

A HIGH PERFORMANCE MIL-STD-1773 DATA BUS

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ABSTRACT

This paper gives detailed ideas and methods about the design and development of high performance MIL-STD-1773 airborne fiber optic data bus. To reject impulsive interference efficaciously, the large core and large numerical aperture fiber optics are adopted, as well as high- emitted power LEDs and a low noise optical receiver structure to get high signal-to-noise ratio at decision time. Two new modulation technique----digital frequency shift keying and partial tri- level Manchester are recommended, which are very attractive in the disign of modern optical bus. Meanwhile, VLSI chips COM1553B are used to construct bus control interface unit, thus many advantages have been brought out.

INTRODUCTION

MIL-STD-1553B, a military standard for a 1Mb/s serial data bus released as an official document on September 21, 1978 by SAE-A2K, is gaining acceptance in the military aerospace community. However, the integration of increasingly complex avionic systems and the transmission of data at higher and higher rate pose many new problems for the aircraft manufacturers, most of which focus on the questions of electromagnetic compatibility (EMC) and the spread of channel bandwidth capacity. Moreover, to reduce the weight of aircraft is a very important aspect by a new kind of medium. It is difficult to settle these questions in MIL-STD-1553B data buses, where shielded twisted copper pair is used. As a transmission medium for avionic multiplexed data bus applications, optical fibers have many advantages over cables, which include the immunity of electromagnetic interference (EMI), radio frequency interference (RFI) and electromagnetic pulse (EMP); high reliability; enormous bandwidth; good secrecy; lightness and thinness; and the potential cost reduction. In May 1976, a Fiber Optic Task Group was formed under the purview of SAE-A2K to develop a fiber optic multiplexing standard compatible with MIL-STD-1553B, and MIL-STD-1773, which is an optical version of MIL-STD-1553B wire bus, was promulgated by the Department of Defense of U.S. in May 1988 [1]. The document in MIL-STD-1773 for data bus protocol, bit assignment and related bus traffic management is designed to correspond exactly with MIL-STD-1553B, and optical fibers are only provided as the transmission medium for hardware terminals developed according to MIL-STD-1553B. MIL-STD-1773 anticipates the advantages offered by optical fibers will lead to the replacement of MIL-STD-1553B with fiber optic channels in the new generation of airborne data buses

For airborne optical data bus systems, the reliability is one of the most important factors, which mainly relies on the design of hardware and software in data buses. The principles improving system reliability are studied thoroughly and effective measures are adopted, which include increasing received average optical signal power to reject impulsive noise, and adopting a good modulation, and using VLSI chips to construct bus control interface unit, thus the optical network gets high reliability in practice.

SYSTEM ARCHITECTURE

The block diagram of this airborne MIL-STD-1773 optical bus is shown in Figure 1,

The transmissive star (8-port) optic data bus configuration is adopted in this high performance optical network. Eight remote terminals (RTs) are linked with the bus, and the distance between RTs can be as long as 60 meters, and each RT consists of a microprocessor (INTEL 8086) card, a bus control interface unit (BCIU) card and an optical transceiver card. The signals of the air data computer (ADC) are transmitted to

