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# A GUIDE TO THE IMPACT OF MODULAR AVIONICS ON EMC DESIGN AND TEST PHILOSOPHY

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**Members of the Working Group**

## 1 EXECUTIVE SUMMARY

This brief document has been prepared by the ASSC Modular Avionics Electromagnetic Hazards and Compatibility Working Group to provide initial guidance on both design and testing specifically aimed at modular avionics. It is based on original information, and does not assume any particular implementation. Initial tests on some commercial modules in a rack give optimism that qualification testing of modules could be carried out economically.

The document is intended to supplement rather than supersede existing guidance and test specifications that apply to avionics based on specific-function-LRU architectures. Modular avionics could pose particular EMC problems where modules are obtained from a variety of vendors and may be inserted in a variety of positions within an enclosing rack or cabinet.

Although the guide has been prepared primarily for military applications, much of the information is equally applicable to civil avionics, and consideration of civil developments has been included.

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It concludes that modular avionics will require some modification to the current philosophies on EMC design and testing.  Further practical tests will be required to augment this initial exercise.

# GLOSSARY

| | |
|---|---|
| ASAAC | Allied Standard Avionics Architecture Council |
| BCI | Bulk Current Injection |
| BIT | Built-in-test |
| CNI | Communication/Navigation/Identification |
| COTS | Commercial-off-the-shelf |
| EED | Electro-explosive Device |
| EM | Electromagnetic |
| EMC | Electromagnetic Compatibility |
| EMH | Electromagnetic Hazards |
| EMH&C | Electromagnetic Hazards and Compatibility |
| ESD | Electrostatic Discharge |
| HF | High Frequency |
| ISS | Integrated Sensor System |
| JSF | Joint Strike Fighter |
| LCC | Life-cycle Costs |
| LRM | Line Replaceable Module |
| LRIM | Line Replaceable Interface Module |
| LRU | Line Replaceable Unit |
| MCM | Multi-chip-module |
| MMIC | Milli-metric wavelength Integrated Circuit |
| PCB | Printed-circuit Board |
| RF | Radio Frequency |
| SEM-E | Standard Electronic Module-Type E |
| SDC | Signal Data Concentrator |
| VSTOL | Very Short Take-off and Landing |

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# PART A: THE RANGE OF MODULAR AVIONIC POSSIBILITIES

## 2 THE NATURE OF MODULAR AVIONICS

### 2.1 Introduction

An avionic system is a complete entity designed to carry out a set of functions satisfying the mission, operational and life-cycle cost requirements of the platform. The functionality, which includes platform control, stores management, navigation, communications and radar, is provided by modules, both of hardware and software, data interconnects, sensor front-ends, controls and displays etc.

There are two fundamentally different avionic architectures; a federated architecture in which each function is physically and logically independent; and an integrated architecture in which the electronic processing for all functions is carried out in a common core. Both architectures may be partly modular in form, but the modules may or may not be common to the different functions. The concepts are shown in figures 1 and 2.

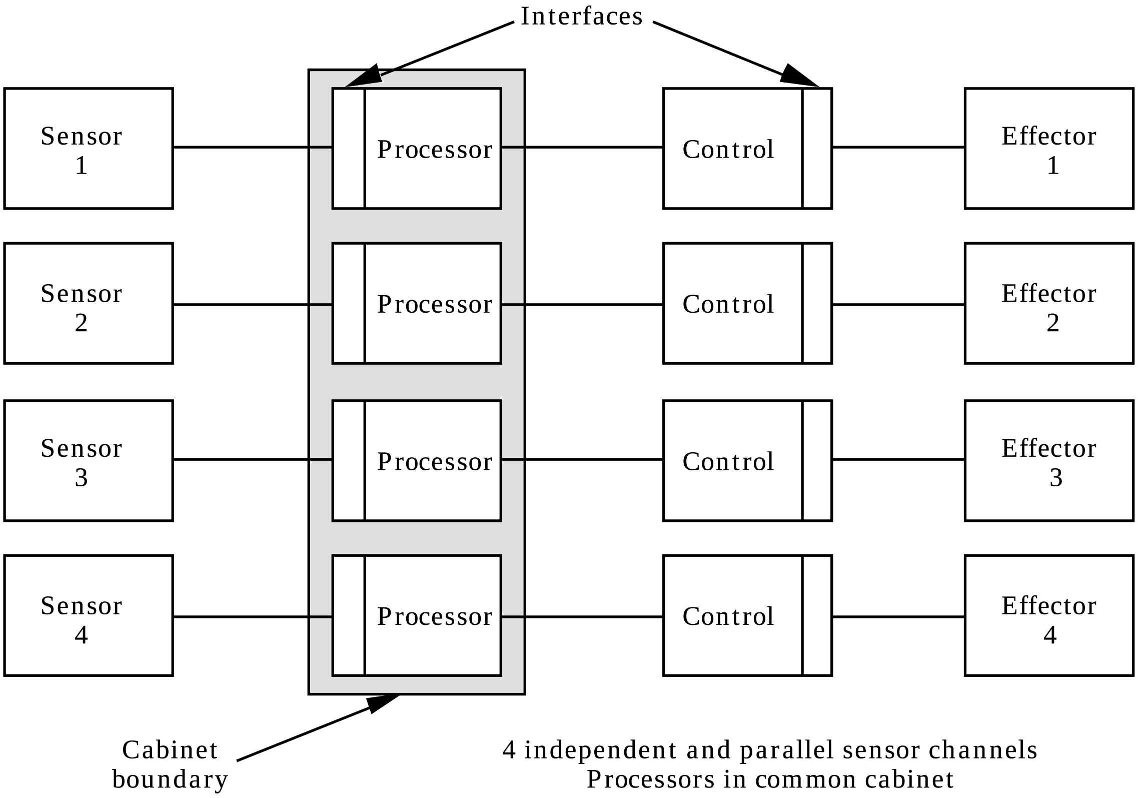
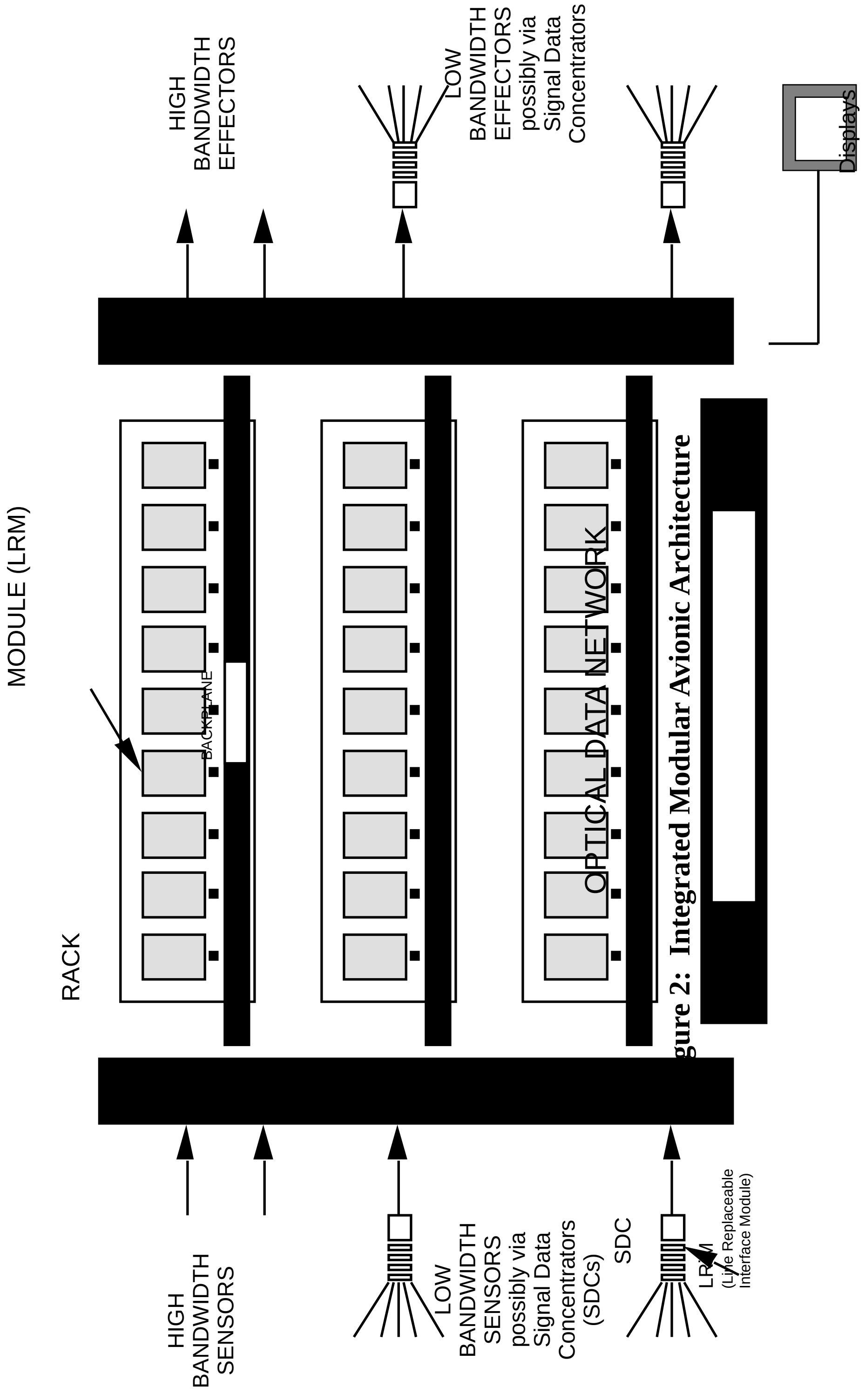


