Unified Interconnect System for Next Generation Fighter Aircraft

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Abstract

This paper details the studies carried out to identify the need for high speed data bus for next generation fighter aircrafts, comparison of various high speed data bus technologies and selection of Fibre channel Avionics Environment(FC-AE) data bus protocol. Based on this study, avionics architecture with FC-AE network to meet next generation fighter aircraft requirements is proposed .The need for this study is driven by the shortcomings in current federated avionics architecture based on MIL STD 1553B for data communication and STANAG 3350 based analog video distribution networks. Limitation of MIL STD -1553B maximum speed is 1 Mbit/sec and STANAG 3350 maximum video resolution is 760 by 575 pixels. Current avionics architecture uses multiple protocols for data, video and control functions. Use of multiple network protocols can be replaced with single redundant Commercial Off the Shelf network, which can save space, cost, and weight, while increasing the network capacity. Weight is especially critical for avionics and every fighter aircraft has limited space in which to house its avionics and its interconnect system. In next generation fighter aircrafts, number of new functional requirements is increased which need to be realized within the weight budget constraint. The proposed solution is advanced integrated avionics with unified interconnect system based on FC-AE network.

Keywords

Fibre Channel, FC-AE, MIL-STD-1553B, AFDX, Fiber Optics, IMA, ASM

I. Introduction

Most military avionics flying today are based on a federated avionics architecture with functionally partitioned and distributed LRUs interconnected via a Mil-Std-1553B data bus as shown in fig. 1. The deployment of federated architectures using the time division multiplex 1Mbps Mil-Std-1553B data bus have demonstrated dramatically simplified physical integration and retrofit problems on military aircrafts. Implementation of federated network architectures does not distinguish between hardware and software, but rather between devices specially built for a single purpose (display computer, mission computer, communication system, sensor etc.,). These Line Replaceable Units(LRUs) are thus unique to a certain degree and also need to be certified as a whole. As there is no distinction between hardware and software, re-certification needs to take place even if only software was updated or replaced. If any new function is required , then one more additional unit is required which result in increase in weight, cost and wiring complexities.

Due to the above mentioned limitations, the aerospace industry has begun to move away from federated architectures in favor of Integrated Modular Avionics (IMA). Most importantly, IMA does discriminate between software and hardware and defines an abstraction layer between physical hardware and software-implemented functionality. The Modular avionics concept relies on the limited range of standard modules which are packaged in a standard modular format and installed in a small number of common racks. The concept of modular equipment is not new whereas IMA approach is integration of data and signal processing across traditionally separate aircraft sub systems enabling wide scale use of reconfiguration to improve reliability via resource sharing. To enable signal processing in central computer, it demands for high speed data bus to transmit sensor front end raw data in next generation aircrafts. The integration of the various sub-system to increase mission effectiveness requires an inter-connection network system capable of two way communication of serial digital data at high speed. Present MIL-STD-1553B data bus system have limitation of 1Mbps data rate and the number of LRUs per bus is limited by 31.To overcome these problems, a number of higher speed transmission systems are being considered.

Traditionally Avionics Architectures have been built around a variety of digital interconnects, each specific to a particular domain. Advances in technology has resulted in new high speed interconnects, paving the way for a unified interconnect encompassing the Sensor Network, Video Network, the Avionics Bus and the Module Interconnect Buses.

