Insight

Enabling High-Speed Data Rates in Connectors for Aerospace and Defense Applications

Matthew McAlonis
Development Engineering

Executive Summary

A new high-speed connector system for aerospace and defense applications builds on industry-proven technology to achieve new levels of ruggedness. By combining the designs of cutting-edge high-speed connectors with proven MIL-SPEC contacts, the new Fortis Zd connector meets the demands of emerging military applications by enabling data rates of 10 Gb/s+ while performing in military-level vibration and shock conditions.

Introduction: The Need for Speed

High speed is a relative term used within the interconnect industry. High-speed electronic circuits must respond to fast input signals. A measure of the ability of a circuit to respond to fast input signals is known as an edge rate or rise time (as illustrated in Figure 1). When this time is 500 picoseconds or less, a high-speed connector is required. The progressive advancements in electronic technology drive the data rate of the signals which pass through connectors (Figure 2) and have been steadily increasing. To function properly in systems operating at higher speeds, the connectors and the layouts of the connector footprints on the circuit boards must be carefully designed with specific emphasis on the high-speed electrical performance. Ideally the connector should be "invisible" in the system; hence, the integrity of the electrical signal as it passes through the interconnect and the interconnect footprint must be maintained.

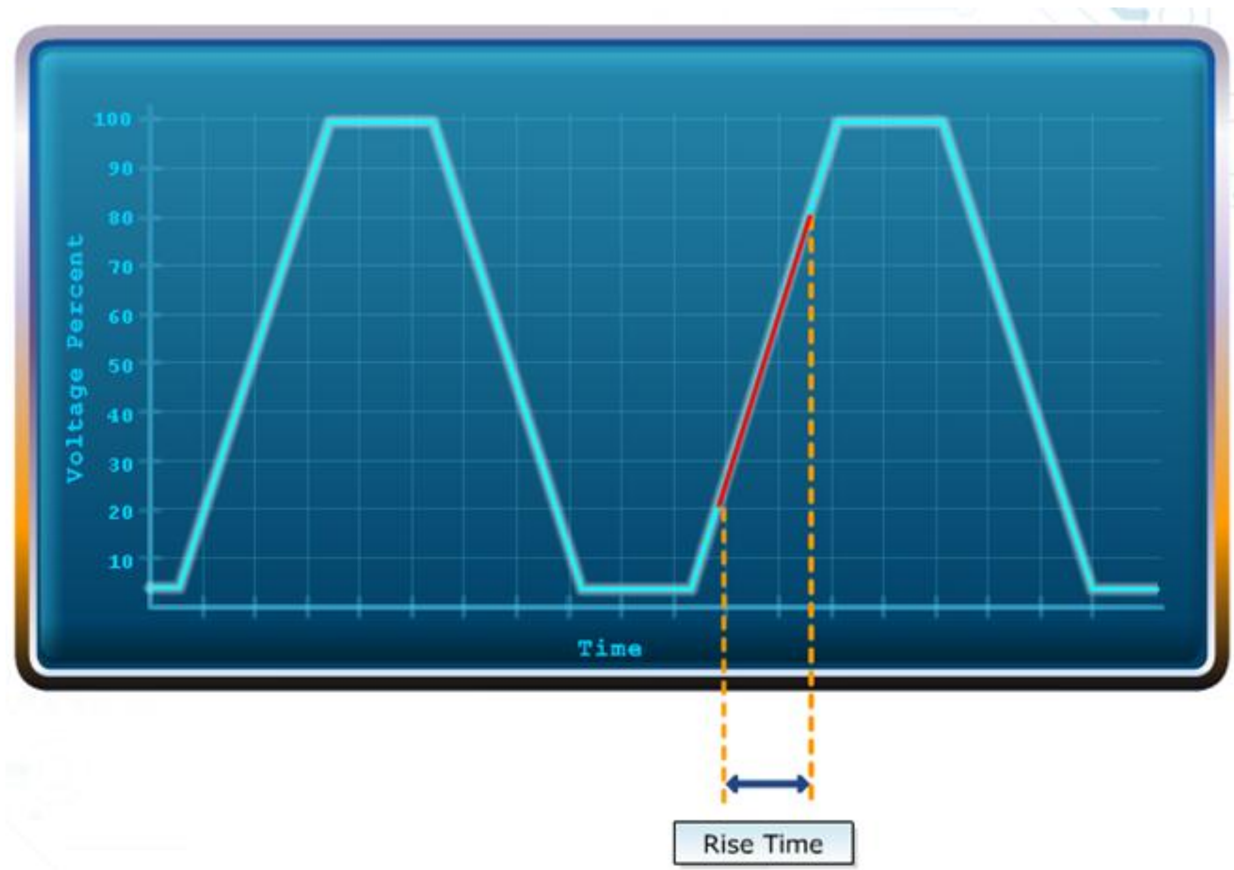

Figure 1. A faster rise time means that data pulses can be transmitted more rapidly. When this time is 500 picoseconds or less, a high-speed connector is required.

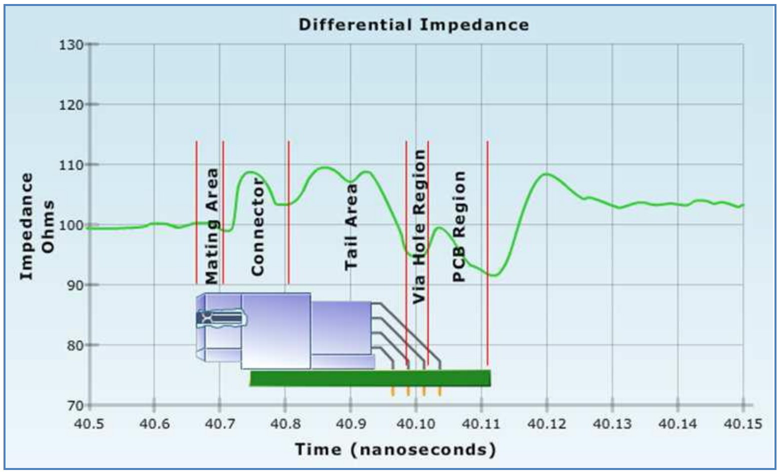

Figure 2. The integrity of the electrical signal as it passes through the interconnect and pcb footprints must be maintained.