**Figure 1: Federated Architecture**

Figure 1 shows the federated architecture of independent functions, but parts of each function may be in the same cabinet. The modules within the cabinet may be dissimilar or common in the sense that they are identical but not shared between functions.  Yet again, these modules could be printed-circuit boards (PCBs) of the same physical form and fit, but supporting different electronic functions.  As an example, a minimum set of seven common modules are proposed in the Allied Standard Avionics Architecture Council (ASAAC) programme to consist of standard complex integrated circuits or multi-chip-modules (MCMs) mounted on such PCBs.  This set forms the building blocks of a common core processing unit.



gure 2:  Integrated Modular Avionic Architecture

Figure 2 shows an integrated architecture in which sensor outputs are switched into a common processing core and then separately interfaced to different output devices. the common core may have common modules which are identical PCBs or just identical integrated circuits.

In the sophisticated systems planned for the next generation of military platforms the capabilities of the common core will include automatic built-in-test (BIT) and reconfiguration to increase reliability and fault tolerance.

The distinctions between federated and integrated architectures are sometimes blurred by connecting buses into the system. For example, a control or maintenance bus with ports on each of the parallel channels of a federated system directly reduces the independence of those channels.

For EMC design, the issues involve:

- The form of interconnections between the potentially sensitive, functional blocks
- The topology of the shielded volumes
- The ability to rigorously specify the building blocks such that they can be reliably operated together without spurious interactions.

## 2.2 Advantages of Modular Avionics

### 2.2.1 Military Avionics

The major desired benefit from modular avionics is greatly reduced life-cycle costs (LCC) as a result of:

- Reduction, or even removal of, 2nd and 3rd line maintenance
- Reduction in variety of spares holdings
- Improved reliability
- Reduced module costs because of numbers arising from commonality.

### 2.2.2 Civil Avionics

The adoption of integrated modular avionics (IMA) contributes to the primary objectives of reducing aircraft life-cycle costs by improving reliability and maintainability, saving weight and releasing space in the avionics bay.

The former of these objectives is achieved by reducing recurring and non-recurring costs, and reducing the number and variety of spares holding. Maintenance practice is also improved by having simpler installations, easier fault diagnosis, reduced wiring and number of connectors. All of these factors decrease repair times.

A major difference between military and civil IMA systems, from the EMH&C protection point of view, is the use of COTS which is easier in civilian aircraft in the relatively benign environment of the avionic cabinets compared to the difficulty of incorporating COTS in the hostile military aircraft environment. Life cycle costs can be reduced by IMA in civilian aircraft since it is easier to find the balance between a technology revolution and that which is economically sound. An example of civil IMA is given later in Annex A.

### 2.3 The Challenge for EMC Engineers

The challenges for EMC engineers are:

- To ensure that adequate protection can be provided in a modular avionic system
- To ensure that qualification costs remain commensurate with the reduced module costs without impinging on system flexibility.

## 3 THE WORK OF OTHER CONTROLLING ORGANISATIONS

Other national and international organisations will be specifying integrated modular avionic systems, both civil and military, and it is anticipated that appropriate draft standards on EMC for such systems will be produced. These activities may be concurrent with both our initial document and also the subsequent updates, but at the time of writing no standards or design guides specifically addressing EMC in modular avionics have been identified. However it will be necessary to review other initiatives and future documents as they emerge and relate them to our own recommendations.

Organisations from which relevant documents may be expected to emerge include:

### 3.1 Society of Automotive Engineers (SAE)

Under the Aerospace Electronics and Electrical Division are 3 committees of relevance:

**a) Committee AE-4 Electromagnetic Compatibility**, which provides a technical, co-ordinating and advisory function in the field of aerospace electromagnetic interference and produces standards in this area.

**b) Subcommittee AE-4R High Intensity Radiated Fields (HIRF)**, which develops standards for use in FAA Advisory Circulars and related user's manuals for HIRF issues applicable to commercial aircraft.

**c) Subcommittee AE-4L Lightning**, which develops and harmonises international documents on lightning strikes and effects on aircraft.

### 3.2 RTCA and EUROCAE

The following 2 organisations have been tasked by the FAA and JAA respectively to develop appropriate compliance procedures:

**a) RTCA Special Committee SC-135 Environmental Testing** produces the international de facto standard for environmental testing of commercial avionics through its document DO-160 Environmental Conditions and Test Procedures for Airborne Equipment, currently at Issue C, but working towards Issue D. There is a specific Working Group dealing with HIRF.

**b) European Organisation for Civil Aviation Electronics (EUROCAE) Working Group 14** which is responsible for document ED-14 (equivalent to DO-160), have delegated responsibility for the EMC sections to **Working Group 33, Sub-group 3**. **Working Group 31** is also relevant for lightning.

### 3.3 Aviation Rulemaking Advisory Committee (ARAC)

A Working Group under ARAC called the Electromagnetic Effects Harmonisation Working Group (EEHWG) was formed to take the outputs from EUROCAE and SAE and produce harmonised documentation. This group now does most of the work in defining EM environmental levels for HIRF and lightning.

### 3.4 British Standards Institute (BSI)

The Technical Committee ACE/66 Electromagnetic Compatibility of Aircraft has taken on board the writing of document BS G 257 Design of electromagnetic hazard protection of civil aircraft:

Pt 1 Guide to electromagnetic theory and the electromagnetic threats posed to aircraft
Pt 2 Guide to protection
Pt 3 Guide to clearance and testing.

## PART B: EMC DESIGN

## 4 EMC DESIGN ISSUES

### 4.1 Comments on EMH Protection and Testing of Integrated Modular Avionics

There are a number of differences between current avionic systems and IMA systems envisaged. These differences will effect EMH protection and testing and are as follows:

- The reconfigurability of an IMA system via software and hardware.
- Current aircraft tests for susceptibility rely on localised illumination / current injection, this will no longer be valid if the system is capable of transferring a function to another processor, possibly mounted in a different location on the aircraft, in the event of a failure.
- An IMA system has no identifiable LRUs and no defined wiring bundles. Present EMC test techniques are based around LRUs and their associated wiring.
- It is likely that an IMA system will rely on a common shielded and filtered rack to provide protection to the individual modules. Different manufacturers may have different ideas on the level of protection offered by the rack and the module. This could lead to problems as the modules are intended to be interchangeable and may be movable between racks. As a result there is a need to develop module qualification and rack performance test techniques.

### 4.2 Electromagnetic Topology of the Modules and Racks

When considering the design of system architectures from an EMH point of view, it is useful to think of the system as a number of topologic shells, with an electromagnetic shielding performance limited by leakage through apertures, diffusive areas and conducting penetrations.

The first step is to consider the possible physical geometry and topology of a future system.

The LRMs will be grouped in close proximity within the racks, (see figure 3), each rack performing one or more major airborne system function (e.g. Navigation/ Communications, Radar, Flight Control and Weapon Control).

