

Design of electromagnetic hazard protection of civil aircraft —

Part 3: Guide to clearance and testing

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- Civil Aviation Authority (Airworthiness Division)
- ERA Technology Ltd.
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- Society of British Aerospace Companies

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Foreword

This part of BS G 257 has been prepared by Technical Committee ACE/66, and provides information to engineers involved in all levels in the hardening of civil aircraft and their systems against electromagnetic hazards (EMH).

BS G 257, *Design of electromagnetic hazard protection of civil aircraft*, is published in three parts:

- *Part 1: Guide to the theory and threats;*
- *Part 2: Guide to protection;*
- *Part 3: Guide to clearance and testing.*

The way to effectively ensure that a complex electronic system will be resilient to the effects of EMH is to impose a visible and tightly controlled design, procurement and development process to control electromagnetic compatibility (EMC) issues, from the very beginning of a project. The way in which this is achieved is very much a matter of policy within individual companies. This part outlines the main aspects of an effective EMC design and control process.

The testing required to achieve EMC clearance by demonstrating that an aircraft is free of critical EMC problems is a process that starts as early as possible and continues throughout the development of the aircraft. The testing can be divided up into four types; component testing, rig testing, testing during assembly and whole aircraft testing. The degree of testing will depend on the criticality of the system, with systems performing functions such as flight and engine control being subject to more strenuous requirements than systems of a lower criticality.

WARNING This British Standard calls for the use of substances and/or procedures that may be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage. Wherever tests involve the radiation of radio frequency (RF) energy, attention is drawn to all the relevant safety procedures; including those concerning biological radiation hazards, fuel vapour explosion hazards and the inadvertent initiation of electro-explosive devices (EEDs).

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 37 and a back cover.

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Introduction

In the past, aircraft were flown using mechanical systems to control the engines and to move the flying control surfaces. Many of the functions previously performed solely by mechanical systems have either been assisted or replaced by electronic circuits. Likewise, many of the cockpit instruments which previously were mechanical in nature have been integrated into electronic instrument systems. As aircraft systems become increasingly complex, aircraft are dependant upon electronic-based systems to provide not only basic flight and engine control functions, but also flight data displays and navigation. Increased reliance upon electronic equipment and systems makes protection against EMHs a prime requirement, with the number of EMHs which can potentially result in interference with normal system operation rising rapidly. As a result, a complete aircraft EMC test is complicated and needs careful thought and planning.

The system modes which need to be tested have to be carefully considered, as do the failure criteria and the means by which the system behaviour is monitored during testing so the electromagnetic behaviour of the aircraft and its systems is not invalidated.

EMHs for civil aircraft include the direct and indirect effects of lightning, static charging, high intensity radiated fields (HIRF) from external emitters, the on-board RF environment due to the aircraft's own transmitters and the self-generated RF and electrical induced transients. However, this standard only covers the clearance and testing for the indirect effects of lightning, HIRF and inter-system EMC.

1 Scope

This part of BS G 257 is written to assist engineers working at all levels within companies involved in the aircraft industry to meet the applicable EMH requirements.

This part of BS G 257 is intended to assist engineers with planning the certification process and to ensure that the correct processes are applied to the writing of procedures and plans, and that the presently recognized methods of test are appropriately used.

The guide does not contain mandatory requirements, only guidance to assist in the solution of design problems.

The guide does not cover:

- a) the protection of the airframe against the structurally damaging, direct effects of lightning;
- b) the design of communication systems in order to produce interference free operation since it is felt that these aspects of RF systems design are covered in adequate detail in other documents e.g. *Minimum Operational Performance Specification* (MOPS). The problems of interaction between radio receivers and transmitters are still an important aspect of EMC problems;
- c) electrostatic discharge.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of BS G 257. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS G 257-1, *Design of electromagnetic hazard protection of civil aircraft — Part 1: Guide to the theory and threats.*

BS G 257-2, *Design of electromagnetic hazard protection of civil aircraft — Part 2: Guide to protection.*

3 Certification process

3.1 Planning

3.1.1 Aircraft systems should operate safely during and after exposure to any EMHs in order that safe take-off, flight and landing are achieved. To ensure safe operation, systems should be assessed to determine how an aircraft reacts to an encounter with an electromagnetic effect. The outcome of this evaluation is an EMH criticality list which identifies the EMH criticality of each piece of equipment. The purpose of the criticality list is to optimize the EMC design and test effort.