Connectors that have been designed in this manner are often referred to as high-speed connectors. The need for faster data rates, and decreasing signal rise times, requires better performing, high-speed connectors. TE Connectivity (TE) is at the forefront for providing its customers with outstanding performing connectors that support their system data rate requirements. The system data rate, or the speed at which the signals are transmitted, for TE' high-speed backplane connectors can currently be supported for data rates up to and beyond 20 Gb/s.

Presently commercial high-speed backplane connectors are found primarily in industry applications including data storage, servers, switches, souters, and optical transport equipment. These products offer superior high-speed electrical performance, which requires sophisticated connector designs and often intricate/delicate physical features for the housings and electrical contacts. Although these characteristics are adequate for a relatively benign, climate controlled office environment, often these products have inherent design margins well suited for use in harsher environments in applications that include radar, digital video, digital infrared, and other data and signal processing [1]. Furthermore, some products can be "uparmored" by incorporating metal hardware kits that add extra physical protection to the connector components.

TE AD&M development engineering has provided uparmoring solutions to several production backplane connector designs including HM-Zd, Universal Power Module, and MULTIGIG RT2. These ruggedized connector solutions are called HSR (High Speed Ruggedized) and MULTIGIG Extreme.

Commercial connectors, however, are frequently limited in terms of ruggedness with respect to the highest performance demands of aerospace and defense applications. Engineering embedded computing products for harsh military applications requires solutions that are designed from the ground up to give years of reliable operation in extremes of operating temperature, shock, vibration, and corrosive atmospheres. These devices must survive extreme environments such as those encountered in aerial combat situations and gunfire shock and vibration where human lives depend on system reliability.

