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Beyond Speed: Design Tradeoffs with Fiber-Optic Cable

Electronic Design
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Fri, 2016-03-11 10:31

The one word that usually comes to mind when the topic of fiber-optic cable comes up is "speed"—the kind of blinding speed needed in high-performance computing for within-box processing as well as between-box communications. Fiber optics has been adopted as the basic clay of the telecommunications and commercial IT industries, not to mention thousands of miles of high-performance optical networks currently connecting corporations and research institutions around the world.

Aerospace and defense has begun to embrace fiber-optic designs, particularly airborne applications, with naval and ground mobile also coming on board. While the technical need for fiber is driven by high-speed processing, fiber optics offers other benefits aside from simple speed, some of which pack a significant punch in aerospace and defense applications. These benefits do, however, require expertise in the handling of fiber-optic cable in order to prevent difficult-to-diagnose failures.

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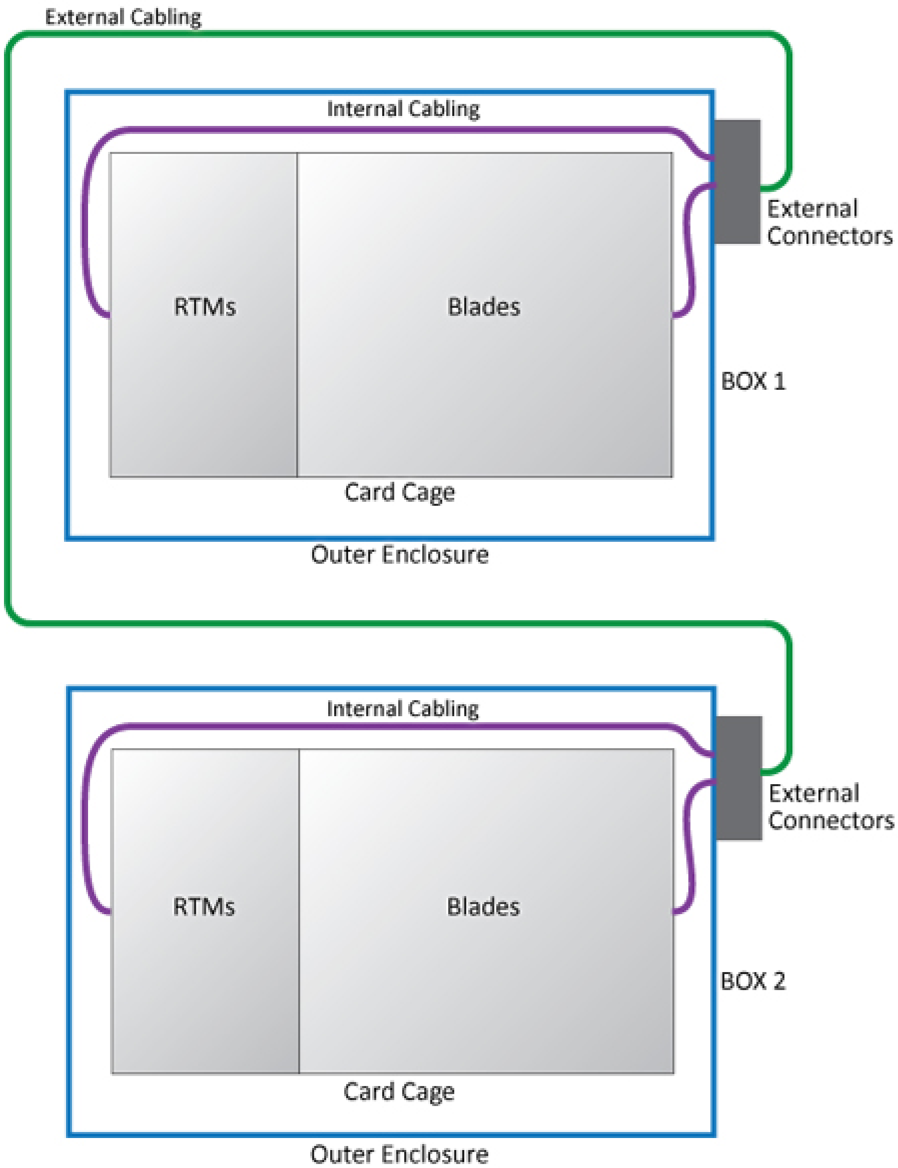
Airborne applications were among the first to adopt fiber-optic-based design. In such an environment, weight, reliability, and immunity from electromagnetic interference (EMI) are critical concerns. And given the use of airborne platforms in graphics- and processing-intensive Command, Control, Communications, Intelligence, Surveillance, and Reconnaissance (C3ISR) functions, any enclosure must be designed to support extremely high-performance computing.

Within each enclosure are multiple blades and rear transition modules (RTMs), most with internal I/O that must be externalized via connectors on the chassis. Of course, separate enclosures must be cabled to one another as well.

Counting the within-chassis cabling (approx. 2 ft.), the between-chassis cabling (approx. 20 ft.), and all external connectors as "cabling," and focusing on the comparison of 1 Gigabit Ethernet over copper versus fiber, results in some interesting points of comparison between the two. The cables under comparison consist of single-mode, loose-structure, pull-proof optical fiber that will support 12 Ethernet connections versus copper Quadrax, supporting six Ethernet connections.