3.1.2 The interactions which should be considered as requiring testing for clearance include the following:

- a) interaction between systems which unintentionally produce and/or are susceptible to electromagnetic interference;
- b) interaction between systems which intentionally transmit electromagnetic radiation and/or are susceptible (e.g. the ILS and VHF systems, the fuel gauging system and HF transmission);
- c) interaction between the external electromagnetic environment and the potentially susceptible systems (e.g. the induced effects of lightning on fly-by-wire systems).

3.2 Route to certification

3.2.1 In general, the process described in Figure 1 applies to all certifications. Clauses 4 to 13 of this guide describe in greater detail the major elements of the route to certification against the effects of electromagnetic hazards.

3.2.2 A number of philosophies exist to achieve the certification of systems installed in aircraft. The choice of which is most appropriate depends on the criticality of the function performed by the system and the amount of electromagnetic data available (see Clause 4). Before any further progress can be made towards certification, a definition of the effects of the failure of all functions should be made and agreed with the certification authorities.

3.2.3 Having agreed the criticalities of the functions to be certified, it is then possible to adopt a philosophy that will result in the most cost effective route to certification. It is necessary to consider whether a whole aircraft test is required, or if it is possible to determine the data needed to demonstrate adequate immunity by other means, such as analysis, equipment tests or similarity (see Clause 5).

3.2.4 Both internal and external environments should be considered when producing a certification plan (see Clause 6).

3.2.5 Testing at both aircraft (see Clause 11) and equipment (see Clause 8) level is appropriate for the clearance of some elements of the total certification process. This should follow an agreed test plan (see Clause 7) which should cover all aspects of the electromagnetic environment within which the functions being certified are located (see Clauses 10 to 12).

3.2.6 Having obtained all the data needed for the agreed test plans, a certification report should be produced (see Clause 13).

