Computer Networks & Software, Inc.

Multi-function, Multi-mode Digital Avionics (MMDA) Architecture and SC200 Integrated Modular Avionics Analysis Report

to

NASA GRC

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Mid term Report

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1. INTRODUCTION

The National Aeronautics and Space Administration's (NASA) Glenn Research Center (GRC) plans to develop and demonstrate the flexible capabilities of multi-function, multi-mode digital avionics (MMDA) for civil aviation applications such as communications, navigation and surveillance. To achieve this objective GRC requires a MMDA radio architecture. GRC issued a task order to Computer Networks & Software, Inc. to develop MMDA architecture. AvioniCon, Inc. supported Computer Networks & Software, Inc. in producing this report.

For the purposes of this task, the term, "multi-function" refers to multiple communications, navigation and/or surveillance functions that can be performed by avionics either sequentially or simultaneously (e.g., VHF Digital Link (VDL) communications, Global Positioning System (GPS)-based navigation, and/or Automatic Dependent Surveillance Broadcast (ADS-B) transmissions). "Multi-mode" refers to the capability to perform sequentially, two or more operational modes of a given communications, navigation or surveillance function (e.g., communications via either VHF analog voice mode or VDL Mode 2). "Digital avionics" refers to onboard aircraft electronics hardware and software that are either software defined or re-configurable for multiple functions and/or modes of operation.

The current and planned avionics and associated technologies to be assessed under this task apply to a wide range of aircraft classes including commercial carrier and cargo transport aircraft, business jets, general aviation, and military aircraft.

GRC's intent is to utilize the architecture and certification techniques developed under this task to identify the unique role NASA can perform to facilitate:

- Leveraging and advancing the state of the art in avionics technology
- Reducing the cost, size and power consumption of commercial avionics
- Improving the flexibility and capability of avionics to interoperate with existing and future international standards
- Reducing the time and cost to initially certify and potentially re-certify aircraft with software-defined avionics in the future.

Specifically, GRC intends to use the results from this task to develop a statement of work to develop a prototype MMDA radio. The purpose of the MMDA prototype is to ensure the avionics and software developed under the Advanced Communications, Navigation and Surveillance Architectures and System Technologies (ACAST) project complies with the technical and certification standards that will provide a path to eventual certification. The capability to get an avionics product certified is essential for commercial fielding of the product, which will yield a benefit to the users of the National Airspace System (NAS).

The paper incorporates the SC-200 (Integrated Modular Avionics guidance working paper) report, which provides a certification strategy and guidance for the development of multi-mode, multi-function digital avionics (MMDA).

1.1. ACAST Project Overview

NASA, in cooperation with the Federal Aviation Administration (FAA), is investigating new technologies to increase the capacity and efficiency of the NAS. The ACAST Project led by GRC in Cleveland, Ohio will be developing architectures and system technologies to initiate the transition of today's systems into a high-performance network-centric digital infrastructure to support the transformation of the National Airspace System.

The overall ACAST goal is to develop and design the transitional architecture and enabling system technologies to transform the NAS through a high-performance integrated Communications Navigation and Surveillance (CNS) system. Other specific elements of the ACAST Project include the definition of a global air/ground network architecture, the development and identification of efficient aviation spectrum utilization, the implementation of efficient oceanic/remote operations through improved communications and surveillance, and increased air-ground data link performance and capacity for terminal, en-route and surface operations.

An essential element that is complementary to the advanced technology development will be the assessment of the policies, strategies and action plans related to operational concepts, business case development and transition strategies. The areas are not separate tasks, but an integration of activities that deliver valid, supportable concepts that the user community can embrace and understand sufficiently that they will actually support the technology and transition.

1.2. Scope

This report identifies a MMDA architecture, working groups relevant to MMDA, software-defined and/or software reconfigurable avionics capabilities, technologies, and/or certification methodologies.

It will provide a certification strategy and guidance for the development of multi-mode, multi-function digital avionics (MMDA) based on a SC-200 Integrated Modular Avionics guidance working paper that accomplishes the following tasks:

A. Report on relevant SC-200 activities and changes and their impact on NASA sponsored development of a certification-ready multi-mode, multi-function digital avionics prototype. The report makes a distinction between findings relevant to avionics that are only multi-mode from those that are both multi-mode and multi-function. A distinction is also made between sequential and simultaneous operation of both multi-mode and multi-function avionics.

B. Provide guidance and requirements for architecture, design, development data, and documentation created during development of the prototype.

C. Provide recommended procedures, strategies and requirements based on SC-200 final paper.

D. Provide recommendations on a strategy for segmentation of multi-mode, multi-function digital avionics into discrete, potentially reusable modules.

1.3. Statement of Work Compliance - Sectional Reference

The following table presents the cross sectional reference to the tasks specified in the scope section 1.2., as a means to illustrate compliance.

Table 1-1. SOW Compliance – Sectional Reference

Scope - Task	*Sectional Reference*
A	6.[1], 6.1., 6.2., 7.
B	2., 2.1., 2.2., 2.3., 2.4., 5., 5.1., 5.2., 5.3., 5.4., 5.5., 5.6.
C	6.2., 6.2.1., 6.2.2., 6.3., 6.3.1., 6.3.2., 6.4., 6.4.1., 6.4.2., 6.4.3., 6.5., 6.5.1., 6.5.2., 6.5.3., 6.5.4., 6.5.5., 6.5.6.
D	5., 5.1., 5.1.1., 5.1.2., 5.1.3., 5.5., 5.5.1., 5.5.2., 5.5.3., 5.5.4., 5.5.5.

1.4. Document Organization

This report is organized into six sections supported by two appendixes:

Section 1 provides an introduction and overview.

Section 2 contains background about Software Defined Radio.

Section 3 describes the Trends in Avionics Architecture.

Section 4 describes the Communications, Navigation and Surveillance protocols.

Section 5 presents the MMDA Logical Architecture.

Section 6 outlines the SC-200 Integrated Modular Avionics Analysis & System Certification

Section 7 lists the Recommendations

Section 8 presents the MMDA Related References.

Appendix A contains an acronym reference listing.

Appendix B contains a detailed description of the Data Link protocols

[1] The SC-200/WG-60 document is currently being jointly drafted by RTCA SC-200 and EUROCAE WG 60.

2. SOFTWARE DEFINED RADIO BACKGROUND

The Software Defined Radio (SDR) concept began with the introduction of multimode radios operating in the VHF band followed by development of an architecture to support multifunction, multi-band airborne radios in the 30 MHz – 1600 MHz band. The next step was to develop a processor capable of handling simultaneous waveform operation. In the interim, the Department of Defense (DoD) used the SDR technology to consolidate a family of discrete military radios into a single platform utilizing software radio technology. To accomplish this goal, the U.S. Government invited industry to participate in the Modular Multifunction Information Transfer Systems (MMITS) forum. This forum initially functioned as a body to establish open architecture standards for DoD programs. The MMITS forum eventually shifted its focus from the government community to the commercial community, and the MMITS forum officially changed its name to the SDR Forum. Since then, the SDR Forum has promoted SDR technologies with applications for commercial cellular, Personal Communication Systems (PCS), and emerging third-generation (3G) and fourth-generation (4G) cellular services.

One of the goals of the ACAST program is to develop a prototype MMDA radio for Air/Ground Communications. The MMDA radio can provide potential benefits for the aviation community by:

- Accommodating multiple air-interface standards
- Facilitating transition by bridging legacy and future technologies
- Allowing multiple services – incentives for equipage
- Implementing “future-proof” concepts – capable for insertions of future technologies
- Allowing easy upgrades
- Implementing open-architecture to allow multiple vendors to supply or participate
- Offering declining prices
- Reducing product development time
- Enabling other advanced commercial technologies to be adapted to offer user’s services and benefits

2.1. Software Defined Radio Technology

The SDR Forum defines the ultimate software radio as one that accepts fully programmable traffic and control information and supports a broad range of frequencies, air-interfaces, and applications software. A good working definition of a software radio is “a radio that is substantially defined in software and whose behavior can be significantly altered through changes to its software.” The degree of reconfigurability is largely determined by a complex interaction between a numbers of common issues in radio design, including systems engineering, antenna form factors, radio frequency (RF) electronics, baseband processing, speed and reconfigurability of the hardware, and power supply management.

The term software radio generally refers to a radio that derives its flexibility through software while using a static hardware platform. The functionality of conventional radio architectures are usually determined by the hardware with minimal configurability through software. The hardware consists of the amplifiers, filters, mixers (probably several stages), and oscillators. The software is confined to controlling the network interface, stripping the headers and error correction codes from the data packets, and determining where the data packets need to be routed based on the header information. In short, software radios represent a paradigm shift from fixed, hardware-intensive radios to multi-band, multimode, software-intensive radios.

SDR transceivers implement many functions by running software on general-purpose hardware. The analog hardware for functions such as frequency tuning, filtering, modulation, and demodulation is replaced by software that implements these functions digitally. Such an arrangement enables a single radio to configure its mixers and filters to handle multiple modulation schemes and to work across many frequency bands.

The first step in transforming a conventional radio into an SDR system is to make as much of the circuitry digital as possible. To start, this means eliminating the baseband analog operations. These are carried out on the input signal while it is still occupying its native region of the spectrum and before it modulates a carrier and are thereby translated to a higher frequency band.

The component technologies that form the backbone of SDR systems- and set their performance limits- are ADCs (Analog to Digital Converters), digital signal processors, filters, and RF amplifiers. The ADC is the most critical element of an SDR since its speed determines how close to the antenna the analog-to-digital conversion can be accomplished. Defining ADC performance is always difficult because it involves specifying both analog and digital parameters. In essence, three areas must be characterized: speed (number of samples per second), resolution (how many) bits each sample is coded into), and linearity (how accurately the digital output codes are related to the analog input values).

There are three system level and architectural issues that defines the capabilities of a software designed radio. There are:

- Interoperability support
- Software download approach
- Extent of software use

2.2. Interoperability Support and Software Communications Architecture

A key enabler for software defined radio technology is the Software Communications Architecture (SCA) developed by the Modular Software-Programmable Radio Consortium (MSRC) under contract to the Joint Tactical Radio System (JTRS) Program Office. This architecture “objectizes” the radio structure, and defines a standard application framework (referred to as the *core framework*) for instantiating and connecting the waveform objects associated with each radio channel. The SCA is designed to ensure portability of waveforms across the various radios in the JTRS family.

There are limits, however, on the level of portability supported. The SCA does not constrain the modem architecture, allowing the use of any combination of general-purpose processor (GPP), digital signal processor (DSP), and field programmable gate array (FPGA) devices the radio developer deems necessary within the modem to support the physical layer implementation of the target waveforms. As such, one radio developer may choose to implement the modem architecture using a set of processing devices that are connected together in a specific manner. This architecture may be fundamentally incompatible with software components developed by another radio vendor targeting a different set of devices or interconnect topology. Waveform portability in a SCA-compliant radio can therefore only be guaranteed at the modem interfaces, as defined in the SCA 2.2 API supplement.

That said, by extending the SCA core framework inside the modem, a standard mechanism is provided for setting up, tearing down, and controlling software components representing the algorithmic elements of a modem application running on the physical devices within the modem architecture. In addition, the core framework enables the connection of these software components in a manner that maintains hardware independence while ensuring that the modem implementation meets all performance parameters. Core framework support within the modem thus extends waveform portability by allowing waveform developers to retarget algorithms for a specific modem application across a range of processing devices while maintaining a common hardware-independent application interface.

Today, SCA is the most significant manifestation and realization of the Software Defined Radio concept. The SCA provides a framework that supports an industrial resource-based and component-based approach to build versatile radio sets, each offering several configurations. Furthermore, some of the waveform related Application Program Interfaces (APIs) are specified in the Object Management Groups SCA API supplemental document. However, it must be recognized that the SCA is more focused on management and control facilities than providing radio business services for waveforms developers, and the API supplement is far from being complete.

In general, the use of GPP devices support a POSIX-based operating environment and a programming model that allows for Common Object Request Broker Architecture (CORBA) based communication interfaces, both of which are required by SCA and serve to maximize the portability of software components targeted to the devices.

The SCA addresses the interoperability issue. SCA is a set of specifications describing the interaction between the different software and hardware components of a radio and providing software commands for their control. The SCA offers truly interoperable radios based on open source to avoid incompatible proprietary solutions. Interoperability is supported with software-based waveforms. The waveform software includes not only the actual RF signal in space, but also the entire set of radio functions that occur from the user input to the RF output and vice versa. Waveform portability means the basic waveform software is developed in such a way that it may be "ported" to multiple hardware platforms and operating systems.

Implementation of the ideal software radio would require either the digitization at the antenna, allowing complete flexibility in the digital domain, or the design of a completely flexible RF front-end for handling a wide range of carrier frequencies and modulation formats. The ideal software radio, however, is not yet fully exploited in commercial systems due to technology limitations and cost considerations. However, the present technology is constantly advancing closer to the RF antenna, with recent advances in the VLSI design, which allows high speed Analog to Digital Converters (ADC) and Digital to Analog Converters (DAC). Direct conversion receivers are slowly getting into the market, even though they still have to overcome some technical problems like DC offset, and signal isolation. With the availability of high speed DSPs, FPGAs , ADCs and DACs, it is possible to design a multimode digital radio by using different RF modules for different frequency bands while sharing the same Baseband Modules (digital). Once the signal has been digitized using ADC/DAC converters, the rest of the radio functionality can be completely described in software. If the interface between the RF Modules (analog section) and the Baseband Module (digital) is standardized, then it is possible for different modules made by different companies to be interoperable.

2.3. Software Download

A multimode radio requires the radio to have real-time reconfiguration capability to interface and communicate with heterogeneous networks. Such a multimode operation with limited resources demands efficient implementation of heterogeneous systems on a common hardware platform. Software download for software-defined radio (SDR) and reconfigurable devices can be accomplished by a technician at a service facility, self-service kiosk, subscriber identity module (SIM) card, or over the air. Approaches for over the air down load of radio software is being standardized by a number of standards bodies. The software download capability is needed for adding new services and capabilities to the radio. SDR must be viewed as a system comprising the device, the infrastructure, the servers, and other relevant elements - a most critical architectural view when addressing the download of radio software.

Device reconfiguration is the change of operational software (programs, parameters, or the software aspects of the processing environment) or hardware (i.e., the reconfiguration of the hardware aspects of the processing environment). In general, reconfiguration can concern arbitrary components of communication equipment such as protocol stacks, applications and the hardware configuration.

Requirements for radio software download can be broadly divided into general requirements, requirements related to each individual step in the download process, SDR device requirements, and requirements for the network that supports radio software downloads. A critical general requirement is that any downloaded radio software installed on an SDR device must not malfunction or cause the SDR device to emit undesirable radio frequency waves.

The process of downloading radio software to an SDR device can be broken down into several individual steps such as discovery of the need for download, initiation of download, download setup, mutual authentication, authorization, capability exchange, download acceptance exchange, protection (encryption), software download, installation, in situ testing, non-repudiation, reset and recovery, and termination.

A crucial requirement for reconfigurable SDR devices that support radio software download is a reconfiguration manager (RM) that oversees the processes of radio software download, installation, reconfiguration, in-site testing, and recovery. Such an RM resides on the SDR device in a secure software area that is not subject to reconfiguration. It is responsible for enabling full or partial reconfiguration of all protocol stack layers of the SDR device, controlling and managing reconfiguration processes at the SDR device, ensuring that the anticipated configuration adheres to the given radio access system standards, and communicating with any RM entities residing on the network side to coordinate radio software download and reconfiguration.

SDR devices are required to perform mode monitoring and service discovery to seek alternative modes of operation and services, and select the most appropriate mode of operation for the desired service, including radio software download. SDR devices also need to be equipped with sufficient additional memory space beyond that required for normal modes of operation to support all of the above-mentioned functions. Additional memory is no longer considered an impediment to the implementation of SDR capabilities.

A network supporting radio software downloads needs to meet certain specific requirements. The architecture of such a network needs to also support reconfiguration management (RM) functionalities. These network RM functionalities are responsible for maintaining a database of current configurations and capabilities of SDR devices in the network. They are also responsible for scheduling radio software downloads to SDR devices, supporting efficient downloads to a large number of SDR devices, maintaining and coordinating access to software repositories of third-party vendor and original equipment manufacturer (OEM) software modules. In addition, they communicate with local RMs residing on each SDR device to coordinate radio software download, reconfiguration, mode identification, mode monitoring, mode negotiation, and mode switching.

Software download is a process of moving bits from one location to another. The bits can be anything from multimedia content or a user application to software that causes a hardware reconfiguration. The transport of the bits requires agreed to protocols between the server and the client. Other aspects of download may or may not be required depending on the nature of the bits being transported. In general, all activities that occur before transport are pre-download, and all activities that occur after the download are post-download.

Another RM related requirement is that the radio must not operate with an unapproved configuration. Therefore, a security mechanism must be built into the radio to prevent malicious or accidental reconfiguration. It is desirable that any over the air download be independent of the radio interface technology and the core network to the greatest extent possible.

A number of key industry forums that are leading the standardization of SDR, software download, and associated security aspects. These include the SDR Forum, Object Management Group (OMG), 3rd Generation Partnership Project (3GPP), and 3GPP2. The SDR Forum has been working to facilitate the introduction of equipment capabilities to support device flexibility and reconfiguration.

The Open Mobile Alliance (OMA) has developed a suite of specifications that address device management and application software download. These specifications are a foundation for the standards required for operational software download solutions. Additionally, the International

Telecommunication Union – Radio Communication Standardization Sector (ITU-R) has an SDR work item.

2.4. Characteristics and Extent of Software Use in Software Defined Radio

Figure 2-1 presents a model of a practical software radio. The receiver begins with a smart antenna that provides a gain versus direction characteristic to minimize interference, multipath, and noise. The smart antenna provides similar benefits for the transmitter.

Most practical software radios digitize the signal as early as possible in the receiver chain while keeping the signal in the digital domain and converting to the analog domain as late as possible for the transmitter using a DAC. Often the received signal is digitized in the IF band. Conventional radio architectures employ a super heterodyne receiver, in which the RF signal is picked up by the antenna along with other spurious/unwanted signals, filtered, amplified with a low noise amplifier (LNA), and mixed with a local oscillator (LO) to an IF.

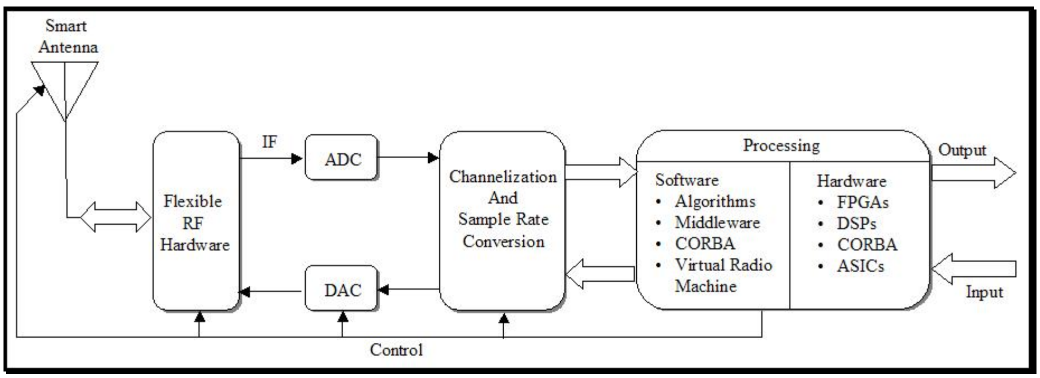

Figure 2-1. A Software Defined Radio Model

Depending on the application, the number of stages of this operation may vary. Finally, the IF is mixed exactly to baseband. Digitizing the signal with an analog-to-digital converter (ADC) in the IF range eliminates the last stage in the conventional model in which problems such as carrier offset and imaging are encountered. When sampled, digital IF signals give spectral replicas that can be placed accurately near the baseband frequency, allowing frequency translation and digitization to be carried out simultaneously. Digital filtering (channelization) and sample rate conversion are often needed to interface the output of the ADC to the processing hardware to implement the receiver. Likewise, digital filtering and sample rate conversion are often necessary to interface the digital hardware that creates the modulated waveforms to the DAC. Processing is performed in software using digital signal processors (DSPs), field programmable gate arrays (FPGAs), or application specific integrated circuits (ASICs).

The algorithm used to modulate and demodulate the signal may use a variety of software methodologies (such as middleware) or virtual radio machines, which are similar in function to JAVA virtual machines.

The software radio provides a flexible radio architecture that allows changing the radio personality, possibly in real-time, and in the process somewhat guarantees a desired Quality of

Service (QoS). The flexibility in the architecture allows service providers to upgrade the infrastructure and market new services quickly. This flexibility in hardware architecture combined with flexibility in software architecture (through the implementation of techniques such as object oriented programming and object brokers) provides the software radio with the ability to seamlessly integrate into multiple networks with wildly different air and data interfaces. In addition, software radio architecture gives the system new capabilities that are easily implemented with software. For example, typical upgrades may include interference rejection techniques, encryption, voice recognition and compression, software-enabled power minimization and control, different addressing protocols, and advanced error recovery schemes.

3. TRENDS IN AVIONICS ARCHITECTURE

The Multi-Mode Receiver (MMR) and ARINC 750 are examples of existing standards that imply a certain level of integration in implementation. The ARINC 750 radio handles 25 KHz and 8.33 KHz amplitude modulated voice, ACARS using 2400 BPS Minimum-Shift Keying (MSK) data, and VDL Mode 2 using differential 8-phase shift keying (D8PSK) at 31.5 Kbps. The commercial airborne VHF radio executes one communication method at a time. These two radios do not use SDR or the complete JTRS architecture. However, using a flexible, expandable architecture, such as the one defined at the top-level for JTRS, would allow an easy implementation when the next mode arrives.

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3.1. ARINC 755-2 Multi-Mode Receiver (MMR)

This standard describes the characteristics of a radio/processor capable of receiving Instrument Landing System (ILS), Microwave Landing System (MLS) and Global Navigation Satellite System (GNSS) source inputs. This is an example of multiple navigation functions implemented in a single radio. The MMR is used to provide flight path deviation guidance to the aircraft during the final approach and landing phases of flight. This radio is an example of MMDA implemented without using SDR technology.

3.2. ARINC 750-3 VHF Data Radio (VDR)

This standard specifies the form, fit and functional definitions for a VHF transceiver capable of voice and data communications. The VHF transceiver supports, 8.33 KHz AM and 25 KHz AM voice, and VHF Digital Link Mode 2 (VDL-2) data link communications as defined by ICAO. This radio integrated multiple communications function in a single radio. Implementation of the radio did not make use of SDR technology.

3.3. Joint Tactical Radio System

The JTRS program is developing software-defined radios for ground and airborne usage. The civil aviation equivalent of an airborne unit is an MMDA. The SCA is a key concept that is significantly affecting the design and development of military radios using the JTRS, open architecture concepts and requirements.

While JTRS is focused on resolving interoperability issues and providing enhanced communications capability for DoD radio systems, the JTRS approach – particularly the SCA – offers a solution to interoperability problems in many other arenas. JTRS could prove particularly beneficial to civil aviation. JTRS has the potential to provide general aviation users with a low-cost, SCA-compliant capability for air and surface transmission of position, weather and traffic conditions.

3.4. Aircraft Architecture

Figure 3-1[2] shows the Airbus A380 aircraft network architecture. The network is based on AEEC 664 Ethernet specification. The Ethernet based architecture allows certain amount of flexibility compared to the traditional avionics bus architectures in terms of bandwidth and distance. In addition, it allows the avionics functions such as display, applications and radio to be integrated into multimode multifunction devices. Once integrated, these devices can be connected to an Ethernet subnetwork.

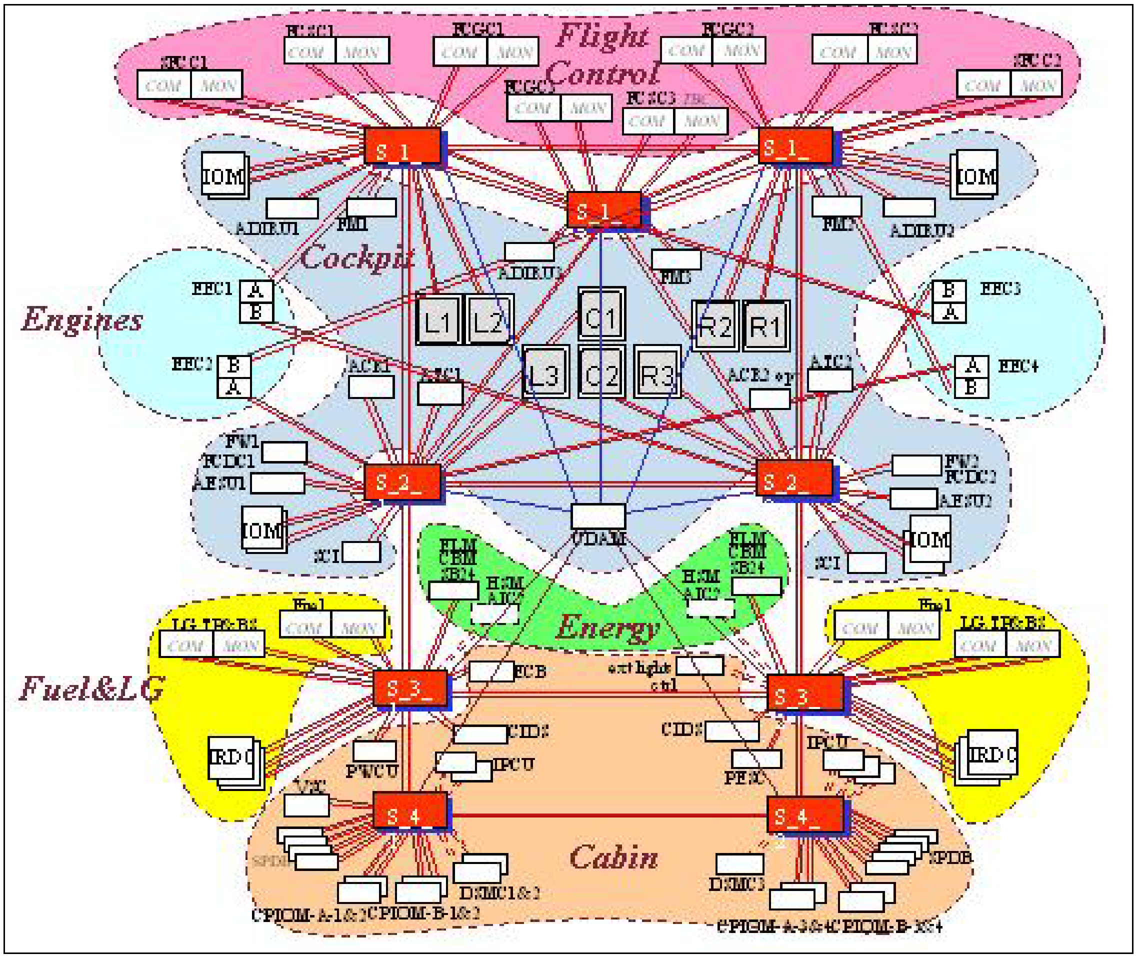

Figure 3-1. A380 Ethernet Based Aircraft Network Architecture

Figure 3-2[3] presents Boeing 787's avionics network. Boeing is using the industry standard AEEC 664 Aircraft Data Network.

[2] Figure 3-1 courtesy Airbus presentation to AEEC Data Link Users Forum

[3] Figure 3-2 courtesy Seagull Technology Inc.

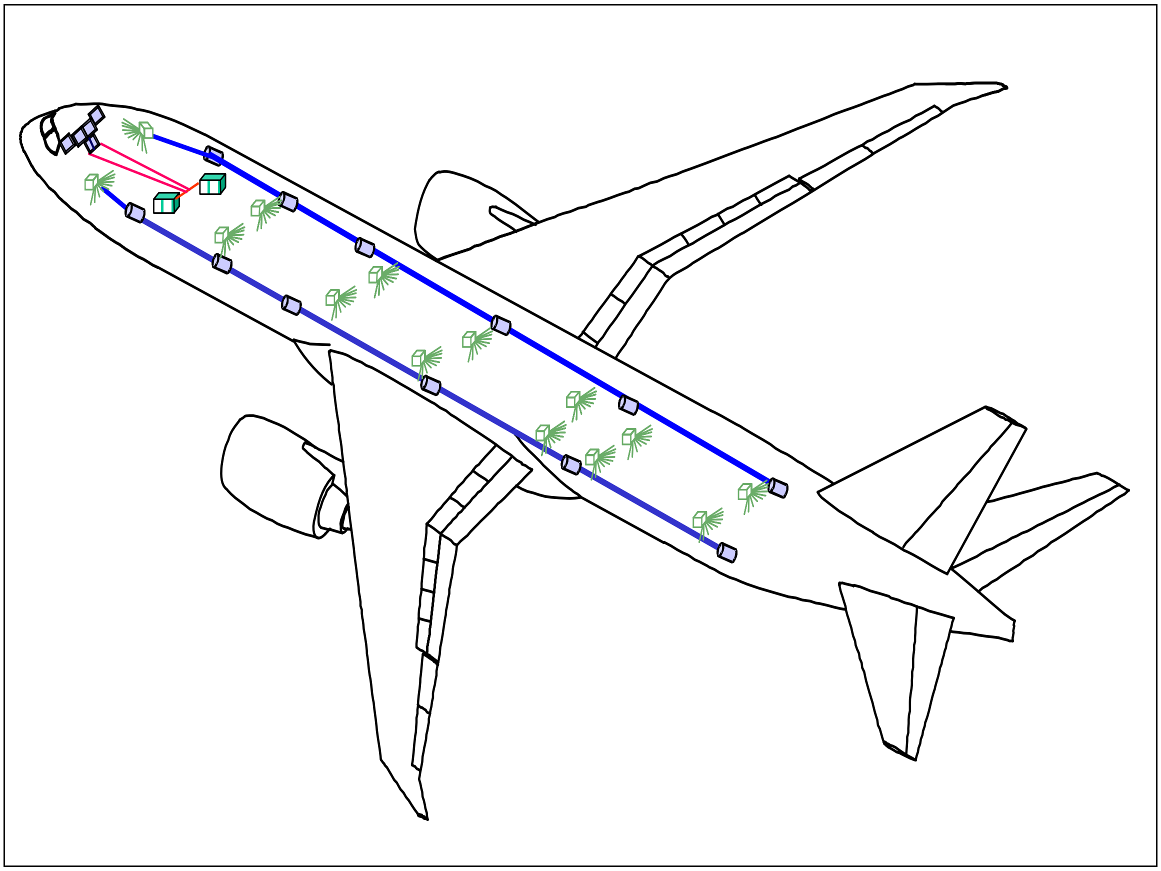

Figure 3-2. Boeing 787 Ethernet Based Aircraft Network Architecture

4. COMMUNICATIONS, NAVIGATION, AND SURVEILLANCE PROTOCOLS

In the communications world, the seven-layer OSI model is used as a reference model to describe network architecture and protocol. The pre-OSI communication protocols were developed to minimize overhead and maximize efficient use of link bandwidth. In the civil aviation world, the legacy data communication protocols, such as Aircraft Communications Addressing and Reporting System (ACARS), were designed with a simplified link level protocol. Figure 4-1 shows the ACARS, ATN and TCP/IP protocol stacks with reference to the OSI protocol stack.

