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Avionics Modification Research Analysis: From Electromechanical to Digital Avionics and from Digital to Integrated Modular Avionics (IMA)

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Avionics Modification Research Analysis: From Electromechanical to Digital Avionics and from Digital to Integrated Modular Avionics (IMA)

BY

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DIPLOMA THESIS FOR DEGREE

Master in Aerospace Science and Technology

AT

Universitat Politècnica de Catalunya

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ABSTRACT

The electronic sets that are being used in aviation industry are commonly summarized as “avionic = aviation electronic equipment”. Nearly seventy years ago the first avionics devices used on aircraft were communication and navigation systems based on old gauge instruments and analog systems. Since then, the industry has evolved a lot and today the avionics systems require for new and smarter functionalities thus driving the overall aviation research to an exponential rate towards high grade avionics systems and architectures.

In this research project, a complete investigation has been performed regarding to the maturity of avionics systems from different phases of the development. The report describes in detail the methodologies and constraints related to the avionics modification from electromechanical to digital avionics bus. In addition, the problems regarding to the maintenance and modification of legacy aircraft has been presented in detail.

Using the knowledge acquired in the different phases of avionics modernization, two different top level avionics system design architectures have been developed for a medium jet civilian aircraft with digital avionics systems involving military standard 1553B (MIL-STD-1553B) bus and Integrated Modular Avionics (IMA) e.g. ARINC 653 and ARINC 664 protocols. The top level design presents the complete avionics architecture of the aircraft, the avionics systems used, the data communication between different avionics systems and the complete hardware and software layout architecture.

During the research, some military aircraft such as C-130 Hercules (American) and IL-78 Ilyushin (Russian) were taken as the main study and reference avionics architectures for the modification from electromechanical to digital systems. Apart from these two models, several other aircraft such as F-22 Raptor, Boeing B777 and Airbus A380 were taken as the study cases for the Integrated Modular Avionics (IMA) technology.

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Dedication

To my mother whose prayers were the reason of all the milestones I achieved in my life,

To my father whose guidance always kept me motivated,

To my siblings who always loved and cared for me,

and most importantly!!

To all my course-mates of G-67, Pakistan Air force Academy Rislapur specially Aviation Cadet Mudassir, Sub Lieutenant Syed Yaser Abbas and Flight Lieutenant Muhammad Hamza Nafees who are in heaven now....I dedicate this to all of you my loving brothers.....

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INTRODUCTION

From last three decades it has been huge advancement in the aircraft avionics and electrical systems. The industry has evolved from electromechanical avionics systems to the latest integrated modular avionics systems. Today, the modern avionics systems are more reliable and efficient than the legacy avionics systems. This advancement in the avionics industry passed through several periods of improvement and modification.

In this report, a complete research has been done in order to analyze and identify the different phases of avionics modification from electromechanical systems to the latest digital state of art avionics systems. Hence, in depth research is done to identify the key areas for avionics modification. Several avionics buses and architectures such as MIL-STD-1553B, ARINC 629, ARINC 653, ARINC 664 and architectures of legacy avionics systems have been studied in detail. Furthermore, avionics architectures of several aircraft such as C130 Hercules, Ilyushin IL-78, F22-Raptor, Boeing 777, Airbus A380 and Joint Strike Fighter F-35 also critically analyzed.

Following is a brief introduction to the avionics buses and architectures used for the research:

MIL-STD-1553B: Originally conceived by the US Air Force Wright Patterson development laboratories, it evolved through two iterations from a basic standard, finally ending up with the 1553B standard (see [19]). MIL-STD-1553B is the military specification defining a digital time division command/response multiplexed data bus. The 1553B data bus is a dual-redundant, bidirectional, Manchester II encoded data bus with a high bit error reliability. All bus communications are controlled and initiated by a main bus controller. Remote terminal devices attached to the bus respond to controller commands (see [19]). The 1553B data bus has higher data rate (up to 100mb/sec) then the civilian data buses such as ARINC 429 and ARINC 629 and due to the federated digital architecture and layout, thirty one subsystems or remote terminals can be connected in parallel (see [28]).

ARINC 653: ARINC 653 is a standard developed by aviation system developers that specifies a baseline-operating environment for application software used within the integrated modular avionics system domain. ARINC 653 provides a general-purpose Application Executive (APEX) interface between the Real time Operating System (RTOS) of an avionics computer resource and the application software. ARINC 653 was first adopted in 1997 by the Airlines Electronic Engineering Committee (AEEC). The acceptance of ARINC 653 by both Airbus and Boeing for their latest aircraft has solidified the role of ARINC 653 as an industry standard (see [33][31]).

ARINC 664: It is a specification developed by ARINC and it defines data network that utilizes standard Ethernet like IEE 802.3 and upper layer protocols based on the internet protocols like UDP, IP, and SNMP. ARINC 664 consists of 8 documents. To study Avionics Full-Duplex Switched Ethernet

(AFDX) the main focus is on the part 7 document which is called as avionics full duplex switched Ethernet (see [29]). It is best described as an implementation of the deterministic Ethernet as specified by the ARINC 664 part 7. So AFDX is the implementation of ARINC 664 part 7 network. Developed by the Airbus originally for the A380 program and also used in A350 aircraft (see [33]). It is the trademark term of the Airbus.

Methodology for the research project

This project is divided into five main aspects.

First part: Analysis of legacy avionics systems

In the first part of the project, the theoretical research analysis is done regarding to the aircraft problems with the ageing avionics systems and the problems in the electromechanical avionics systems where many of these aircraft are still being used and are considered airworthy. In this part of analysis, the practical knowledge is also been used from the previous work experience and international visits with the Pakistan Air Force, South African Air Force, Nikolayev aircraft repair plant (Ukraine), Thales and Aquiline international. During this phase of the project two aircraft study cases (i.e. IL-78 and C-130) have been analyzed in detail for the avionics modification.

Furthermore, some solutions have also been proposed for the avionics modification of these aircraft. Also, the constraints and limitations for conducting avionics modification in the legacy aircraft have been researched and analyzed in detail.

Second part: Development of top level avionics system design architecture

In this part of the project the complete theoretical research study is performed on the avionics modification from electromechanical to digital avionics systems. In this phase of the project, the requirements of the avionics modifications have been analyzed in detail. For the avionics modification, the digital avionics buses such as ARINC 629 and MIL-STD-1553B have been studied. Then all the research study regarding to the MIL-STD-1553B has been implemented to develop the top level avionics system design architecture of a medium civilian jet aircraft.

Furthermore, in this part of the research, the baseline of the research study is concentrated on the avionics modification program of United States of America known as C-130 avionics modernization program (AMP) which has used MIL-STD-1553B bus for the avionics modification.

Third part: Research analysis of IMA architecture

This part consist of in depth research study of the Integrated Modular Avionics (IMA) based on the two basic concepts regarding to the Integrated Modular avionics e.g. the ARINC 653 (avionics application standard software interface) and ARINC 664 (avionics full-duplex switched Ethernet). In the course of this research the complete perspective of IMA has been described in detail and at the end of the chapter the complete message protocol layout has been developed regarding to the IMA architecture.

Fourth part: IMA integration process

This part describes the hardware and software system integration process for Integrated Modular Avionics (IMA) architecture of aircraft involving ARINC 653 and ARINC 664 avionics protocols. This chapter focuses on the practical integration process of the IMA system. The concepts regarding to the software and hardware integration and the roles of different suppliers and contractors involved in providing the necessary systems for avionics integration has been described in detail. The main theme of this part relies on the "seven step avionics integration process" which describes in detail that how the IMA system should be developed and installed in an aircraft.

Fifth part: Development of top level avionics design for IMA architecture

Finally in the last chapter of the research, a complete top level avionics design of a medium jet civilian aircraft has been developed involving the state of art IMA architecture. Furthermore, a new IMA design model has been proposed for the aircraft communication, navigation and identification suite that can be employed in the next generation civilian aircraft.

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Chapter 1

Avionics Modification Analysis from Electromechanical to Digital Avionics Systems

1.1. Introduction

Avionics typically referred as "aviation engineering and electronics engineering" is a word that represents all of the communication, navigation and flight management systems used in aircraft for an adequate and safe flight. It also describes the weapon guidance and delivery systems in typical military aircraft.

1.2. Development of avionics over the ages

The legendary Wright brothers had used an avionics instrument known as "anemometer" to calculate the airspeed. Shortly following the visualization of avionics, airplanes were been fitted with magnetic compasses to determine heading and small pressure tubes to measure altitude. In early 1930s, radio navigation and landing aids were developed for aircraft. The Second World War resulted in the development of the avionics systems of aircraft such as "radar" and VHF/UHF and HF communication. In 1960s more advanced systems like autopilots, integrated flight instruments and computerized warning and monitoring systems were developed. At the end of 1970 decade and in early 1980s; digital processors were made, thus supporting the pilots in flying and navigating their aircraft with high level of maturity.

As the technology progressed, the industry developed multi-function high definition displays where now the data can also be displayed in variety of ways. This advancement in display machinery showed the way to so-called glass cockpits.

1.3. Legacy avionics systems

Avionics in current military aircraft around the world are been operated many years further than the formerly projected design life and the average avionics age has exceeded more than 20 years. A parallel condition exists in typical old commercial aircraft. Although the airline industry's fleet size is growing each day, several commercial and transport airlines are still flying the aircraft that were built in the 1970s (see [2][16]).

The costs of maintaining the legacy avionics systems are swiftly increasing owing to several factors such as increasing malfunction rates, less numbers of spare suppliers due to obsolete systems, out-dated instrument parts that cannot be purchased and most importantly the lack of resources to procure replacements for out-dated tools and testers that are used to maintain these legacy aircraft avionics systems.

To deeply analyze the problems associated with the ageing avionics systems and their solutions; some study cases has been analyzed and investigated.

1.4. Study case 1: Ilyushin-78 "IL-78"

IL-78 MP (Multipurpose i.e. for both refuelling and cargo missions both) which is a variant of IL-76 was conceived in 1984. Since then it has being widely used by several air forces in the world for refuelling and cargo missions. Apart from the military usage, it is widely being used as a big cargo aircraft around the world due to the high loading capacity (see [9][11]).

Figure 1.1 Ilyushin-78 "IL-78"

1.4.1. Analog avionics

Since it has been built in the early 80s, the avionics of this aircraft is quiet old. Most of the equipment are analog based and have high power consumption and weight. Each individual avionics system has several Line Replaceable Units (LRUs), which has made the complete avionics system as a very large set of equipment.

Following are the main avionics systems: (see[11]).

- The avionics include two very heavy radars i.e. a ground mapping radar and a weather radar, each with a range of 400 nautical miles.
- Two separate Instrument Landing Systems (ILS)
- Automatic Direction Finders (ADFs)
- Doppler navigation system
- Auto Flight Control System (AFCS)
- Distance Measuring Equipment (DME)
- VHF Omnidirectional Range (VOR)
- Radio altimeter
- Inertial Navigation System (INS)

- The system has V/UHF and HF communication radios and an emergency radio station which enhances the communication link of the system.
- The aircraft has a very reliable and accurate Air Data Computer (ADC) which is providing the aircraft flight parameters for the analog display and also to the different avionics systems.
- There is also a "master computer system" which is used for the execution of navigation and combat formation flights. It is the core of all the systems where it can obtain the output of any system. The master computer is mainly used by the navigator for in-flight computing. It has some redundant set of computing modules which are always present in the aircraft for any adverse case.

Following are the aggregated set of avionics systems which were installed later during the modifications carried out by the avionics designers.

- Ground Proximity Warning System (GPWS).
- Traffic Collision and Avoidance System (TCAS).
- The aircraft is also Reduced Vertical Separation Minima (RVSM) compatible.
- Global Positioning System (GPS) which is an ad on capability in the presence of Inertial Navigation System (INS).

1.4.2. Cockpit arena

IL-78 aircraft has a unique and huge cockpit. There are a total of 5 crew members i.e. pilot, co-pilot, flight engineer, radio operator and navigator. The display of all the avionics systems in the cockpit is analog, where there is no concept of digital display. In the pilot and co-pilot consoles the indicators consist of angle of attack indicator, mach/airspeed indicator, gyro horizon, radio altimeter indicator, turn slip indicator, radio magnetic indicator, vertical speed indicator, course indicator, flight control indicator, distance measuring equipment, course selector and flight instrument indicators.

Figure 1.2 IL-78 Analog Cockpit

In the flight engineers domain consist of the fuel gauge control, throttle and engine starting unit and autopilot engagement modes. The radio operator has separate cabin where the communication system i.e. V/UHF and HF systems are installed and the radio operator is responsible for air-ground or air-air communication link.

1.4.3. Avionics problems and reasons for upgrade

Today in the 21st century, the glass cockpit is the future of aviation industry. The IL-78 aircraft has an old analog avionics system which has to be modified according to the new avionics architecture. The existing cockpit consists of electromechanical systems of 80s technology with individual control panels and instrumentation circulated throughout the aircraft. Breakdown rates are sometimes soaring and the repairing capability has been restricted significantly as the technology has changed.
Not only are the maintenance to the IL-78‘s existing suite costly, but means more down time for aircraft while repairs are made. Modern commercial avionics are more reliable than those on-board the IL-78. The mission capable rate of the aircraft continues to fall due to the unavailability of the avionics required to be fully or partially mission capable (partially mission capable may be due to maintenance, supply, or both). Cost to support aging avionics architectures and hardware is a primary driver for the avionics upgrades for IL-78. The technologies used in the early life of the fleet have relatively low reliability and maintainability compared to modern designs which are used in the glass cockpit avionics. The processing equipment on-board IL-78 has a distributed architecture often with several large and heavy components comprising a fairly simple set of subsystem functionality. For example, the function of a simple ILS system is comprised of five line replaceable units (LRUs).

Following are the main reasons for the upgrade of avionics systems.

- **New and enhanced mission requirements:** This legacy avionics design is generally based on technology that is at least 28 years old (see [9]) and at least 2-3 orders of magnitude slower than commercial equipment available today. Thus, legacy designs do not have sufficient capacity to meet requirements demanded by the new and enhanced mission requirements.

- **Increased reliability and better fault isolation:** Upgrades using modern technology allow for increased reliability because fewer parts and fewer interfaces are required to provide the same functionality, thus providing Life Cycle Cost (LCC) savings potential. This can also lead to better fault isolation.

- **Component obsolescence:** The components used on legacy systems are becoming obsolete at an increasing rate. This provides an opportunity to upgrade the system using Commercial Off The Shelf (COTS) parts and thus providing substantial LCC savings.

1.4.4. Avionics modification analysis

As commented above, the IL-78 aircraft has analog avionics systems. This aircraft needs a major avionics modification. There are three possible options in order to modify the avionics of this aircraft.

1.4.4.1. By installing the digital bus on the aircraft thus making it a glass cockpit aircraft

Taking the first option, which is a costly option but a good and reliable option is the complete avionics modification of the aircraft, where a multiplex bus must be incorporated and a new state of art glass cockpit should be made. This is and will be a very tough, demanding and costly option but it will be a long lasting effort if the industry wants to use this aircraft for extended period of time.

1.4.4.2. By replacing individual systems on the aircraft

The second option that is the replacement of an individual system is not an easy task; even more difficult when there is no avionics bus installed and the coupling of each system has to be analyzed in deep. This is a very difficult task and have analyzed in much detail (see [11]) the avionics architecture where the coupling of avionics systems is very intense especially with the major systems such as air data computer, compass system and auto flight control system. For this, the industry will have to change the major avionics controls of the aircraft. The volume, weight, power requirement, heat generation, physical makeup, environmental constraints and unique restrictions such as cable lengths have to be studied in detail before proceeding for such modification. Furthermore, if existing on-board software or hardware requires modification, all of the interfaces will need to be re-analyzed and tested. This may require re-qualification of the impacted systems with full tests to insure that they are still functioning; where overall systems analysis will be performed again.

1.4.4.3. By adding new systems on the aircraft in the presence of existing ones

The third option which is not an exceptional option but it is a cost effective and straightforward option, where the individual systems will not be changed or replaced rather new systems will be installed, which will definitely enhance the redundancy of the system and enhance the cockpit layout. Now this layout will be an add-on feature on the IL-78 aircraft because the previous systems will be remained as same but it will definitely give some improvement. Examples of such modifications are the re-layout of controls and displays on consoles, external modifications for antennas/ radomes, additional wire/cable runs, flight control modifications and improving the interfaces with other systems.

These are the three practical solutions on avionics modification of IL-78 aircraft.

1.4.5. Constraints related to avionics modification

To modify the avionics of the aircraft the three main aspects have already been presented in the above paragraphs. Following are some of the constraints that should be analyzed while modifying the avionics of the aircraft.

1.4.5.1. Aircraft avionics modification without using digital multiplex bus

Without the digital avionics bus there are primarily two options for avionics modification; first by replacing individual systems on the aircraft by digital systems and second by adding new systems on the aircraft in the presence of existing ones. A list of considerations which should be taken into account when avionics equipment is been installed in an aircraft is shown as following.

1.4.5.2. Verification of power consumption

The verification of the overall power consumption, specific load analysis and frequency voltages for each phase of flight is the key for adding new avionics systems in an aircraft. These include verifications of line voltage variations, power usage during ground running (Auxiliary Power Unit (APU) or ground power) and power consumptions in engine failure circumstances.

1.4.5.3. Antenna locations possible problems

Does the antenna systems require shadowing? And does the antennas systems need any special requirements (e.g. some instruments requires preamplifiers).

1.4.5.4. Electromagnetic Compatibility (EMC)

The designer must be conscious of the types of signals on all of the wires and cables leading to and from the equipment for the electromagnetic interference issue.

1.4.5.5. Physical location

Calculation of the actual length of power cables which is related to the power loss factor and calculation of the actual length of antenna cables which is related to the signal loss factor.

1.4.5.6. Documentation and technical orders

Amendment and modifications in the documentation and certifications of all of the wiring drawings, structural drawings, Electromagnetic Interference (EMI) test plan and revision in the pilot’s instruction manual.

1.4.6. Aircraft avionics modification using digital multiplex bus

The other method of avionics modification is by installing the digital bus on the aircraft thus making it a glass cockpit aircraft. To modify the existing platform with the state of art new glass cockpit; the aircraft avionics system requires a lot of considerations and costs.

- Complete wiring of the aircraft is being replaced by new digital avionics multiplex buses.
- The flight control system is replaced with the fly-by-wire control system.
- All the avionics systems are replaced by those systems which can be coupled with the digital bus.
- It should be kept into consideration that the new avionics system installed has got similar or more functionalities than the previous avionics system and no key parameter of aircraft performance has been disturbed.

1.5. Study case 2: C-130 Hercules

The Lockheed C-130 "Hercules" is a four-engine turboprop military transport aircraft which was designed and built by Lockheed Martin. It was built in 1950s and since then several versions of this aircraft have been developed.

The C-130 is an efficient, multipurpose aircraft that is ideal for the airlift, aero medical and natural disaster relief missions. The aircraft's range of displays is located in areas dictated by the specific mission model requirements (see [15]). Many of the instruments are old, difficult to locate, require frequent maintenance and are expensive to purchase.

Thus as this aircraft is part of the legacy aircraft with ageing avionics systems, in late 90's the US DOD (United States Department of Defense) decided to modernize the avionics with the state of art digital glass cockpit (see [3]).

