The SANDRA Communications Concept – Integration of Radios

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Abstract. The Single European Sky Air Traffic Management (ATM) research programme SESAR has identified continued growth in demand for aircraft communications as air traffic increases and communications become more network centric. Alongside existing systems such as VHF Data Link Mode 2, new systems such as the L-band Digital Aeronautical Communication System (LDACS) and the Aeronautical Mobile Airport Communications System (AeroMACS) are being proposed. This growth is likely to increase the size, weight and cost of avionics radio communication equipment, so there is a need to examine new radio architectures which will help limit these increases. SANDRA is a European Commission programme which aims to design and demonstrate an integrated communications system using software defined radio techniques. The concepts behind the integrated communications system are described, including improved modularity using high-speed digital links, security, redundancy and certification. The specific requirements of the SANDRA programme and details of the proof-of-concept demonstrator are outlined.

Keywords: integrated modular radio, integrated communications system, aeronautical communications system, software defined radio, avionics.

1 Introduction

Over the years, systems for aeronautical communications have grown and evolved in order to meet increasing demands and support new technologies. Increasing demand has arisen from the continued growth in air traffic and the need to exchange increasing amounts of data. New technologies have included the transition from analogue to digital systems and the more recent preference for Internet Protocol (IP) - centric services.

These trends are set to continue for the foreseeable future. Air traffic in Europe is projected to nearly double by 2025, increasing from 9 million flights per year in 2005 to 17 million in 2025 [1]. In Europe, new developments are being coordinated through the Single European Sky ATM (Air Traffic Management) Research Joint Undertaking

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(SESAR JU) programme, whose founding members are the European Commission and EUROCONTROL [2].

Typical application areas for aeronautical communications include Air Traffic Management (ATM), Aircraft Operational Control (AOC), Airline Administrative Communication (AAC) and Airline Passenger Communications (APC). In order to support growth in these areas, additional radio systems have been proposed, including:

- EUROCONTROL L-band Digital Aeronautical Communication System (LDACS) to augment the VHF systems
- European Space Agency Iris Programme for Air Traffic Management (ATM)
- Aeronautical Mobile Airport Communications System (AeroMACS) [3], based on Worldwide Interoperability for Microwave Access (WiMAX)
- High-bandwidth satellite communications systems based on Digital Video Broadcasting (DVB) standards.

However, supporting these new systems represents a considerable extra burden of size, weight, complexity and cost in aircraft avionics equipment, should the new radio systems be implemented in stand-alone equipment as has been traditionally the case. Moreover, although it has been suggested that the new systems will eventually replace the legacy communications systems, the likelihood is that there will be a lengthy period where aircraft will need to be fitted with all of the systems for global interoperability. This is the forecast expressed by SESAR, and the additional airborne equipment required during this transition phase severely threatens the realisation of the future communications vision.

A different approach aiming at a broader level of integration is therefore needed in order to achieve the required increase of capacity, safety, security and efficiency of air transportation operations while at the same time keeping the complexity and cost of on-board networks and equipment at a sustainable level.

In October 2009, the European Commission (EC) launched a Seventh Framework Programme called SANDRA [4] to examine "Seamless Aeronautical Networking through integration of Data links, Radios, and Antennas". SANDRA aims to design, specify and develop an integrated aircraft radio communication architecture to improve efficiency and cost-effectiveness by ensuring a high degree of flexibility, scalability, modularity and reconfigurability. The programme will examine a number of integration possibilities, including:

- the integration of communication service provision at the network layer using the Internet Protocol (IP) as a unification technology
- the integration of radios which typically cover the realisation of the physical layers, data link layers and network layers of specific radio communications waveforms
- the integration of an L-Band antenna with a Ku-Band antenna.

SANDRA aims to provide a truly integrated modular approach for a global aeronautical network and communication architecture. The overall programme is designed to lead to performance evaluation of the system in a laboratory environment, followed by flight trials.

A number of concepts relating to the integration of radio systems are described, covering issues such as system boundaries, separation of processing from transceivers, security, segregation, redundancy and certification. The SANDRA functional architecture is briefly described, splitting it into the Integrated Router (IR) and the Integrated Modular Radio (IMR). Special attention is then paid to the SANDRA Proof-of-Concept IMR, looking at some of the design choices that are being made and highlighting how the programme will exercise IMR concepts.