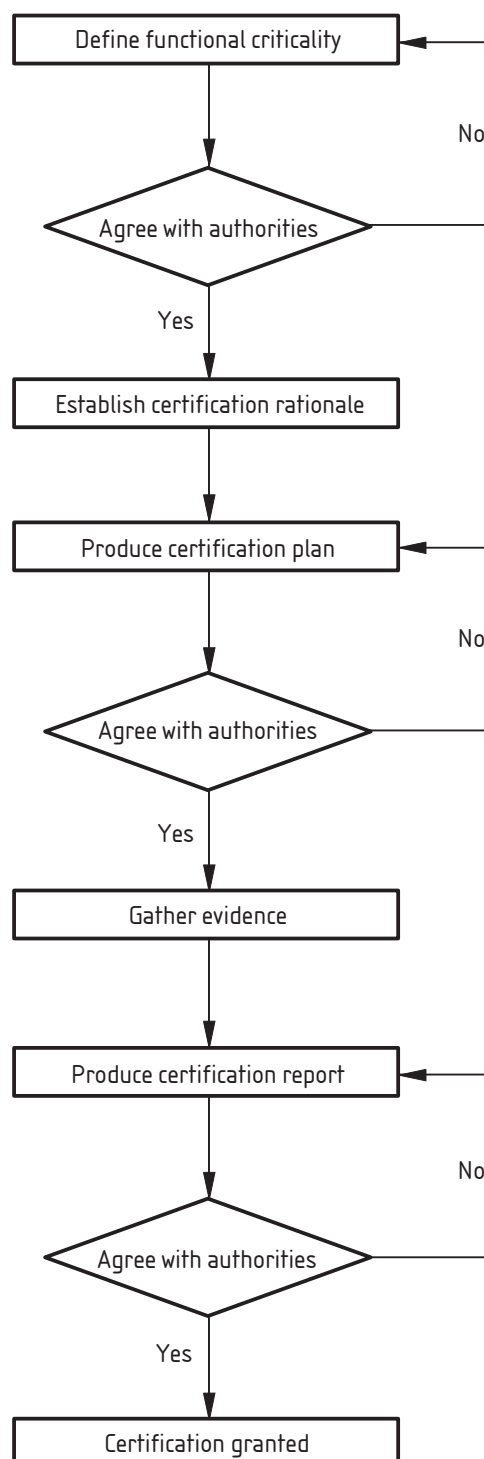


Figure 1 — Route to certification

4 Functional criticality

4.1 General

4.1.1 Early in the project design phase, the effect of system failures should be assessed. This normally takes the form of a *Functional Hazard Assessment* (FHA) which identifies the effects of the failure modes of the equipment being installed and classifies them in their functional and operational terms. This document provides the basis for the full *System Safety Assessment* (SSA) which analyses the causes of failures leading to the effect in the FHA. The output from the assessment is that the functional failures are classified as one of catastrophic, hazardous, severe-major, major or minor.

4.1.2 EMH effects are unique because of their common-mode effect on system failures, that is where all elements of a particular sub-system are affected simultaneously. Thus the FHA should be extended to ensure that common-mode failures are taken into account.

4.1.3 An aircraft's operating phases should be considered since the classification of a function failure may change dependant upon the phase of flight the aircraft is in. For example, a failure in the automatic flight control system (AFCS) might be insignificant when the aircraft is cruising but the same failure when the aircraft is on an approach could be significant.

4.2 Assessment of criticality

4.2.1 Conformity with the appropriate airworthiness regulation is required for any system which can cause, or contribute to, an effect upon the safety of flight of the aircraft. The SSA is based on an FHA which considers only the effects of the identified failures. The effects of an encounter with, for example, HIRF should be assessed in a manner which allows the determination of the degree to which the aircraft and/or its systems may be influenced with respect to safety of flight. The operation of systems, separately and in combination with and/or in relation to other systems, should be addressed in this respect. The assessment should include all modes of normal operation and of failures and their subsequent effect upon the aircraft, considering the stage of flight and operating conditions and the awareness of the crew to the failure. Levels of protection for electrical and electronic systems are established dependant upon the system failure condition category (see Table 1).

4.2.2 The system failure condition category should be assessed by performing an FHA during the certification process, and should be approved by the appropriate airworthiness authority. Since the FHA defines the functional criticality of the system(s) under consideration, it leads to a definition of the level of immunity required by each system with respect to electromagnetic hazards.

4.2.3 For a complete definition of failure condition categories, refer to the applicable regulations and guidance material, for example Joint Aviation Authorities' advisory material AMJ 25.1309 [1]. The failure condition categories listed in Table 1 are derived from this guidance material and are included to assist in the use of this document.

5 Certification rationale

5.1 General

5.1.1 The rationale adopted for any particular function will be dependant upon the FHA, described in Clause 4. In all cases, the work should consider the effects of HIRF, both direct and indirect effects of lightning and the compatibility with on-board systems. It is recommended that the guidance in the appropriate advisory material is always followed.

5.1.2 Where the aircraft is wholly new or contains modifications that are significantly different electromagnetically from the previously certified standard, it is important that a valid appraisal of its EMC is performed. The approach adopted should be fully discussed in the *Certification Plan* (see Clause 6).

5.1.3 Depending on the maturity of the aircraft and the available certification data, it could be possible to achieve certification by means of similarity or by the use of existing test data. Alternatively, analytical methods could be more cost effective than test if a fully verified modelling system is available. This may be dealt with in a number of ways as described in 5.2, 5.3, 5.4 and 5.5.