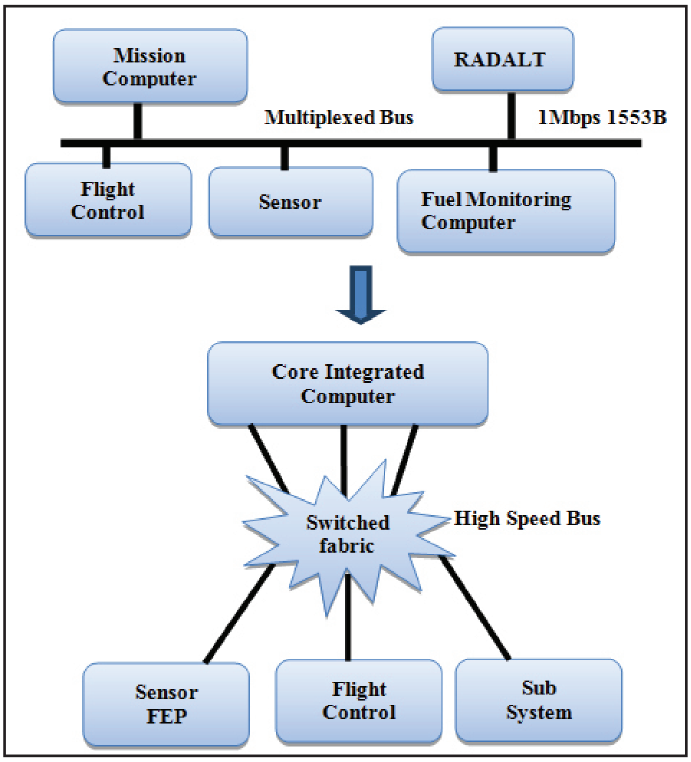

Fig. 1: Migration from Federated to Integrated Avionics Architecture

II. Need for High Speed Data Bus

The section details the Need for High speed data bus & drawback of existing avionics system to meet next generation fighter aircrafts requirements. New advanced avionics applications in next generation fighter aircrafts have an increasing need for enhanced bandwidth while maintaining the real time characteristics of low latency, determinism, and reliability.

Next generation fighter aircrafts features advanced functions to reduce the pilot workload such as sensor data fusion for Enhanced

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Situation Awareness, automated missions. Sensor data fusion requires high bandwidth to transfer data from sensor front end to core computer. As the combat scenario is changing to network centric operations and all next generation aircrafts requires net centric warfare capability with high data rate bus. Integrated vehicle health management(IVHM) is another new applications which demands high speed data bus to reduce the maintenance intervals of aircraft. IVHM generates data at high frequency demands more than 1 Gbps bus bandwidth. In addition, advanced avionics technologies generate data in the form of voice and video data at higher rates such as SAR, IRST, ATR which needs more bandwidth to transfer image and video. Also Network interfaces for future "smart" weapons will need to support applications such as transfers of terrain maps, target templates, program files, and digitized images and video for weapon launch. These applications will require the use of a high-speed data interface. Deployment of large screen multifunction displays with high resolution video demands high speed data bus of more than 2 Gbps. Obviously, MIL-STD-1553B cannot satisfy the requirement, so the avionics system has to choose another data bus to process the high- speed transmission. This arises to the fact that present avionics system which has multiple buses synchronously, and it virtually enhances the complexity of avionics system integration design to meet new requirements of next generation aircraft. Therefore, it is necessary to research new generation data bus for aircraft.

From the requirement analysis, it is clear that to meet the demands of next generation fighter avionics data network should be High speed (>2Gbps), simultaneous multiple communication links with Support for 1553 back ward compatibility for legacy system interface, deterministic and Fault tolerant.

III. COTS High Speed Data Buses -A Comparative Study

The trade off study was carried out to compare various COTS(Commercial off the shelf) high speed buses for avionics application. Table 1 summarizes the salient features of various avionics data buses. Based on this preliminary, it is found that at present AFDX and Fibre Channel are the two competitive buses for avionics applications. AFDX is widely adapted by commercial airlines and Fibre channel by military aircraft programs. The following are the data buses considered for the comparative study,

1. MIL-STD-1553
2. MIL-STD-1773
3. AFDX(Avionics Full Duplex Switched Ethernet)
4. FC-AE(Fiber Channel Avionics Environment)

Fiber Channel is a set of advanced data transport standards that allow large amounts of data to be moved reliably at multi-gigabit speeds between processors, servers, memory devices and other IO devices. Fibre channel is a high speed serial transmission protocol, with the properties of high speed, low delay, strong anti-interference and it has become the primary candidate protocol for future avionics networks. This is an ANSI Standard. To meet the demands of mission critical applications, the American National Standards Institute(ANSI) task group X3T11 developed FC-AE which has been applied in some advanced fighter planes such as F35/JSF, F18, E2C. Fiber Channel- Avionics Environment is an upper level protocol that specifies fibre channel options for devices connected by fabric and/or loop topologies that are pertinent to their use in military aerospace industries. The primary area of interest include avionics command, control, instrumentation, signal processing and sensor and video data distribution. Due to its capability to support upper layer protocol for data, video, audio & control functions that makes it unified interconnect system.

