

The Challenge in Packaging Microelectronics and Optoelectronics

Rick C. Stevens, Fahad M. Siddiqui, Brian L. Uhlhorn, Kevin J. Thorson

Lockheed Martin

3333 Pilot Knob Road

Eagan, MN 55121

651-456-3118, rick.c.stevens@lmco.com

Abstract

The bandwidths needed for military tactical aircraft mission systems mandate the use of fiber optic interconnects. Without these optical interconnects system capability would be degraded due to the Size, Weight and Power (SWaP) burden of electrical interconnects versus optical interconnects. However, along with the many benefits of fiber optic based communication (bandwidth, weight, EMI immunity, scalability, protocol independence, etc.) come unique microelectronics and optoelectronics packaging challenges. Connecting the optical chips that perform the electrical-to-optical (laserdiodes) and optical-to-electrical (photodiodes) conversion to the system require unique design considerations. Additionally, these designs depend on materials and process steps that address the optical coupling requirements that are beyond what is necessary for electrical designs. This paper will describe a military qualified multimode multi-channel optical transceiver design that has been fielded in military tactical mission systems and how the design compares and contrasts to non-optical microelectronics designs.

Keywords: Packaging, microelectronics, optoelectronics, fiber, optics, copper, military

1.0 Introduction

The need for high bandwidth, high quality communication solutions have become essential in the military environment. Fiber optics have been replacing copper solutions more frequently as the requirements for bandwidth, size, weight, EMI, and power have been becoming an issue. However, the use of optoelectronics is not without their own challenges, especially in the military environment. These challenges include meeting requirements in packaging, temperature, size, environmental durabilities, as well as issues with alignment, out of plane optical routing, and temperature performance sensitivities.

The purpose of this paper is to explain why the use of fiber optics is a necessity, discuss the challenges faced working in the military environment which may not occur in the commercial

world, and present solutions that have been developed for this very purpose. After reading this paper, one will have a good understanding of what to expect when working with optoelectronics in a military environment.

2.0 Need for Optoelectronics in the Future

As communication systems become more complex and demanding, the uses of copper-based interconnection methods are reaching their limits. Systems are requiring higher bandwidth and travelling longer distances while requiring reduced weight. Copper cabling cannot carry much more than 10 gigabits per second (Gbps), while fiber optics can carry hundreds of gigabits per second on one line. Additionally, copper cabling loses much of its signal strength after 100 meters in length, while fiber can carry 1000 meters without much loss. In

addition to this, fiber optical cables do not have the Electromagnetic Interference (EMI) issues that copper cabling has, and transmitting through fiber can also be considered more secure.

2.1 Weight and Bandwidth Comparison

One of the greatest benefits of using optical devices instead of copper-based electronics is the substantial weight and bandwidth differences. A majority of this is due to the weight of cabling, where one fiber optic cable is roughly one-third the weight of a typical copper cable. Additionally, as bandwidth requirements increase, bulkier copper cables are required, but the weight of fiber cables do not change by a great amount. So the higher the bandwidth is, the greater the weight difference between copper and fiber cabling [1].

When comparing a simple copper-based network with a fiber-based one, the weight differences become obvious. In the sections below, copper-based and fiber-based setups are compared at 1 Gbps and 10 Gbps in order to get an idea on how large this weight difference is with respect to bandwidth. Considering each network is comprised of a transceiver on each end, and cabling sufficient for one transmit and one receive with each cable being 10 meters long, the comparison is made.

2.2 System Weight at 1 Gbps

The copper-based transceiver used for the 1 Gbps comparison was the Linksys MGBT1, which weighs 18 grams per device [2], and requires a CAT 5 cable to carry the transmit and receive signals. A 10 meter long CAT 5 cable is roughly 288 grams. Since two transceivers would be used, the total weight for this system would be 324 grams.

The fiber-based transceiver used was the Cisco SFP-GE-S [3], which weighs 17 grams per unit. Two fiber cables, in this case the FlightGuide fiber optic cable, weighing 40 grams each were required. The two transceivers and two cables weighed out to be 230 grams.

2.3 System Weight at 10 Gbps

The copper-based transceiver used at this bandwidth range was the HP J8440A [4], which had a weight of 80 grams. This transceiver supports a CX4 cable, which weighs about 576 grams. The weight of the transceivers and cable total up to 736 grams.