Table 1 — Functional criticality

Functional criticality	Definition
Functions whose failure would have a CATASTROPHIC effect	Function whose failure condition would prevent continued safe flight and landing
Functions whose failure would have a HAZARDOUS or SEVERE-MAJOR effect	Function whose failure condition would reduce the capability of the aircraft/rotorcraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be: a) a large reduction in safety margins of functional capabilities; b) physical distress or higher workload such that the flight crew could not be relied upon to perform their tasks accurately or completely; c) serious (or fatal) injury to a relatively small number of occupants
Functions whose failure would have a MAJOR effect	Function whose failure condition would reduce the capability of the aircraft/rotorcraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries
Functions whose failure would have a MINOR effect	Function whose failure would not significantly reduce aircraft/rotorcraft safety, and which involve crew actions that are well within capabilities. Minor failure conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some inconvenience to occupants
Functions whose failure would have NO EFFECT	Failure conditions which do not affect the operational capabilities of the aircraft or increase crew workload

5.2 Whole aircraft test

This test should be used when systems performing functions whose failure will have a catastrophic effect are to be certified and valid data concerning the effects of HIRF do not exist. It might not be cost effective to use a whole aircraft test to investigate the effects of lightning, either direct or indirect. An overview of the compatibility of the systems installed on an aircraft may be obtained by exercising each system in turn, and monitoring all potential susceptors for upset. Inter-system testing is described in Clause 10.

5.3 Equipment tests

Equipment level tests are necessary to support the evaluation of compatibility. Whether for immunity against the effects of HIRF or of lightning, an internationally recognized standard, such as EUROCAE ED-14D/RTCA DO-160 [2], should be used to evaluate the immunity of the equipment against the particular environment under consideration.

5.4 Analysis

It may be cost-effective to analyse the indirect effects of lightning or of HIRF, using a fully-verified model of the interaction. This analysis involves construction of a computer model of the structure containing the LRUs to be tested and routing of all the wiring within it. The model is then used to evaluate the internal environment to which the LRU and its associated wiring are exposed. This can be compared with the outcome of the equipment level tests, providing that these have been performed in a manner that is accepted as being representative of the actual installation by the airworthiness authorities.

5.5 Similarity

5.5.1 General

Where information already exists concerning the electromagnetic environment and it can be shown that this information is applicable to the new installation then compatibility may be shown by similarity.

5.5.2 HIRF and lightning

5.5.2.1 For systems performing functions whose failure has a catastrophic effect, the existing data need to be based on the results of aircraft level testing for HIRF and on the findings of either aircraft level tests or of an analysis using a fully-validated code for the indirect effects of lightning.

5.5.2.2 For systems that perform functions whose failure would have a hazardous or major effect, then the existing data may be based on bench tests or on the use of generic curves for HIRF.

6 Certification plan

6.1 General

The certification plan is based on the FHA and should be produced as early in the certification process as possible so the certification authorities are aware of the work that is planned for demonstration of conformity. The certification plan should be agreed with the authorities before work commences.

6.2 Contents

The certification plan should typically contain:

- a) a brief system description;
- b) a definition of the certification requirements which are to be met;
- c) a summary of the functional criticalities;
- d) a detailed description of the planned work i.e. test, analysis, or both which will be undertaken and a justification of the validity of the approach taken;
- e) a list of documents to be submitted in support of the application for certification.

7 Test plan

7.1 Test plan key elements

The key elements for inclusion in a test plan are:

- a) an outline description of the operation of the systems to be tested;
- b) the pass/fail criteria for each of the systems;
- c) the methods of achieving testable system modes;
- d) the methods of response measurement to be used;
- e) the approach to calibrating the system prior to test;
- f) the approach to calibrating the aircraft prior to test.

7.2 Outline description of the operation of the systems to be tested

It is important to understand the way in which each system operates in order to identify modes in which it needs to be operated for the tests and the way in which the system could be monitored for malfunction. This description only gives an overview of the system behaviour, the full system description being referenced for additional information. In addition, interference behaviour is unpredictable and when effects are observed, an understanding of the operation of the system is useful.

7.3 Pass/fail criteria for each of the systems

7.3.1 One of the more difficult areas of EMC testing is the necessity of testing on the ground, resulting in the absence of airframe motion and aerodynamic feedback. Methods for overcoming this should be considered when planning a test and judging the results.

7.3.2 There should be a basis upon which the system is deemed to have failed the test. This judgement can require considerable analysis prior to the test and should be in place and agreed by all parties concerned.