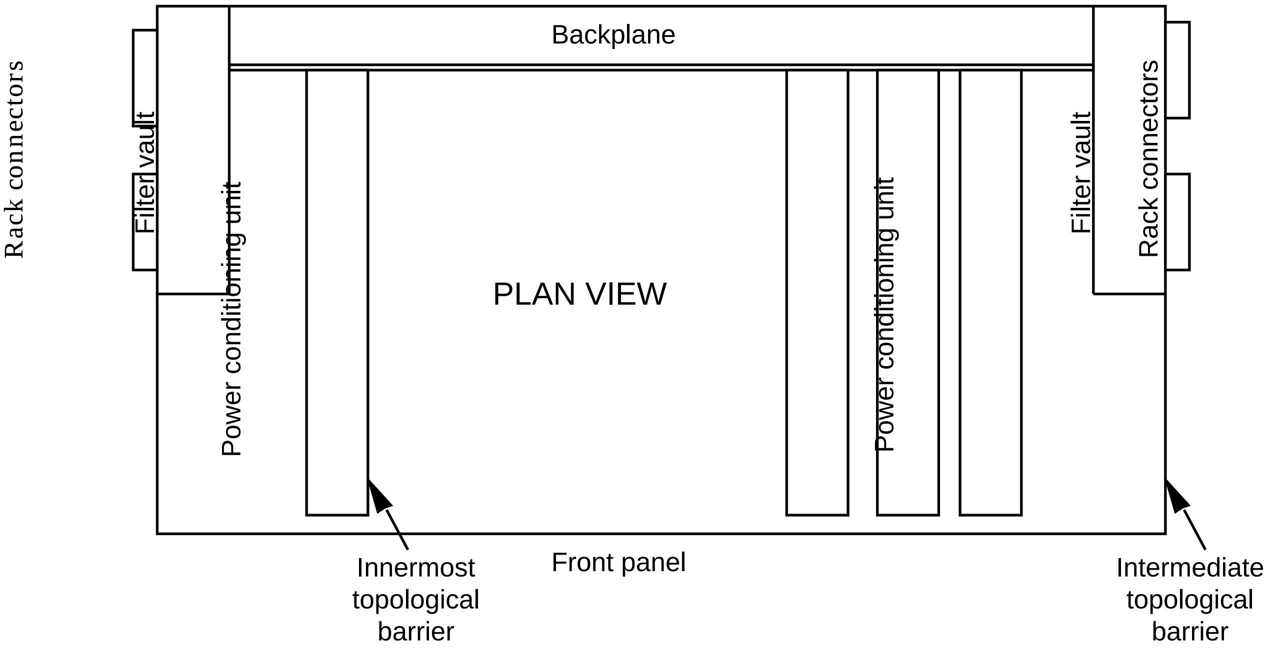


**Figure 3: Likely Arrangement of the Rack**

The module shields combined with any filtering of the conductive connection to the modules form the innermost electromagnetic topological barrier. Groups of modules will be contained within 'racks' which could be the intermediate topological barrier. The modules will be connected together within the racks via a backplane, which may comprise a mix of conducting and optical channels. Each rack, for example, could contain two power conditioning units (for integrity) which will take aircraft power (either DC or 3 phase AC; 400 Hz) and feed an appropriate DC power supply along the backplane to the modules. It is likely that in the future the power supply cables will be the only conducting penetration of the rack, all other interfaces would be by optical cables. However in practice, it is likely that modular avionic implementation for some years ahead will have many low bandwidth (<1 MHz) conductive penetrations. These, together with the power supplies will require filtering to maintain the integrity of any shielding performance of the rack. It is worth noting that a future trend towards variable frequency power supplies may introduce added EMC concerns.

The individual modules will be exposed to interference via the following coupling routes:

- Free field radiation from the external environment penetrating the innermost topological barrier.
- Free field radiation inducing currents onto the wiring feeding the racks.
- Free field radiation inducing currents directly onto the backplane within the rack.

- Induced currents as a result of lightning, via the wiring feeding the rack.
- Radiated interference between the modules, near field E/H.
- Conducted interference between the modules, via the backplane.
- Radiated coupling between the backplane and the modules.

### 4.3 Modular Avionics Installed Architecture

In general, apart from the aircraft generation system, the racks are connected to sensors, actuators and displays. The bandwidth of some of the sensors and displays are high (>10MHz) and connection via fibre optic cable is reasonable, although, as fibre optic bandwidth increases, it is more likely that a number of low bandwidth sensors may be multiplexed onto a single fibre optic cable. Low bandwidth sensors and actuators will be multiplexed locally in signal data concentrators (SDCs) and converted into a high bandwidth optical signal. These signal data concentrators will themselves be racks containing small modules of a standard format.

The major objective of signal data concentrators will be to provide a local collection point for low-bandwidth digital and analogue input and output signals. SDCs will provide suitable input and output interfaces, conditioning and digitisation prior to multiplexing together on to a high-bandwidth optical data network. Each SDC will contain certain line-replaceable interface modules (LRIMs) of a common format in a rack. It should be pointed out that such local collection of signals reduces cable lengths, thereby improving EMC behaviour.

The use of modular avionics resulting in a reduction in the number of equipment racks may make the use of dedicated power supply returns more attractive in airframes utilising large quantities of Carbon Fibre Composites (CFC).

# 5 EMC ISSUES RELATED TO MODULAR AVIONICS

## 5.1 Shielding and Cooling

The simplest and most economical method of applying forced air cooling requires vents in the electronic container to be effective. However, air vents can cause radiated emission and susceptibility. A preferred cooling method uses the cold wall concept, whether the medium is liquid or gaseous the cold wall construction allows a continuous electromagnetic shield.

In general the cooling mechanism impinges on the EMC shielding performance, therefore the chosen solution should be optimised for a combination of EMC and cooling requirements.

A typical module in the ASAAC programme needs to dissipate 100W on a SEM-E sized PCB, rendering air cooling impracticable. Various types of liquid cooling have been investigated. However the requirement that modules must be easily replaceable means that the liquid circuit needs to be broken.

## 5.2 Reconfigurable Systems

Reconfiguration can occur at several levels, but the concept in the ASAAC programme will be considered as typical. Here the functionality of common hardware processor modules is achieved by software control.

Reconfiguration will change the EMC behaviour of the system and therefore EMC protection design and qualification philosophy must take this into account.

## 5.3 Relative Advantage and Performance of Fibre Optic Systems

Fibre optic cables are not susceptible to electromagnetic (EM) fields in the physical space of the optics, but where the optical signal is converted to an electronic signal it can become susceptible to EM radiation. In particular, the electronic receivers are very broad band and hence potentially very susceptible to EM radiation. Nevertheless, with due regard for this broad band susceptibility it is recognised that the overall susceptibility of a fibre optic system is well below that of an all-electrical system.

## 5.4 Power Supply Distribution

Where there are large, complex PCBs there will be an increased tendency in the future to use distributed power systems with small dc-dc converters on each module. A large capacity ac-dc converter or the 28V dc line will supply all these modules in parallel. The main impact of this distribution is to remove all high voltages from the modules, leaving only ±5V and ±15V at most, actually on the modules.

In the near-field E field radiation is related to voltage levels whereas H field radiation is related to the amount of current flowing. Lowering the voltage may lead to more susceptible/vulnerable units. In addition to this, by reducing the the voltage the H field may be increased. The higher currents may require bulkier filtering to avoid saturation in the cores.

### 5.5 TEMPEST Design of Modular Avionic Systems

It is becoming clear that segregation of certain types of systems into dedicated racks may be needed in order to achieve the required EMC and TEMPEST performance.

In the case of aircraft communication systems (including flight deck intercom) there are enormous benefits to be gained from having a dedicated rack for such functions. All conductive i/o to the rack should be screened or filtered and/or encrypted depending on the security level of the signal. In this way signals leaving the rack cannot emanate compromising data.

It is also worth considering electromagnetic segregation within the rack in order to prevent compromising data being coupled onto high speed i/o lines. Although screening would prevent radiation of such data en route it could subsequently cross-couple within another equipment which might not be designed for TEMPEST.

### 5.6 Ionising Radiation

There are two sources of ionising radiation which are of potential concern for the aircraft system designer, namely:

- Ionising radiation from nuclear explosions.
- Cosmic radiation, particularly at cruising altitude

Both sources have similar effects on high performance electronics. The former source has been considered for some time. The latter source is becoming of growing concern as gate sizes and operating voltages reduce and there is a growing body of evidence that the problem is with us now in commercial, high performance electronics when used at high altitude (>30,000ft). The problem is increasing at lower altitudes as gate sizes and operating voltages further reduce.

There are circuit based mitigation techniques available, ranging from simple design techniques through to special chip design. This latter technique is unlikely to happen for aircraft use because of the small market share and the cost of in-service maintenance.