Figure 1.3 C-130 Hercules. Courtesy Airliners.net (see [45])

1.5.1. C-130 Avionics Modernization Program (AMP)

The contract was given to Boeing in June 2001, and by the end of 2003 the initial design review was completed and in January 2005, the first aircraft was received with the new state of art glass cockpit. The C-130 AMP was started to modernize, standardize and decrease the total ownership costs for the United States Air Force C-130 fleet (see [3])

The central building block for Boeing's AMP design is communication, navigation, surveillance / air traffic management compliance. Without these systems, the C-130 fleet would be prohibited from certain worldwide air-navigation routes.

The main features of the avionics modification program is as follows: (see [3][8][9][15])

- Complete set of avionics systems are being replaced by the state of art digital avionics systems.
- The 1553B digital multiplex bus architecture is being utilized as the core system design layout architecture for the avionics systems of the aircraft.
- Modern digital glass cockpit featuring Multi-Function Displays (MFDs), pilot and co-pilot wide field of view Head Up Displays (HUDs), two Communication and Navigation Control Panels (CNCPs), and Night Vision Imaging System (NVIS) compliance.
- These modifications thus prepare the C-130 for another 30 years of service.

Thus with AMP the avionics of C-130's are being modernized from old electromechanical to the digital state of art avionics systems.

Figure 1.4 Modified version of C130. Courtesy Boeing (see [3])

1.5.2. Key benefits of the avionics modernization

Following are the main benefits of AMP: (see [3][8][9][15])

- The enhanced digital avionics of the AMP upgrade increases the overall situational awareness over the old analog cockpits.
- The system makes more information readily available.
- It simplifies tasks and decreases the work-load, which then maximizes performance and minimizes the possibility for accidents.
- The configuration of the AMP cockpit also cuts the time that crews need to calibrate, remove and repair instruments. So there is less down-time for the aircraft, greater repair part accessibility, less chance for human error due to misinterpretation or unfamiliarity with the equipment and improved morale of the maintainer.
- The aircrew size and application of new digital equipment in a standardized glass cockpit configuration will allow for reduction of and savings in manpower and ease of reassignment and deployment.

The C-130 AMP is a comprehensive program that features digital displays and the Boeing 737 commercial airliner's proven flight management system, both of which provide navigation, safety, and communication improvements to meet Communication Navigation Surveillance / Air Traffic Management (CNS/ATM) requirements.

1.6. Future of old electromechanical aircraft systems: Installation of digital bus

The cockpits of the early transport aircraft were quite different from those developed today. Older cockpits contained numerous "old steam gauge" style indicators. These indicators were displaying essential aircraft information such as altitude, airspeed, fuel and various engine parameters. As technology advanced, these older electromechanical indicators were gradually replaced by newer and more reliable digital systems.

Initially, each of the digital system had a "stand-alone" system performing the intended function. The human interface is given little consideration in the layout of the cockpit. Human qualities and failure modes were not taken into account in the cockpit design process. As the number of systems, components, indicators and switches multiplied, the potential for human and instrument error also grew.

These stand-alone systems, along with their related indicators and switches, have now been implemented using digital technology. The integration of digital flight control and avionics systems has given a new trend in aviation systems. This trend yields cockpits of greater complexity and has lessen the amount of information for the crew. The way the pilot controls and monitors the present digital state of the art aircraft has also been greatly influenced by the increased use of digital systems. Digital flight control and avionics systems have significant advantages, such as higher speed, less power consumption, reduced weight, lower volume, and lower cost when contrasted to older electromechanical systems. These systems are being used increasingly in modern aircraft.

The use of this technology has opened the door for massive integration of the once stand-alone systems, through the use of data bus interconnections. Additionally, new methods of aircraft system monitoring and control are being researched and implemented. All this is possible due to the employment of digital bus in the cockpits where the new state of art glass cockpit is being developed using the digital bus technology such as ARINC 629 and MIL-STD-1553B.

1.7. Avionics modification: Concluding remarks

In this first part of this report, two aircraft models have been analyzed i.e. one which is still flying with the old electrometrical systems (IL-78) and the second one which is now being modified with state of art new glass cockpit (C130).

During the last three decades in the aviation industry, specific set of system level improvements were executed to meet latest requirements in the legacy aircraft. Thus, these bit-by-bit enhancements in the avionics systems had resulted in designs that only support a particular proposed problem and specific aircraft platform.

Furthermore, several of these small bit upgrades were not valid to successive modifications and upgrades of the equivalent subsystem, and in due course of time these upgrades were layered and layered upon each other; thus increasing the maintenance problems of the aircraft. These new coupling and links of the old systems had made the certification problem even more complex as major parts of the avionics system were to be recertified, thus making this a very costly option.

Nowadays the commercial digital technologies have been improved a lot over the past decade. The new advanced data and signal processing capability enhances the prospects for extending the life expectancy of the legacy aircraft. Thus the only way to use these legacy aircraft platforms for long-term usage is to perform a complete avionics modification involving a digital multiplex bus and making an avionics architecture which should be in line with the Global Air Transport Management (GATM) and other aviation standards for adequate flying.

Chapter 2

Top Level Avionics System Design Architecture for MIL-STD-1553B Bus

2.1. Introduction

In this chapter the background involving the avionics architecture has been presented and then top level avionics system design architecture of a medium jet aircraft has been developed using the digital avionics bus 1553B. The platform selected is the commercial medium jet aircraft such as Cessna Citation Excel, Learjet 45, and Hawker 800XP (see [17]). Normally the civilian aircraft use ARINC 429/629 buses for their avionics architectures (see [12]).

In this research the military avionics bus such as MIL-STD-1553B has been used to design the top level avionics architecture of a medium civilian jet aircraft. The key features of MIL-STD-1553B and federated architecture have been used to make new design architecture for a civilian platform.

2.2. Background for developing an avionics architecture

While designing the avionics architecture of the aircraft, the platform of the system and the mission requirements are the two primary driving sources. On behalf of military the ministry of defence prepares the technical document named as the statement of purpose and give the exact requirements to the industry designers (see [12]). In that document all the rationales regarding to mission requirements, principles and rules of engagement are being analyzed carefully. The aircraft of the civil industry are driven by the customer airline needs. Also, the safety and balanced set of avionics systems is the key for designing an adequate architecture for civilian platforms. For the overall design all the mission and flight phases are being examined at the lowest possible level to establish the avionics design requirements.

2.3. Avionics architecture

For designing the architecture of this platform; the federated digital architecture is chosen which is shown in Figure 2.1. This architecture is principally based upon the availability of the extremely widely used MIL-STD-1553B data bus. Originally conceived by the US Air Force Wright Patterson development laboratories, as they were called at the time, it evolved through two iterations from a basic standard, finally ending-up with the 1553B standard (see [19]).

The traditional implementation technique for avionics can be characterized as federated; this means that each aircraft function consists of a stand-alone composition of sensors, processing units and actuators. Characteristics of these federated architectures (Figure 2.1) are that each system has its own interface to sensors and actuators.

Salient features of federated architecture.

- Each system has own computers performing individual functions
- Employs digital bus
- Reliability and availability determined by LRUs

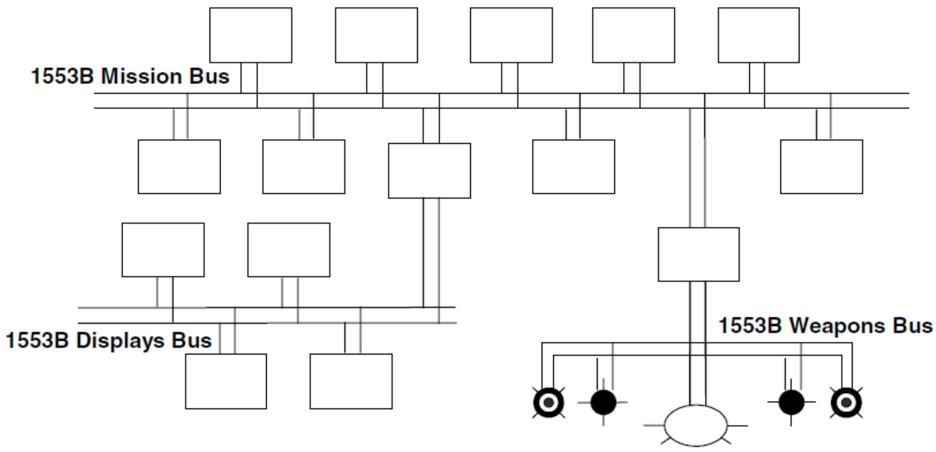

Figure 2.1 Federated digital architecture of a military aircraft (see [12])

Federated architectures generally use dedicated 1553B-interfaced line replaceable units (LRUs) and subsystems. MIL-STD-1553B is the military specification defining a digital time division command/response multiplexed data bus. The 1553B data bus is a dual-redundant, bidirectional, Manchester II encoded data bus with a high bit error reliability. All bus communications are controlled and initiated by a main bus controller. Remote terminal devices attached to the bus respond to controller commands (see [19]). The 1553B data bus has higher data rate (1mb/sec to 100mb/sec) (see [28]) then the civilian data buses such as ARINC 429 (100kb/sec) and ARINC 629 (2mb/sec) (see [28]) and due to the federated digital architecture and layout, thirty one subsystems or remote terminals can be connected in parallel.

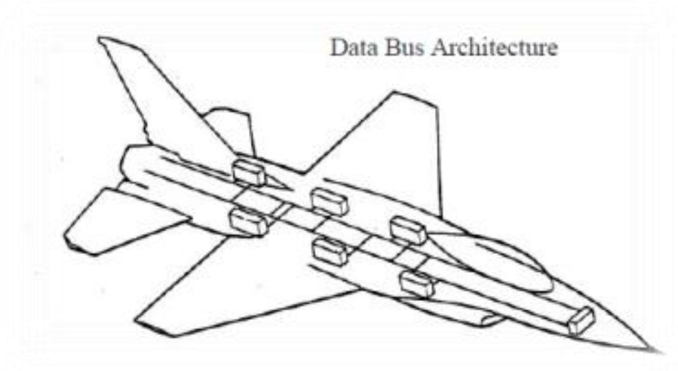

Figure 2.2 MIL-STD-1553B Data bus architecture (see [19])

2.4. Main avionics systems

The platform selected is the commercial medium jet aircraft such as Cessna Citation Excel, Learjet 45 or Hawker 800XP. Following are the typical avionics systems used in these types of aircraft (see [21]).

- Head Up Display (HUD)
- Hands On Throttle And Stick (HOTAS)
- Multifunction Displays (MFD)
- Digital video recorder (DVR)
- Combined inertial navigation and Global Navigation Satellite System (GNSS) platform
- Altitude Heading and Reference System (AHRS)
- VHF/UHF Communication radio (COM 1)
- HF Communication radio (COM 2)
- Radio Altimeter (RA)
- Instrument Landing System (ILS)
- VHF Omni-directional Range (VOR)
- Distance Measuring Equipment (DME)
- Non-Directional radio Beacon (NDB)/Automatic Direction Finder (ADF)
- Air Data Computer (ADC)
- Traffic Collision And Avoidance System (TCAS)
- Electronic Ground Proximity Warning System (EGPWS)
- Radar

2.5. Federated avionics architecture: MIL-STD-1553B Bus

Typically federated avionics architecture consists of several specialized processors to execute avionics functions. These processors are managed by the mission computer also known as "Master Computer" and are connected by a multiplex data bus 1553B with all the avionics systems. The data bus 1553B is designed to have a bus controller which manages the data within a bus; and that is the "Master Computer".

Now in the next part of the research the theoretical and practical knowledge has been used to make the top level avionics system design architecture of a medium civilian jet aircraft. All the avionics subsystems are connected through 1553B bus. Some systems also make use of serial data bus such as RS-422 and RS-232 (see [18]) for point to point communication between specific avionics systems. The architecture has twice redundant multiplex bus as Bus A and Bus B and all the critical avionics systems are dual redundant. These avionics systems include air data computer, communication radios, mission computer, multifunction displays, avoidance systems and global navigation satellite system.

Following are the main avionics systems with their subsystems.

1. Mission Management Subsystem

- Mission Management Computer 1 (MMC1)
- Mission Management Computer 2 (MMC2)
- Head Up Display (HUD)
- Hands On Throttle And Stick (HOTAS)
- Three Multifunction display (left multifunction display, right multifunction display, center multifunction display) (MFDs)
- Center Control Panel (CCP)
- System avionics startup panel
- Digital video recorder

2. Inertial navigation system

- Combined inertial navigation and Global Navigation Satellite System (GNSS) platform (INS/GNSS)
- Altitude Heading and Reference System (AHRS)

3. Communication, Navigation and Identification (CNI) suite

- Twice redundant VHF/UHF communication radio and HF communication radio
- Audio Control panel
- Radio Altimeter (RA)
- Instrument Landing System (ILS)
- Distance Measuring Equipment (DME)
- Non-Directional radio Beacon (NDB)/Automatic Direction Finder (ADF)

4. Mission electro mechanical management system

- Mission Electromechanical Management Computer (MEMC)
- Backup Avionics Display Unit (BADU)
- Warning System (WS)

5. **Air Data Computer (ADC)**
6. **Aerial flight data: Bus monitor**
7. **Weather Radar**
8. **Avoidance systems**

- Traffic Collision and Avoidance System (TCAS)
- Electronic Ground Proximity Warning System (EGPWS)

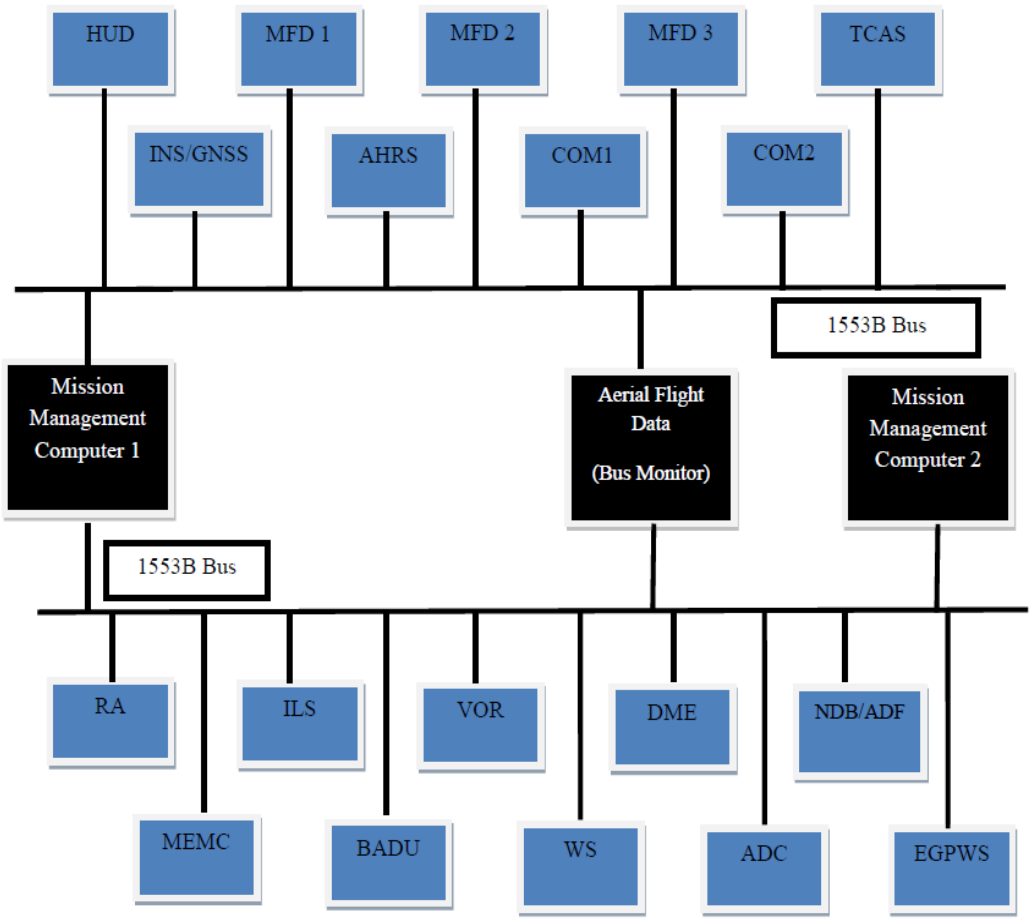

Figure 2.3 Top level design of the aircraft avionics architecture

2.5.1. Mission management subsystem

In this system there are all the avionics systems which are used for controlling and monitoring the different mission phases of the flight. Following are the main sub-systems.

2.5.1.1. Mission Management Computer (MMC1)

The mission management computer is the management controller of the complete aircraft avionics systems. It plays the role of integrated management of the avionics system. It acts as an avionics multiplex bus controller; controls and implement the overall mission plans and navigation and controls in general the flight control system. Furthermore it is also responsible for the data transfer and storage, warning messages and display recording. Mission management computer directly implements the controls of hands on throttle and stick (HOTAS), central control panel and system avionics startup panel. It routes all the data information from different avionics systems to the MFDs and HUD.

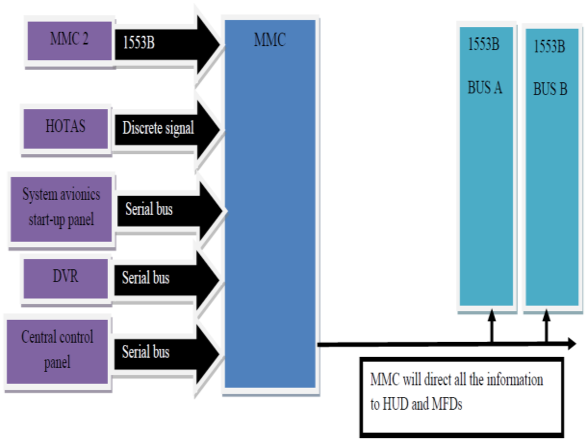

Figure 2.4 MMC layout architecture

2.5.1.2. Mission Management Computer (MMC2)

The MMC2 has all the same functionalities as of MMC1. This system is used as a redundant or a backup system. In case of failure of MMC1 the MMC2 will take over the command of aircraft avionics systems.

2.5.1.3. Head Up Display (HUD)

It is an optical and electronic device that projects symbols of key aircraft parameters in the pilot forward field of view. The HUD is directly linked with the 1553B Bus where all the required data is provided by different avionics systems where the MMC directs the information from avionics systems to HUD. The main parameters shown on the HUD are airspeed, altitude, horizon line, heading, flight path vector, angle of attack indicator and cues on ILS systems.

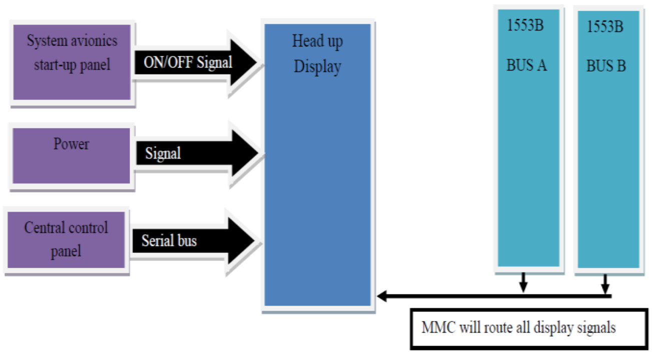

Figure 2.5 HUD layout architecture

2.5.1.4. Hands On Throttle And Stick (HOTAS)

It allows pilot to control the main aircraft functions without removing his hands from the stick. This system is connected with MMC through serial link (see [18]). The HOTAS controls the autopilot engage or disengage mode ,controlling of the radar, selection of the MFDs control, thrust control functions and flight control function.