2 Integrated Communication System Concepts

2.1 System Boundaries

The system boundary for an integrated communications system includes all avionics radio sub-systems and is illustrated in Figure 1. Items such as Subscriber Identity Module (SIM) cards, which are required for certain waveforms, are considered to be part of the system.

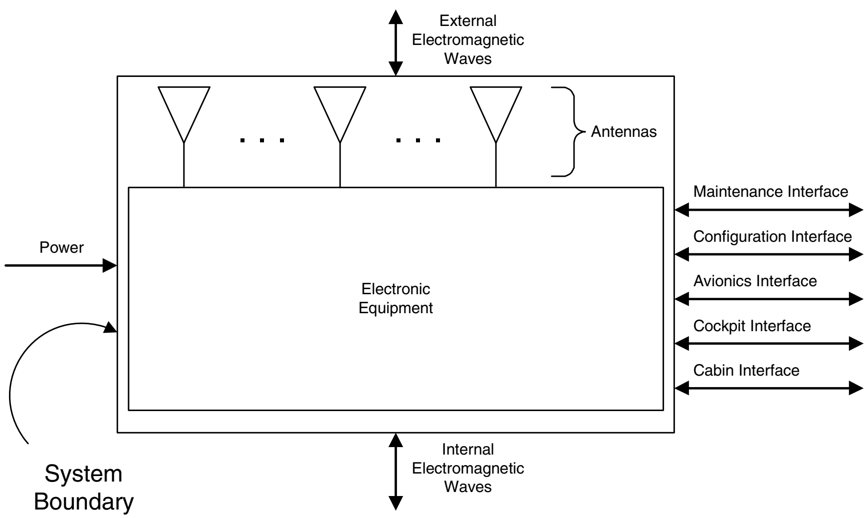

Fig. 1. System Boundary for Integrated Communications System

The boundary for the maximum system covers the following interfaces:

- *Maintenance interface* – this allows the system to be installed and maintained, and includes the ability to upgrade software and firmware
- *Configuration interface* – this allows the system to be configured, for example, setting certain internal IP addresses
- *Avionics interface* – this provides access to avionic systems outside the IMR, for example, to obtain or provide navigation information
- *Cockpit interface* – this provides voice and data services to the cockpit

- *Cabin interface* – this provides voice and data services to the cabin, for example, through the In Flight Entertainment (IFE) system
- *Electromagnetic wave interfaces for radio services* - the Radio Frequency (RF) electromagnetic wave interfaces at the antennas. The actual antennas are within the system boundary
- *Power input* - this provides power to the system.

2.2 Candidate Waveform Examples

A number of candidate example waveforms are listed in Table 1. This provides an illustration of the range of different waveforms that may need to be supported, but is not a comprehensive list. The tables include the currently anticipated Design Assurance Level for each system, but this may change in the future.

Table 1. Candidate Waveform Examples

System	Tx/Rx	Frequency Range (MHz)		Modes	Expected Design Assurance Level
HF	Tx/Rx	2.8	24	Analogue Voice Data (HFDL ACARS)	D
VHF	Tx/Rx	118	137	Analogue Voice Data (VDL Mode 2) Data (VDL Mode 4)	C
Aircell CDMA	Rx Tx	849 894	851 896		E
L-DACS	Tx/Rx	960	1215		C
Inmarsat	Rx Tx	1530 1626.5	1559 1660.5	Aero C Aero H/H+ Aero I Aero L Mini M Aero	D
				Swift64 SwiftBroadband	E
Iris	Rx Tx	1545 1646.5	1555 1656.5		C
Iridium	Tx/Rx	1616	1626.5		D/C
Iridium NEXT	Tx/Rx	1616	1626.5		D/C
AeroMACS	Tx/Rx	5091	5150		C
DVB-S2	Rx	10700	12750		E
	Tx	14000	14500		

2.3 Separation of Processing from Transceivers

Key to the integrated communications system approach is the partitioning of the radio functionality in order to identify common functionality which can be combined or hosted more efficiently. With this in mind, radio functionality may be split into the following major areas:

- *Front-end Functionality* – This covers antennas and other items that may need to be located close to the antennas, such as antenna matching units, diplexers, low noise amplifiers and high power amplifiers.
- *Transceiver Functionality* – This broadly covers the analogue aspects of radio technology, typically operating in the Intermediate Frequency (IF) and Radio Frequency (RF) domains. It usually includes amplifiers, mixers and filters to provide up and down conversions between an IF representation of and an RF representation of signals. It also covers the conversion between analogue and digital representation of signals.
- *Processing Functionality* – This broadly covers the digital aspects of radio technology, where processing is typically carried out in Field Programmable Gate Arrays (FPGAs) and processors. The later have traditionally been split into Digital Signal Processors (DSPs) and General Purpose Processors (GPPs), but this distinction is less important today since some processors can carry out both digital signal processing and general purpose processing efficiently.

An example partitioning of radio functionality is illustrated in Fig. 2. There is some flexibility in the location of certain functions. For example digital up/down conversion

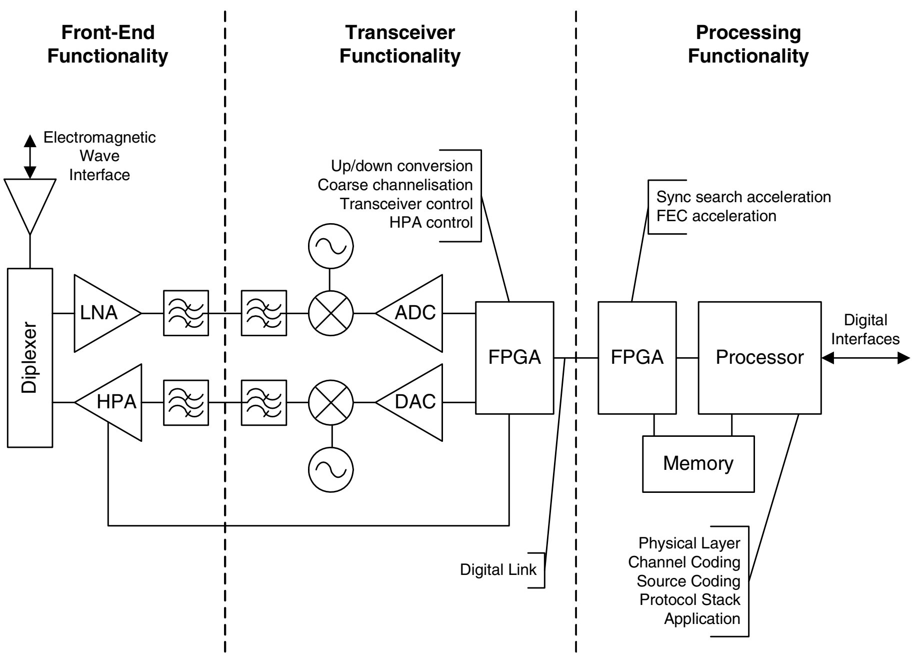

Fig. 2. Example Partitioning of Radio Functionality

and coarse channelisation may be viewed as part of transceiver functionality or processing functionality. Alternatively, it may be split between the two.

Avionics radio equipment has traditionally been based on a federated architecture where a dedicated radio is provided for each type of radio system (e.g. VHF). The above functional partitioning illustrates an opportunity for an integrated communications system where the processing capability is common across different radio systems and can either be reused or shared. This approach is similar to the Integrated Modular Avionics (IMA) [5] approach which moved the provision of other types of avionics equipment from a federated architecture to an integrated architecture. In fact, the integration of the communications system within the IMA is also being examined within the SANDRA programme.

2.4 Digital Serial Links

The partitioning of radio functionality described above supports an architecture where a common baseband processing solution is used in combination with transceiver functionality that is designed for different systems or area of the spectrum. This gives the potential for cost saving by maximising reuse of the design, isolating the transceiver functionality if required and physically separating the location of transceiver functionality and processing functionality. It also provides architectural flexibility since in some systems, it is desirable for the transceiver functionality to be located close to the antenna to reduce cable losses.