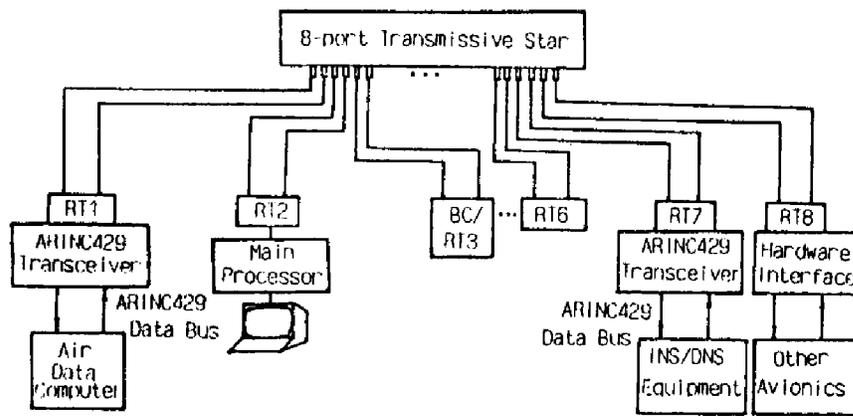


Fig. 1 The Block Diagram of MIL-STD-1773 Data Bus

MIL-STD-1773 data bus and other information returned to ADC by ARINC-429 data bus. Other airborne equipments such as inertial navigation systems (INS) and Doppler navigation systems (DNS) can also be linked with the optical bus. All inter-terminal communication is conducted under the control of a dedicated bus controller (BC), which initiates all data transfers and monitors their success or failure. In this optical bus, BC and RT are designed as an organic whole.

FIBER OPTIC DATA BUS CONFIGURATION

Five fundamental fiber optic data bus configurations are given in MIL-STD-1773, which are reflective star coupled bus, transmissive star coupled bus, bi-directional T-coupled bus, uni-directional T-coupled bus and bi-directional hybrid coupled bus [1]. Of the basic optical bus configurations, the bi-directional T-coupled configuration is closest in form to the MIL-STD-1553B wire bus. Actually, the optical bus configurations are flexible, and a reunited hybrid configuration can be adopted according to practical requirements. A reflective or a transmissive star coupled bus possesses the characteristics of minimal optical transmissive losses and optical signal range (OSR), and the harm of optical fibers in a terminal can not affect other terminals' functions, so a star network must be prior considered in a small terminal-network, although the needs for optical fibers are not the least in this configuration, the defect only appears in a large terminal-network.

However, in an aircraft, it is found that RTs are substantially grouped into a few physically distant zones, for example aircraft cockpit, aft avionics bay, and engine bay. In this situation a signal star coupler based interconnect, with a fiber, or pair of fibers, running from each RT to the star coupler, becomes unacceptably unwieldy, expensive and vulnerable. In response to these major limitations, a flexible and elegant full passive multi-star fiber network topology----local star bus can be adopted [2], which is therefore

efficient in terms of fiber cabling and versatile while being well tailored to typical aircraft requirements, but large OSR is required in optical receivers.

REJECTION OF IMPULSIVE INTERFERENCE

The impulsive noise appears in the form of burst or cluster and usually leads to burst errors or error group and has very great effect on airborne MIL-STD-1773 data buses. Although MIL-STD-1773 optical systems completely eliminates the possibility introducing impulsive interference by transmission medium, impulsive noise may be brought in through power lines due to very strong electromagnetic interference (EMI) sources existed in aircraft. Bad ground, all kinds of radiation to optical receivers whose shelters may be not the best, and metal cable with various uses in optical fiber cable can also introduce impulsive interference into systems [3]. A kind of impulsive noise with representative amplitude distribution----double exponential distribution is studied, which can comparatively coincide in practice. When 1Mb/s Manchester II code is transmitted in MIL-STD-1773 data buses, the relation between signal-to-noise ratio (SNR) at decision time and bit error rate (BER) is shown in Figure 2.

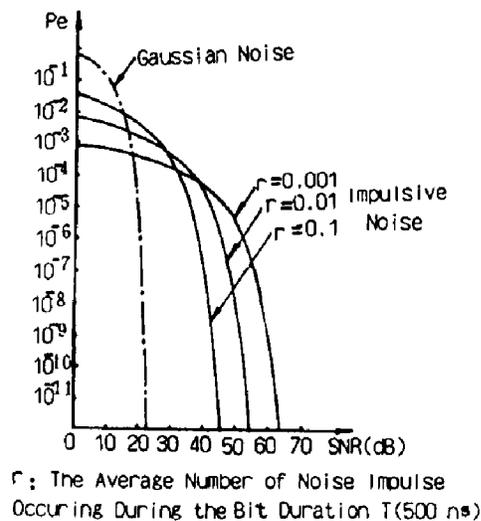


Fig. 2 BER Versus SNR for MIL-STD-1773 Data Bus

In optical buses where impulsive noise and Gaussian noise exist together, Gaussian noise is main factor of bit error when SNR lower, whereas impulse noise will play a main role in causing errors when SNR higher. For MIL-STD-1773 data bus, the BER should not be greater than 10^9 at 1Mb/s, so the optical network requires high SNR (above 50dB) which is usually ensured by system design, and the burst error is actually caused by impulsive interference. Figure 2 shows that impulsive noise is a primary source of interference and a principal performance-limiting factor in high SNR MIL-STD-1773 systems. The way of improving the interference rejection can be divided into two aspects, one can utilize all