The presentation, session, transport and network protocol layers are absent in the ACARS protocol stack and applications interface directly to the link level layer called VDL Mode 0. In the 1990s, ICAO developed a network architecture based on the OSI protocol called the Aeronautical Telecommunications Network (ATN) to support worldwide interoperability among aeronautical applications. The ATN architecture replaced the presentation and session layers of the OSI reference model by more efficient presentation and session layers. The ATN protocol was defined to be subnetwork independent and therefore can work with various types of subnetworks. Subnetworks include VDL Mode 2, Mode 3 and Mode4, and satellite.

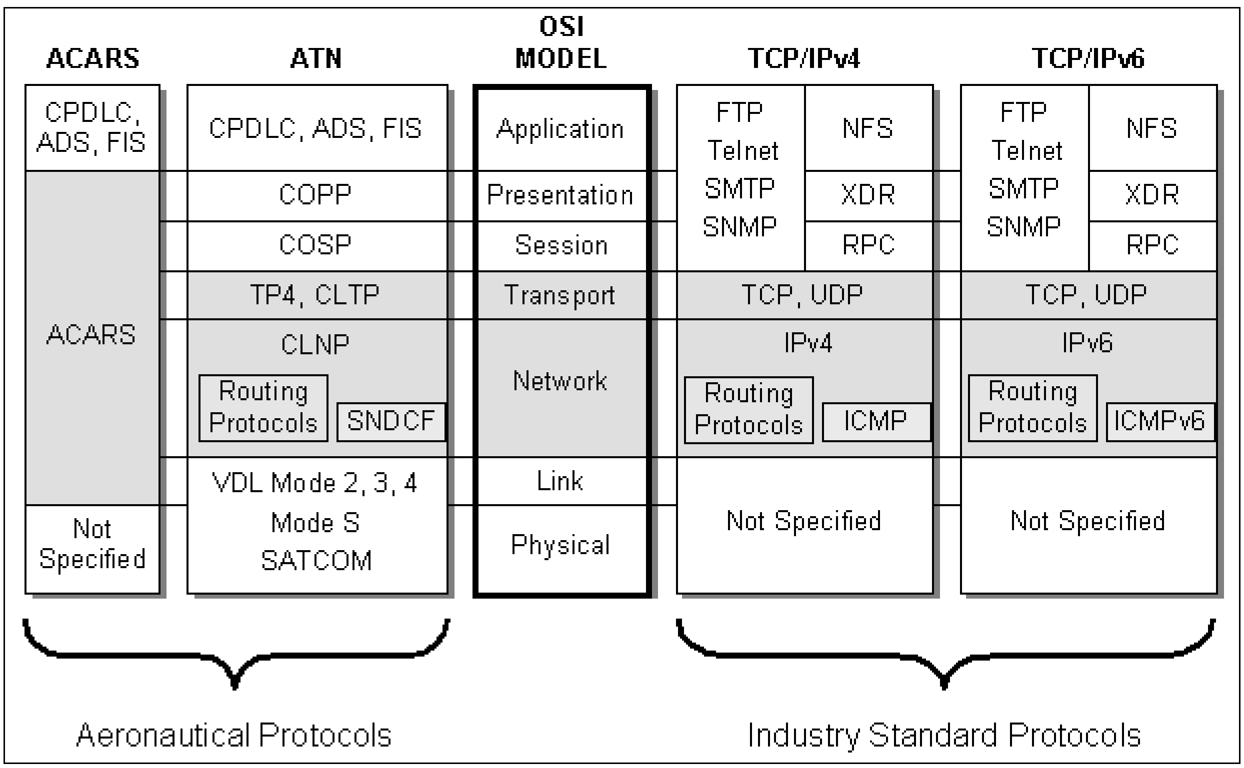

Figure 4-1. Comparison of Protocol Architectures

Service providers such as ARINC and SITA, and the FAA use the TCP/IP protocol suite to support their ground infrastructure. In the TCP/IP protocol stack, applications interface to the transport layer. The TCP/IP protocol stack does not support the presentation and session layers of the OSI reference model explicitly.

4.1. Data Link Characteristics

Table 4-1 presents the list of data link candidates for the MMDA development. Appendix B presents a detailed description of the data links.

Table 4-1. Data Link Protocols

Data Link Technology
Communications
High Frequency Data Link (HF DL)
VHF Mode 0 (ACARS)
VHF Data Link Mode 2 (VDLM2)
VHF Data Link Mode 2 – Broadcast (VDLM2 - B)
VHF Data Link Mode 3 (VDLM3)
VHF Data Link Mode 4 (VDLM4)
VHF Voice (25 KHz)
VHF Voice (8.33 KHz channels)
Satellite Systems
Inmarsat INM-3/4 Aero (Low Gain Antenna)
Inmarsat INM-3/4 Aero (Intermediate Gain Antenna)
Inmarsat INM-3/4 Aero (High Gain Antenna)
Inmarsat Commercial INM-3 (Aero-M)
Inmarsat Commercial INM-3 (High Speed Data)
Inmarsat Commercial INM-3 (M4 Service)
Inmarsat Commercial INM-3 (Mobile Packet Data Service)
Inmarsat INM-4 (Previous-generation aero services)
Inmarsat INM-4 (M4 Service)
Inmarsat INM-4 (BGAN-SwiftBroadband)
Iridium
Navigation
Global Positioning System (GPS)
VHF Omni-directional Range (VOR)
Tactical Air Navigation (TACAN)
VOR/TACAN (VORTAC)
Local Area Augmentation System (LAAS)
Wide Area Augmentation System (WAAS)
Surveillance
Traffic Alert and Collision Avoidance System (TCAS)
1090 MHz Extended Squitter
Universal Access Transceivers (UAT)
Radar
Airport Surface Detection Equipment (ASDE)
Public Safety Systems

Data Link Technology
APCO Project 25 LMR Systems
APCO Project 34 TIA Project MESA

Table 4-2 presents the data link characteristics.

Table 4-2. Data Link Characteristics

Data Link	Frequency (Band)	Bandwidth	Data Rate	Modulation Scheme	Channel Access Mechanism
Communications					
VHF ACARS	117.975-136.80 MHz	25 KHz/channel	2.4 Kbps	MSK	CSMA
VHF Data Link Mode 2 (VDL-2)	117.975-136 MHz	25 KHz/channel	31.5 Kbps	D8PSK	p-persistent CSMA
VHF Data Link Mode 3 (VDL- 3)	117.975-136 MHz	25 KHz/ channel	31.5 Kbps	D8PSK	TDMA
VHF Data Link Mode 4 (VDL-4)	Tx: 118-137 MHz Rx: 108-137 MHz	25 KHz/ channel	19.2 Kbps	Binary GFSK	Self-organizing TDMA
VHF Voice	117.975 – 137.00 MHz	25 KHz/ channel	-	AM	-
VHF Voice	117.975 – 137.00 MHz	8.33 KHz/channel	-	AM	-
Satellite					
Inmarsat SATCOM L Band	D/L: 1.625-1.6605 GHz U/L: 1.525-1.559 GHz	34 MHz (total)	200 Kbps/ aircraft	BPSK / Q-PAM / Orthogonal QPSK / AQSK (choice of modulation technique depends on service)	TDMA(Data) + FDMA (Voice)
Iridium SATCOM Band	D/L: 1.610-1.6265 GHz U/L: 1.610-1.6265 GHz	10.5 MHz (41.67 kHz/channel)	Duplex voice channel at 4800bps & half-duplex data channel at 2400bps	PSK modulation for user links	FDMA/TDMA
Navigation					

Data Link	Frequency (Band)	Bandwidth	Data Rate	Modulation Scheme	Channel Access Mechanism
Automated Surface Observation System (ASOS)	117.975 to 136.975 MHz Specific Frequencies allocated by FAA (MHz) 118.325,118.375,118.525,119.025,119.275	Single fixed frequency	-	-	Continuous broadcast
Automated Weather Observation System (AWOS)	117.975 to 136.975 MHz Specific Frequencies allocated by FAA (MHz) 118.325,118.375,118.525,119.025,119.275	Single fixed frequency	-	-	Continuous broadcast
ATIS	VHF band	Single fixed frequency	2400 bps	-	Continuous broadcast on a single fixed frequency
CTAF	118-136 MHz	Single fixed frequency	-	-	-
MLS	5092-5250 MHz	150 kHz	-	AM/DPSK	-
VOR	108.0-117.95 MHz	50 kHz	-	FM/AM	Continuous broadcast on a single fixed frequency
DME	962 – 1213 MHz	100 kHz	-	PCM	Continuous broadcast on a single fixed frequency
WAAS	GPS L1 (1575.42 MHz)		1,200 bps	BPSK	
LAAS	108.0-117.975 MHz	25 kHz	31,500 bps	D8PSK	TDMA
GPS	GPS L1 (1575.42 MHz) GPS L2 (1227.60 MHz)		50 bps		
Surveillance					
Mode S	1030/1090 MHz	-	-	DPSK and PPM	Continuous broadcast
Universal Access Transceiver (UAT)	978 (980) MHz	624 kHz	1.041667 Mbps	Binary GFSK	TDMA

Data Link	Frequency (Band)	Bandwidth	Data Rate	Modulation Scheme	Channel Access Mechanism
Multilateration Systems (ASDE-X)	-	-	-	-	-
Primary Surveillance Radar	2700 – 2900 MHz	-	-		Continuous broadcast
Secondary Surveillance Radar	1030/1090 MHz	-	-		Continuous broadcast / interrogation
Public Safety System					
Project 25 LMR System	30 – 900 MHz	25 – 30 kHz	> 2 Mbps	C4FM/FM	TDMA

5. MMDA LOGICAL ARCHITECTURE

The ultimate goal in the design of MMDA architecture is to completely define the radio functionality in software. However, the present state of the art in RF component design does not allow for the design of antennas and power amplifiers that operate over a wide range of frequencies. Cost, power, and weight issues demand a more pragmatic architecture. Therefore, the MMDA architecture defined to support multiple CNS applications focuses on a radio that uses software to support radio waveforms and protocols, with the exception of the RF front end.

With the advent of high speed reconfigurable FPGAs, high performance digital signal processors and high speed ADCs and DACs, it is currently possible to definite a radio in software up to the RF power amplifier. Further, with the arrival of direct conversion receivers, it is possible to digitize the RF signal immediately after the low noise amplifier, allowing the rest of the radio modem to be defined in software. This MMDA architecture provides the following benefits:

- Simultaneously supports multiple air standards
- Allows a smooth transition from legacy to future technologies
- Easier transitions to new evolving technologies
- Reductions in cost by utilizing modules developed by multiple vendors based on an open architecture
- An open architecture facilitates design and development of more reliable CNS functionality with reduced product development cycle
- Reduces the time required to meet certification

5.1. Modem Architecture

Figure 5-1 presents a typical modem receiver chain for a super heterodyne receiver. In this design, the frequency is down converted twice, first in the analog domain using an RF Mixer, and the second time in the digital domain using reconfigurable FPGA's or programmable DSP's. The ADC and DAC define the point beyond which all radio waveform functionalities can be implemented in software using DSP's and FPGA's. Modern high speed ADC and DAC allow the digital domain to be moved as close as possible to the antenna. In a direct conversion receiver, the ADC and DAC are placed adjacent to the low noise amplifier. However, higher speed ADC means more digital data to be processed by the FPGA and DSP; hence, faster DSP and FPGA are required, resulting in higher cost. Therefore, the placement of the ADC/DAC is a tradeoff between cost and programmability in the design of the modem.

The modem architecture shown in Figure 5-1 identifies three different modules: the RF in red, baseband in orange and the Link/Network in green. These three modules completely define the modem. The RF Module consists mostly of tunable analog components like low noise amplifiers, oscillators, power amplifiers. These components can be tuned within a certain range to operate at different frequencies, however the frequencies are limited to a particular band like VHF, UHF etc. The unwanted signals and interference is filtered using analog filters and the center frequency of the signal is converted to be suitable for the ADC/DAC with minimum distortion. The ADC/DAC converter is the point where the signal is represented in the digital domain.

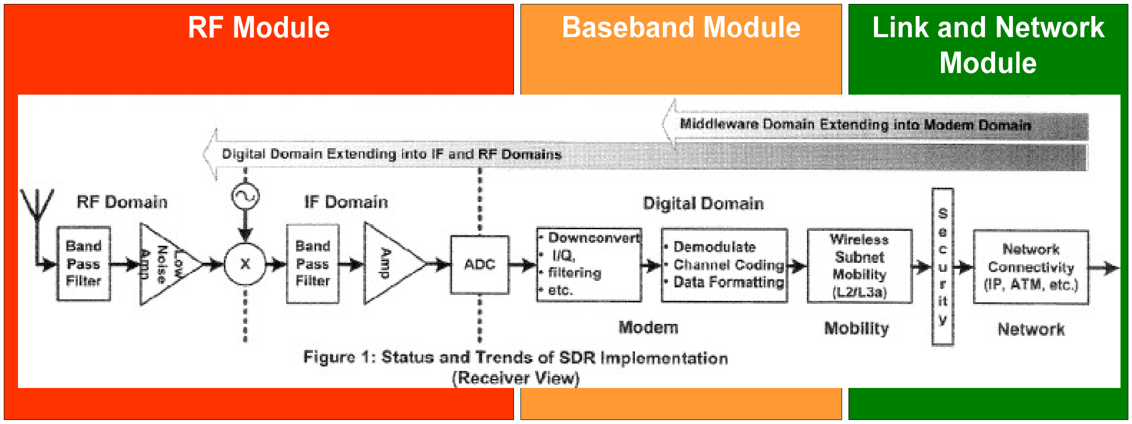

Figure 5-1. Typical Modem Architecture

The baseband module consists of a FPGA and a DSP processor to demodulate and decode the radio channel. Further, different radio channels can be selected in the digital domain using software tunable filters and down converters. The baseband module could also support some modem specific protocols such as medium access control on a general-purpose processor. The Link layer module, typically implements the data link layer and the network layer of the radio. In addition, it could implement mobility, security management, and access control functions. . The Link layer interfaces to the CNS applications using an Ethernet/Serial/Parallel interface. The key elements in the definition of MMDA architecture are:

- System engineering aspects and support for application and network protocols
- Software architecture definition
- Baseband module hardware architecture selection
- RF module architecture selection
  - Choice of ADC/DAC
- Link and network module architecture
- Radio validation and certification

5.1.1. Radio Frequency Module Architecture

The specification of the radio frequency module must take into account a number of factors. The placement of the ADC and DAC and precision of the ADC is one of the factors. The following factors play an important role in the successful design:

- Selection of ADC and DAC requires a trade among the power consumption, dynamic range and sampling rate
- Choice of dynamic range and frequency translation requirements of the RF Chain
- Dynamic range of the RF Chain should be equal to the dynamic range of the ADC/DAC

To avoid DC bias at the mixer output RF module the oscillator should be properly isolated from the mixer. The size and shape of the antenna defines the frequency at which it resonates, so it is extremely difficult to design an antenna that has good gain characteristics over a wide range of frequencies. Therefore, the selection of an antenna that is suitable for the specific frequency band of operation is very important since most of the gains can be either achieved or lost in this selection. The Duplexer should be designed to provide sufficient isolation between transmit and receive signals as required by the air interfaces.

The RF filters, low noise amplifiers, IF filters and Image Reject filters in the RF domain should inject minimal noise because these noises degrade the signal quality when they are amplified in the digital domain. The automatic gain control should be designed with the capability to track the signal strength variations to effectively use the dynamic range of the ADC. However, it should not induce any amplitude variations by changing very fast. An efficient design is a tradeoff between a dual conversion receiver and a direct conversion receiver. The following factors have to be taken into account:

- Dual conversion receiver leads to better isolation and low noise leading to better sensitivity (ability to detect low signal strengths). However, it has more components and leads to higher power consumption and cost.
- Direct conversion receivers have fewer components and higher flexibility to implement various RF waveforms. However, significant challenges have to be overcome to reduce noise and to achieve sufficient signal isolation between signals.

5.1.2. Baseband Module Hardware Architecture

The baseband module is typically composed of FPGAs, DSPs and General Purpose Processors (GPP). GPPs offers the most flexibility, while they have less computational power. Therefore, they are typically used for implementing control logic and air interface specific protocols. The choice of distribution of radio functionality between FPGA’s and DSP typically depends upon the computational capacity needed. The data computational capacity needed is typically governed by the bandwidth of the channels, and the speed of the ADC and DAC. The design of the baseband module has to take into account the following factors:

- Speed of the FPGA and DSP
- Trade off between DSP and FPGA based design. The DSP based design offers the most flexibility in algorithm implementation, however they consume significant power. In addition, the computation power of DSP is less than that of FPGA.
- Trade off among FPGA, ASIC and DSP based design. FPGA consumes a medium amount of power and offers better computational power with moderate flexibility. However, modern FPGAs are capable of improved flexibility with the support of softcore embedded processors on the chip.
- Investigate the choice of the General Purpose Processor to implement various modem specific protocols and security algorithms
- Trade off among distribution of baseband module functionality among GPP, DSP, FPGA depending on the specific radio interface, power consumption and computational requirements

5.1.3. Link and Network Module Architecture

This module provides the interface between the modem and the rest of the system. This module is typically implemented on a GPP**.** A real time operating systems is required if a GPP serves multiple purposes. The computational power required depends upon the requirements of the protocols and network interfaces implemented on the module.

5.2. Desired Design Features of MMDA Modem Architecture

In designing a MMDA radio, the following features are considered desirable:

- A defined modular, standardized and open structure
- A design based on open standard digital interfaces
- Logical modules controlled using the digital interfaces
- The open standards based interface guarantees compatibility and interoperability between different modules
- A scalable and modular design to support future avionic radio interfaces
- The modular structure supports both serial and parallel operation of different CNS functions
- Fault tolerant configuration
- Built in Test support
- Automatic system recovery and initialization
- Ability to detect failures and automatically reconfigure the modem
- The architecture supports future air interfaces
- Ability to control / manage remotely
- Support hot swappable capability

5.3. Desired Functional Capabilities of MMDA Modem Architecture

The following are some of the desirable capabilities in MMDA modem architecture:

- Support for different modulation and coding schemes
- Adaptive modulation and coding
- Tunable RF components
- Smart antennas

5.4. Logical MMDA Architecture Based on Digital Interfaces to Control Various Modules

In the design of avionics systems, reliability and fault tolerant issues lead to higher costs. To meet the safety requirements, it is importance to build MMDA architecture with fault tolerance and reliability. The different components/modules in the architecture should have the ability to reconfigure the modem when a fault is detected. Further, the architecture should support the capability for easy physical replacement of faulty modules. It is highly desirable to design the modules so that they can meet the tight space requirement in the aircraft. The logical architecture presented addresses the control of various components through digital interfaces. The control logic in this architecture could support hot swap[4] capability of individual modules.

Figure 5-2 shows a logical architecture with digital interfaces to control various modules. In this architecture, four logical blocks are identified: a RF block consisting of RF modules, a Baseband block consisting of baseband modules, a Link and Network block consisting of Link and Network modules, and a Control block containing various control modules. Figure 5-2 presents a logical architecture only and does not place any restrictions on implementation. In this architecture, various blocks are connected through digital interfaces. In conventional modem designs, different modules are hardwired to each other as shown in Figure 5-1. In order to provide a flexible architecture with fault tolerance, the architecture should support arbitrary interconnection to implement a particular radio air interface. This architecture is similar to a network on a chip wherein each module can interconnect to other modules using digital interfaces.

To facilitate arbitrary connections, each digital interface is represented as a protocol stack consisting of the physical, link and application layers. The physical layer supports the following functions:

- Generates Frames
- Line coding of data
- Synchronizes with the bus and frame

The functions supported by the link layer are:

- End-to-End Connection, routing information / slot number (TDMA) is pre determined by the control block
- Ensures data reliability
- Facilitates arbitrary interconnection of modules

The capabilities of the application layer are:

- Mapping of application data to interface data units

It is essential that the digital interface supports real time data transfer between modules. However, inter module communication data rates do not vary significantly, for example, the RF module will always transmit at a fixed data rate based on the sampling rate of the analog to digital converter. Therefore, a time division multiple access (TDMA) based digital interface would be a good choice. Further, while setting up the routing table for a required data transfer, rates can be met by allocating a number of time slots required to meet the data rate. This ensures real time data transfer between modules. The digital interface is characterized by its physical layer electrical interface and the data rate.

The logical architecture in Figure 5-2 shows three interfaces and they are:

[4] Commentary - Hot swap refers to the capability to remove and replace component(s) of a system, while the power is still on, and the unit still operating.

- RF-Baseband interface to connect RF and baseband modules
- Baseband-Link interface to connect baseband and link modules.
- Control interface to connect control block with all the RF, baseband and link modules

Since the digital interfaces constitute an important part of the architecture, it should be configured for one-fault tolerant with double redundancy.

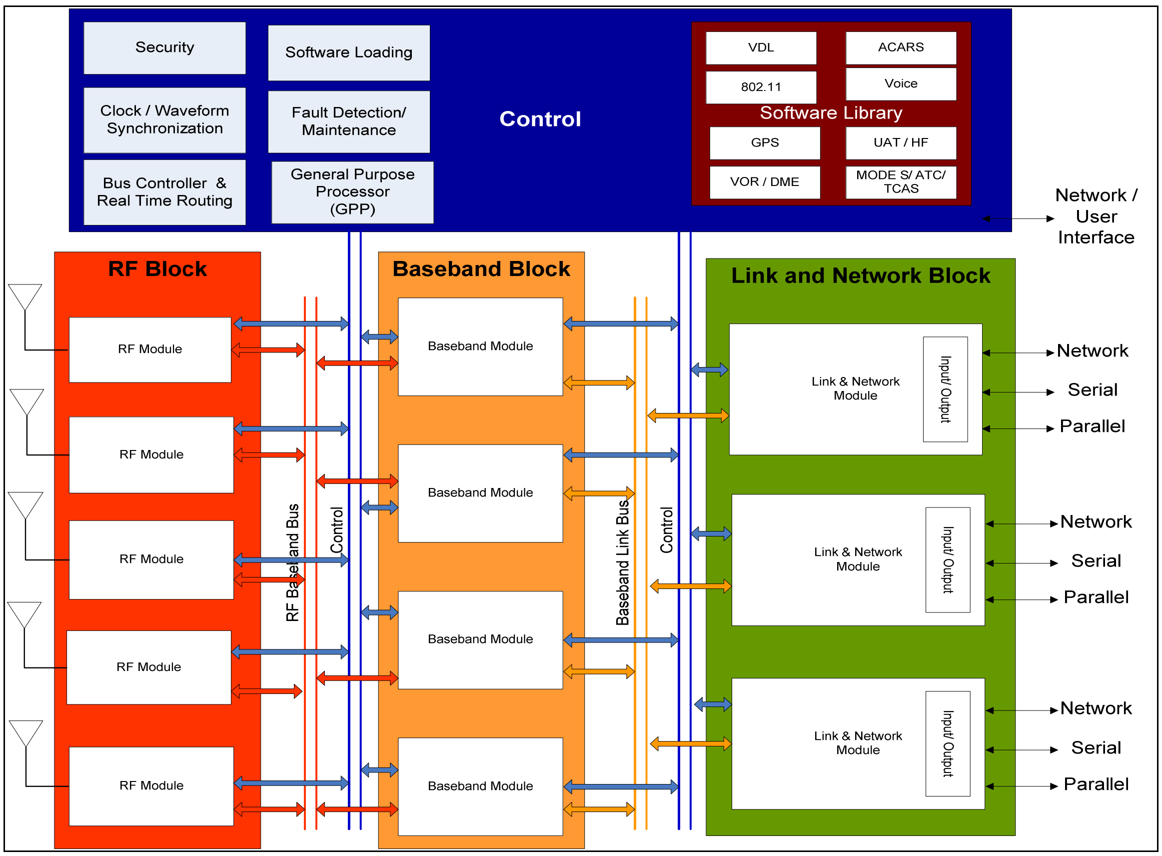

Figure 5-2. Logical MMDA Architecture

5.5. Mesh Interconnection of Various Modules

A modem or a radio air interface specification typically consists of an RF module, baseband module, link module and control logic as shown in Figure 5-1. Figure 5-3 shows a typical interconnection approach to support communication among modules. If a baseband module can support data from multiple RF modules, they can be connected as shown in Figure 5-3. A typical example is a GPS and HF communication using a single baseband module, but different RF modules because they are in different frequency bands.

Another possible interconnection approach is shown in Figure 5-3. A single RF module is connected to two baseband modules. This can be the case when VHF and ACARS are sharing a single RF module, because they are in the same band, while using different baseband modules for waveform implementation. Another example is a point-to-point connection between an RF module and a baseband module. This configuration may be used for the implementation of the 802.11 family of standards. In fact, broadcast mode of communication can be established so the control block transfers a general control message to all modules. A similar type of interconnection can be used between the baseband modules and the Link & Network modules. Further, redundant RF and baseband modules are configured to ensure support for fault tolerance. However, the RF module may not be entirely programmable. The baseband module is digital hardware and can be quickly reconfigured to support any radio interface standard.

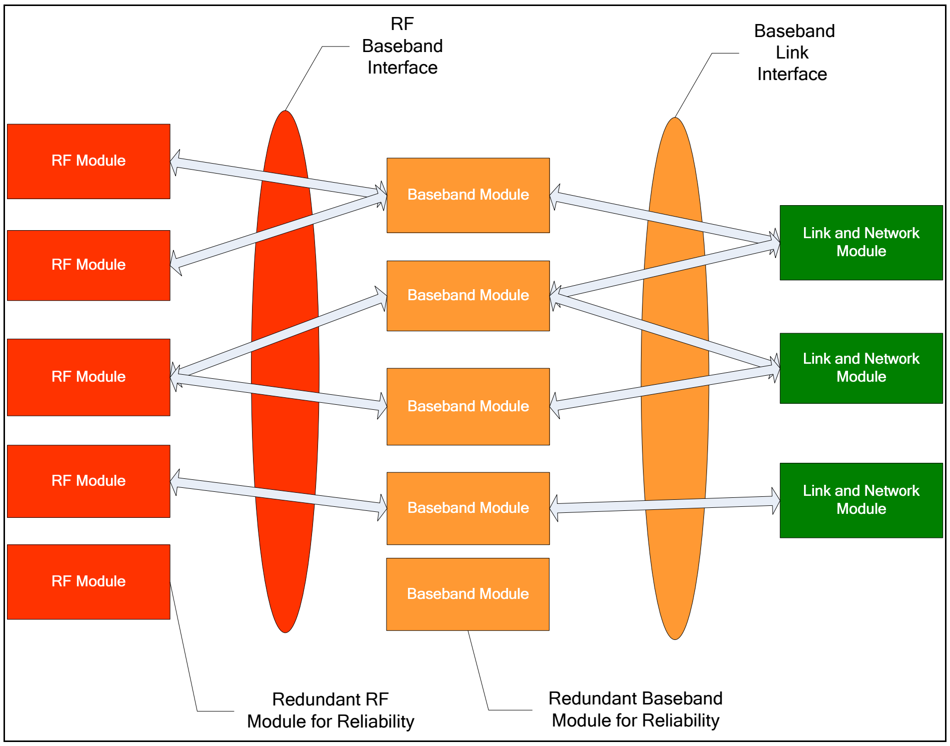

Figure 5-3. Interconnection of Modules

5.5.1. Interfaces between Modules

Each interface has its own data transmission requirements warranting a different physical layer specification. The physical layer communication interface for RF baseband, Baseband link layer, and Control function are presented below:

- RF baseband interface
  - Typically a TDMA based bus can be used for real time data transfer
  - Very high speed bus (100Mbps-10Gbps).
  - Point-to-point serial bus.
- Baseband link layer interface
  - Relatively low speed bus
  - Serial bus
  - Depending on data transfer rates, ethernet could also be used

- Control interface
  - Provides clock and synchronization signals
  - Low data rate control information
  - Link routing table / slot allotment to facilitate real time data transfer between modules
  - Operation and maintenance data transfer
- Software reload

5.5.2. Link and Network Block

Figure 5-4 presents the Link and Network modules. The link and network module provides the interface between the applications and the radio.

