

**(R) Guide to Certification of Aircraft in a High-Intensity
Radiated Field (HIRF) Environment**

RATIONALE

This revision incorporates changes throughout that are consistent with new Federal Aviation Administration HIRF certification regulations and certification guidance adopted in 2007. It also includes revised test methods that were developed after the original release of this ARP. The organization of the ARP was revised to be consistent with the certification steps described in AC 20-158.

Due to the extensive re-work and re-organization of this revision the standard 'change bar' indications for the changes are not shown, therefore, an 'R' has been placed before the document title.

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1. SCOPE

This guide provides detailed information, guidance, and methods related to the Federal Aviation Administration (FAA) Advisory Circular (AC) 20-158 and European Aviation Safety Agency (EASA) draft Advisory Material Joint (AMJ), both titled "The Certification of Aircraft Electrical and Electronic Systems for Operation in the High-Intensity Radiated Fields (HIRF) Environment". The AC provides acceptable means, but not the only means, of compliance with Title 14, Code of Federal Regulations (14 CFR) 23.1308, 25.1317, 27.1317, and 29.1317, High-Intensity Radiated Fields (HIRF) protection for Aircraft Electrical and Electronic Systems, and applicable FAA HIRF Special Conditions to prevent hazards to aircraft electrical and electronic systems due to HIRF produced by external transmitters. It is also intended for this guide to provide the same information, guidance, and methods to the European Aviation Safety Agency (EASA) interim HIRF policies certification requirements.

This guide is neither mandatory nor regulatory in nature and does not constitute a regulation or legal interpretation of the regulation. The information in this guide represents a collection of best engineering practices that have been used to certify aircraft HIRF protection. An applicant may elect to establish an alternative method of compliance that is acceptable to the cognizant airworthiness authorities.

This document is consistent with the guidance in FAA AC 20-158. The AC 20-158 and draft HIRF AMJ may be referenced in aircraft certification requirements such as JAA/EASA certification review items. While this document is generally consistent with AC 20-158 and draft HIRF AMJ, users of this document should verify that the guidance in this document is acceptable to the cognizant airworthiness authorities.

1.1 Purpose

This document provides technical guidance to demonstrate compliance with aircraft High-Intensity Radiated Field (HIRF) regulations. This guide may be applied to new aircraft, modification of existing aircraft, and installation of existing systems on an aircraft that has not previously used that equipment. The HIRF regulations apply to aircraft electrical and electronic systems, including power distribution systems, electrical generating systems, electronic engine control systems, electronic flight control systems, and navigation, communication, and flight reference systems. The term 'systems' refers to electrical and electronic equipment; interconnecting power, signal, and control wiring; indicators; control panels; sensors; and software.

The HIRF regulations apply to systems installed on transport airplanes, normal and transport category rotorcraft, and small airplanes. A certification applicant must demonstrate that aircraft systems that perform functions whose failure could prevent continued safe flight and landing are not adversely affected when the aircraft is exposed to the HIRF Environment I, II or III, as specified in the regulations. Additionally, systems performing functions related to the ability of the flight crew and aircraft to operate in adverse operating conditions must not be adversely affected during and after exposure to equipment test levels specified in the regulations. The approach to achieving HIRF certification is through appropriate system protection, qualification, and installation.

Aircraft operate in a number of electromagnetic environments. This document, however, only addresses HIRF. For other electromagnetic environments, reference the appropriate regulations, requirements, standards, and guides.

To avoid confusion with other electromagnetic environments and to provide a means of readily identifying the engineering associated with these regulations, the term 'high intensity radiated fields' will be used along with the abbreviation HIRF in this document.

1.2 Aircraft and HIRF

In the past most aircraft used a series of cables, chains, cranks, and mechanical mechanisms to operate the systems which gave the aircraft its ability to fly. With the advent of the transistor many mechanical devices have been replaced or augmented with electronic circuits. Electronic circuits have increasingly been designed and used for flight critical aircraft control systems, due to their ability to accurately control complex functions and increase reliability. Electronic circuits, however, not only respond to their internal electrical signal flow, but may respond to any input which can couple into the wire bundles, wires, IC leads, and electrical junctions. The Electromagnetic Environment (EME) is one of these inputs that by its nature has access to all these electronic circuits and may result in disabling effects called Electromagnetic Interference (EMI).

