Photonic Packaging for Space Applications

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Abstract

Industrial, NASA and DoD spacecraft designers have slowly but surely recognized the advantages of using fiber optic components and networks for their internal satellite data handling needs. The benefits include the total elimination of cable-to-cable and box-to-box EMI; significant size, weight and power reduction; greater on-orbit and I&T flexibility and significantly lower I&T costs. Additionally, intra-satellite data rates of 1 to 10 Gbps appear to be an absolute requirement for a number of advanced systems planned for development in the next few years. The only practical way to support these data rates is with fiber optics. Space Photonics' FireFiber™ components and networks are designed specifically to meet these onboard, high data rate needs using NASA approved materials, packaging processes and radiation tolerant devices.

Background: Spaceborne Data Networks

The bandwidth requirements of aerospace remote sensing payloads continues to push the demands of onboard data handling networks while cost pushes interface designs toward flexible, non-proprietary, open architectures and standards. Equally important, spacecraft data handling networks must support the real-time needs of the aerospace remote sensing environment. In order to achieve high data handling performance while maintaining low size, weight and power, onboard data handling subsystems not only must employ highly integrated components, but must also avoid unnecessary overhead functions associated with protocols found in most commercial networks. Additionally, spaceborne networks must be fault tolerant and able to withstand the rigors of launch and the harsh space environment.

Historically, high-end, high performance, commercially developed electronics have been slow to find a home on board satellites. This is due primarily to the difficulties associated with identifying and/or fabricating components that are tolerant to the radiation environments and meet the strict lifetime and outgassing specifications for spaceborne electronics [1]. In a similar fashion, high-end commercially developed optoelectronic systems have only slowly begun to migrate aboard spacecraft [2].

One of our core missions is to accelerate this migration of photonics into space systems by carefully leveraging advances in optoelectronic device technologies and by exclusive use of materials approved by NASA and the DoD. Our high speed, high performance FireFiber™ products, implemented using our state-of-the-art packaging processes, meet or exceed all requirements for space qualified applications. These fiber optic transmitters and receivers support link bandwidths from DC to 2.5 Gbps over link distances of up to 100 meters using space qualified multi-mode fiber [3,4,5]. This allows the use of fiber optic cable with cores of 50 to 100 microns. Thus, eliminating the need for the expensive, precision connectors associated with single-mode fiber optic cables with cores of 5 to 9 microns.

The Radiation Effects Branches of NASA, the Naval Research Laboratory, the Department of Energy and others, have accumulated a considerable amount of total dose and single event upset radiation test data on numerous photonic devices. The data shows that the physical layer devices (laser diodes, detectors, fiber) operating at or near 1300 nm provide the by far the best performance in space environments [2]. Additionally, the performance of these devices meets or exceeds the operational requirements for space qualified applications. Space Photonic's FireFiber™ products and processes use 1300 nm devices that have been tested by one or more of these agencies [1,4,6,7]. In addition, our components employ either a hermetic polyimide fiber coating or a NASA approved acrylate coating, both exceeding NASA's outgassing requirements. We also use space qualified multi-port connectors that have been designed and built specifically for fiber cable [3]. These multimode fibers have been demonstrated to be radiation hard with negligible increase in signal loss over a ten-year life in space radiation environments.

Fiber Optics in Space

Advantages of fiber optics for space applications over conventional twisted shielded pairs are well established; these include immunity to electromagnetic interference (EMI), reduced weight, and relative ease of integration [2]. But due to the very conservative approach to spacecraft systems design and assembly, very few missions have employed fiber optics. The few missions that have flown fiber have been limited in speed and utility, used primarily for command and telemetry. Of these missions, SAMPEX (1992), XTE (1996), HST (1997) were limited to 1 Mbps data rates. The MPTB experiment (1997) and MAP (2000) demonstrated operational data rates of 20 Mbps. Although limited in performance, these missions clearly demonstrated the cost effectiveness of fiber optic systems for space applications.

Component Specifications for Space

Although orbital environments vary, for our *FireFiber™* components we have selected a comprehensive set of requirements that provide full Level III qualification levels in accordance with IEEE-1156.4, the Standard for Environmental Specifications for Spaceborne Computer Modules, and IEEE-1393, the Standard for Spaceborne Fiber Optic Data Busses. These specifications are provided in Table I, with applicable references for conditions and test methods. As described in IEEE-1156.4, the radiation levels delineated in Table I assume that 100 mils of aluminum shielding are used. These specifications meet the requirements of Geosynchronous orbits and most Deep Space orbits, as well as all requirements for low earth orbit (LEO) and medium level (500 to 1200 km) orbits. However, for cost benefit, specific thermal cycling and radiation qualification requirements can be reduced for specific missions. For many Military applications, special testing is required, specifically for certain radiation environments. Table II delineates specific requirements for the optical fiber and connectors.