Such an architecture is enabled by modern high-speed digital links which can be placed between the processing units and transceiver units. Recent technology trends have moved from multi-drop parallel buses to point-to-point serial links, examples being Serial RapidIO (SRIO), Peripheral Computer Interconnect Express (PCIExpress), Ethernet and the Common Public Radio Interface (CPRI) [6].

Point-to-point links are attractive since they are faster, simpler and more reliable than multi-drop links. Modern high-speed serial links include equalisers at the receivers to improve signal integrity. The higher speeds are also achieved because the clock is embedded in the signal, and there is no need to keep several electrical lines synchronised as is required with parallel buses.

2.5 Security

Security is an important consideration in the provision of avionics equipment and can be viewed as covering confidentiality, integrity and availability of systems and data.

Confidentiality problems can be caused, for example, by eavesdropping on communications and gaining unauthorised access to systems through loopholes in the access control measures.

In terms of integrity, attackers may, for example, attempt to modify data, inject false data or simply selectively delete data and thereby cause the aircraft systems to make incorrect decisions due to erroneous or missing information. This could be achieved by intercepting communications, for example, or by introducing malicious software onto a processing platform.

Availability problems can be caused by attackers blocking communications or causing vital systems to fail through, for example, exploitation of software bugs in the applications or their underlying operating systems.

There are several groups and organisations that are looking at various aspects of security for avionics. The activities of these groups and organisations are summarised below.

Airlines Electronic Engineering Committee (AEEC) is an airlines and airframe manufacturers standards group that co-ordinates several security activities for avionics. The standards and working groups of interest are:

- ARINC 811 – Aircraft Information Security Process. This is a model for assessing security risk, implementing appropriate countermeasures, operating these countermeasures and feeding results back to risk assessment.
- ARINC Manager of Air-Ground Interface Connection (MAGIC) – This group is looking at integrated communications systems on board aircraft, initially for airline and passenger systems but with the ability to extend this to ATM and AOC systems later on.

Radio Technical Commission for Aeronautics (RTCA) Inc is a US based organisation that develops aviation standards. A similar organisation in Europe is the *European Organisation for Civil Aviation Equipment* (EUROCAE). The RTCA SC-216 group is working on security issues, and so is the EUROCAE WG-72 group. Both groups are collaborating to develop the following security related documents:

- Minimum Aviation System Performance Standards (MASPS) for Aeronautical Electronic and Networked Systems Security
- Security Assurance and Assessment Processes and Methods for Safety-related Aircraft Systems.

Air Transport Association of America, Inc (ATA) is an airline trade association based in the US. The following working group and specification cover security matters:

- Digital Security Working Group – this group provides a forum for addressing the application of digital security technologies and establishing best practice and conventions.
- Spec 42: Aviation Industry Standards for Digital Information Security – this specifies identity management solutions based on Public Key Infrastructure (PKI) technology.

EUROCONTROL is the European organisation for the safety of air navigation, and the *Federal Aviation Administration (FAA)* is an agency of the US government that regulates and oversees all aspects of civil aviation in the US. The following study has been carried out by EUROCONTROL and the FAA:

- Communications Operating Concept and Requirements for the Future Radio System (COCR) [7] – This focuses on air traffic control and air operations, and includes a security risk assessment in these areas. Confidentiality is rated as of low importance except for business needs, but integrity and availability are rated as potentially of very high importance across a wide range of systems. The main recommendation is the use of cryptographic communications security as the main form of protection.

The above specifications and studies for security are likely to be relevant to the integrated communications system approach.

2.6 Segregation

Segregation applies at two levels in the context of the integrated communications system approach. First of all there is often a need to segregate the provision of services, for example, segregating cockpit services used by the crew from the cabin services used by passengers. Secondly, where software applications share the same resources (e.g. processor and memory) there is a need to segregate the software applications so that they cannot interfere with each other.

The more traditional federated approach has seen an application performed by dedicated resources, i.e. a software application would run on its own processor with dedicated memory and other peripheral resources. The segregation between the various applications was clear and generally defined in hardware such that a fault occurring in that unit could easily be prevented from affecting other applications. However, the obvious drawback with the federated approach is the use of more resources than necessary, which often requires duplication for fault tolerance, further exacerbating the problem.