The fiber-based transceiver chosen for the 10 Gbps comparison was the D-Link DEM-422XT [5]. This device weighs 68 grams per unit. The same fiber-optic cables used in the 1 Gbps comparison can be used for this test, which were the FlightGuide cables at 40 grams each. Totaling up this hardware gives a weight of 216 grams.

2.4 Comparison Results

Table 1 below summarizes the results of the comparisons done above.

Table 1: Weight comparison of copper and fiber-based cabling with transceivers.

Data Rate	Copper System	Fiber System
1 Gbps	324 g	230 g
10 Gbps	736 g	216 g

Although the table shows that the total weight of the fiber-based system went down as the data rate went up, this is only due to the different devices chosen for the comparison. If Table 1 is broken down further, one can see that the major difference lies in the cable weights (Table 2).

Table 2: Weight comparison of copper and fiber cabling.

Data Rate	Copper Cabling	Fiber Cabling
1 Gbps	288 g	80 g
10 Gbps	576 g	80 g

Finally, Figure 1 shows the benefits in using fiber over copper as a percentage over cable length in meters. You will see that the benefit of using a fiber

cable at 1 Gbps is about 72% better, and at 10 Gbps it is 86% better. As the distance between transceivers increase, the weight of the transceivers become less significant in determining the better solution.

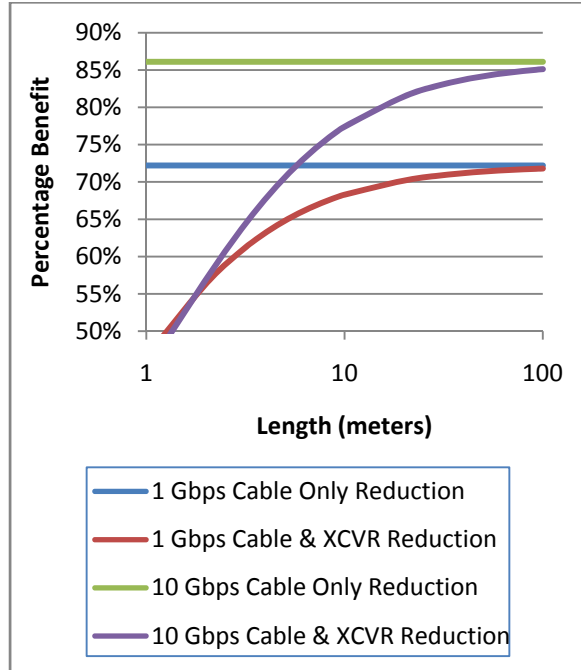


Figure 1: Percentage Benefit of Fiber over Copper with respect to length.

3.0 Challenge in Packaging

Many optoelectronic products exist in the marketplace today. Although several currently available optoelectronic solutions are adequate for the commercial marketplace, such is not the case in the military environment. The primary focus of this paper will be optical transceivers, where many commercial solutions exist, but very few transceivers exist which meet military standards. While commercial transceivers perform well for commercial telecommunication systems, they are not subject to the stringent requirements that military aircrafts, ships, and facilities have. For this reason, specialized packaging needed to be developed.

In the military environment, namely in avionics, devices are subject to extreme temperatures, shock and vibration, and limited space. This can result in performance issues, misalignment, size, and space

constraints. All of these issues need to be accounted for as performance and reliability is critical in avionic systems. For this reason, custom packaging and design enhancements were incorporated to ensure the reliability of the products being developed.

3.1 Anatomy of an Optical Transceiver

An optical transceiver consists of a transmitter and a receiver. The transmitter portion includes a VCSEL driver and a light source, while the receiver portion includes a photodetector, and a transimpedance amplifier (TIA). Optical transceivers commonly use vertical cavity surface-emitting lasers (VCSELs) as a light source, where the light source driver, or VCSEL driver, drives current through the transmitter. The electrical signal is converted into an optical signal, and sent through fiber optic cables in an interconnected system via a VCSEL array. On the other end of the interconnected system would be a photodetector, or PIN diode array, which detects the laser signal and excites a current into the TIA circuit.