kinds of methods based on principles of EMC, the other can adopt advanced technique such as error-correcting codes, good modulation- demodulation and detection and so on. One of principal aspects is to pursue the improvement of SNR at decision time. For simple direct optic-electronic device-fiber coupling, the coupling efficiency is approximately proportional to the square of optical fiber numerical aperture (NA) as well as core diameter, so the large core and large NA fiber optics should be adopted, as well as high quality and high-emitted power LEDs, PINs with high responsibility and low noise, and a low noise optical receiver structure to get high SNR at decision time, therefore, not only can errors caused by Gaussian noise be eliminated basically, but also the impulse interference can be rejected effectively.

This airborne optical bus operates at a wavelength of 850 nm, the LEDs are pigtailed to a fiber whose core diameter is 140 μm (NA= 0.32), the average output power (50% duty cycle) of LEDs measured at the end of 1 meter long fiber is above 400 μW at 100 mA when operated at 1 Mb/s. The model of PINs is RCA C30957, and a dynamic range of a optical receiver is 12dB.

OPTICAL MODULATION SCHEMES

The optical modulation technique is a very important topic which heavily affects the reliability and complexity of airborne buses. Whether a modulation scheme is adopted or not mainly depends on whether Three Electrical Output States are directly gotten at an optical receiver. If this design goal is accomplished, less response time is needed, and retrofit of wire receivers with optical receivers will be possible at the protocol interface. Moreover, the communication-quality must be kept excellent, the interface must be simple, and a job must not be miscellaneous when this modulation adopted.

Figure 3 shows the four optical data modulation schemes proposed by SAE-A2K Fiber Optic Task Group, which are bi-level full width Manchester code, pulse position Manchester code, tri-level Manchester code, and frequency shift keying (FSK).