Concern for the safety of flight of aircraft employing electrical/electronic systems when subjected to the effects of an external HIRF environment has increased substantially due to the following principal factors:

- a. Greater dependence on electrical/electronic systems performing functions required for continued safe flight and landing.
- b. Possibility of reduced Electromagnetic (EM) shielding afforded by composite materials.
- c. Potential increase in susceptibility of integrated circuits due to increased operating speed and density.
- d. The expectation that the external RF environment will become increasingly severe due to an increase in the number and power of RF emitters.

The reliance upon similar redundancy as a means of protection against the effects of HIRF may be negated if the backup systems are also electronic and susceptible to HIRF.

The aircraft skin and structure have also evolved. The classic aircraft is made of aluminum and titanium structure with an aluminum skin. Modern technology and the desire to develop more efficient aircraft (the efficiency being an aircraft that can carry more payload further) have driven the introduction of carbon-epoxy structure, carbon-epoxy skins, and aramid fiber-epoxy skins in civil aircraft. Aluminum may be a good EM shield against HIRF and hence electronic circuits are provided inherent protection. However, some composites are poor EM shields, causing HIRF to irradiate the electronic systems on such aircraft with relatively little attenuation (when compared to aluminum aircraft structure and skin).

This guide stresses the need to balance the HIRF hardening design between equipment and the aircraft to provide adequate protection from HIRF. The intended result is an aircraft certification wherein the safety of flight will not be compromised when the aircraft encounters HIRF.

2. REFERENCES

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of the other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE International Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP4754 Certification Considerations for Highly-Integrated or Complex Aircraft Systems

ARP4761 Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

2.2 Other Publications

- a. 14 CFR/JAR and EASA CS
- b. HIRF AC 20-158

NOTE: AC 20-158 referenced in this guide refers to the latest version available.

- c. This guide
- d. RTCA DO-160 and EUROCAE ED-14

NOTE: DO-160/ED-14 referenced in this guide refers to RTCA DO-160F (or latest issue) and EUROCAE ED-14F (or latest issue).

- e. EUROCAE ED-79, "Certification Considerations for Highly-Integrated or Complex Aircraft Systems"
- f. EUROCAE ED-135, "Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment"
- g. Naval Air Warfare Center Aircraft Division (NAWCAD) Technical Memorandum, Report No. NAWCADPAX-98-156-TM, High-intensity Radiated Field External Environments for Civil Aircraft Operating in the United States of America (Unclassified), dated November 12, 1998. A copy of the NAWCAD Technical Memorandum is available at: <http://www.tc.faa.gov/its/worldpac/techrpt/ar98-69.pdf>
- h. D A Bull, ERA Technology, Inc., ERA Report 98-0816, Development of the HIRF Environment, October 1998

2.3 Applicable Documents

2.3.1 Federal Aviation Administration Documents

The following documents can be obtained from the U.S. Department of Transportation; Subsequent Distribution Office; Ardmore East Business Center; 3341 Q 75th Avenue; Landover, MD 20785, www.faa.gov.

U.S. Title 14, Code of Federal Regulations (14 CFR) 23.1308, 25.1317, 27.1317, 29.1317, and applicable HIRF Special Conditions.

Advisory Circular 20-158, "The Certification of Aircraft Electrical/Electronic Systems for Operation in the High-Intensity Radiated Fields (HIRF) Environment".

2.3.2 Joint Airworthiness Authorities Documents

Interim Policies 23/1, 25/2, 27, 29/1, Protection from the effects of HIRF.

2.3.3 EASA Documents

EASA CS-23/25/27/29, interim HIRF policies and Certification Review Items (CRIs).

2.3.4 RTCA Publications

The following document can be obtained from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160F Environmental Conditions and Test Procedures for Airborne Equipment

RTCA DO-294C Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft

RTCA DO-307 Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

2.3.5 EUROCAE Documents

The following documents can be obtained from EUROCAE, 102, rue Etienne Dolet, 92240 Malakoff, FRANCE, www.eurocae.eu.

EUROCAE ED-14F Environmental Conditions and Test Procedures for Airborne Equipment

EUROCAE ED-79 Certification Consideration for Highly Integrated or Complex Aircraft Systems

EUROCAE ED-135 Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment"

2.4 Related Documents

The related reading material is vast and broad. The following list is intended to provide both the non-technical and technical person with sources of information. Many of the references contain their own bibliographies and provide additional information. Many of the documents in the following list have been updated and revised. Although only the basic document number is listed, it is recommended that the reader consult the appropriate version of the referenced documents.