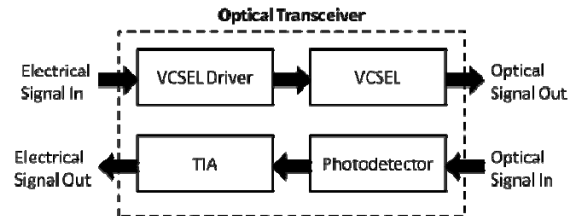


Figure 2: Block diagram showing signal flow within an optical transceiver.

3.2 VCSEL and PIN Diode Structures

The advent of VCSELs have greatly reduced the costs associated with manufacturing and testing of lasers. When VCSELs are created on a Gallium Arsenide (GaAs) wafer, the functional and defective devices can be separated without first cutting the individual lasers from the wafer (Figure 3). This greatly reduces the labor costs in production. PIN diode arrays work in the same manner as VCSELs, except on the receiving end [6].

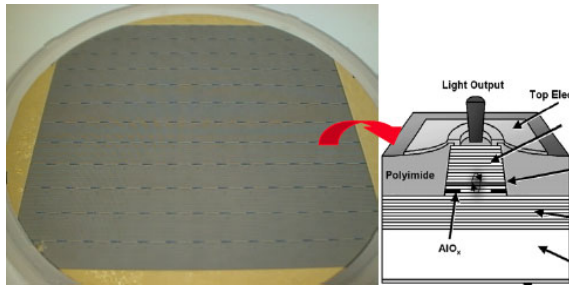


Figure 3: A wafer containing several thousands of VCSELs [7].

3.3 Packaging Height

Tactical avionics require that military electronics have packages which have a low profile package height on board their systems. Many commercial transceivers fail to meet this height requirement. In general, the problem with using VCSELs is when a VCSEL array is mounted on a printed circuit board, the laser emits vertically. A means of capturing the light and redirecting it is necessary, especially when one wishes to send the laser output parallel to the surface of the circuit board. Similarly on the receiving end, the PIN diode structure is meant to receive light vertically.

In order to reduce the packaging height, it would have been ideal if the VCSELs and photodiodes were transmitting or receiving horizontally instead of vertically. One manner of bending the light perpendicular to its source is by using a 45° lens placed above the VCSEL array or PIN diode structure [8]. A strategically placed lens would then reflect the light into the desired location, without much loss. The problem with this method is that it requires a very stable setup. Shock and vibrations could cause intermittent connections, and would not qualify for military avionics.

The other method, which was used in the design described in this paper, is by using a flexible assembly. This flexible assembly would contain electrical components, electrical traces, and a VCSEL or PIN diode array on the end of the assembly. The flex assembly itself would be bent 90°, and the end with the VCSEL array would then typically be attached to an MT connector (Figure 4), which would

then send the optical signal through the fiber optic cable [9], [10], [11].

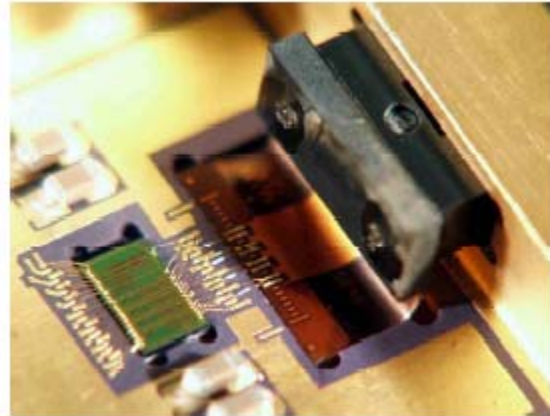


Figure 4: Flex assembly attached to MT connector.

3.4 Alignment Issues

Proper alignment of a VCSEL or photodiode array with an array of optical fibers can be a challenging task. Proper alignment is critical in the military environment, and the tolerance in variation is very small. Additionally, military specifications require that the bit error rate (BER) of a communication device be 10E-12 or better. This means that the system needs to be error free for every 10E12 bits sent, so a system running at 2.125 Gbps, the system needs to remain error free for approximately 8 minutes. In order to withstand harsh environments, a rugged design needed to be established in order to ensure that connectivity was kept intact while withstanding unforgiving combat situations.

In order to properly align and maintain a firm connection between the VCSEL or diode array and the optical fibers, a passive optical alignment technique is used to position the optics at the correct angle and spacing required for the optimum alignment and minimal attenuation and variation of the optical signal [9], [10], [11].

