HIGH SPEED OPTICAL FIBER TRANSMISSION TECHNOLOGY FOR AVIONICS APPLICATIONS

Shi Jieqin, Zhang Chunxi, Duan Jingyuan
Optical and Electronic Institution of Beihang University

Keywords: *Communication Technology, Gb/s Fiber Optic Links, VCSEL, RC-LED, Avionics*

Abstract

This paper analyzed the requirement of high-speed communications network in avionics systems first. The technology of high-speed fiber transmission and standard was also introduced. In the end, the transmission design of glass optical fiber (GOF) and plastic optical fiber (POF) based on IEEE1394b and related BER measurements were described in detail. The result indicated that the GOF transmission and the POF transmission meet the requirement of Bit Error Rate (BER) which is less than 10^{-12}, having abundant link margin besides. It was concluded that the fiber-optic network may provide future avionics systems with high performance and low cost interconnections.

1 Introduction

Civil and military avionics systems will continue to incorporate data-rate sensors, parallel processors, and shared memory with high levels of integration. Current avionics architectures based on the MIL-STD-1553B data communication system will be unable to meet the requirements of future data processing, multisensor fusion, and automatic operations. Higher bandwidth, lightweight and lower cost I/O interconnection systems will be needed in future avionics architectures.

Photonic networks, which represent the next major step forward in lightweight avionics network design, have the potential to revolutionize future avionics systems and deliver outstanding improvements in the performance, reliability and flexibility of communications systems. The predominantly passive nature of optical components provides for lower cost, greater simplicity and robustness, in spite of the significantly higher bandwidth and greater levels of integration photonic networks will be expected to support. IEEE 1394b is the major candidate for avionics data bus of next generation. Optical fiber is convenient to transmit high speed digital signal for a long distance. Therefore, it is easy to realize the digital network by utilizing this interface.

2 Requirements of an avionics databus

Avionics fiber optic links are different from most commercial links in several ways. Near-term demand for data will increase, and general data will rate to 10 Gb/s over the next 5 to 10 years [1]. To ensure growth for future upgrades, many designs created today at lower rates will need to take these higher rates into account when choosing fiber and connectors. In addition, lots of disconnects, high and low temperatures, potential contamination, high vibration and shock, make military aircraft have higher requirements for link quality in fiber-optic networks.

3 High-Speed Bus Protocol

IEEE-1394 was developed by Apple Computer in the late 1980s and is an emerging standard for transferring digital audio and video data between multiple devices. It is a major contender to substitute commercial standard of 1553B [2]. IEEE-1394 can transmit both video/audio and packet data through the same line simultaneously, having scalable architecture, flexible peer-to-peer topology, and high-speed deterministic communication. Each bus will support up to 63 nodes. IEEE-1394 interface chips on each node handle all details of the standard protocol, such as the packet structure, arbitration on the bus, etc.

In contrast with former versions, 1394.b defines a different coding scheme, allowing 1394.b devices to be interconnected for longer distances and faster speeds. Indeed, optical transmission technology based on a polymethyl methacrylate POF (PMMA-POF) had been proposed for IEEE 1394b interface. Table 1 indicates specifications related to IEEE 1394b interface. Figure 1 shows the basic components of a connection between a 1394b PHY and a FOT.

Table 1. IEEE 1394b Media Speeds and Distances

	200Mbps	400Mbps	800Mbps	1.6Gbps	3.2Gbps
POF	50m				
HPCF	100m	future			
GOF	100m	100m	100m	100m	100m
STP	4.5m	4.5m	4.5m	4.5m	4.5m

Legend:
HPCF- Hard Polymer-Clad Plastic Optical Fiber
STP- Shielded Twisted Pair Copper

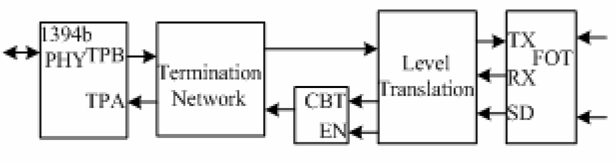

Fig. 1. Basic Fiber-Optic Components

4 Designs of fiber links

The key problem in designing IEEE 1394b optical link is to select appropriate Fiber-Optic-Transceiver (FOT) and related fiber. Transceiver converts electrical signal into optical signal transmitted in fiber. Fiber behaves various transmission characteristics due to various major materials in fiber manufacture. Low loss window of GOF locates at 850nm, 1310nm and 1550nm, while low loss window of POF locates at 650nm, 580nm and 520nm, as shown in Figure 2. Absorption attenuation of fiber is restricted through the choice of transparent window.