2.5.1.5. Three Multifunction Displays (MFDs) (Left multifunction display, Right multifunction display, Center multifunction display)

The MFDs are capable of displaying, and generating graphics or text. Push button switches on the front main panel of MFDs are used to ask or request certain display options from external display processor connected to MFDs. All the avionics information can be taken on any of the three MFDs. It will be according to the pilot's discretion that what type of data exactly he needs on each display. The MFDs communicates with MMC through 1553B bus and with backup avionics display unit. If in worst case scenario the MMC has failed or there is a big problem in the twice redundant bus the key aircraft parameters from the avionics system will be received by the backup avionics display unit and then it will be transferred to the MFDs.

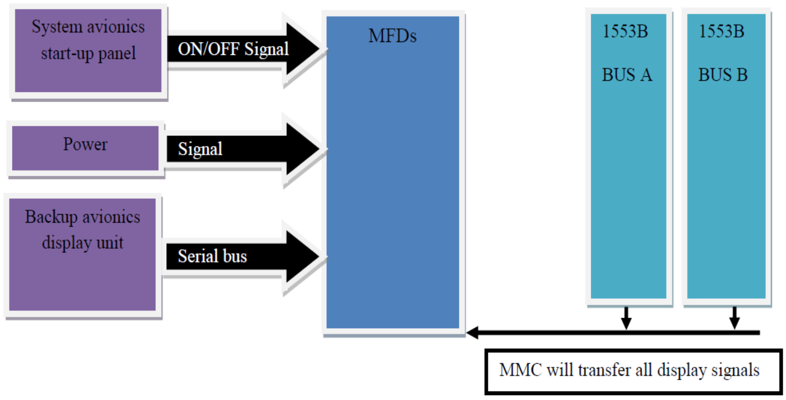

Figure 2.6 MFD layout architecture

2.5.1.6. Center Control Panel (CCP)

It is a keyboard combined with alphanumeric display. It will enable the pilot to update navigation and guidance, communication and autopilot data to operate the functions. It is like Flight Management System (FMS) where this central control panel acts as a Control Display Unit (CDU) as in FMS and the MMC also acts as the Flight management computer (FMC).

2.5.1.7. System avionics startup panel

It is the system used for the activation (power on/off) of the avionics systems in the aircraft.

2.5.1.8. Digital video recorder

It is used for the video collection and display recording while aircraft is flying.

2.5.2. Inertial Navigation System (INS)

This system calculates the inertial navigation parameters of the aircraft and sends them for display.

2.5.2.1. Combined Inertial Navigation and Global Navigation Satellite System platform (INS/GNSS)

It is a navigator system designed for the aircraft. The INS/GNSS platform receives the real-time data of the GNSS for the cross solution. It measures the angular rates and linear accelerations of the aircraft provide following output data for display such as accelerations, velocity, position (longitude, latitude, altitude), magnetic variation, attitude (pitch and roll) and heading.

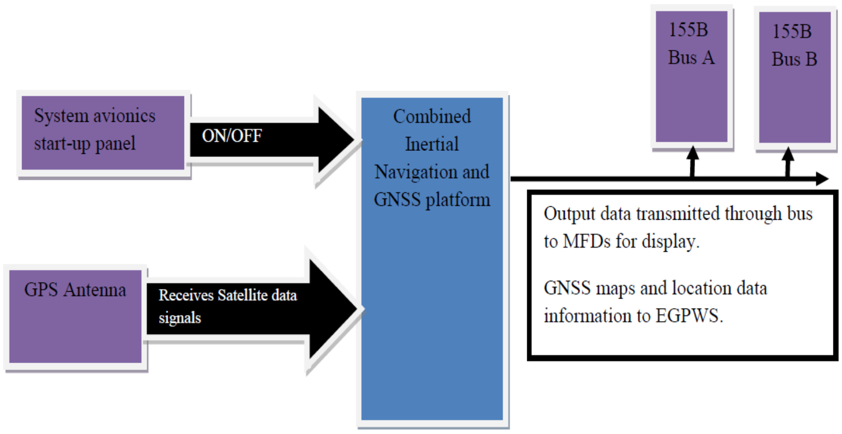

Figure 2.7 INS/GNSS layout architecture

2.5.2.2. Altitude heading and reference system (AHRS)

It is the backup of the INS system in providing heading and attitude signals. Thus it provides the real-time parameters of attitude (roll, pitch) and heading signals for the aircraft. The AHRS acquires airspeed and true angle of attack from pressure transducers and corrects the attitude using kalman filtering. Also it receives the magnetic heading signals from strap down magnetic sensor to correct heading. At last AHRS outputs the attitude and heading signals to MMC for recording and system backup redundant avionics display unit for display. It receives three axis earth magnetic field and signals from magnetic sensor, airspeed and angle of attack from pressure transducers and angular velocity and linear acceleration data from AHRS. It sends heading and attitude information to backup avionics display unit and MMC for recording.

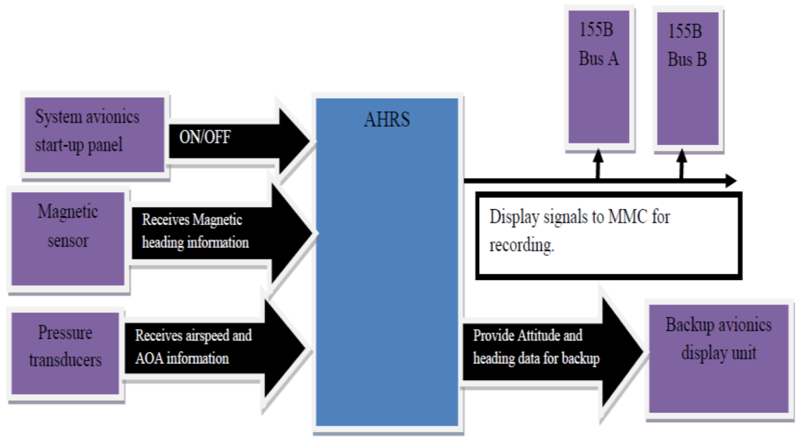

Figure 2.8 AHRS layout architecture

2.5.3. Communication, Navigation and Identification (CNI) suite

This complete suite provides the communication navigation and identification of aircraft with ground installations and aerial vehicles.

2.5.3.1. Twice redundant VHF/UHF and HF communication radio

There are two communication radios COM1 and COM2. Both the radios work on the VHF/UHF frequencies and also provide data link capability. Also there is HF radio for long distance communication. The HOTAS unit is connected to MMC for Push to Talk (PTT) inquiry. Thus the pilot sends the command from PTT button on HOTAS which is indirectly delivered to the COM radios and then when pilot speaks, his voice is been transmitted. The pilot microphone and the head set are directly connected to the COM radios.

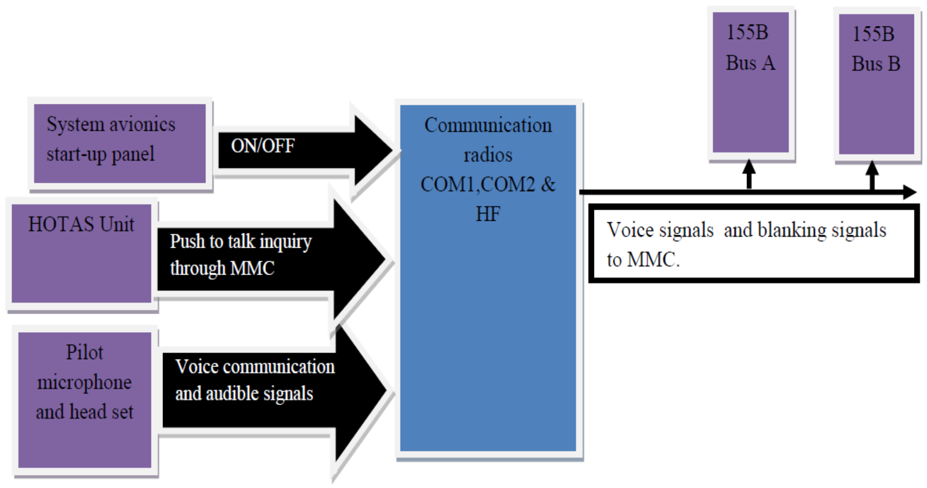

Figure 2.9 Communication system layout architecture

2.5.3.2. Audio control panel

This is the control panel to manage the audio setup of the aircraft communication system.

2.5.3.3. Radio altimeter

This subsystem works on principle of radar technology to calculate the height of the aircraft from ground. The main components include the transceiver and a receiving and transmitting antenna which calculates the height related to ground. This altitude data is being used by the electronic ground proximity warning system and displayed on the MFDs.

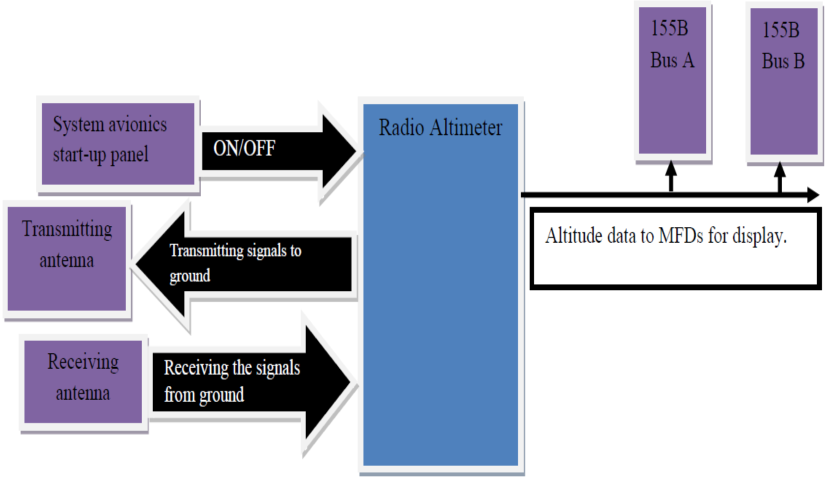

Figure 2.10 Radio altimeter layout architecture

2.5.3.4. Instrument Landing System (ILS)

It will provide azimuth and elevation from landing course for approach and landing phase. The main components include the receiver unit, antenna coupler and the antennas. The main outputs include the ILS audio identification signals and aircraft azimuth and elevation signals for the backup display.

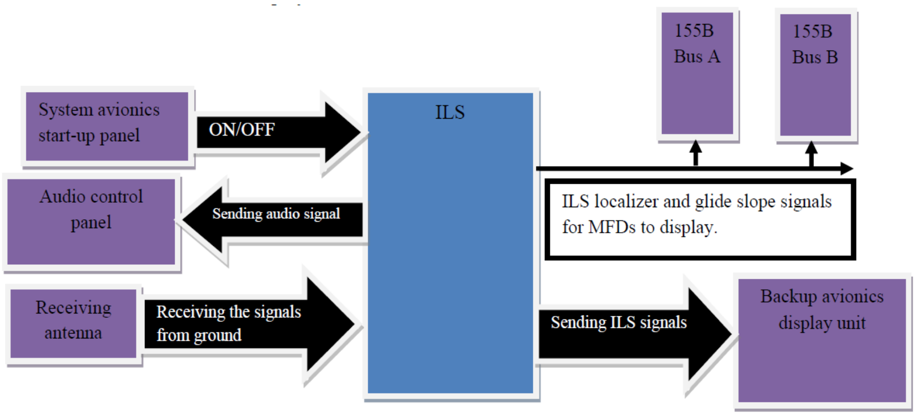

Figure 2.11 ILS layout architecture

2.5.3.5. VHF Omni-directional Range (VOR)

It provides continuous selection of course around a circle with round station at the center. The main components include the VOR receiver and antenna. The data will be displayed on the MFDs.

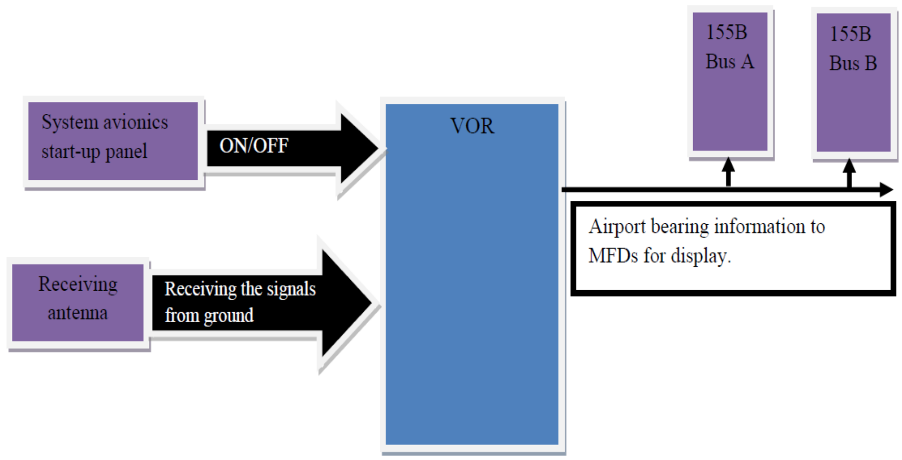

Figure 2.12 VOR layout architecture

2.5.3.6. Distance Measuring Equipment (DME)

It behaves like secondary radar. To measure the distance, interrogator (transponder airborne part of the DME) transmits an encoded signal. The ground station containing a transponder replies to the interrogation. The main parts include an interrogator/transponder and an antenna. The resulted distance is being displayed on the MFDs.

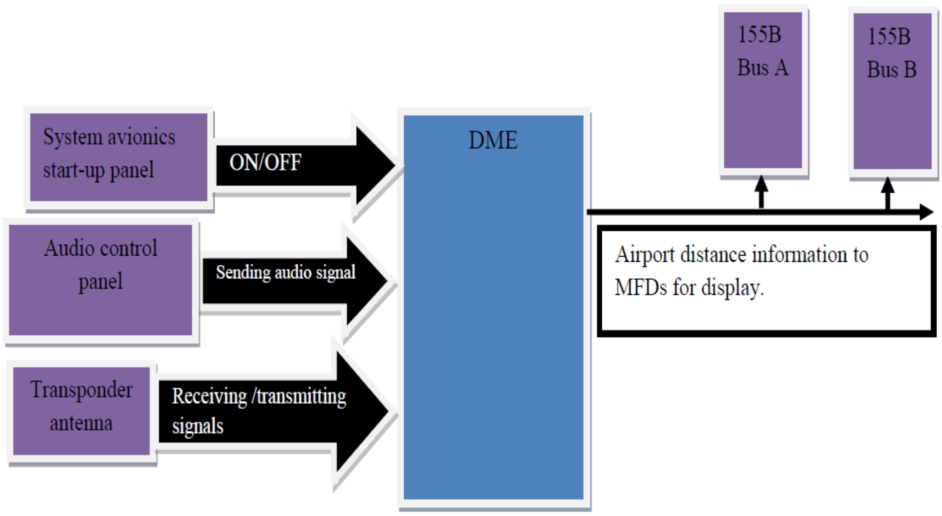

Figure 2.13 DME layout architecture

2.5.3.7. Non-Directional radio Beacon (NDB) / Automatic Direction Finder (ADF)

The NDB receives the correct bearing of the airport in the HF frequency range. It will provide the audio signals when approaching a fixed range to the airdrome zone.

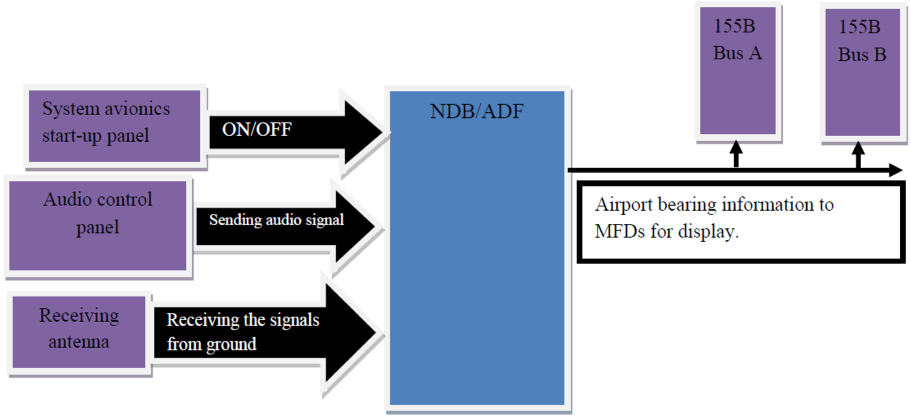

Figure 2.14 NDB/ADF layout architecture

2.5.4. Mission electro mechanical management system

This system manages the mechanical part of the aircraft avionics system.

2.5.4.1. Mission Electromechanical Management Computer (MEMC)

It is used for the data acquisition and management of all the electric and mechanical systems on the aircraft, and transfers the related parameters to aircraft systems and avionics system. Major functions include as monitoring of non avionics subsystems, data acquisition, and transfer non avionics subsystem display upon request and record aircraft flight parameters. Following are non avionics system interfaces with MEMC which provide all their information to this system. The MEMC will give this information to MMC for pilot display and action.

- Engine system
- Landing gear
- Fuel system
- Hydraulic system
- Cockpit Pressurization system
- Flight Control system

Following systems information are needed by the MEMC for the configuration of other mechanical systems such cockpit pressurization system and for recording.

- Air Data computer
- AHRS

- Backup avionics display unit

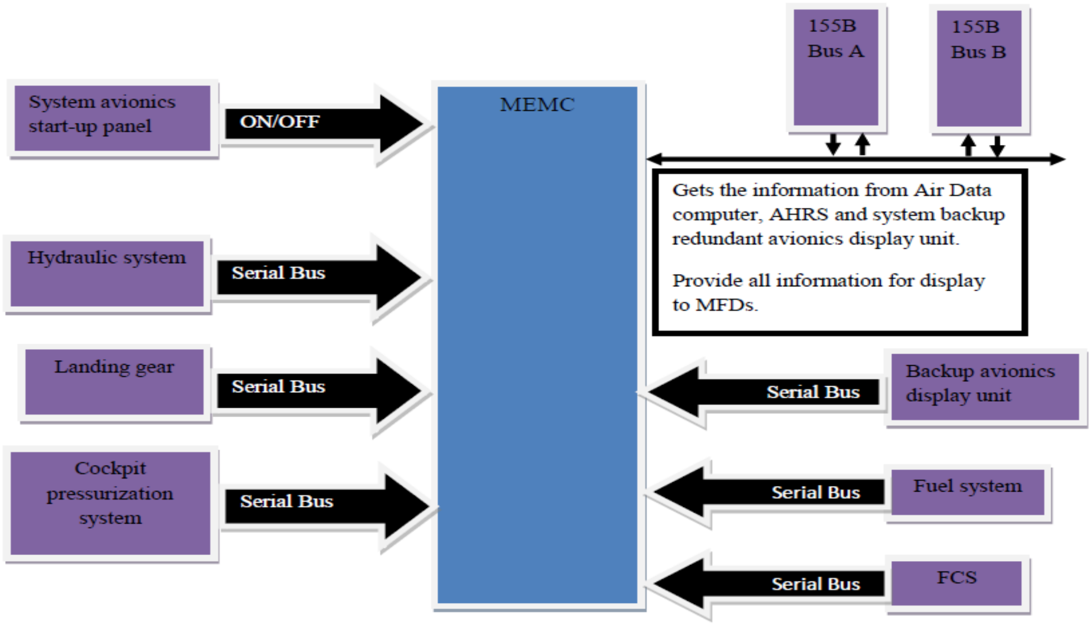

Figure 2.15 MEMC layout architecture

2.5.4.2. Backup avionics display unit

It is a backup unit of the avionics systems, which gives the backup output information to the MFDs for display in case of any major avionics system failure. This system obtains key information from Air data computer, Altitude heading and reference system, engine parameters, ILS, hydraulic system and fuel system. The main outputs include such as fuel quantity, magnetic heading, pitch, roll, calibrated airspeed, mach no, angle of attack, cockpit pressure, brakes pressure, localizer and glide slope deviation

It receives information from pressure transducers of air data computer, magnetic heading and attitude information from altitude heading and reference system, localizer deviation and glide slope deviation from ILS, engine parameters from engines and fuel quantity data from fuel measurement units. Then it transmits all the data to MFDs for display and MMC for recording.