Table I: Space Qualification Levels for Space Photonic's *FireFiber*™ Components

PARAMETER	NON-OPERATING CONDITIONS	OPERATING CONDITIONS	STANDARDS, REFERENCES & TEST METHODS
Thermal/ Vacuum	-46°C to +81°C	-46°C to +71°C 1 Cycle, 144 hrs hot, 24 hrs cold, $\Delta T/\Delta t$ = 10°C/min	IEEE-1156.4 EIA RS-455-52 IEEE-1393
Thermal Cycles	-46°C to +81°C	-46°C to +71°C 200 up to 1000 Cycles $\Delta T/\Delta t$ = 10°C/min Attenuation rate <0.5 dB/km at 1300 nm.	IEEE-1156.4 IEEE-1393 EIA RS-455-52
Temperature shock		-46°C to +71°C $\Delta T/\Delta t$ = 30°C/min	IEEE-1393 DOD-Std-1678, method 4020,Test condition A
Outgassing		Maximum volatile condensable material content of 0.1 percent Maximum total mass loss of 1.0 percent	IEEE-1156.4 IEEE-1393 SP-R-0022 when tested in accordance with ASTM-E-595
Pressure	Sea Level to $5x10^{-6}$ Torr	Sea Level to $5x10^{-6}$ Torr $\Delta P/\Delta t$ = 100 Torr/sec	IEEE-1156.4 IEEE-1393
Relative Humidity	0 % to 95% Noncondensing	0 % to 95% Noncondensing	
Pyrotechnic Shock		30 G at 100 Hz, 3000G from 1 kHz to 10 kHz, 3 shocks per axis	IEEE-1156.4 IEEE-1393
Random Vibration		20 Hz - 0.125 G^2/Hz 50 Hz - 800 Hz - 0.8 G^2/Hz 2000 Hz - 0.125 G^2/Hz 3 min in each axis. Attenuation rate shall not increase by more than 0.5 dB/km at 1300 nm. Peak acceleration must be at least 20 g.	IEEE-1156.4 IEEE-1393 EIA RS-455-11
RADIATION	**TYPE**	**TEST LEVELS & DESCRIPTION**	
		After a total ionizing radiation dose of 10kRad(Si) (dose rate of 1300 Rads/min), the fiber attenuation rate shall not increase by more than 20 dB/km at 1300 nm over the attenuation rate due to other effects. The system shall operate when exposed to a proton flux of 10^5 protons/sq. cm.	IEEE-1393 EIA RS455-49
Total Radiation Dose per year	Trapped e- and p, heavy ion	30 to 200 krad(Si) per year *Special testing required for Military	IEEE-1156.4 IEEE-1393
SEE Rate	Non-Destructive	<$3x10^{-3}$ events per day	IEEE-1156.4
SEE Rate	Destructive	<$3x10^{-5}$ events per day	IEEE-1156.4
		30 to 200 krad(Si) per year *Special testing required for Military	IEEE-1156.4 IEEE-1393

Table II: Special Requirements for Optical Fiber and Connectors

OPTICAL FIBER	**DESCRIPTION**	**CONDITIONS & REQUIREMENTS**	**STANDARDS & TEST METHODS**
Type	1300 nm Graded Index Multimode	100 ± 3 microns Core 140 ± 2 microns Cladding 170 ± 2 microns Protective Hermetic Coating when required	IEEE-1393 EIA RS-455-58. EIA RS-455-45. EIA RS-455-55.
Performance		Cable lengths up to 200 m Attenuation < 5.0 dB/km at 1300 nm Numerical aperture shall be 0.29 ± 0.01	IEEE-1393 EIA RS-455-46 EIA RS-455-50,Pr.A
Dispersion limited bandwidth		400 MHz-Km at 1300 nm	IEEE-1393 EIA RS-455-30,54
Outgassing		Maximum volatile condensable material content of 0.10 % maximum total mass loss of 1.0 %	IEEE-1393 ASTM-E-595 SP-R-0022
Hermeticity		Fiber hermetically sealed when required. Hermetic coatings shall be 20 ± 5 nm.	IEEE-1393
Tensile Strength		Proof-tested tensile strength shall be at least 100,000 psi.	IEEE-1393 EIA RS-455-31
Life Requirements	Attenuation Aging Test 0° C to 110°C, 240 hours	Shall not increase by more than 0.5 dB at 1300 nm When returned to ambient temperature, the fiber coatings shall not be cracked or melted. No scratches, nicks, or inclusions in the stripped fibers or residual coating material on the stripped fiber which cannot be easily removed.	IEEE-1393 MIL-STD-202, method 8 EIA RS-455-31
CONNECTORS			
Attenuation		Maximum of 0.75 dB at 1300 nm	IEEE-1393
Reflection		Less than -40 dB	IEEE-1393
Connector Life	Attenuation & Aging Test 0° C to 110°C, 240 hours	Shall not increase by more than 0.25 dB at 1300 nm over losses attributed to the optical fiber or original connection	IEEE-1393 MIL-STD-202, method 8 EIA RS-455-31