Table 1: Comparison of Avionics Data Buses

Features	MIL STD 1553	MIL STD 1773	AFDX	FC-AE
Topologies	Shared Bus, Half Duplex	Star Network Half Duplex	Switched Network Full Duplex	Point-to-Point Ring & Switched Network , Full Duplex
Data Rates	1Mbps	1Mbps , 20 Mbps	10Mbps 100Mbps	1,2, 4, 10 Gbps
Physical I/F	Electrical	Optical	Electrical ,Optical	Electrical,Optical
ULP support	NO	NO	NO	YES(FC-AE-1553)
Data Pay Load	32 words with 16 bit data	Same as 1553	1471 bytes	2112 bytes
Error Checking	Parity bit	Parity Bit	CRC	CRC
Confirmed transfer	Supported	Supported	Time Slot	End to End & Buffer to Buffer Credit
Primary Application	Military Avionics Bus	-	Commercial Avionics Core Network	Military Avionics Core Network, Stores, Video interface.

During the past decade, Fibre Channel has emerged as a winning solution from several competing technologies, for example, Scalable Coherent Interface (SCI), Gigabit Ethernet, Infiniband and Asynchronous Transfer Mode(ATM). One characteristic that all competing technologies share with Fibre Channel is that they are all based on high speed serial transmissions placed in routed switched architecture. Although relatively new to the avionics marketplace, Fibre Channel is already a high speed digital data bus for avionics. For example, it is already being implemented on major programs such as the F18, F16, E-2C, B1B, F-35, F-22, MMH Helicopter, FA-18 E/F, B-2 and FGFA [9].

Avionics Full Duplex Switched Ethernet (AFDX) is a standard that defines the electrical and protocol specifications (IEEE 802.3 and ARINC 664, Part 7) for the exchange of data between Avionics Subsystems. At present it is available for speeds up to 1Gbps and used in commercial aircraft industry where there are no sensor high bandwidth requirements as in military. FC bus is more deterministic than AFDX, as the Buffer to Buffer credit is checked prior to data transfer. In addition, FC provides the option to connect the legacy 1553 systems with upper layer protocol as FC-AE-1553. FC is available with bus speed 3 times higher than AFDX. Hence Fibre Channel is best suited for Fighter Avionics Interconnect.

FC which meets the requirements of the advanced avionics system, and therefore it can be the main candidate of avionics network protocol to realize the processing of signal and data and the integration of the sensor to the broadest extend is the primary feature of the advanced avionic system in addition to its capability as to support various upper layer protocols which makes it unified interconnect system.

Apart from above mentioned 4 buses, ARINC 429, ARINC 629, STANAG 3910, CAN, TTP and IEEE1394 buses which are popular in aerospace industry were also considered during this study. All these buses are low speed buses which does not meet the future requirements.

Advantages of ANSI Standard Fibre Channel

- Deterministic – Buffer to Buffer & end to end Credit
- Fault Tolerance – Ack signal enables fast fault recovery
- High Speed – up to 10 Gbps
- Backward compatibility with Mil-Std-1553 for Legacy systems interface
- BER < 10^{-12}
- Fiber optic cable [Noise Immunity & Not affected by Magnetic field]
- Proven Bus : F-22, JSF, FGFA

Comparing the above networks we find that Fiber Channel has an edge over the AFDX with respect to flexibility in Upper layer protocols, MIL-STD-1553 compatibility, flow control and real time reliability.

IV. Avionics Media

Electrical and optical physical layers are needed to meet the range of requirements a unified network must support. Electrical implementations are cheapest (at this point in time) and generally suitable for module to module communications inside a rack. Optical interconnects are immune to EMI and can travel long distances. However, the Optical connectors and cabling for military environments have to be carefully evaluated. Fibre optic system allows WDM (wave division multiplexed) to be implemented to reduce the number physical lines to get weight advantages which finds wide application in sensors. The general level of fault tolerance required of the interconnect is that failures should have a high probability of detection and that no single failure should take down the entire interconnect. Generally this requires a redundant interconnect.
The Table 2 shows the comparison of 3 most popular interconnect media used,