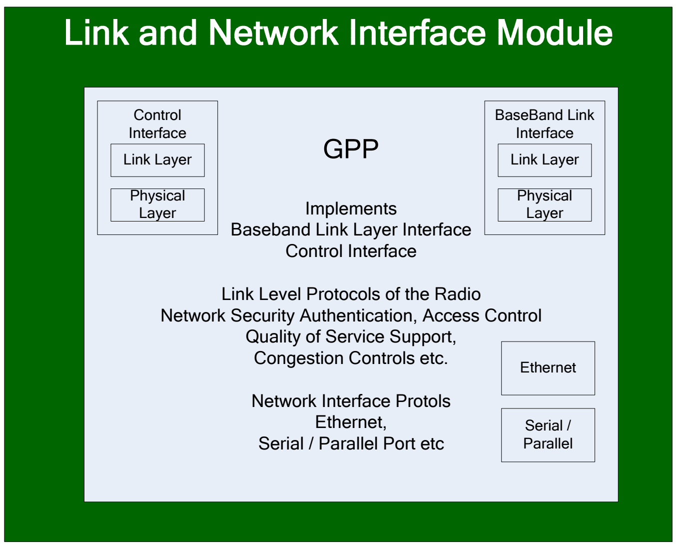

Figure 5-4. Link and Network Interface Module

The link layer can be interfaced using either a serial port, parallel port or an Ethernet port. Further, the link and Network Block should have support for Quality of Service to distinguish and support different application layer requirements. The following listed functions are desirable for the link and Network Block:

- Support multiple air interfaces at the same time (Concurrently)
- Support multiple modules to support various network interfaces
- Hot swappable modules
- Support QoS
  - Throughput, delay requirements
  - Congestion management, priority, resource allocation
- Support external network interface functions
  - Ethernet
- Internal networking functions
  - Interface to control/management (Control block)

  - Interface to baseband
- Network interface protocol termination
- Synchronization functions
  - support synchronous network interfaces
- OAM&P functions (generic for all modules)
- Security functions
  - Authentication, access control, encryption

5.5.3. Control Module

Figure 5-5 shows the control module functions. The control module controls the operations of the modules in the Multimode digital radio. It is responsible for the proper operation of the radio modules. It typically contains a library of software modules that can be arbitrarily loaded in the radio modules to reconfigure the radio. Further, security functions should be built into the control module to authenticate the configuration of the multimode radio. When the radio is being reconfigured it should also be fault tolerant and be able to restore to the original configuration in case a fault occurs. This module is also responsible for fault detection and monitoring. In the event that a fault in a module is detected, it should be ale to take appropriate actions to restore communications on the radio. Futher, the Control module is responsible for real time data transfer between different modules. The routing table and slot allocation on the bus are predetermined by the control module based on data transfer needs. Once the routing information is determined, the bus controller on the control module assures data is routed in real time between modules. The control module should be able to support the following functions shown below:

- Multiple air interfaces at the same time (Concurrently)
- Multiple modules to support various network interfaces
- Hot swappable feature
- Congestion control
  - Detect and reports the occurrence of Link/baseband/RF block overload conditions to take corrective actions.
- RF scheduling
  - To support serial access to different air interfaces.
- System clock generation and distribution to different modules

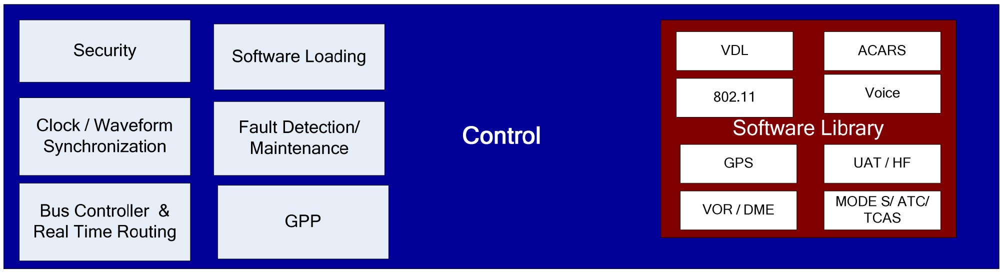

Figure 5-5. Control Module

5.5.4. Baseband Module

The baseband module can be completely configured in software. The control module can typically program a baseband module to implement different air interfaces. The baseband is typically composed on FPGA's, DSP's and GPP's, which can be completely reconfigured. A typical set of operations performed by the baseband module is shown below:

- Multiple air interfaces at the same time (concurrently)
- Multiple modules to support various network interfaces
- Hot swappable feature
- Channel encoding / decoding
  - Convolution codes/ RS codes
- Interleaving
- Error detection CRC
- Multiplexing/demultiplexing feature
- Bit detection / demodulation
  - Eg Decision feedback equalizers adaptive linear equalizers
- Encryption/ decryption
- Diversity reception /transmission with multiple antennas
- Frame protocol processing
- Communication with other blocks
- Higher layer protocols
  - Medium access control

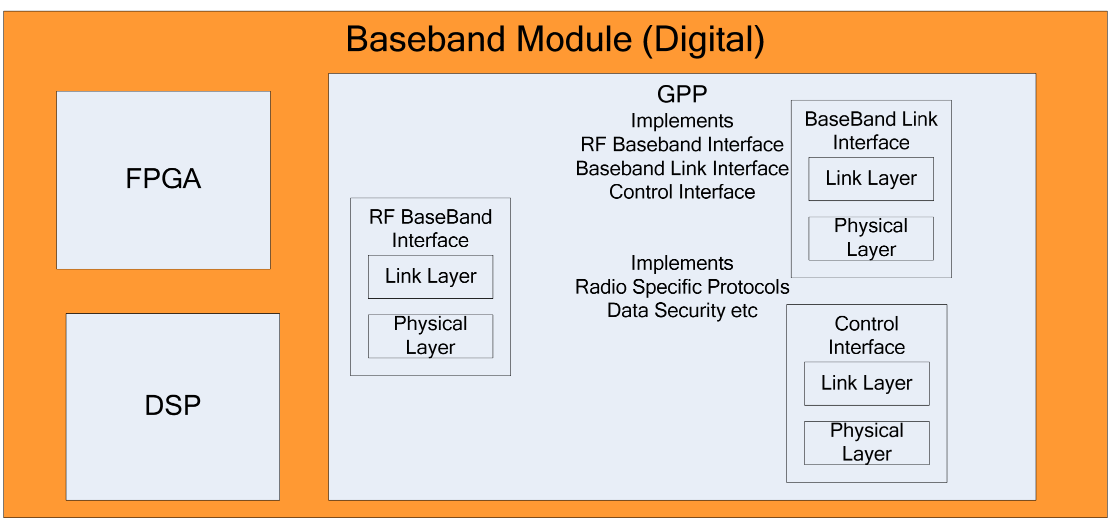

Figure 5-6. Baseband Module

5.5.5. RF Module

The functions of the RF module are shown in Figure 5-7. The components on the RF module are typically designed using analog circuits. Although this module is not completely reconfigurable, the components can be tuned within a certain frequency band to meet different air interface requirements. As it is extremely difficult to design Radio Frequency components over a broad range of frequency bands, each RF module is typically designed for a certain band of frequencies and the band width of the channels. A typical set of operations performed by the RF module is shown below:

- Multiple air interfaces at the same time (Concurrently)
- Multiple modules to support various network interfaces
- Hot swappable feature
- Modulation
- D/A and A/D conversion
- Up/down conversion
- Carrier selection
- Linear power amplification (for transmitting signals)
- Automatic Gain Control
- Frequency Synchronization and Tracking

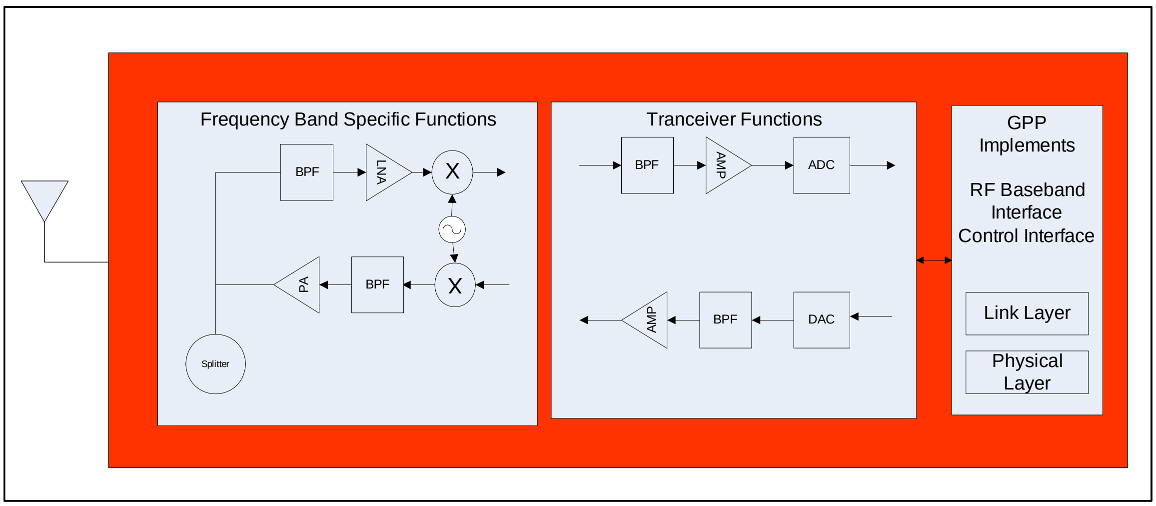

Figure 5-7. RF Module

5.6. Example Architecture: VDL Mode 2 Radio

Figure 5-8 is an example of an architecture to support VDL mode 2 radio. It shows the allocation of the various VDL Mode 2 radio capabilities to the modules of the architecture described in the previous sections. In addition, some of the communication primitives used for communication across the various interfaces are presented.

5.6.1. Operations and Maintenance Principles

Operation and maintenance functions may be overlooked in the initial design of a system. Trying to add them at a later phase may lead to non-optimum interfaces and implementation. Therefore, it essential that MMDA architecture should incorporate the operations and maintenance functions as an integral part of the architecture. Some of the functions are:

- Configuration management
  - Able to configure and deploy different modules
- Fault management
  - Monitor the health of the modules
- Performance management
  - Monitor performance metrics and record them
- Software management
  - Install/ update software

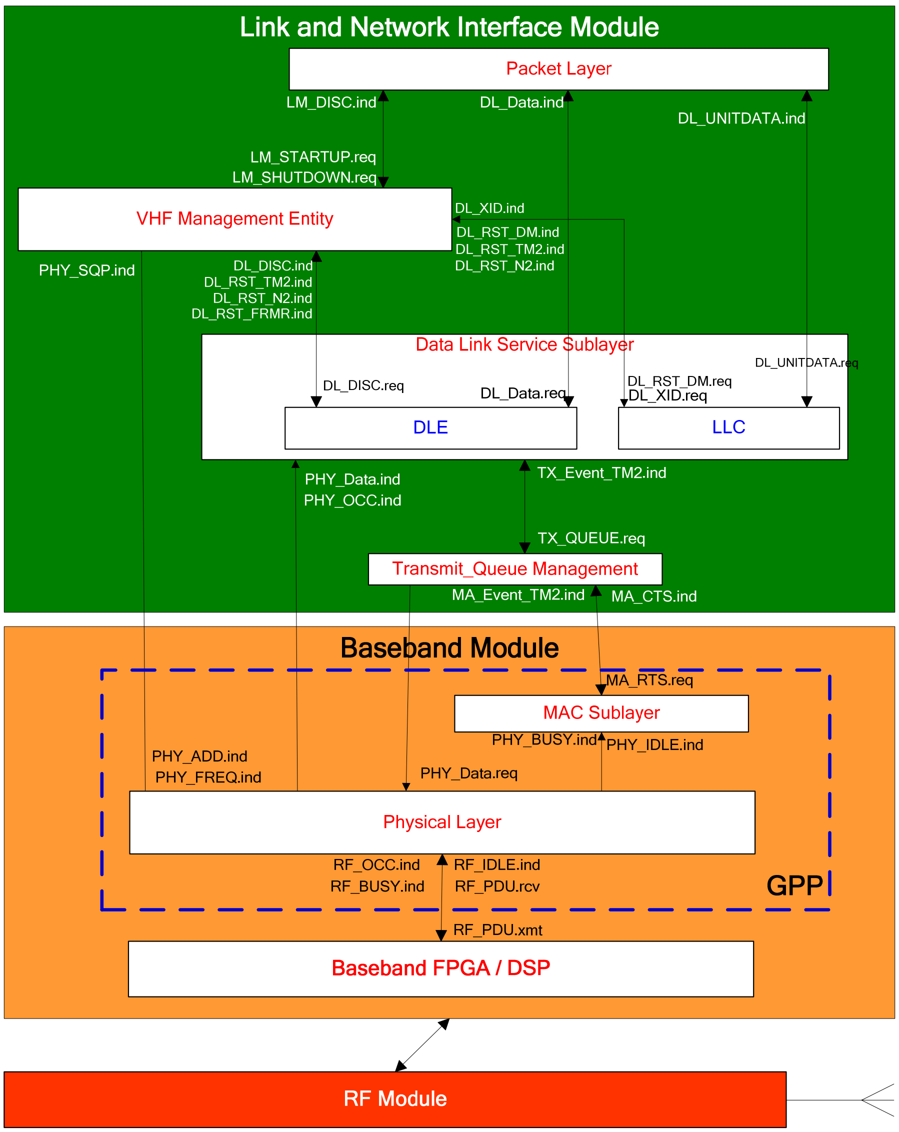

Figure 5-8. Example Architecture: VDL Mode 2 Radio

6. SC-200 INTEGRATED MODULAR AVIONICS & SYSTEM CERTIFICATION

This section discusses aspects of the MMDA architecture in the context of its expected functionality and offers a recommended modest set of MMDA functions that would adequately demonstrate the concept. A major portion of this section is devoted to presenting material from a draft document "Integrated Modular Avionics (IMA) Development Guidelines and Certification Considerations" (draft title) being jointly prepared by RTCA Special Committee 200 (SC-200) and EUROCAE Working Group 60 (WG-60). This material is intended to be used in the preparation of a Request for Proposal to develop and build an MMDA radio.

6.1. Candidate MMDA Architectures and Functionality

For the purposes of this task it is interpreted that Multifunction, Multimode Digital Avionics (MMDA) is an integrated modular avionics assembly capable of simultaneously performing more than one function, such as communication, navigation, and/or surveillance and concurrently exercising multiple modes within a function, such as communicating in VHF Data Link (VDL) Mode 1, 2, and/or 3. It is important to note that "simultaneous" refers to the user (crew) perspective only. Presently there are no avionics processors that can simultaneously perform multiple tasks; individual tasks are performed in different duration sequential clock intervals that are so short that the tasks appear to the user to be simultaneously executed.

The multiple functions (at least one each from communication, navigation and surveillance) must be very carefully chosen to be of typical or higher criticality and difficulty to implement if the MMDA is to present a credible example of its intended performance. AvioniCon recommends the following:

- Communications: VDL modes 2 and 3 and either HF data link or satellite communications
- Navigation: Tuning a VOR and computing the time and distance to the next waypoint (given a dummy current position and flight path)
- Surveillance: Formatting and simulating the broadcast of an ADS-B message.

These are all rated as essential (i.e., Category B in DO-178 and DO-254) functions by the FAA. The planned MMDA Request for Proposal (RFP) should reference the appropriate FAA Technical Standard Orders (TSOs) for minimum performance requirements for these functions. If FAA documents are not available the relevant RTCA document should be cited. The MMDA obviously could be designed to accommodate many more functions, but the ones suggested should be adequate to demonstrate the capability of the concept.

There are multiple architecture issues at the aircraft and the avionics levels. These issues are driven by the criticality of the aircraft functions and the avionics functions. The Airbus A380 and the Boeing B-787 should be examined for guidance on emerging practices and technology. The A-380 will have a switched Ethernet data bus referred to as an Avionics Full Duplex Switched Ethernet (AFDX) network. See Figure 3-1. The B-787 will have a similar bus designated as the Common Core System (CCS). See Figure 3-2. Both of these buses are based on ARINC 664

Aircraft Data Networks, Part 7. Rockwell Collins is manufacturing the bus chips for both of these aircraft based on their success with a predecessor similar bus on the Boeing B-767-400. Both the A-380 and the B-787 will have significant integration of functions into modular avionics. Triple redundancy of data buses and dual or triple redundancy of processing units are key features of the avionics in these two aircraft.

Since an aircraft architecture can be assumed for the MMDA design, the MMDA architecture is the larger issue. Given the MMDA is modular concept, basic design decisions include the allocation of functions to modules, level of redundancy, and partitioning of multiple functions. Intuitively there should be modules for the RF sections that are separate from the processing and I/O modules but included in the same module cabinet or rack.

6.2. SC-200/WG-60 Draft Document Guidance for Inclusion in the MMDA RFP

Notice: The following material is extracted from a draft of the document being prepared jointly by RTCA Special Committee 200 Integrated Modular Avionics and EUROCAE Working Group 60 (same name). Details in this material may change somewhat as the document is put in final form but the intent will remain the same. It is anticipated that the SC-200/WG-60 document will be published by the time a contract may be awarded to develop and demonstrate an MMDA so the referenced paragraphs can be reviewed at that time. **Any document in which this material is used must include this notice.**

6.2.1. IMA Design Terminology

The following terms are used to describe IMA systems.

Aircraft Function**:** The capability of the aircraft that is provided by the hardware and software of the systems on the aircraft. Functions include flight control, autopilot, engine control, braking, fuel management, flight instruments, etc. IMA has a potential to broaden the definition of avionics to include any aircraft function.

Application**:** Software and/or application-specific hardware with a defined set of logical interfaces that, when integrated with a platform, performs a function.

Component**:** A self-contained hardware part, software part, database, or combination thereof that typically is configuration controlled. A component does not provide an aircraft function by itself.

Core Software**:** The operating system and support software that manage resources to provide an environment in which application can execute. Core software is a necessary component of a platform. Core software is typically comprised of one or more modules.

IMA System**:** Consists of an IMA Platform and a defined set of Hosted Applications.

Interoperable**:** The capability of several integrated modules to operate together to accomplish a specific goal or function. This requires defined interface boundaries between the modules and allows the use of other interoperable components. To describe this concept in physical terms, an

IMA platform may include interoperable modules and components such as physical devices, such as a processor, memory, electrical power, Input/Output (I/O) devices, and logical elements, such as an operating system, and communication software.

***Module*:** A component or collection of components that may be accepted by themselves or in the context of IMA. A module may also comprise other modules. A module may be software, hardware, or a combination of hardware and software, which provides resources to the IMA-hosted applications. Modules may be distributed within the aircraft or may be co-located.

***Partitioning*:** An architectural technique to provide the necessary separation and independence of functions or applications to ensure that only intended coupling occurs. The mechanisms for providing the protection in an IMA platform are specified to a required level of integrity.

***Platform*:** Module or group of modules, including core software that manages resources in a manner sufficient to support at least one application. IMA hardware resources and core software are designed and managed in a way to provide computational, communication, and interface capabilities for hosting at least one application. Platforms, by themselves, do not provide any aircraft functionality. The platform establishes a computing environment, support services, platform-related Built-In Test (BIT) capability, and fault detection and recovery. The IMA platform may be accepted independently of hosted applications.

***Resource*:** Any object (processor, memory, software, data, etc.) or component used by an IMA platform or application. A resource may be shared by multiple functions or dedicated to a specific function. A resource may be physical (a hardware device) or logical (a piece of information).

***Reusable*:** The design assurance data of previously accepted modules and applications may be used in a subsequent aircraft system design with the reduced need for redesign or additional acceptance.

6.2.2. Certification Terminology

A primary purpose of this document is to provide a means of compliance for IMA systems seeking acceptance, approval and certification of their installation on an aircraft. To accomplish this purpose, it is important to understand the certification terminology. The primary certification terms are defined below:

***Certification*:** Legal recognition by the certification authority that a product, service, organization or person complies with the requirements. Such certification includes the activities of technically checking the product, service, organization or person, and a formal recognition of compliance with the applicable regulations and airworthiness requirements by issuance of a certificate, license, approval or other documents as required by national laws and procedures. In particular, certification of a product includes:

a. the certification applicant process of assessing the design of a product and demonstrating to the certification authority that it complies with the applicable regulations and a set of standards applicable to that type of product so as to demonstrate an acceptable level of safety;

b. the process of assessing products to ensure they conform with the approved type design for that product;
c. the certification authority process of finding compliance and the issuance of a certificate required by national laws to declare that compliance and/or conformity has been found with standards in accordance with items a or b above.

***TSO Authorization*:** Legal recognition by the certification authority that a system, equipment, or part satisfies the TSO requirements and minimum specification applicable for that equipment. This term is equally applicable to European TSO (ETSO) authorizations.

***Acceptance*:** Acknowledgement by the certification authority that the module, application, or system complies with its defined requirements. Acceptance is recognition by the certification authority (typically in the form of a letter or stamped data sheet) signifying that the submission of data, justification, or claim of equivalence satisfies applicable guidance or requirements. The goal of acceptance is to achieve credit for future use in a certification project.

***Approval*:** The act or instance of giving formal or official acknowledgement of compliance with regulations. In the context of IMA there are typically two forms of approval:

a. approval of submitted life cycle data by the certification authority (usually demonstrated by issuance of a stamped and signed data item or a letter),
b. installation approval by the issuance of an aircraft or engine type certificate and/or airworthiness certificate.

***Incremental acceptance*:** A process for obtaining credit toward approval and certification by accepting or finding that an IMA module, application, and/or off-aircraft IMA system complies with specific requirements. This incremental acceptance is divided into tasks. Credit granted for individual tasks contributes to the overall certification goal. Incremental acceptance provides the ability to integrate and accept new applications and/or modules in an IMA system, and maintain existing applications and/or modules, without the need for re-acceptance.

6.3. Key Characteristics

The key characteristics of IMA platforms and hosted applications influence the IMA system architecture, the detailed system design, and, ultimately, the IMA platform and system acceptance process.

6.3.1. Platforms and Hosted Applications

Two primary building blocks of an IMA system are the platform and the hosted applications. The key characteristics for the IMA platform are provided in Table 6-1.

Table 6-1. Key IMA Platform Characteristics

Key IMA Platform Characteristics	Description
Platform resources are shared by multiple applications	Integration implies sharing of resources. An IMA platform is able to host multiple applications through partitioning and other protection capabilities provided by the IMA platform.
An IMA Platform provides robust partitioning of shared resources	This characteristic ensures that shared platform resources are available to the hosted applications as needed, and that those resources are protected from any anomalous behavior of the applications using them. IMA platform resource management ensures only specified, intentional usage, interactions, and interfaces are allowed by the platform and applications sharing the resources. Robust partitioning will ensure that any hosted application or function has no unintended effect on other hosted applications or functions.
An IMA Platform only allows hosted applications to interact with the platform and other hosted applications through a well defined interfaces.	An IMA platform is a general purpose computing platform able to host one or more aircraft functions or applications. As such, platform behavior may be verified independent of specific applications (e.g., it may be shown to meet its module requirement specification). The IMA platform is viewed as a separately accepted component of an IMA system. This characteristic is necessary to isolate changes between the platform and hosted applications. The intent is to allow modification of the IMA platform with minimum impact on the hosted applications, and changes to applications with minimum impact on the platform. The platform provides documented (and verified) Application Programming Interfaces (API) to allow applications access to platform services and resources.
Shared IMA platform resources are configurable	IMA platform resources are configurable to support the resource requirements of hosted applications.

The key characteristics for IMA hosted applications are provided in Table 6-2.

Table 6-2. Key Application Characteristics

Key Application Characteristics	Description
An application may be designed independent of other applications and obtain incremental acceptance on the IMA platform independently of other applications	Hosted applications may be individually verified on the platform without the full suite of intended applications. The incremental acceptance for each hosted application can be used to support the accumulation of credit toward approval of the IMA system installation on the aircraft.
Applications can be integrated onto a platform without unintended interactions with other hosted applications.	As the different applications reach completion and are verified individually, they should be integrated on the platform as a complete suite of hosted applications. Interactions between applications should be verified.
Applications may be reusable	Application modularity and portability may enable and facilitate integration with different projects.
Applications are independently modifiable.	Each application is modifiable with little or no impact on other applications and platform resources and modules. Any impact should be identified and coordinated with any other affected components.

6.3.2. Shared Resources

IMA systems may host several applications that share resources. For example, resources may be shared by the method of access time. This applies to processing resources and hardware. Each shared resource has the potential to become a single point failure that can affect all applications using that resource. Accordingly, appropriate mitigation techniques should be applied as determined by the system safety assessment process.

Processing resource refers to a physical element that may contain CPU(s), memory and associated interfaces. Memory is capable of storing machine-readable computer programs and associated data. The IMA hosted applications will communicate using shared resources provided by the IMA platform, for example, I/O devices, data buses, shared memory, etc. IMA systems may have multiple electrical power sources that are shared. A resource or portion of a resource can be allocated per unit time. For example, this can be processor cycles or communication bandwidth.

The IMA platform provides resource management capabilities for shared resources and health monitoring and fault management capabilities to support the protection of shared resources.

6.4. IMA System Development Process

The overall development process for IMA should follow a structured process such as ARP 4754/ED-79. The IMA system development process should consider the primary characteristics of IMA: flexible, reusable and interoperable. These characteristics influence the development process. The system development process should address as a minimum:

- The IMA platform – Definition of a reusable, sharable resources
- The hosted applications – Definition of the interfaces and system contracts to allow a given hosted application to reside on the given platform.
- The IMA system – Integration of the specific set of hosted applications onto a given IMA platform.

The process outlined in this section is intended to propose an approach that would maximize the reuse of the IMA platform and hosted application development data on another aircraft.

Notes on terminology used in this process:

- IMA platform consists of the IMA modules without any aircraft functions or applications installed.
- IMA platform architecture refers to the means of structuring, connecting and combining IMA modules to support the requirements of the hosted applications and aircraft functions.
- IMA system consists of the IMA platform(s) and the hosted applications.
- IMA system architecture consists of the IMA platform(s), connections and components required to meet the requirements of all of the hosted applications and aircraft functions.

6.4.1. Reusable IMA Platform Development Process

The IMA platform should be defined and developed independently of the specific aircraft functions and the hosted applications. When this is achieved, it may be possible for the data developed for an IMA platform to be reusable with a different set of hosted applications.

One of the primary goals of IMA is to develop an IMA platform that can be reused on different aircraft and with different applications. A reusable IMA platform might be developed using the process described below.

a. Define the IMA platform concept. The concept definition should include as a minimum:
    1) The architecture definition, which contains the type and general function of the various IMA components and how they will interact (e.g., distributed vs. centralized architecture).
    2) An approach for integrating hosted applications, both hardware and software, onto the IMA Platform.
    3) An IMA platform acceptance approach

4) An IMA system certification approach which includes support for hosted applications and stakeholder roles and responsibilities for developing compliance data.
5) A list of platform services to be provided to the hosted applications.
6) The level of aircraft function's availability and integrity needed and platform capabilities to support it and methods provided for supporting it
7) The health management and fault management approaches (excluding the actual external interface as this will be dependent on the aircraft HM and crew alerting systems)
8) The platform and IMA system configuration management approaches

b. Define the IMA platform requirements, including:
   1) Safety capabilities
      - identification of the top level platform failure events that could affect hosted applications,
      - definition of the acceptable failure rates (reliability requirements of platform hardware modules) associated with each failure event
      - development of guidance for use of the above data in meeting the availability and integrity requirements of an aircraft and potential hosted functions.
      - Safety requirements, including robust partitioning, health monitoring, fault management, resource management, other safety features and other protection means.
   2) Performance capabilities
   3) Configuration management approach
   4) Environmental conditions the platform modules are intended to operate under. Where modules share a common environment – like a cabinet with common power or a common data bus – a definition of the conditions for the common environment should also be described.
   5) Fault management and reporting approach and requirements, including considerations for: fault tolerance, fault isolation to modules, detection and isolation of single failures putting IMA platform one failure away from significant loss of capability (internal power lane failures, redundant inter-module communication channels, and other similar resources should be considered)
   6) Detailed requirements for each aspect of the concept definition
   7) IMA platform architecture which has been defined and evaluated to the required safety capabilities

c. Develop and implement the IMA platform design. The software and hardware development processes should follow DO-178B and DO-254 at the appropriate level to meet the required safety requirements. Additionally, common cause analysis (CCA) should be performed and qualitative failure analysis for the various top level events defined for the platform should be developed.

d. Verify and validate the IMA platform addressing the following activities:

1) Perform environmental qualification testing to the specified environmental conditions.
2) Perform a partitioning analysis and verification testing; verify other protection capabilities and safety features (i.e., resource management, health monitoring, fault management, built-in test (initial and continuous), etc.
3) Complete the CCA
4) Complete the numerical analysis showing that implementation meets the reliability requirements and capabilities
5) Consider modules sharing an environment and resources together. Non-IMA modules sharing the same environment will need to be part of this exercise. If there are only IMA modules sharing the environment and the total complement of modules is fixed, then the combined partial environmental qualification can be done prior to full integration on an aircraft.

e. Obtain IMA platform acceptance using the module acceptance approach described in Section 4. All IMA platform requirements should be validated and verified. Traceability between the requirements, implementation, and verification activities should be developed and maintained.

6.4.2. Hosted Application Development Process

Development of hosted applications follows the same development processes as used in non-IMA systems, but should address the following additional considerations:

a. Identify IMA platform resources to be used (part of interface definition)
b. Quantify required IMA platform resources (part of interface definition)
c. Map host application safety analysis to IMA platform safety capabilities (PSSA, FHA, CCA)
d. Define HM/FM requirements for the hosted application, define interactions with IMA platform HM/FM functions.
e. Identify dedicated resources peripheral to the IMA platform
f. Specify environmental qualification dedicated resources
g. Remainder of development process activities are addressed by existing guidance.
h. Human factors requirements must be balanced against IMA platform performance.

6.4.3. IMA System Development Process

The IMA system development process is intended for composing an IMA system from an IMA platform and hosted applications that preserves the independence between the IMA platform and hosted applications is described below:

a. Identify aircraft functions, including functional and performance requirements, availability requirements, and integrity requirements.

b. Allocate IMA resources to the aircraft functions considering the aircraft-level FHA, resource requirements (interface contract), safety capabilities of the IMA platform and MMEL considerations. Determine what hosted applications or aircraft functions need isolation and/or protection from other hosted applications and functions and other protection mechanisms or safety features needed.

c. Develop the IMA System Architecture, addressing the following aspects:
   i. Develop IMA System Certification Plan based on aircraft requirements, hosted applications and IMA system certification approach.
   ii. Determine the quantity, quality and type of IMA platform modules needed to provide the capability to meet all application requirements, including performance requirements, availability requirements, and integrity requirements.
   iii. Determine any aircraft application requirements driven by the capabilities of the IMA platform modules, for example:
      - Availability requirements beyond that available from a single IMA module which could drive the application to be hosted on multiple modules and/or platforms.
      - Applications using multiple modules need to determine application redundancy management requirements
      - Integrity requirements beyond that available from IMA components that could drive the use of multiple instances of the application and/or data that may be compared to achieve the necessary integrity.
   iv. Perform a Preliminary System Safety Assessment (PSSA) for each application using the IMA platform safety requirements.
   v. Evaluate the aircraft effects from the combination of platform and shared resource failures.
   vi. Identify changes required to the allocation of IMA platform resources to correct any issues identified from the individual and combined PSSA activities.

d. Implementation of the IMA system, including the following activities:
   i. Develop the applications and perform the partial verification.
   ii. Integrate applications onto the platform, complete platform core software verification, complete application's verification, and perform IMA system V&V activities, including application/platform integration testing (software, integration testing, hardware/software integration testing).
   iii. Perform aircraft ground and flight testing to validate assumptions in requirements and environmental definitions
   iv. Develop initial IMA system failure analysis using IMA platform top level events as basic events for the hosted application failure analyses.
   v. Evaluate the combination of IMA platform component failures affecting hosted applications leading to aircraft level effects and adjust allocation or application implementation as necessary. (IMA platform component failures should have a unique top level event.)

e. Integrate, validate, verify, and obtain acceptance of the IMA System (off aircraft). Specific configuration of applications in the IMA system should be shown to meet their requirements (including performance, redundancy management, and IMA platform interface requirements). Numerical analyses for each hosted function should be developed to show it complies with its FHA. Additionally, the hosted function numerical analyses should be combined into an IMA system hardware numerical analysis that shows that the combined events satisfy the aircraft level safety requirements

The integration activities and the relationship to the acceptance tasks are shown in Table 6-3. The activities are general and can be scaled appropriately to align with the size of development. The acceptance process of IMA is described by six tasks.

