ADVANCED FIBER-OPTIC COMPONENTS ENABLE NEW APPLICATIONS IN AEROSPACE AND DEFENSE

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Recent advances in fiber-optic technology have led to a growing demand for optical data links and sensors in aerospace and defense applications. In comparison with copper-based data links, which have been deployed extensively in military applications, fiber-optic data links offer a number of advantages such as high bandwidth-to-weight ratio, increased immunity to electromagnetic interference, high tolerance to vibration and mechanical shock, minimal spark or fire hazard, and improved performance. In this article we will look at some of the benefits and limitations of traditional fiber-optic components for aerospace and defense, how new Planar Lightwave Circuit (PLC) technology is revolutionizing this market, and how PLC technology is being deployed in next-generation systems.

The design of new military and aerospace vehicles imposes many restrictions on size and weight of components, while also requiring many more embedded sensors for monitoring the condition of the airframe and critical systems. The routing of these systems is significantly complicated by the available space and weight allowance inside the vehicle structure.

New materials have also affected the way modern vehicles are manufactured. Advanced composite materials are becoming commonplace in modern vehicles. While these materials can save a lot of weight, they are effectively transparent to electromagnetic energy like radio waves. These vehicles can therefore be more susceptible to electromagnetic interference than the more traditional metal structures which acted in part like a Faraday cage to partially protect the electronics inside.

Shipboard communication networks have also evolved dramatically in recent years. The communication infrastructure found on many ships is now more comparable to what previously might have serviced an entire city. While legacy systems might have run at 155 Mb/s, new shipboard technologies can pack 10 or more channels on a single optical fiber, each channel supporting 10 Gb/s. Fiber-based optical networks offer a number of significant advantages for defense and aerospace applications over conventional copper-based networks. It has been demonstrated that optical links have the capability to transport mixed digital and analog signals at speeds in excess of 10 Gbps, compared to 100 Mbps which is more typical of copper connections. Along with higher data rates, optical fibers can also transmit light with losses as low as 0.2 dB/km, which is effectively lossless for most ship and aircraft applications, allowing power budgets to be kept low. Traditional fiber-optic components have some limitations in aerospace and defense applications, but in this article we will look at how Planar Lightwave Circuits are poised to displace incumbent technologies in many present and future applications.

THE STRENGTHS AND LIMITATIONS OF FIBER-OPTICS

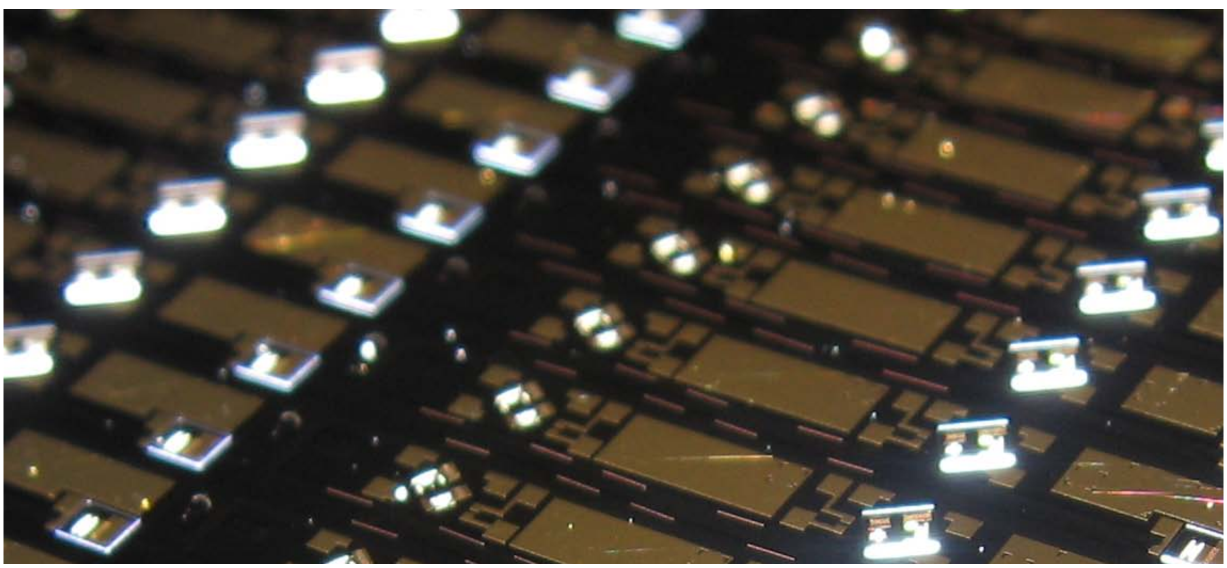
Fiber-optics allow the use of Wavelength Division Multiplexing (WDM) technology, where many different channels can be transmitted down the same fiber by sending them on different colors (or wavelengths) of light. This can significantly reduce the size, weight, and complexity of cable routing.