2.4.1 U.S. Government Documents

The following documents can be obtained from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, www.ntis.gov.

National Institute of Standards and Technology (NIST) Tech. Note 1066, "Eigenmodes and the Composite Quality Factor of a Reverberating Chamber"

NIST Tech. Note 1092 Design, Evaluation and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements

NIST Tech. Note 1342 Measurement and Evaluation of a TEM/Reverberating Chamber

NIST Tech. Note 1361 Aperture Excitation of Electrically Large, Lossy Cavities

McConnell, Roger A., FAA Report DOT/FAA/CT 87/19, "Avionics System Design for High Energy Fields"

Clarke, Clifton A. and William E. Larsen, FAA Report DOT/FAA/CT 86/40, "Aircraft Electromagnetic Compatibility", June 1987

2.4.2 Military Standards

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.dpas.dla.mil/quicksearch/>.

MIL-STD-461F Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, dated 10 December 2007

MIL-STD-464A Electromagnetic Environmental Effects Requirements for Systems, dated 19 December 2002

MIL-STD-882D System Safety Program Requirements, dated 10 February 2000

2.5 Abbreviations

λ wave length

A ampere

AC alternating current

C capacitance or centigrade

cm centimeter

d distance

dB decibel

DC direct current

f or F	frequency
ft	feet
G	gain
GHz	gigahertz
Hz	hertz
I	current
J	skin current or joule
K	constant
kHz	kilohertz
km	kilometer
L	inductance
m	meter
mA	milliampere
MHz	megahertz
μ F	microfarad
μ m	micrometer
mm	millimeter
P	power
rms or RMS	root mean square
RPM	revolution per minute
s	second (time)
t	time
v	velocity
V	volt

2.6 Acronyms

A/C	Aircraft
AC	Advisory Circular
AM	Amplitude Modulation
AMJ	Advisory Material Joint

ARINC	Aeronautical Radio, Incorporated
ATC	Air Traffic Control
BCI	Bulk Current Injection
CFR	Code of Federal Regulations
COM	Communication
CPU	Central Processing Unit
CS	Conducted Susceptibility or Certification Specification (EASA)
CW	Continuous Wave
E	Electric Field
EASA	European Aviation Safety Agency
EM	Electromagnetic
EMI	Electromagnetic Interference
EUROCAE	European Organization for Civil Aviation Equipment
EUT	Equipment Under Test
FAA	Federal Aviation Administration
FM	Frequency Modulation
FO	Fiber Optic
GPS	Global Positioning System
HF	High Frequency
HIRF	High Intensity Radiated Fields
HLDD	High Level Direct Drive
HMI	Hazardously Misleading Information
ILS	Instrument Landing System
IC	Integrated Circuit
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JAA	Joint Airworthiness Authority
JAR	Joint Airworthiness Requirements
LF	Low Frequency

LLC	Low Level Coupling
LLDD	Low Level Direct Drive
LLSF	Low Level Swept Fields
LLSC	Low Level Swept Current
LRU	Line Replaceable Unit
MF	Medium Frequency
NIST	National Institute of Standards and Technology
NWA	Network Analyzer
PCB	Printed Circuit Board
PED	Portable Electronic Device
PRF	Pulse Repetition Frequency
PW	Pulse Width
RF	Radio Frequency
RS	Radiated Susceptibility
RTCA	Radio Technical Committee on Aeronautics
Rx	Receive or Receiver
SHF	Super High Frequency
SSA	System Safety Analysis/Assessment
T-PED	Transmitting Portable Electronic Device
TACAN	Tactical Air Navigation
TV	Television
Tx	Transmit or Transmitter
UHF	Ultra High Frequency
VFR	Visual Flight Rules
VHF	Very High Frequency

3. ELECTROMAGNETIC ENVIRONMENT

This section presents the external environments found to exist due to radiation of Radio Frequency (RF) electromagnetic energy into free space. This energy is radiated from radio, television, radar emitters, and from other sources. Contributing to the electromagnetic environment are more than 500 000 emitters in the U.S. and Western Europe. In addition to the presentation of the HIRF environments, this section discusses the history and background of the development of these environments. This section also presents the foundation, rationale, and assumptions that were used to establish these environments and discusses the impact these factors had on the final outcome.

