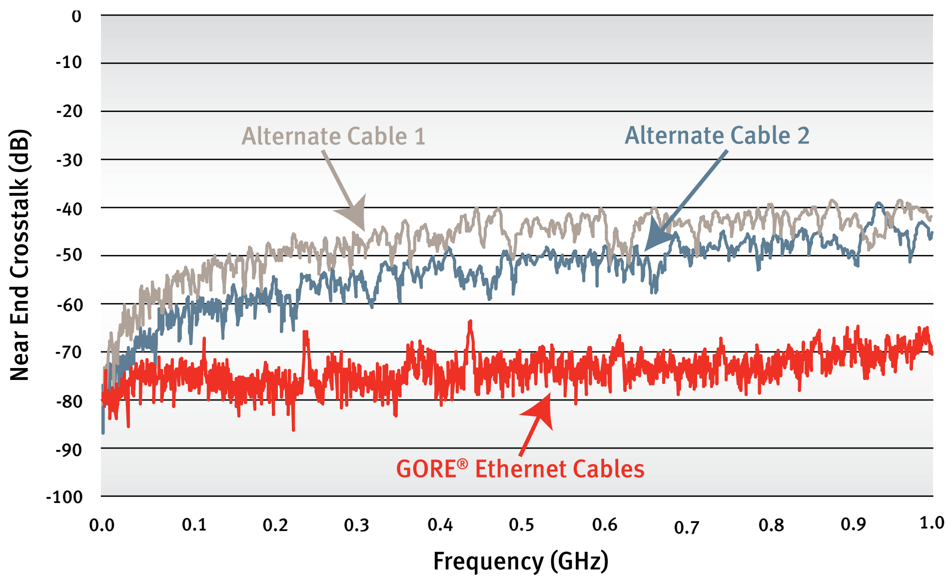
The results showed that GORE® Ethernet Cables provided enhanced electrical performance with lower signal attenuation by as much as 10 dB/100m at 500 MHz when compared to alternative cables (Figure 7). GORE® Ethernet Cables meet the requirements for signal transmission up to 10 Gb/s for up to 80 meters for 24 AWG and 65 meters for 26 AWG.

Figure 7: Attenuation Comparison of Cat6a Cables



Similarly, results showed that GORE® Ethernet Cables can reduce crosstalk by as much as 10 dB compared to alternative cable designs (Figure 8). The shielding over each individual twisted pair also increases shielding effectiveness for better noise immunity and reduced EMI emissions.

Figure 8: Near-End Crosstalk (NEXT) Comparison of Cat6a Cables



Conclusion

As the civil aerospace industry is demanding faster digital networks with increased performance, aircraft interconnects need to provide more reliable signal integrity and deliver high-speed data transmission over longer distances. As a result, many aircraft designers are adopting commercial protocols for new system interconnects and requesting Ethernet cables operating at 10 Gb/s to handle higher data rates. However, it is essential to identify all of the potential issues that can affect the electrical and mechanical performance of the cable system. Designers should carefully consider unique cable material restrictions, regulatory requirements, and space constraints during the initial design process, and they should perform thorough testing to ensure the cable system will perform reliability in specific applications.

Gore's testing demonstrates the importance of selecting the right Ethernet cables to ensure reliable performance in challenging aerospace environments. GORE® Ethernet Cables meet the electrical and mechanical requirements for Cat6a protocol, delivering reliable signal integrity for high-speed data transmission up to 10 Gb/s for up to 80 meters for 24 AWG, and up to 65 meters for 26 AWG. They have a unique high-density construction that is 24 percent smaller and 25 percent lighter while providing durable protection against the rigors of installation and harsh conditions of aerospace. In addition, GORE® Ethernet Cables can be easily retrofitted into existing aircraft structures because they are smaller and more flexible with a tighter bend radius for easy routing in confined spaces.

All of this translates to easy installation, improved EMI immunity, reduced emissions, lower attenuation, and minimal crosstalk to ensure reliable system performance over the life of the aircraft.

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W. L. Gore & Associates

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