Since only light signals are traveling along these optical fibers, they are effectively immune to electromagnetic interference. Moreover, optical fiber presents no spark or fire hazard, and can even be routed alongside or through fuel bays if required.

One of the most significant drawbacks of fiber-optics has been the reliance on traditional micro-optic assemblies used in most applications to date. Virtually all optical components to date have been built using miniature lenses, filters, and other optical components that are aligned by hand and glued in place. There are several potential issues with this approach.

First, the labor involved with aligning these micro-optic components is a very significant portion of the cost, which has resulted in nearly all this assembly being done overseas. Also, many piece parts epoxied together presents a risk of a sub-component being knocked out of alignment in harsh environments, high vibration, or mechanical shock. This is particularly important in aerospace applications where vibration or shock up to 20 g acceleration are not uncommon. Finally, the amount of functionality that can be included in a single optical module is significantly limited by the shear number of sub-components that can be reliably aligned in a single package.

Planar Lightwave Circuit (PLC) optical-chip technology addresses all of these shortcomings. This PLC platform collapses many of the same optical functions onto a silicon chip. Custom optical circuits can be designed and developed for virtually any application. These optical chips look visually similar to their electronic chip counterparts, as shown in Figure 1, and are in fact fabricated using very similar processes. However, along with the typical electrical connections found on any silicon chip, these PLC chips also have optical connections that receive or transmit signals optically into and out of the PLC chip.



[Figure 1 | Similar to their electronic counterparts, optical chips are fabricated on silicon wafers, making them small, lightweight, and rugged.]

This optical chip is housed in a small package designed for soldering onto a common printed circuit board. The result is a very compact, lightweight optical module that is effectively a single chip when assembled, minimizing any chance of parts becoming misaligned during high vibration or shock. A complete bi-directional transceiver capable of transmitting and receiving data at 2.5 Gb/s can be integrated on a chip that is smaller than 4 x 10 mm, weighing less than 5 grams. These chip-based transceivers can withstand harsh g-forces, including sinusoidal vibrations with amplitude of 20 g acceleration, followed by mechanical shock of 500 g acceleration. The components are capable of temperature cycling through a range of more than 125^{o} Celsius.

PLC'S DELIVER FUNCTIONALITY NOT POSSIBLE IN OTHER PLATFORMS

While virtually any optical function can be integrated on the silicon chip, in some cases a hybrid approach is advantageous, where small chips are also integrated onto the PLC platform. For example, very high-performance lasers can be fabricated in indium phosphide and integrated onto the PLC as part of a hybrid approach. This allows the optical chip to provide state-of-the-art performance, leveraging different material systems as needed.

All of this hybrid integration can be accomplished using robotic pick-and-place machines typically used for electronic assembly. These customized machines can bond a new chip every 20 seconds, with extremely good repeatability, making them ideally suited for volume production. Equally important, this approach requires very minimal hands-on labor, allowing these products to be manufactured domestically rather than overseas.

The photonic integration technology allows the development of ultra compact and lightweight communication components such as optical transceivers. Optical transceivers are essential components in fiber-optic communication systems. They contain both a transmitter and a receiver in a single housing, and can carry upstream and downstream mixed digital and analog signals through a single fiber.

At present, the optical transceivers designed and produced for aerospace and defense applications are built using traditional micro-optic technology. The complexity of assembling a large number of critically aligned micro-optic components in a single hermetic package makes these transceivers expensive and susceptible to failure in harsh military applications.

Planar Lightwave Circuit technologies have the capability to deliver outstanding improvements in the reliability and cost of optical transceivers, and represent a major step forward in aerospace and defense communication systems.

