FIBER OPTIC AFDX FOR FLIGHT CONTROL SYSTEMS

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Introduction

Fiber optic systems are often cited as a way to gain EMI immunity, reduce weight, and increase bandwidth. Avionics Full-Duplex Switched Ethernet (AFDX), specified in ARINC 664 Aircraft Data Network, Part 7, is a fiber optic avionics bus specification used on the Airbus A380, Boeing 787, and others. It was designed as an upgrade to the standard Ethernet protocol which added guaranteed determinism with bounded jitter and latency. This was done to allow hard real time, critical systems to communicate using standard IEEE 802.3 Ethernet protocol. It uses dual redundancy and full duplex links to minimize jitter and latency and eliminate packet collisions. Although AFDX was designed with hard real time systems in mind, it has not yet been used in a safety critical flight control system. Airbus has expressed interest in extending its use of AFDX from mission critical to flight critical systems[1]. The use of AFDX for flight control systems could provide a number of benefits over legacy systems such as MIL STD 1553 and ARINC 429 (A429). Other fiber optic busses do exist, including MIL STD 1773, ARINC 629, ARINC 636 and Fiber Channel, but these are not currently used for flight controls and comparisons to these busses is beyond the scope of this study.

Flight Control Concerns

Modern digital flight control systems (FCS) are often quadruple redundant with a second, quadruple redundant backup FCS. This redundancy contributes towards meeting the extremely low, 10^{-6} to 10^{-8}, probability of loss of control (PLOC) numbers required by SAE AS94900 and other flight control system regulations and guidelines. There is some concern that jitter and latency introduced by a switched network topology may cause stability problems in flight control systems due to a reduction in phase and gain margin and a reduction in sensor accuracy. Also, aircraft maintenance is a primary concern for fiber optic links because of hands-on labor requirements. Most fiber optic connectors are rated to 250 mating cycles and require specialized cleaning/handling which is not suitable for a FCS.

Fiber Optic AFDX versus Legacy Avionics Busses

A given fiber optic link weighs less than a copper cable even when substituted on a 1 for 1 basis[1]. However, the high reliability, electromagnetic interference (EMI) immunity and high bandwidth of fiber links may offer several intriguing possibilities for modernization, such as reduction in physical redundancy requirements through the use of Cross Channel Data Links (CCDL) or other advanced techniques. Moreover, the use of AFDX enables performance improvements due to increased bandwidth and/or word size; possibly resulting in higher loop closure rates, more precise sensor measurements, or additional bandwidth-limited capabilities, such as CCDL.

AFDX has a raw bit rate of 100 Mbits/s vs. 1 Mbits/s for 1553 and 100 kbits/s for ARINC 429. The switched nature of AFDX naturally leads to contention when two or more devices transmit simultaneously. Although a properly designed AFDX bus will not drop packets, the required network buffers can and do lead to delays. One paper claims that an AFDX bus needs to be run at 10-20% capacity to minimize latency and jitter[2]. However, other busses suffer from similar problems. An A429 bus is single direction; two independent links are required for two-way communication between devices. Thus a single, realistically loaded AFDX network can transmit 100-200 times more than an A429 link. 1553 allows for two way communication without contention using Time Division Multiplexing (TDM), but at the cost of extremely high overhead. Per the specification, the 1553 TDM scheme works best below 400 Hz and only marginally up to 3 kHz.

AFDX versus IEEE 1394

A state of the art manned FCS for manned military aircraft, such as the Joint Strike Fighter, is known to use IEEE 1394b, which is comparable to AFDX [3]. Based on the written standards, AFDX and 1394 are similar in bit rate and integrity. 1394 is slightly better in timing accuracy. AFDX specifies network examples in which the latency and jitter have maxima of 75 µs and 500 µs. Better absolute limits are possible dependent on both hardware and network topology. 1394 is a serial bus and out of order packets are not possible. AFDX can also guarantee ordinal packet flow through proper network design. Contention on a 1394 bus leads to an arbitration sequence which lasts a fixed 3.7 µs. Repeated collisions can occur and lead to a bus reset after a fixed number of occurrences. AFDX does not have collisions, and contention is handled by buffering packets. IEEE 1394 and AFDX use the same Cyclic Redundancy Check (CRC) algorithm for error checking. They may provide differing levels of integrity based on packet sizes as well as assumed bit error rates due to physical construction. Signal integrity of IEEE 1394 versus AFDX is an area for future investigation.

Table 1. Comparison of AFDX Timing Parameters vs. Other Busses

Databus	Latency	Max Jitter	Contention	Multiplex Type
AFDX	75 µs*	500 µs*	Yes	Packet Switching
IEEE 1394	125 µs	25 ns*	Yes	A-synch or TDM
MIL STD 1553	26 - 646 µs ** + TDM	8 µs	No	TDM
ARINC 429	960 µs - 81.6 ms**	19 - 816 µs**	No	None

* Dependent on network architecture ** Dominated by message timing (length x bandwidth)

Further Work

- In-depth analysis on overall flight control system architecture to assess data bus latency effects on overall system latency.
- FAA AC 25.1309 requires $1x10^{-9}$ likelihood of catastrophic failure for a safety critical flight control system. The Bit Error Rate (BER) and algorithm used to detect bit errors of on AFDX link do not provide this level of integrity, nor does it need to by itself. Additional integrity layers need to be investigated.
- Signal latency and jitter reduce phase and gain margins, time available for computation, and possibly sensor accuracy. These effects must be studied.
- Non-Physical Contact (NPC) connectors were used on the ARINC 636 bus in the Boeing 777 to mitigate mating durability and cleanliness problems. 636 link budget requirements also address receiver saturation issues encountered in NASA/AFRL Smart actuator testing. The use of NPC connectors needs to be studied to determine if this technology will bring similar benefits to AFDX.

Conclusion

AFDX was designed to enable the use of Ethernet protocols for real time systems. This testing will explore the use of AFDX in a flight control system. Several challenges specific to the flight control system have been identified which require further analysis and testing. Future work should identify specific solutions and technical limitations which will guide the use of AFDX in this application.

References

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