3.5 Operating Temperature and Sensitivity

Another major issue lies in the operating, or case temperature of the optical transceiver. Military standards require an operational range of

-40°C to +85°C, while most commercial transceivers are not meant to be operated below 0°C. Part of the reason for this is because it is difficult to maintain the required BER, or optimal eye pattern (Figure 5), below 0°C. One drawback in using optoelectronics is the fact that optical circuitry changes signal output with a change in temperature. This is especially the case in VCSELs. Some VCSEL drivers have temperature compensation [12], but most of the time even this does not work below 0°C. For this reason, a method to regulate the bias and modulation currents of the VCSEL driver needs to be established over the desired temperature range. One way to overcome this is by use of a microcontroller and an on-board temperature sensor. At certain temperature points, the bias and modulation currents are modified to give the optimal eye pattern and power level.

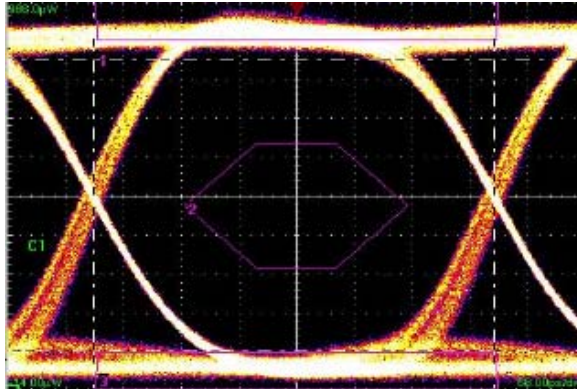


Figure 5: Optimal optical eye pattern.

4.0 Commercial vs. Military Transceivers

The following section will elaborate on different commercial transceivers available on the market, and why they are or are not suitable in the military environment. Following this, a military transceiver will be described, and how it differs from commercial devices.

4.1 Commercial Transceivers

Most of the commercial transceivers are either available in small form-factor pluggable (SFP) or 10 gigabit small form-factor pluggable (XFP) format. These do not meet the package height requirements or case temperature requirements for tactical avionics. Table 3 shows a few commercial transceivers available on the market. The transceivers shown in Table 3 make use of VCSELs to transmit a multimode signal at a wavelength of 850 nm. They do not meet the temperature requirements of -40°C to +85°C, nor do they meet the height restriction of 0.200 inches.

4.2 Military Transceivers

The military transceiver defined in Table 3 is specifically designed for severe conditions. The internal components, including the VCSEL driver and receiver, are commercially available components which have gone through testing to ensure that they

Table 3: Comparison of various commercial transceivers with a military transceiver. Cells in green meet military standards, while cells in red do not.

Transceiver Type	Commercial				Military
Manufacturer / Part Number	Agilent HFBR-5911L [13]	Optech OP6F-MX1-85-IM [14]	Avago AFBR-79Q4Z [15]	Emcore QTR3500 [16]	Lockheed Martin 7394140 [17]
Number of Channels	1	1	4	4	4
Operating Temperature	0°C to +85°C	-20°C to +85°C	0°C to +70°C	0°C to +70°C	-40°C to +85°C
Bandwidth (Gbps)	1.25	4.25	10	5	2.125
Wavelength (nm)	850	850	850	850	850
Package Height (inch)	0.39	0.33	0.50	0.59	0.20

function in the conditions required by military requirements. As you can see, the operating temperature meets the requirements of -40°C to $+85^{\circ}\text{C}$, as well as the maximum height of 0.200 inches [17].

5.0 Conclusion

A wide variety of interconnection products are available on the market today. The largest determining factors in using optical as opposed to electrical only copper networks are bandwidth limitations presented by copper cabling, and the overall additional weight in copper-based networks. As more efficient methods of interconnection are being developed, fiber optics are becoming the standard in networking systems.

However, a number of initial design considerations need to be made in order to use fiber optics in an interconnected network. In military environments, even further design considerations need to be made to address critical size, weight and power (SWaP) requirements. Even so, these additional challenges in the packaging of optoelectronics can be satisfied using the design techniques described in this paper.

Through all of this, fiber optics still remain the choice of the future, as conventional copper-based designs reach their limitations.



Figure 6: A commercial SFP transceiver [13].



