Insight

Enabling 10 Gbit-Ethernet in Miniature I/O Connectors for Aerospace and Defense Applications

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Executive Summary

The CeeLok FAS-T connector, a new high-speed circular I/O, combines the ruggedness of a MIL-C-38999-style design with an insert specifically configured for 10 Gbit-Ethernet transmission. Additionally, it is a small-form-factor connector system that is field repairable and supports data rate requirements for current and next-generation electronic systems in Aerospace and Defense applications.

The Need for High-Speed, Ruggedized I/O Interconnections

Advancements in electronic data processing in Military and Aerospace applications have propagated throughout these systems in recent years. A wide range of applications such as aircraft avionics, communications, ground vehicle, smart munitions and soldier systems, all require the ability to process data at increasing rates. While the electronic components inside the embedded computer system have been designed to increase their data transmission rates, the I/O connector interface (see Figure 1) has lagged behind. The I/O interface has thus become a limiting factor to the speed at which these systems can operate.

Figure 1. Typical I/O interface of an embedded computer system [1]

The 38999 I/O interface was designed decades ago, when the primary concerns were ruggedness and field repairability. This connection had to be rugged to survive the harsh environmental conditions to which they would typically be exposed. These conditions included high vibration and mechanical shock levels, temperature extremes, hundreds of mating cycles and sealing of the contact interface against corrosive fluids and chemicals. Easy field repairability is also key as these systems are often deployed in remote locations where repair facilities are scarce and critical missions can be compromised with a system failure. The ability to remove and replace a damaged contact interface with readily available hand tools to restore system operation was a key part of the design criteria. Data transmission rates, however, were not a key consideration in the initial connector design.

As the need for a high-speed interconnect solution for this application has become apparent, the 10 Gbit-Ethernet protocol has emerged as the solution of choice. Ethernet has a long history of successful networking applications and has become the most widely adopted networking technology in the world. 10 Gbit-Ethernet is a natural evolution of this technology, which further increases the line speeds of the network. The current solutions typically can only operate at the 1 Gbit-Ethernet level. Adoption of this protocol in a ruggedized format will thus allow a 10X increase in data transmission rates. The fact that it is also a copper wire-based solution with conductors in the 24-26 AWG wire range makes it a desirable solution as tools to strip wire, crimp, insert and extract contacts to these conductors have long been established and are widely available. In order to successfully incorporate this protocol, there are connector design guidelines for signal integrity that must be considered. The geometry of the contact interface, the pattern in which it is arranged and the material used for the insert all affect the impedance (100 ±10 ohms), cross-talk, and insertion and return loss limits that must be met to enable the protocol.

Integration of the embedded computer system in the smallest possible envelope has also become an important design goal. By reducing size and weight of the system, it can be integrated in a wide range of applications where these parameters are critical such as missiles, UAVs, and soldier systems. It can also free up space for other components or munitions to be integrated, extend the range of aircraft or vehicles, or increase vehicle payloads due to the weight savings. As the internal components of the computer system are miniaturized, the I/O connector can be the component that limits the reduction in the box size due to the physical space required to mount it to the panel.

The CeeLok FAS-T connector system uniquely combines the ruggedness and repairability features of the 38999 Series III connector with an insert interface design for signal integrity and contact density optimization to produce an envelope 50% smaller and 75% lighter than the traditional I/O connector system (see Figure 2).

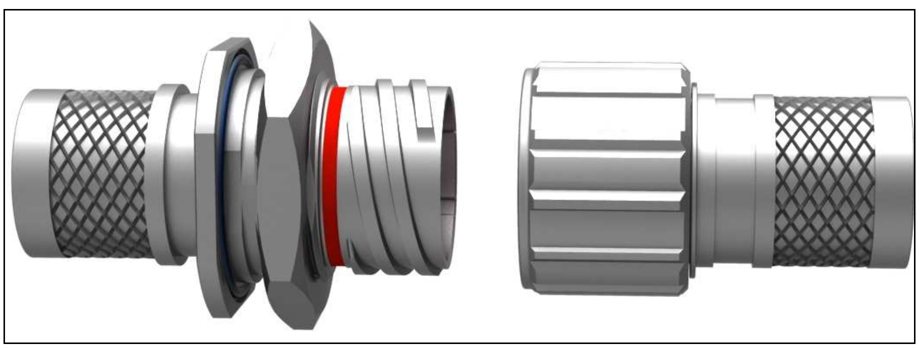

Figure 2. CeeLok FAS-T plug and receptacle connector:
50% smaller and 75% lighter than a shell size 19 38999 connector