7.4 Methods of achieving testable system modes

7.4.1 Many systems on the aircraft obtain stimuli or inputs from a number of sources. Similarly, they can produce outputs to a number of points. Not all inputs and outputs are being utilized at all times; this can depend on the mode in which the system is being operated which in turn can be a matter of pilot choice or flight condition.

7.4.2 It is imperative that testing of the complete aircraft covers all possibilities and that monitoring methods ensure that responses are being observed at the correct point and that the inputs which are being tested for interference effects at any one time are those which are active at the same time.

7.4.3 In order to ensure system conditions are such that certain inputs and outputs are active whilst the aircraft is on the ground, sensor inputs and outputs might have to be provided or simulated by ground test equipment. This should be achieved in a manner which does not alter the electromagnetic condition of the aircraft or system.

7.5 Methods of response measurement to be used

7.5.1 The coupling paths which should be considered during an analysis of the system for the purposes of writing a test procedure include:

- a) conducted paths via deliberate connection for system function; the most common concern is the power supply network;
- b) cable-to-cable coupling, often between adjacent cables in the same loom, particularly below a few hundred megahertz;
- c) field-to-cable coupling (e.g. transmitting antenna to system cables), again more likely below a few hundred megahertz; the reverse process causing noise on RF systems is becoming more common; and
- d) field-to-aperture coupling (e.g. transmitting antenna to equipment case aperture), more likely above a few hundred megahertz.

7.5.2 The increased use of digital interfaces has eased the monitoring and stimulation of systems in a manner that does not alter the electromagnetic condition of the aircraft or system. Fibre optic cables can be used to penetrate the airframe or system without corruption of the test environment.

7.5.3 Ground services can cause problems. Careful routing and earthing can usually overcome these difficulties.

7.5.4 Battery-operated stimuli may be used and placed within the fuselage of the aircraft.

7.5.5 RF telemetry is also useful as a non-ohmic means of system monitoring.

7.6 Preparing the aircraft and/or system prior to test

7.6.1 The aircraft, or relevant part of the aircraft to be tested, should be in a representative and defined working condition prior to the test and such a condition should be ensured as part of the test plan. It is preferable to use a complete and fully functional aircraft or system.

7.6.2 RF transmitters should be checked for specified output power and the antennas and feeders need to be checked for installed voltage standing wave ratio (VSWR) or impedance match.

7.6.3 Non-radiating systems should be checked for correct functionality prior to testing. This is greatly eased by built-in test equipment (BITE).

7.6.4 Documentation, in terms of electrical bonding, cable and equipment installation, should be checked to provide the necessary assurance that the aircraft or equipment is representative of its type.

7.6.5 Large departures of aircraft or equipment EMC behaviour from previously acquired laboratory test results should initially be treated with suspicion arising from possible installation problems.

8 Equipment level testing

8.1 General

8.1.1 EUROCAE ED-14/RTCA DO-160 [2] is the standard document for civil aircraft equipment level testing. This document is being continually updated and hence the latest version of test techniques and levels should always be considered. It has been endorsed and implemented as an International Standard, ISO 7137, which has been further endorsed in the UK as BS G 229.

8.1.2 EUROCAE ED-14/RTCA DO-160 [2] defines a series of standard environmental test conditions (categories) and applicable test procedures for airborne equipment. The purpose of these tests is to provide a means of determining the performance characteristics of airborne equipment in environmental conditions representative of those which may be encountered. Equipment with special characteristics may require test variations as specified by equipment or airframe manufacturers. These tests are sufficient to obtain environmental qualification of the equipment. Additional tests may be necessary to certify the installation of systems in an aircraft dependant on the functions performed.

8.1.3 The standard environmental test conditions and applicable test procedures contained therein may be used as a minimum set of environmental conditions and tests, which can assure a sufficient degree of confidence in performance during operation. The environments specified in EUROCAE ED-14/RTCA DO-160 [2] need to be used carefully and always compared with the actual internal environment to which the system will be exposed. Tests from EUROCAE ED-14/RTCA DO-160 are described in **8.2** to **8.9.3**.

8.2 Magnetic effect

This test determines the magnetic effect of the equipment in terms of its influence on a free compass to assist the installer in choosing the proper location of the equipment in the aircraft.