Table 2: Comparison of Different Media

Twisted Pair Cable	Co-Axial Cable	Fibre Optic (MM)
Electrical transmission	Electrical transmission	Optical transmission
Low Noise Immunity	Moderate Noise Immunity	Highest Noise Immunity
Affected by External Magnetic field	Less affected by External Magnetic field	Not affected by Magnetic field
Weight ≈ 16.66kg/km (24 AWG)	Weight ≈30kg/km	Weight<4~5kg/km
Cheapest	Moderately expensive	Expensive
Low Bandwidth	Moderately high bandwidth	Very High Bandwidth
High Attenuation	Low Attenuation	Very Low Attenuation
Easy Installation	Fairly Easy Installation	Difficult Installation

From the table it is clear that fibre optic has the advantages over twisted pair & co-axial cable for military applications where weight is a major constraint. It has low cross talk and low power dissipation with reduced cabling density over conventional copper-based interconnect.

V. Fibre Channel Protocol Overview

FC is a technology of network and bus based communication, which possesses the features of high transfer rate, low latency, long transfer distance and high reliability. FC combines the best features of I/O channel and network communication, such as simple and fast rate of I/O channel, flexibility and strong connection ability of network communication. FC is a hierarchy standard system, and it is composed of five layers as shown in fig. 2.

FC-0, the lowest Fibre Channel layer defines the physical media used to link two Fibre Channel ports, including cable types, data rate, transfer distance, signal mechanism and so on. FC-1 defines the transmission protocol including serial encoding and decoding and error control. The layer also controls the media access, defining the receiving and transmitting. The signalling protocol layer (FC-2) serves as the transport mechanism of Fibre Channel. It defines the data transfer rules, and provides the transmission mechanism between two ports. The FC-2 layer is the most complex layer in the FC structure. It provides different kinds of service such as grouping, sorting, detecting error, subsection, recomposing and flow control. The FC-3 layer is intended to provide the common services required for advanced features including some essential link services, extended link services, network management services and so on. FC-4, the highest level in the FC structure defines the application interfaces that can execute over Fibre Channel.

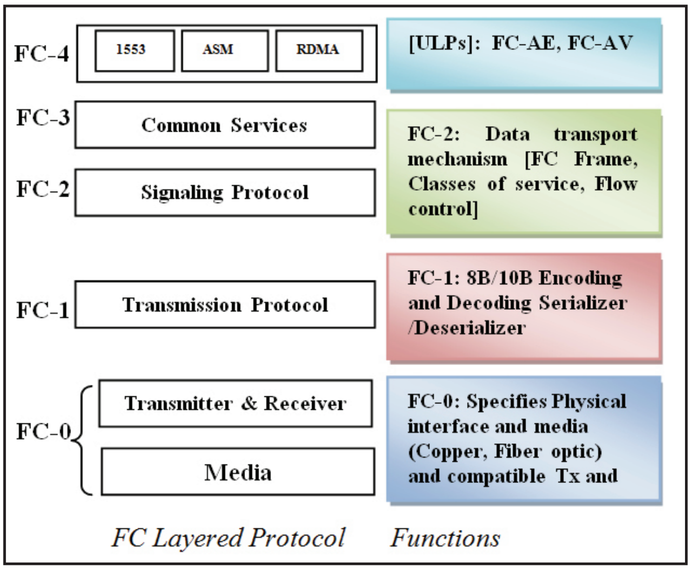

Fig. 2: FC Layered Architecture

The following Upper Layer Protocols (ULP) mapping are currently specified are Small Computer System Interface(SCSI), Internet Protocol (IP), IEEE 802.2, FC-AV,ARINC 818, FC-AE as shown in figure 2. FC-AE are applied widely in military avionics applications.

VI. Fibre Channel Topology

There are three basic types of topologies supported by FC as shown in fig. 3.

- Point-to-point topology
- Fabric topology
- Arbitrated Loop topology

The point to point topology directly connects two N_ports with a bi-direction link and provides maximal private bandwidth. The arbitrated loop connects devices with single direction circular link and provides bi-direction point to point service in logic layer between two L_ports.The fabric topology is the strongest one in FC structure, its core is the fabric which is composed of one or multi –switch and it allows multiple devices communicating in high speed at one time.