Table 6-3. Relationship between integration activities and acceptance tasks

Integration Activity	Acceptance Tasks	
Integrate components and/or modules to form a platform	Task 1	Module and/or platform acceptance
Integrate a single application with the platform	Task 2	Application acceptance (software and/or hardware)
Integrate multiple applications with the platform and one another	Task 3	IMA system acceptance
Integrate IMA system(s) with aircraft and its systems	Task 4	Aircraft integration
Identify changes and their impacts, and need for re-verification	Task 5[5]	Change
Identify and use IMA components on other IMA systems and installations	Task 6[6]	Reuse

6.5. Overview of the Certification Process

An important aspect of the certification process for IMA systems is to obtain incremental acceptance of and certification credit for IMA platforms, modules and/or applications, cumulating in IMA system installation approval on an aircraft product, and resulting in issuance of the product certificate.

Typical development processes are divided into six tasks that define the incremental acceptance activities for the certification process for IMA systems:

[5,2] Tasks 5 and 6 are performed at the aircraft system-level and may include tier 1 - 5 activities

- Task 1: Module acceptance
- Task 2: Application software/hardware acceptance
- Task 3: IMA system acceptance
- Task 4: Aircraft integration of IMA system – including V&V
- Task 5: Change of modules or applications
- Task 6: Reuse of modules or applications

The six tasks are illustrated in Figure and will serve as a structure for the remaining sub-sections of this section. Some of these tasks may be concurrent and in some projects some tasks may not be applicable. A subsection is dedicated to each task.

The initial acceptance of a module, application, or IMA system should occur in the framework of an aircraft or engine certification program (TC) or modification project (STC). That is, IMA acceptance can only be proposed in the context of an actual certification project.

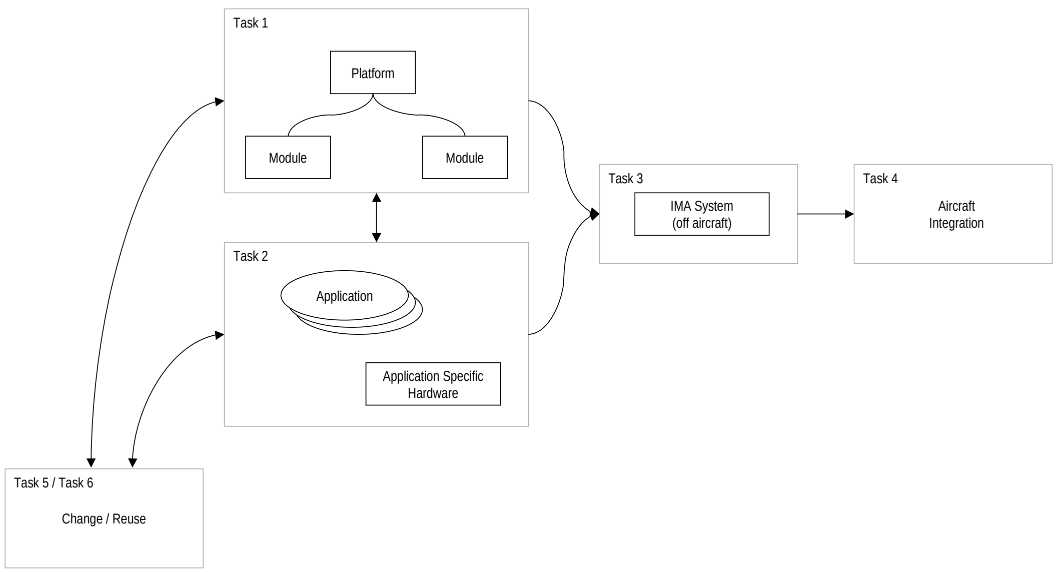

Figure 6-1. IMA System certification tasks illustration

Table 6-4 provides a summary and overview of the certification tasks, their references in this document, and the typical means that acceptance is granted. In some cases the compliance data may be approved (with a stamp or letter) prior to issuance of an acceptance letter, which may occur later in the certification project after integration, i.e., at or near the certification date of the aircraft product.

The life cycle data to be generated for each task is represented in the appropriate. In many cases stakeholders may have pre-existing processes or may package their data differently. If alternate titles or packaging is used, the stakeholder should develop a document mapping to demonstrate that all the applicable data is available.

Table 6-4. Overview of IMA Certification Tasks

Task	Reference/ Objectives	Example means of granting acceptance
Task 1: Module acceptance	Section 7.5.1	Acceptance letter[7] or stamped data sheet Stamped or approved module acceptance data package RSC acceptance letter (Software only) as defined in AC 20-148. TSO-C153 authorization letter (Hardware only)
Task 2: Application acceptance	Section 7.5.2	Acceptance letter[1] or stamped data sheet RSC acceptance letter Stamped or approved IMA platform-hosted application compliance data package
Task 3: IMA System acceptance	Section 7.5.3	Acceptance letter[1] or stamped data sheet Accepted or approved compliance data package
Task 4: Aircraft Integration of IMA system – including V&V	Section 7.5.4	TC, STC, ATC, ASTC
Task 5: Change of modules or applications	Section N/A	Same as Task 1 if change of module Same as Task 2 if change of application (both depend on significance of change, aspects of Tasks 3 and 4 may need to be performed also)
Task 6: Reuse of modules or applications	Section N/A	Same as Task 1 if reuse of module Same as Task 2 if reuse of application (both depend on similarity of reuse environment, aspects of Tasks 3 and 4 may need to be performed also)

[7] Contents of acceptance letter would be similar to the RSC acceptance letter described in AC 20-148, i.e., it should fully describe the content and limitations of the accepted task.

6.5.1. Task 1: Module Acceptance

The purpose of module acceptance within the overall certification process is to demonstrate the module characteristics, performance, and interfaces to obtain incremental acceptance of the module. This is accomplished by providing documented evidence (acceptance and/or compliance data) for the benefit of the other IMA system acceptance tasks and for potential reuse. Acceptance of a module can only be performed in the context of the aircraft or engine certification program or modification project.

The module acceptance process allows an applicant to separately accept and gain incremental acceptance for individual components of the IMA platform (e.g., processing module, core software services (e.g., operating system, health monitoring function, fault management function), power module, interface module) toward gaining acceptance of the IMA platform. The platform itself may also be accepted as a module, which typically contains multiple other modules.

6.5.1.1. Module Acceptance Objectives:

The objectives of the module acceptance process are:

- Plan the acceptance tasks to meet all of the applicable certification requirements. Ensure other stakeholders agree with the acceptance plans.
- Develop specifications for the module and demonstrate compliance with the Module Requirements Specification (MRS) (where the module supplier may develop the MRS based on assumptions for the intended use).
- Demonstrate compliance of resource intrinsic properties such as time and space partitioning, fault management, health monitoring, other safety features, determinism, latency, resource management, resource configuration, and application parameters. The usage domain properties should be predefined within the boundaries of the usability of resources.
- Verify compliance of resource properties with established requirements in terms of the MRS such as performance, interfaces, services, safety, fault management and robustness (fault tolerance).
- Develop the basic software (e.g., operating system, API, and core services) and/or hardware, as relevant to the module and show compliance to the applicable guidance and regulations.
- Develop and make available the module acceptance data for certification authority acceptance.
- Provide users of the module with the necessary information to properly use, integrate and interface with the module, e.g., user's guide, module data sheet and interface specifications.
- If the module is a platform, integrate the platform modules
- Assess and qualify as needed tools used in the development and verification of the module.
- Implement quality assurance, configuration management, integration, validation, verification, and certification liaison for the module acceptance.

- Provide users with the necessary information so that they can properly manage the configuration of the module. Modules should contain a means for the users to determine their configuration (physical part number, electronic part number / version, software identifiers), and when that module has changed.
- Define, specify, assess and qualify, as needed module supporting tools to be provided to and used by module users. If shared tools are used, develop an approach for sharing the tool data (e.g., user's guide, tool qualification data, tool specifications).
- If reuse is a desired outcome for the module development, reuse should be addressed during the development of the module

6.5.2. Task 2: Application Acceptance

An application is software and/or application-specific hardware with a defined set of logical interfaces that when integrated with a platform performs a function. The main goal of application acceptance within the overall IMA system acceptance process is to demonstrate that the application complies with the applicable regulations and requirements allocated by IMA system design, performs within the module limitations, and provides the characteristics and performance as specified. Another goal is to provide acceptance data and compliance evidence for the benefit of the integration of the application in the IMA system and its potential reuse on subsequent projects. A process for accepting the application life cycle data, e.g., acceptance letter, stamped data, data approval letter, should be coordinated with the certification authorities.

Software and/or hardware applications intended for future reuse should be developed using available guidance such as AC 20-148, DO-178/ED-12, and DO-254/ED-80.

6.5.2.1. Application Acceptance Objectives:

The objectives of the application acceptance process are:

- Demonstrate that the application performs its intended function and satisfies applicable regulations while properly utilizing the appropriate platform resources and interfacing with other modules and/or applications.
- Define the platform resources required by the application.
- Verify that the application uses the platform resources in accordance with the appropriate module requirements specification and user guide.
- Ensure that other acceptance and approval activities are addressed as appropriate.
- Develop the necessary application life cycle data. This data may be organized in a way to support future application reuse.
- Validate and verify the operation of the application when integrated with its target IMA platform.
- Maintain configuration control and ensure properly configured tools and modules are used for the development, integration, and verification processes.
- If reuse is desired for the application, consideration should be given during the development of the application.

6.5.3. Task 3: IMA System Acceptance

The main goal of IMA system acceptance is to demonstrate that the integrated, modules, applications and the platform continue to perform their intended functions and do not adversely affect other hosted applications or modules. The activities may be performed on or off the aircraft. For off-aircraft activities, a major goal is to perform V&V activities that can be applied toward the overall aircraft certification effort. The level of certification credit obtained for the particular off-aircraft V&V should be coordinated in advance with the certification authorities.

The delineation between tasks 3 and 4 will vary significantly by project. Therefore, the life cycle data for tasks 3 and 4 may be combined or allocated as appropriate. Any life cycle data not addressed in task 3 should be completed in task 4.

6.5.3.1. IMA System Acceptance Objectives:

The objectives of the IMA system acceptance process are:

- Plan the IMA platform and system activities with the intent of using the integration, validation, and verification for aircraft-level certification credit.
- Verify proper interaction between all applications, modules and platform resources including robustness testing, correct resource allocation and management, correct redundancy management, no adverse impact on performance of individual applications, and satisfaction of safety and partitioning requirements.
- Demonstrate compliance with appropriate regulations, guidance and requirements.
- Demonstrate that configuration of IMA system is correct and approved processes are followed.
- Perform integration, V&V activities on the IMA system.
- Develop IMA system acceptance and compliance data.

6.5.4. Task 4: Aircraft Integration of IMA system (Including V&V)

The final IMA system installation, integration, V&V activities are similar to those that would be conducted on a federated system architecture, demonstrating that each aircraft function and hosted application functions as intended, supports the aircraft safety objectives, and complies with the applicable regulations. However, during the installation activities the interactions between hosted applications relative to the provided aircraft functions should be verified and validated during aircraft ground and flight testing. Also, the interactions, interfaces and connections between the IMA system and other aircraft systems should be verified and validated. Any IMA system life cycle data not addressed in Task 3 should be completed in Task 4.

6.5.4.1. Aircraft Integration Objectives:

The objectives of the IMA aircraft integration process are:

- Plan the activities for installation, integration, validation, and verification of the IMA system on the aircraft.

- Demonstrate compliance for intended functionality and safety requirements, using laboratory, appropriate analyses, ground, and flight tests.
- Verify IMA system resource management, fault tolerance and management, health monitoring, degraded modes and reversion capabilities.
- Demonstrate compliance to the regulations appropriate for the aircraft or engine certification basis
- Evaluate repercussion of specific anomalies, such as a loss or malfunction of multiple applications or of entire shared resources.
- Perform V&V activities to address module failure modes affecting several hosted applications (intra-module analysis); common failure modes on module level affecting several hosting applications (inter-module analysis); and failure modes affecting multiple aircraft systems. Back up systems and mitigation means should also be addressed.
- Address human factors issues regarding multiple aircraft functions failure and anomalous behavior especially under abnormal operating conditions and degraded modes.
- Perform High Intensity Radiated Fields (HIRF) and Indirect Effects of Lightning (IEL) testing in regards to multiple aircraft function's failure and anomalous behavior, as required.
- Verify proper interaction and interfaces between all IMA platforms, including their resources and hosted applications, and ensure there is no adverse impact on the performance of individual applications, modules or any other aircraft systems.
- Verify the failure effects of each IMA module and resource affecting more than one hosted application in the IMA system safety assessment.
- Develop aircraft-level IMA system compliance data for acceptance by the certification applicant and authorities
- Develop an aircraft-level safety assessment that addresses all failure effects of the IMA systems, including the integration and interdependencies with aircraft systems and functions. It may not be necessary to address any failure effects of IMA modules that affect only a single application provided it can be shown that the safety assessment of the IMA system using that single application fully addresses those failure effects. These assessments must address generic, and cascade failures taking, into account all possible combinations failures.
- Integrate the IMA system onto the aircraft.

6.5.5. Task 5: Change of modules or applications

Changes to IMA system components will likely occur throughout the life cycle of the IMA system. A change may involve modification to resources, modules or hosted applications, including addition, deletion, fixing or modification of IMA functions. In some cases components may be changed in the modules to address obsolescence, reliability, etc. without affecting functionality of the IMA system. There are a variety of types of changes that may occur, such as a new application being hosted on the IMA platform, modification to an existing hosted application, new supporting software and processing hardware, a modification to existing supporting software or hardware, or addition of new network infrastructure. Changes will require re-acceptance or approval by the certification authorities.

6.5.5.1. Change Objectives:

A primary objective of the IMA system development and acceptance process is to minimize the impacts of an IMA system component change on the IMA system and aircraft certification. Only the changed module(s) and/or application(s) could require re-acceptance or re-approval when considering installation, safety, operational, or functional performance issues. The main goal of the change process within the IMA system is to bound changes in such a way that their effects are known and can be fully verified and validated. The objectives of the change process are to:

- Develop a change management process and coordinate it with all stakeholders. The process should identify how the various levels of developers, suppliers, integrators, and certification applicants will coordinate and address changes.
- Perform changes using the approved change management process.
- Conduct and document the change impact analysis.
- Reintegrate the changed component into the IMA system. Perform all necessary verification, validation, and integration activities (regression testing) to obtain acceptance of the modified module or application and to ensure that the change has no adverse impact on affected, but unchanged modules and applications.
- Maintain configuration control of all life cycle data related to the change.

6.5.6. Task 6: Reuse of modules or applications

IMA systems are composed of modules and applications that can be used in many different configurations. Reuse involves the use of certification credit (i.e., full, partial, none) for modules and/or applications in a subsequent installation. This subsection focuses on the reuse of module acceptance data. The goal is to reuse acceptance data without reassessing the data itself but rather to assess its suitability for and integration into the new installation.

6.5.6.1. Objectives of the Reuse Process

The main goal of reuse is to be able to use module or application life cycle data that has been previously assured and accepted, with minimal need for oversight by the certification authorities. Reuse should be planned during the initial development process. Modules are accepted with the intent of being reused in multiple systems. Once the module or application has been accepted, the objectives of the reuse process are to:

- Ensure that the module or application life cycle data is unchanged from what was previously accepted.
- Ensure that the limitations, assumptions, etc. documented in the module or application acceptance data sheet are addressed in the subsequent installation.
- Analyze the suitability of the module or application for reuse by performing a usage domain analysis to ensure that the module or application is being reused in the same way it was originally intended and accepted. A usage domain analysis includes V&V that the subsequent installation characteristics fall within the usage domain.

- Evaluate any open problem reports of the module or application to ensure that the problem does not adversely impact safety, functionality, performance, or operations.
- Integrate the module or application into the subsequent installation and verify its proper functionality in the IMA system.
- Minimize the need for re-evaluation of accepted modules or accepted applications.
- Submit necessary plans and data to the certification authorities and users.

Table 6-5 presents the system design and assurance objectives that are integral to tasks 1 through 6.

Table 6-5. IMA System Design and Assurance Objectives

ID	Objective Summary	Doc ref	Life Cycle Data Description
1	Aircraft functions allocated to a specific IMA system (including safety and security requirements and human factors requirements) are consistent with the design of the system.	3.2, 3.3, 3.4	Module, Application, and IMA System Verification Data (including traceability data) Module, Application, and IMA System Requirements & Design Data Module, Application, and IMA System Configuration Indexes
2	Behavior of any hosted application is prevented from adversely affecting the behavior of any other application or function by the design of the IMA platform. The platform has robust partitioning, resource management and other protection means appropriate to the aircraft functions and hosted applications	3.5	Module, Application, and IMA System Requirements & Design Data Aircraft-IMA system interface specifications Module, Application, and IMA System Verification and Validation Data Partitioning Analysis and Verification Data
3	Health monitoring and fault management functions of the IMA are provided for the platform to meet specified requirements of the IMA platform	3.6	Module/Platform, Application, and IMA System Verification and Validation Data (including traceability data) Module/Platform, Application, and IMA System Requirements & Design Data
4	Configuration management for the IMA platform, applications, integrator and certification applicant are established and maintained	3.7	Module CM Plan, Software CM Plan, Hardware CM Plan, IMA System CM Plan, Traceability Data, Integration Data, Verification and Validation Data, Onboard and/or off-aircraft CM system

ID	Objective Summary	Doc ref	Life Cycle Data Description
5	Resource management of shared resources are developed and verified, including addressing periodic and aperiodic modification intervals, to ensure that modifications do not aversely affect the behavior of aircraft functions using these resources.	3.8	Field-Loadable Software or Hardware Procedures, Maintenance Procedures and Instructions, Plans for Verifying Update-able Resources, Integration Requirements Data Traceability Data Verification Data
6	An IMA certification plan is developed that satisfies the objectives of this document and describes how this plan relates to other aircraft certification activities and plans.	3.1.3	Planning Data – Aircraft and/or IMA System CP, Platform Acceptance Plan (AP), Module AP, Application AP QA Plans
7	Perform safety assessment addressing IMA implementation on the aircraft.	5.1	PSSA, FHA, SSA, FTA, FMEA, … Verification and Validation Plans
8	Perform design assurance activities to address the system, software, hardware, EQT, and security assurance.	5.2	Plans, Development Data, Verification and Validation Data, CM Records, QA Records, Accomplishment Summaries Aircraft Ground and Flight Test Results
9	Perform integration of IMA tiers.	5.3	Module, Platform, Application, System and Aircraft Integration Data
10	Perform V&V of the IMA system.	5.4	Verification and Validation Results
11	Address continued airworthiness training, maintenance, and post initial certification change process	6.1, 6.2, 6.3	Instructions for Continued Airworthiness, Flight Manual, Maintenance Manuals

7. RECOMMENDATIONS

This section provides guidance in the form of recommendations, for the development of MMDA that can be certified based on SC-200 Integrated Modular Avionics guidance working paper. The report identifies a logical MMDA architecture that is designed to support multiple CNS applications, and promotes a radio that uses software to support radio waveforms and protocols. The report provides a certification methodology for the MMDA prototype, as advocated by the SC-200 IMA group.

A summary of the recommendations follows:

- ***Logical MMDA Architecture:*** This report identifies a logical MMDA Architecture that can support CNS capabilities. The MMDA architecture will provide guidelines for building the MMDA prototype. A list of potential benefits that could result due to the development of a scalable and modularly designed MMDA is contained in the report. It is recommended that this logical architecture be part of any Government solicitation for the prototype (refer to system specification below).

- ***Industry/Military Systems:*** The DoD is sponsoring the development of the JTRS, while the aviation, industry is developing avionics that embody the integrated and modular concept. The ARINC 755 Multi-Mode Receiver and the ARINC 750-3 Voice + Data radio are examples. The ARINC Specification 653-1, Avionics Application Software Standard Interface specifies the baseline-operating environment for application software used within Integrated Modular Avionics (IMA) and traditional ARINC 700-series avionics. It defines a general-purpose APEX (APplication/EXecutive) interface between the Operating System (O/S) of an avionics computer resource and the application software. Included within this specification, are the interface requirements between the application software and the O/S and the list of services that allow the application software to control the scheduling, communication, and status information of its internal processing elements. Vendors such as Green Hill, WindRiver, Thales, Smith, BAE, and Boeing are implementing APEX interface to their real time operating systems. It is recommended that the MMDA implementation make use of one of these operating systems

- ***MMDA Development and Certification:*** The development process of the MMDA could follow the guidelines laid out in the SC-200 IMA document. The IMA platform requires the reusability and sharing of resources by several applications, which leads to lower developmental costs. The SC-200 IMA document also provides the steps to perform certification by obtaining incremental acceptance of and certification credit for IMA platforms, modules and/or applications, cumulating in IMA system installation approval on an aircraft product, and resulting in issuance of the product certificate. This SC-200 approach will have to be compared to the “6 sigma” approach being developed in Task 1 of the ACAST Business and Certification Analysis Project. Ideally, both processes could be used for certification of the prototype MMDA component in order to contrast and compare the methodologies.

- ***Industry Support:*** The RTCA SC-200 and EUROCAE WG-60 is jointly preparing the "Integrated Modular Avionics (IMA) Development Guidelines and Certification Considerations". This material provides a step by step approach to obtain certification of IMA type devices. It is recommended that the MMDA radio development process closely follow the SC-200 specification. In addition, it is strongly recommended that NASA GRC continue to support the SC-200 industry activity.

- ***System Specification:*** When NASA GRC decides to proceed with the development of a prototype MMDA system, it is highly recommended that a system requirements specification be developed to accompany the SOW. This will be necessary in order to evaluate offers and to provide a baseline for each offer's proposals. The MMDA system specification should be developed and released for industry comment prior to official solicitation (RFP). The system specification will make use of the logical MMDA architecture defined in this report, one or both methods for certification (pure SC-200 or the proposed 6 Sigma), and will include a logical aircraft system architecture. Lastly, the specifications developer will be restricted from bidding on the prototype development, but could serve as an evaluator, and/or in a role of testing.

- ***Software Communications Architecture:*** The JTRS SCA is a platform standard, which was developed to specifically target the DoD domain. It supports ubiquitous interoperability among various military radio systems. The SCA mandates the use of CORBA (Common Object Request Broker Architecture) middleware to connect software components. The GRC MMDA development effort should borrow the waveform software that is applicable in the commercial aeronautical environment, instead of redeveloping the waveform software. Thus, making the MMDA prototype SCA compliant could provide cost benefits to the developmental effort.

- ***Software Downloads:*** The software download capability is needed for adding new services and capabilities to the radio. Software download for software-defined radio (SDR) and reconfigurable devices can be accomplished by a number of techniques. One of the techniques that is being standardized is the "over the air" down load of software. This approach is attractive, but requires an infrastructure to support the process of downloading the software. It is recommended that the MMDA radio use the local memory to download software in the MMDA devices.

- ***Software Use:*** A radio that is substantially defined in software and whose behavior can be significantly altered through changes to its software is desired. However, the present state of the art in RF component design does not allow for the design of antennas and power amplifiers that operate over a wide range of frequencies. Cost, power, and weight issues demand a more pragmatic architecture that focuses on a radio that uses software to support radio waveforms and protocols, and uses hardware components for the RF front end. In order to reduce the cost of the MMDA radio, the state of the art in technology during the design and development process should decide how far to move the software close to the antenna as possible. Thus, any system specification will have to make clear the boundary between software and hardware approaches that allow for hardware intensive front ends.

8. MMDA RELATED REFERENCES

No.	Reference
RTCA	
DO-278	Guidelines For Communication, Navigation, Surveillance, and Air Traffic Management (CNS/ATM) Systems Software Integrity Assurance
DO-282	Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance Broadcast (ADS-B).
DO-267A	Minimum Aviation System Performance Standards for Flight Information Services Broadcast (FIS-B) Data Link.
DO-264	Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communications
DO-254	Design Assurance Guidance for Airborne Electronic Hardware
DO-248B	Final Annual Report For Clarification Of DO-178B "Software Considerations In Airborne Systems And Equipment Certification"
DO-242A	Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast.
DO-212	Minimum Operational Performance Standards for Airborne Automatic Dependent Surveillance (ADS) Equipment
DO-178B	Software Considerations in Airborne Systems and Equipment Certification
	RTCA Task Force 4 Certification
SC-200	SC-200, Modular Avionics
SC-186	SC-186, Automatic Dependent Surveillance - Broadcast (ADS-B)
SC-172	SC-172, VHF Air-Ground Communication
DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
SC-159	SC-159, Global Positioning System (GPS)
SC-147	SC-147, Traffic Alert And Collision Avoidance (TCAS)
SC-135	SC-135, Environmental Testing (DO-160D)
EUROCAE	
EUROCAE ED-78	Guidance material for the Certification of Data Links Supported by ATM services
AEEC	
ARINC 607-3	Design Guidance for Avionics Equipment
ARINC-618	Air-Ground Character-Oriented Protocol Specification
ARINC 620	Data Link Ground System Standard and interface Specification (DGSS/IS)
ARINC 622	ATS Data Link Applications Over ACARS Air-Ground Network

No.	Reference
ARINC 629	Part 1-5 - Multi-Transmitter Data Bus, Part 1-Technical Description
ARINC 629	Part 2-2 Multi-Transmitter Data Bus, Part 2-Application Guide
ARINC 651	Design Guidance for Integrated Modular Avionics
ARINC 652	Guidance for Avionics Software Management
ARINC 653-1	Avionics Application Software Standard Interface
ARINC 654	Environmental Design Guidelines for Integrated Modular Avionics
ARINC 660	CNS/ATM Avionics, Functional Allocation and Recommended Architectures
ARINC 664P1	Aircraft Data Network, Part 1, Systems Concepts and Overview
ARINC 664P2	Aircraft Data Networks, Part 2, Ethernet Physical and Data-Link Layer Specification
ARINC 664P3	Aircraft Data Network, Part 3, Internet Based Protocols and Services
ARINC 664P4	Aircraft Data Network, Part 4, Internet Based Address Structures and Assigned Numbers
ARINC 716	Airborne VHF Communications Transceiver
ARINC 750	VHF Data Radio
ARINC 755	Multi-Mode Landing System - Digital
ARINC 755-2	Multi-Mode Receiver (MMR) - Digital
ARINC 756	GNSS Navigation and Landing System (GNLU)
ARINC 768	Integrated Surveillance System (ISS)
OMG	
formal/2002-12-02	Common Object Request Broker Architecture (CORBA/IIOP)
Chapter 24 of CORBA/IIOP 3.0.2	Common Secure Interoperability (CSIv2)
formal/2002-06-65	CORBA Component Model
formal/2002-03-13	CORBA-FTAM/FTP Interworking
formal/2001-01-01	CORBA / TC Interworking and SCCP-Inter ORB Protocol
formal/2003-11-02	CORBA-WSDL/SOAP Interworking
Chapter 23 of CORBA/IIOP 3.0.2	Fault Tolerance
ptc/2003-08-20	GIOP SCTP
formal/2000-08-01	Interworking between CORBA and TMN Systems
formal/2004-04-02	Wireless Access & Terminal Mobility in CORBA (Telecom Wireless)
formal/2004-04-01	WSDL/SOAP-CORBA Interworking
ptc/2003-07-07	Data Distribution
ptc/2003-03-05	Data Parallel Processing

No.	Reference
ptc/2002-09-14	Real-Time CORBA (Dynamic Scheduling)
formal/2002-08-02	Real-Time CORBA (Static Scheduling)
ptc/2003-01-11	Unreliable Multicast
formal/2002-09-03	Additional Structuring Mechanisms for the OTS
formal/2002-08-03	Collection Service
formal/2000-06-14	Concurrency Service
formal/2002-05-07	Enhanced View of Time
formal/2001-03-01	Event Service
formal/2000-06-16	Externalization Service
formal/2002-09-01	Life Cycle Service
realtime/2003-10-03	Lightweight Services
formal/2001-06-03	Management of Event Domains
formal/2002-09-02	Naming Service
formal/2002-08-04	Notification Service
dtc/2003-06-01	Notification / JMS Interworking
formal/2002-09-06	Persistent State Service
formal/2000-06-22	Property Service
formal/2000-06-23	Query Service
formal/2000-06-24	Relationship Service
formal/2002-03-11	Security Service
formal/2003-06-01	Telecoms Log Service
formal/2002-05-06	Time Service
formal/2000-06-27	Trading Object Service
formal/2003-09-02	Transaction Service
formal/2000-05-01	Air Traffic Control
formal/2003-03-62	Surveillance User Interface (Surveillance Manager)
formal/2002-12-01	Telecom Service & Access Subscription (TSAS)
	Security Protocol (SECP) 1.1: Platform Independent Specification, which is a specification of the SECP protocol message formats and state machine that is independent of the underlying transport protocol
	Specification for PIM and PSM for SWRADIO Components
SAE	
ARP4754	Certification Considerations for Highly-Integrated Or Complex Aircraft Systems