IMA has emerged as a design approach challenging the federated architecture by reducing the costs associated with acquisition, space, power, weight, cooling, installation and maintenance. IMA uses a single computer system (with replication for fault tolerance), to provide a common computing resource for several applications. This is achieved by employing an operating system that provides space (i.e. memory) and time partitioning for example, an ARINC 653 compliant operating system.

Similar issues apply in the integrated communications system approach. Cockpit and cabin services segregation can be achieved through software partitioning, or by using different processing platforms for the different services. Software partitioning can also be provided through an appropriate operating system. However, it should be noted that the tolerable latencies in software defined radio applications are generally less than those in current IMA applications. Latency issues limit the number of waveform applications that can share the same processing platforms using time partitioning.

2.7 Redundancy

Authorities, such as the FAA, specify a minimum level of redundancy of equipment that must be operational before an aircraft is allowed to take off. This redundancy is specified so that a single failure does not cause the loss of any vital communication channel.

In the federated approach, redundancy is provided by replicating dedicated equipment, taking up space and adding weight. In the integrated communications system approach, there are more opportunities for supporting redundancy, including the ability to switch from one processing unit to another in the case of failure.

2.8 Certification

Certification is one of the most difficult areas in the development of avionics systems. It needs, for good reasons, to be done thoroughly, and tends to err on the side of caution to ensure that safety requirements are fully satisfied. The subject is large and complex and addressed in various documents, including the following:

- SAE ARP4754 Guidelines for Development of Civil Aircraft and Systems [8]
- RTCA DO-178B / ED-12B: Software Considerations in Airborne Systems and Equipment Certification [9]
- RTCA DO-248B: Final Report for Clarification of DO-178B [10]
- RTCA DO-254 / ED-80: Design Assurance Guidance for Airborne Electronic Hardware [11]
- RTCA DO-297: Integrated Modular Avionics (IMA) Development Guidance and Certification Considerations [12].

A careful examination is required between the certification impact for dedicated radio equipment as in the federated approach, and the certification impact where common processor platforms are employed, as in the integrated communications system approach.

3 SANDRA Overview and Functional Architecture

The SANDRA programme aims to design and demonstrate an integrated communications system for civil aviation. The network architecture is illustrated in Fig. 3 and supports the following waveforms:

- Analogue VHF and Voice Data Link Mode 2 (VDL2) in the VHF band
- Inmarsat Broadband Global Access Network (BGAN) in L-Band
- Aeronautical Mobile Airport Communications System (AeroMACS) in C-Band
- Digital Video Broadcasting - Satellite - Second Generation (DVB-S2) in Ku-band (receive only).

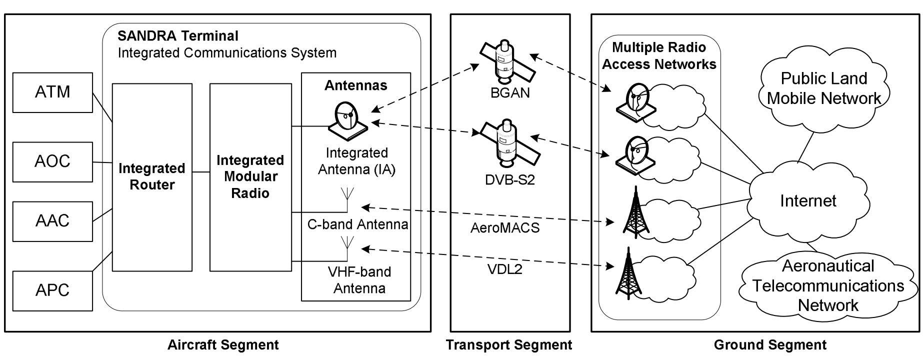

Fig. 3. SANDRA Network Architecture

The SANDRA Terminal in Fig. 3 is an integrated communications system made up of an Integrated Router (IR), an Integrated Modular Radio (IMR) and a number of antennas. The IR carries out high level functions such as routing, security, Quality of Service (QoS) provision and mobility. The IMR carries out low level functions such as the radio communication layers, radio resource allocation and QoS mapping. The IR/IMR split is in fact an arbitrary but pragmatic partitioning within the SANDRA programme that has been necessary to allow the scope of the work packages to be more easily delimited.