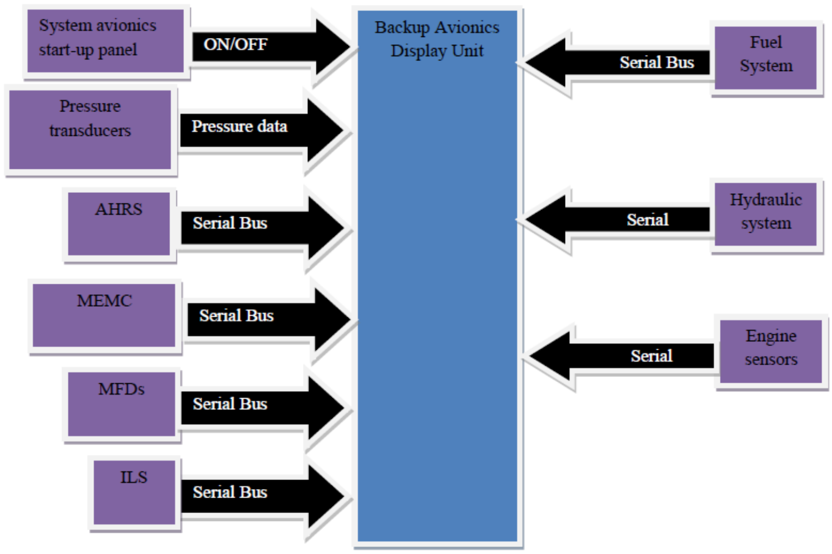

Figure 2.16 Backup avionics display unit layout architecture

2.5.4.3. Warning system

The warning system includes warning computer and two or three lamp warning panels according to the system configuration. It provides pilot with the fault warning information of aircraft system and equipment, operational status information of important system and warning of FCS systems.

It has interface with engine, fuel system, power supply, hydraulic system, brakes, and cockpit pressurization system, FCS, MMC and EMMC.

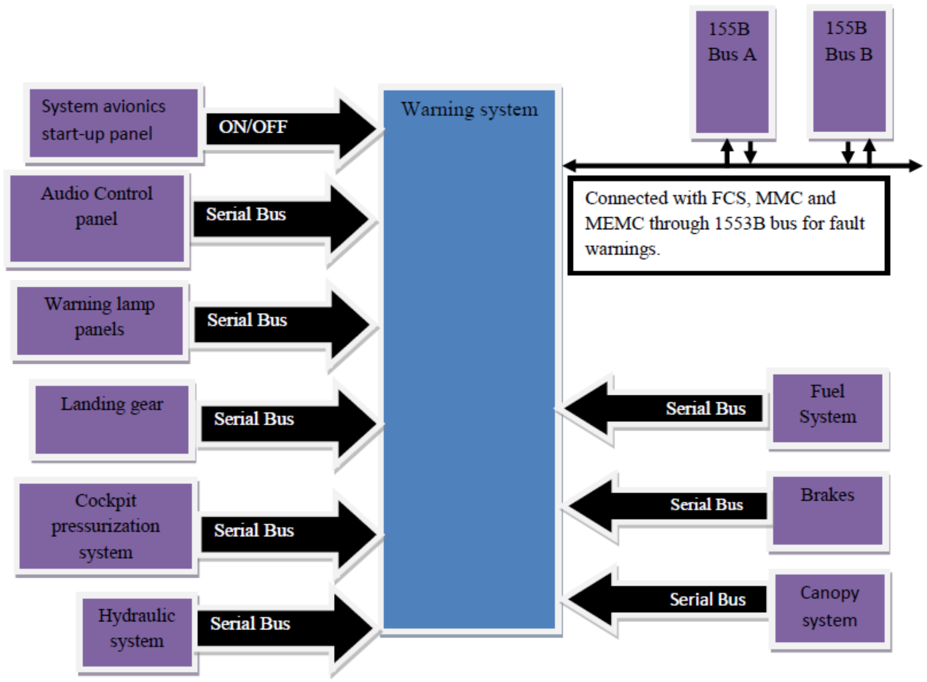

Figure 2.17 Warning systems layout architecture

2.5.5. Air data computer

It will supply triple source of dynamic pressure, static pressure and angle of attack for the FCS. These parameters will be transferred to MMC for display and MEMC for the subsystems. The system consists of main parts such as three pressure transducers such as Left pressure transducer, right pressure transducer and major pressure transducer and the digital computer.

The ADC will calculate following main parameters such as static pressure, total pressure, and mach no, total temp, pressure altitude, barometric reference altitude, calibrated airspeed, true airspeed and climb rate.

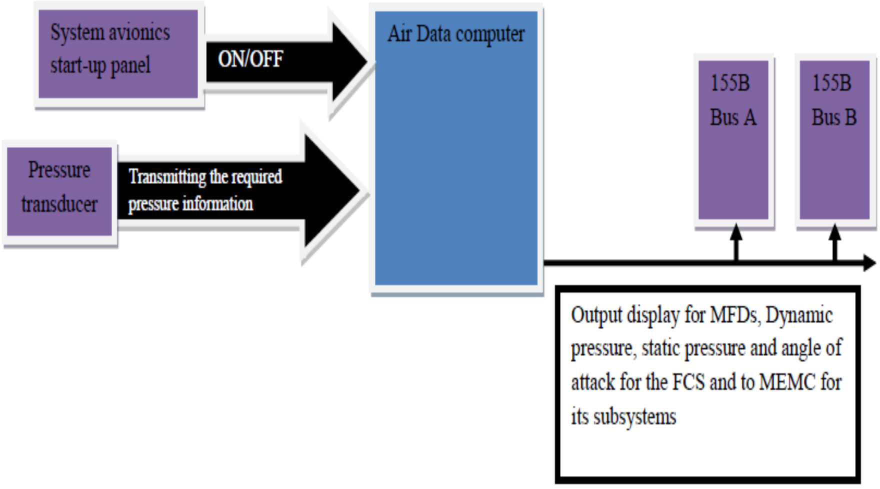

Figure 2.18 Air data computer layout architecture

2.5.6. Aerial flight Data: Bus monitor

It is the Bus Monitor (BM) of the avionics system data bus 1553B.It listens to all messages on the bus and records selected activities. The BM is a passive device that collects data for real-time or post capture analysis. The BM can store all or portions of traffic on the bus, including electrical and protocol errors. BMs are primarily used for instrumentation and data bus testing.

2.5.7. Weather radar

It will provide the aircraft with the adequate weather information for smooth flying. The main system components include the radar antenna, transceiver and digital computer. It is connected with the MFDs for providing the video signals and MMC for providing blanking signals through 1553B bus.

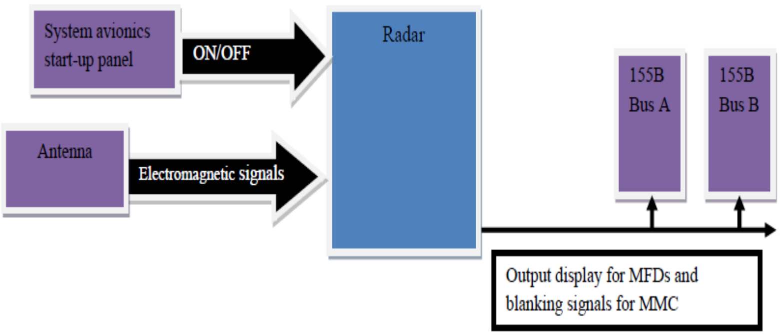

Figure 2.19 Radar layout architecture

2.5.8. Avoidance systems

2.5.8.1. Traffic Collision and Avoidance System (TCAS)

TCAS monitors the airspace around an aircraft for detecting the other aircraft that are equipped with a corresponding active transponder, independent of the air traffic control, and warns pilots of the presence of other transponder-equipped aircraft which may present a threat of mid-air collision (MAC). The system consists of parts such as transponder, antenna and digital computer. The system is coupled with the 1553B bus for showing the real-time scenario on MFDs.

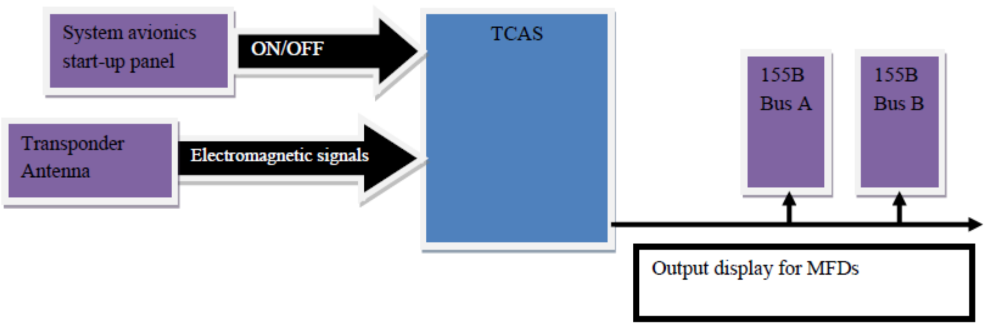

Figure 2.20 TCAS layout architecture

2.5.8.2. Electronic Ground Proximity Warning System (EGPWS)

The system will warn the pilot for low altitude conditions and also in sudden rate of change of altitude. It is coupled with the radio altimeter and the GPS system maps so providing the exact digital altitude map layout for adequate flying. The output is being displayed on the MFDs via MMC.

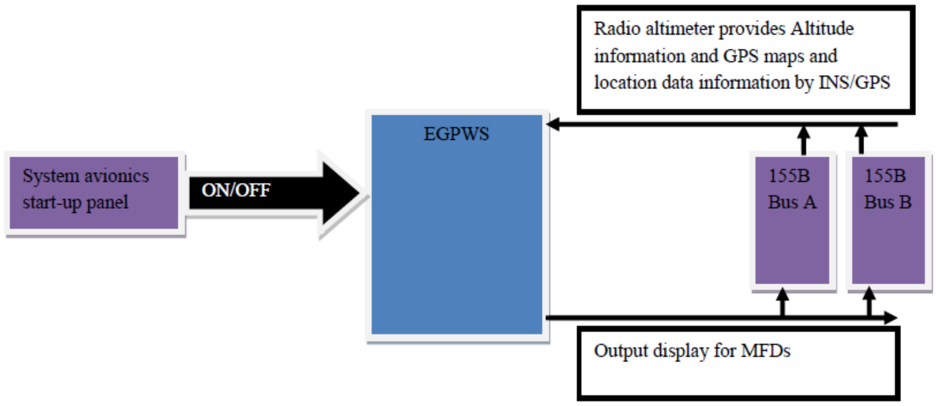

Figure 2.21 EGPWS layout architecture

2.6. Concluding remarks

Military services and contractors originally adopted MIL-STD-1553 as an avionics data bus due to the high reliability, 1 Megabit per sec (Mbps) transfer rate and extremely low error rate of 1 word fault per 10 million words, on a dual-redundant architecture (see [19]). This reliability has proven equally effective on communication networks in submarines, tanks, target drones, missile and satellite systems, land-based and launch vehicles, and space system including the current international space station and shuttle programs.

The main advantages for using the 1553B in this aircraft platform is that it will give the aircraft with ample amount of data rate and remote terminal space to install and upgrade the avionics systems. Furthermore, the avionics system architecture will have ease in data sharing and transfer due to 1553B federated bus architecture.

With respect to cost there will not be huge differences between the ARINC 629/429 architecture and 1553B architecture. This is because the set of avionics used in the industry for both architectures are available commercial off the shelf.

The main drawback of this kind of technology is the reality that each box has a precise function, with specially developed hardware and software. Every system is made from scratch and later it causes the lack of technology reuse. Particularly due to the technology development the hardware components bear from obsolescence problems.

Chapter 3
Future of Aviation: Integrated Modular Avionics (IMA) Systems

3.1. Introduction

Today for designing the architecture of avionics systems the safety analysis of the aircraft systems under risky situations, dependability of avionics systems on each other and most importantly the real-time constraints have a direct impact on architecture design. Therefore, industry has to show compliance with international regulations. They have to ensure and establish the safety requirements are enforced, the real-time performances of each system is evaluated correctly and the software and hardware is developed according to the guidelines of international aviation regulation authorities. This complete process of designing and verifying the avionic architecture is a special and complex task than for developing classical systems and software.

The traditional model of "one function = one computer" which is broadly used in all the "Federated" avionics architectures may perhaps no longer be retained and used in the aviation industry. This is because in the early nineties system suppliers developed concepts where multiple software functions of different criticality level were integrated on single avionic computing devices in order to keep the volume, weight, power consumption and cost of avionic within rational limits.

In the end of 90s, the majority of the civilian aircraft platforms such as A320, A330 and A340, were based on the federated architecture standard. Nevertheless, from last one and half decade the airlines desire for more and smarter functionality aircraft systems such as better entertainment systems for passengers, accurate flight management capabilities and on-board self maintenance systems. The early model of “one function = one subsystem” may perhaps cannot give the required set of hardware and software functionalities to support the latest aviation trends.

Thus a new concept categorized as "Integrated Modular Avionic (IMA)”, initially developed by Honeywell for state of art cockpit functions on the Boeing 777 aircraft in the early 1995 (see [33]) brought the solution. The IMA model is established to meet the reliability, performance and flexibility requirements for extremely integrated avionic systems. In this chapter the theoretical concepts relating the IMA architecture will be discussed in detail.

3.2. The architectural change

Table 3.1 The architectural difference

Federated systems	IMA architecture
Separate processing line replaceable units or small scale processors	Shared processing modules with partitioned application software (ARINC 653 (avionics application standard software interface)
Separate infrastructure for each avionics system	A Common infrastructure
Separate input and output resource for each functional unit	Dedicated or shared input and Output via shared Remote Interface Units (RIUs)
Internal system bus such as ARINC 429/629 and MIL-STD-1553B.	Distributed Systems Bus (ARINC 664 (avionics full-duplex switched Ethernet).

3.3. IMA: Basic conceptual theory

The processor and memory resource sharing and robust partitioning are the two fundamental design conceptual layouts for the IMA model. They are primarily stand on two fundamental standards. The ARINC 653 which defines partitioning principles in processing modules between different avionics applications and ARINC 664 which defines partitioning principles for communications between avionics applications in different modules.

3.3.1. Resources partitioning based on the ARINC 653 concept

The platform integrator allocates a set of memory spatial resource for every avionics application. He assigns maximum allowed resources to each partition while respecting space segregation between them. The operating system provides the protection for partition data against any modification from the other partitions. The real-time operating system (RTOS) monitors each avionics application activity with reference to allowed resources which are allocated through configuration files and tables.

3.3.2. Temporal partitioning based on the ARINC 664 concept

The scheduling of data transfer on each module is defined by a cyclic chain of slots ordered in a time-frame named as the major time frame (MAF). Each avionics application is specifically allocated a time slot for execution. At the end of this time slot the avionics application partition is suspended and execution is given to another avionics application. Consequently, every avionics application periodically performs data transfer at fixed time intervals.

The introduction of "Integrated Modular Avionics" (IMA) by the Radio Technical Commission for Aeronautics (RTCA DO-297) in November 2005 gave focus to new industry standards. "Avionics Full Duplex Switched Network" (ARINC 644 Part 7 "AFDX") and "Application Executive interface" (ARINC 653 "APEX") emerged offering new levels of modularity and communality to avionic systems (see [30]).

The following analysis will be detailed more on these two important standards: AFDX/ARINC 664 and ARINC-653 where the first main theoretical layout of both the standards will be discussed and then some design constraints and challenges will be presented that the system designers and academic researchers may face while developing the avionics architecture of IMA.

3.4. ARINC 653/Avionics application standard software interface

3.4.1. Background

In the mid 90s the aviation industry recognized that all digital avionics systems had some common components such as central processor, input and output resource and memory unit. The Real Time Operating System (RTOS) is also recognized as a very important part that needs particular consideration. The avionics systems that were developed in 80s and 90s, among them the RTOS was being developed on an ad-hoc basis for every avionics system. This approach was costly and provided a lot of problems relating to aircraft maintenance. With the identification of RTOS as the main centre of future development, the spotlight of standardization moved from component hardware to software. Thus aviation industry developed the software standards for IMA as "ARINC 653: Avionics Application Software Standard Interface".

ARINC 653 is a standard developed by aviation system developers that specifies a baseline-operating environment for application software used within the IMA system domain. ARINC 653 provides a general-purpose application executive (APEX) interface between the RTOS of an avionics computer resource and the application software. ARINC 653 was first adopted in 1997 by the Airlines Electronic Engineering Committee (AEEC). The acceptance of ARINC 653 by both Airbus and Boeing for their latest aircraft has solidified the role of ARINC 653 as an industry standard (see [33][31]).

IMA with ARINC 653 standard provides a shared processing module with common infrastructure. This module is known as "Common Processing Module" (CPM). The CPM is an independent computing platform that hosts core software and provides the hosted applications a robust partitioned environment and infrastructure services including input/output, health monitor, storage and recovery based on the ARINC 653 standard.

The high-level architecture of the ARINC 653 consists of following layers.

3.4.2. Application layer

Application software performs a precise function on the aircraft. Today functions like flight management and data link communications management can be implemented in software, using generic IMA computing resources. The software applications are specified, developed and verified to the level of criticality appropriate to the function. Within an IMA platform, each application software module operates independently using the resources provided by the IMA platform. Application software is independent of hardware, though some applications will require dedicated input/output sensors, such as a pitot static probe and antennas. Application software may be developed by independent software manufacturers and integrated into the IMA platform.

3.4.3. The Application Executive (APEX) interface

The prime objective of the APEX interface is to provide a general purpose interface between the application software and the RTOS. Proper standardization of this interface boundary permits for software application portability between ARINC 653 compliant avionics platforms. Furthermore it also allows for the procurement of hardware and software from a wide range of contractors. Thus this promotes competition in the aviation industry, reduces development and ownership cost.

3.4.4. ARINC 653 Real Time Operating System (RTOS)

The RTOS is responsible for allocating processor time and memory regions to each application. These are managed by the avionics system integrator. IMA architectures promote the integration of many avionics application software functions. Special mechanisms are supplied by the RTOS to manage the communication flow between software applications and the data on which they operate through specific partitions. Each partition is analogous to that of a general multitasking software application within a general purpose computer. Each partition consists of one or more simultaneously executing processes, sharing access to processor resources based upon the requirements of the application.