It is likely that a systems approach to the problem is required with consideration of both hardware and software but the approach must be considered at the systems design stage and treated like other transient phenomena which are recognised.

At present the Cosmic radiation can cause a number of types of problem:

- A momentary disruption to the normal operation of a system.
- A latched fault requiring resetting of the system.
- A latched fault which cannot be reset and leading to subsequent damage as a result of the improper state of the circuit.

Designers of future systems must recognise the inevitability of these types of problems and design the system accordingly.

# 6 EM PROTECTION OF INTEGRATED MODULAR AVIONICS

## 6.1 Introduction

As discussed earlier the rack can be constructed such that it provides protection to the modules housed within it, see figure 3. There are two basic types of protection that can be offered:

- Shielding from the external free field environment.
- Filtering of any conducting penetrations.

The shielding is achieved by constructing the rack as a Faraday cage. However it will be necessary to penetrate this Faraday cage with various connections to the modules, i.e. power cables, signal cables and cooling pipes/vents. To maintain the integrity of the Faraday cage these penetrations will need to be filtered. The type of filtering will depend on the penetration, i.e. conventional electronic filters for wires and wave guide beyond cut-off for vents, optical fibres etc. These filters will offer protection to all the modules housed within the rack and can thus be referred to as common filters, i.e. common to all modules.

The use of a common filter module is attractive as many modules can be protected by one filter, thus reducing the overall size, weight and cost. However it should be recognised that, although this approach offers protection to the modules from the external environment, it does not offer any protection between the modules within the rack.

It is conceivable that the only electrical connections to a rack will be power cables with all signals being fed via optical fibres, with the optical signals being converted to electrical signals for use on the backplane.

Any interference signals present on the backplane could be fed directly into a module if there is no filtering. It thus appears that filters will be required in the modules anyway, begging the question of why bother with a common filter?

If the rack is to provide any protection then, as stated above, a common filter must be used to maintain the integrity of the Faraday cage. Otherwise interference signals will be conducted into the enclosure and re-radiated.

Basically there are two options:

i. Do not build any protection into the rack, then shield and filter each module so that it will successfully operate in the surrounding environment.
ii. Shield and filter the rack to produce a more controlled environment for the modules. Then appropriately shield and filter each module in accordance with this controlled environment.

For option (ii) the external environment is considered to be considerably more severe than the controlled internal environment, thus the shield and filter performance of the rack will need to be superior to that required for the modules. However for option (i) each module will require the superior shielding and filtering characteristics. If it is assumed that the size, weight and cost of shielding and filtering is related to the performance, then it is obvious, that for a rack that may contain 10 modules, the second option makes sense. In addition to this, spreading the protection across several levels can improve the reliability. In the event of a failure, protection at a reduced level will still be available.

### 6.1.1 Shielding and Protection of the Rack

If the rack can be used to provide a screened environment for the modules, the field strengths experienced by the enclosed modules will be significantly lower than the external environment.

The benefits of placing as much EM protection into the rack structure will allow the individual modules to be designed to operate in a more controlled environment. This will permit individual modules to have reduced protection, implying reduced cost and weight. Of course access to the modules will be required and therefore the rack will require a door or access panel. This will effect the level and repeatability of the shielding offered. Careful consideration must be given to the type of gasketing used.

A high performance Faraday cage that screens radiated fields up to 40 GHz, unfortunately leads to cooling complications; the optimum performance balance that can be achieved will be determined during the development of modular systems.

Protection from lightning-induced surges is likely to be needed at the rack boundary. This can be provided by means of transorbs on the primary power supply at the entry to the rack.

### 6.1.2 Rack Common Filter Module

A common filter module would reduce the level of the interference currents on the backplane. The filter unit should condition all conducting connections to and from the rack, however it should be remembered that this approach offers no protection between the modules within the rack.

### 6.2 Module Protection

Protection at the rack level affords protection to the modules from the racks external environment. However it is conceivable that the rack's internal environment could still be too harsh for sensitive electronics to operate in. The internal environment will comprise of emissions from the housed modules and a residual environment, (after the shielding and filtering of the rack). In addition, there will be conducted interaction between modules on the backplane, so it may therefore be necessary to provide protection at the module level.

Again the protection will take the form of shielding and filtering. There are the usual cooling problems associated with the shielding and if every connection to a module is to be filtered, several hundred filters may be required. See 8.4 for testing.

In addition to protection against lightning at the rack boundary, there is a need to consider some auxiliary protection at module level by means of smaller transorbs, filters or capacitors.

The two alternative philosophies of protection, ie a common filter module/shielded rack OR all the protection incorporated in each module can be applied to both the core processing rack and the SDCs. However, the attractiveness of one solution over another depends on the extent of connectivity between modules in the rack.

## 7 LIFE - CYCLE COSTS

The potential benefits that could be achieved through the use of modular avionics with respect to EMC are dependent upon the implementation adopted. The wisdom of applying EMC ground rules to systems at the conception are as applicable to modular avionic systems as they are to traditional systems, and are not discussed here. Providing that due recognition of EMC design issues is made, it is possible to achieve EMC improvements together with reduced life-cycle costs.

### 7.1 Procurement and Development Costs

It is clear that the EMC protection design and qualification costs associated with traditional LRUs cannot be loaded on the much lower module costs. This situation can be avoided by taking advantage of two particular features of modules and their application:

- The potential for placement in a relatively benign environment
- Their geometrically consistent relationship with each other.

Use of specially developed test techniques and the minimising of the protection requirements will greatly reduce development and procurement costs.

### 7.2 In-Service Costs

With respect to in-service EMC performance assessments and maintenance, it is unlikely that the replacement of LRUs with LRMs in an aircraft will significantly affect the direct costs of the modules themselves. However, the use of RF shielded racks will introduce items that require maintenance, both in terms of radiated shielding and filter performance.

The level of maintenance required will depend on the degree of protection required.

The use of a common filter module is expected to reduce costs as it will hopefully remove the requirement for protecting individual modules, allowing single filters to protect the power lines, etc. In addition, it will become possible to test the performance of the filter module directly using techniques such as insertion loss (see 8.4). In comparison, the construction of current LRUs makes the assessment of filtering within an LRU difficult without removing the case.

# PART C: EMC TESTS

## 8 TESTING PHILOSOPHY

### 8.1 Overview

There are currently normally two primary stages in EMC testing:

- Equipment level qualification testing. At this level equipment is tested under laboratory conditions to the requirements of the equipment EMC specification to determine if its emission and susceptibility levels are such that it has a good chance of operating correctly in the final aircraft installation. This is a risk reduction requirement on behalf of the airframer.
- Aircraft certification testing. This is the final stage in the procurement cycle, and provides the evidence that the final aircraft installation meets its EMC requirements.

Modular avionics presents challenges to the normal EMC testing processes as individual equipments are no longer uniquely identifiable and reconfigurablilty increases the number of test combinations. The following flow chart presents the various levels and types of test that may be applicable to modular avionics. These are discussed in more detail in the following sections. Some of the techniques such as direct current injection (DCI) and mode stirred chamber testing are under development; other techniques still have to be developed such as at module qualification level.