Managing the I/O Connector Design Requirements

Through decades of application experience and testing in Military and Industry laboratories, the environmental requirements for Aerospace and Military I/O connectors have been well understood and documented. Connector design parameters have been established in specifications (such as MIL-C-38999) to ensure these requirements can be reliably met. While these specifications define the physical and material requirements of the connector design, they do not take into consideration the signal integrity parameters such as crosstalk cancellation and impedance matching required for 10 Gbit-Ethernet signal transmission. The CeeLok FAS-T connector combines an insert specifically designed to address these issues in a MIL-C-38999 connector configuration. This combination yields a design with the robustness and field repairability of a MIL-C-38999 connector with signal integrity optimization to enable the 10 Gbit-Ethernet protocol. The insert and shell design were also optimized for contact density (0.075" spacing) space and weight to achieve the smallest form-factor possible.

Current Technology

Since the environmental resistance requirements for Aerospace and Military applications are well established, the primary design focus of the CeeLok FAS-T connector system was the optimization of the contact insert pattern and density for signal integrity performance. Through key customer interviews, it was determined that an 8-position insert with 39029-style crimp contacts could achieve 1 Gbit-Ethernet or 10 Gbit-Ethernet data rates when used with cables designed for these applications, such as Cat 5e, 6A, 7, or Quadrax. Customer feedback required the need to address concerns in enabling these protocols in existing applications. Two common solutions to enable these protocols are to selectively pin an existing 38999 connector in a pattern that minimizes crosstalk between pairs directly by isolation or indirectly by symmetry cancellation (see Figure 3) or by integrating a commercially available insert into a rugged 38999 connector shell (see Figure 4).

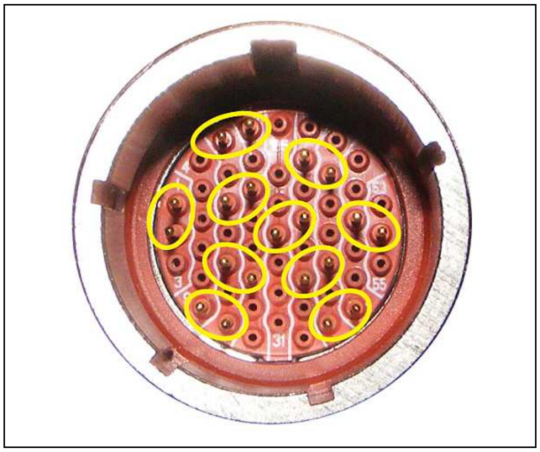

Figure 3. Proposed ARINC 664 PC pin out pattern in a 38999 connector:
Requires optimization for impedance matching and crosstalk cancellation