Following are the main functional components of RTOS.

3.4.4.1. Partition and time manager

The partition and time management services of the RTOS are responsible for assigning priorities and timing constraints for the individual application partitions.

3.4.4.2. Memory management

It manages the memory allocations for each partition application that is running.

3.4.4.3. Port manger

Avionics applications use communications ports to send messages to each other. Communication ports, which are typically part of the operating system API, provide a programming mechanism for sending and receiving messages. Port manager manages the data transmission and scheduling between the ports. Two types of communications ports play role in avionic subsystems: sampling and queuing ports. Avionics applications are allocated explicit ports such as queuing ports, which are first in first out (FIFO) buffers for packets, and sampling ports which are single packet buffers to be overwritten on each iteration.

3.4.4.4. Health monitor function

The health monitor function resides with the RTOS and interfaces with a recovery strategy table defined by the aircraft designer or system integrator. The health monitor is responsible for monitoring any hardware faults within IMA platform and faults within the RTOS.

3.4.5. Hardware processor

Every computing system has a set of hardware components on which processing can operate. There are several basic criteria specifications made about the hardware, as specified in ARINC 653.In these specifications the processor should provide sufficient processing throughput to meet each application’s time requirements, processor should provide required memory resources, processor should have access to time resources to enable sharing of processing unit cycles based on time and lastly the processor should provide a mechanism for the RTOS to take control if any avionics application attempts to perform an operation that is not valid for the specific application.

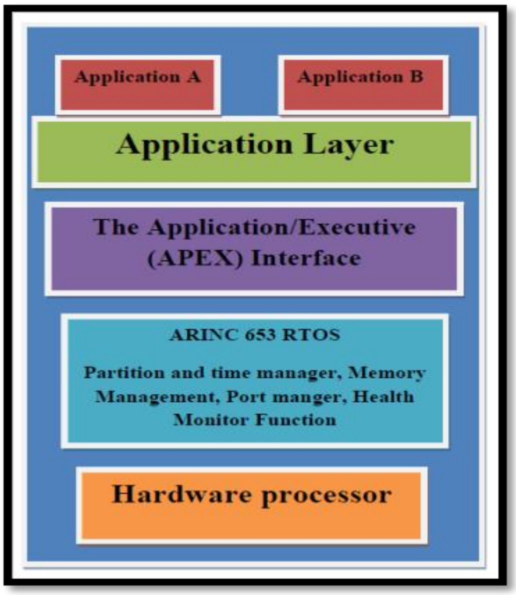

Figure 3.1 Architecture of ARINC 653

3.5. ARINC 664 Avionics Full-Duplex Switched Ethernet (AFDX)

It is a specification developed by ARINC and it defines data network that utilizes standard Ethernet like IEE 802.3 and upper layer protocols based on the internet protocols like User Datagram Protocol (UDP), Internet Protocol (IP) and Simple Network Management Protocol (SNMP). ARINC 664 consists of 8 documents. To study AFDX the main focus is on the part 7 document of ARINC 664 which is called as avionics full duplex switched Ethernet (see [29]).

3.5.1. AFDX

It is best described as an implementation of the deterministic Ethernet as specified by the ARINC 664 part 7. So AFDX is the implementation of ARINC 664 part 7 network. It is developed by the Airbus originally for the A380 program and also used in A400M and A350. It is the trademark term of the Airbus. Similar implementations of ARINC 664 part 7 are also used on Boeing 787 and Bombardier C series.

3.5.2. Background

AFDX replaces ARINC 429 and ARINC 629. ARINC 429 has point-to-point wiring which is heavy and trouble prone and ARINC 629 is complex and expensive. Ethernet is very cheap, very well proven and being constantly improved by the industry. Unfortunately Ethernet is not real-time and often loses packets. Ethernet only has the ability to prioritize packet types whereas avionics has a clear difference between periodic and critical data and background data transfers. AFDX takes advantage of Ethernet proven technologies while adding its own requirements to cater the avionics applications. By limiting the bandwidth of each end systems AFDX can guarantee that each packet that has been sent will be received within acceptable parameters.

3.5.3. Ethernet real-time

The most critical change to standard Ethernet is pre-estimation of the path each data source to each definition. Switches are programmed with a path based on media access control (MAC) header. Limiting the data that each end system may transmit guarantees that the switches are not overboard.

3.6. Basic network components

AFDX network uses star topology[1]. Backbone is the interconnection of the Ethernet switches and then end systems that give access to the network by a connection to a local switch. So basically it has the switches, the end systems

[1] In a star network devices are connected to a central computer, called a hub. Nodes communicate across the network by passing data through the hub.

and the 802.3 Ethernet links that are connected to the components. The end system implements the protocol stack up to basically the application layer. So in the protocol stack at the end systems we have the Ethernet, IP, UDP and management protocols as an SNMP.

Following are the basic network components.

3.6.1. End systems

A processing module system is capable of supporting multiple avionics applications. Partitions provide isolation between avionics applications within the same avionics processing module. These avionics applications are connected to the AFDX network through the communication ports which are managed by the end systems. So in general layout, the end systems are connected to the avionics subsystems or processing module. Thus end systems provide a suitable communications interface for supporting sampling and queuing ports with the avionics software partitions. End systems are identified using two 8-bit quantities .i.e. a network ID and an equipment ID.

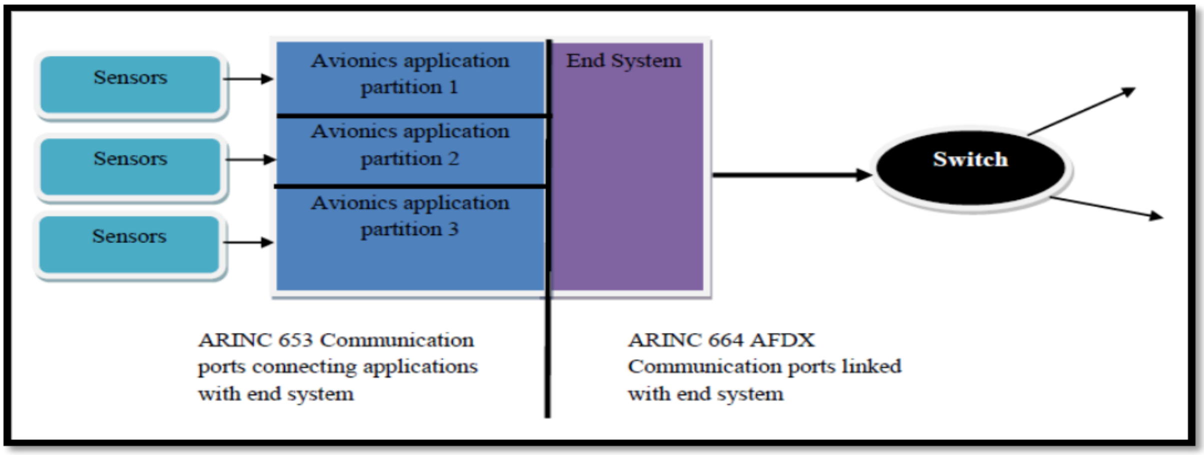

Figure 3.2 End system connected with avionics subsystems

3.6.2. Full-duplex Ethernet switch

Full-duplex switched Ethernet eliminates the possibility of transmission collisions. In the switched network each avionics subsystem or processing module like autopilot or heads-up display is directly connected to a switch over a full duplex link that contains two twisted pair cables; one pair to transmit and one pair to receive.

Following are the main working components inside the switch.

3.6.2.1. Receiving (Rx) and Transmitting (Tx) buffers

The Receiving (Rx) and Transmitting (Tx) buffers in the switch are able of storing various incoming and outgoing packets in FIFO (first in, first out) order.

3.6.2.2. Input/output (I/O) processing unit

The function of the I/O processing unit is to move packets from the incoming Rx buffers to the outgoing Tx buffers. It does this by examining each arriving packet that is next in line in the Rx buffer to determine the destination address i.e. the virtual link identifier.

3.6.2.3. Forwarding table

The forwarding table determines which Tx buffers are to receive the packet.

3.6.2.4. Memory bus

The packet are copied into the Tx buffers, through the memory bus, and transmitted (in FIFO order) on the outgoing link to the selected avionic subsystem or to another switch.

Note: With this full-duplex switch architecture the contention encountered with half-duplex Ethernet is eliminated, simply because the architecture eliminates collisions. Theoretically, an Rx or Tx buffer could overflow, but if the buffer requirement in an avionics system are sized correctly, overflow can be avoided.

3.6.3. AFDX communications ports

Avionics subsystems use communications ports to send messages to each other. Communication ports, which are typically part of the operating system application program interface (API), provide a programming mechanism for sending and receiving messages. Two types of communications ports play a role in Avionics subsystems: sampling and queuing ports. AFDX end systems must provide both sampling and queuing port services, as described in ARINC 653.

A sampling port has buffer storage for a single message; arriving messages overwrite the message presently stored in the buffer. Reading a message from a sampling port does not remove the message from the buffer, and therefore it can be read repeatedly. Each sampling port must provide an indication of the freshness of the message contained in the port buffer. Without this indication, it would be impossible to know whether the transmitting avionics subsystem has stopped transmitting or is repeatedly sending the same message. A queuing port has sufficient storage for a fixed number of messages (a configuration parameter), and new messages are appended to the queue. Reading from a queuing port removes the message from the queue (FIFO) (see [39]).

3.6.4. Virtual link (VL)

The idea of VL is based on the ARINC 429 label which may be transmitted from a single transmitter to multiple receivers. In AFDX the switch is responsible for this routing. It may route a single input to several output ports.

If multiple input ports have to transmit to same output port then the switch will buffer some of the data. In example below in figure 3.3, when the source end system 1 sends an Ethernet frame with a Virtual Link ID VLID 10 to the network, the AFDX switches send the frame to a predetermined set of destination end systems (2 and 3).

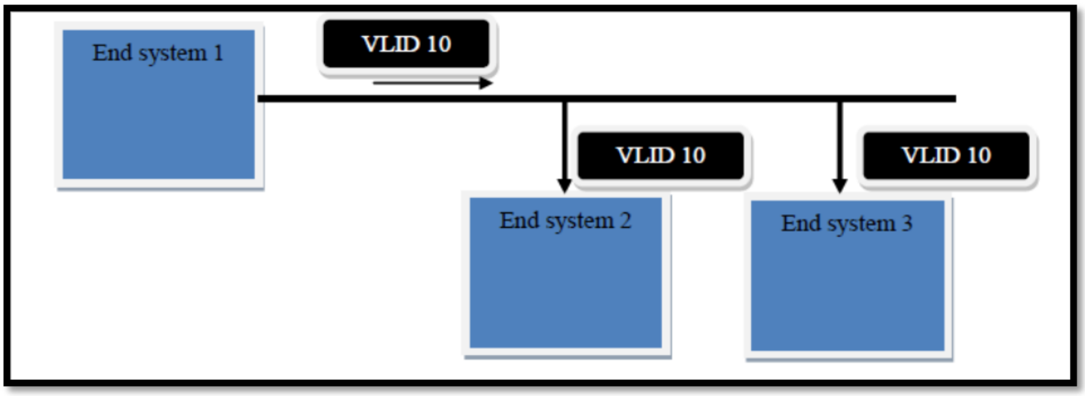

Figure 3.3 Message transmission by Virtual links

An End System can support multiple virtual links. These virtual links share the bandwidth of the physical link. Each virtual link is always assigned two parameters:

- Bandwidth Allocation Gap (BAG), a value ranging in powers of 2 from 1 to 128 milliseconds
- Lmax, the largest Ethernet frame, in bytes, that can be transmitted on the virtual link

The key distinctiveness defining the virtual links (VLs) is BAG which is specified in milliseconds and the maximum allowed Ethernet frame length. Together they specify the maximum bandwidth used by the VL. The BAG will estimate the minimum time between the transmissions of successive frames for VL. So it represents how fast the VL is allowed to transmit a frame and if the maximum size of a frame is known then the maximum bandwidth that VL will consume on the link can easily be calculated. If a virtual link with a BAG of 16 milliseconds, then Ethernet packets are never sent faster than one packet every 16 milliseconds.

Useful information that is associated with VL is the maximum jitter (difference between maximum and minimum latency). Jitter is the difference between the maximum times from source to destination in VL to minimum time from source to destination in VL. What causes jitter in the network is may be due to the several VLs sharing the physical Ethernet link. As the BAG value of VL defines a time schedule the frame can be transmitted so in reality it just really defines a speed limit for VL. The chance for congestion occurs when two VLs can have frame eligible for transmission on same VL exactly on the same time and one of those VL has to wait for the shared link to be transmitted. So, essentially the large amount of virtual links in the communication link are the real cause for the jitter. More VLs are there in the communication link subsequently more is the possibility that there will be contention.

Hence the solution is that the designers estimate the values of BAG and maximum frame length and with this preconfigured information about the network they calculate the maximum worst case jitter for every virtual link and then have that information known for the other network designers.

3.6.5. Virtual link scheduling

Every AFDX communication port is connected and linked with a virtual link. The transmission of Ethernet frames in a virtual link line is scheduled by the end system's virtual link scheduler. The virtual link scheduler is in charge for arrangement of transmissions of all the virtual links with the end system. It is in charge for ensuring that all virtual links conforms to their assigned bandwidth limitations.

3.6.6. Redundancy management

There are two independent switched networks in an AFDX system, the A and B Networks. Each packet transmitted by an end system is sent on both networks. Therefore, under normal operation, each end system will receive two copies of each packet.

End Systems requires a way to recognize corresponding copy packets that appear on the A and B networks. In AFDX, all the packets send out over virtual link are provided with a 1 byte sequence number field. The sequence numbers begin with 0, continue till 255, and then roll over to 1. The sequence numbers are provided on each virtual link basis. On each virtual link and network port, the receiving end system checks that the sequence numbers on successive frames are in order. This is referred to as "integrity checking." After integrity checking is finished, the end system decides whether to pass the packet along or drop it because the replica has previously been sent along. This is called redundancy management.

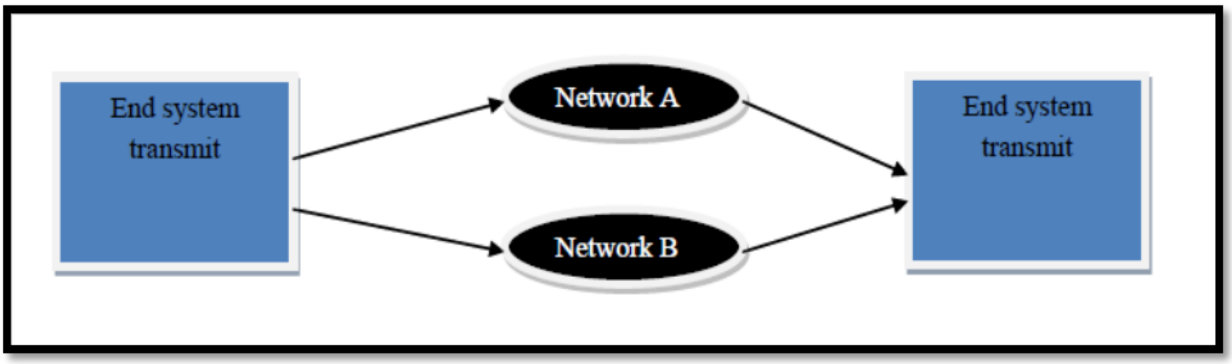

Figure 3.4 Redundancy management in A and B networks

3.7. The complete protocol layout

The transmission (Tx) protocol begins with a message being sent to an AFDX port. The User Datagram Protocol (UDP) transport layer is responsible for adding the UDP header, which includes the appropriate source and destination UDP port numbers. These numbers are, in most cases, determined by the system configuration and are fixed for each AFDX communications port.

After getting the UDP headers the message gets the appropriate BAG value, Lmax value and the correct virtual link is being assigned. These values are already been determined by the designers so each message knows the value of BAG, Lmax and the virtual link to be assigned. The IP network layer receives the UDP packet and determines whether it needs to be fragmented. It uses the appropriate virtual link's Lmax to determine whether fragmentation is necessary. After that the IP header is added to the message.

The virtual link layer scheduler is responsible for scheduling the Ethernet frames for transmission, adding the sequence numbers (on a per-VL basis), and then passing the frames to the redundancy management unit, where the frames are replicated and sequence number is added and the Ethernet source address is updated with the physical port ID on which the frame is transmitted.

Then the message is transmitted through two different network links or virtual network links. The messages are received by the switches. The Rx and Tx buffers in the switch are both capable of storing multiple incoming/outgoing packets in FIFO (first in, first out) order. The role of the I/O central processing unit (CPU) is to move packets from the incoming Rx buffers to the outgoing Tx buffers. It does this by examining each arriving packet that is next in line in the Rx buffer to determine the destination address (virtual link identifier) and then goes to the Forwarding Table to determine which Tx buffers are to receive the packet. The packet is then copied into the Tx buffers, through the Memory Bus, and transmitted (in FIFO order) on the outgoing link to the selected avionic subsystem or to another switch. This type of switching architecture is referred to as store and forward.

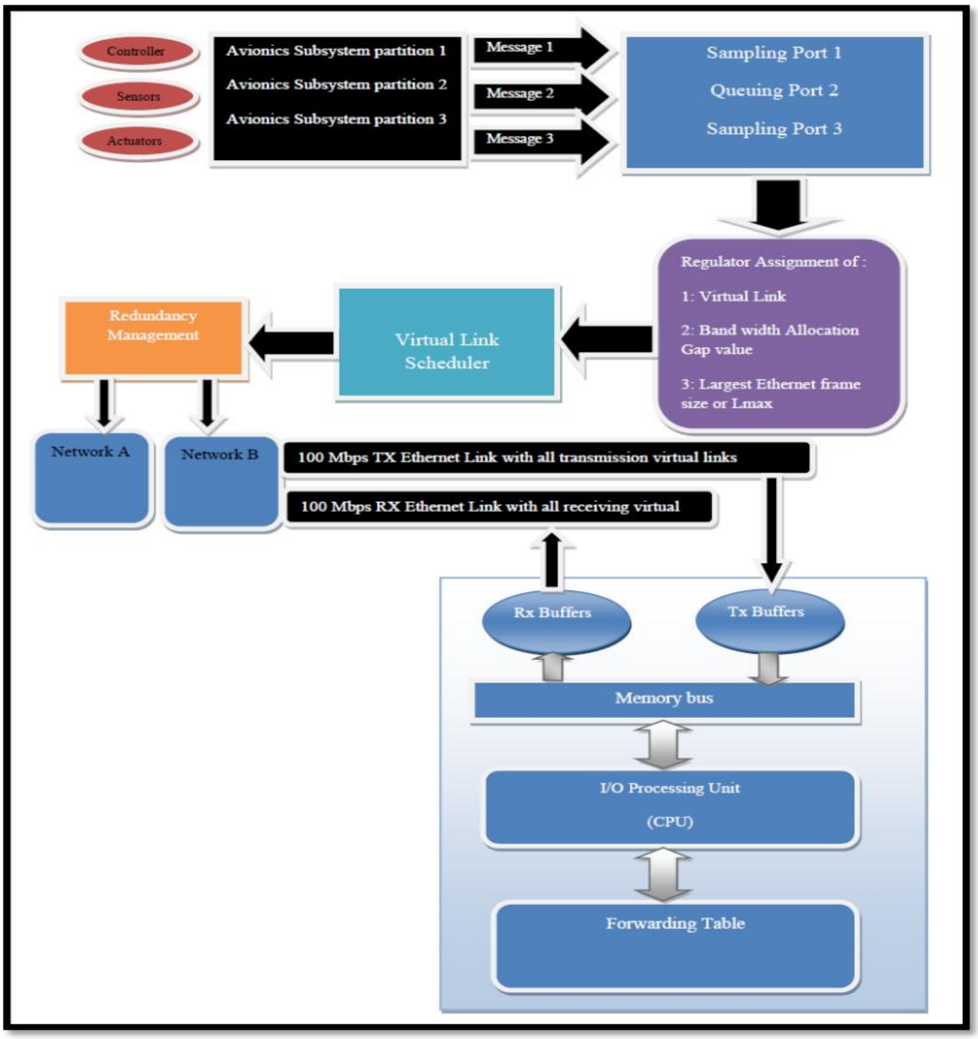

Figure 3.5 The protocol architecture of ARINC 664

3.8. Conclusion

The avionics system designers that are prepared to adopt AFDX and ARINC-653 standards in their aircraft need to decide on several AFDX network configurations and constraints. These constraints include how much the bandwidth allocation gaps (BAGs) to select, how many virtual links in the system and how many AFDX switches in the network.