Costs vs. Weight: Benefits and Tradeoffs



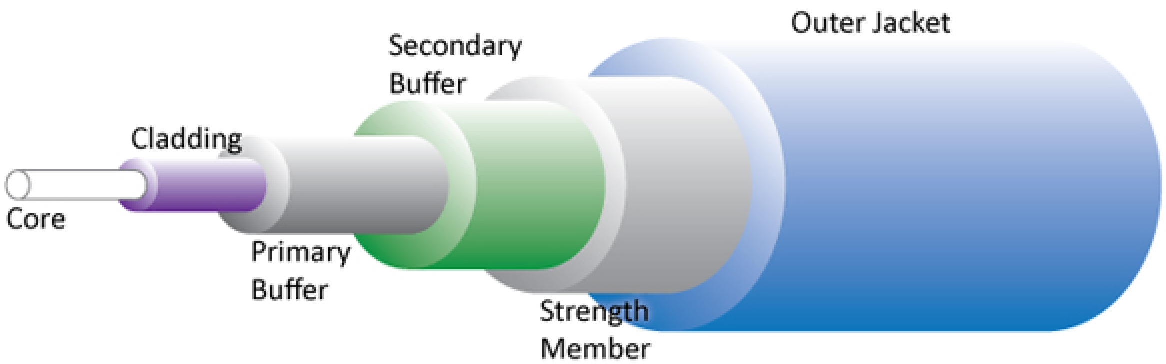
To compare the overall costs of providing 12 Ethernet connections from the boards in a hypothetical Box 1 to those in Box 2 *(Fig. 1)*—including cabling and all connectors—via optical fiber versus Quadrax, a few basic assumptions must first be made. First, for shorter cables, little cost difference exists between optical fiber and Quadrax; however, fiber becomes more expensive for longer runs. Regarding the connectors, while fiber connectors are more expensive than Quadrax, they also support a higher density. In addition, Quadrax connectors must provide strain relief due to the greater weight of the cables. Consequently, the within-box costs are roughly the same; however, the costs between boxes run up to 35% higher for optical fiber.

When considering the weight savings in the same configuration, though, the reasons to opt for this increased cost become obvious, particularly in airborne and other weight-sensitive applications. While connector weights are roughly the same, the optical cable itself is significantly lighter than Quadrax. Such weight economy also has the added benefit of making optical fiber much less prone to the chafing that arises due to vibration, which can significantly impact Quadrax.

And “significantly” lighter is no exaggeration: Between two similar systems cabled with Quadrax and optical fiber, the Quadrax solution would weigh 16.4 lb., and the fiber-based solution a mere 2 lb. Thus, fiber is 12% the weight of Quadrax—not 12% lighter, but *12% of the total weight of the Quadrax solution*. With weight savings this, it's easy to see why fiber-based designs have been so widely adopted in airborne applications ahead of ers, and why they're making inroads into naval and ground mobile applications as well.

Optical Cable 101: Handling, Routing, Bend Radius

However, once it's decided that the benefits of optical cable are worth the investment, fiber-specific routing and handling expertise is required to ensure that the resulting system enjoys the performance, serviceability, and long-term reliability required by military applications. Providing strain relief and minimizing chafing for Quadrax, and minimizing bend radius for optical fiber, are of paramount concern. There's also a great deal more industry experience with Quadrax, whereas optical fiber is in many cases still a relatively new technology.



In addition to understanding some basics of handling fiber-optic cable, including the use of pull-proof connectors with loose-structure cable and non-pull-proof connectors with tight-structure cable, where tight and loose are defined as whether movement is permitted between the outer jacket and the strength member *(Fig. 2)*, there's also the all-important consideration of bend radius. While this is a concern for Quadrax cables, too, it's a far greater one for the more delicate optical cable because time-to-failure decreases precipitously with increasing bend stress. Much of this can be ameliorated with the addition of service loops, along with a scrupulous adherence to maintaining the fiber bend radius larger than one inch during installation in addition to final dressing and operation.

However, there's more than one way to "bend" a fiber, and both installation and thermal cycling can result in internal stresses within the cable that create compression "ripples." In other words, multiple bends may occur within the body of the cable of extremely small radius, which greatly increases the possibility of cable failure.

When an optical cable is seated against the face of a connector, the face of the cable core and cladding will be pushed into the body of the cable by a very small amount, on the order of millimeters, at both ends. Moreover, When an optical cable is subjected to thermal cycling, swinging back and forth between the extremes of its operating temperatures, this can cause the cable jacketing to shrink slightly. In both cases, the end result is an optical cable where the core and cladding has become compressed within the jacketing and is not free to move in a manner that would relieve the stress. This increases light loss across the fiber and heightens the chance for what's called a "blocked cable failure" *(Fig. 3)*.

These issues can be addressed via thermal preconditioning (cycling a pre-cut length of fiber multiple times between its anticipated operating temperatures to stabilize the jacketing shrinkage), the use of service loops, and limits placed on the restriction of fiber movement. Lastly, the use of an optical backscatter reflectometer can also return useful information about the internal structure of a fiber-optic cable, including very small compression-caused bends within the jacket.

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