The global electromagnetic environment is uncertain because environmental data is not available from other nations that may operate high power transmitters. The International Civil Aviation Organization (ICAO) has been requested to obtain HIRF data from its member states. The currently defined HIRF envelopes may be expanded to include this data when it becomes available. The cognizant airworthiness authorities together with other government agencies and international agencies such as ICAO and the International Telecommunications Union (ITU) plan a program to monitor the future growth of the electromagnetic environment.

3.1 Environment Development Process

It took several years to develop a detailed environmental model in the frequency range of 10 kHz to 40 GHz. These environments reflect the electromagnetic fields which civil aircraft flying under existing flight rules might encounter. The environments presented here were a result of lengthier deliberations and far greater refinements than had been available previously in either the military or civil aviation communities. The environments were defined from deployed emitters located in the continental United States, Hawaii, Alaska, and Puerto Rico, plus the five participating European countries: United Kingdom, Germany, Sweden, France, and the Netherlands.

The HIRF environments are a composite of transmitters that are airborne, land-based, off-shore platforms, and ship-based. These transmitters are becoming more sophisticated, more efficient, more powerful, and more numerous. The emitters cover the entire RF spectrum and their radiated fields vary greatly in energy levels and signal characteristics.

The subcommittee established the following environments:

- The Fixed Wing Severe HIRF environment was based on the worst case estimate of electromagnetic field strengths that a civil airplane might encounter. ICAO rules of the air allow flight to within 500 feet of the ground under Visual Flight Rules (VFR). At such an altitude, aircraft have the potential to come close to terrestrial-based emitters that produce RF field levels at the aircraft in excess of 7000 volts per meter.
- A subset of this environment was then created and called the Normal HIRF environment. The Normal HIRF environment contains just those emitters in the vicinity of representative airports in the United States and Europe. This Normal HIRF environment is considered to be the environment which civil aircraft encounter during normal flight operations. The Normal HIRF environment is identified as HIRF Environment II in the HIRF regulations and AC 20-158.
- Because of the very high field strengths estimated in the Fixed Wing Severe HIRF Environment, the committee developed a reduced environment suitable for the certification of Parts 23 and 25 airplanes. This new environment is called the Certification HIRF Environment, identified as HIRF Environment I in the FAA HIRF regulations and the AC 20-158. The distance assumption for non-airfield fixed transmitters was changed from 500 feet (VFR) to 1000 feet (IFR). This change was deemed appropriate taking into account likelihood of encounter and providing balanced requirements for all fixed wing airplane categories. HIRF Environment I is appropriate for fixed wing airplanes and rotorcraft Level A systems whose failure would be catastrophic in IFR operations.
- In addition, national flight operating rules may allow rotorcraft to fly and hover closer than 500 feet from obstacles and the ground during VFR operations. This resulted in the committee establishing the Rotorcraft Severe HIRF environment. The Rotorcraft Severe HIRF environment is identified as HIRF Environment III in the HIRF regulations and AC 20-158. HIRF Environment III is appropriate for rotorcraft Level A systems whose failure would be catastrophic in VFR operations

The field strength level in each band of the HIRF Environment I was the higher of the U.S. and the European environments. This section of the User's Guide explains how these environments were assembled and how they can be applied to determine the specific environment that would be used in the certification of a particular aircraft and its systems. In addition, this section describes the assumptions used to define the HIRF environments and methods used to calculate the field strength values.

Summarizing, the four following environments were established. The environment descriptions used in the HIRF regulations are in parentheses.

- a. Fixed Wing Severe (not used in HIRF regulations)
- b. Certification (HIRF Environment I)

- c. Normal (HIRF Environment II)
- d. Rotorcraft Severe (HIRF Environment III)

3.2 How the Environment was Computed

The RF environment has historically been divided into segments that reflect usage, power level, antenna gain effects, and propagation path losses. When the committee began its task of assembling the environments, it asked each member country to compile information on the emitters in their database. The emitter information was provided for each of the traditional frequency segments in the frequency allocation bands and included calculated field strengths arriving at an aircraft given a specified distance to each type of emitter. The power and other characteristics of that emitter used were those filed in the license application.