Manned vehicles and aircraft as well as precision guided weapons are able to bring information to the battlefield much faster with today's technology than was available previously. Mounted on long endurance, unmanned platforms, an array of sensor technologies can deliver the persistent surveillance necessary to find and fix an elusive, insurgent enemy [2]. Information can be sent to who wants to see it, and how they want to see it, either to Capitol Hill or to the PFC on the streets of Baghdad. Next-generation defense programs, such as the Army modernization strategy, have further stimulated the growth of technology in aerospace and defense applications, including next-generation radar systems, unmanned/manned ground vehicles, unmanned air surveillance vehicles that can record high-definition video, unattended munitions, ground soldier systems, mobile command centers, and a state-of-the-art network; all of which drive the need for increased signal processing and data transmission. Once deployed, such Army modernization programs will provide safety and knowledge to our armed forces with unprecedented capability to see, engage, and defeat the enemy on today's and tomorrow's battlefield [3].

Defining the Requirements for Next-Generation Military Backplane Connectors

Unfortunately, the paradigms of "ruggedness" and "signal integrity at high speeds" often contradict. A connector built to withstand the rugged environments traditionally cannot perform to the high-speed requirements. Thus there exists a need for a connector system that offers signal integrity at high speeds while withstanding increased shock and vibration levels.

The current vision within TE AD&M development engineering team is to provide ruggedization improvements in the high-speed backplane connector designs through marrying an electrically sophisticated, high-speed contact leadframe with a robust, industry-proven separable contact interface. This configuration can then be packaged in a metal shell to offer an even higher degree of robustness both in the mating interface as well as in the outer shell of the connector. This resulting connector design must be electrically analyzed with regards to signal integrity performance then tested to ensure it can withstand the demands of the targeted application environments. Electrical analysis tools include 2D impedance and 3D HFSS electrical modeling, followed by signal integrity verification testing. It is expected that this new TE connector system, known currently as "Fortis Zd," will provide a path for the next generation of electronic systems in ruggedized environments enabling better equipment, improved communications, unmatched situational awareness, and technologically superior logistics and training (Figure 3).

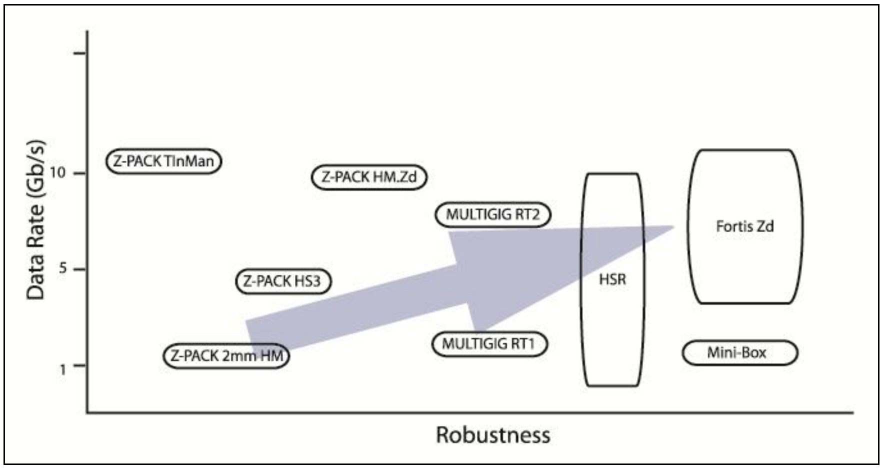

Figure 3. The Fortis Zd connector will provide a path for the next generation of electronic systems in ruggedized environments by combining the performance characteristics of high-speed connectors with a mil-qualified contact interface.