Pulse spreads caused by group velocity dispersion and modal dispersion limit system data rate significantly. Graded index multimode fiber can reduce mode dispersion and laser diode can reduce the impact of chromatic dispersion.

4.1 Optical Source

Vertical-cavity surface-emitting laser (VCSEL) combines both ideas: quantum-well and Distributed Feedback (DFB), into a laser diode. As compared to edge-emitting lasers, VCSELs are cheaper to test and transmit at high bandwidth, having characteristics of low driving current, high modulation bandwidth and small size, etc. Temperature dependence is a common problem with laser diodes. Threshold current depends heavily on temperature [3]. This dependence is approximated by the following formula:

$$I_{th}(T) = I_0 \exp(T / T_0) \qquad (1)$$

Where I_0 and T_0 are characteristic constants whose value depends on the diode's material and structure. Bias-T driving circuit with temperature-dependent resistors R_V and R_{mod} in the dc and ac branches incorporated in the laser transmitter module could be used to ensure output power is held nearly constant over the whole temperature range [4], as shown in Fig. 2.

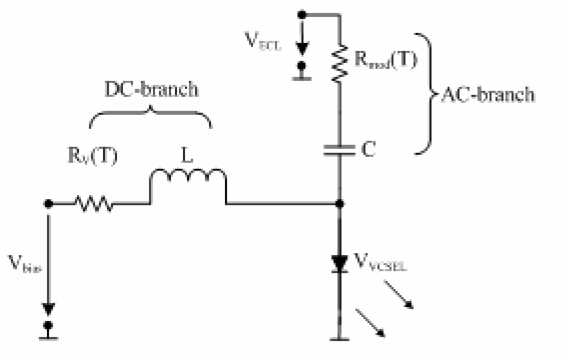

Fig. 2. Bias-T Driving Circuit with Temperature-Dependent Resistors to Compensate Output Power Variations

Resonant-cavity light-emitting diode (RC-LED) also has resonant cavity similar to that of VCSEL, but has less cost and overcomes LED's disadvantages of emitting power and data rate, so it is suitable to be applied in short reach (SR) network. Because the spectral shift is very small (about 0.07nm/℃) [3], considering the loss window of PMMA-POF, optical transceiver based on the RC-LED can transmit the high quality digital signal without using any temperature controlled-electronic circuits.

4.2 Optical Fiber

Because of disadvantages of singlemode as compared multimode including increased connect ion cost, sensitivity to installation stress, and reduced launch power, avionics data networks almost use multimode fiber. VCSEL radiates a circular well-directed beam that is easy to couple to an optical fiber, which allows using it with graded index multimode fiber (GI-MMF). A GI MMF having a core diameter of 62.5um was used as an optical fiber, with an attenuation of 0.003dB/m.

RC-LED allows connection to GI PMMA getting better. When transmission distance does not exceed 50m, GI PMMA can rate to 500Mb/s. POF has broad application prospects because of large NA, high coupling performance, easy fabrication and interconnection. A GI PMMA having a core diameter of 980um was used as an optical fiber, with an attenuation of 0.14dB/m.

4.3 Demonstration of 1394.b Transmission

First approach of GOF utilizes Agilent GOF transceiver (HFBR-53D5), which includes VCSEL locating at 850nm and Si pin-PD. The HFBR-53D5 which incorporates duplex SC connector is compliant with specifications for IEEE- 802.3z Gigabit Ethernet, rates to 1.25Gb/s, allowing it to transmit S800 signals as specified in the IEEE 1394 standard.

Second approach of POF utilizes Toshiba POF transceiver (TODX2402), which includes RC-LED locating at 650nm and Si pin-PD. The TODX2402 is an optical transceiving module which is compatible with SMI (Small Multimedia Interface) optical connectors and is suitable for use in applications involving communications between personal computers and digital consumer electronic devices. This transceiving module communicates at a speed of 250 Mb/s, allowing it to transmit S200 signals as specified in the IEEE 1394 standard.