No.	Reference
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
AIR4289	Handbook for the SAE AS4075 High Speed Ring Bus Standard
AIR5610	Enhanced Bit Rate Digital Time Division Command/Response Multiplex Data Bus 10 Megabit/sec Network Configuration
AS4893	Generic Open Architecture (GOA) Framework
AIR5614	Avionics Operating System Application Program Interface Requirements
AIR5617	Generic Open Architecture (GOA) Rationale and Overview of Preferred Standards for Avionics Domain
ARD5441	Avionics Operating System Application Program Interface (API) Guidance Document
AS5506	Architecture Analysis and Design Language (AADL)
IEEE	
1003.1-2001	Standard for Information Technology - Portable Operating System Interface (POSIX).
SDR FOURM	
SCA 2.2	API supplement, http://jtrs.army.mil/pages/sections/technicalinformation/fset_technical_sca.html
	A. Akhurst, "Scalability Aspects of the SRA," SDR Forum contrib., 25 May 2001, http://www.sdrforum.org/2001_docs.html
	D. Murotake, "JTRS SCA Platform Hardware Scalability," SDR Forum Contribution, 13 Nov 2001, http://www.sdrforum.org/ 2001_docs.html
	SCA Training Course Day 3 — Waveform Design, http://jtrs.army.mil/pages/sections/technicalinformation/fset_technical_waveforms.html
	D. Dohse *et al.*, "Successfully Introducing CORBA into the Signal Processing Chain of a Software Defined Radio," *COTS J.*, Jan 2003.
	D. Murotake, "Use of Switched Fabrics in Implementation of Software Defined Radio Smart Antenna and Interference Cancellation Signal Processing,"*Proc. SDR Forum 2002 Tech. Conf.*, vol. 2, 12 Nov. 2002.
Others	
ETSI	EN-300-676 EMC and Radio Matters (ERM); Hand held, mobile and fixed radio transmitters, receivers and transceivers for VHF aeronautical mobile service using amplitude modulation; Technical characteristics and methods for measurement.
ISO/IEC	ISO/IEC 7498 Information Technology-Open Systems Interconnection-Basic Reference Model, November 1994

9. APPENDIX A: ACRONYMS

Acronym	Meaning
3GPP	3rd Generation Partnership Project
4GPP	4th Generation Mobile Systems
A/G	Air to Ground
AAC	Aeronautical Administrative Communications
ACARS	Aircraft Communications and Addressing Reporting System
ACK	Acknowledgement
ADLP	Air Data Link Processor
ADM	Administration
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance – Broadcast
ADSU	Automatic Dependent Surveillance Unit
AE	Application Entity
AEEC	Airline Electronics Engineering Committee
AES	Aeronautical Earth Station
AFI	Authority Format Identifier
AGATE	Advanced General Aviation Transport Experiments
AH	Authentication Header
AI	Airborne Internet
AIN	Advanced Intelligent Network
AINSC	Aeronautical Industry Service Communication
AMCP	Aeronautical Mobile Communications Panel
AMPS	Analog Mobile Phone Service
AM(R)S	Aeronautical Mobile (R) Service
AMS(R)S	Aeronautical Mobile Satellite (R) Service
AMSC	American Mobile Satellite Corporation
AMSS	Aeronautical Mobile Satellite System
AOA	ACARS Over AVLC
AOC	Aeronautical Operations Control
APC	Aeronautical Passenger Communications
ARIB	Association of Radio Industries and Business
ARNS	Aeronautical Radio/Navigation Service
ARP	Address Resolution Protocol
ARQ	Automatic Repeat Request
ARS	Administrative Regional Selector
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Center
AS	Anti-Spoofing

Acronym	Meaning
ASC	Aviation System Capacity
ASDE	Airport Surface Detection Equipment
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Automated Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
ATS	Air Traffic Service
ATSC	Air Traffic Services Communications
AVC	Analog Voice Channel
AVLC	Aviation VHF Link Control
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
C/A	Coarse Acquisition
C2	Command and Control
CAA	Civil Aviation Authority
CCITT	International Consultative Committee on Telegraphy and Telephony
CCK	Complementary Code Keying
CLNP	Connectionless Network Protocol
CLTP	Connection-less Transport Protocol
CLTS	Connection-less Transport Service
CMU	Communications Management Unit
CNS	Communications, Navigation, and Surveillance
CNS/ATM	Communications, Navigation, and Surveillance/Air Traffic Management
COPP	Connection-Oriented Presentation Protocol
COSP	Connection-Oriented Session Protocol
COTS	Commercial Off-The-Shelf
COTS	Connection-mode Transport Service
CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
CTS	Cleared to Send
D8PSK	Differentially encoded 8 Phase Shift Keying
DL	Downlink
DME	Distance Measuring Equipment
DSP	Domain Specific Part
ES	Earth Station
ETSI	European Telecommunications Standards Institute
EUROCAE	European Organization for Civil Aviation Equipment

Acronym	Meaning
FAA	Federal Aviation Administration
FANS	Future Air Navigation Systems
FCS	Frame Check Sequence
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FM	Frequency Modulation
GES	Ground Earth Station
GFSK	Gaussian Frequency Shift Keying
GLONASS	Global Orbiting Navigation Satellite System
GMSK	Gaussian Minimum Shift Keying
GPS	Global Positioning System
GRC	Glenn Research Center
GEO	Geosynchronous Earth Orbit
HDLC	High-Level Data Link Control
HF	High Frequency
HFDL	High Frequency Data Link
ICAO	International Civil Aviation Organization
ICS	Internet Communication Service
IDI	Initial Domain Identifier
IDP	Initial Domain Port
IEEE	Institute of Electrical and Electronic Engineers
IFR	Instrument Flight Rules
IP	Internet Protocol
IPI	Initial Protocol Identifier
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISDN	Integrated Services Digital Network
ISO	International Organization for Standardization
ITU	International Telecommunications Union
LAAS	Local Area Augmentation Signal
LEO	Low Earth Orbit
MAC	Media Access Control
MASPS	Minimum Aviation System Performance Standards
MEO	Medium Earth Orbit
MLS	Microwave Landing System
MMSS	Maritime Mobile Satellite System
Mode S	Mode Select

Acronym	Meaning
MOPS	Minimum Operational Performance Standards
MSK	Modulation Shift Keying
NAS	National Airspace System
NASA	National Aeronautics & Space Administration
NEXRAD	Next Generation Weather Radar
NSAP	Network Service Access Point
NSDU	Network Service Data Unit
NSEL	Network Selector
OEM	Original Equipment Manufacturer
ORB	Object Request Broker
OSI	Open Systems Interconnection
p/4-DQPSK	pi/4 - Differential Quadrature Phase Shift Keying
p-CSMA	Persistent CSMA
PSK	Phase Shift keying
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RCP	Required Communications Performance
RF	Radio Frequency
RH	Routing Header
RNP	Required Navigation Performance
RTCA	Communications Standards Body
RTS	Request to Send
SARPs	Standards and Recommended Practices
SATCOM	Satellite Communications
SIM	Subscriber Indentification Module
SSR	Secondary Surveillance Radar
SUA	Special Use Airspace
SV	Space Vehicle
TACAN	Tactical Air Navigation
TCAS	Traffic Alert and Collision Avoidance System
TCP	Transport Control Protocol
TCP/IP	Transport Control Protocol/Internet Protocol
TCP/IPv4	Transport Control Protocol/Internet Protocol version 4
TCP/IPv6	Transport Control Protocol/Internet Protocol version 6
TDMA	Time Division Multiple Access

Acronym	Meaning
TDWR	Terminal Doppler Weather Radar
TIS	Traffic Information Service
TIS-B	Traffic Information Service – Broadcast
ToS	Type of Service
TP4	Transport Protocol Class 4
TP4/CLNP	Transport Protocol Class 4/Connectionless Network Protocol
TSEL	Transport Selector
UAT	Universal Access Transceiver
UHF	Ultra High Frequency
UL	Uplink
ULCS	Upper Layer Communications Services
VDL	VHF Data Link
VDR	VHF Data Radio
VER	Version
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
VORTAC	Combined VOR and TACAN
WAAS	Wide Area Augmentation Signal
WARC	World Administrative Radio Conference
WRC	World Radio Conference

10. APPENDIX B: CNS ARCHITECTURES AND PROTOCOLS

B.1 Communications Datalinks

B.1.1 High Frequency Data Link (HFDL)

The High Frequency Data Link (HFDL) provides worldwide communications directly between aircraft in flight and ground stations via HF radio and HF ground networks. It supports Air Route Traffic Control Centers (ARTCCs) and aircraft operating authorities. Communication services accommodated by this datalink include two categories of messaging, Air Traffic Services (ATS) and Aeronautical Operational Control (AOC). The architecture defines system characteristics that are needed to support a minimum worldwide interoperability function and is based upon the OSI model. The channel access protocol is a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). The ground station assigns the TDMA slots on a dynamic basis using a combination of reservation, polling and random access assignments.. A number of frequencies (channels) are available for HF Data Link users. Each of the active frequencies is divided into frames with 13 slots. The frame duration is 32 seconds and slot duration is 2.461538 seconds.

The first slot of each frame is reserved for use by the ground station to broadcast link management data. The remaining slots are ground assigned for either uplink or downlink traffic. The HFDL operates at an information data rate of 1800, 1200, 600 or 300 bps that is dynamically selectable to maximize communication throughput. HFDL is not used in service operations within the NAS, except for international oceanic operations requirements.

B.1.2 VHF Data Link Mode 0 (VDL Mode 0-Character Mode ACARS)

The Aircraft Communications Addressing and Reporting System (ACARS) is an air - ground - air radio data system developed by Aeronautical Radio Inc. (ARINC) in the 1970's for commercial aircraft to ground communications. Data sensors on board the aircraft register "events" which are fed into a computer to be converted into data packets to be sent to ground stations via the aircraft’s normal VHF voice radio. The receiving ground system routes the data packets via ARINC's Electronic Switching System and central computer to the relevant carrier.

B.1.2.1 Overview of ACARS

ACARS is an air-to-ground communications system that includes networking software protocols. The primary sub-systems of ACARS include:

- Airborne Subsystem consisting of the:
  - Management Unit (MU), which receives ground-to-air messages via the VHF radio transceiver and also controls the replies.
  - Control Unit (CU), which is the aircrew interface with the ACARS system, consisting of a display screen and printer.

- Ground Subsystem, which consists of all the of the service provider's ACARS remote transmitting and receiving stations and the computer and networking systems.
- Air Carrier C2 (Command and Control) and Management subsystem which is basically all the ground based airline operations such as operations control, maintenance, crew scheduling and the like, linked with the ACARS system.
- ACARS messages, which can be categorized in two ways:
  - "Downlinks" are those ACARS transmissions originating in the aircraft.
  - "Uplinks" are those messages sent from the ground station to the aircraft.

B.1.2.2 VHF ACARS Communications

In the VHF ACARS data link, data is passed over the air-ground link on an aeronautical VHF radio frequency. A VHF communications transceiver on the aircraft provides the airborne ACARS CMU (Communications & Management Unit) with access to the RF environment. A VHF ACARS data link permits transmission of a typical 200 character message across the VHF channel in 1 second.

In some installations, the VHF transceiver which provides data communications may be shared between the ACARS and a voice communications function, each of which utilizes different channel frequencies. (The switchover from data link to voice communications can be controlled manually or automatically via an external control panel.) In other installations, VHF transceivers are identical to those used for voice communications. They are not adapted in any way to accommodate transmission of data. Data is exchanged between the ACARS CMU and the transceiver in the form of analog sinusoidal signals having two possible frequencies. These frequencies are used to modulate the VHF transceiver for messages to be sent to the ground

Before each transmission of an ACARS data block on the VHF frequency, a preamble consisting of Pre-Key, Bit-Sync and Character-Sync is sent. In addition, the modulation scheme (Minimum Shift Keying) selected for VHF ACARS necessitates the presence of a final character to enable the last bit of the Block Check Sequence field to be decoded. With the exception of the pre-key and the block check sequence, the MSB of each byte transmitted is set to render odd parity to the byte. Before data transmission, the CMU converts the 2400 bits per second downlink message serial bit-stream into VHF radio modulating signals using MSK. On the other side, the CMU demodulates the MSK modulated signals, thereby extracting data from the delivered waveform.

The eventual data rate experienced by an individual aircraft is less than the ACARS data rate of 2400 bps, each RF link relies on access to a radio spectrum shared by all equipped aircraft.

ACARS is a character-oriented internetworking system. All data is transmitted as ASCII characters. "Line Feed" characters separate fields of a message. Mobility in the ACARS system is simplified due to its centralized nature. All ACARS messages pass through a central node (or central processor). The central node has the ability to track messages and determine where the aircraft is located. The process by which mobility in ACARS is implemented is quite simple and can be illustrated as follows:

- ACARS downlink (from aircraft to ground).
- A VHF, HF or SATCOM ground station receives an ACARS message.
- Upon receipt of the downlink, the ground station forwards the ACARS message to the system central node for processing and routing.
- The central node, upon receiving the ACARS downlink, reformats the message from the air-ground data protocol into the ground-ground data protocol (i.e., it is an application gateway / translator); addresses the message to the one or more destinations and forwards the message to the appropriate stationary end system(s).
- ACARS uplink (from ground to aircraft).
- The central node receives an ACARS message transmitted from a stationary ground end-system.
- Upon receipt, the central node reformats the message into the air-ground protocol, determines the destination aircraft (because of how aircraft can be addressed, errors are made in the lookup), and forwards the message to the appropriate ground station for transmission. The central node chooses the ground station based on criteria such as best signal quality or other determining factors. However, because aircraft transmit at a slower rate when they transition between ground stations, a fairly high percentage (3-5%) of messages cannot be delivered as the system has lost track of the aircraft.
- The ground station, upon receiving an uplink message from the central node, transmits the message to the aircraft.

Table B-1. VDL Mode 0

Characteristic	Description and Comment
Frequency band	117.975– 136 MHz Receive and Transmit
Bit Rate	2.4 Kbps
Modulation	MSK
Message length	Frame length of 220 bytes; multi-frame allowed
Address	Yes: IATA 5 character sub labels
Transmitter Power	Aircraft radio 10W; ground system radio 100 W (dependent on provider)
Polarization	Vertical
Other	FEC implemented at the data frame level
Message Transmission rate	Random access
Media Access Technique	CSMA
RF Channel	1 ea. 25 KHz operated in simplex access mode
Effective data rate	300 – 1200 bps
Demonstrated range	200 nmi (at altitude; line-of-sight)
International Standard	No (AEEC 618, 619 specification adopted by aircraft operators)

Characteristic	Description and Comment
Performance	Low data throughput

The formats for ACARS messages are shown in Figure B-1.

Name	SOH	Mode	Aircraft Registration Number	TAK	Label	DBI	STX	MSN	Flight ID	Appl. Text	Suffix	BCS	BCS Suffix
Size	1	1	7	1	2	1	1	4	6	0-210	1	2	1

(a) General Format of Air/Ground Downlink Message

Name	SOH	Mode	Aircraft Registration Number	TAK	Label	UBI	STX	Appl. Text	Suffix	BCS	BCS Suffix
Size	1	1	7	1	2	1	1	0-220	1	2	1

(b) General Format of Air/Ground Uplink Message

Figure B-1. Message formats for air-ground uplink and downlink messages in ACARS

B.1.3 VHF Data Link Mode 1 (VDL Mode 1 - ACARS)

The Airline Electronics Engineering Committee (AEEC) standards group originally defined this mode of ACARS as an upgrade path for VDL Mode 0 ACARS equipped aircraft. Its specification anticipated application of AVPAC protocols using CSMA channel access and MSK modulation on a new RF waveform. However, as the international standards for VDL Mode 2 progressed, activity on this standard was terminated and made obsolete. No hardware was built or fielded to support this protocol.

B.1.4 VHF Data Link Mode 2 (VDL Mode 2)

VHF Data link Mode 2 (VDL-2) is a replacement system for ACARS. It provides high-speed, bit-oriented data link functions over the same aviation VHF frequency spectrum now supporting ACARS. The 136.795 MHz frequency is used as a common signaling channel (CSC) for VDL Mode 2 to advertise the availability of VDL services.

It uses differential 8-phase shift keying D8PSK for modulation and p-persistent CSMA for channel access. It can provide a data rate of 31,500 bits/sec which amounts to 10,500 symbols/sec (given that D8PSK is used as a modulation scheme, it uses 3 bits/symbols). With VDL Mode 2, bit error rates of 10^{-4} can be achieved using the Reed-Solomon Forward Error Correction technique assuming a signal level at the receiver of –87 dBm (The VDL-2 BER increases to approximately 10^{-3} for a signal level at the receiver of –98 dBm.). Reed-Solomon "Forward Error Correction" (FEC) is applied to the decoded RF data (RS (255,249) 2^8 coding is specified for VDL) to correct up to three erroneous bytes in any 255-byte data block. Beyond the FEC, a 16-bit link-layer Cyclic Redundancy Check (CRC) is used to give the VDL-2 link an overall undetected bit error rate (BER) approaching 10^{-9}. VDL-2 can achieve a range (limited by line-of-sight) of over 160 nautical miles using a 15 Watt transmitter. (When an aircraft is on the ground, its transmitter power is limited to 4 watts, and its effective range is reduced to about 100 nautical miles.) VDL-2 defines a distributed topology with mechanisms for link establishment and handoff to set up and manage air-ground connections. In the next few sub-sections we talk about the specifics of the physical and link layer with respect to VDL-2.

VDL/2 was intended initially as an ATN subnetwork; however, because of the delays in deploying ATN, the airlines have developed their own protocol called ACARS over AVLC[8] (AOA). The message flow in VDL/2/AOA is similar to that of ACARS, except for taking advantage of the higher bit rates and simplified interfaces provided by the ARINC 750 VDR.

AVLC is based on ISO 4335 (i.e., HDLC) and increases system capacity by improving a number of facets of the link layer protocol. IP can be implemented above AVLC similar to the AOA stack. Alternatively, IP can be implemented above 8208 similar to the ATN stack. A difference between ACARS (especially Cat A ACARS – implemented by ARINC) and VDL/2 is the existence of a link layer between the aircraft and a ground station (rather than the aircraft and the central node). The aircraft is continually monitoring its ability to reach the ground station as well as other ground stations to ensure a viable link. Consequently, message delivery is improved as the likelihood that the central system lost an aircraft is reduced.

Because of the problems (both actual and theoretical) associated with the central node reformatting all traffic between the aircraft and ground systems, one of the requirements of the next generation designs (VDL/2 and ATN) was to have end-to-end transport connectivity. The slow data rate was improved without sacrificing performance by going from an AM-modulated sub-carrier to direct carrier modulation. Other improvements were made in the link layer to improve the performance of the channel.

Table B-2. VDL Mode 2

Characteristic	Description and Comment
Frequency band	117.975– 136 MHz Receive and Transmit
Bit Rate	31.5 Kbps

[8] Aviation VHF Link Control (AVLC) is the link layer of VDL/2.

Characteristic	Description and Comment
Modulation	Differentially encoded 8 Phase Shift Keying (D8PSK)
Message length	11 bytes min. 1 kbyte max frame size
Address	27 bit source and destination address
Transmitter Power	42 dBm
Receiver MTL	< -92 dBm
Polarization	Vertical
Other	FEC implemented at the data frame level
Message Transmission rate	Random access
Media Access Technique	p-persistent CSMA
RF Channel	1 ea. 25 KHz operated in simplex access mode
Effective data rate	5-7 kbps
Multi-channel comm. ops	Yes (requires multiple units with external control logic for concurrent operation)
Demonstrated range	200 nmi (at altitude; line-of-sight)
International Standard	Yes

B.1.4.2 VDL Mode 2 Physical Layer

As was discussed above, VDL-2 utilizes D8PSK modulation and p-persistent CSMA for its media-access (MAC) processing. The net result is a 31,500 bits/second raw transmission rate on the RF channel. VDL-2 provides for fully-binary messages (as opposed to the character-oriented ACARS). VDL-2 is based on a distributed network topology with multiple routers selecting the best message path (unlike the centralized ACARS topology). The VDL-2 system utilizes a sophisticated method of link establishment and handoff to control the selection of a ground station to communicate with a given aircraft (while ACARS is a broadcast system).

The format of a VDL-2 transmission "burst" is shown in Figure B-2. Each transmission burst starts with a ramp-up of transmitter power (a string of zero symbols), followed by a synchronization string used to identify the start of the data. The "reserved symbol" might be used in future versions of the system to identify alternate formats – it is set to zero for now. The next value in the VDL-2 transmission is the length (in bits) of the VDL-2 frame. The maximum VDL-2 burst length is 131,071 bits. The VDL-2 header block is preceded by Forward Error Correction (FEC) Reed Solomon code check value that is used to correct errors in the header. Following the header is the VDL-2 data, interleaved with FEC for the data. The VDL-2 FEC algorithms (combined with the link-layer frame-check described in sub-section b. below) will yield an expected overall undetected BER of approximately 10^{-9}. The VDL-2 transmission burst concludes with a transmitter ramp-down. The VDL-2 data is further broken down into "frames" (VDL-2 frames are discussed in sub-section b. below). A VDL-2 transmission burst may contain one or more frames. The default maximum length for a VDL-2 frame is 8,312 bits. The maximum frame size available in the VDL-2 system is 16,504 bits.

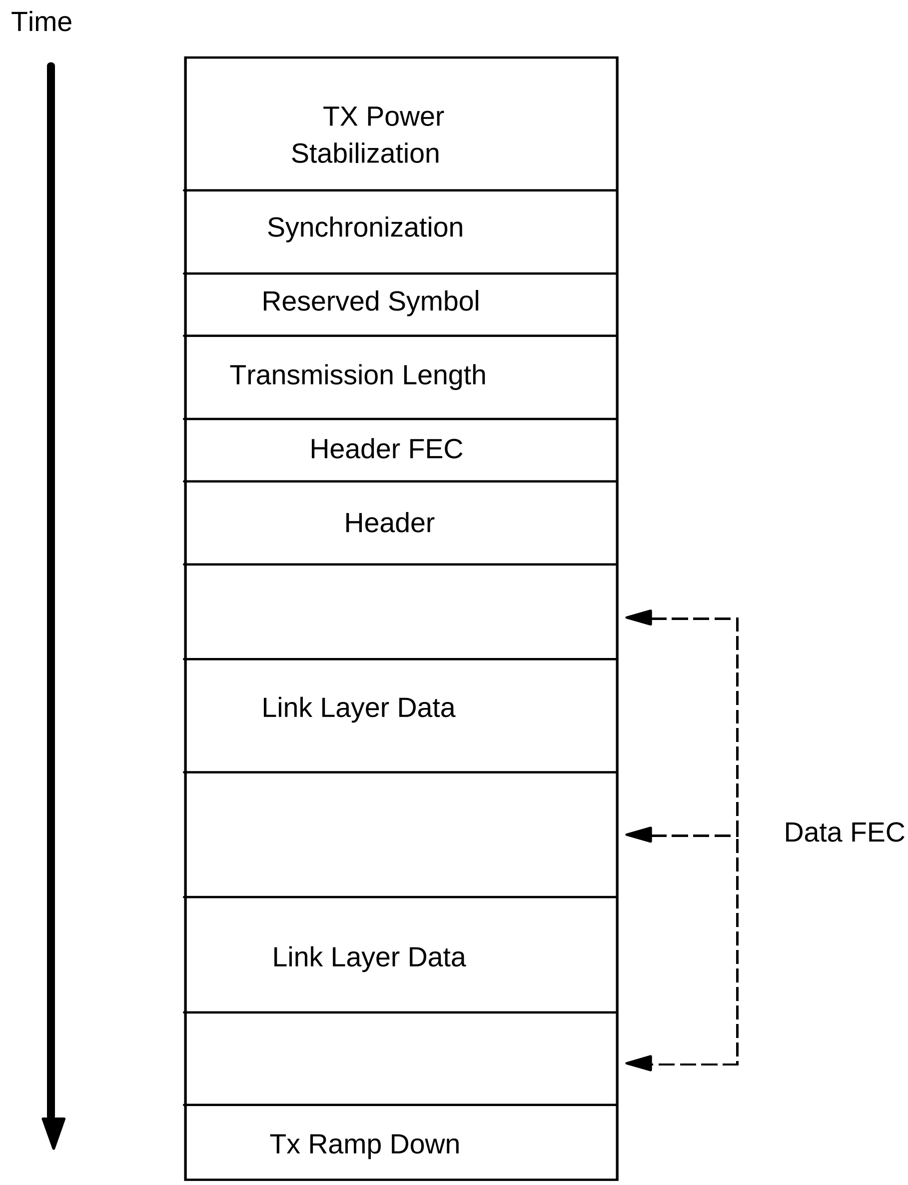

Figure B-2. VDL-2 Transmission Burst Format

B.1.4.3 VDL Mode 2 Data Link Layer

The data link protocol used by the VDL-2 system is an extended version of the standard High Level Data Link Control (HDLC) protocol defined in [HDLC]. The VDL-2 variant of the HDLC protocol is called “Aviation VHF Link Control” (AVLC). AVLC extends HDLC by providing mechanisms for VDL link establishment and handoff. Effectively, AVLC is able to maintain a consistent VDL-2 air-ground “connection” even though the aircraft moves from the coverage of a given VDL-2 ground station to another, and may need to retune its radio frequency from time to time. These AVLC extensions are implemented in software functions termed the “VDL

Management Entity" (VME) and the "Link Management Entity" (LME) that are hosted in the VDL-2 "Communications Management Unit" (CMU). The VME defined in [A758] decides when to establish a link and performs the necessary handoffs. The VME also notifies the other software entities about the status of the VDL connection. The LMEs also defined in [A758] manage a given air-ground connection – there will be an LME instantiation for each connection that a given CMU is currently maintaining. The LME performs link establishment (at the command of the VME) and controls the flow of VDL-2 frames between the aircraft and ground station. The LME also informs the VME of changes in its link status.

Figure B-3 illustrates the structure of an AVLC Frame. Each frame is delimited by "flag" bytes that provide for synchronization of the VDL-2 bit stream. Note that the AVLC frame is of variable length – the ending flag byte marks the termination of a given frame (and, possibly, the start of another frame). The flag bytes have a unique value (0x7E) that cannot occur anywhere inside the AVLC frame (just as in HDLC). To prevent this, the AVLC protocol (just as the HDLC protocol) performs a function termed "bit stuffing". If a pattern of five consecutive 1-bits are encountered in the data, the AVLC protocol inserts an extra zero bit during transmission. The AVLC protocol replaces these extra zero bits with one bit during reception. Bit stuffing is transparent to the higher VDL-2 protocol levels.

AVLC Frame

Flag	Address	Link Control	Information Field	FCS	Flag
1	8	1	n	2	1

Figure B-3. AVLC Frame Structure.

The AVLC frame starts with 8 bytes of addressing (AVLC addressing will be described further in the next sub-section). There is a single byte of link control (also described further below). This is followed by the variable-length data field of the frame. The AVLC frame concludes with a 16-bit Frame Check Sequence (FCS) that provides a high level of link error detection. (This AVLC FCS link error detection operates on top of the VDL-2 physical layer FEC error detection and correction algorithm.) An AVLC frame that fails its FCS test is immediately discarded.

B.1.5 VHF Data Link Mode 2-B

There are several ground-based applications that require delivery of static or slowly changing information to airborne users. These include applications such as aviation weather, flight information services, traffic information services, ground based local area augmentation services, etc. The FAA along with the industry, having developed VDL Mode 2 to support air ground communications, is now planning to use the VDL Mode 2 RF waveform to support ground broadcast services. In these applications, only D8PSK based VDL receivers are required on the airborne platform. The ground service applies all the data packet formatting and manipulation necessary to support the airborne user. For example, to provide local area GPS augmentation services, the LAAS plans to use VDL Mode 2 in an 8 frame per second segment basis to transfer the requisite DGPS information. These data frames may contain corrections for multiple regions or under some schemes may contain different "quality" of DGPS corrections (Cat I, Cat II, etc.). Individual civil aviation administrations worldwide will make similar choices and those that standardize on VDL Mode 4 for air ground communications will use it to accomplish similar broadcast services.

All the basic technical characteristics of VDL Mode 2 apply, (except that the airborne unit is a receiver only while the ground unit is the transmitter).

B.1.6 VHF Data Link Mode 3 (VDL Mode 3)

The VDL Mode 3 (VDL-3) system supports functionally simultaneous voice and data communications services between aircraft and ground-based users. It provides an integrated digital half-duplex voice and digital data link of the same bandwidth as VDL-2. VDL-3 uses the same modulation scheme (D8PSK) as VDL-2 and provides the same raw data rate of 31,500 Kb/s. Both the VDL-2 and VDL-3 are capable of operating on a 25 kHz center frequency between the 117.975 MHz and 137 MHz band. VDL Mode 3 uses a Time Division Multiple Access (TDMA) approach for providing user access to a communication channel, thereby allocating time slots among a defined set of users for transmitting on a particular 25 kHz frequency assignment. Remaining consistent with current ATC operations, the system is primarily sector-based with a dedicated circuit for each control sector and the participating aircraft, referred to here as a user group (or net). The network control concept used is based on a centralized system with the ground station serving as the network controller. The ground station controls the system configuration, timing, user group entry and exit, and discrete addressing services.

The ground radio maintains control of the network by communicating signaling information with the aircraft radios in a Management (M) channel. In most system configurations, the M channel is a small sub-slot of each time slot. The aircraft radios also use the M channel to respond to up-linked channel management information and make various requests, responses and reporting, such as Data Reservation Request, Acknowledgement and Leaving Net messages. A fundamental principle for VDL Mode 3 voice operation is that it is consistent with the current air-ground voice radio system. However, since VDL Mode 3 is a digital system and the current system is analog, there are system characteristics that are different. Inherent in the VDL Mode 3 radio are a number of system features intended to help provide an opportunity to reduce user workload, support efficient use of the communication channel and provide the users with indications of radio operational states.

The half-duplex digital voice operation is based on "Listen-Before Push-To-Talk" channel access scheme. One of the most important characteristic of the VDL Mode 3 voice operation is that it supports "party line" operation and maintains the first come first serve access to the voice channel. At the same time, the incidence of step-on situations will be reduced through the use of active channel management between aircraft and ground radios. This will improve the efficiency of voice communication. A by-product of providing these characteristics in the digital system is that when any user is transmitting, the other radios in the user group are placed in receive-only mode to prevent undesirable interference on the channel. There is a feature in the VDL Mode 3 system to inform users when the voice channel is occupied. Another feature of the VDL Mode 3 system is to provide ATS specialists the ability to override an aircraft voice transmission when the operational situation warrants. The aircraft and the ground station access the physical medium in a simplex mode as in VDL-2.