Voice of the Customer

The Lean Design process began by surveying industry leaders on specific needs for high-speed interconnections in naval radar, military avionics and electronic systems, embedded computing, munitions, and space avionics. By choosing companies involved with leading edge programs and technology, such Voice of Customer visits helped ensure complete and accurate customer requirements were collected. A comprehensive tool kit of Lean Design tools were used to validate and prioritize the design requirements. Among the highlights for design requirements were:

- Faster data rates
- More robust connectors and contact interfaces
- Industry-proven legacy contact systems
- Reliable "4-point" separable interface contact designs
- Small connector sizes to minimize impact on pcb real estate
- Scalable modular designs that can be customized
- Repairable connectors
- Protected contacts, especially on the backplane side

Because of the strong customer emphasis on proven contact designs, both MIL-DTL-83513 twist-pin contacts and MIL-DTL-55302 Mini-Box contacts were evaluated for the next-generation, high-speed ruggedized design. Both contact designs, shown in Figure 4, are industry proven and reliable contact systems in ruggedized applications.

Figure 4. Both twist-pin (left) and the Mini-Box (right) contacts were evaluated for performance and manufacturing complexity.

After evaluating high-speed connector designs to benchmark, the popular Z-PACK TinMan connector system (Figure 5), which supports data rates of 12+ Gb/s was selected based on its proven electrical performance and excellent functional density.

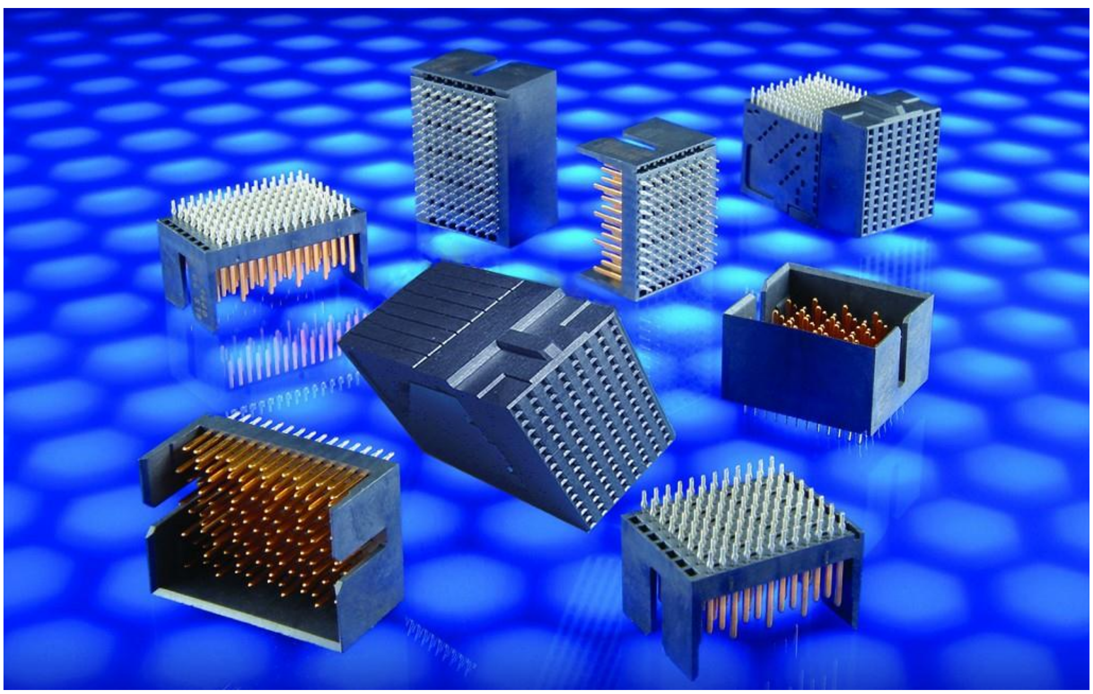

Figure 5. The Z-PACK TinMan connector system was selected to benchmark based on its proven electrical performance and excellent functional density.

The challenge was to incorporate a rugged contact interface into a high-speed connector design.