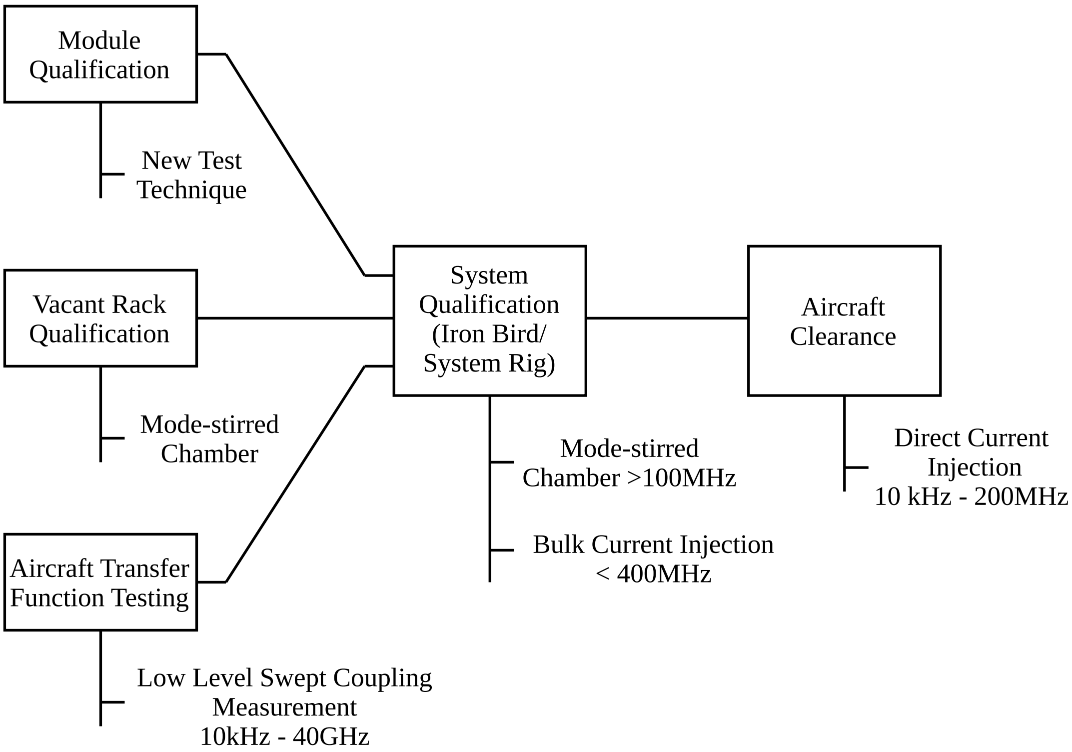


**Figure 4: Flowchart of EMC Tests**

From the flowchart it can be seen that three levels of testing are proposed to enable some of the technical difficulties to be overcome:

- Module qualification level
- System qualification level
- Aircraft certification level.

It is proposed that vulnerability testing at aircraft level is only used where cable coupling dominates. Direct current injection testing at aircraft level offers the potential of achieving future required levels more efficiently than the current free field radiation techniques. In view of the distributed nature of modular avionics systems, above about 200 MHz it is suggested that system rig testing is used as the currently only practical way of ensuring adequate testing. The test levels to be used at system rig level and for the DCI test are determined from the aircraft transfer function measurements.

### 8.2 Qualification Testing

When qualifying modular avionic systems two problems need to be considered, the effects of the external environment and inter-module interactions.

External environment effect testing will be similar to that currently employed and will include radiated/conducted emissions, radiated/conducted susceptibility, power line transients, etc. The recommended procedure is to test the modules and rack as a complete system. However, by determining the electromagnetic protection offered by the rack, qualification testing could be performed at the module level using the required environment adjusted accordingly. This method will lead to increased errors due to changes in the physical layout which will affect the coupling routes.

For inter-module effects new test procedures will need to be developed and introduced due to the close spacing of the modules (see Section 9).

As a result, it will be possible to completely characterise the performance of LRMs, both in terms of radiated external environment (far field) and inter-module (near field) effects. This will offer the potential for reducing the amount of on-aircraft assessment.

### 8.3 On-aircraft/System Rig Testing

The ability of modules to reconfigure within an integrated modular avionics based aircraft complicates EMC testing of modules on the aircraft. This is because the physical location of a particular function can change, hence the complete aircraft will need to be illuminated with RF rather than local illumination of equipment bays. Furthermore, the number of possible test configurations become untenable.

In the interim it is unlikely that aircraft test philosophy will change from that applied presently. However, further techniques are currently under development and it is hoped that new whole aircraft test procedures will be available up to 200 – 400MHz. Above this frequency whole aircraft testing will be limited to qualification of the coupling of the external and on-board electromagnetic environment to the racks. Such measurements can be related to module/rack qualification test levels.

### 8.4 In-service Testing

#### 8.4.1 In-situ Verification of Suppression Components

It is difficult to verify the in-situ performance/continued operation of suppression devices if they are installed within modules, since measurements can only be made from one side of the connector, but specially designed filter and transient test sets have become commercially available.

### 8.4.2 Filter Performance Test Set

In addition to the in-situ performance measurement of filters, there is a test set available for measuring non-linear transient suppression devices. The transient test set is connected in a similar mode to the filter test set. However, it uses a transient generator, variable attenuator and digitiser to generate fast transients which are adjusted in amplitude to determine the threshold switching values of suppressors and the voltage clamping level achieved.

The connector/plug is removed from the module under test and the filter test set is connected. The test set operates by applying an RF signal of a known level to the component under test and measures the resulting voltage at that component. The frequency is stepped from 10kHz to 50MHz and the frequency profile of the of the component is stored for comparison with the profile of the equipment when built and filters were known to be working.

The insertion loss measurement is determined by the ratio of the RF voltage measured with and without the filter connected across the RF source.

## 9 DEVELOPMENT OF PROCEDURES FOR INTER-MODULE EMC QUALIFICATION TESTING

When addressing the comments in section 8.2 the main concern for specifications is in the detailed definition of tests to be carried out on the modules as individual items.

The electrical and mechanical standardisation associated with modular avionics leads to the possibility of a standard test rig being proposed for radiated susceptibility testing. This would allow a module to be mounted in isolation and exercised and diagnosed fully during testing. A transmitting antenna could be placed alongside the module, at the correct inter-module spacing. RF power could then be fed into this antenna, up to a predetermined level, to demonstrate immunity. Several different antennas will probably be required to cover the frequency range and cope with the high and low field impedance.

Some practical tests have been performed on three ruggedised VME modules in a 16-slot relatively unscreened rack to develop test procedures for qualifying modules (see ASSC/215/3/44 Iss 1). While the modules were not up-to-date in terms of clock speed, the set-up was felt to be adequate for an initial investigation and the assessment/development of test procedures. Results were felt to be encouraging, but indicated that further work was required to develop and calibrate probes, to make a scanning system and to automate the procedures to make testing more economical.

### 9.1 Radiated Susceptibility

Radiated susceptibility tests may be required on modules for both magnetic fields (low impedance) and electric fields (high impedance). This arises because of the very close proximity of the potential sources. Frequencies for which the inter-module spacing is 1/6 wavelength may be of concern.

It was expected that the use of dipoles and shielded loops would satisfy the different wave impedance requirements. However development and validation of an appropriate technique and limits would be required.

Practical tests for magnetic susceptibility involved multi-turn loops close to each rack face. There were no failures exhibited by the modules when applying levels from Def Stan 59-41 and MIL-STD-461.

Electric field tests were performed using a Cavitenna electric field antenna and levels from Def Stan 59-41, which resulted in one repeatable module failure at 300MHz.

Some near field susceptibility testing was performed using a multi-turn coil for magnetic levels and a simple dipole antenna for electric levels, which appeared to relevant and adequate, resulting in no module failures.

### 9.2 Radiated Emissions

In the case of qualification testing for radiated emissions, the same considerations must be made with respect to wave impedance. The high and low impedance radiated fields will need to be determined. This could be achieved using the same arrangement as outlined in section 9.1. The position used for the transmitting antenna would be equally applicable for a receiving antenna.

Results of practical tests show that magnetic field emissions from modules can clearly be distinguished from those of the rack or jig and realistically measured using an active loop antenna placed outside the rack.

It has also been shown that electric field emissions can be adequately measured with a Bilog antenna outside the rack.

Near field testing was also performed experimentally using an electric ball probe and a 6 cm dia magnetic probe, and results were encouragingly low, although more work needs to be carried out.

### 9.3 Conducted Susceptibility

In a modular avionic system there are two routes for conducted susceptibility that need to be considered:

- Connections to and from the rack.
- The backplane within the rack that the various modules plug in to.

In the case of the first route, conventional tests such as bulk current injection (BCI) can be employed. As stated earlier, it is perceived that the only electrical connection to the rack is likely to be the power cables.

However, testing for conducted susceptibility on the backplane, i.e. module level conducted susceptibility, introduces several physical and technical problems. New test procedures will need to be developed to address the coupling routes mentioned earlier in the document.
It is first worth considering the source / route of any unwanted signals on the backplane:

- Conducted along the connections feeding the rack, after the common filter.
- The residual external environment within the rack, coupling onto the backplane.
- Radiated emissions from the modules coupling onto the backplane.
- Conducted emissions from the modules.

Practical tests for conducted susceptibility have not yet been performed because of the potential damage to the modules that were made available to us. Nevertheless, such testing will be essential for future qualification tests. It is suggested that the test methods contained in the VMEbus specification could be used to carry out such tests.

### 9.4 Conducted Emissions

The problems associated with conducted susceptibility also apply to the conducted emissions measurement.

Practical tests were performed to measure module-to-module conducted emissions by measurement on a vacant pin on the backplane interconnect. This method is considered adequate for qualification testing.