To provide additional flexibility, a VDL Mode 3 system can be configured where resource allocations for both voice and data are made strictly on a demand basis. This configuration could also be used to support a high capacity data-only service if desired. The system configuration established for a user group is communicated to the aircraft radios through a beacon signal, which is periodically broadcast by the ground station. Aircraft radios acquire this beacon and adapt to the system configuration of the ground radio with which communications will be established. This adaptation to the proper system configuration is completely transparent to the users. There are 4-slot configurations and 3-slot configurations shown in Figure B-4. Application of these two basic levels is range dependent. The 4-slot configurations provide guard time sufficient to allow interference-free communication for up to a range of 200 nautical miles (NM). For longer range scenarios, the 3-slot configurations can be used.

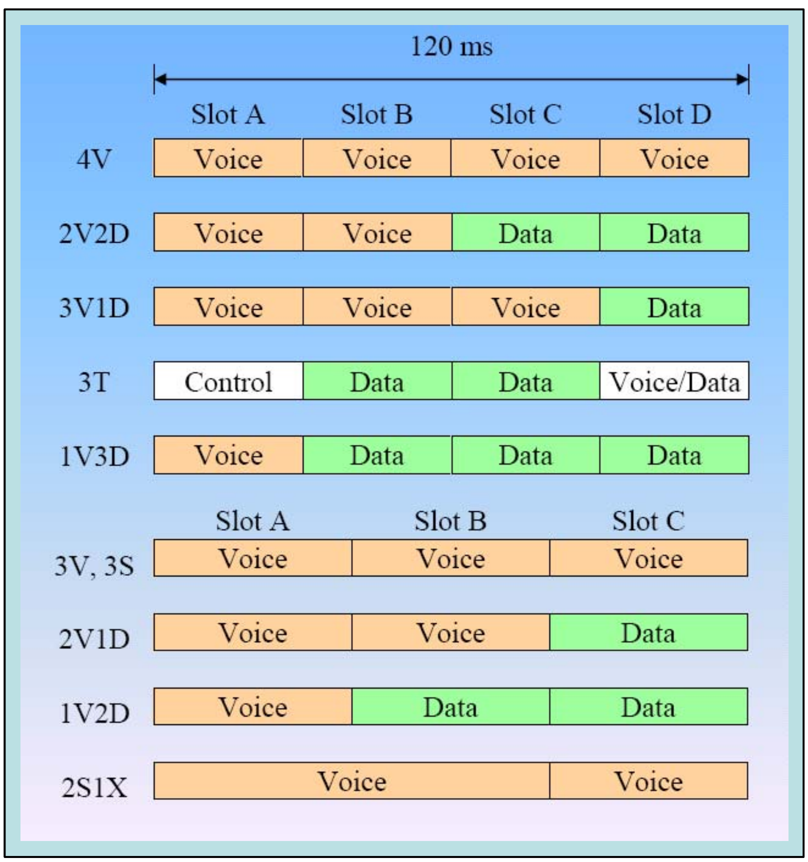

Figure B-4. 4 Slot and 3 Slot Configuration

The 4-slot configurations include the following:

- 4V - Provides 4 voice channels (no data) in one 25 kHz frequency assignment.
- 2V2D - Provides 2 voice channels and 2 data channels in one 25 kHz frequency assignment. These are paired so that one user group uses one voice and data time slot pair and a second, independent, group uses the other voice and data pair.
- 3V1D - Provides 3 voice channels and 1 data channel in one 25 kHz frequency assignment. The three voice channels are completely independent; however, the three user groups share the single data channel.
- 3T - Provides a trunk capability shared by all users in one 25 kHz frequency assignment. This is a data mode over which voice communications can be accommodated.

The 3-slot configurations include the following:

- 3V - Provides 3 voice channels (no data) in one 25 kHz frequency assignment.
- 2V1D - Provides 2 voice channels and 1 data channel in one 25 kHz frequency assignment.
- 3S - Provides a single voice channel in one 25 kHz frequency assignment. The same digital voice bit-stream can be transmitted in each of 3 time slots used by 3 separate ground sites to provide coverage over an area larger than that which could be provided by a single ground site.
- 2S1X - Provides 1 wide area voice channel for 2 separate ground stations and reserves another independent channel in one 25 kHz frequency assignment. The independent channel is defined separately in its own beacon.

Each TDMA frame is 120 ms with either 3 or 4 slots per frame as determined by the system configuration mentioned above. Two such TDMA frames (Even Frame + Odd Frame) together form a MAC cycle, producing a 240 ms burst.

Other pertinent characteristics of the VDL Mode 3 data link are shown in table B-3.

Table B-3. VDL Mode 3

Characteristic	Description and Comment
Frequency band	117.975– 136 MHz Receive and Transmit
Bit Rate	31.5 Kbps
Modulation	Differentially encoded 8 Phase Shift Keying (D8PSK)
Message length	30 or 40 msec. Consisting of a Management (M) burst and a Voice or Data (V/D) burst.
Address	Up to 60 logical users per data channel
Transmitter Power	42 dBm
Receiver MTL	< -92 dBm

Characteristic	Description and Comment
Polarization	Vertical
Other	FEC implemented at the data frame level
Message Transmission rate	TDMA system that permits operation in either a 3 or 4 TDMA time slot mode with each frame being 120 msec duration. (time slots are 30 or 40 msec each)
Media Access Technique	TDMA slotting and resource allocation controlled from ground station
RF Channel	1 ea. 25 KHz operated in simplex access mode
Effective data rate	8 kbps (based on 3T mode de-rated for control info, etc.)
Demonstrated range	200 nmi (at altitude; line-of-sight)
International Standard	Yes

B.1.7 VHF Data Link Mode 4 (VDL Mode 4)

VDL Mode 4 is a time-critical VHF data link that provides communication between mobile stations such as aircraft and airport surface vehicles as well as between mobile stations and fixed ground stations. It is designed for periodic (e.g., ADS-B) and aperiodic (e.g., communications) data.

VDL Mode 4 transmits data in a 25 kHz channel and uses a medium access method called Self-Organizing Time Division Multiple Access (STDMA). STDMA divides the channel into segments. The biggest segment is called a super-frame and it consists in turn of time slots. A super-frame, shown in Figure B-5 has 4500 time slots and each slot has a length of 13.33 ms. Each slot offers an opportunity for a station to transmit. The maximum allowed length for a transmission is one second, which results in the maximum number 75 time slots per transmission.

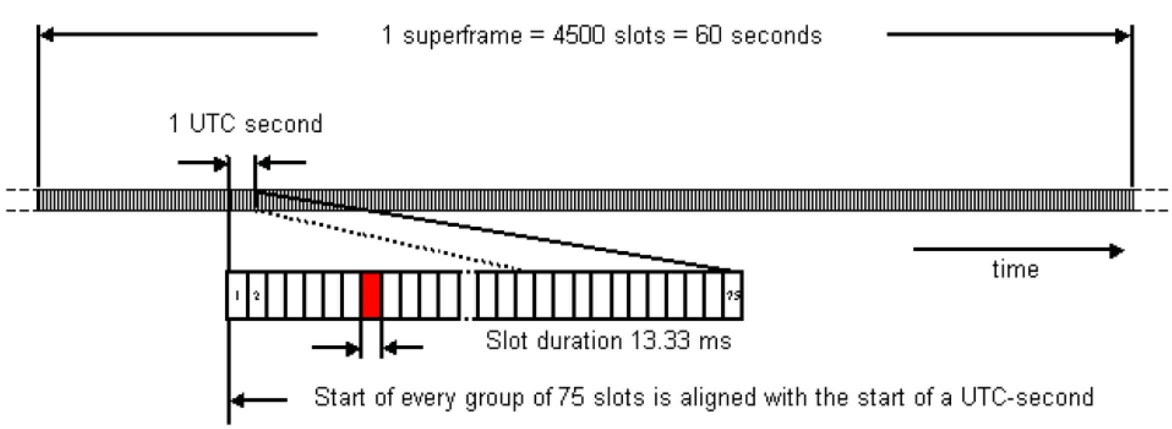

Figure B-5. Frame structure in VDL Mode 4

VDL Mode 4 operates within the spectrum band 108-136.975 MHz. VDL/4 divides the 19.2 kilobits per second available into 75 slots of 32 bytes each (a transmission can span multiple slots). Every transmission includes a reservation type that reserves specified slots for future transmissions for it and/or peer stations. All stations are required to transmit at least once per minute (although aircraft will typically transmit once per 4-10 seconds) and include their current position in the transmission. Consequently, although the other VDL modes must rely upon signal strength and other propagation phenomena, VDL/4 can rely upon geometry as well as signal strength to maintain reliable links. Further, the ground system is unlikely to lose track of an aircraft as it is continuously transmitting its current position.

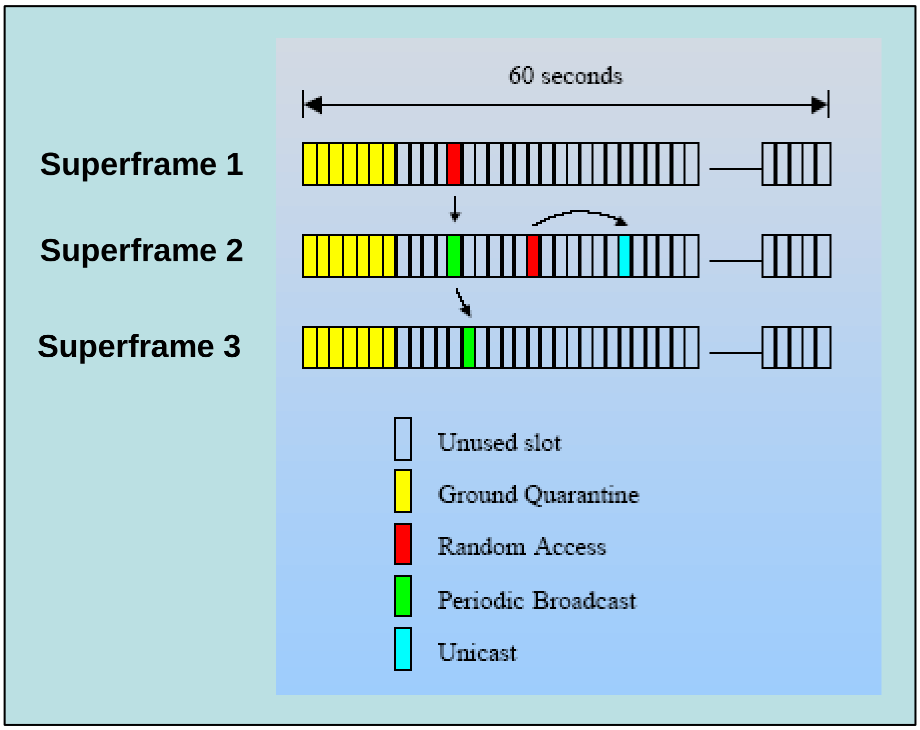

Figure B-6. Superframe Structure

In addition, VDL/4 requires the carriage of multiple receivers. ADS-B, coupled with the multiple channel capability has a number of synergistic benefits:

- Make-before-break connection establishment across frequencies is possible
- Additional capacity to an aircraft can be added by monitoring another channel
- Different priority messages can be segregated on different channels
- The hardest part of air-to-air messaging is station discovery. Since each aircraft is broadcasting its identity, position, and intent (i.e., ADS-B data), air-air messaging is straightforward. In addition, stations can use intermediate aircraft to relay traffic – thus providing a zero marginal cost beyond-the-horizon network when aircraft densities are sufficiently high to provide reasonable assurance that the link can be closed.

Specialized reservations are defined in VDL/4 to improve data communications. These reservations:

- reduce the affect of hidden terminals (as an RTS-CTS protocol is used so the peer reserves the slots for a long data transmission)
- eliminate the dead-time waiting for an acknowledgment that might not arrive (as the acknowledgement (ack) slot is predefined so the transmitting station knows exactly when to expect the ack).

The raw channel rate is 19200 bps. Assuming 256 byte user messages (8 slots of data transmitted in 9 slots), the maximum capacity of a VDL/4 channel is 19200 * [8 data slots / (9 message slots + 3 request slots + 1 CTS slot + 1 ack slot)] = 10971 bps. (Three request slots are required since each RTS is a random access using slotted Aloha.) On the other hand, VDL/4 has the capability of separating the data and control (RTS, CTS, and acks) on different channels. This means that one control channel could support a very large number of data channels with each data channel at near 100% utilization (as all accesses are reserved).

VDL/4, as are VDL/2 and VDL/3, is designed to handle the ATN or IP networks. Consequently, there is no need for the message formatting that occurs in central server based systems.

Table B-4. VDL Mode 4

Characteristic	Description and Comment
Frequency band	118 – 137 MHz Transmit and 108 – 137 MHz Receive
Bit Rate	19.2 Kbps per active channel
Modulation	Binary GFSK/FM
Message length	192 bits
Address	24 + 3 (ICAO address + official source designator)
Airborne position	Yes; resolution to 1 meter
Transmitter Power	43-44.5 dBm high-end and 39-40.5 dBm low-end
Receiver MTL	< -103 dBm
Polarization	Vertical
Message Transmission rate	1, 2, 5, or 10 per sec. Per channel. Can be varied, event driven or commanded for ADS-B applications
Media Access Technique	Self-organized TDMA (75 slots/sec per channel)
RF Channel	2 Channels defined (minimum configuration)

B.1.8 VHF Voice (25 KHz)

Transceivers used in the aviation VHF band (117.975 MHz to 137.000 MHz) must be operated on 25 KHz spaced channel assignments within the internationally allocated band. Channel spacing may vary from country to country. With the exception of VDL Mode 3 specification and avionics under development, all transmissions of voice information are presently conducted using analog DSB-AM waveform. Voice communication will be conducted under the FAA NAS/ATS policy regarding ATC communications. When AOC communications are required, assigned frequencies will be used.

B.1.9 VHF Voice (8.33 KHz)

Transceivers that employ 8.33 KHz channel spacing for analog voice are not permitted in the NAS. However, Europe has adopted this channel separation for high altitude air-ground ATC communications. Further expansion of use of 8.33 KHz channel spacing is planned in Europe and other parts of the world. The FAA is evaluating application of this scheme in conjunction with the implementation of VDL Mode 2 and/or VDL Mode 3 as a transition technology.

B.2 General Satellite Technology

The following sections identify the satellite technologies that may be used to support aeronautic applications.

B.2.1 Frequency Spectrum

B.2.1.1 VHF

Small portions of the VHF band have been allotted to "Little LEO" satellite constellations (e.g., ORBCOMM, FAISAT, and VITA). Obviously, available bandwidth is small; such systems have been designed primarily to support store-and-forward, short-message services. This is based on the potential commonality with VHF aeronautical equipment, the FCC requirement for them to be operational by 2004, and the possible availability of significant bandwidth in delimited areas of the U.S. Initial contacts with the system operators have been somewhat encouraging.

- Primary Frequency Bands: Downlink 137-138 MHz and 400 MHz; Uplink - 148-150 MHz; various sharing allotments among uplinks, downlinks and feeder links at these frequencies
- Satellite Transponder power: *circa* 13 dBW EIRP
- Pros: Contiguous with VHF aeronautical frequencies; potentially simple avionics
- Cons: Interference issues with aero, government (e.g., NOAA satellites); low scalability of throughput

B.2.1.2 L Band

The L Band is currently the most widely used bands in mobile-satellite communications because of favorable propagation characteristics.

- Principal Frequency Bands: Downlink–1.6 (1.610-1.660.5) GHz; Uplink–1.5 (1525-1559) GHz

- Pros: Signals are essentially unaffected by atmospherics, can penetrate physical structures, requires less powerful transmitters, simple terminal antennas; economies of scale with commercial and aero users
- Cons: Band already crowded, although new SATCOM technologies offer relief.

B.2.1.3 S Band

New spectrum for mobile-satellite communications has been, and is being, carved from spectrum in the range of 1.8-2.6 GHz. At these frequencies, propagation issues are somewhat more difficult, but are reasonably manageable with current technologies. Some new LEO/MEO mobile-satellite systems use L-band for service uplinks and S-band for service downlinks.

- Primary Frequency Bands: Downlink - 2.165-2.2 GHz and 2.483-2.5 GHz; Uplink - 1.99-2.025 GHz; bear-term consideration of adding frequencies in the band 2.5-2.69 GHz
- Satellite Transponder power: Highly dependent on constellation architecture
- Pros: Bands allocated to MSS, hence potentially acceptable for AMS(R)S; propagation and terminal characteristics similar to L-band; potentially higher throughput per user as compared with current L-band systems; economies of scale with commercial and aero users
- Cons: Interference issues, particularly in 2.483-2.5 GHz band

B.2.1.4 C Band

The world's first commercial satellite systems used the C band frequency range of 3.7 to 4.2 GHz. The amount of power that any C band satellite could transmit had to be limited to a level that would not cause interference to terrestrial microwave links.

- Frequency Bands: Downlink (fixed-service satellite systems) - 4 (3.7- 4.2) GHz; Uplink - 6 (5.9-6.4) GHz;
- Satellite Transponder power: 10 to 17 Watts for high-gain Earth station antennas
- Pros: Relatively low atmospheric and precipitation losses
- Cons: Band already crowded; interference issues.

B.2.1.5 Ku Band

The first commercial Ku band satellites made their appearance in the late 1970s and early 1980s. Relatively few terrestrial communications networks are assigned to use this frequency band; Ku-band satellites could therefore transmit higher-powered signals than their C-band counterparts without causing interference problems on the ground.

- Frequency bands: Downlink - 11 (11.7-12.2) GHz; Uplink - 14 (14.0-14.5) GHz
- Satellite Transponder power: 20 to 120 watts
- Pros: Provides broadband services–high speed; multimedia interactive services

- Cons: Susceptible to rain outages making it unsuitable for use in areas with high rainfall density; difficult mobile terminal antenna problems

B.2.1.6 Ka Band

An alternative to the highly congested C and Ku bands, Ka band systems promise advanced high-speed networks at 64 Mbps and higher. Proposed services include high speed Internet and Intranet access, data trunking, video conferencing, and private data networks.

- Frequency bands: Downlink - 20 (17.7 - 21.7) GHz; Uplink - 30 (27.5 – 30.5) GHz
- Pros: High bandwidth availability to provide broadband services
- Cons: More susceptible to attenuation due to rain than Ku-beams, high equipment cost, latency, and requires powerful transmitters; difficult mobile terminal antenna problems

B.2.2 Satellite Orbits

This section covers the Geosynchronous Earth, Medium Earth, and Low Earth satellite orbits.

B.2.2.1 Geosynchronous Earth Orbit (GEO)

A satellite that appears to remain in the same position above the Earth is called a "geostationary satellite." The orbit is circular and its inclination is zero degree, which means that it is above the Earth's equator. The altitude is approximately 22,300 miles and the satellite travels at 3 kilometers per second. The satellite's orbital period is close to the Earth's rotational period, roughly 24 hours. Many weather observation satellites and most communications satellite constellations are placed in this orbit.

An orbit in which the satellite completes one circuit around the Earth in one day, then appears in the same position above the Earth's surface, is known as a "synchronous orbit." The duration of one orbit of the satellite is the same as the Earth's rotational period. So while a geostationary orbit is one form of synchronous orbit, the latter differs in that the orbital inclination is not always zero and its form may be elliptical. A typical role for a satellite in synchronous orbit is the monitoring of, and providing communications for, areas in the Earth's higher latitudes. Polar coverage is impossible for a satellite in geostationary orbit.

Satellites operating in the GEO orbit have a signal round trip time of 0.5 seconds. Satellites in this orbit are usually not spaced closer than 2 degrees, dictated by the discrimination required for inter-system interference control. With a spacing of 2 degrees, there can be only 180 GEO communication satellites in the sky at once.

Merits of GEO systems include constant view, no problems due to Doppler, and very large foot print (covers 42.2 % of the earth’s surface). Demerits include very large round trip delays, high satellite power, no coverage at high latitudes and expensive end systems to cope with weak signals.

B.2.2.2 Medium Earth Orbit (MEO)

Medium earth orbit altitudes are typically between 6,000 and 12,000 miles above the earth. Since MEO satellites are located at a higher altitude, they have larger earth foot prints when compared to LEOs, but have a higher latency. The orbital periods range from 2 to 12 hours. Some MEO satellites orbit in near perfect circles, and therefore have constant altitude and travel at a constant speed. Other MEO satellites revolve in elongated orbits. The perigee (lowest altitude) of an elliptical-orbit satellite is much less than its apogee (greatest altitude). The orbital speed is much greater near perigee than near apogee. As seen from a point on the surface, a satellite in an elongated orbit crosses the sky in just a few minutes when it is near perigee, as compared to several hours when it is near apogee. Elliptical-orbit satellites are easiest to access near apogee, because the earth-based antenna orientation does not have to be changed rapidly, and the satellite is above the horizon for a fairly long time.

A fleet of several MEO satellites, with orbits appropriately coordinated, can provide global wireless communication coverage. Because MEO satellites are closer to the earth than geostationary satellites, earth-based transmitters with relatively low power and modest antennas can access the system. MEO satellites orbit at higher altitudes than LEO satellites and the useful footprint (coverage area on the earth's surface) is greater for each satellite. Thus a global-coverage constellation of MEO satellites can have fewer members than a global-coverage constellation of LEO satellites.

Merits of MEOs, compared with GSO satellites, include moderate launch cost, lower round trip delays, lower propagation losses, and shorter satellite development cycles. Demerits include higher network complexity as compared with GSO satellites, and greater propagation loss as compared with LEO constellations.

B.2.2.3 Low Earth Orbit (LEO)

Low Earth Orbit satellites are in orbits between 400 and 1,000 miles above the earth. This type of orbit greatly reduces propagation losses, and also reduces transmission times as compared to GSO. LEO satellites typically have a round trip time between 20 ms and 40 ms, but can be greater when networking is performed directly among a constellation's satellites. A LEO orbit can also be used to cover a polar region, which the GSO cannot accomplish.

The foot print of an individual LEO satellite is smaller when compared with MEOs and GSOs. Each revolution takes between 90 minutes to a few hours. Since it does not appear stationary to earth stations, however, earth stations need an antenna assembly that will track the motion of the satellite.

Merits of LEOs include low launch cost for satellites, normally short round trip delays, availability of Doppler effect for position determining, and lowest path loss leading to simple terminal configurations. Demerits include complex networking for bent-pipe satellites.

B.2.3 Service Providers

Information about service providers is shown in Table B-5.

Table B-5. Satellite Service Providers

Provider	*Constellation*	*Frequency Bands*	*AMS®S ?*	*RF Channel Rate**	*Comments*
Inmarsat INM-3/4 Aero Low Gain Antenna (Aero-L) — Packet Mode Intermediate Gain Antenna (Aero-I & H+) — Packet & Circuit Modes High Gain Antenna (Aero-H) — Packet & Circuit Modes — High-Speed Data Service (ckt mode)	GSO	L band To A/C: 1.525 GHz – 1.559 GHz From A/C: 1.625 GHz – 1.660 GHz	Yes Yes Yes No	P = 600/1200 bps P = 8.4 kbps C = 8.4 kbps P = 10.5 kbps C = 21 kbps C = ~64 kbps	• "L" service necessary for system mgmt & signaling • Will not provide Air-Air links; only Air-Ground links possible
Inmarsat Commercial INM-3 Aero-M — Circuit Mode (data and/or voice) High Speed Data — Circuit Mode M4 Service — Circuit Mode (data and/or voice) Mobile Packet Data Service — Packet Mode	GSO	L band To A/C: 1.525 GHz – 1.559 GHz From A/C: 1.625 GHz – 1.660 GHz	No No No No	≈ 40 kbps ≈ 40 kbps ≈ 40 kbps	• Currently, no aero terminals (except "Aero-M") • INM-4 constellation in 2004; higher-gain spot beams [≈ 3-5 db advantage over "I"?] • These services do not operate through Aero GESs, thus do not meet "®" requirements
Inmarsat INM-4 (2005 and beyond) Previous-generation aero services + BGAN service M4 Service — Circuit Mode (data and/or voice) Mobile Packet Data Service — Packet Mode	GSO	L band To A/C: 1.525 GHz – 1.559 GHz From A/C: 1.625 GHz – 1.660 GHz	Yes No No ?	(same) ~64 kbps >64 kbps	• backward compatible • capabilities extrapolated from INM-3 and using Aero-I antenna

Provider	*Constellation*	*Frequency Bands*	*AMS®S ?*	*RF Channel Rate**	*Comments*
Iridium 1.Uses F/TDMA as access scheme 2.Can provide Air-Air link 3.Possesses a band of frequencies for AMS®S	LEO	To A/C: 1.610 GHz – 1.6265 GHz From A/C: 1.610 GHz – 1.6265 GHz	Yes	51 kbps	• GSM format for system protocols • Channel-ganging possible • Packet mode not yet implemented • Fair scalability, good continuity, high integrity • Voice-only aero-qualified avionics now available • High probability of circuit mode data within the next two years

*P = packet mode
C = circuit mode

B.2.3.1 SATCOM System Data

Table B-6. General Information

System	*Coverage*	*Orbit*	*Operational Satellites (less spares)*	*Aeronautical Intent*		*Operational Status*
				AMSS	*AMS(R)S*	
INMARSAT INM-3	Global beam: To ± 75-80° latitude Spot beam: Land masses (except N.Z.) and main oceanic air route	GSO	4	Yes	Yes	Operational (1 INM-3 spare and INM-2's as backup)
AeroMini-M	"					
INM-4	Major land masses					INM-4 planned for 2005; smaller/high-power spot beams]
IRIDIUM	100% of the Earth for a minimum of 99.5% of the time	LEO	66	old = Yes new = Yes	old = Yes new = ??	Operational globally

Table B-7. Performance Data

System & Operator	*System Availability*	*User Data Rate to-AC/from-AC (bps)*	*Integrity*	*Subsystem Interface Standards*	*Priority & Preemp-tion*	*Comments*
INMARSAT-3						
Aero-L (pkt mode)	now	10/35 bps	$10^{-4*}/10^{-5**}$		Yes	fully qualified aero
Aero-H/I	---	---	---	---	---	---
4.Pkt Mode	now	?/?	$10^{-4*}/10^{-5**}$		Yes	fully qualified aero
5.Ckt Mode	now	4.8 kbps	10^{-5}		Yes	"
Aero Mini-M	now	4.8 kbps	10^{-3}	RS-232	No	not AMS(R)S
6.M4	now		?		No	initially no aero
Aero HSD	now		?		No	not AMS(R)S
MPDS	2002 ?		?		No	initially no aero
Aero-M4	2002 ?		?		No	speculated
Aero-MPDS	2003 ?		?		No ?	speculated
IRIDIUM	now	3500 bps per time slot, 4 time slots per carrier, each direction.			system capable	Airsat 1, no P3

**from-aircraft direction, shared among all aircraft using same channel.*
***to-aircraft direction, shared among all aircraft using same channel.@for user message lengths ranging from 10 to ~400 octets, expressed as (to-aircraft/from-aircraft) directions*

Table B-8. System Coverage Information

System & Operator	*Oceanic*	*Continental*	*Polar*	*Minimum Elevation Angle*	*GESs Required*	*Capacity Per Satellite*	
						Total	*For Aero*
INMARSAT-3	Depends on Gateway Placements	Complete	No		4 (one per ocean region) (23 GESs currently installed)	1100 ckts Glob. 4300 ckts Spot	
IRIDIUM	100%	100%	Yes	8.2	min. of 1 (+ bkup) globally	1100 calls	all, by preemption

Table B-9. Status Assessment

System & Operator	*AMS(R)S Service Offered*	*License for AMS(R)S*		*AMS(R)S System*			*AMS(R)S Avionics*			*Comments*
		Filed	*Granted*	*Design*	*Development in Progress*	*Operation Available*	*Design*	*Development in Progress*	*Available*	
INMARSAT-3 (Aero L, I, H, H+)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
IRIDIUM	Yes	Yes	No*	Yes	Yes*	No	Yes	Yes**	No	* Accepted by FAA/ICAO due to S5.367. However, given FCC 2 GHz Order, AMS(R)S license is moot. "(R)" development stalled by BK March 2000

Table B-10. Miscellaneous Information

Parameter	***INMARSAT-3 (GSO)***	***IRIDIUM (LEO)***
Altitude (km)	36,000	780
Number of Satellites	4	66
Number of Spares	1	6 - 12
Operation Start Date	4/96	1998
BOL Mass (kg)	1,900	700
Power (watts, EOL)	6,000+	1,200
Access Method	FDMA/TDMA	FDMA/TDMA
Modulation	BPSK/QPSK with FDMA/SCPC, DAMA/TDMA	QPSK with FDMA/TDMA
Sat Antenna Size (m)	1.2	> 2
Number of Beams	6	48
Onboard Processing	No	Yes
Intersatellite Links	No	Yes
Capacity (circuits)	27,000	56,000
System Life (years)	13	5-7
System Cost ($Billion)		
Circuit Cost/Year		
User Terminal Cost (non-Aero)		
User Terminal Cost (Aero)		
Air-time Charge/Min		
Voice Digitizing Rate	4.8 & 9.6 Kbps	TBD
User Data Rates (circuit mode)	up to 9.6 kbps	2.4 kbps std; higher optional
Fax	Yes	Yes
Paging	Yes	Yes
Position Location	No	10 km (99% CEP)
Land Mobile Interface	PSTN type & GSM (in 1997)	GSM
Terrestrial Interface	PSTN & Private	PSTN & Private

Parameter	***INMARSAT-3 (GSO)***	***IRIDIUM (LEO)***
User Terminal to Satellite	1.6 GHz (L-band)	1.6 GHz (L-band)
Satellite to User Terminal	1.5 GHz (L-band)	1.6 GHz (L-band)
Gateway to Satellite	4 GHz (C-band)	30 GHz (Ka-band)
Satellite to Gateway	6 GHz (C-band)	20 GHz (Ka-band)
Gross Oceanic Coverage	100%	100 % Global
Gross Continental Coverage	100% with lower availability over the poles	100 % Global
Transmission Delay		270-390 msec
Aeronautical Terminals (AMSS)	Yes	Yes

B.2.4 Spectrum Regulations

B.2.4.1 Background

As aeronautical CNS systems that use the RF spectrum are involved in critical safety of life and property applications, the portions of the spectrum they use are subject to particular rules governing their protection from harmful interference. Generally, portions of the spectrum are set aside for exclusive allocation to the aeronautical services by national regulations as "government frequencies," and internationally by the International Telecommunications Union (ITU). For purposes of communications via ground-based facilities, such portions are designated as the Aeronautical Mobile (R) Service (AM(R)S)[9] where the "(R)" designates that the operational applications are primarily on civil aviation Routes. Aeronautical communications via satellite are designated as the Aeronautical Mobile-Satellite (R) Service (AMS(R)S), and are defined by ITU Articles S43 and S44.