It was found that in each band there are typically a few emitters (or families of emitters radiated from identical equipment) which are noticeably greater than the other emitters in that band. Those emitters are called "band drivers." It would have been possible to subdivide the traditional frequency bands into finer and finer segments so that in some segments there would be a lowering of the environment from that which is presented in this report. There were national security difficulties in doing this. Additionally different countries have allocated adjacent segments for the same class of service. To construct an environment that is representative of the worst case on a worldwide basis, the risk cannot be taken of narrowing down to the frequencies that U.S. and participating European emitters are licensed to emit in but rather to consider those worst case emitters operating in the entire band which would be allocated to this use internationally.

Considerable effort was expended in isolating particularly strong emitters into narrow bands so as to diminish their effect on the overall environment. To summarize, in a band of frequencies only a few transmitters were on the air at very specific frequencies representing the most severe level of HIRF in that band.

This conservatism contributes to the robustness of the process and resulting influences for protection of the aircraft and results in intrinsic margin to the demonstration - at least in the radar frequency ranges - since the most effective coupling frequency in the band (i.e. aircraft/system frequency resonances) have to be considered for that frequency and its harmonics.

For further information on the development of the HIRF environments, consult:

- Naval Air Warfare Center Aircraft Division (NAWCAD) Technical Memorandum, Report No. NAWCADPAX-98-156-TM, High-intensity Radiated Field External Environments for Civil Aircraft Operating in the United States of America (Unclassified), dated November 12, 1998. A copy of the NAWCAD Technical Memorandum is available at: <http://www.tc.faa.gov/its/worldpac/techrpt/ar98-69.pdf>.
- D A Bull, ERA Technology, Inc., ERA Report 98-0816, Development of the HIRF Environment, October 1998.

The assumptions for aircraft exposure scenarios used for calculation of the environment, direct or slant as described in the paragraphs below, are taken out of NAWCAD report. The same assumptions were used for calculation of the USA and European environments although the terms used in the ERA report are slant and adjusted slant respectively.

3.3 Fixed Wing Severe HIRF Environment

The fixed wing Severe HIRF Environment has been assembled from four separate environments:

- a. Airport,
- b. Non-airport ground,
- c. Shipboard, and
- d. Air-to-air.

While on the ground, the aircraft will be exposed to emitters in the airport environment which include other aircraft emitters being operated on the ground. In flight the aircraft will also be exposed to emitters in the aircraft-to-aircraft, shipboard, and ground environments.

The emitters used in the calculation of field strength for the environments are:

a. Airport - fixed ground emitters:

1. Marker beacons,
2. ILS (localizer and glideslope),
3. Ground controlled approach radars,
4. Distance measuring equipment,
5. Tactical Air Navigation (TACAN),
6. Microwave landing systems,
7. Airport surface detection systems,
8. Non-directional beacons,
9. Airport surveillance radars,
10. Air-route surveillance radars,
11. Weather radars,
12. ATC - Radar Beacon System (RBS) interrogators, and
13. VHF and UHF communications and telemetry.

b. Airport - mobile ground emitters:

1. HF, VHF, and UHF communications,
2. TACAN,
3. Doppler navigation radars,
4. Weather radars,
5. Radio altimeter, and
6. ATC transponder.

c. Non-airport ground emitters:

1. Commercial MF; HF; VHF AM and FM; and TV broadcast transmitters,
2. Radars,
3. Troposcatter communications,
4. Loran C installations,
5. Satellites, and
6. Command and control facilities.

- d. Shipboard emitters:
 - 1. HF, VHF, and UHF communications,
 - 2. Navigation and tracking radars, and
 - 3. IFF/ Selective Identification Feature (SIF).
- e. Air-to-air (interceptor) emitters:
 - 1. Tracking radars,
 - 2. Various on-board radars, and
 - 3. HF, VHF, and UHF communications.
- f. Air-to-air (non-interceptor) emitters:
 - 1. Weather radars, and
 - 2. HF, VHF, and UHF communications.

3.3.1 Assumptions for the Calculation of the Fixed Wing Severe HIRF Environment

The Fixed Wing Severe HIRF Environment is a worst case estimate of the electromagnetic field strength levels in the airspace in which fixed wing flight operations are permitted.