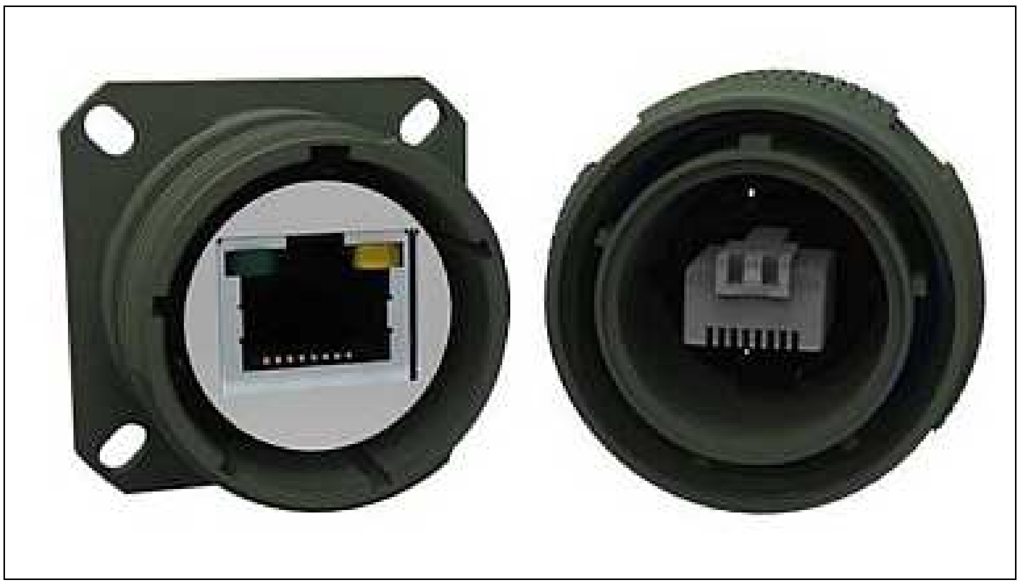

Figure 4. RJ45 commercial interface in a size 19 38999 shell:
Interface demands redesign for rugged environements and shell size reduction

Selectively pinning an existing 38999 connector (see Figure 3) can minimize cross-talk through isolation. The contact system is designed to be mechanically robust and repairable, which meets the requirements of the connector's original design many years ago. However, these solutions do not address requirements of superior return loss, which is critical for the connector to satisfy high-speed requirements. The contact geometry and location is not designed for matched impedance and contributes to increased return loss.

Adaptation of a commercial Ethernet RJ45 insert (see Figure 4), into a rugged shell has the advantage of being a known interface, but has not been designed for rugged applications or field repairability, or with consideration of the small available real estate.

Although the 38999 style connector is regarded as very rugged, there are cases where insert bond joints can fail in field applications. This causes sealing failures, which can lead to connector/electrical failures. Replacement of this feature with a highly reliable, mechanical design that is not dependent on bonding was greatly desired.

CeeLok FAS-T Connector Design Details

In order to address all of the requirements associated with these applications, several unique features were designed into the CeeLok FAS-T connector system. To minimize the effects of crosstalk within the interface, a symmetrical cancellation approach was taken. By arranging the interface with a symmetrical contact pair pattern, the full effects of cancellation can be realized, reducing the amount of required pair separation. This has the added advantage of allowing for higher contact density. A "T" pattern (see Figure 5) was selected as the best way to achieve crosstalk cancellation. This pattern was selected based on an existing TE Connectivity commercial connector interface that had met 10 Gbit-Ethernet data transmission through Signal Integrity 3D modeling software analysis and physical testing.

Figure 5. Contact "T" pattern for dedicated signal integrity performance and repairability

Once the pattern was established, there were opportunities for further optimization for contact density within the CeeLok FAS-T connector shell. A parameter that can influence the amount of crosstalk coupling between contact pairs or conductive connector shells is the dielectric resistance of the insulating material. Thermoplastics used in high-temperature connector applications have relatively high dielectric strengths to prevent arcing between adjacent contacts at the required operating voltages, but has a negative effect on resistance to electrical coupling between conductive elements. A further optimization of the CeeLok FAS-T connector's insert design was to strategically place air pockets within the interface to reduce crosstalk coupling (see Figure 6). The dielectric of air is approximately 33% of the insulating material. By placing a low dielectric feature between diagonal contact pairs and the connector metal shell, coupling between these features is reduced and allows for further contact density optimization than would be achievable with the insert material properties alone.

In order for a contact system to be field repairable, the contact needs to be able to be extracted from the connector body, so that it can be cut from the wire, with a new contact crimped to the wire and re-inserted into the connector, securely locking itself in place. An internal spring clip is assembled into each circuit cavity to allow for this repairability. The clip typically extends approximately 360° within the perimeter of the cavity and includes two spring tines, located 180° from each other that engage a shoulder on the contact to lock it in place. To remove the contact, a tool is inserted into the cavity, which also extends approximately 360° within the circuit cavity and deflects the spring beams to release them from the contact so that it can be extracted. This component defines the minimum size of the circuit cavity geometry and, thus, is the limiting factor on how close contacts can be physically located to each other. This geometry results in a much larger contact body relative to the wire cross-section, which means increased return loss due to impedance mismatch.