On behalf of the ARINC 653 the concerns about time and task synchronization must be addressed. Furthermore the following issues will concern in relation to ARINC 653 that how long must be the time of each avionics partition, how many processing modules in the system and how many avionics partitions will be made on each module.

With the introduction of IMA, the novel aviation industry standards such as AFDX and APEX present new advanced challenges for system designers and avionics system integrators. In the coming years, more speculative studies will be required as time critical avionics applications developed using AFDX and ARINC-653 are mature enough.

Chapter 4
Integrated Modular Avionic (IMA) System Integration Process

4.1. Introduction

The concept of integrated modular avionics came due to the huge advancements in the electronics industry, increased functional complexity in the avionics systems and need for smart integrated and modular systems. The concept of integrated modular avionics came in mid 90's due to huge investments made by the airline industries on more integrated platforms. The basic concept behind IMA is sharing the common set of “cabinets” with ARINC 653 specifications that are connected simultaneously with other secondary equipment through number of multiple access networks which are based on ARINC 664 specifications. Each cabinet is a high-power computing hub which substitutes a number of avionics applications. Each cabinet has an adequate processing and interface capability to maintain the required integration of avionics functionality. The system specific application software is designed to match the appropriate standards of the application executive interface specification (APEX). Thus this application standard also allows the application software reusability on processors of diverse hardware designs.

4.2. ARINC 653 and ARINC 664

ARINC 653 is an industry specification originating from the civil aviation industry. It defines the partitioning of software and addresses the issues related to the overall software standardization of avionics systems. The ARINC 653 philosophy has a layered approach shown in the figure 5.1. These layers provide the following.

- At the top level, an ARINC 653 compliant software infrastructure or application programming interface (API) provides the partitioning of avionics systems functions that are developed specifically for the platform.
- The API infrastructure interfaces with the RTOS which will generally be a commercial package. In many cases the RTOS will be DO-178B compliant (see [43]).
- The hardware layer based upon COTS expertise is not dependent on the software layer for the architectural implementation. The decoupling of the hardware processor from the application software means that the hardware obsolescence can be contained and technology advances can be enjoyed while the investment in software applications and system functionality is protected (see [43]).

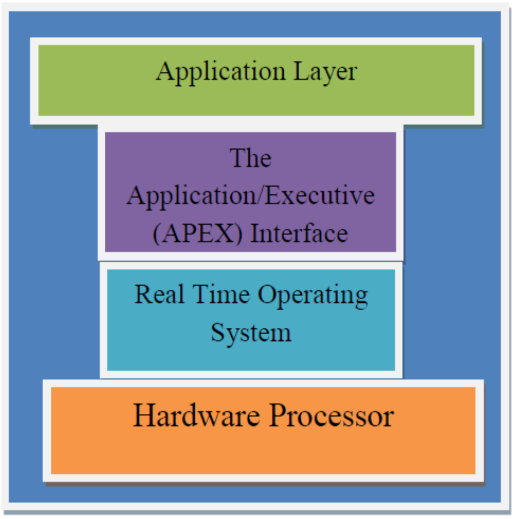

Figure 4.1 Layered approach of the Cabinet module using ARINC 653 specifications

The “AFDX” standard is the Part 7 (see [27][28]) of the ARINC-664 “aircraft data network” standard, called “Avionics Full Duplex Switched Ethernet network” (AFDX) introduced formally in 2005. It describes a “more deterministic” switched Ethernet/IP network. The network is based on standard IEEE 802.3 Ethernet technology. The benefits from using Commercial-Off-The-Shelf (COTS) Ethernet components include reduced overall costs, faster system development and less-costly maintenance for the system network. Hardware components, cables and test equipment for Ethernet are field proven and much more affordable than typical avionics solutions (see [29]).

4.3. The IMA system integration process

The aim of this integration procedure is to get the majority of the aircraft system level task and functions which are being operated on standardized IMA platforms and connect them to the Aircraft Data Communication Network (ADCN) which is primarily based on the aeronautical full duplex (100Mbit AFDX) (see [29][39]) switched Ethernet state of art technology.

For the manufacturing and integration of the IMA system in an aircraft platform there are several suppliers, manufacturers and contractors which are associated during the whole process.

Following are the responsibilities defined for each contractor:

4.3.1. The IMA system integrator

The IMA system integrator performs the complete integration in all the stages of the assimilation process. The IMA system integrator must deal with all interfaces linked with the IMA system configuration. It has to deal with the each selected avionics applications to be hosted and provide the memory resource allocation, configuration files and tables adjustments and in general validating the performance of the integrated system

4.3.2. Platform contractor

The platform contractor supplies the processing hardware resources with the core software (operating system). The operating system also includes interfacing software that links the hardware components with the operating system.

4.3.3. The Real Time Operating System (RTOS) provider

The RTOS provider identifies the hardware aspects of the IMA systems and conveys them to the platform contractor. The RTOS provider supplies the guidelines and configuration files for temporal and physical partitioning, communication ports and input/output resource management.

4.3.4. Avionics software application supplier

The avionics software application supplier creates the application .i.e. a specific aircraft task. The avionics software application is developed usually with no concerns and consideration for other avionics application tasks, except those tasks that are interconnected, e.g. communication with other avionics applications.

4.4. Top seven key design layout for IMA

The complete integration process is distributed in the following 7 steps.

4.4.1. Defining the requirements of IMA module

The top level avionics designer or the IMA system integrator first collects and combine the precise requirements of the diverse avionics system functions, which will be processed by IMA modules. These requirements include the avionics systems function, the task layout of each avionics system, the signal types, memory usage by each system and electromagnetic compatibilities to be combined to the basic module specification. Then on the basis of these standardized specifications the IMA system integrator develops the respective concept for the standardized multipurpose IMA modules also known as CPM (Common Processing Module).

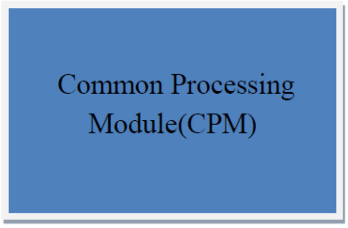

Figure 4.2 The CPM box developed by the IMA system integrator

4.4.2. Development of hardware and software of IMA module

In this stage, the IMA system integrator integrate the operating system to the hardware components and other modules to form an operational IMA system or the CPM. The platform contractor provides the necessary hardware to maintain the avionics software applications. Typically this hardware consists of a microprocessor, memory and input/output devices. The RTOS provider normally provides a board support package of software that will allow the RTOS software to run on a range of different hardware configurations. The platform contractor and the RTOS provider also provide a few additional functionalities to support specific input /output devices and device drivers.

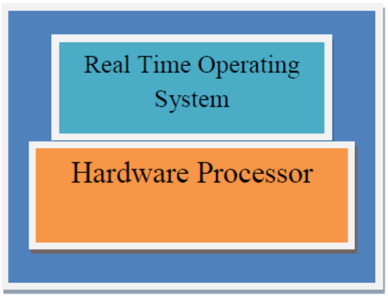

Figure 4.3 CPM with processor and real-time operating system installed

4.4.3. CPM user guide formulation

In parallel these top level system design specifications are issued to the avionics software application supplier. The avionics software application suppliers have to be provided with a very detailed description and layout sketch of the CPM. This is the “CPM User Guide”, a manual, which specifically clarify the CPM complete design characteristics and how it must be operated. These suppliers will create the avionics system application software on the basis of these design characteristics which will be installed on the CPM.

4.4.4. Application software integration on IMA module

When the IMA modules are prepared and ready for the avionics software installation the IMA system integrator provides the CPMs to each avionics software application suppliers who run their application on these modules.

Thus different avionics software application suppliers perform their local single function integration and system qualification for each CPM. Each avionics software application supplier only installs his own functional application software to the CPM module without any hindrance from other software suppliers.

The other avionics software applications will be installed and integrated to the same module afterwards when the first supplier has finished the installation. This step by step software integration and qualification approach is maintained by the strong partitioning property of the IMA modules.

To make sure that the all the avionics applications execute in stiff conditions, the avionics software application supplier and the IMA system integrator should agree on the minimum resources to be granted to the software applications so that it can be confirmed and verified with those allocated resource settings. As an example, the timing specifications for the application must be used to validate the performance under the temporal configuration settings.

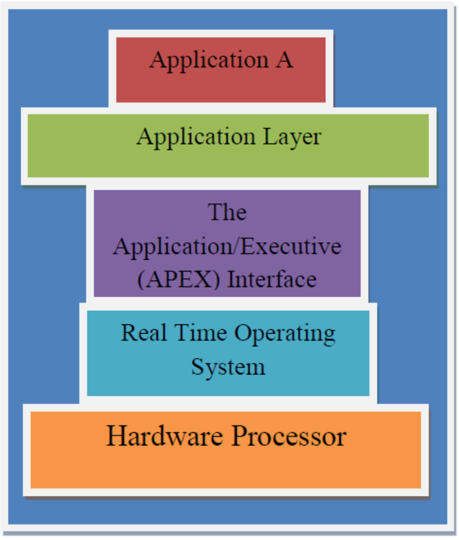

Figure 4.4 CPM with single avionics software application running

4.4.5. Multiple application software validation and certification process

After the software integration process, the validation of the partitioning process of each CPM has to be confirmed. For this purpose, an explicit analysis and test and trial procedure is applied to the modules. If the different software application partitions on a CPM are not interfering and obstructing each other functions under any condition, then the CPM is certified. These tests must fulfill the demands and constraints of the aircraft certification processes related to the IMA design layout.

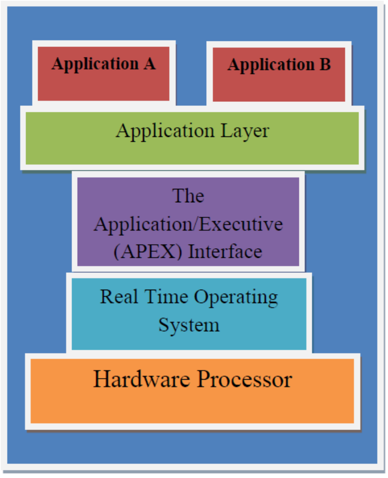

Figure 4.5 CPM with multiple avionics software application running

4.4.6. Integration of ARINC 653 IMA module with AFDX/ADCN ARINC 664 network

After the certification of CPMs the IMA system integrator integrates the empty CPMs (without any software application installed) with the AFDX/ADCN ARINC664 on the aircraft in order to create the complete platform system computing resource for different CPMs attached. For this procedure suitable network software configuration files have to be made and integrated for the AFDX communication network and for the CPM operation. The networks are primarily based on copper-cabling but fiber optics will be utilized in future (see [28]). This integration requires two main configurations.

- The AFDX/ADCN ARINC664 configuration primarily concerns the address tables of the Ethernet switches, the data frame size of each virtual link (VL), the bandwidth allocation gap values (BAG) and the required bandwidth of the virtual links (VL).

- The configuration process of the CPM includes the allocation of memory space to each software application, signal ports designations (the queuing and sampling ports) and processing cycle time layout designations to the different software application partitions. This configuration data is arranged in configuration files and loaded on the CPM in order to get the operating system perform as required by the different software applications that are being executed on each module.

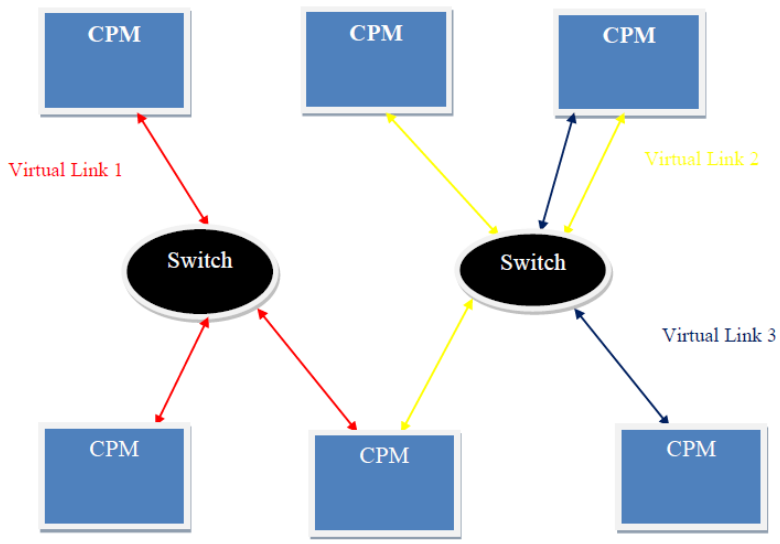

Figure 4.6 The integrated network: The color (red, yellow, blue) arrows shows the virtual links

4.4.7. Installation of CPMs and configuration tables on aircraft

After completion of the local functional qualification test and certification; the avionics application software providers supply their respective application software partitions to the IMA system integrator which adds the respective configuration tables to each avionics application partition and then the qualification test procedures are being executed to certify that the complete integrated system is been working perfectly. Thus, finally the application software partitions and the configuration files make up the final software load that is delivered to the final assembly line where it is loaded to the empty CPMs on the aircraft under production.

4.5. Conclusion

The seven key design layout can provide a great advantage in the integration of modular avionics for any type of aircraft program. The level of system integration and openness of the avionics platform for any particular aircraft type mainly depends upon the aircraft manufacturer.

AFDX implementations still remain relatively conservative, using a proven and mature technology base instead of state-of-the-art hardware. For example, the Airbus A380’s and A350’s networks are based on copper-cabling, while optical cabling has become the genuine standard for high speed interconnections. However, ARINC 664 architectures can integrate future technology seamlessly. Future AFDX implementations like the one used in Boeing’s 787 will use fiber optics (see [28]).

Within ARINC 653 the module architecture has influence on the working of RTOS and its execution; however it does not have any effect on the APEX interface which is used by the application software of each partition. The application software must be portable between modules without modifying the interface with the RTOS.

As the aircraft systems are developing into more and more digital systems through the utilization of smart and small peripheral devices and remote data sensors, the requirement of analogue and discrete input/output interface links within computing platforms will diminish.

Thus the future that is expected from IMA is the use of multiple application types running on a computing module, where each module hosting variety of avionics system applications with smart peripherals and they are networked together by means of high-speed data buses such as ARINC 664.

Chapter 5
Top Level Avionics System Design Architecture for Integrated Modular Avionics (IMA)

5.1. Introduction

The integrated modular avionics is a hardware and software platform that offers real-time computing, communication and input-output services for executing real-time embedded systems. Multiple avionics applications or avionics systems can be architected on the partitioned software platform resource to make an extremely integrated system with an exceptional feature of full separation and autonomy of each individual system or avionics application.

In this research, the concepts and methodologies that have been researched and studied regarding to the IMA architecture (ARINC 653 (avionics application standard software interface) and ARINC 664 (avionics full-duplex switched Ethernet) will be employed to develop the top level IMA avionics system design architecture.

5.2. Platform

The platform selected is the commercial medium jet aircraft such as Cessna Citation Excel, Learjet 45 or Hawker 800XP. Normally the medium jet civilian aircraft use ARINC 429/629 buses for their avionics architectures. In this research the IMA architecture has been used to design the top level avionics architecture of a medium civilian jet aircraft. The key features of IMA such as ARINC 653 and ARINC 664 protocols are the baseline research areas to make the new design architecture for a medium jet civilian platform.

Following are the typical avionics systems used in these types of aircraft (see [21]).

- Head Up Display (HUD)
- Hands On Throttle And Stick (HOTAS)
- Multifunction Displays (MFD)
- Digital video recorder
- Combined inertial navigation and GPS platform
- Altitude heading and reference system
- VHF/UHF communication radio
- HF communication radio
- Radio altimeter
- Instrument Landing System (ILS)
- VHF Omni-directional Range (VOR)

- Distance Measuring Equipment (DME)
- Non-Directional Radio Beacon (NDB)/Automatic Direction Finder (ADF)
- Air data computer
- Traffic Collision and Avoidance System (TCAS)
- Electronic Ground Proximity Warning System (EGPWS)
- Radar

For this research, the IMA architecture has been used for all these avionics systems. Furthermore, mechanical and flight control systems have been combined to develop the top level avionics design of a commercial medium jet aircraft.

5.3. Common Processing Module (CPM)

The top level avionics designer or the IMA system integrator first collects and combines the precise requirements of the diverse avionics system applications, that will be processed by each IMA module. These requirements include the avionics systems function, the task layout of each avionics system, the signal type, memory usage by each system and electromagnetic compatibilities to be combined to the basic module specification. Then on the basis of these standardized specifications the avionic module manufacturer develops the respective concept for the standardized multipurpose IMA modules also known as Common Processing Module (CPM).

All the systems and subsystems of this platform are divided into four categories according to their functionalities and hardware interconnections. Then each category is named as a CPM where the different avionics software applications will be running. The concept and layout behind CPM architecture is based on the theoretical study of Boeing B-777 and Genesis platform (see [41]).

5.4. Top level avionics design architecture for each Common Processing Module (CPM)

Following are the names and detailed functionalities of each CPM.

- CPM 1: Mission management processing module
- CPM 2: Communication, Navigation and Identification(CNI) module
- CPM 3: Mission electro mechanical management system module
- CMP 4: Aerial flight data and avoidance systems module

5.4.1. CPM 1: Mission Management Processing Module (MMPM)

This module performs two important functions; firstly it gets all the required information and data from the other CPMs and then it transfers this data in specific message chunks to the Head Up Display (HUD) and Multifunction Display (MFD). All the avionics information can be taken on any of the three MFDs. It will be according to the pilot's discretion that what type of data exactly he needs on each display.

Secondly it transmit the pilot's commands and processes the information from Hands on throttle and stick, flight management system, system avionics startup panel and audio control panel to the appropriate CPMs for the required actions. The black and blue arrows in the Figure 5.1 are the queuing and sampling ports connecting the end system which is the Avionics Full-Duplex Switched Ethernet (AFDX) network layer with the common processing module.

Furthermore it also stores all the necessary data and do the video collection. In the Figure 5.1 it can be seen that the avionics applications are connected to the end system through the communication ports. This information is then routed through switch with specific virtual links to all the devices connected and to other CPMs that needs the appropriate information or commands. Following are the main avionics applications running on the real-time operating system.