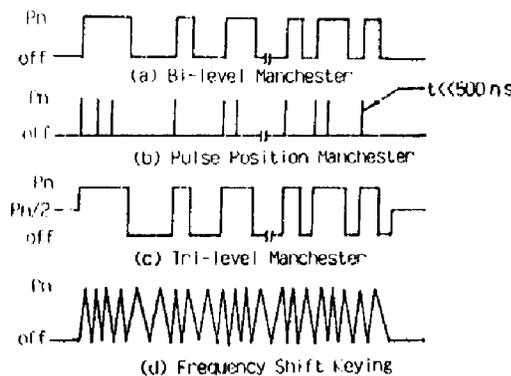


Fig. 3 Optical Modulation Schemes

Manchester II bi-phase level code is proposed by MIL-STD-1773 because it has the greatest compatibility with MIL-STD-1553B modulation protocol, but it is not easy to provided Three Electrical Output States in an optical receiver which correspond to 'positive pulse', 'zero level', and 'data bus quietness'. Unlike the electrical signals in MIL-STD-1553B where three signal levels (I. e. ; +V, -V, and Zero Level) are contained, in optical fiber transmission systems with intensity modulation, there are only two states ---- power-ON and power-OFF, negative optical power does not exist, so the optical input signals to a receiver have only two states, therefore, the electrical output signals have only two states, and two states ---- 'data bus quietness (power- OFF)' and 'zero level (power-OFF)' can not be distinguished. When a message ends and a response is expected, there is a $0.5 \mu s$ difference in the length of the message, measured to encompass the start and end ON-times of the message and depending on whether the last message bit is a '1' or a '0', the former may result in the shorter Message the $0.5 \mu s$. In order to solve the problem related to three states output, the more complicated data processing technique should be used at optical receivers, but it results in longer processing time which may not be acceptable to MIL-STD-1773 (I. e. , 4.0 to $12.0 \mu s$ response time). Therefore, we think the bi-level full width Manchester modulation is not a good scheme in a successful avionic optical buses. Pulse position Manchester code uses narrow pulses (duty cycle is much less than 0.5) to mitigate the average value problem, but great system -band-width and complex optical receivers and transmitters and high-required LED-PINs are in use, and it can not give three electrical output states in an optical receiver. FSK, with one frequency established at about 20MHz during half of an information bit or sync code time and a second frequency set at about 19MHz during the other half, mitigates the average value problem and existence of a signal in both halves of the information bit or sync code makes it possible to distinguish the data bus quietness state from the power- OFF state during a message, which is impossible using bi-level Manchester II code, so FSK is constantly adopted in optical network. But a miscellaneous job must be done, greater bandwidth LEDs are required. We pursue high- emitted power of LEDs in this optical bus, leading to the 20MHz LEDs bandwidth, thus FSK can not be adopted in this optical network. With tri-level optical Manchester modulation, the baseline drift caused by band-pass characteristic of fiber optic receivers is eliminated because the optical power level is continuously ON at the average of the peak and OFF values when no message is being transmitted, and three electrical output states of optical receivers can be gotten directly. However, there is a fatal weakness always existing direct optical power $P_n/2$ (P_n is the peak optical power output of one optical transmitter when message is '1') when no message. In a single 32-port star coupler network, the signal amplitude $P_n/64$ much less than $P_n/2$ overlaps on direct optic power $P_n/2$ when message exists, thus average life-span of LED-PINs is reduce and large random noise and coherent noise are caused, making tri-level Manchester code unattractive in a many -terminal situation.

We recommend two optical data modulations----digital frequency shift keying (DFSK) and partial tri -level Manchester code, which are very helpful in the design of modern airborne fiber optic data buses. The modulations are shown in Figure 4.