EARLY APPLICATIONS IN AEROSPACE AND DEFENSE

As an example, this rugged PLC platform is ideally suited for the development of multichannel redundant transceivers. Photonic technology originally developed for the telecommunication industry has been leveraged to combine multiple signals at different wavelengths onto a common fiber, using proprietary filtering technology that is integrated into the PLC chip, requiring no external filters or lenses. If one transceiver fails, the others still provide support for critical avionics systems. The transceiver shown in Figure 2 is capable of 2.5 Gbps transmission, while simultaneously receiving downstream traffic at 2.5 Gbps, while also receiving analog video signals on a third channel.

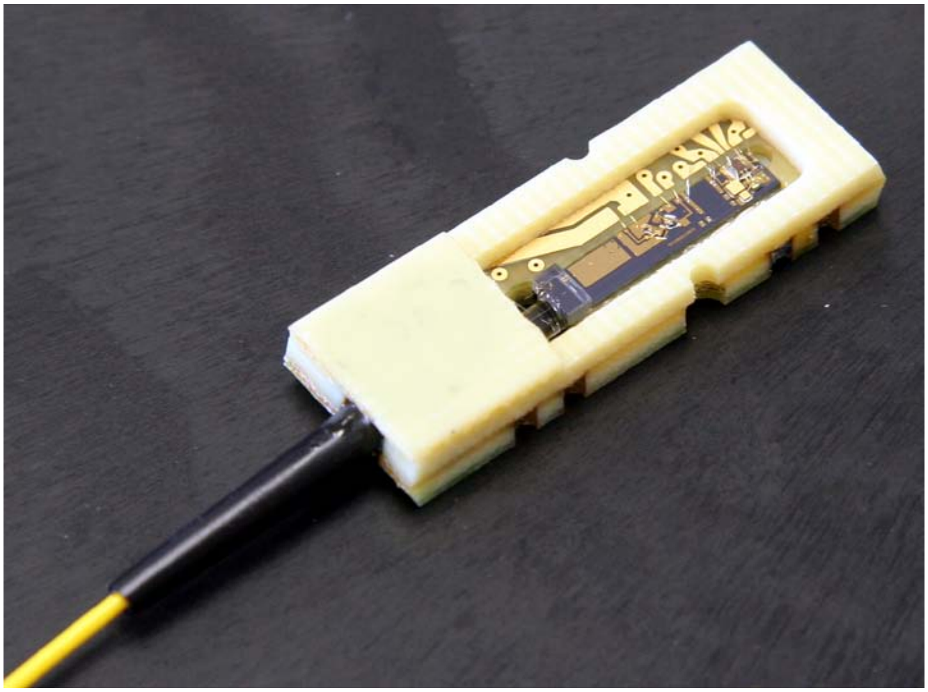


Figure 2 **|** *A compact, lightweight, bidirectional optical transceiver that can transmit and receive simultaneously at 2.5 Gbps, while also receiving analog video signals at up to 1 GHz on a third channel.*

This transceiver is packaged in a very compact housing, and designed for easy mounting and soldering onto a standard printed circuit board. This transceiver module was originally developed for use in Unmanned Aerial Vehicles (UAVs), although it has since been customized for a number of other applications.

While the transceiver shown in Figure 2 supports three channels each running at up to 2.5 Gbps, some applications require even more capacity. The very flexible PLC platform is fully scalable in both channel count and data rate. Enablence Technologies manufactures PLC-based multi-channel receiver modules that include an 8-channel wavelength division multiplexer, and 8 receiver channels each running over 10 Gb/s, all integrated on a silicon platform. This receiver module, along with a matching transmitter module, is designed to form the basis of a shipboard communications network. Even more of the manufacturing efforts at Enablence are focused on custom modules unique to specific applications.

THE FUTURE OF OPTICAL COMPONENTS

In this article we have looked at some basic examples of optical modules that can be developed based on Planar Lightwave Circuits. It is not uncommon for these modules to be significantly more advanced, often containing dozens or even hundreds of optical elements on a single chip. This level of functionality is typically not even feasible using more traditional optical platforms, and is opening up new applications for fiber-optics in aerospace and defense applications, including communications, sensors, and monitoring. When reviewing some of the strengths and limitations of traditional fiber-optics, it becomes clear how PLCs are poised to displace these technologies in present and future defense applications.

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