8.3 Power input

This test defines the quality of electrical power applied to the terminals of the equipment under test.

8.4 Voltage spike

This test determines whether the equipment can withstand the effects of voltage spikes at the equipment on its power leads, either a.c. or d.c.

8.5 Audio frequency conducted susceptibility — Power outputs

This test determines whether the equipment will tolerate frequency components of a magnitude normally expected when the equipment is installed in the aircraft. These frequency components are normally harmonically related to the power source fundamental frequency.

8.6 Induced susceptibility

This test determines whether the equipment will accept a level of audio frequency signals and transients that are generated by other on-board equipment.

8.7 RF susceptibility (radiated and conducted)

8.7.1 These tests determine whether equipment will operate within performance specifications when the equipment and its interconnecting wiring are exposed to a level of RF modulated power, either by a radiated RF field or by injection onto the power lines and interface circuit wiring.

8.7.2 The tests simultaneously exposes the circuits associated with the equipment connector(s). There may be circumstances where it becomes necessary to assess interface circuits on an individual basis. The individual circuits may require other levels (at their corresponding frequencies) when unique installation conditions prevail. Large equipment with multiple connectors may preclude use of the injection probe method and require other test equipment and conditions.

8.8 Emission of RF energy

These tests determine that the equipment does not emit undesired RF noise in excess of the levels specified.

8.9 Lightning-induced transient susceptibility

8.9.1 These test methods and procedures apply idealized waveforms to verify the capability of equipment to withstand effects of lightning-induced electrical transients.

8.9.2 Two groups of tests may be used for equipment qualification. The first is a damage tolerance test performed using pin injection, the second group evaluates the functional upset tolerance of equipment when transients are applied to interconnecting cable bundles. Cable bundle tests can also provide an indication of damage tolerance.

8.9.3 These tests may not cover all aspects of lightning-induced interaction and effects on equipment, particularly when incorporated into a system. Additional tests, such as simultaneous cable bundle injection, multiple stroke, multiple burst and/or multiple frequency, could be required to achieve system certification.

9 Power supply disturbances

9.1 Main areas of disturbance

Upset of system function can occur in the event of incompatibility between the power supply and the load. As a consequence, the compatibility of a system and its power supply should be demonstrated. Three main areas of disturbance should be considered as described in **9.2**, **9.3** and **9.4**.

9.2 Transients

9.2.1 These arise from power supply switching when load carrying devices change state or when the load changes significantly. The only effective way to demonstrate that transients do not upset system function is by test. This is usually performed on an iron bird or system rig which has a largely representative aircraft wiring standard. Alternatively an aircraft can be used.

9.2.2 The process of test follows closely that of the demonstration of immunity from internally generated EMI (see Clause 8). Prior to any testing, an analysis should be performed to produce a matrix of all equipment modes against all significant bus-bar switching operations. This should include the selection/deselection of equipment either by switching or by tripping circuit breakers. The matrix should then be systematically worked through on the rig or aircraft, recording the effects of each change of state on the equipment under test. It is useful to record the waveforms of any/all transients generated for future use.

9.3 Over and under voltages

These arise from significant load changes, e.g. during an engine start cycle. Under these circumstances the variation in power supply can cause upset or even disconnect the function. Equipment is tested against over and under voltages during qualification and it is generally the airframe manufacturer's responsibility to ensure that the aircraft power supplies are of adequate quality. An uninterruptable supply may be required.

9.4 Harmonics

Harmonics result from a significant change of load impedance or from rapid switching such as is found in switch mode power supplies. Equipment containing switch mode power supplies should be qualified to a well-defined standard and, consequently, should not emit harmonics which can cause problems of compatibility. To ensure that no problems occur, the system needs to be tested, either on a representative systems bench or on the aircraft. Significant changes of load impedance should be assessed during tests to identify the effects of transients.

10 Inter-system EMC

10.1 General

10.1.1 There is an increasing use of complex flight safety critical avionic systems and sensitive navigation and communication equipment in modern aircraft. It is essential to ensure that adequate EMC exists between these systems when installed in the airframe.