Both the twist-pin and Mini-Box contact designs offer a minimum of four points of contact at the mating interface which is desired for redundancy and reliability. Relative to commercial high-speed connector interfaces, the additional metal in these rugged contact systems would, however, affect the differential impedance of the connector, thus necessitating careful analysis. As with many high-speed connectors, the differential impedance target for Fortis Zd connector is 100 ohms ±10%.

Signal Integrity Analysis

The initial design approach was to evaluate the use of the twist-pin and Mini-Box contacts, which are considered to be two of the industry's most rugged and reliable contact systems. As will be discussed, further analysis of both designs in terms of signal integrity, durability, contact density, and design complexity shows the Mini-Box design was the better choice.

Complicated high-speed connector designs such as this can take up to one hundred or more design iterations during the development process. Figure 6 shows the basic configuration of the differential pairs and ground pins. Each differential pair in a column is separated by a ground contact. Alternating contact columns are staggered for optimal performance.

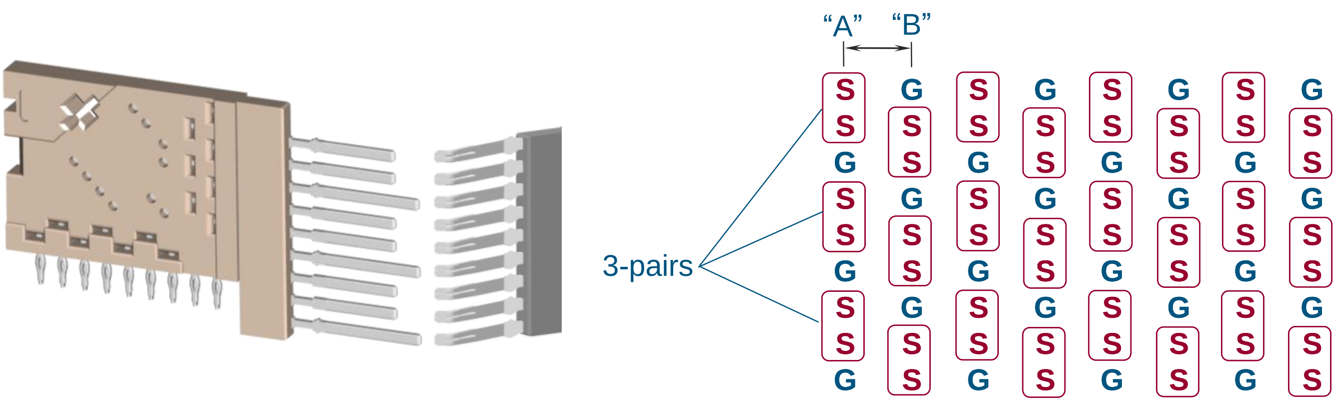

Figure 6. The Fortis Zd design benchmarked the Z-PACK TinMan connector, which is capable of data rates of 12+ Gb/s. Each differential pair in a column is separated by a ground contact.

Impedance analysis provides guidance for both the contact spacing pattern and the contact circuit cavity design. Initial electrical modeling of the twist-pin design suggested promising data rates around 10 Gb/s while meeting the 100 ohms ±10% requirement. A mechanical prototype was built to prove the overall design and manufacturing feasibility. However, because of its known design simplicity and producibility, the development team also decided to evaluate a connector design variation based on the Mini-Box contact system.

Using the original twist pin contact pattern, the Mini-Box concept was analyzed for impedance. The resulting analysis plots suggested that the Mini-Box contact system could achieve the 100-

ohm goal with contacts spaced even closer together. This, of course, meets the customer requirement for high functional densities.

Additional design optimization and tuning, along with frequent signal integrity simulations, showed the Mini-Box design offered significant data speed improvements. The Mini-Box contact offers many benefits such as:

- Design simplicity
- Points of contact on all four sides of the mating pin
- A distinct cost advantage over other complex contact designs
- High-speed differential pair capable
- Optimized functional density in a small connector footprint

As a result of these analyses, the new connector was based on the Z-PACK TinMan leadframe and Mini-Box contacts (Figure 6).