The realisation of the IMR within the programme will now be described, illustrating how it will demonstrate some of the key concepts in the integrated communications system approach.

4 SANDRA Proof-of-Concept Integrated Modular Radio

4.1 High-Speed Digital Serial Link Selection

The IMR architecture employs a high-speed digital serial link between transceiver functionality and the processing functionality illustrated in Fig. 2. This link mainly carries baseband samples of the receive signal and baseband samples or symbols of the transmit signal. In addition, it carries control and status signals. An important requirement for this link is the required bit rate. The estimated bit rate for each system is given in Table 2, based on 16 bit samples and two times oversampling with reference to the minimum Nyquist requirement for the bandwidth of interest.

Table 2. Bit Rate Requirement for High-Speed Digital Links

	VHF	BGAN	AeroMACS	DVB-S2
Max channel bandwidth (MHz)	0.025	0.20	20[1]	36[1]
Bit rate for 16 bit samples with 2x oversampling (Mbit/s)	1.6	12.8	1280	2304
Estimated total bit rate including controls and status (Mbit/s)	1.8	13.0	1300	2400
Note 1: The proof-of-concept demonstrator covers lower bandwidths				

Latency is an important issue in radio equipment, and is relevant to the high-speed serial link.

At the protocol level, radio communication systems are often based on frames which are about 10 ms or more in duration. Protocols typically allow a period of a frame or more in between a radio receiving a frame and generating a response. This period allows items such as physical layer receive completion, block error correction, protocol handling and transmit preparation to be carried out after a frame has been received. For this purpose, a useful scheme is to deliver receive sample blocks and take out transmit sample blocks every 0.5 ms in order to realise a suitable degree of block processing granularity. A link latency of the order of 100 μs ensures that the round trip delay over the link is less than the granularity of 0.5 ms and so reduces the impact of the link delay.

In radio communications applications, other controls such as fast Automatic Gain Control (AGC) or inner loop power control can require significantly shorter response times. For example, the maximum round trip delay in the CPRI specification (excluding cable delays) is 5 µs, in order to support the UTRA-FDD (UMTS Terrestrial Radio Access - Frequency Division Duplexing) inner loop power control.

The required latency of the link depends on the types of applications that need to be supported and the desired location of functionality at each end of the link. A round trip delay of the order of 100 µs means that fast responses such as fast AGC or inner loop power control will need to be implemented at the *transceiver* unit. A round trip delay with the CPRI figure of 5 µs means that fast responses such as fast AGC or inner loop power control can be implemented at the *processing* unit.

The required alignment of a transmit burst to a receive signal varies from system to system. One method of achieving alignment is to drive the Analogue to Digital Converter (ADC) and Digital to Analogue Converter (DAC) from the same clock source, thus providing a fixed relationship between transmit samples and receive samples. A transmit function in software or firmware can then set up a transmission aligned to the timing defined by the ADC and DAC pair. In this scenario, the only impact of the performance of the link (i.e. its latency) will be on the amount of memory required in the transceiver unit to buffer receive and transmit samples.

Additional requirements include environmental requirements and support for locating transceiver functionality and processing functionality at different ends of the aircraft, for example through the use of optical fibres.

The following candidate high-speed serial interfaces have been examined:

- PCI Express (PCIe)
- Serial RapidIO (SRIO)
- Common Public Radio Interface (CPRI).

CPRI has been selected for use in the SANDRA demonstrator since it has the following desirable characteristics:

- specifically designed for links between transceiver functionality and processing functionality
- supports line rates of up to 6144 Mbit/s, well in excess of the requirements of Table 2
- supports electrical and optical media, with the latter supporting distances of over 10 km
- supports the distribution of frequency references, should this be desirable
- flexible enough to support a variety of radio waveforms
- round trip delay is guaranteed to be as low as 5 µs since unlike PCIe and SRIO, it is framed based rather than packet based
- supports a number of topologies such as chains, trees and rings.

4.2 Processing Card and FPGA Card Selection

The processing platform for the SANDRA demonstrator is hosted in a compact PCI chassis. A Commercial Off-The-Shelf (COTS) card has been selected from Concurrent Technologies, with an Intel i7 processor. It also provides Express Mezzanine Card (XMC) sites connected to the processor via PCIExpress.