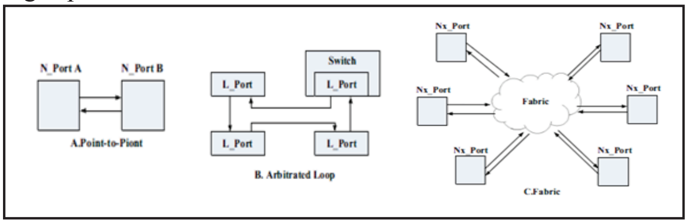

Fig. 3: FC Topologies

Classes of service are distinguished primarily by the level of delivery integrity required for an application. Classes of service are topology independent.
Fibre Channel supports five classes of services.

Class 1 - Circuit Switch

- Guaranteed Bandwidth and Delivery
- Connection Service
- End-to-End Flow Control
- In-Order Delivery
- Circuit Switched

Class 2 - Frame Switch

- Guaranteed Delivery
- Connectionless Service
- Buffer-to-Buffer Flow Control
- Packet Switched

Class 3 - Datagram

- Best Effort Delivery
- Broadcast Datagram
- Packet Switched

Class 4 -Virtual Circuit

- Fabric-assisted, Connection service
- Guaranteed Delivery
- Virtual Connections Between Ports
- Guaranteed Quality of Service

Class 6- Multicast.

- Connection Oriented Service
- The data will be delivered by the fabric by each recipient & acknowledged to the initiator by the fabric.

Class 1 (circuit switch) is a circuit switched operation which guarantees bandwidth and delivery of data. Once a connection is made through a fabric it is maintained until broken by one of the connected N-Ports. Class 1 also offers in-order delivery of data because the connection is maintained and not broken or changed. Latency is minimal because once a connection is made the packet headers are not looked at for destination addressing.

Class 2 (frame switch) is a packet (frame) switched service where packets may be switched on packet frame boundaries within the Fabric. Flow control and data acknowledgments are implemented guaranteeing delivery of the data. Also bandwidth is not guaranteed even though the flow control mechanisms will deliver the data eventually.

Fibre Channel Class 3 (datagram) services is a datagram packet switched service with no guarantees of delivery. Packets may be dropped by the fabric if collisions occur and because there are no acknowledgments, hence, the packet will not be resent.

Fibre Channel Class 4 (virtual circuit) is a fractional connection oriented service which allows a portion of the bandwidth of a connection to an N-Port to be allocated and guaranteed. An N-Port may have up to 254 Virtual Circuits maintained with Quality of Service parameters which include guaranteed bandwidth and latency.

Class 6 is a multicast connection oriented service where data will be delivered by the fabric by each recipient & acknowledged to the initiator by the fabric.

VII. Fibre Channel Frame Format

Communication using Fibre Channel is conducted using a construct called an “exchange.” An exchange in turn, is composed of one or more non-concurring “sequences” for a single operation, with each sequence composed of a series of “frames”.
Each frame consists of

- A start of frame (SOF) indicator (4 Bytes).
- A frame Header (up to 24 Bytes).
- The Payload (2112 Bytes)
- Error checking using cyclic redundancy check (CRC) (4 Bytes)
- The end of frame (EOF) indicator (4 Bytes).

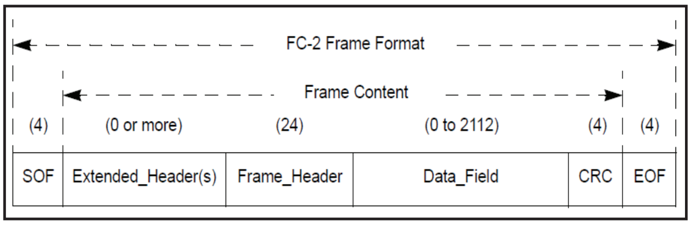

Fig. 4: FC2 Frame Format

Bits Word	31 .. 24	23 .. 16	15 .. 08	07 .. 00
0	R_CTL	D_ID		
1	CS_CTL/Priority	S_ID		
2	TYPE	F_CTL		
3	SEQ_ID	DF_CTL	SEQ_CNT	
4	OX_ID		RX_ID	
5	Parameter			

Fig. 5: Frame_Header Format

The frame Header is used to control link operations and device protocol transfers as well as detect missing or out of order frames. The frame header consists of R_CTL (Routing Control), Address identifier (S_ID, D_ID),CS_CTL /Priority, Type, F_CTL, SEQ_ID, DF_CTL, SEQ_CTL, OX_ID, RX_ID, Parameter. Type Codes are 48h for MIL STD 1553, 49h for FC-AE-ASM, 60h for FC-AV and 61h for ARINC 818.