## 10 SAFETY MARGINS

A safety margin criterion will be required in respect to EMC tests performed on aircraft embodied with modular avionics. Normally it is derived as a result of two requirements. The first is for variation in aircraft fleet of the same type, where it is known the build standard configuration control can vary in respect to cable lay-ups, routing of cable bundles and the quality of bonding and earthing, all of which can have an impact on the degree of susceptibility of particular airframes of the same type. The second, is to take account of variations in the applied EMC test methods, where both equipment tolerance and site locations must not be ignored.

In practice, for full-threat radiated testing in the UK, a margin is applied for aircraft clearance (not including weapons) to take account of fleet variation. This also falls into line with requirements given in MIL-STD-464 for flight safety critical systems. Where extrapolative techniques are used an **additional** safety margin is applied to allow for deviation from full aircraft test.

## 11 CONCLUSIONS AND RECOMMENDATIONS

This design guide is still at a development stage, even though some initial testing on hardware modules has been performed. As a result only top level protection philosophies are presented, with little or no quantitative data in terms of costs, volume or weight penalties arising from the alternative philosophies. However it is felt that the document is a useful publication to raise awareness of the EMH problem amongst design engineers involved in system designs and various standardisation activities, which at the moment are focused on a small range of design constraints with probably little or no cognisance of EMH.

The major point arising from the document is that in attempting to push down the costs of modules, and increase their flexibility of use across platforms, a different approach must be considered to reduce significantly the cost of qualification in comparison with the predicted reduced cost of modules. In EMH terms modules cannot economically be treated as small LRUs This guide suggests two approaches which, when combined, could achieve the aim. These are:

- Reduced environment for the modules
- Standardised jig-based qualification testing

Without consideration of these issues it is not possible to reduce EMH qualification costs to a reasonably small percentage of the reported total cost of £5000 for a module. This figure of £5000 represents about one week in an EMC test house - probably not enough to carry out tests to Def Stan 59-41, the least costly qualification standard for military use.

## ANNEX A: POSSIBLE IMPLEMENTATION OF INTEGRATED MODULAR AVIONIC SYSTEMS

As avionics systems develop they will make ever increasing use of modular avionic concepts. This process will be gradual with initial implementations introducing modularity at the hardware level only. This introduction will take place during retrofits or mid-life-updates to otherwise traditional LRU based federated system designs. For new projects modular avionics will be considered at the outset to take full advantage of the technology by using advanced (modular) processing hardware, software and packaging techniques. Three major trends will be involved: Firstly that of ever increasing power of the processing hardware using microcircuits with increased gate numbers and densities, secondly that of an evolving and changing communications architecture using new and higher bandwidth data networks and thirdly the introduction of re-configuration of functions mapped to different processing resources.

The ultimate modular avionic systems will consist of high performance modular processing resources implemented as Standard Modules within integrated racks installed within the airframe in strategic positions with inter-rack communications via high speed fibre optic based data networks.

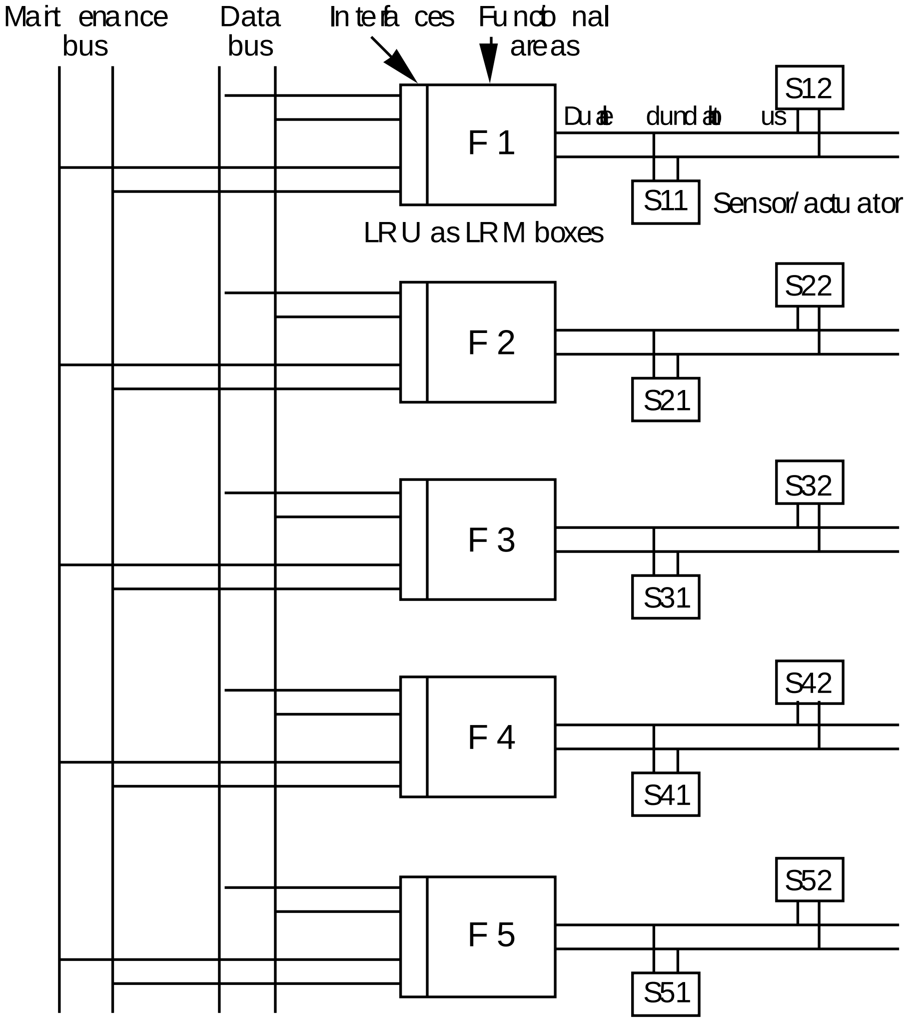
A few embryo modular avionic programmes are described below as a basis for discussing the EMC design and test requirements described in other sections of this guide document.

### a) Retrofit Architecture

It is considered both technically and economically feasible to update present day federated avionic systems to include integrated modular avionic system concepts. The process can be total or partial, with several identifiable hybrid stages in moving from a completely federated to a completely IMA based architecture.

One important hybrid stage is shown in figure 5 where the functional areas are independent, but can be made interactive by the introduction of two common buses (maintenance and data in this case) across all the functions.

Federated LRUs usually consist of 'standardised' PCBs within the boxes which are often proprietary to the box manufacturer. To introduce IMA concepts each LRU can have additional PCBs added to provide interfaces to the new data buses.



F1 to Fn are functional areas, eg stores, navigation etc.
Sj are sensors or actuators in the functional areas

**Figure 5 : Retrofit Architecture applied to Federated System**

By means of this architecture the controller of the maintenance bus can potentially re-configure the LRU functional areas using the spare processing capacity of another LRU. The data outputs from the functional areas can also be co-ordinated for control and display purposes by the sharing of these data on the common data buses.

PCBs would be modified to contain updated components to achieve the same or more processing power in less volume and weight, further there would be increased commonality of components across functions and the use of redundant processors within functions to enable the possibility of local re-configuration to take place.

The flexibility of this architecture has important advantages in achieving the main characteristics of IMA. Firstly, for reduced Life Cycle Costs a balance must be achieved between the use of high technology and that which is cost effective. Not all the functional areas need be updated at one time because the hybrid solution of federated and an IMA system is perfectly viable. This has the advantages both of spreading the cost of update over several years and also of timing the incorporation of new technology in functional areas as and when they mature. It is even theoretically possible to map this architecture on to an advanced concept such as ASAAC if such a requirement became essential.

Comparing the retrofit architecture to an advanced IMA concept such as ASAAC, the following main points emerge:

- LCC reduction are easier to establish for the retrofit architecture.
- Many independent functional areas of the retrofit architecture are combined in the ASAAC common core.
- ASAAC has weight and volume advantages over the retrofit architecture.
- ASAAC automatic BIT and automatic re-configuration is very complex but far more versatile.

### b) Pave-Pillar Programme

The first integrated modular avionic initiative was in the USA under the Pave Pillar Programme and was limited by the available technology of the day. This implementation tended to be too heavy and there were problems of high pin count/density and limited data network capabilities.