5.4.1.1. Hands On Throttle And Stick (HOTAS)

It allows pilot to control the main aircraft functions without removing his hands from the stick and throttle. This application is a very critical application because it transmits all the necessary pilot commands to the important aircraft systems. This application mainly controls the following main aircraft functions.

- Autopilot engage or disengage mode
- Controlling of the radar
- Selection of the MFDs control
- Thrust control functions
- Flight control
- Communication radios

5.4.1.2. Flight management system (FMS)

This system will enable the pilot to update navigation and guidance, communication and autopilot data to operate the flight functions. It gets the required information from all other CPMs and uses this information data for running the flight management application.

5.4.1.3. System Avionics Startup Panel (SASP)

It is the system used for the activation or the power-on of the avionics systems in the aircraft.

5.4.1.4. Audio Control Panel (ACP)

This is the control panel to manage the audio and communication setup of the aircraft communication system. The microphone and headset is connected to this application. When the pilot sends command from HOTAS which is indirectly delivered to the audio control panel and the VHF/UHF or HF applications in CPM2. The pilot microphone and the head set are directly connected to the audio control panel. Then when pilot speaks, his voice is transmitted to the audio control panel software application in CPM1. From there, the voice signals are transmitted to appropriate communication radios for transmission.

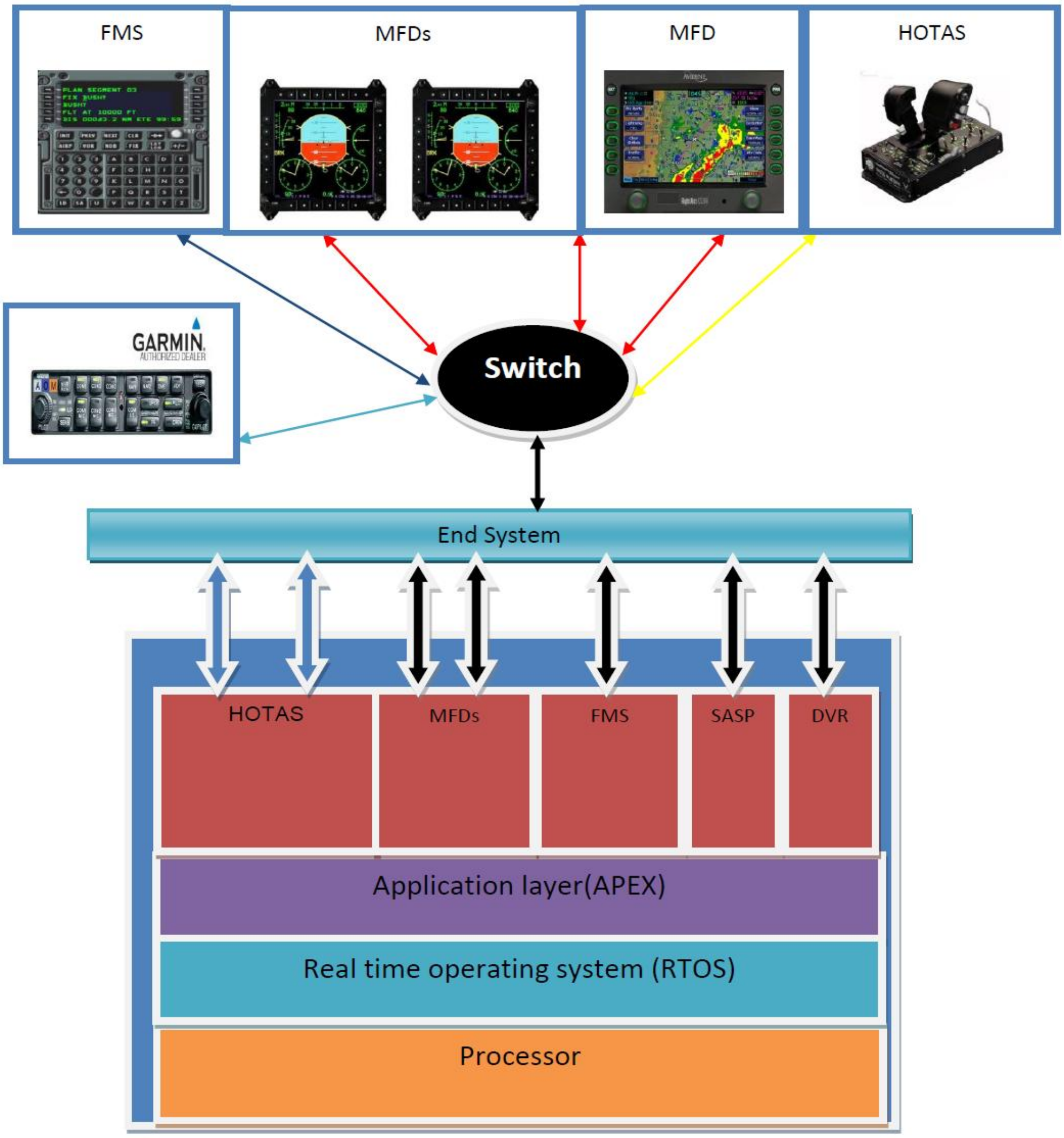

Figure 5.1 Top level IMA architecture of CPM1: Mission Management Processing Module (MMPM)

5.4.2. CPM2: Communication, Navigation and Identification (CNI) module

This complete suite provides the communication navigation and identification of aircraft with ground installations and aerial vehicles. Before going into the details of this suite; there is one more important aspect related to radio frequency subsystems which needs to be highlighted and used for our research studies.

Another region where the aircraft can benefit from integration is in the region of the Radio-Frequency (RF) subsystems. Aircraft are fitted with an excess of RF systems, some of which are listed below.

- Twice redundant VHF/UHF communication radio
- HF communication radio
- Instrument Landing System (ILS)
- VHF Omni-directional Range (VOR)
- Distance Measuring Equipment (DME)
- Non Directional Radio Beacon (NDB)/Automatic Direction Finder(ADF)
- Combined inertial navigation and GNSS platform

These sub-systems have their own antennas, RF sections, signal transmitters and receptors and data processing modules; thus the result is an enormous collection of non-standard and sometimes unreliable hardware modules.
This area of research has been recognized for quite some time that this is an area mature for advancement and functional integration. Today, the advances in RF processing technology are offering the great prospect of large scale integration of RF systems.

5.4.2.1. Background and evolution

The evolution in the integration of communication and navigation systems can be divided into following main eras.

5.4.2.1.1.From 1950s till early 1960s

Integration of the communication and navigation functions has been taking place over the past four decades, even though at a sluggish rate. These systems were analogue in nature and moderately similar to the distributed analogue system.

5.4.2.1.2.From later 1960s till 1970

In this era of avionics modernization, the communications and navigation systems were integrated into a mission system with a display providing a more integrated and incorporated mission picture rather than each subsystem data. Even though, these systems were largely analogue, later modification did introduce some digital subsystems. Most of the avionics system interconnection is still undertaken by hardwiring as data buses were not just very mature and established at that stage.

5.4.2.1.3.1980s period

During the 1980s the accessibility and maturity of established and cost-effective data buses such as MIL-STD-1553 and ARINC 629 simplified the avionics integration task and removed much of the interconnecting wiring, leading to the multiplex bus federated system seen in the military aircraft such as F-16 Fighting Falcon (see [46]).

5.4.2.1.4.Evolutionary period of 90s

Since 1990's the necessity for standardization and modularization of the overall hardware and software were recognized as the main targets of the advanced digital technology. The concept of common integrated processor cabinets provides a modular computing resource for all the mission functions.

5.4.2.2. Future of RF integration

As studies and research is done on integrating the avionics functions on one module; still the researchers are missing the concept and research area of RF system integration in avionics systems. The RF content of the avionics system is increasing at a high rate and the requirement for proper integration of the RF system such as sharing of the receiver, signal processor and transmitter resource is direly needed. As a result, research studies have been carried out to think about the course of action for future development of avionics integration.

The large scale research in the RF integration resulted in the Joint Advanced Strike Fighter (JAST) F-35 architecture (see [44]). This research highlighted the adoption of a number of technologies to aid system integration, but possibly the most novel idea of this research program is the concept of using shared aperture and antenna for the RF architecture.

For these research studies, the engineers and researchers identified all the main areas for research such as apertures, sub-systems, type of antenna, number of active elements, frequency bands, location of each system, the RF amplification, detection and signal modulation and demodulation and the power amplification for outgoing signals.

5.4.2.3. Shared aperture architecture utilized in F-35

The aim of this research, which was conducted by the engineers and researchers involved with the development of F-35, was to provide an integrated RF sensor system for the avionics systems which are dependent on the resource of electromagnetic spectrum. These include radar, electronic warfare systems, electro optics sensors and systems, communication and navigation systems and aircraft identification sensors.[2]

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[2] *This research is being carried on for the civilian medium jet aircraft model so it will focus only on the integration of communication, navigation and identification sensors.*

The sharing of resources between the functional systems can enable significant savings in cost, weight, volume and reliability. Studies have quantified these savings by comparing both the generation aircraft of the Lockheed Martin i.e. F-22 Raptor and F-35 (see [44])

5.4.2.4. RF integration concept in F-35

The primary arrays may typically comprise a large active array: Multiarm Spiral Arrays (MASAs), slot arrays and Multiturn Loops (MTLs). These arrays are connected via a RF interconnect to a collection of receive frequency converters that change the signal to intermediate frequency (IF). The IF received signals are fed through an IF interconnect to the receiver modules. After detection, the baseband in-phase (I) and quadrature (Q) components are fed through the fibre-optic interconnect to the integrated core processing. For transmission the reverse occurs, signals are passed to the multifunction modulators and through a separate IF interconnect to the transmit frequency converters. After modulation and power amplification, the output signals are passed via the RF interconnect to the appropriate arrays. It is the sharing of these functions within a common RF host that enables the major savings. (see [44]).

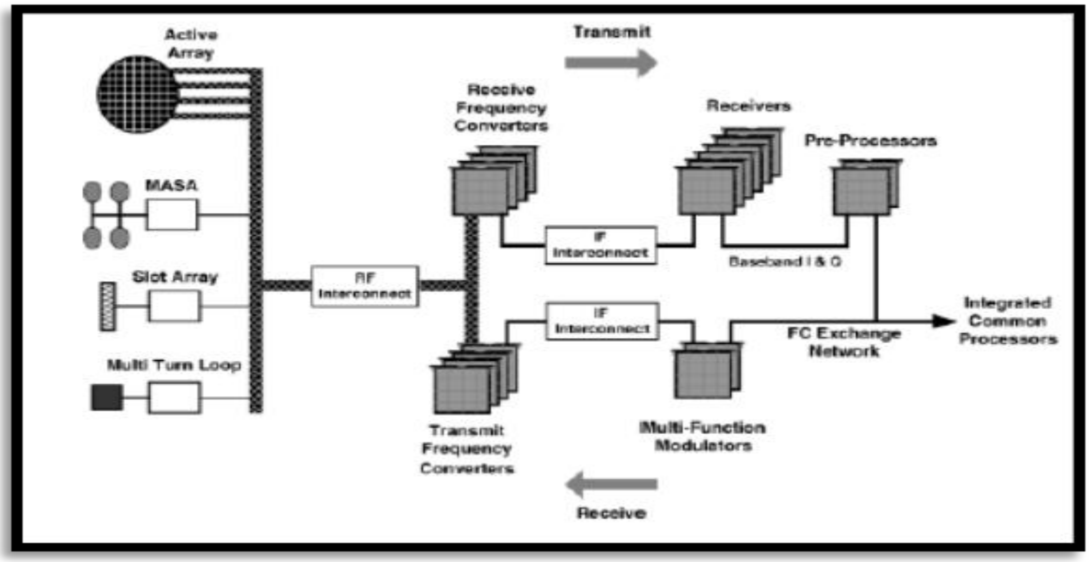

Figure 5.2 Integrated RF architecture of F-35

5.4.2.5. RF integration for Integrated Communication, Navigation and Identification Suite (ICNIS) with IMA architecture

In this part of the research, it has been analyzed in detail the different dimensions of IMA architecture and guidelines to develop an IMA system. Then some concepts were analyzed regarding to the RF integration in F-35 and F-22 Raptor. For implementing these concepts in this research and developing a new architecture on the basis of these research studies; a concept for common processing module for an Integrated Communication, Navigation and Identification Suite (ICNIS) with IMA architecture has been developed. Thus the aim is to employ the concepts of RF integration with avionics software integration (involved in IMA) and develop top level design architecture for avionics systems in civil aviation. The name of this design architecture is "RF Integrated modular avionics CNI suite" for civil aviation aircraft. This design an be employed in the future civilian platforms and it would be great benefit in terms of cost, reliability, weight and volume of the aircraft systems.

5.4.2.6. RF Integrated modular avionics CNI suite

As it has been shown in the Figure 5.3 that different avionics applications are running in parallel on the real-time operating system with a high graded processor giving all the necessary time and memory partition to each application. The black and blue arrows are the queuing and sampling ports connecting the end system Avionics Full-Duplex Switched Ethernet (AFDX) network layer with the common processing module .i.e. the CNI suite. This avionics application layer is also connected in parallel to the remote interface unit (RIU) which converts the received analog signals to digital for the avionics application layer and digital signals to analog for transmission.

Furthermore after receiving the electromagnetic signals from the antennas; RIU converts them to Intermediate Frequency (IF) through receiver frequency converters. The IF receives signals are supplied through an IF interconnect to the baseband frequency receiver unit. After detection of the baseband signals, the signals are transmitted to the actual ports of the avionics application layer through the sampling and queuing ports.

The RIU treats the suitable group of signals as an interface for the exact avionics application. Basically, the RIU accumulates bytes received from these sensors and route this data to specific ARINC 664 ports within the ARINC 664 end system.

For transmission, the reverse occurs; signals are passed to the multifunction modulators and through a separate IF interconnect to the transmit frequency converters. After suitable modulation and power amplification, the output signals are passed via the RF interconnect to the appropriate antenna arrays for transmission.

For transmissions, the RIU takes bytes from precise communication ports in the ARINC 664 end system and directs these to transmitting antennas.

5.4.2.6.1.VHF/UHF communication radio and HF communication radio

The communication radio (COM) works on the VHF/UHF frequencies. Also there is redundant HF radio for long distance communication. The Hand On Throttle And Stick (HOTAS) application in CPM1 is used for Push-To-Talk (PTT) inquiry. Thus the pilot sends the command from PTT button on HOTAS which is indirectly delivered to the audio control panel and this VHF/UHF communication (COM) or HF COM radios. Then when pilot speaks, his voice is transmitted. The pilot microphone and the head set are directly connected to the audio control panel in CPM1. When pilot speaks his voice is directly goes to the audio control panel application from where it is routed through specific virtual links to the VHF/UHF or HF application layer. From there, the voice is sent through queuing ports to the RIU which converts the signals from analog to digital and then after modulation sends it to the appropriate frequency channel.

5.4.2.6.2.Instrument Landing System (ILS)

The ILS (localizer and glide slope) signals are received by the receptive antennas and the received signals will be sent to the ILS application through the RIU. These signals are processed in the ILS application layer. The ILS application software provides azimuth and elevation from landing course for approach and landing phase to the displays. The main outputs include the ILS audio identification signals for the audio control panel application and aircraft azimuth and elevation signals for the MFDs application in CPM1.The appropriate signals are transmitted to both applications of CMP1 through precise Virtual Links (VL).

5.4.2.6.3.VHF Omni-directional Range (VOR)

It provides continuous selection of course around a circle with round station at the center. The VOR signals are received by the receptive antennas and from the RIU the received signals are sent to the VOR application. After processing the course signals will be sent on the MFDs application in CPM1 through virtual link.

5.4.2.6.4. Distance Measuring Equipment (DME)

To measure the distance, the interrogator (transponder airborne part of the DME) transmits an encoded signal. The ground station containing a transponder replies to the interrogation. The RIU receives this information and sends this data to DME application layer for processing. The resulted distance from DME application is send through virtual link to the MFDs application in CPM1.

5.4.2.6.5. Non-Directional radio Beacon (NDB) and Automatic Direction Finder (ADF)

The NDB application receives the correct bearing of the airport in the HF frequency range from the RIU. Then the NDB application provides the audio signals to the audio control panel application and course bearing signals for the MFDs application in CPM1.The appropriate signals are transmitted to both applications of CPM1 through precise virtual links (VL).

5.4.2.6.6. Combined Inertial Navigation System (INS) and GPS platform

The INS/GPS application platform receives the real-time data of the GPS for the cross solution. It measures the angular rates and linear accelerations of the aircraft through the gyros and accelerometers connected to the application software. After calculation, it provides following output data for the MFDs application for display in CPM1.

- Accelerations
- Velocity
- Position (longitude, latitude, altitude)
- Magnetic variation
- Attitude (pitch and roll)
- Heading

5.4.2.6.7. Radio Altimeter (RA)

This avionics application works on principle of radar technology to calculate the altitude of the aircraft from ground. The antennas connected to the RIU transmit the RF signals to ground and receives the returning signal and therefore calculates the altitude. The signals are transmitted from the RIU to the radio altimeter application which processes the altitude data. This altitude data is sent to electronic ground proximity warning system application in CPM4 and to the MFDs application in CPM1 for display.

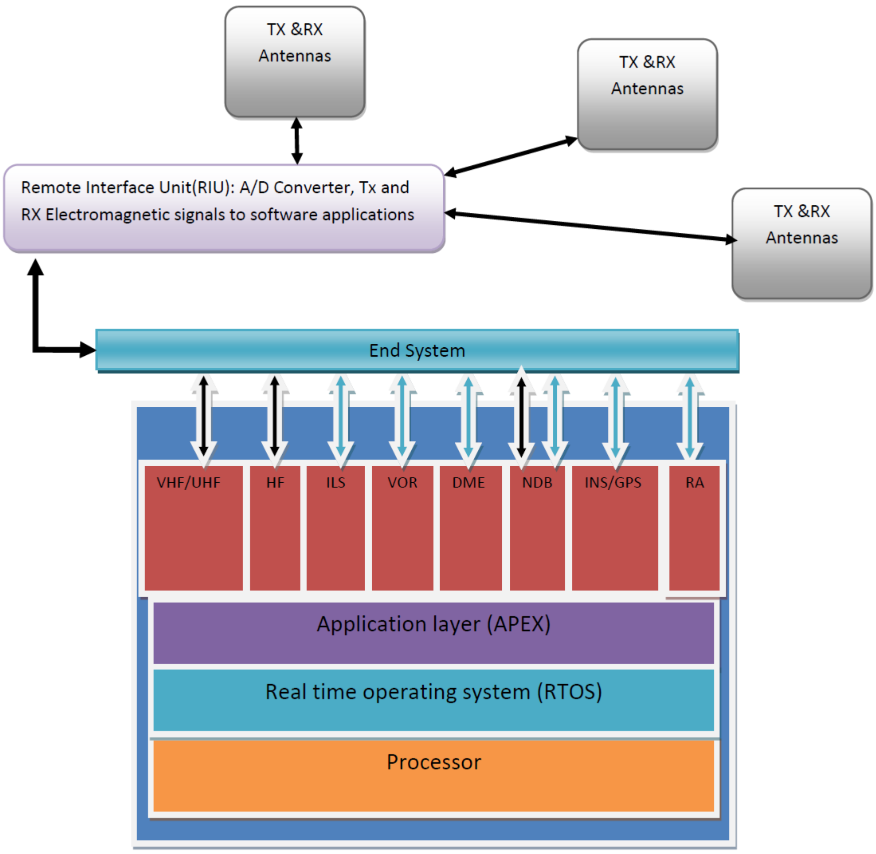

Figure 5.3 CPM 2: RF Integrated modular avionics CNI suite

5.4.3. CPM 3: Mission electro mechanical management system

This system manages the mechanical part of the aircraft avionics system.