Multi-Port Fiber Optic Transmitters and Receivers

Our packaging endeavors have focused on multi-channel fiber optic transmitters and receivers. Our first components were developed in cooperation with the University of Arkansas' High Density Electronics Center (HiDEC) producing 12-Channel multimode transmitters and receivers through Small Business Innovation Research (SBIR) funding from NASA's Goddard Space Flight Center (GSFC) and NASA's Jet Propulsion Lab (JPL), and other funding from DoD. HiDEC's facilities provide a wide range of multichip module (MCM) technologies, including advanced thin film, silicon and ceramic based packages. HiDEC also provides a full suite of test and development equipment for producing fully packaged MCMs from start to finish.

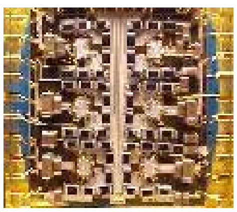
Our current development efforts utilize the HiDEC wafer and MCM production capability, while the final assemblies and fiber optic subassemblies are produced in Space Photonic's Class 1000 Clean Room. Electrical characterization is carried out at both HiDEC and Space Photonics facilities with test equipment for as high as 40 Gbps. Reliability testing is carried out in HiDEC's Reliability Labs. Vibration and radiation testing is carried out in cooperation with NASA/GSFC Radiation Effects and Analysis Group.

Wafer Fab in HiDEC's Class 100 Clean Room

HiDEC's Wafer Probe Testing

We utilize advanced laser and photodiode array devices and standard Silicon V-Groove fiber alignment techniques with NASA/DOD approved epoxies and other adhesives for our fiber-to-device assemblies.

Space Photonic's Class 1000 Clean-Room for Optoelectronic MCM Assemblies



12-Channel OEMCM

Our 4, 8 and 12 channel transmitters and receivers are implemented using standard multi–channel fiber optic ribbon cable. This reduces the cost of production and provides a standard physical layer interface.

FireFiber^{TM} MP12-155TX

For subsystem-to-subsystem interconnection, we use NASA approved 12-fiber MTP multi-channel connectors. We also provide fan-outs to standard FC-PC or other type of single fiber connectors as required.

MTP and FC-PC Connectors

Space Photonic's Electronics Lab

Our IEEE 1393-1999, Test and Development Systems (TDS) built for NASA's NMP EO-1 spacecraft used a 12-channel parallel physical layer (MP12-155TX/RX) to implement the 1 Gbps real-time ring network. The TDS contains one control node and two data host nodes. This LabView based TDS supports flight software development, interface testing and operational testing of high bandwidth payload subsystems [8].

IEEE 1393-1999 Real-Time Ring Network Test and Development System

FireFiber^{TM} Products

Our multi-port transmitters and receivers are compatible with all network protocols. These include ATM/SONET, Fibre Channel, Gigabit Ethernet, Firewire (IEEE 1394), and HIC (IEEE 1355), and IEEE-1393. The last component listed in Table III will be compliant with the new IEEE 1394b (FireWire^{TM}) standard. This new standard defines a second generation of FireWire^{TM} networks with data rates of 400 Mbps, 800 Mbps, 1600 Mbps and 3200 Mbps. This product is being developed specifically to support FireWire^{TM} networks in aircraft and spacecraft applications.

Table III: FireFiber^{TM} Products and Availability

Part Number	Max Data Rate per Channel	No. of Channels	Availability
FireFiber^{TM} MP*xx*-155TX & RX	155 Mbps	4, 8, 10 or 12	2002
FireFiber^{TM} MP*xx*-1250TX & RX	1.25 Gbps	4, 8	2002
FireFiber^{TM} MP*xx*-2500TX & RX	2.5 Gbps	4, 8	2002
FireFiber^{TM} MP*xx*-10000TX & RX	10 Gbps	4, 8	2004
FireFiber^{TM} 1394b-rrrrTX & RX	400, 800, 1600 & 3200 Mbps	1,2,3	2004

MP = Multi-Port, xx = channel number, rrrr = data rate
FireFiber^{TM} is a registered trademark of Space Photonics, Incorporated.
Firewire^{TM} is a registered trademark of Apple Computer Corporation.

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