To reduce the limitation that the contact retention clip places on contact density and impedance matching, the CeeLok FAS-T connector design incorporates a retention clip with a single spring tine that only extends approximately 180° within the circuit cavity perimeter. By locating the clips within adjacent circuit cavities 180° away from each other, the spacing between the cavities can be reduced. Since the single tine clip occupies only half the space, it offers improved impedance matching (see Figure 6).

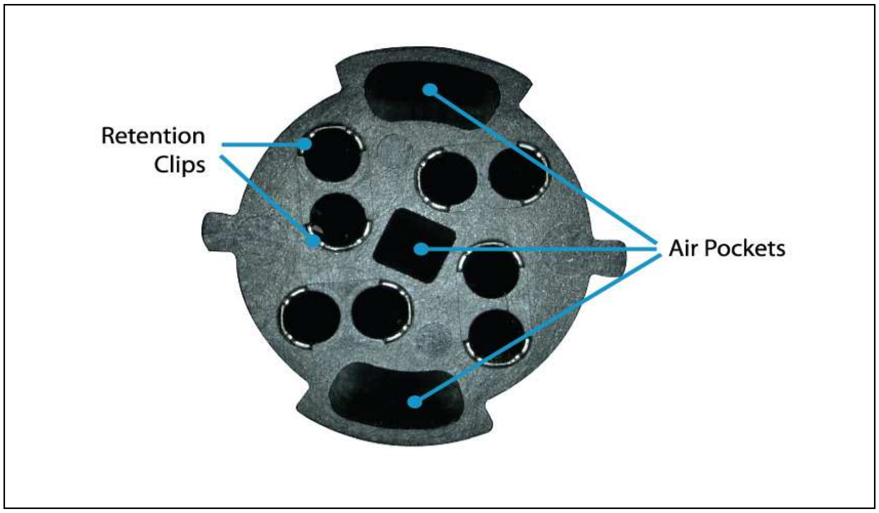

Figure 6. Contact retention clip orientation and air pockets

An additional improvement to the insert design was the replacement of the insert bond joint through the incorporation of an internal snap ring retention system. A snap ring is assembled into an internal groove in the connector body located behind the connector insert, wire entry seal, and wire entry guide. The snap ring prevents the insert from pushing out when a load is applied to the connector mating face. A flange in the front of the shell engages a shoulder on the connector insert to prevent it from moving forward. This results in a retention mechanism that can withstand up to 200 pounds of force (verified through TE testing) as compared to the minimum retention requirement of 25 pounds per the 38999 specification. In order to replace the sealing feature of the bond joint, three external sealing ribs were incorporated into the wire entry seal design. The wire entry seal material is fluorosilicone, which remains compliant over the wide range of environmental conditions. The triple rib design adds redundancy not available with a bond joint.

A further enhancement of the CeeLok FAS-T connector design was incorporated into the metal shell. A typical 38999 connector incorporates a threaded portion to accept various backshell accessories for strain relief and cable braid termination. These accessories add size, weight, and complexity to the inter-connect system. The CeeLok FAS-T connector replaces the threaded portion of the shell with a raised shoulder and knurled portion machined directly into the shell. This allows for braid termination and strain relief without requiring an additional backshell. The braid can be terminated directly to the connector shell through the use of a micro-band strap and hand application tool (see Figure 7). This method is simple to apply and has been used throughout the Military and Aerospace industries in a wide range of applications. The micro-band strap provides excellent retention forces and low level braid to shell resistance values while remaining field repairable by simply cutting it off and replacing with a new strap. To provide strain relief and cable sealing, an array of heat shrink boots can be applied over the braid termination. They shrink to conform to the geometry of the connector and cable and are retained with a formed lip molded into the boot engaging the shoulder machined into the connector shell. The boot is applied through application of heat with a heat gun and can be replaced when repairs are needed.