Regarding ground-based facilities, distinctions have historically been made between communications and navigation services (the latter including also surveillance applications such as radar). For example, the portion of the aeronautical VHF band between roughly 108-118 MHz is allocated to the Aeronautical Radio Navigation Service (ARNS), and the portion roughly 110-137 MHz is allocated to AM(R)S. However, recent developments in data link technologies, and the applications enabled by them, have spawned the realization that the data links have no way of knowing what applications may be using them, such as communications and various forms of Automatic Dependent Surveillance (ADS). Consequently, the rigid classical distinctions are beginning to blur.

In satellite communications, such distinctions have become even more blurred. As a result of World Radio Conference 2000, ITU frequency allocations permit and protect AMS(R)S operation in certain portions of the spectrum allocated to the generic mobile satellite service (MSS), and permit MSS operations in spectrum previously allocated exclusively to AMS(R)S. Generally in the region below 2000 MHz, these portions are in the bands 1545-1555 MHz in the space-to-Earth (to-aircraft) direction and 1646.5-1656.5 MHz in the Earth-to-space (from-aircraft) direction, in accordance with ITU Radio Regulation (RR) S5.357A among others. AMS(R)S is also permitted in the band 1610-1626.5 MHz and 5000-5250 MHz in both directions in accordance with RR S5.367. Certain national regulations (e.g., US308) provide for additional frequencies, allocations and restrictions. MSS systems operating in such spectrum may provide AMS(R)S services subject to particular requirements according the safety services priority of access, preemption of non-aeronautical-safety services if necessary, and protection from harmful interference.[10]

[9] AMSS, absent the "(R)," is now considered a super-set of aeronautical services comprising both AMS(R)S (safety communications) and non-safety communications (e.g., related to passengers).

[10] In the U.S.A., the FCC explicitly affirmed its view that AMS(R)S can operate in any band allocated to MSS, by virtue of its general 2 GHz Order, 17 July 2001, and specifically reiterated this in the license order to Boeing, same date..

The early basis for this situation was the desire of the users to offset the embedded amortization of large satellite system costs in service charges, and the relatively high costs of avionics, by purely commercial utilization (e.g., cabin and passenger communications). ICAO endorsed the notion in its material[11] codifying the FANS concept of satellite-based global CNS-ATM systems:

- Guideline 1): Arrangements should enable all AMSS functions (Air Traffic Service [ATS], Aeronautical Operations Control [AOC], Aeronautical Administrative Communications [AAC] and Aeronautical Passenger Communications [APC])[12] to be provided through common avionics equipment in the aircraft
- Guideline 2): Arrangements should make all four identified satellite services (ATS, AOC, AAC and APC) available through any given satellite in any region of the world

The result was the encouragement of serving both safety and non-safety applications through common systems and equipment. The downside risk was to invite attention to the AMSS/AMS(R)S spectrum by the purely commercial mobile satellite interests, for whom the favorable propagation characteristics of the L-band were as attractive for general mobile satellite purposes as they were favorable to aviation. Further, aviation was not utilizing the considerable portions of spectrum reserved for it. Those potential consequences have now been realized in the aforementioned WRC actions, which went even further in defining a generic Mobile Satellite Service (MSS), erasing the previous distinctions between AMSS, Maritime Mobile-Satellite Service (MMSS) and Land Mobile-Satellite Service (LMSS). However, AMS(R)S still enjoys the special provisions for protection from harmful interference, and preemptive access, if necessary, to spectrum and system facilities. These provisions are unlikely to be removed.

B.2.4.2 Inmarsat Service

Inmarsat delivers global connectivity to aviation users though a constellation of geostationary satellites. The global (hemispherical) and spot beams radiated by the Inmarsat satellites support voice and data links for multiple simultaneous users all over the world between 82 degrees north and south latitude.

Communications traffic from the ground to the satellites and in the opposite direction passes through ground earth stations (GESs). These facilities are located around the world and act as the link between the Inmarsat system and public and private telecommunications networks on the ground all over the world.

In the aircraft, the Satellite Data Unit (SDU) forms its satellite avionics. The SDU serves as the critical piece of equipment used to communicate between various interfaces on the aircraft and

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11 Report of the 10th Air Navigation Conference, Appendix A to the Report on Agenda Item 4, Appendix A.

12 Air Traffic Services (ATS) and Aeronautical Operational Control (AOC) are the safety communications services designated as AMS(R)S. The non-safety services comprise Aeronautical Administrative Communications (AAC) and Aeronautical Passenger Communications (APC).

the ground. Interfaces on the aircraft can include telephones, fax machines, laptop PCs, in-flight entertainment systems, and crew/cabin management systems.

Inmarsat's primary satellite constellation consists of four Inmarsat I-3 spacecraft in geostationary orbit. Between them, the main hemispherical "global" beams of the satellites provide overlapping coverage of the whole surface of the Earth apart from the poles. The Inmarsat I-3 satellites are backed up by a fifth Inmarsat I-3 and four previous-generation Inmarsat I-2s, also in geostationary orbit. The Inmarsat I-3 communications payload can generate a global beam and a maximum of seven spot beams. The spot beams are used as required to make extra power and thus additional communications channels are made available in areas where demand from users is high. Spot beams cover the areas of operation of about 95 per cent of all commercial air traffic.

SATCOM Services offered by Inmarsat include:

- Swift64 - Based on Inmarsat's Global Area Network (GAN) technology, Swift64 offers Mobile ISDN and IP-based Mobile Packet Data Service (MPDS) connectivity at a basic rate of 64kbit/s to support high-quality voice, fax and data communications for air transport.
- Aero H - The original Inmarsat voice and data service, Aero H supports multi-channel voice, fax and data communications at up to 9.6kbit/s anywhere in the satellites' global (hemispherical) beams for air transport. Aero H+ is an evolution of Aero H. When an Aero H+ equipped aircraft is operating within a high-power spot beam from an Inmarsat I-3 satellite it can receive Aero H levels of service at lower cost. Outside the spot beams the terminal works with the global beam as if it were a standard Aero H system.
- Aero I - Using the spot beam power of the Inmarsat I-3 satellites, Aero I provides multi-channel voice, fax and data at up to 4.8kbit/s.
- Aero L - Low-speed (600 bit/s) real-time data, mainly for airline ATC, operational and administrative communications.
- Aero mini-M - Single-channel voice, fax and 2.4kbit/s data for small corporate aircraft and general aviation.
- Aero C - The aeronautical version of the Inmarsat C low-rate data system, Aero C allows non-safety-related text or data messages to be sent and received by general-aviation and military aircraft operating almost anywhere in the world. Aero C operates on a store-and-forward basis - messages are transmitted packet-by-packet, reassembled and delivered in non-real-time.

Inmarsat uses a combination of TDMA and FDMA as its media access technique. If voice services are being performed, FDMA is the technique employed, while TDMA is the media access technique when data is the services provided. Inmarsat uses BPSK/O-QPSK/A-QPSK/Q-PAM modulation techniques that vary with the type of service offered.

Traditional voice and data services offered under Inmarsat's 2/3 satellites met important requirements for air transport needs. Due to the growing demand from corporate mobile satellite users for high speed Internet access and multimedia connectivity, Inmarsat is introducing its fourth generation of satellites (I-4), based on 3G/UMTS technology, and will provide at least 10 times the communications capacity as today's Inmarsat network. Inmarsat I-4 will make use of the Broadband Inmarsat's Global Area Network (BGAN) technology. BGAN is also called SwiftBroadband in industry terminology.

B.2.4.3 Industry SATCOM Systems

Currently, industry SATCOM systems employ the legacy ARINC 741/761 systems, and provide services like Swift64, Aero H/H+/I/L/mini-M/C. The next generation ARINC 781 system which is expected to use the BGAN technology, proposes to have twice the number of voice channels, data channels (Aero-H+ functionality), and twice the number of integrated SwiftBroadband channels. The ARINC 781 system will provide aeronautical services in the L-band (Receiving Band: 1525-1559 MHz; Transmitting Band: 1626.5-1660.5 MHz). In addition to providing BGAN services, ARINC 781 will also provide Classic Aero H/I/H+ and Swift 64 services.

B.3 Navigation

These navigation technologies either are currently in use or planned for use in support of navigation functions within the NAS.

B.3.1 Global Positioning System (GPS)

The Global Navigation Satellite System (GNSS) of which the Global Positioning System (GPS) is a subsystem, is a world-wide position, velocity and time determination system that includes one or more satellite constellations, receivers, and system integrity monitoring, augmented as necessary to support the required navigation performance of the actual phase of operation. The GNSS includes the ground control and monitoring stations, satellites and avionics and currently consists of the United States Global Positioning System (GPS) and the Russian Federation Global Orbiting Navigation Satellite System (GLONASS). Specific characteristics of GPS include:

- Civil users worldwide use the SPS without charge or restrictions. Most receivers are capable of receiving and using the SPS signal.
- SPS Predictable Accuracy
- 100 meter horizontal accuracy
- 156 meter vertical accuracy
- 340 nanoseconds time accuracy
- The Space Vehicles (SV) transmit two microwave carrier signals. The L1 frequency (1575.42 MHz) carries the navigation message and the SPS code signals. The L2 frequency (1227.60 MHz) is used to measure the ionospheric delay by PPS equipped receivers.
- Three binary codes shift the L1 and/or L2 carrier phase.
- The C/A Code (Coarse Acquisition) modulates the L1 carrier phase. The C/A code is a repeating 1 MHz Pseudo Random Noise (PRN) Code. The C/A code that modulates the L1 carrier is the basis for the civil SPS.
- The P-Code (Precise) modulates both the L1 and L2 carrier phases. In the Anti-Spoofing (AS) mode of operation, the P-Code is encrypted into the Y-Code. The

encrypted Y-Code requires a classified AS Module for each receiver channel and is for use only by authorized users with cryptographic keys. The P (Y)-Code is the basis for the PPS.

- The Navigation Message also modulates the L1-C/A code signal. The Navigation Message is a 50 Hz signal consisting of data bits that describe the GPS satellite orbits, clock corrections, and other system parameters.

B.3.2 GPS Data Link

The GPS Navigation Message consists of time-tagged data bits marking the time of transmission of each subframe at the time they are transmitted by the SV. A data bit frame consists of 1500 bits divided into five 300-bit subframes. A data frame is transmitted every thirty seconds. Three six-second subframes contain orbital and clock data. SV Clock corrections are sent in subframe one and precise SV orbital data sets (ephemeris data parameters) for the transmitting SV are sent in subframes two and three. Subframes four and five are used to transmit different pages of system data. Data frames (1500 bits) are sent every thirty seconds. Each frame consists of five subframes. Data bit subframes (300 bits transmitted over six seconds) contain parity bits that allow for data checking and limited error correction.

B.3.3 VHF Omni-directional Range/Distance Measuring Equipment (VOR/DME)

VOR (VHF Omni-directional Range) is a type of radio navigation system for aircraft, while DME (Distance Measuring equipment) provides the pilot with the aircraft's distance from the ground station. Many VOR and DME systems co-exist in the same location.

VORs broadcast a VHF radio signal encoding both the identity of the station and the angle to it, telling the pilot in what direction he lies from the VOR station, referred to as the radial. Comparing two such measures on a chart allows for a fix. When the VOR stations also provide distance measurement, as is the case with many installations, it allows for a one-station fix.

VORs became the major radio navigation system in the 1960s, when they took over from the older radio beacon system. The older system retroactively became known as non-direction beacons, or NDBs. VOR's major advantage is that the radio signal provides more information, allowing pilots to follow a line in the sky more easily than with an NDB. A major network of “air highways”, known as airways, was set up linking the VORs and airports. On any particular part of the journey the airway would say to fly at a specific angle from a particular station, in which case the pilot simply tunes in the station on the radio, dials that angle into the indicator, and then keeps a pointer centered in a display.

VORs also provided considerably greater accuracy and reliability than NDBs due to a combination of factors in their construction. But these same factors also make VOR broadcasters and receivers rather expensive. In addition VORs have a limited range of about 160km, which means that an extensive network of stations needs to be used to provide reasonable coverage. The VOR network is a major cost in operating the current air navigation standards[13].

Each VOR operates on a radio frequency assigned to it between 108.0 MHz (Megahertz) and 117.95 MHz, which is in the VHF (very high frequency) range. The channel width is 50 kHz. VHF was selected because it travels only in straight lines, resisting bending due to atmospheric effects, thereby making angle measurements accurate. However this also means that the signals do not operate "over the horizon", VOR is line-of-sight only, limiting the operating radius to 160 km.

VOR systems use a phase relationship between two signals to encode direction. The main "carrier" signal is a simple AM tone broadcasting the identity of the station in Morse code. The second signal is sent on a 9960 Hz sideband, and is modulated with a 30 Hz signal. Both are sent from the highly directional antenna, rotating the signal 30 times a second. Note that the transmitter need not be physically rotating - most VOR transmitters use a phased array of antennae such that the signal is "rotated" electronically.

When the signal is received in the aircraft, the FM signal is decoded from the sideband and the frequency extracted. The two signals are then paired, resulting in a phase difference between the two signals. The phase difference between the two signals is the angle of the antenna at the instant the signal was sent, thereby encoding the direction to the station as the narrow beam washed over the receiver. The phase difference is then mixed with a constant phase produced locally. This has the effect of changing the angle. The result is then sent to an amplifier, the output of which drives the signal pointers on a compass card. By changing the locally produced phase, using a knob known as the OBS, the pilot can zero out the angle to a station. For instance, if the pilot wishes to fly at 90 degrees to a station, the OBS mixes in a -90 phase, thereby making the indicator needle read zero (centered) when the plane is flying at 90 degrees to the station.

Some VORs are low power for regional navigation and others are high power for high altitude long range navigation.

Many VORs have another navigation aid called DME at the same location. The combination may be called a VOR-DME or VORTAC, depending on the agency operating the DME. A VORTAC, for example, is a civilian VOR co-located with a military TACAN navigation system. Both VOR-DME and TACAN share the same DME system.

DME provides the pilot with the aircraft's distance from the ground station. By knowing both the distance and radial from the station, the aircraft's position can be plotted on an aeronautical chart from a single station.

Aircrafts use DME to determine their distance from a land-based transponder by sending two pulses with a random time interval between them. The transponder echoes the pulses. The DME

[13] VORs are quickly being ignored in favor the much more user-friendly GPS system, and it is generally thought that they will be turned off around 2010. Oddly the airways have become so important to air traffic control that aircraft are forced to follow them even when they are using GPS for navigation

receiver then searches for two pulses with the correct time interval between them and measures the delay between the pulse transmission and the pulse reception. Once the receiver is locked on, it has a narrower window in which to look for the echoes and can retain lock. A typical DME transponder can provide concurrent distance information to about 100 aircraft.

DME frequencies are paired to VOR frequencies. So generally a DME interrogator is designed to automatically tune to the corresponding frequency when the co-located VOR is selected. Airplane's DME instrument uses frequencies from 1025 to 1150 MHz. DME transponders transmit on 962 to 1150 MHz and receive on 962 to 1213 MHz. The channel width is 100 kHz.

One important thing to understand is that DME provides the physical distance from the aircraft to the DME transponder. This distance is often referred to as 'slant range' and depends trigonometrically upon both the altitude above the transponder and the ground distance from it.

B.3.4 Tactical Air Navigation (TACAN)

TACAN (Tactical Air Navigation) is a military navigation system. It works in the UHF band, between 960 and 1,215 MHz, and gives a pilot continuous information as to his range and bearing from a beacon.

The airborne equipment consists of an interrogating transmitter and a receiver which includes suitable demodulating circuits to enable the information contained in the beacon's response to be extracted.

The ground equipment[14] consists of a beacon provided with a rotating aerial system. In the absence of interrogating signals the beacon transmits a series of random pulses together with groups of marker or reference pulses which are locked to the aerial rotation. Bearing information (direction) can be obtained without interrogation since the beacon is continuously transmitting. In addition to transmitting a random series of pulses the beacon also periodically transmits a signal by which it identifies itself. To determine range, the airborne transmitter radiates a series of pairs of pulses. These are received at the beacon and, after a fixed delay, are re-transmitted in place of the particular random pulses that the beacon would have transmitted in the absence of interrogation. The time delay between the emission of any interrogating pulse and the receipt of the reply is measured, from which the range can be measured. To avoid mistakes arising from multiple interrogations the airborne transmitter emits its pairs of pulses at random intervals. The receiver only recognizes an exactly similar set of reply pulses all delayed by the same amount.

The FAA has been integrating the civilian VOR system with the military TACAN navigation system; the result is a VORTAC[15] end system.

[14] TACAN ground equipment consists of either a fixed or mobile transmitting unit while the airborne unit in conjunction with the ground unit reduces the transmitted signal to a visual presentation of both azimuth and distance information. TACAN is a pulse system and operates in the UHF band of frequencies. Its use requires TACAN airborne equipment and does not operate through conventional VOR equipment.

[15] Although the theoretical, or technical principles of operation of TACAN equipment are quite different from those of VOR/DME facilities, the end result, as far as the navigating pilot is concerned, is the same.

B.3.5 VHF Omni-directional Range/Tactical Air Navigation (VORTAC)

A VORTAC is a facility consisting of two components, VOR and TACAN, which provides three individual services: VOR azimuth, TACAN azimuth and TACAN distance (DME) at one site. Although consisting of more than one component, incorporating more than one operating frequency, and using more than one antenna system, a VORTAC is considered to be a unified navigational aid. Both components of a VORTAC are envisioned as operating simultaneously and providing the three services at all times. Transmitted signals of VOR and TACAN are each identified by three-letter code transmission and are interlocked so that pilots using VOR azimuth with TACAN distance can be assured that both signals being received are definitely from the same ground station. The frequency channels of the VOR and the TACAN at each VORTAC facility are “paired" in accordance with a national plan to simplify airborne operation.

B.3.6 Local Area Augmentation Signal (LAAS) and Special Category I (SCAT-I)

VHF transmissions of differential corrections to aid in the use of GPS for navigation in terminal and surface movement operations have been authorized by the FAA. Certification and operational procedures for their use are still in developmental processes. In all cases, the GPS correction information will be transmitted in the VHF navigation band (108 to 117.95 MHz band). As with other navigation signals used in aviation, no other airborne transmitters are permitted on the frequency and therefore, networked communications will not be directly associated with these services. The LAAS system specifically consists of the following three components: the GNSS subsystem, the airborne (GNSS based navigation and VHF receiving) subsystem and the ground based (VHF) transmitting subsystem. The three subsystems cooperatively participate in providing the necessary GNSS augmentation information to the airborne navigation system to assure the navigation integrity, availability and reliability of the position determination system.

The overall objective of the LAAS program is to define signals in space that can support Cat I through Cat IIIB landing approaches to suitably equipped aircraft. Presently MASPS and MOPS are in development for Cat I approach procedures. No operational LAAS stations exist. However, SCAT-I based ground stations could be the first adopters of this technology.

Table B-11. LAAS Communications Characteristics

#	Parameter	Value
1	Information Unit Size	64 bytes
2	Occurrence	1 per second (broadcast)
3	Required Response or Delay Time	N/A
4	Estimated bandwidth required	1,200 bps
5	Precedence	None
6	Integrity Required (Undetected Error Rate)	$< 10^{-6}$

#	Parameter	Value
7	Availability	99.99%
8	Encryption	No
9	Authentication	Yes

B.3.7 Wide Area Augmentation Signal (WAAS)

The Wide Area Augmentation Signal (GPS) is transmitted from geostationary satellites on the GPS L1 frequency (1575.42 MHz). The 500 symbols/second WAAS data stream is added modulo-2 to a 1023-bit PRN code, which is modulated on the L1 carrier frequency at a rate of 1.023 Mega-chips/sec. The operational goal of the WAAS is to augment the DoD GPS SPS so that GPS/WAAS is the only radio navigation equipment required onboard aircraft to meet aviation remote area and domestic enroute, terminal, non precision, and Category I precision approach phases of flight. No other data communication services are anticipated within the WAAS service and therefore, this capability is not of consideration for the SATS program. It will be expected that all SATS aircraft that apply GPS based navigation solutions will be appropriately equipped with WAAS certified receivers when phases of flight fall within the scope of WAAS.

B.4 Surveillance

Future surveillance programs will depend heavily upon non-radar based technologies to support the surveillance functions required to operate in free flight environments. Specifically, autonomous self-separation and conflict detection and resolution functions will need to be performed without the aid of ground based radar for support. Accordingly, a key success criteria will need the implementation of highly robust navigation-surveillance technologies that can function with a high degree of robustness and integrity. To support ATS requirements, the navigation-surveillance functions may also require independent means for verification of surveillance products.

B.4.1 Universal Access Transponder (UAT)

The Universal Access Transponder (UAT) was developed under an Independent Research and Development project at the MITRE Corporation. UAT was a “clean sheet” design optimized toward the support of broadcast applications, both air and ground based to support surveillance and situational awareness.

The FAA has chosen the Universal Access Transceiver (UAT) to be the primary medium for the ADS-B system for use in General Aviation aircraft. UAT was developed in the USA specifically for ADS-B operation.

The UAT data link system also supports TIS-B and FIS-B services. UAT users would have access to the additional ground based aeronautical data and would receive reports from proximate traffic (FIS-B and TIS-B).

A 1 MHz channel in the 900 MHz frequency range (978 MHz in the DME band is used) is dedicated for transmission of airborne ADS-B reports and for broadcast of ground based aeronautical information. It transmits and receives on the same frequency allowing full connectivity for ADS-B. All aircraft access the frequency autonomously without the need for centralized ground control. ADS-B aircraft transmit all the time without regard to whether they are being received by any ground station or aircraft.

The UAT channel rate is approximately 1 megabit/sec within a message. Access to the UAT medium is time-multiplexed within a 1-second frame between ground-based broadcast services and an ADS-B segment. Figure B-7 shows the format of a UAT frame

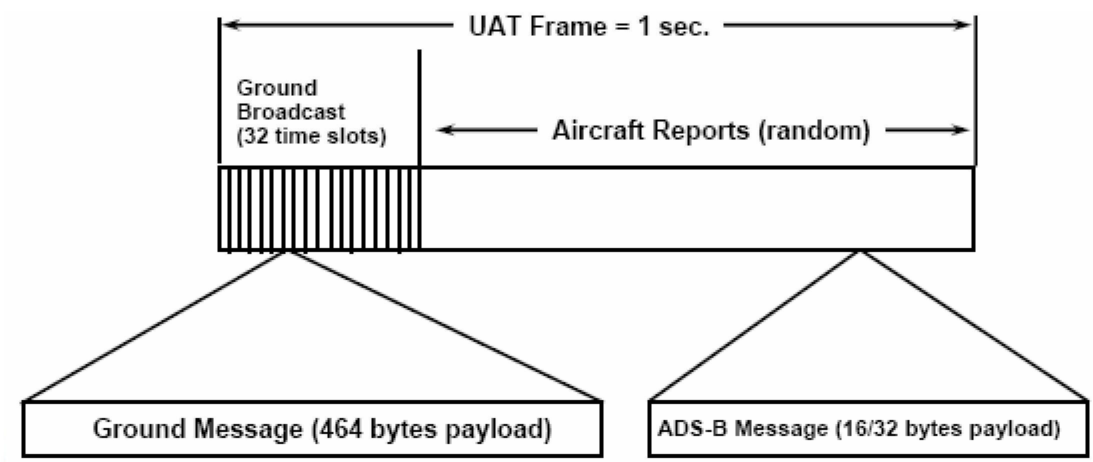

Figure B-7. UAT Frame Format

UAT supports two types of messages. The first is broadcast transmissions from aircraft, supporting aircraft-to-aircraft or aircraft-to-ground surveillance applications. These include position reports, velocity vector, intent and other relevant information about the aircraft, commonly referred to as ADS-B. Aircraft in the same airspace will be able to "see" each other through ADS-B.

The second type of transmission supported by UAT is the uplink broadcast of information from fixed ground stations. Potential services that can be supported with this uplink capability are:

- Weather broadcasts and aeronautical information (e.g., status information on airports, navaids, special-use airspace, and uncharted obstacles), referred to as FIS-B
- Traffic information broadcasts derived from ground-based radar systems referred to as TIS-B

Table B-12 presents critical characteristics of the UAT.

Table B-12. UAT

Characteristic	Description and Comment
Frequency band	980 MHz.
Bit Rate	1.041667 Megabit/sec
Modulation	Binary GFSK +/- 312 KHz.
Message length	246 bits short and 372 bits long
Address	25 (ICAO address + 1 to indicate valid ICAO or anonymous)
Airborne position	Yes; resolution to 2.3 meters
Transmitter Power	50-54 dBm high-end and 44-48 dBm low-end
Receiver MTL	< -93 dBm
Polarization	Vertical
Message Transmission rate	1 every second fixed rate of transmission random access on pre-defined start opportunities in the last 812 msec of each UTC second. (mobile ADS-B users only) Ground uplink transmissions up to 32-4196 bits messages can be supported during the first 188 msec of each UTC second.
Media Access Technique	Pre-defined ground broadcast segment in each second frame. Aircraft use random access in remainder of the second.
RF Channel	Single fixed, globally assigned

B.4.2 1090 MHz Extended Squitter

For cases in which an ADS-B aircraft is equipped with a Mode S transponder, a basic form of Traffic Information Service (TIS) has been developed using the Mode S data link. Position messages are transmitted to the aircraft from a Mode S ground station, using the data block in Mode S interrogations. In addition to the interrogation(s) used for surveillance, up to three additional interrogations may be transmitted to supply the TIS information when necessary. This application has completed operational test and evaluation by the FAA Technical Center, RTCA has issued MOPS (DO-239) for avionics implementation, definition of TIS is included in the ICAO Manual of Mode S Specific Services, and terminal Mode S radars having the TIS function are deployed nationwide.

An extension of Extended Squitter to provide a broadcast form of TIS (called TIS-B) has been proposed for purposes of the Safe Flight 21 link comparison. In this concept, TIS information would be broadcast from the ground, using formats similar to Extended Squitter, based on surveillance information obtained from an SSR. This service is intended to support the application of enhanced see-and-avoid in the cockpit. TIS-B information is not transmitted for aircraft currently transmitting ADS-B information. Position and velocity are included in a single TIS-B message.

The rate and power of TIS-B transmissions can be estimated for purposes of the current study, whereas these are important system parameters whose final values would be determined in a more comprehensive development program. The TIS-B transmission rate is determined by the objective of providing reliable reception once per SSR scan (4.7 seconds). In considering interference, the TIS-B transmissions for a given non-ADS-B aircraft under surveillance can be compared with the corresponding ADS-B transmissions that would be transmitted by that same aircraft if it were ADS-B equipped, namely 4.2 squitters per second. This rate equals 19 squitters/scan. That rate is more than sufficient for reliable reception. Therefore a serviceable estimate of the TIS-B transmission rate is 2 per second (which equals 9 per radar scan) for each aircraft represented by TIS-B. This rate is approximately half the normal per aircraft ADS-B transmission rate.

Similarly, Flight Information Services (FIS) can be transmitted to aircraft using Mode S signals. FIS information may include weather advisories, weather maps, ATIS, PIREPS, and SUA reports. A form of FIS included as a part of Mode S surveillance of aircraft from SSR ground stations has been developed by the FAA and tested extensively in recent years. In this service, the FIS information is transmitted to aircraft using Mode S interrogations in the 1030 MHz band. An extension of Extended Squitter to provide a broadcast form of FIS (called FIS-B) has been proposed for purposes of the Safe Flight 21 link comparison. In this concept, FIS information would be broadcast from the ground. Data rate analysis by the Link Evaluation Team has concluded that an effective amount of FIS-B information can be conveyed with a data rate of 100 bits/sec. This rate refers to the information delivered, not including any parity transmitted for integrity reasons, nor any repeated transmissions intended to increase reliability.

B.4.3 Traffic Alert and Collision Avoidance System (TCAS)

TCAS operates as a ground independent collision avoidance system. It uses the 1030 MHz and 1090 MHz frequencies to operate independently of all other surveillance systems. TCAS employs a low gain directional antenna on top of the aircraft along with an omnidirectional antenna on the bottom of the aircraft. TCAS is able to interrogate and track both Air Traffic Control Radar Beacon System (ATCRBS) and Mode S transponder equipped aircraft. Interrogation and tracking of ATCRBS transponder traffic is via a whisper shout technique. This consists of 84 modified Mode C interrogations spaced 1 msec apart, each preceded by a lower power suppression pulse followed by another suppression pulse.

Aircraft with Mode S transponders are interrogated and tracked by TCAS via discrete interrogation and reply. The aircraft are initially acquired by TCAS via unsolicited squitter reply transmissions that announce the transponder’s identity. Each TCAS equipped aircraft will thus produce additional activity on 1030 MHz (approximately 84 additional interrogations per second).

TCAS I provide pilots with Traffic Alerts and TCAS II provides TAs and Resolution Advisories. The RAs are coordinated using air-to-air Mode S data link communications. Both 1030 MHz and 1090 MHz are protected frequencies for surveillance applications. TCAS IV improves the performance of TCAS II and provides additional enhancements and vertical RAs. By use of an extended squitter (112 bits rather than 56 bits) additional position and velocity information is broadcast.

B.4.4 Automatic Dependent Surveillance (ADS-Contract Mode)

ADS services have been defined for use in en route and ocean air space. This service is often referred to as contract mode ADS (versus the prevailing standardization activities associated with ADS-B for broadcast mode operations). In this application, position velocity and other heading information is reported by the aircraft to a ground system under an addressed contract established between the aircraft and the ground. The contract mode establishment process sets-up the reporting rate (frequency of reports to be transmitted) and a time or termination end-point when the contract expires or is to be renewed. In this manner, ground monitoring of an aircraft in flight over space that is sparsely equipped can be supported. Delivery of ADS information relies upon three physical domains of the ATN: the avionics local network, the air-ground data link, and the ground network. The avionics portion of the ADS system will require a minimum configuration of one Automatic Dependent Surveillance Unit (ADSU), one Communications Management Unit (CMU), containing an ATN router and one or more data link devices. The data link may be accomplished by one or more communication paths (satellite, HF, or VHF) each requiring the appropriate avionics and corresponding ground subsystem(s) to provide the data transfer path. Typically, the best physical path would migrate among the three technologies using a policy based decision process. ADS messages are routed via the ATN between the ground system in contact with the aircraft and the ground facility responsible for control of the aircraft and monitoring the flight in progress.