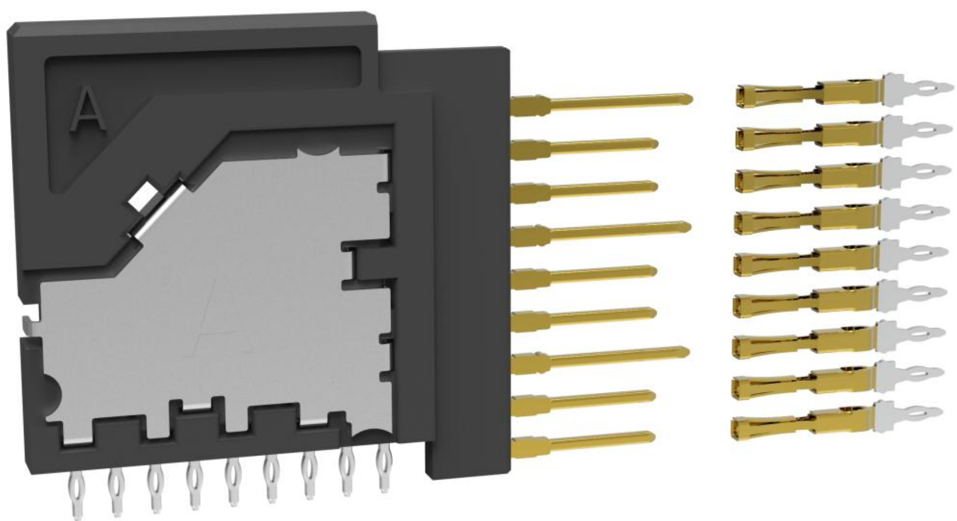

Figure 6. The Fortis Zd connector is based on industry-proven technology: MIL-DTL 55302 Mini-Box contacts and a cutting-edge high-speed connector (Z-PACK TinMan).

To alleviate a common industry concern of performance under vibration, a test was set up to induce motion of Mini-Box connectors at the mating interface. Connectors were mounted in a test fixture that simulated the motion of a backplane under vibration, and moved a displacement of 0.25 mm for 100,000 cycles. This test showed that low-level contact resistance was stable and SEM evaluation revealed excellent mechanical performance under this durability evaluation.

Fortis Zd connectors show excellent signal integrity with impedance variations well within design goals. Figure 7 shows results of an HFSS simulation. While the simulation considers the connector by itself, real-world electrical performance depends on the actual application configuration. Any high-speed connector should always be evaluated under actual application conditions. The physical layout of the backplane and daughtercards and the conditioning of the signal can affect the performance. Even so, the results show that the connector system meets or exceeds basic requirements.

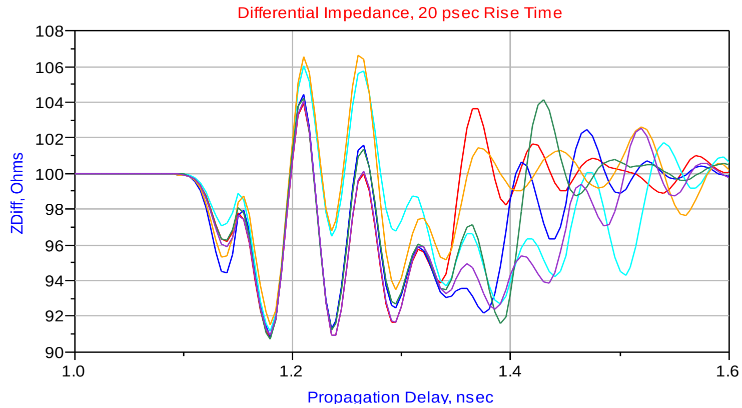

Figure 7. Electrical performance of the Fortis Zd connector shows electrical performance equal to that of high-speed commercial connectors.