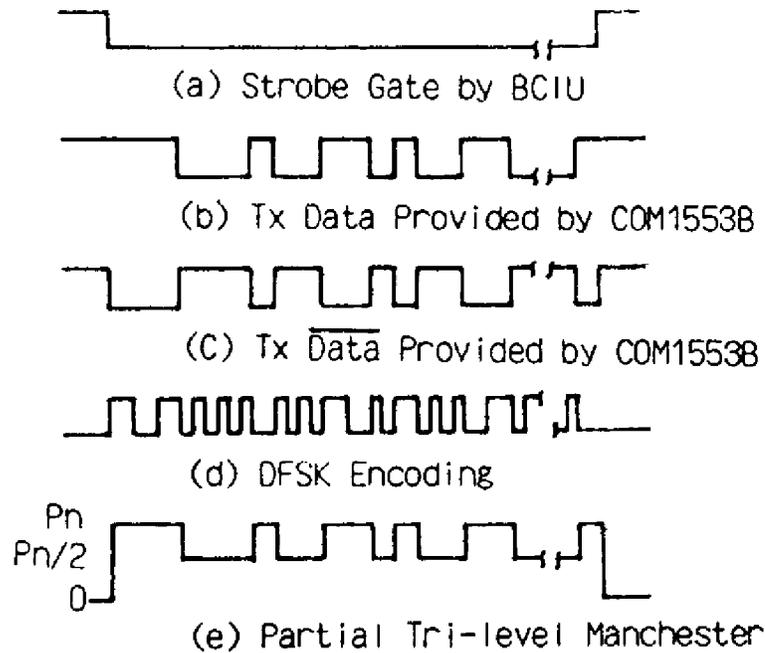


Fig. 4 DFSK Encoding and Partial Tri-level Manchester Modulation

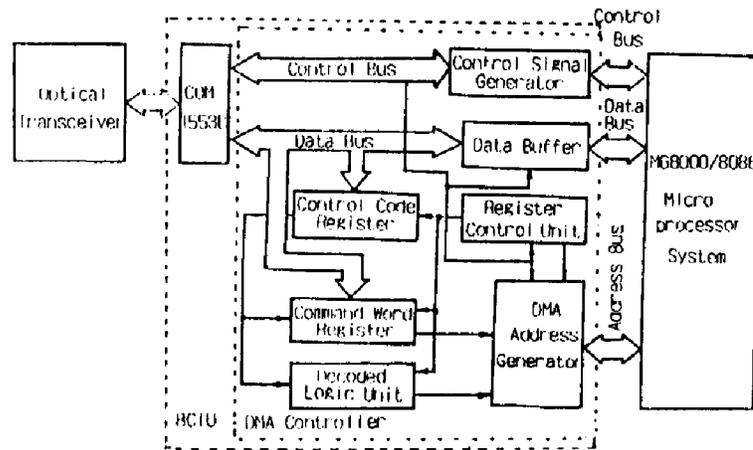
In DFSK modulation, electrical data bus signals '1' are coded as one frequency (1MHz), '0' are coded as a second frequency (2MHz), and when the electrical bus would be quiet the optical bus is also quiet. Three electrical output states of optical receivers can be offered in DFSK scheme, simply finishing coding and decoding of DFSK by digital circuits, the highest bit rate of DFSK is only 2MHz, and better immunity to the various second order effects. DFSK scheme is adopted in this optical network.

Actually, partial tri-level Manchester is a modulation scheme based on tri-level Manchester. We can make optical transmitters nolight when bus quiet and modulated by tri-level Manchester when bus transmitting making use of the strobe gate provided by BCIU. The fatal weakness that a direct power $P_n/2$ exists when no message is eliminated, the advantages tri- level Manchester possesses are maintained.

BCIU CONSTRUCTED BY VLSI CHIP

Protocols for MIL-STD-1773 are so complex that two to three circuit boards packed with discrete devices and many SSI/MSI circuits have been required to interface equipment subsystems and the physical bus. Many famous corporations such as Circuit Technology,

Inc. (CTI). Grumman, Hamilton Standard/Mostek, Harris Semiconductor, Standard Microsystems, and Rockwell International are devoted to the development of VLSI chips which are used to construct the BCIU in MIL-STD-1773, and many VLSI chips supporting MIL-STD-1773 are put into commercial use. The VLSI chips---COM1553B produced by Standard Microsystems Corporation are used to construct BCIU in this optical bus, thus greatly simplifying the interface between microprocessor and MIL-STD-1773 data bus, with the reduction of system volume, improvement of the design of BC/RT as an organic whole, and of data bus reliability.



The BCIU block diagram is shown in Figure 5.

Fig. 5 BCIU Block Diagram

The BCIU lay between the optical transceiver (including DFSK coding and decoding circuits) and microprocessor (INTEL 8086) has main function converting the data from a serial to a parallel format (when receiving) or from a parallel to a serial format (when transmitting). The BCIU and the microprocessor make the subsystems linked with RTs communicate each other according to MIL-STD-1773 protocols. The RT contained BCIU, microprocessor and optical transceiver is key part in data bus system, it decides the data bus ability to exchange and process information and tolerate errors. The VLSI chip COM1553B is linked with microprocessor by DMA mode due to high efficiency of DMA. DMA controller is used to manage communication between COM1553B and micro-processor.

CONCLUSION

The optical data bus has been carried out test in practice and operates very well for a long time according to MIL-STD-1773 protocols. The effective measures adopted above ensure the optical network to have high reliability in all kinds of extremely complicated and

adverse circumstances of EMI. However, it is important to note that this application does not utilize the enormous bandwidth potential offered by fiber optics, optical fibers are only transmission medium for the equipments developed by MIL-STD-1553B, and the characteristic of very great bandwidth of fiber optics will be fully utilized when MIL-STD-1773 is upgraded in the new generation of high performance aircraft (the next generation airborne data bus should work at ~ 50Mb/s or higher).

REFERENCES

- [1] MIL-STD-1773 Fiber Optics Mechanization of an Aircraft Internal Time Division Command/Response Multiplex Data Bus, Department of Defense, US, 20 May 1988 .
- [2] M.J. Kennett, The Development of a Fiber Optic Data Bus for Helicopters, ICAS, Vol. 2, 1986, pp. 1490-1496.
- [3] Li Zheng and Zhang Jian-Guo, The Sensitivity and Interference Rejection Performance of Pulse Width Modulation Optical Fiber Data Bus, RTCA Proceedings, Technical Symposium on Digital Avionics, May 25-27, 1988, pp.51-57.