It has been about 50 years since the groundwork was laid for transmitting light in glass fibers, and about 40 since the commercialization of the laser. Glass-drawing breakthroughs made fiber optics practical back in the 1970s. Photonics now seems ubiquitous. So why don’t we see more of it in aerospace?

In truth, it is there, but in forms and for reasons that are not what most people expect. Guided-wave photonics has a long, but low-profile, history in aerospace. Even before the breakthroughs that made long-distance fiber optics practical, aerospace engineers were trying to use photonic systems. There were many perceived benefits, but there were also many difficulties that caused aerospace photonics to have a long, quiet development. The reasons for the delay are rooted in expectations and assumptions. To increase the penetration of photonics in the aerospace market, suppliers must concentrate on the benefits from the aerospace point of view.

Benefits of Light

From the start, aerospace and telecom differed in what they wanted from photonics. For telecom, bandwidth is key. For aerospace, the greatest attraction of photonics is the safety provided to fueled aircraft, followed closely by electromagnetic interference (EMI) immunity. High bandwidth is a benefit, but mostly in the context of its ability to reduce system weight.

Safety benefits come in two forms: safety improvement by the elimination of spark hazards, and safety improvement through robustness. EMI immunity is related to safety, but also to cost. Remember, photonics technology is not intrinsically EMI immune; or, rather, fiber-optic technology is immune, but optoelectronic technology is not. To achieve the benefits of EMI immunity, the system designer must protect the optoelectronic components. Even with that requirement, though, photonics can improve safety and reduce costs, for it is easier to shield a few boxes than to shield the entire network. Also, recurring costs are reduced, and long-term safety enhanced, if one eliminates difficult inspections of cable shield integrity required by electrical systems.

In aerospace, bandwidth has only recently become important for its own sake. For many years, vehicles did not need the ability to move large amounts of information. Instead, bandwidth was a way to reduce weight. This came into play only if enough low-speed signals were gathered to take advantage of the bandwidth benefit, which in turn required new networks. To be practical, the weight, volume, and cost of the added photonic components had to be less than the corresponding parameters for electrical networks.

Today, processor speeds and memory sizes allow new avionic functions. Those new functions demand photonic-level bandwidths, though the levels are still far below those required by leading-edge telecom networks. In aerospace, a system with an aggregate bandwidth of 10 Gb/s over a wide temperature range is more useful than a 40 Gb/s system that requires precise temperature control.

Aerospace Versus Telecom

With the many benefits offered by photonics for aerospace applications, one could ask why it has taken so long to be applied. The reasons lie in the nature of the aerospace application, and in the impact of the small aerospace market on costs.
The physical environment significantly impedes aerospace photonics, but the effect is not uniform (see table). For cable plants, much of the aerospace environment is not dramatically more severe than for telecom. Operating temperature range, vibration, and shock are worse, and fluids are different. In areas such as freeze/thaw, however, telecom requirements are as harsh as those for aerospace. Consequently, aerospace cable-plant components are tested according to industry-established testing procedures. Many testing protocols resemble MIL-STD-810 and MIL-STD-1344. The most important parameters to test are system response to thermal cycling, thermal shock, vibration, mechanical shock, fluid immersion, humidity, EMI, radiation, contamination, and, especially, handling.

In terms of connectivity, aerospace and telecom needs are similar. Networks for both often feature many nodes. The available technologies differ, however. Singlemode connectors are difficult to use in aerospace, for example, which complicates optical amplification. The different usable technologies mean connectivity approaches differ. With the exception of singlemode connectors (which are almost ready), cable-plant solutions that tolerate the aerospace environment exist. Difficulties remain for active devices, however. Commercial devices require tight thermal control for optimal performance. In general, though, it is not practical to closely control temperature on a vehicle. As a result, only rarely can an aerospace engineer find a commercial system that can tolerate the aerospace environment. Experience has shown that the most effective approach is to put individual commercial parts into units, such as boards, that will work for aerospace.

**Failure and Cost**

In terms of failure, there are significant differences between aerospace and commercial applications. Failures in aerospace often lead directly to safety problems. In contrast, telecom failures can lead to safety problems, but usually via a chain of secondary events. As a result of the impact of failure, aerospace systems have greater redundancy and fail-safe requirements.