Mechanical Performance

Given its target applications, the Fortis Zd connector meets much more rigorous mechanical specifications for shock and vibration than COTS-grade counterparts. Figure 8 compares the performance of the Fortis Zd connector to that of a typical commercial backplane connector.

Test	Commercial Connector	Fortis Zd Connector
Random Vibration	3.1 g_{rms} 20 to 500 Hz	11.5 g_{rms} 20 to 2000 Hz
Mechanical Shock	50 g 1/2 sine pulse	100 g Sawtooth pulse
Durability	200 mating cycles, min.	500 mating cycles, min.
Thermal Shock	-65 to +90°C 5 cycles	-65 to +125°C 500 cycles
Temperature/Humidity Cycling	+5 to +85°C, 80% to 100% RH 50 cycles	
Product Specification	108-2303	108-2409

Figure 8. Fortis Zd connectors are mechanically and environmentally more robust than commercial connectors.

Conclusion

Bringing the best blend of signal integrity, ruggedness, manufacturability, functional density, and cost, the design and manufacturing team finalized the development of the Fortis Zd platform based on the Mini-Box contact system.

The base product platform is a 3-pair, 10-column connector which offers 30 differential contact pairs per module. Product extension options include 20-column connectors for a larger pin count, and 2-pair connectors for customers who require a smaller connector profile for tighter card slot pitches.

A three-tier choice of connector shells (Figure 9) meets varying degrees of mechanical and shielding performance.

- All-plastic shell similar to the Z-PACK TinMan connector provides connector guidance and pin protection, similar to commercial backplane products
- Stamped metal shell, which can be retrofitted to the all-plastic shell, for enhanced mechanical protection as well as EMI shielding
- Machined metal 6010 Aluminum shell for the ultimate in connector protection and robustness

All three variations are fully backwards compatible and intermateable allowing for system upgradeability and customization.

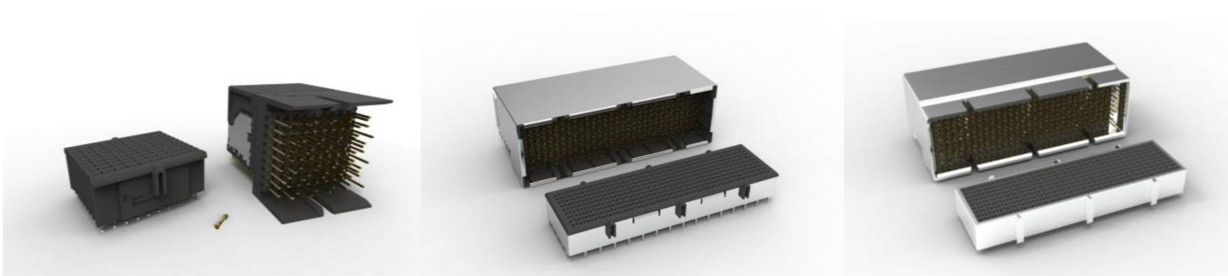

Figure 9. The Fortis Zd connector is available with three shell options- plastic, metal shield, and machined metal shell- to meet a variety of electromechanical protection needs. All options are backwards compatible and intermateable.

Because the Fortis Zd connector system is based on the existing Z-PACK connector architecture, it can use existing guidance and keying hardware as well as power, RF, and fiber optics modules. Together with the repackaging of existing products, and with new products such as Fortis Zd, designed from the ground up to meet harsh military applications, TE Connectivity will provide customers with products capable of years of reliable operation in extremes of operating temperature, shock, vibration, and corrosive atmospheres, enabling the technology that provides our armed forces with unprecedented capability to see, engage, and defeat the enemy on today's and tomorrow's battlefield.

References

[1] Curtiss Wright Embedded Computing, cwembedded.com, "Ruggedization Design Overview."

[2] Mercury Computer Systems, Technology Brief, "Tactical Smart Processing: Process, Exploit, and Disseminate the Power of Persistent Surveillance Directly from Sensor to Tactical User."

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