VIII. Fibre Channel Avionics Environment (FC-AE)

For avionics applications the FC-AE standard specifies a number of upper-level protocols (ULPs) that align more directly with aerospace applications. These are:

- FC-AE-1553;
- FC-AE-ASM (Anonymous Subscriber Messaging);
- FC-AE-RDMA (Remote Direct Memory Access);
- FC-AE-LP (Lightweight Protocol).

FC-AE-1553 is very useful as it allows the MIL-STD-1553 protocol to be mapped on to the high bandwidth FC network, creating a low-overhead highly deterministic protocol with a high bandwidth capability. FC-AE-1553 allows a large number of nodes to communicate increasing from 32 for the baseline 1553 implementation to 2^{24}, while the number of possible sub addresses increases from 32 to 2^{32}. Likewise, the maximum word count increases from 32 to 2^{32}. While these features offer an enormous increase in capability, a further benefit is that FC-AE-1553 provides a bridge between legacy 1553 networks and the much higher-bandwidth FC networks. Therefore, an upgrade introducing an FC network to provide additional bandwidth in certain parts of an avionics architecture can be readily achieved while maintaining those parts that do not require a bandwidth increase intact. The FC-AE-ASM, RDMA and LP options are lightweight protocols that can be variously adopted for specific avionics applications, depending upon the exact requirement.

FC-AE-ASM is a low-latency FC-4 layer communication protocol designed for avionic command, control, and signal processing usage. FC-AE-ASM protocol defines some necessary functions offered in FC-2 layer in order to provide corresponding ASM service in FC-4 layer. Every message in FC-AE-ASM comes from a single unidirectional exchange sequence. The protocol defines that a recipient may expect the message to arrive at a predetermined rate and does not know where the message is originating. If an ASM message exceeds the payload limit of a single FC frame, multiple frames will be used for transmission, and these frames will be reassembled based on Message ID field in ASM header. Moreover, FC-AE-ASM mainly uses Class 3 service which is a connectionless service without any notification of non-delivery. In this way, frames could be routed in different link to arrive at destination and decrease processing overhead brought by notification, which contributes to improve the utilization ratio in FC networks.

ASM protocol that was invented for use of modern avionics programs. It is a very simple Producer-Consumer paradigm. The idea is that avionics applications are designed to be run at periodic rates. Applications by design, expect to consume certain data elements at well-known periodic rates. They will also generate data elements at well-known rates. These applications do not need to be instructed by a master controller when to consume and generate data, they will do it by design. Also inherent in the design is that both the producers of data and the consumers of data are anonymous. FC-AE-ASM can be used to transmit video data with mapping of ADVB frame to ASM frames.

FC-AE RDMA allows a node direct access to a remote node's memory for either reading or writing. FC-AE-LP is a pure FC2 layer hence it is called as RAW mode which provides high throughput and low latency. It is suitable for data monitoring applications.

IX. Proposed Avionics unified Interconnect system based on FC-AE

Based on the preliminary study carried out, it is propose to use FC AE switched fabric network to meet next generation military aircrafts requirements as shown in fig. 6. It's a dual redundant switched fabric network for fault tolerant. It provides the simultaneous communication links between system simultaneously. The proposed upper layer protocols are FC-AE-ASM, FC-AE-1553, FC-AE-RDMA, FC-AE-LP and digital Video frames over ASM for video transmission. Fibre channel broadcast and multicast options are proposed for broadcast data and IRIG B timing synchronisation for Network.

X. Conclusion and Future Work

The avionics system must be able to support new requirements which are forcing changes in the avionics architecture. Conceptual studies have been carried out successfully and worked out the unified network which meets the future aircraft requirement based FC AE protocol. In order to gain the confidence in applying new concept to aircraft, it is planned to setup a lab with the capability of dual redundant switched fabric network.