Additionally, on-demand ADS reports can be solicited from ground monitoring functions. Aircraft initiated reports are unsolicited reports which are received by the ground system by an ATS Processor. The ground need not acknowledge these reports. Application and use of ADS under this mode, requires the ground system to establish a contract with the aircraft and initiate a monitoring process to determine the status of flights in progress. Data parameters provided in the ADS report include figure-of-merit (FOM) indicators to establish validity of the aircraft supplied information. ADS is not a candidate application for free flight or the SATS program since this function will be supported via ADS-B using one or more data link technologies that he FAA is currently evaluating.

B.4.5 Traffic Information Service (TIS)

Individual aircraft request the service and are provided with location and other information regarding nearby aircraft. RTCA SC-169 has developed a MOPS for discretely addressed TIS using Mode S data link. This approach requires the ground system to track and service each requesting aircraft individually and it added a significant data load in busy air space. Current approaches to defining ADS-B and TIS-B services using VHF or UHF frequencies will replace this service.

B.4.6 Automatic Dependent Surveillance – Broadcast (ADS-B)

ADS-B is a system for aircraft in flight or surface vehicles operating within the airport surface movement area that periodically transmits state vector information (horizontal and vertical position, horizontal and vertical velocity) and other information. ADS-B is automatic because no other external stimulus is required; it is dependent because it relies upon on-board navigation sources and on-board broadcast transmission systems to provide surveillance information to others. The aircraft or vehicle originating the broadcast may or may not have knowledge of which users are receiving the broadcast; any user, either aircraft or ground-based, within range of the broadcast may choose to receive and process the ADS-B surveillance information. ADS-B supports improved surface surveillance and enhanced safety such as conflict management.

The FAA under its Safe Flight 21 Program is evaluating multiple technologies to support ADS-B for application of free flight concepts in NAS flight operations. As an integral component of this program, ADS-B information is being applied to verify and support Traffic Information Services (Broadcast) TIS-B. Ground based TIS-B information will be uplinked to ADS-B equipped aircraft to permit the aircraft to obtain a "complete" situation awareness display in the flight deck and to assist in self-separation and conflict detection and avoidance applications.

RTCA SC 186 is charged with developing the MASPS for the suite of ADS-B and supporting technologies to be applied to free flight operations.

B.4.7 Traffic Information Service – Broadcast (TIS-B)

As currently being developed by the standards community, (RTCA SC-186) TIS-B is to provide operators of aircraft equipped with an ADS-B system the ability to receive state information on proximate traffic that are not ADS-B equipped, but that can be tracked by an alternative surveillance system. To accomplish this, the TIS-B will provide traffic information:

- With sufficient accuracy, integrity and availability to achieve the Required Surveillance Performance (RSP) for a given operational application.
- That is of sufficient quality that they may used by pilots of all classes of commercial, private and military aircraft.
- to minimize, to the extent possible, the data processing complexity of the avionics by:
  - Performing comparable processing in ground systems
  - Delivering traffic information in a manner consistent and compatible with ADS-B
- Independent of the radio or frequency spectrum used to deliver the content.
- To minimize the amount of processing and communication delay, such that the traffic information displayed in the cockpit sufficiently matches the pilot's visual scene.
- To pilots that is consistent with the information provided to controllers (i.e., the potential for misidentifying proximate traffic is minimized).
- To users with adequate information about the service for them to determine where the service is available, the extent of the service coverage and any changes in service performance.
- As a service that does not require user actions to activate, select or manage service connections.

B.4.8 Radar

Several different kinds of radar are in operation to support the surveillance requirements of the NAS. Specifically they include:

Air Route Surveillance Radar (ARSR) – used for en route, long-range surveillance to support ATC facilities in their role of monitoring aircraft and weather patterns outside terminal airspace. These are pulsed radar with a fan-beam antenna that perform a full 360-deg. azimuth scan. Maximum range of this radar is approximately 250 miles and they operate in the 1215 to 1400 MHz band.

Airport Surveillance Radar (ASR) – is the mainstay of air traffic control management around the major airports. The FAA operates this radar (also called terminal radar) at over 250 airports for management and control of aircraft in the terminal airspace. Each ASR uses two frequencies. In some cases their frequency pairs must be at least 60 MHz spaced. Several models of this radar exist, with each model providing improved reliability, and granularity of aircraft tracking. The current spectrum assigned for this radar is in the 3500 to 3700 MHz band.

Terminal Doppler Weather Radar (TDWR) – The TDWR system is used to detect microbursts, gust fronts, wind shifts and precipitation in the vicinity of airports. It provides alerts of hazardous weather conditions in the terminal area and gives an advance notice of changing wind conditions to permit timely changes of active runways. It is deployed near airports and is usually located within 15 kilometers of the center of the airport. TDWR operates in the 5600 to 5650 MHz band with a pulse width of 1.2 microseconds and a repetitive rate varying between 400 and 1000 Hz.

Airborne Weather Radar – Airborne radar are usually multi-purpose pulsed radar whose primary purpose is to support weather front detection and forward looking wind shear detection. They are often also used to support ground mapping and to support display of significant land contours. Most of this radar operates in the 5350 to 5470 MHz band (C band) and the 9300 to 9500 MHz (X-band).

Secondary Surveillance Radar (SSR) – SSR provides surveillance information necessary to complement primary surveillance radar from appropriately equipped aircraft. SSR requires an uplink interrogation, a reception and response by a cooperative airborne transponder, and reception of the transponder's downlink reply. The FAA uses SSR to detect and identify targets that might otherwise remain unidentified or lost in clutter of a primary radar system. All SSR systems use 1030 MHz for the uplink interrogation and 1090 MHz for receipt of the transponder reply.

Other supporting radar includes Air Traffic Control Radar Beacon System (ATCRBS) and the Monopulse ATCRBS.

B.4.9 Airport Surface Detection Equipment (ASDE)

The ASDE system provides ground radar surveillance of taxiing aircraft and airport surface vehicles at high-density airports. This service is necessary especially during low visibility and congestion periods. ASDE-2 (older systems) and ASDE-3 radar support the system. Up to 500 MHz frequency blocks are assigned to each ASDE-3 radar in the 15700 to 17700 MHz band. New versions of the ASDE equipment are being developed to operate in the 9000 to 9200 MHz band. As the SATS program is focused on non-towered airports, it is unlikely that ASDE technology will be directly applicable to the program, except in conditions when SATS aircraft participate in large hub airports.

B.4.10 Public Safety Land Mobile radio (LMR) Systems – P25

Project 25 (P25) is a standard developed for Public Safety Land Mobile Radio (LMR) systems to provide digital, narrowband radios with the best performance possible and to permit maximum interoperability. These standards are a joint effort of U.S. Federal, state, and local governments, with support from the U.S. Telecommunications Industry Association (TIA). State Government is represented by the National Association of State Telecommunications Directors (NASTD) and local government by the Association of Public-safety Communications Officials, International (APCO). The P25 standard exists in the public domain, allowing any manufacturer to produce a P25 compatible radio product.

Public Safety LMR systems operate in various bands from about 30 MHz to 900 MHz, with bandwidths currently 25-30 kHz; new regulations, however, require the bandwidths to be reduced to 12.5 kHz (and potentially to 6.25 kHz). Both digital and analog modulation schemes are currently utilized for Public Safety LMR communications. For these measurements, two types of modulation standards were used – Project 25 digital signals and traditional analog signals. The Project 25 radios used in these measurements have a 4-level frequency shift keyed (C4FM) modulation confined to 12.5-kHz bands. Two-bit symbols are represented by 4 different frequency shifts, each separated by 1.2 kHz. The analog radio configuration used for these measurements has a 12.5-kHz bandwidth and employs a frequency modulation (FM).

At a minimum, a P25 radio system must provide interoperability with two mandatory P25 Standard interface components:

- The Common Air Interface (CAI)
- The Improved Multi-Band Excitation (IMBE) vocoder

The CAI enables P25 radios to interoperate and communicate digitally across P25 networks and directly. This portion of the P25 standard suite was selected to meet the unique radio system needs of the public safety environment, coverage reliability, system design flexibility, and inter-vendor compatibility.

IMBE vocoder sets a uniform standard for converting speech into the digital bit stream. IMBE was selected as the coding scheme most successful at making male and female voices audible against background noises such as moving vehicles, sirens, gunshots, and traffic noise.

P25 compliant radios can communicate in analog mode with legacy radios and in either digital or analog mode with other P25 radios.

B.4.10.1 Three Phases of Development

There are three phases of P25 development.

- Phase I specifies the common air interface and vocoder requirements for 12.5 kHz bandwidth operation in both a conventional and trunked environment, along with several additional functions including encryption and over-the-air rekeying (OTAR). Phase I is now complete and many systems are being implemented using these technologies. The TIA standards for Phase I are described in the 102-series of technical documents available from Global Engineering Documents.
- Phase II will specify additional air interface specifications to provide 6.25 kHz equivalent bandwidth operation to allow better spectrum efficiency. In addition, Phase II work involves console interfacing between repeaters and other subsystems, and man-machine interfaces for console operators that would facilitate centralized training, equipment transition and personnel movement.
- Phase III activities also known as APCO Project 34 and TIA Project MESA) is addressing the operation and functionality of a new wireless digital wideband/broadband public safety radio standard that could be used to transmit and receive, voice, video and high-speed data in a ubiquitous, wide-area, multiple-agency network.

B.5 Aeronautical Telecommunications Network (ATN)

In the early 1980s, the international civil aviation community initiated a study to identify and assess new concepts and new technology in the field of air navigation, including satellite technology. The global communications, navigation, and surveillance/air traffic management (CNS/ATM) systems concept identified the use of data communications and satellite-based systems. The aeronautical telecommunication network (ATN) is an integral part of the CNS/ATM systems.

ATN comprises application entities and communication services that allow ground, air-to-ground, and avionics data subnetworks to interoperate. This is achieved by using common interfaces, services, and protocols based on international standards. ATN has been specified to provide data communications services to Air Traffic Service (ATS) provider organizations and Aircraft Operating agencies for the following types of communications traffic:

- Air Traffic Services Communication (ATSC).
- Aeronautical Operational Control (AOC).
- Aeronautical Administrative Communication (AAC).
- Aeronautical Passenger Communication (APC).

B.5.1 ATN Concept

ATN offers a reliable, robust, and high-integrity communication service between two computer systems (End Systems), either at a fixed location such as an ATS unit, or mobile such as an avionics end system. At the same time, ATN takes into account requirements (e.g., transition paths and end-to-end delay) expressed by supported applications. ATN is distinguished from other data communication systems because it:

- Is specifically and exclusively intended to provide data communication services for the aeronautical community, including ATS providers/users and the aeronautical industry.
- Provides communication services between ground and airborne systems as well as between multiple ground systems, whereby various mechanisms within the communication system (e.g., route selection) are transparent to the user.
- Provides a communication service that has been designed to meet the security and safety requirements of the application services.
- Accommodates various classes of service and message priorities required by various ATN applications.
- Uses and integrates various aeronautical, commercial, and public data networks into a global aeronautical communication infrastructure.

B.5.2 ATN Infrastructure

ATN supports communication between: airline and ATS systems; airline and aircraft systems; ATS and aircraft systems; (ground) ATS systems; and airline systems. The main infrastructure components of the ATN are the subnetworks, ATN routers (intermediate systems or IS) and the end systems (ES). The subnetwork is part of the communication network, but it is not part of the ATN. It is defined as an independent communication network based on a particular communication technology (i.e., X.25 Packet-Switched Network) that is used as the physical means of transferring information between ATN systems.

A variety of ground-ground as well as air-ground subnetworks provide the possibility of multiple data paths between end systems. ATN routers are responsible for connecting various types of subnetworks together. They route data packets across these subnetworks based on the requested class of service and on the current availability of the network infrastructure (i.e., suitable routes to the destination system). ATN end systems host the application services as well as the upper layer protocol stack in order to communicate with peer end systems.

Figure B-8 shows the constituent elements of both ATN end system and intermediate system according to the OSI 7-layer reference model, and presents the end-to-end relationship over these layers.

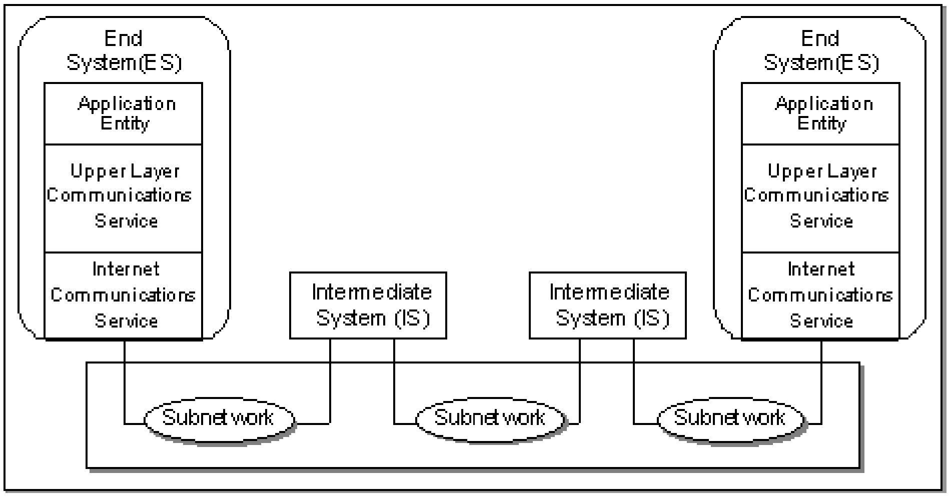

Figure B-8. ATN Network Components

B.5.3 Application Layer

When application processes (APs) in different end systems need to cooperate in order to perform information processing for a particular user application, they include and make use of communication capabilities that are conceptualized as application entities (AEs). An AP may make use of communication capabilities through one or more AEs, but an AE can belong to only one AP.

B.5.4 Upper Layer Communications Services (ULCS)

OSI presentation and session layers are used to support ATN upper layer communications services. For air-ground communications the ATN presentation layer uses the connection-oriented presentation protocol (COPP) and the session layer uses the connection-oriented session protocol (COSP). Amendments to these protocols specify efficient presentation and session protocols. The amendments specify protocol variants that are highly efficient in terms of the protocol overheads required, but offer minimal functionality.

ATN upper layers use the Short Connect and Null Encoding protocol mechanisms to achieve a session protocol with minimal overheads. It is expected that the short-connect protocol option will be used in conjunction with the transport connection set-up to achieve interworking with current implementations. For the case in which the responder also implements this protocol option, an improvement in round-trip efficiency is obtained by setting up the upper layer connections concurrently with the transport connection.

B.5.5 Names and Addresses

The ATN naming and addressing scheme is based on the open systems interconnection (OSI) which supports the principles of unique and unambiguous identification of information objects and global address standardization. The OSI Basic Reference Model distinguishes the concepts of name and address. In brief, a name is an identifier that is expressed in some language and is used to identify an object while an address is used to locate an object. A name stays with an object as long as it exists, while the address of the object may change during its lifetime.

Names typically have meaning and are thus generally expressed in a mnemonic format. Correspondingly, the significance of addresses typically increases when descending in the communications stack. Addresses are generally expressed in a coded or numeric format.

The general philosophy behind the assignment of ATN network addresses is that the higher order address parts are performed by entities with a global scope (i.e., international organizations such as ISO, ICAO, and IATA). Further down in the hierarchical address structure the responsibility for address assignment and administration is delegated to entities with a more restricted scope.

Figure B-9 illustrates this distributed responsibility for address allocation using the example of an ATN transport service access point (TSAP) address. This type of address is composed of 10 consecutive address fields comprising a total length of 21 or 22 bytes (depending on the length of the TSEL field that may be either one or two octets).

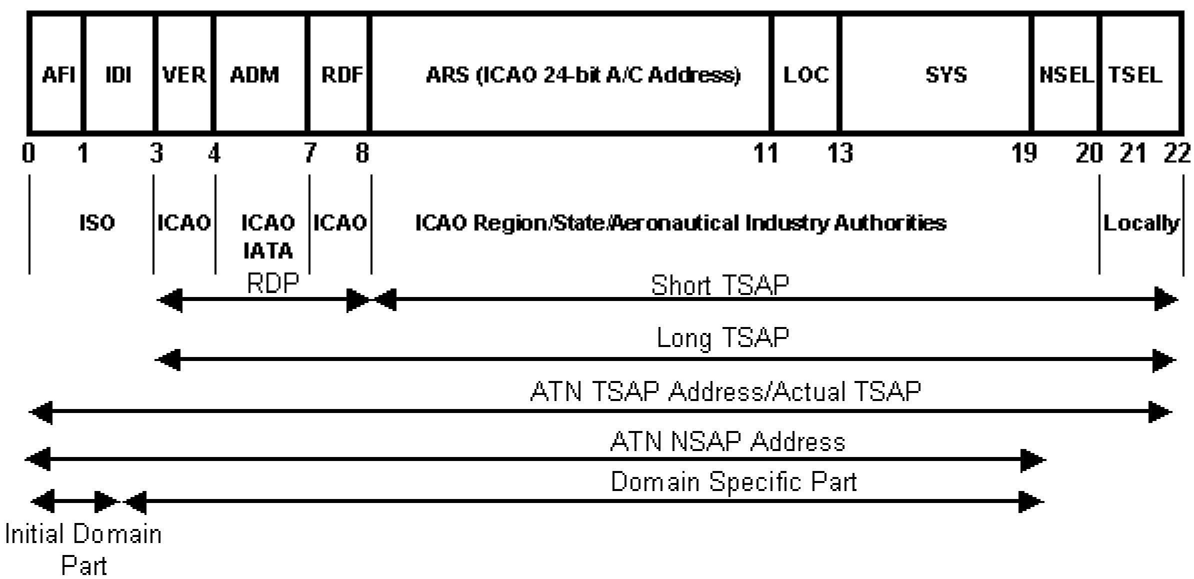

Figure B-9. ATN Transport Service Access Point (TSAP) Address

According to the ATN addressing plan, address values within the first two fields (AFI and IDI) are assigned by ISO. ICAO and IATA or ICAO assigns the next three fields (VER, ADM (administration) and RDF) exclusively. Fields six to nine (ARS, LOC, SYS, and NSEL) are assigned by ICAO Regional authorities, State authorities, and aeronautical organizations.

Administration and address value assignment for the last field (TSEL) of an ATN TSAP address is done locally. It should be noted that, due to this hierarchical structure, several registration authorities exist for an ATN address. Each registration authority is responsible for the allocation and registration of values (address fields) within its address space. The address registration function for the higher order fields of ATN address have already been partially performed in parallel with the development of the ATN SARPs. As a result, the values of the address prefix up to and including the RDF field (bytes 1 through 8) of the ATN addresses for ATSC systems are registered with ISO and ICAO.

B.5.6 Internet Communication Services (ICS)

Internet communications services consist of the services provided by the transport and network layers of the ATN protocol architecture. ATN is a data communications internetwork architecture that:

- Provides a common communications service for all air traffic services communications (ATSC) and aeronautical industry service communication (AINSC) applications that require either ground/ground or air-ground data communications services.
- Integrates and uses existing communications networks and infrastructure wherever possible.
- Provides a communications service which meets the security and safety requirements of ATSC and AINSC applications, including the reliable and timely delivery of user data to its intended destination.
- Accommodates the different grades of service required by each ATSC and AINSC application, and the organizational policies for interconnection and routing specified by each participating organization.

While these capabilities might, at first sight, appear ambitious, the reality is that for the ATN users, the internetwork will be straightforward and simple to use. This is because ATN architecture deliberately places the responsibility for routing and maintaining an internetwork's operational status on the “routers” and therefore enables the End System to have only a minimal networking capability.

B.5.7 ATN Transport Layer

ATN transport layer service provides transparent transfer of data between transport service users. All protocols defined in the transport layer have an ‘End-to-End’ significance, where the ‘Ends’ are defined as co-operating transport entities on two ATN host computers. The transport protocol operates only between end systems. Within ATN, transport layer entities communicate over the ATN using the network service provided by ATN network layer entities.

There are two modes of the transport service - Connectionless mode Transport Service (CLTS) and Connection-mode Transport Service (COTS). The connectionless mode service allows two transport users to exchange individual datagrams, without flow control or the need to have previously established a connection, but with no guarantee of delivery. The connection-mode service allows two transport service users to negotiate a communications channel with a set of common characteristics, including reliable delivery of data units and guaranteed (very high probability) order of delivery.

The two OSI protocols that provide the two modes of the transport service have separate specifications, and operate independently. Based on the higher level protocols operating within a given ATN host computer, one or both of the transport protocols may be implemented. Neither transport protocol is concerned with routing and relaying of data between End Systems, which is the responsibility of the network layer. The protocol in support of the CLTS is specified in ISO/IEC 8602, and the protocol in support of the COTS is specified to be ISO/IEC 8073 Class 4.

B.5.8 ATN Network Layer

The OSI network layer service, like the OSI transport service is specified to provide both a connection mode and a connectionless mode service. However, in ATN the network layer service is restricted to the connectionless mode only. This is because, unlike the transport layer, the same network protocols must be implemented in every system in the internetwork if interoperability is to be guaranteed. In the case of the transport layer, the mode of the service required depends on the requirements of the users. The End Systems that implement the same applications must also implement the same transport layer protocols. However, the internetwork itself must relay the data of all users, regardless of the mode of the transport service used. In order to provide universal connectivity, a consistent set of protocols must be implemented across the internetwork. Even if universal connectivity was ruled out, in practice, most Intermediate Systems (ISs or routers) would still have to support all modes implemented by End Systems (Ess or hosts) because of the tendency for data pathways to cross each other regardless of the network service mode supported by each such data pathway.

It is thus cost effective to support only one mode of the network service. Implementation costs are reduced, and the complexity of validation is also reduced. Furthermore, mobile routing is not yet believed to be practicable when using the connection mode network service. The network layer service is independent of the transport layer service and may be used by ISO/IEC 8602 to provide the CLTS and by ISO/IEC 8073 (class 4 procedures only) to provide the COTS.
The OSI network layer comprises three sub-layers or roles:

- Subnetwork Independent Convergence Role, which is responsible for providing a consistent network layer service regardless of the underlying subnetwork.
- Subnetwork Dependent Convergence Role, which decouples the functions of the subnetwork independent convergence role from the characteristics of different subnetworks.
- Subnetwork Access Role, which contains those aspects of the network layer specific to each subnetwork.

B.6 TCP/IP based Architecture

The concept behind open systems networking is to provide an environment where multi-vendor, interoperable hardware and software systems based on internationally recognized and publicly available documentation can be acquired off the shelf to build information infrastructure. Open systems networking today is about OSI and TCP/IP. The aeronautical community defined the ATN architecture based on the ISO standards. In the mean time TCP/IP has evolved into an open systems networking alternative. In this section, we provide an overview of the five layer TCP/IP architecture and suggest the all IP model for the future.

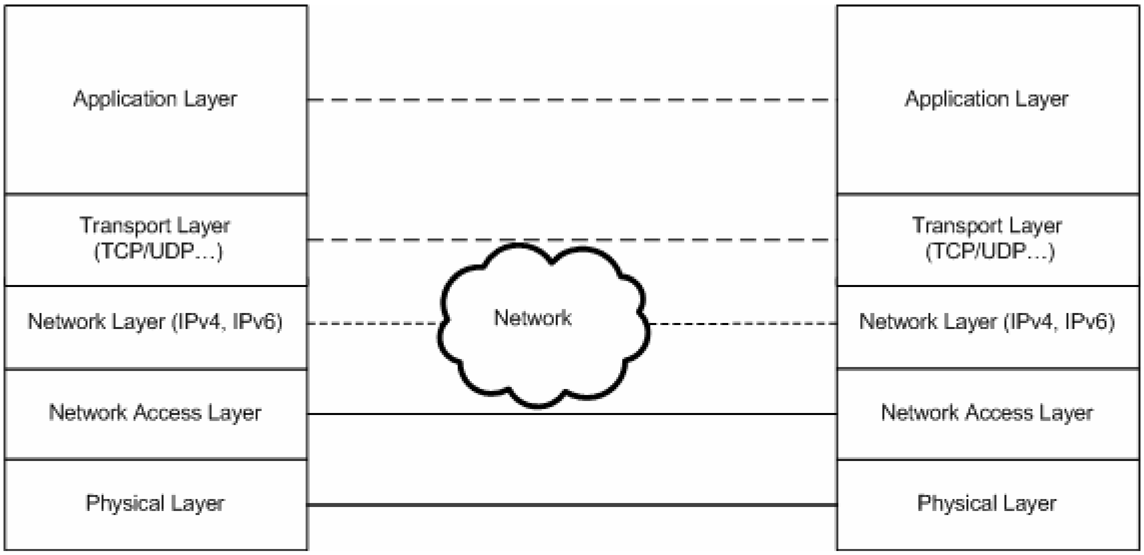

Figure B-10. TCP/IP End-to-end Layered Architecture

The TCP/IP architecture consists of a five layer protocol stack as shown in Figure B-10. The seven layer OSI model is condensed to five layer architecture with some layers in the architecture performing functions of multiple layers of the OSI stack.

B.6.1 Application Layer

The application layer is the uppermost layer of the TCP/IP suite. It encompasses layers 5, 6, and 7 of the OSI protocol stack. It is thus responsible for defining applications that run over the transport layer protocols, their representation in the correct format and session management for running these applications over the network. There are several application protocols like HTTP, FTP, Telnet, and SMTP that are part of the application layer. Also, management protocols like SNMP, DNS, DHCP are defined at the application layer in the TCP/IP suite. For running aeronautical applications over TCP/IP, these applications would have to be eventually ported appropriately to interface with the lower layers of the stack. The ARINC document [A664] serves as a good reference point for inter-operability of ATN applications over IP. Eventually, the idea would be to move to all-IP architecture with all the existing applications ported to an IP platform.

B.6.2 Transport Layer

The TCP/IP transport layer is concerned with establishment and maintenance of end-to-end communication between networked systems. It is also concerned with identification of specific source and destination applications to send and receive data to/from. The end-to-end data delivery may be reliable or unreliable. In case of reliable data communication, the transport layer is concerned with maintaining information about the transfer of data. If any packets are lost en route, the transport layer is responsible for retransmissions and flow control to some extent. Transmission Control Protocol (TCP) is the reliable transport protocol of the IP suite. User Datagram Protocol (UDP) is an example of a transport protocol which is unreliable. Once an end-to-end communication path is established, UDP is not concerned with assuring data delivery. There is no acknowledgement of lost data frames or sequencing and flow control of data. .In ATN, TP4 provides a reliable data path for the upper layers as part of a connection oriented service. The Connection Less Transport Protocol (CLTP) provides simple datagram delivery as part of a connectionless service.

The transport service provided by TP4 and TCP are functionally equivalent. In addition, by examining the process of establishing a transport connection, providing reliable data transfer through retransmission on time out mechanisms and connection termination of each protocol shows they are operationally similar as well. Numerous studies have concluded that TCP and TP4 are functionally equivalent and provide essentially similar services.

B.6.3 Network Layer

The network layer in TCP/IP is called the Internet layer and is concerned primarily with logical addressing of individual devices and routing between these entities. It also performs other typical layer three functions like data manipulation, delivery and classification. This layer is implemented in TCP/IP by the Internet protocol (IP) which is at the heart of the whole suite. Support protocols like ICMP and routing protocols like BGP, RIP, and IGRP are also a part of this layer. The most widely used version of IP is IPv4 which uses 32 bits for the addressing of devices. The latest version of IP is IPv6. IPv6 was developed to address the exhaustion of 32-bit addresses caused by the pervasiveness of network devices. IPv6 has a 128-bit addressing scheme and contains fields for incorporating security, class-based QoS support and other features.

At the network layer, ISO supports the Connectionless Network Protocol (CLNP). The CLNP and IP are functionally identical and both are best effort delivery network protocols. The major difference between the two is that CLNP accommodates variable length addresses, whereas IPv4 supports fixed 32-bit addresses, IPv6 supports 128-bit addresses.

The Internet Control Message Protocol (ICMP) provides elaborate mechanisms for reporting errors in IP datagram processing at hosts and gateways. Equivalent functions are provided for CLNP using a reason for discard option conveyed in the CLNP error report. Both CLNP and IP have multiple options. The sets of options defined for the two protocols are virtually identical, but the processing is slightly different. ICMP defines messages other than error reports. The source quench message serves as a coarse congestion notification mechanism, providing routers with a means to tell hosts to reduce the rate at which they are sending IP packets. The same function is accomplished in OSI using a CLNP error report with the reason for discard field set to the value that specifies congestion experienced. Since the proposed ATN architecture (currently under test) has CLNP as a network protocol, the functional equivalence makes IP a good candidate for the future all-IP based aeronautical network architecture. Migrating to IPv6, with its larger address space, is of increasing importance. IPv6 may well be the next generation aviation network layer protocol.

B.6.4 Network Interface Layer

As the name suggests, this layer represents the interface between the upper layer protocols (that form the key elements of TCP/IP protocol suite) and the local network. The network interface and physical layers are not universally considered a legitimate part of the TCP/IP suite. This is largely due to the protocols at these lower layers not being defined in the suite and the upper layers. They are therefore independent of the sub-network implementation. None of the core protocols of the IP suite run at this layer. Ethernet, Token ring, FDDI, X.25, HDLC among others are some of the protocols that run at the network interface layer. Sometimes the physical layer specification is also included in some of these protocols abstracting the functionality of two protocol layers; network interface and physical specifications into a single network interface layer. This layer is sometimes called the link layer and has its equivalent in the data link layer of the OSI model.

On many TCP/IP networks, there is no TCP/IP protocol running at all on this layer, because it is simply not needed. For example, if you run TCP/IP over an Ethernet, then Ethernet handles layer two (and layer one) functions. However, the TCP/IP standards do define protocols for TCP/IP networks that do not have their own layer two implementation. These protocols; the Serial Line Interface Protocol (SLIP) and the Point-to-Point Protocol (PPP), serve to fill the gap between the network layer and the physical layer. They are commonly used to facilitate TCP/IP over direct serial line connections (such as dial-up telephone networking) and other technologies that operate directly at the physical layer.

For aeronautical networks, the sub-network layers can be implemented using VDL, UAT, SATCOM, HF modes among others. In fact, the ATN architecture is independent of the sub-network layers and only specifies the upper layers of the stack. The future IP based architecture for aeronautical networks can also be analogously independent of these network interface layer and physical layer functionality.