Figure 7: A military small form-factor transceiver [17].

References

- [1] J.A. Kash, "Internal optical interconnects in next generation high performance servers", 2005 IEEE Conference on Avionics Fiber-Optics and Photonics, September 20-22, pp. 29-30, 2005.
- [2] Cisco Systems, "Linksys MGBT1 Gigabit Ethernet 1000 Base-T Mini-GBIC SFP Transceiver", <http://www.linksysworks.com/MGBT1.asp> (accessed August 24, 2009).
- [3] Cisco Systems, "Cisco SFP Optics for Gigabit Ethernet Applications", July 2009. http://www.cisco.com/en/US/prod/collateral/modules/ps5455/ps6577/product_data_sheet0900aecd8033f885.pdf (accessed August 24, 2009).
- [4] Hewlett-Packard Development Company, HP ProCurve 10-GbE X2-CX4 Transceiver (J8440B)", http://www.procurve.com/products/accessories/J8440B/accessory.htm?jumpid=reg_R1002_USEN (accessed August 24, 2009).
- [5] D-Link Corporation, "D-Link DEM-422XT 10GIGABIT XFP (10GBASE-LR)", <http://www.dlink.com/products/?pid=382> (accessed August 24, 2009).

- [6] D.J. Sterling, Jr., "Technician's Guide to Fiber Optics", Delmar Publishers, Third Edition, Albany, New York, pp. 107-108, 2000.
- [7] Furukawa Electric, "The World's Highest Electro-Optical Conversion Efficiency of 62% in Vertical Cavity Surface Emitting Lasers (VCSELs) Has Been Achieved", December 19, 2008. http://www.furukawa.co.jp/english/what/2008/kenkai_081219.htm (accessed August 24, 2009).
- [8] S.H. Hwang, D.D. Seo, J.Y. An, M-H Kim, W.C. Choi, S.R. Cho, S.H. Lee, H-H Park, H.S. Cho, "Parallel Optical Transmitter Module Using Angled Fibers and a V-Grooved Silicon Optical Bench for CSEL Array", IEEE Transactions on Advanced Packaging, Vol. 29, No. 3, August 2006. Pp 457-462
- [9] Sauter, "Vertical Cavity Surface Emitting Laser Array Packaging", U.S. Patent 6,056,448, May 2, 2000.
- [10] Kryzak, "Optical Array Chip Packages with Passive Alignment Features", U.S. Patent 6,322,257 B1, November 27, 2001.
- [11] Kryzak, "Passive Self-Alignment Technique for Array Laser Transmitters and Receivers for Fiber Optic Applications", U.S. Patent 6,685,363 B2, February 3, 2004.
- [12] IPTronics Inc., "IPVD12G011 Quad VCSEL Driver", Nov 2008. [http://www.iptronics.com/36327](http://www.iptronics.com/36327/IPVD12G011:%204%20channel) /IPVD12G011:%204%20channel (accessed August 24, 2009).
- [13] Agilent Technologies, "Agilent HFBR-5911L Small Form Factor Optical Transceiver for Gigabit Ethernet (1.25 Gb/s) and iSCSI Datasheet", February 14, 2002. <http://datasheet.digchip.com/021/021-03266-0-HFBR-5911L.pdf> (accessed August 24, 2009).
- [14] Optech Technology Co., Ltd., "Optech OP6F-MX1-85-CM Datasheet", January 5, 2009. http://www.optech.com.tw/UploadFile/Product_big/20093131011272591.pdf (accessed August 24, 2009).
- [15] Avago Technologies, "Avago AFBR-79Q4xZ 10G QSFP Short Wavelength Transceiver, Pluggable, Parallel-Fiber-Optics Modules Datasheet", February 23, 2009. <http://www.avagotech.com/docs/AV02-1794EN> (accessed August 24, 2009).
- [16] Emcore Corporation, "QTR3500 4-Channel 5 Gbps Infiniband DDR Multi-Rate Media Converter Datasheet", September 2006. <http://www.emcore.com/assets/fiber/pb.QTR3500.2006-09.pdf> (accessed August 24, 2009).
- [17] Lockheed Martin, "Data Sheet for Part Number – 7394140 4-Channel – 2.125 Gigabit Parallel Fiber-Optic Small Form Factor Transceiver." November 17, 2004.