5 Transmission Performance

Bit error rate (BER) is a key parameter for network performance. IEEE 1394b requires BER less than 10^{-12}. Figure 3 shows a block diagram of the BER measurement, including Anritsu high speed BER tester (BERT), EXFO volatile optical attenuator. Before the measurement starts, the 1394b test pattern is pre-programmed into the BERT. FOTs were directly modulated by nonreturn-to-zero (NRZ) pseudorandom binary sequence signals from the BER generator, at a speed of 800Mb/s or 200Mb/s. Detection threshold and delay were optimized manually.

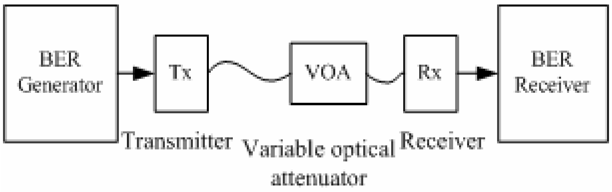

Fig. 3. BER Method Test Setup

Initially, a reference BER curve is directly generated by connecting test jumper. With the cable assembly under test in place, BER curves are generated. As figure 4 shows, the gap between the reference curve and each of these BER curves for the cable assembly under test is the loss for that assembly. The transmission performance over various fiber lengths were simulated by adjustable flange along with test jumper.

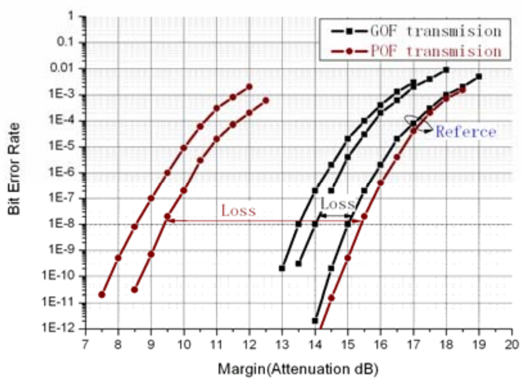

Fig.4. BER Curves Used to Determine System Margin

The test had the result that the GOF transmission of 800Mbps×100m and the POF transmission of 200Mbps × 20m meet the requirement of BER, having abundant link margin besides, as shown Table 2.

Table 2 Power Budget of POF/RC-LED and GOF/VCSEL

Parameter	PMMA/RC-LED	GOF/VCSEL
Attenuation of fiber	2.8dB(20m)	0.3dB(100m)
Connector insertion loss	3dB	0.2dB
Needed power budget	5.8dB	0.5dB
Loss of cable assembly	6	1dB
Reference margin	14.2	14dB
System margin	>8dB	>13dB

6 Conclusion

With the widespread research and development of the fiber transmission technology, the low cost and high performance interconnection is provided for future avionics systems. By using RC-LED and VCSEL, the GOF transmission of 800Mbps × 100m and the POF transmission of 200Mbps × 20m were successfully demonstrated with BER of less than 10^{-12} and some key issues about the choice of FOTs and fibers were analyzed. In addition, by deriving loss from Bit Error Rate measurements, an accurate estimate of component loss can be made. Fiber optical data bus basing on IEEE 1394b is enhancing the way of interconnecting real-time systems, having the potential of replacing 1553B interconnection standard and being integrated into specific aerospace applications.

References

[1] Harres D. Current state and future direction for military aircraft fiber optics networks. *Digital Avionics Systems Conference*, Valencia, Spain, Vol.2, 6, pp B.2-1.8, 2003.

[2] Baltazar G, Chapelle G. Firewire in modern integrated military avionics. *aerospace and electronic systems magazine*, Vol. 16, No. 11, pp 12-16, 2001.

[3] Djafar K, Lowell L. *Fiber-optic communications technology*. 1st edition, Pearson Education, Inc., 2001.

[4] Kibler T, Poferl S and Huber H. Optical data buses for automotive applications. *Aerospace and Electronic Systems Magazine*, Vol. 22, No. 8, pp 2184-2199, 2004.