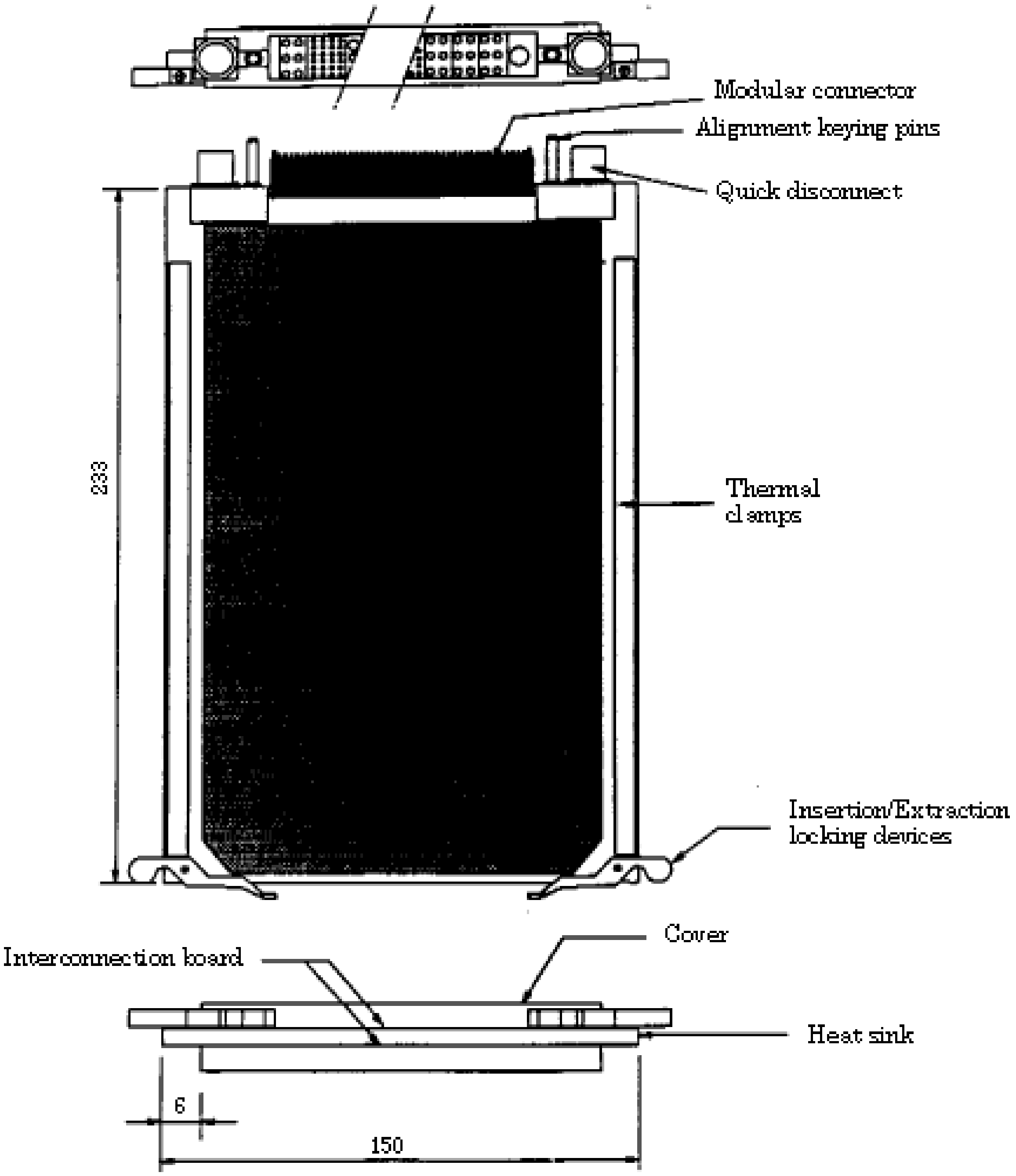
The later implementation in the F-22 aircraft demonstrated physical IMA in a successful working system, but exhibited problems with the liquid cooling requirements and physical implementations. There are a large number of different module types and the re-configuration capability is strictly limited to the module level only.

When the Pave Pillar concept was applied to the Commanche helicopter there was unnecessary duplication of module types and in general a surprising lack of commonality with the modules used in the F-22 programme. Nevertheless, F-22 has gone into production, but an analysis of the programme emphasised the need to reduce further the costs of next generation combat aircraft and the JSF programme was initiated to address these requirements.

### c) ASAAC Programme

The proposed ASAAC concept represents a major step forward from the Pave Pillar initiative. The major feature of the ASAAC architecture is a central digital processing core common to all sensor channels and effectors, with a reduced set of common modules (see figure 6.), possibly only seven types, configured in an advanced architecture dominated by fibre optic connectivity which supports a real time, high data rate bus structure.

The required diverse functionality from the processing modules is obtained using custom software mapped across a hierarchy of modules. Another important feature of the core is automatic BIT and re-configuration so that redundant modules can be deployed to overcome component failure and provide a highly reliable system. The current areas of uncertainty relate to optical switching technology for the data networks and the maximum achievable data rates on the fibre optic links.



Details shown are indicative only.  Dimensions in 'mm' and are not to scale

**Figure 6:  ASAAC-A Format Module**

### d) Integrated Sensor Systems (ISS) Concept

For the future, the Integrated Sensor Systems (ISS) concept is an extension of the ASAAC concept.  The boundary of the common core in ASAAC is extended in the ISS concept to include all the aircraft sensors and their interfaces (see figure 7).