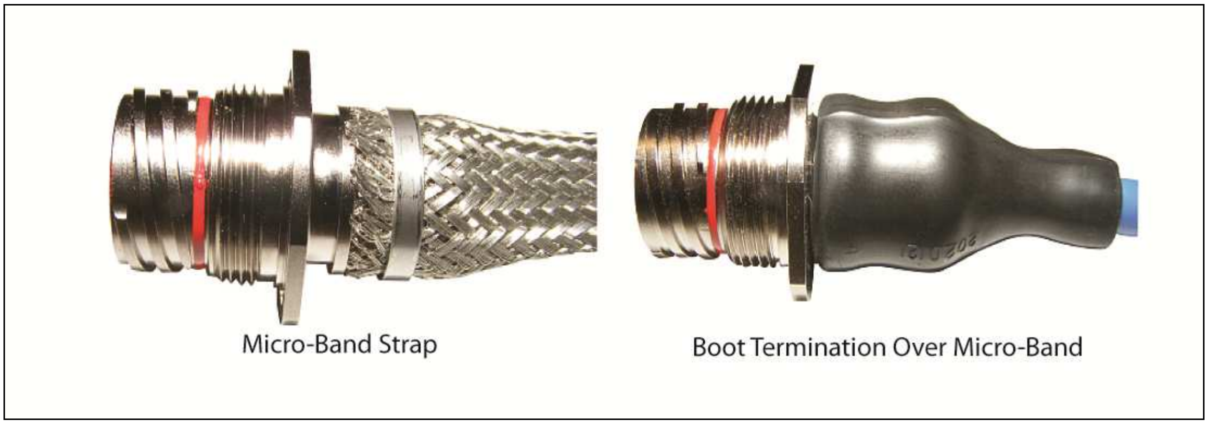

Figure 7. Boot termination over micro-band

The final design of the CeeLok FAS-T connector system enables the application of the 10 Gbit-Ethernet protocol in harsh, Military and Aerospace environments, while remaining mechanically robust and easily field repairable. A size and weight reduction of approximately 50% and 75%, respectively, are also achieved over common, current solutions (see Figure 8).

Feature	38999 Series III Size 19 Shell	CeeLok FAS-T Connector Size 8 Shell	Reduction
Plug Nominal Dia. (with coupling ring)	1.5"	0.75"	50%
Typical Assembly Weight (g)	99 g	24 g	75%

Figure 8. Shell size and weight comparison

Mechanical performance highlights include:

- Altitude immersion sealing to 70,000 feet: aircraft applications
- 175°C maximum temperature rating: high-temperature environments
- 60 G vibration level : rotary wing aircraft applications
- 300 G mechanical shock resistance: munitions and ground vehicle applications
- Salt spray resistance of 48 or 500 hours: shipboard applications

Verification Testing

Once the design parameters had been finalized, signal integrity verification testing was performed to the pass/fail criteria in ANSI/TIA-568-C.2 for the 10 Gbit-Ethernet connector-only levels. For comparison of existing solutions, two 38999 connector configurations were tested as well:

- Shell size 17 connector, selectively pinned as shown in Figure 3. This configuration was selected as an example of contact pair isolation that can be used in high-speed data transmission applications.
- Shell size 10 (0.830"), selectively pinned as shown in Figure 9. This was chosen as an example of the performance that can be achieved in a selectively pinned connector of similar size and density to the CeeLok FAS-T connector, but not specifically designed for Impedance matching and cross-talk cancellation.

Since crosstalk requirements can be accommodated through contact pair separation in existing connector configurations, return loss was chosen as the primary performance criteria since it is directly related to impedance matching. Only the CeeLok FAS-T connector is designed with impedance matching so comparison of these performance criteria to the existing solutions will highlight the advantages the CeeLok FAS-T connector design has to offer over these configurations.

Figure 9. Shell size 10 connector pin-out

Test Results

The connector is characterized for frequencies up to 500 MHz as required by ANSI/TIA-568-C.2 for each test sample. Figures 10-12 show the return loss measurement and the red line is the mask for the connector to meet the specification. The CeeLok FAS-T connector sample was the only connector to meet the return loss specification. This confirms that the "T" pattern formed by the contact pairs is well designed to meet the impedance requirements for 10 Gbit-Ethernet applications. Conversely, the selectively pinned 38999 configurations will not be able to provide the same impedance requirements to meet the return loss specification in the same frequency band.