Another difference between the two is that in the commercial arena, some failure modes are eliminated or ruled out by operating regulations that constrain usage. In aerospace, especially defense, engineers must assume that someone out there will be willing to break any rule. Aerospace designs must thus be robust against common and unusual failures and attacks. Today, in fact, hackers and terrorists are forcing the commercial world to start thinking as defense contractors have thought for generations.

Cost is a complex issue. Some aerospace products are commercial, but many are government-funded. As a result, the tradeoff between cost control and failure avoidance is unclear. Some observations are possible though. One is that telecom photonics comes from an environment in which the greatest cost is that of right-of-way. Such a model favors expensive optoelectronic components if they increase bandwidth and thus give the operator more value for the right-of-way. In aerospace, bandwidth is less important than the fact that a small network may require as many nodes as a campus.
The use of commercial off-the-shelf (COTS) components is necessary because the aerospace market cannot provide enough demand to justify the design of aerospace photonics from scratch. The problem is that commercial versions of sub-systems suitable for aerospace generally do not exist. Twenty years of experience have demonstrated the challenges of using COTS in aerospace applications. This situation opens up an opportunity for suppliers—not in the selling of COTS systems, but in the use of commercial pieceparts in COTS-derived systems that will meet aerospace needs. A significant factor in this model is that aerospace parts are used for long times. Support and upgrade contracts are valuable, and companies that provide them are valued.

The key for photonics suppliers trying to gain market share in the aerospace sector is to study the application requirements and address them. Throwing the technology du jour at aerospace customers is not the path to success. A few years ago, the second-graders at my son’s school had to produce projects about force for a special science event. My wife, son, and I built a 2-ft.-tall trebuchet. At Technology Night there were 15 computers displaying vaguely interactive projects about force, and one trebuchet throwing tennis balls 25 ft. down the hallway.

Guess which one the kids played with?

If the photonics industry gets to know its aerospace customers and addresses their needs, perhaps simultaneously springboarding R&D results from the aerospace to the commercial sector, everyone will benefit.

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Further reading

The armed services and civilian space programs share a growing need for increased communication bandwidth. The fighting forces are becoming highly networked in order to provide significant advances in situation awareness, system health management, real-time targeting, and command and control. Civilian satellite networks and autonomous deep-space spacecraft share these needs. Problems in space can lead to catastrophic failures and loss of life. Spaceborne platforms share the risks found in the industrial environment, for example, but without the advantage of readily available emergency facilities. Aerospace network designs must thus be robust against failures and attacks.

High-speed network architectures such as Gigabit Ethernet and Fibre Channel are readily available in the commercial marketplace. Some have been adapted for the more rugged aerospace applications, such as the Fibre Channel network being developed for the F/A-18E/F. This 1-Gb/s network uses an electronic switch fabric and fiber-optic links to route information among the mission computers, sensors, and displays. The ability of these electrically based switched networks to grow in capacity becomes difficult as the bandwidth increases beyond 1 Gb/s.

Wavelength-division-multiplexed all-optical networks (AON) using array waveguides provide an approach to scale these networks to tens of gigabits per second. The AON is used as a passive transport layer to allow different network architecture protocols such as Fibre Channel to run concurrently within the AON (see figure on p. 17). This permits each protocol to be optimized for its specific use. AON bandwidth growth can permit transmission of more than 40 Gb/s over each channel with a potential of 200 channels that can be switched in approximately 30 ns. This system is based off of commercial off-the-shelf (COTS) technology that needs to be repackaged for use in flight hardware. It is also possible to provide a robust self-healing optical network in both hard-lined and free-space systems using phase-conjugate techniques.

Designing for Space
Aerospace companies have been evaluating gigabit network protocols and photonic components for transmission of very-high-frequency radio-frequency waveforms. To gain insight for fielding the all-optical technology, they are performing medium-speed AON copper-versus-fiber trade studies, including fiber-optic cable plant characterization, transceiver evaluations, optical connector and contact evaluation, network market assessment, and link budget methodology.

The extreme environmental requirements in space present design challenges. There are significant differences between space and commercial terrestrial applications. The space environment can be extreme, from rapid thermal cycling to high radiation doses from solar flares. The most important parameters are thermal cycle, thermal shock, vibration, mechanical