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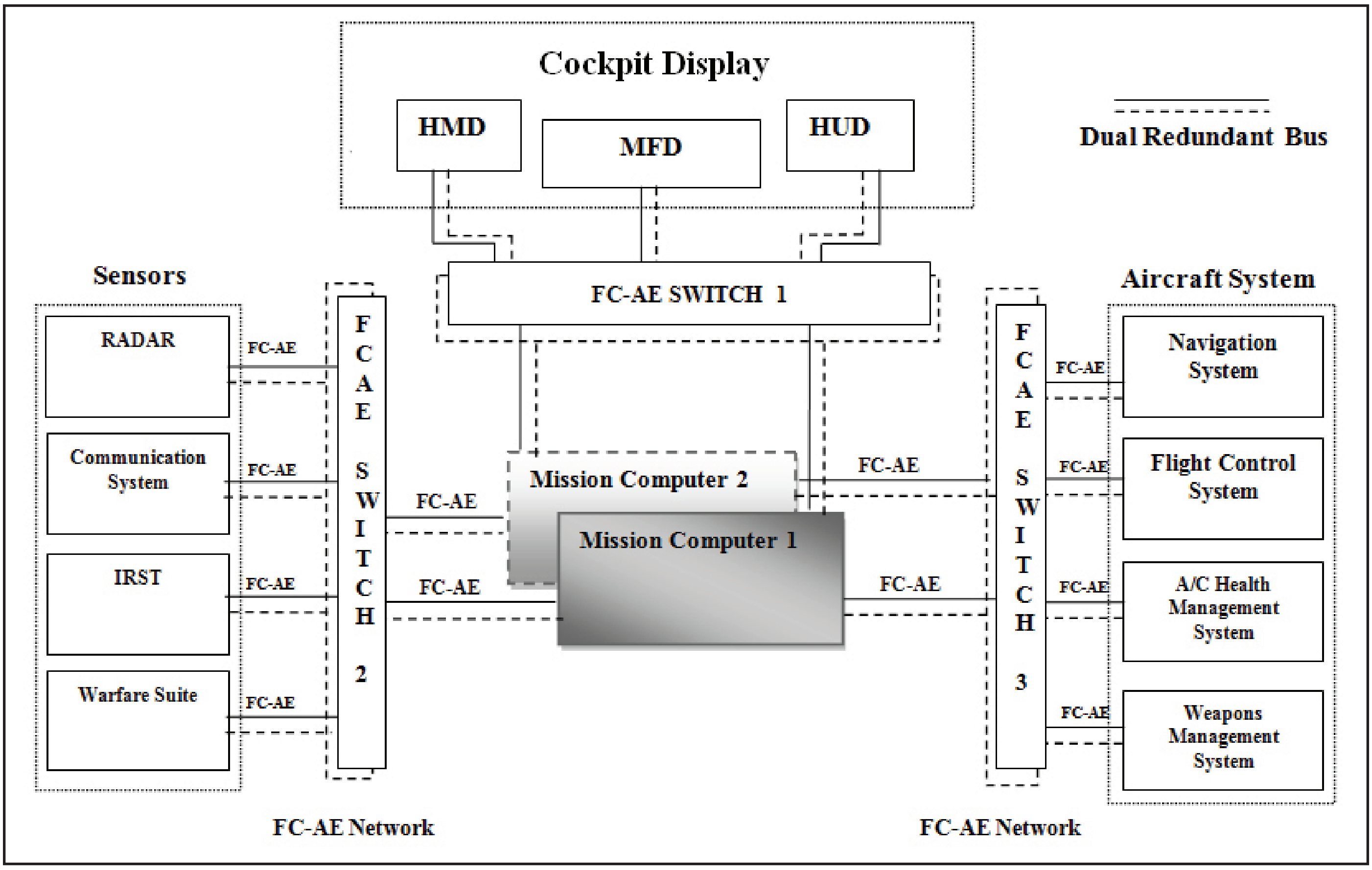

Fig. 6: Proposed Architecture with Switched Fabric Unified Interconnect System