5.4.3.1. Mission Electromechanical Management Computer (MEMC)

It is used for the data acquisition and management of all the electric and mechanical systems on the aircraft, and transfers the related parameters to aircraft systems and avionics system. Major functions include as monitoring of non avionics subsystems, data acquisition and transfer of non avionics subsystem display upon request and record aircraft flight parameters.

Following are non-avionics system interfaces with MEMC which provide all their information to this application. The MEMC will give this information to the MFDs applications in CPM1 for display. Furthermore, the HOTAS application is also sending the required commands to MEMC application.

- Engine system
- Landing gear
- Fuel system
- Hydraulic system
- Cockpit pressurization system
- Flight control system

5.4.3.2. Backup Display Unit (BDU)

It is a backup unit of the avionics systems, which gives the backup output information to the MFDs for display in case of any major avionics system failure in CPM1. This system obtains key information from air data computer, altitude, heading and reference system, engine parameters, ILS, hydraulic system and fuel system. The system outputs the data to MFDs for display.

- Fuel quantity
- Magnetic heading
- Pitch, roll
- Calibrated airspeed
- Mach number
- Angle of attack
- Cockpit pressure
- Brakes pressure
- Localizer and glide slope deviation

5.4.3.3. Warning system

The warning system includes warning computer and two or three lamp warning panels according to the system configuration. It provides the pilot with the fault warning information of aircraft system and equipment, operational status information of important systems and warning of flight control systems.

It gets all the information from the MEMC and shows this information to the warning panels.

- Engine
- Fuel system
- Power supply
- Hydraulic system
- Brakes
- Cockpit pressurization system
- Flight control system

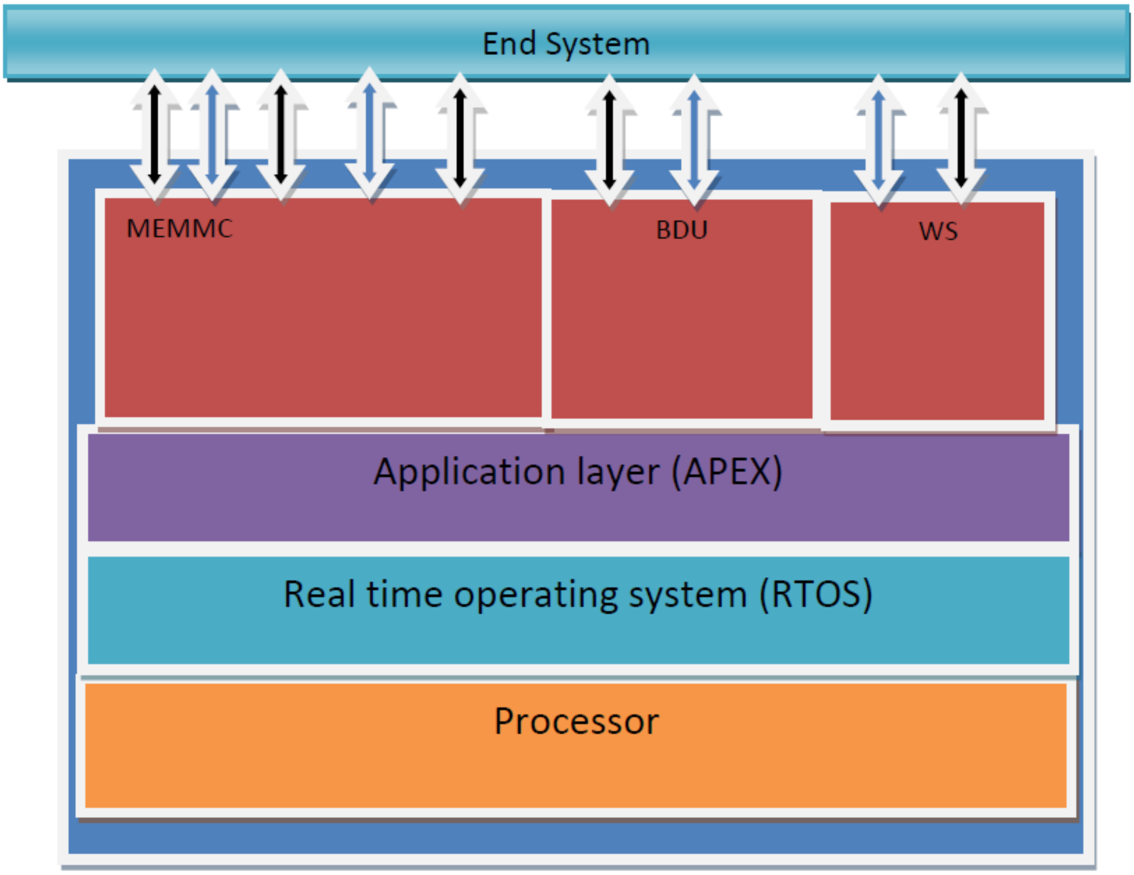

Figure 5.4 CPM 3: Mission electromechanical management system

5.4.4. CMP4: Aerial flight data and avoidance systems module

This CPM provides the information related to the flight data parameters. Furthermore, it provides the information regarding to collision avoidance, low terrain ground proximity warning and adequate weather information for safe flying.

5.4.4.1. Air Data Computer (ADC)

The ADC application software obtains the pressure information in digital signal from the analog-to-digital computer connected to the pitot tubes. The system consists of main parts such as three pressure transducers such as left pressure transducer, right pressure transducer and major pressure transducer and the analog-to-digital computer. The pressure transducers supply the pressure information to the analog to digital computer which converts these signals into digital signal and transfer them through communication ports to air data computer application for the calculation of air data parameters. These parameters are transferred to MFDs avionics application in CPM1 for display and MEMC in CPM2 for the subsystems. The ADC calculates following main parameters.

- Static pressure
- Total pressure
- Mach number
- Total temperature
- Pressure altitude
- Barometric reference altitude
- Calibrated airspeed
- True airspeed
- Climb rate

5.4.4.2. Traffic Collision and Avoidance System (TCAS)

TCAS monitors the airspace around an aircraft for detecting the other aircraft that are equipped with a corresponding active transponder, independent of the air traffic control, and warns to the pilots about the presence of other transponder-equipped aircraft which may present a threat of mid-air collision. The system consists of parts such as transponder and antenna. The TCAS application software obtains the required information from the transponder unit and calculates the active airspace around the aircraft. The results regarding to the airspace are sent to the MFDs application software though the queuing communication ports for showing the real-time scenario.

5.4.4.3. Electronic Ground Proximity Warning System (EGPWS)

The system warns the pilot for low altitude conditions and also for sudden rate of altitude change. This application obtains the altitude data from the radio altimeter application and also the GPS system maps. Thus it provides the exact digital altitude map layout for adequate flying. The output is sent through the communication ports to the MFDs application for display and audio control panel for the low altitude alarms in CPM1.

5.4.4.4. Altitude Heading and Reference System (AHRS)

It is the backup of the INS system in order to provide heading and attitude signals. Thus it provides the real time parameters of attitude (roll, pitch) and heading signals for the aircraft. The AHRS acquires airspeed and true angle of attack from pressure transducers and corrects the attitude using kalman filtering. In addition it also receives the magnetic heading signals from strap down magnetic sensor to correct heading. Finally, the AHRS application sends the attitude and heading signals to backup display unit application.

5.4.4.5. Weather radar

It provides the aircraft with the adequate weather information. The main system components include the radar antenna, transceiver and weather radar application software. The weather information is sent to the MFDs application in CPM1 through queuing communication port.

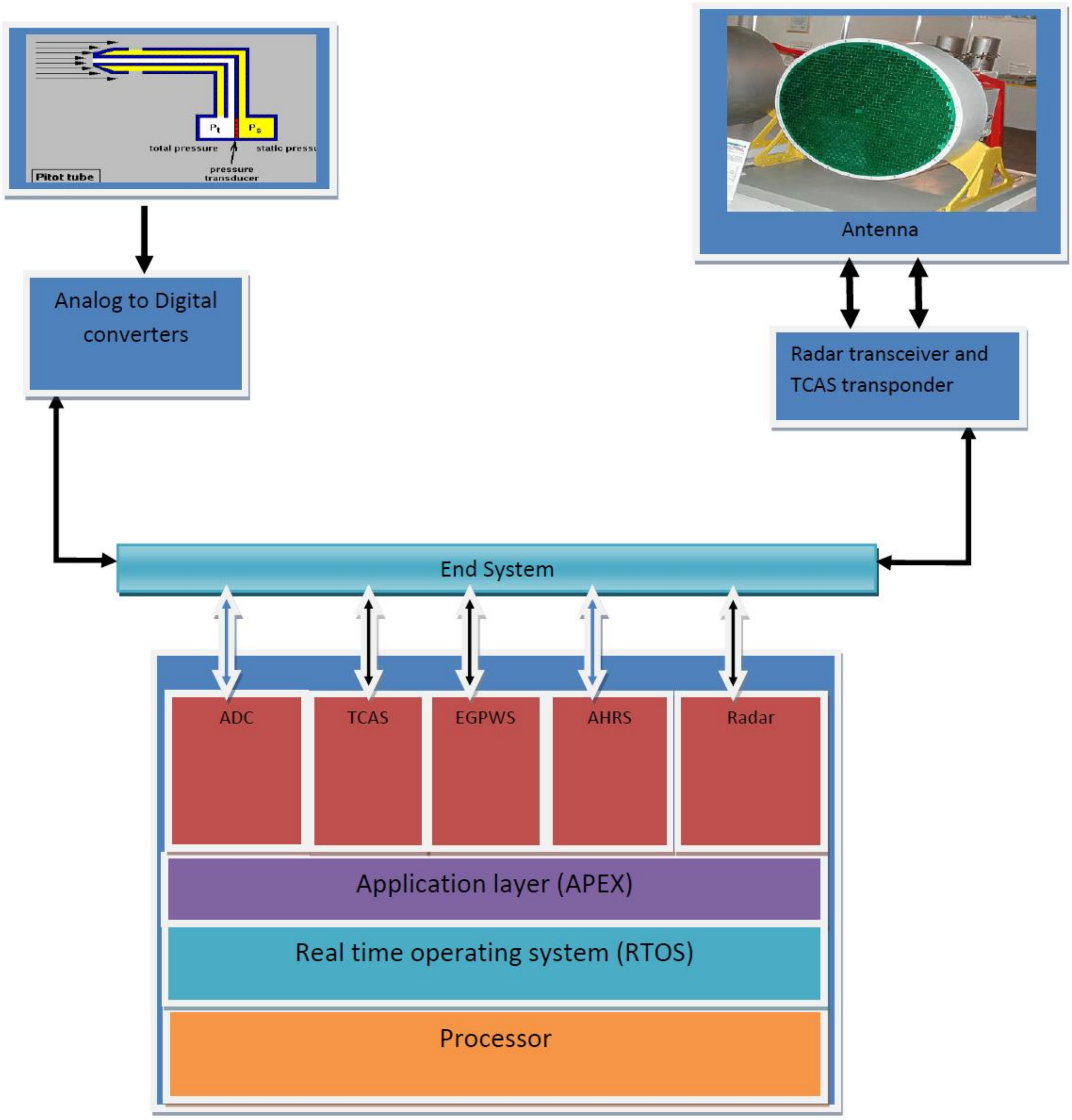

Figure 5.5 CMP 4: Aerial flight data and avoidance systems module

5.5. Top level architecture

In the IMA architecture, the "star topology"[3] is commercially used in the network design architecture for the latest Airbus aircraft such as A380 (see [42]). Utilizing this concept, the star topology is also being used in this architecture.

For this project, the scope is limited for top level design where the network design considerations related to constraints include: how much the bandwidth allocation gaps (BAGs) to select, how many virtual links in the system and how many AFDX switches in the network. All these issues are open with respect to the industry and the avionics designer consideration.

In this report just for better explanation of the top level design, a mock-up network design has been presented with four switches and one hub station.

Each switch is connected to its own CPM and also connected with the hub for transferring the data package to other CPM through appropriate virtual links.

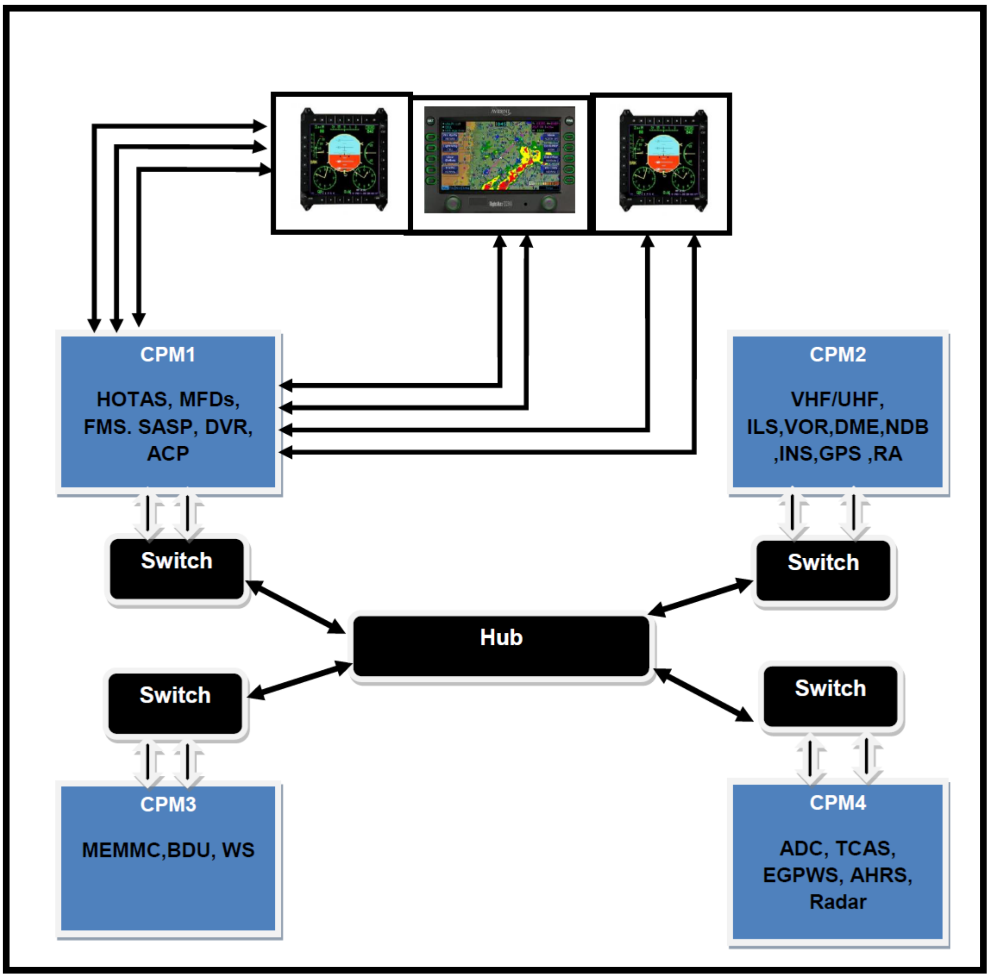

Figure 5.6 Top level IMA design architecture of medium jet aircraft

[3] In a star network devices are connected to a central computer, called a hub. Nodes communicate across the network by passing data through the hub.

Conclusion

The purpose of this project is to obtain in depth knowledge of the background and evolution of the avionics in the aviation industry. The idea and goal was to research and study in detail the different avionics buses and architectures in the aviation industry and then using this knowledge to develop the top level avionics system design of a medium jet civilian aircraft.

During the course of the project a very critical analysis has been done regarding to the growth of avionics systems from analog systems to digital avionics systems involving the avionics buses and protocols such as MIL-STD-1553B, ARINC 653, ARINC 664 and ARINC 629. The knowledge acquired after detailed research and study of the different avionics architectures is implemented to develop the top level avionics design architectures for MIL-STD-1553B and Integrated Modular Avionics (IMA) systems.

Avionics modification analysis from electromechanical to digital avionics systems has been done in detail. It has been critically explained the theoretical and practical research analysis concerning to the aircraft problems with the ageing avionics systems and possible solutions, constraints and recommendations regarding to the avionics modification for legacy aircraft. It has been presented the complete top level avionics design architecture of a medium civilian jet aircraft employing the MIL-STD-1553B bus federated architecture.

It has been described the two basic concepts regarding to the integrated modular avionics e.g. the ARINC 653 (avionics application standard software interface) and ARINC 664 (avionics full-duplex switched Ethernet). A complete protocol layout has been developed for the IMA architecture.

It has been presented the hardware and software system integration process for integrated modular avionics (IMA) architecture of aircraft involving ARINC 653 and ARINC 664 avionics protocols. The seven step avionics integration process can be used in the aviation industry.

Finally, it has been presented the complete top level avionics design architecture of a medium civilian jet aircraft employing the integrated modular avionics architecture. A new and innovative IMA design model has been proposed for the aircraft communication, navigation and identification suite that can be used in the next generation civilian aircraft.

Glossary

ADC	Air Data Computer
ATM	Air Traffic Management
ADCN	Aircraft Data Communication Network
AEEC	Airlines Electronic Engineering Committee
AHRS	Altitude Heading And Reference Systems
API	Application Program Interface
APEX	Application/Executive Interface
ADF	Automatic Direction Finder
APU	Auxiliary Power Unit
AFDX	Avionics Full Duplex Switched Network
AMP	Avionics Modernization Program
BADU	Backup Avionics Display Unit
BAG	Bandwidth Allocation Gap
BSP	Board Support Package
CCP	Center Control Panel
COTS	Commercial Off The Shelf
CPM	Common Processing Module
CNS	Communication Navigation Surveillance
COM	Communication Radios
CNI	Communication, Navigation And Identification
DVR	Digital Video Recorder
DME	Distance Measuring Equipment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EGPWS	Electronic Ground Proximity Warning Systems
FIFI	First In First Out
FCS	Flight Control System
GATM	Global Air Transport Management
GNSS	Global Navigation Satellite Systems
HOTAS	Hand On Throttle And Stick
HUD	Head Up Display
I/O	Input/output
ILS	Instrument Landing System
IF	Intermediate Frequency
IMA	Integrated Modular Avionics
IP	Internet Protocol
Lmax	Largest Ethernet Frame
LCC	Life Cycle Cost
LRU	Line Replaceable Unit

MAF	Major Time Frame
MAC	Media Access Control
MEMC	Mission Electromechanical Management Computer
MMC	Mission Management Computer
MMPM	Mission Management Processing Module
MASA	Multiarm Spiral Arrays
MFD	Multifunction Display
MTL	Multiturn Loops
NDB	Non Directional Beacon
RA	Radio Altimeter
RTOS	Real Time Operating System
RIU	Remote Interface Unit
SNMP	Simple Network Management Protocol
TCAS	Traffic Collisions Avoidance Systems
UDP	User Datagram Protocol
VL	Virtual Link

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