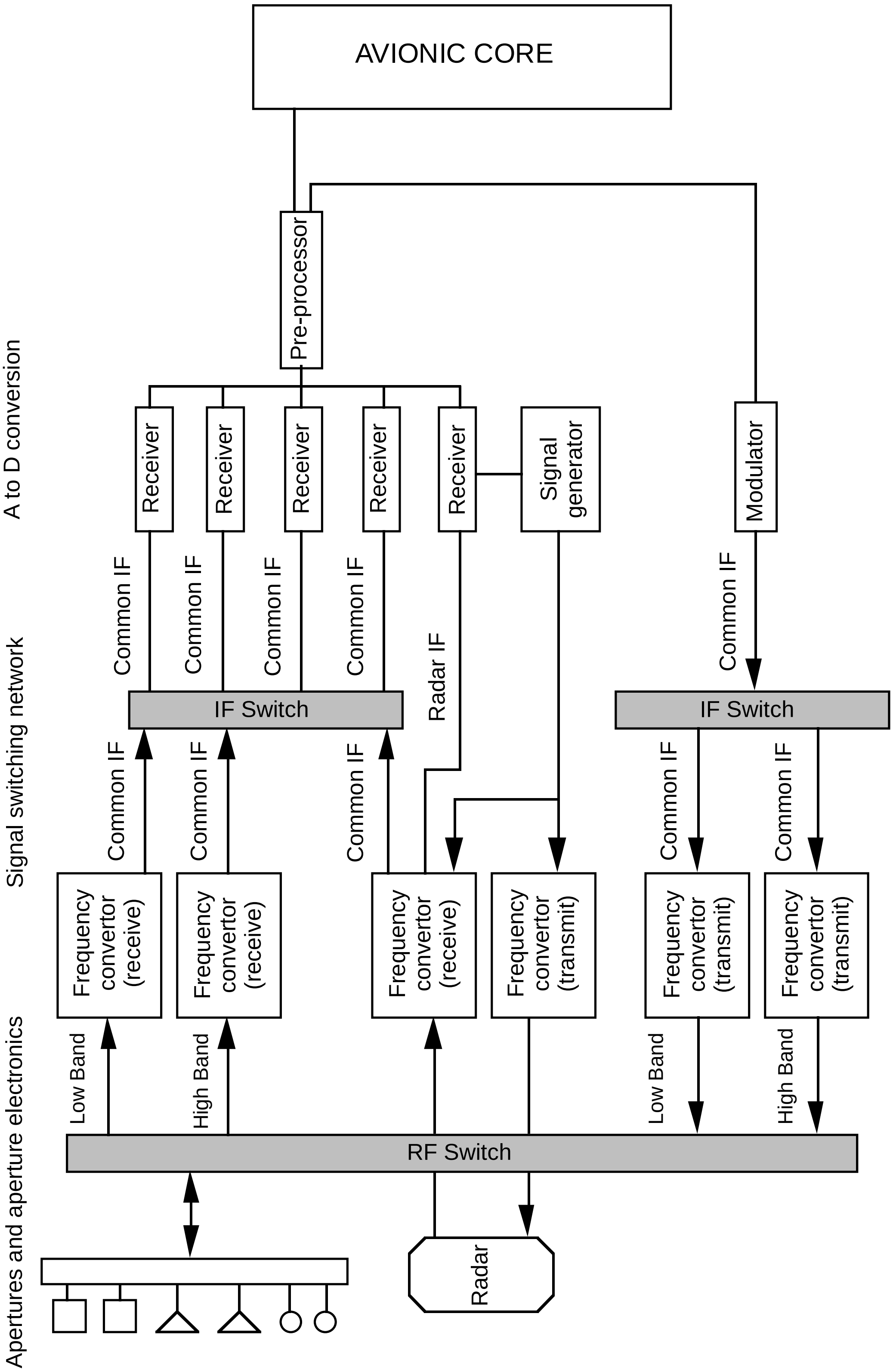


**Figure 7: Interpretation of ISS**

In its most idealistic and extreme form ISS would have only one or two shared apertures for sensors covering the whole frequency spectrum from high frequency (HF) radio sources to light. However the concept is just aimed at reducing the number of apertures significantly and thus applies especially to reducing the numbers of radio frequency (RF) antennas. For this concept to be seriously contemplated there are several critical technological problems that need to be solved, including the supply of re-configurable GaAs Milli-metric wavelength Integrated Circuit (MMIC) components, very wide band optical links and a whole range of new and specialised wide band RF components. The radar would need to be in the form of a linear phased array and at the same time have multi-octave bandwidth capability to cope with communication requirements - a combination which is not currently feasible. One advantage of ISS is that raw sensor data could be made available to a very high data rate optical network to allow for a data fusion capability.

### e) Civil IMA Programmes

Within the UK the best example of civil IMA development came from the Control Technology Programme (CTP) which was a 5 year UK Department of Trade and Industry (DTI) sponsored research programme which ended in 1996. The programme investigated a broad range of issues related to the specification, design, procurement and application of IMA to both future fixed and rotary wing aircraft.

The programme culminated in an IMA technical demonstrator for large civil aircraft primary and secondary flight control functions (Systems Digital Control Laboratory at Airbus, Filton) which consisted of two computing resources (integrated cabinets) housing standard processing and I/O modules connected using dual redundant ARINC 629 data buses. One bus lane was engineered using an experimental fibre optic system.

The CTP was followed by a new programme called Platform Applications for Commercial Aircraft Systems for the 21st Century (PACTS 21) which is currently developing IMA technologies further particularly in the application to IMA to civil aircraft sub-systems such as fuel management and landing gear functionality.

The main components of the CTP/PACTS21 IMA architecture are illustrated in figure 8. The avionic modules are contained in cabinets and interfaced to actuators, sensors and remote data concentrators by means of the redundant 629 data buses.

ARINC have already produced documents and standards supporting the introduction of IMA into civil aircraft. Two that are of interest to the EMC community are ARINC 650 which defines IMA packaging and design issues and ARINC 654 which defines environmental issues.

Considering the schematic of the IMA cabinet shown in figure 8, one of the dominating design features of the cabinet is that cooling of the PCB modules is by natural convection which not only limits power dissipation per board to about 17 W, but requires many ventilation apertures which reduce EMC shielding to about 6dB.  There is still much debate as to whether these two parameters are acceptable.

A necessary improvement to the system is a filter module which prevents EMI coupling between the modules and the data bus.  Conducted emissions and conducted immunity of the power supply system are controlled separately.  A 'strawman' for a proposed filter module has been formulated by a working group of the European Aircraft EMC Research Group.

This avionic system has a limited BIT capability but no automatic re-configuration facility.

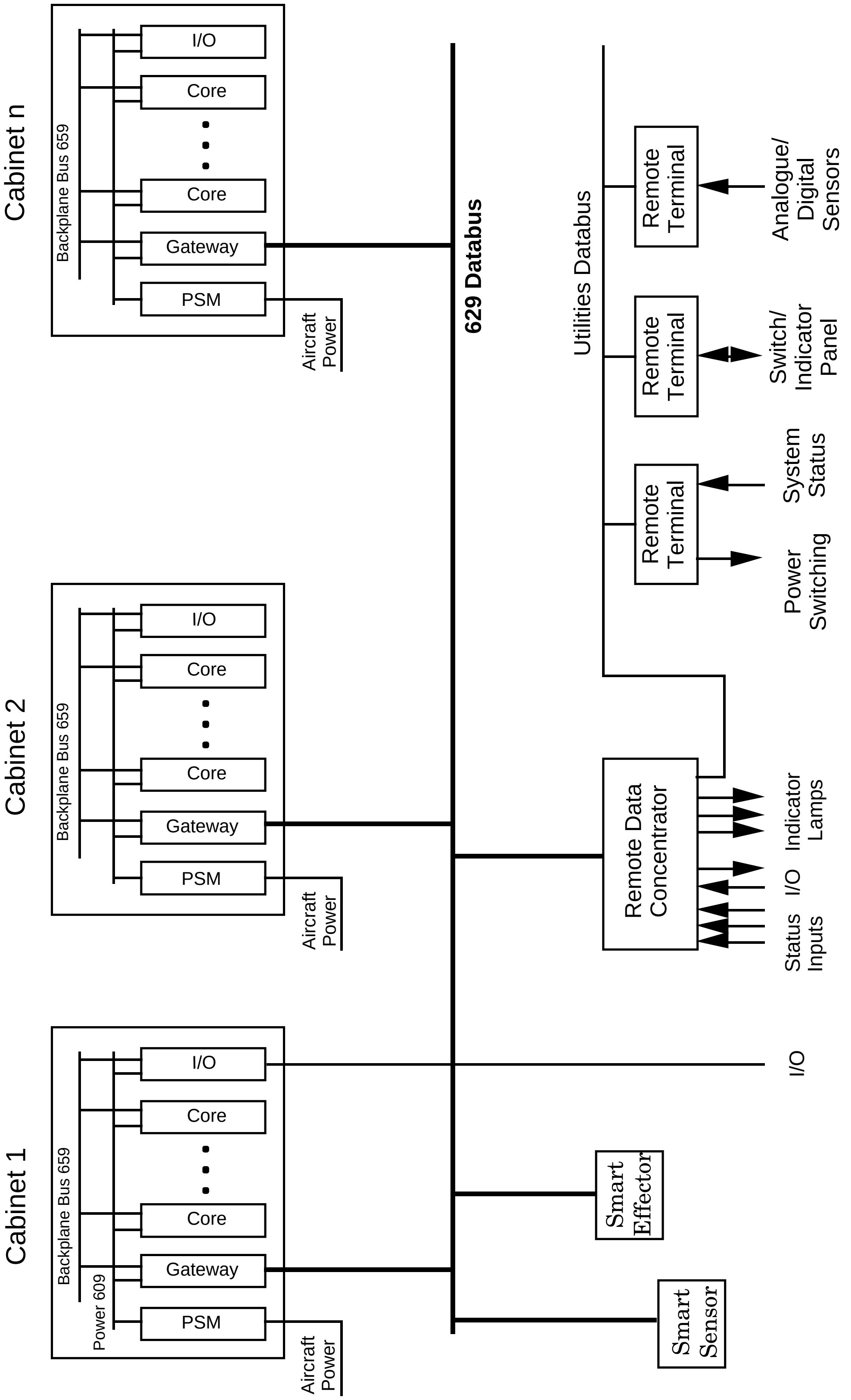


**Figure 8: Civil IMA Architecture for BAe Airbus**

## ANNEX B: EXISTING SPECIFICATIONS AND STANDARDS

(The reader should consult the latest issues of the following standards)

**Def Stan 59-41**

Applicable to complete military systems (not specifically modular avionics).

**RTCA DO-160**

Environmental specifications and tests applicable to equipment and sub-systems, both civil and military. Specific to aircraft.

**MIL-STD-461**

**'Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility'**

Applicable to military equipment and subsystems; US tri-service.
In 2 parts (requirements and handbook, containing rationale, guidance and experience).
Calls up MIL-STD-462.

**MIL-STD-462**

**'Measurement of Electromagnetic Interference Characteristics'**

Applicable to military equipment and subsystems; US tri-service.
In 2 parts (requirements and handbook, containing rationale, guidance and experience).
Calls up MIL-STDs-461 and 45662 (Calibration Systems Requirements).

**MIL-STD-464**

**' Electromagnetic Environment Effects for Equipment'**

Applicable to military equipment and subsystems; US tri-service.