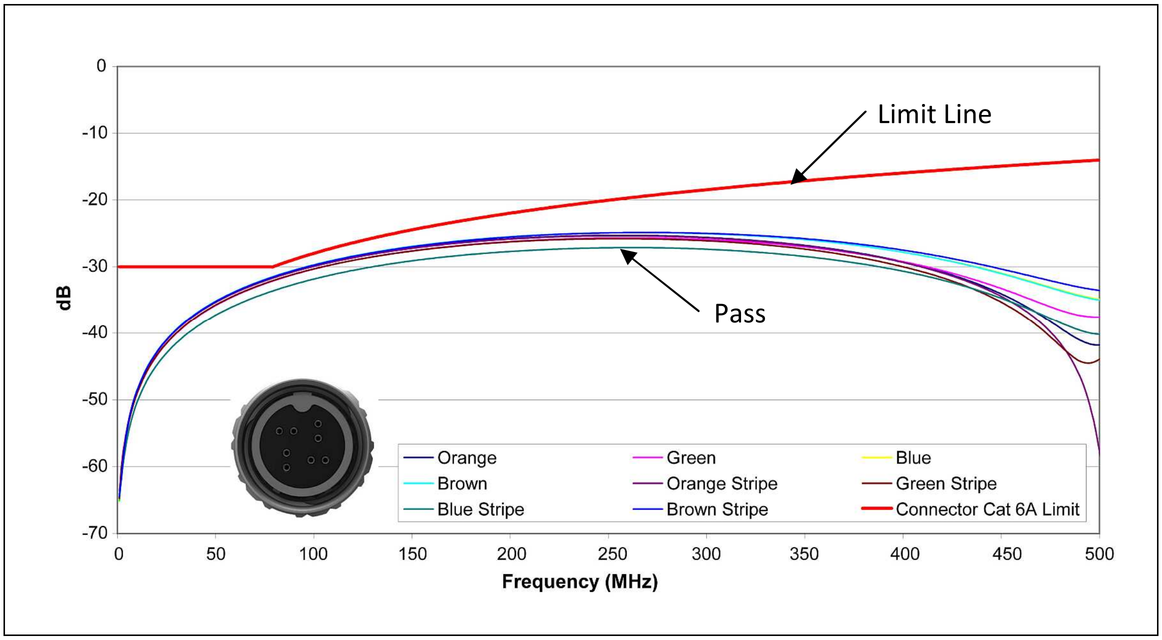

Figure 10. CeeLok FAS-T connector meets return loss limit

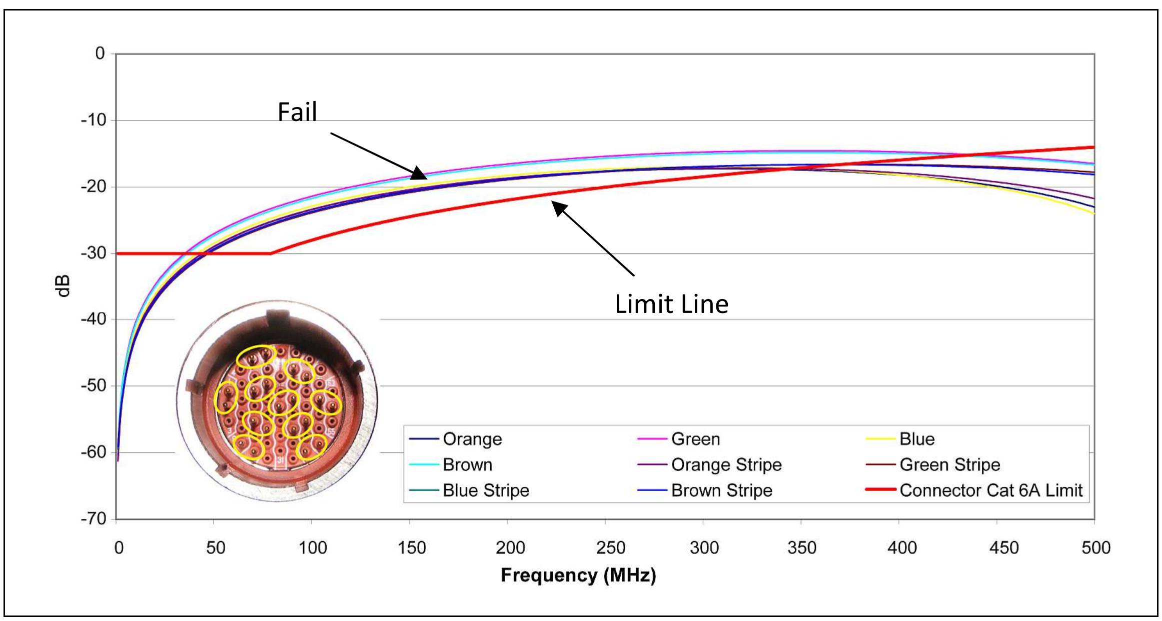

Figure 11. 38999 shell size 17 fails return loss limit

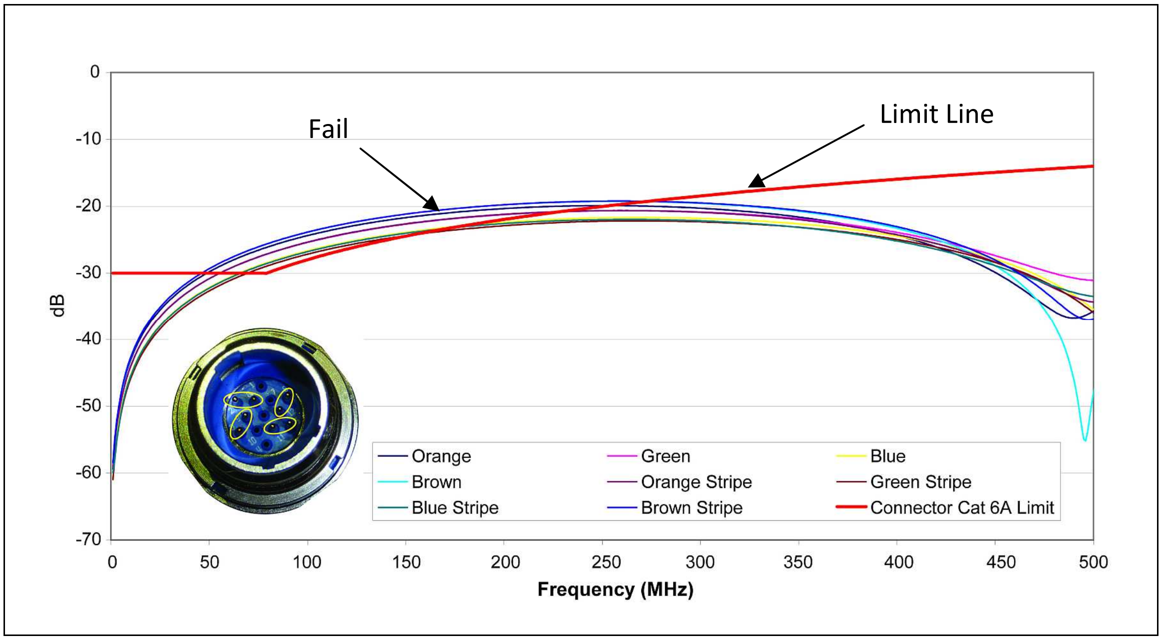

Figure 12. 38999 style shell size 10 fails return loss limit

Conclusion

The CeeLok FAS-T connector design addresses the signal integrity and robust environmental requirements of current Military and Aerospace applications while enabling the facilitation of next generation protocols within the same design. Highlights of the design include:

- "T" contact pattern optimized for signal integrity performance which includes crosstalk cancellation and impedance matching
- Single finger retention clips for increased contact density (0.075" centerlines) and impedance matching
- Mechanical insert retention feature for increased reliability: 200 pounds retention
- Integral backshell for 360° EMI braid termination with micro-band: No additional backshell required
- Compatible with TE shield terminations, molded products, and cable for a complete system solution

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Note

[1] Curtis Wright Embedded Computing, cwembedded.com