A COTS XMC card with a Xilinx SX95T FPGA and Small Form-factor Pluggable (SFP) connectors has been selected from Innovative Integration, to provide an FPGA capability and support CPRI connectivity.

The above choices have been made to support rapid development and demonstration rather than target a product.

4.3 Real-Time Operating System Selection

The QNX Real-Time Operating System (RTOS) has been selected for use on the processing platform since it has a strong micro-kernel architecture, supports the Portable Operating System Interface for Unix (POSIX), supports multi-core processors, supports time partitioning and has very capable trace and debug facilities.

Once again, the choice has been made to support rapid development and demonstration rather than target a product since, for the latter, the choice of operating system would need to be assessed in terms of DO-178B certification.

4.4 SANDRA IMR Demonstrator

The SANDRA IMR demonstrator is illustrated in Fig. 4, showing two common processing platforms, optional frequency references, three transceivers and one receiver. The processing platforms are connected to the transceivers and receiver by CPRI. The processing platforms also connect to each other and to the external Integrated Router (IR) via Ethernet.

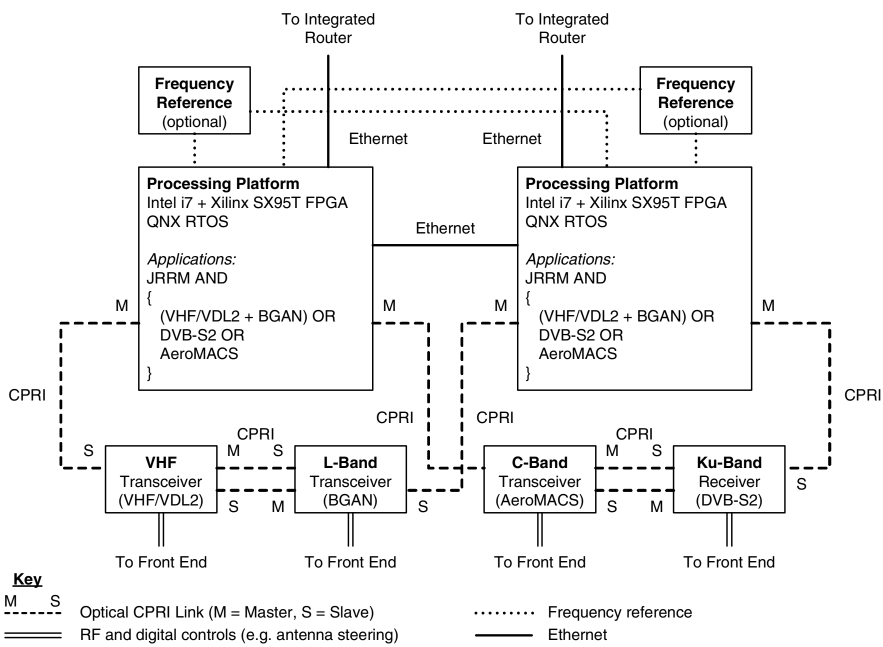

Fig. 4. SANDRA IMR Demonstrator

The processing platforms run Joint Radio Resource Management (JRRM) applications, with one acting as a master and the other as a slave. They interface to the IR for the provision of communication services and decide which waveforms should run on each platform. The platforms are intended to run VHF/VDL2 and BGAN waveforms at the same time, or an AeroMACS waveform or a DVB-S2 waveform.

The IMR demonstrator supports redundancy in terms of the high-speed links and processing platforms. If a processing platform running a high priority waveform goes down, it will be possible to disable the lower priority waveform on the second platform and start running the high priority waveform on that platform.

A full IMR is likely to require CPRI based switches to more easily configure links between processing platforms and transceivers.

5 Conclusions

The SANDRA proof-of-concept demonstrator will allow a number of concepts relating to the Integrated Modular Radio approach for avionics to be examined. These include the separation of processing functionality from transceiver functionality through the use of high-speed digital links, the use of a common processing platform for a variety of waveforms, dynamic radio resource management, support for asymmetric data links through the joint use of BGAN and DVB-S2, support for legacy radio links such as VHF and some support for redundancy.

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