The Fixed Wing Severe HIRF Environment considers transmitters in the following groups and aircraft to transmitter distances:

- a. Airport environment: The aircraft on the ground may be subjected to emitters having unique separation distances and geometries due to local terrain and runway/taxiway layouts. Because of these conditions, minimum separation distances for each category of emitter were specified as follows:
 - 1. 250 feet, Slant Range, for fixed transmitters within a 5 nautical mile boundary around the runway with the exception of airport surveillance radar and air route surveillance radar. For these two radar types a 500 feet Slant range distance was used.
 - 2. 50 feet, Direct Range, for mobile transmitters, including transmitters on other aircraft, and 150 feet Direct range for aircraft weather radar.
- b. Non-airport ground environment: These sources include the following emitters:
 - 1. 500 feet, Slant Range, for fixed transmitters beyond a 5 nautical mile boundary around the airport runway.
 - 2. Aircraft were assumed to be at a minimum flight altitude of 500 feet above local terrain and avoiding all obstructions, including transmitter antennas, by 500 feet.
- c. Shipboard environment: The shipboard environment is the environment aircraft in flight may encounter from military or civil ships operating at sea or in port. The resulting minimum separation is 500 feet Slant range.
- d. Air-to-air environment: The air-to-air environment is the environment between aircraft in flight. It assumes the minimum approach possible between the target aircraft and interceptor or non-interceptor aircraft. The resulting minimum separations are:
 - 1. 500 feet Direct range for non-interceptor aircraft with all transmitters operational.
 - 2. 100 feet Direct range for interceptor aircraft with only non-hostile transmitters operational.



3.3.2 Fixed Wing Severe HIRF Environment Tables

The Fixed Wing Severe HIRF Environment (Table 1) is based on the available data representing all authorized transmitters in the United States and other participating countries.

TABLE 1 - FIXED WING SEVERE HIRF ENVIRONMENT

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz - 100 kHz(1)	50	50
100 kHz - 500 kHz	60	60
500 kHz - 2 MHz	70	70
2 MHz - 30 MHz	200	200
30 MHz - 70 MHz	30	30
70 MHz - 100 MHz	30	30
100 MHz - 200 MHz	90	30
200 MHz - 400 MHz	70	70
400 MHz - 700 MHz	730	80
700 MHz - 1 GHz	1400	240
1 GHz - 2 GHz	3300	160
2 GHz - 4 GHz	4500	490
4 GHz - 6 GHz	7200	300
6 GHz - 8 GHz	1100	170
8 GHz - 12 GHz	2600	330
12 GHz - 18 GHz	2000	330
18 GHz - 40 GHz	1000	420
(1) High impedance fields of 1000 V/m have been found to exist in the frequency band of 10 kHz to 100 kHz. Research shows that these fields induce negligible currents onto aircraft wiring and can be ignored.		

3.4 Rotorcraft Severe HIRF Environment (HIRF Environment III)

The Rotorcraft Severe HIRF Environment (HIRF Environment III) has been assembled from five separate environments:

- Airport/heliport,
- Non-airport/non-heliport ground,
- Shipboard,
- Off-shore platforms, and
- Air-to-air.

While on the ground, the rotorcraft will be exposed to emitters in the airport environment which include other aircraft emitters being operated on the ground. In flight the rotorcraft may also be exposed to emitters in the air-to-air, shipboard, and ground environments.

The emitters used in the calculation of field strength for the environments are:

a. The airport/heliport - fixed ground emitters:

1. Marker beacons,
2. ILS (localizer and glideslope),
3. Ground controlled approach radars,
4. Distance measuring equipment,
5. TACAN,
6. Microwave landing systems,
7. Airport/heliport surface detection systems,
8. Non-directional beacons,
9. Airport/heliport surveillance radars,
10. Air-route surveillance radars,
11. Weather radars,
12. ATC - RBS interrogators, and
13. VHF and UHF communications and telemetry.

b. The airport/heliport - mobile ground emitters:

1. HF, VHF, and UHF communications,
2. TACAN,
3. Doppler navigation radars,
4. Weather radars,
5. Radio altimeter, and
6. ATC transponder.

c. The non-airport/non-heliport ground emitters:

1. Commercial MF, HF, and VHF AM & FM, and TV broadcast transmitters,
2. Radars,
3. Troposcatter communications,
4. Loran C installations,
5. Satellites, and
6. Command and control facilities.

- d. The shipboard emitters:
 - 1. HF, VHF, and UHF communications,
 - 2. Navigation and Tracking radars, and
 - 3. IFF/SIF.
- e. The off-shore platform emitters:
 - 1. HF, VHF, and UHF communications,
 - 2. Navigation and Tracking radars, and
 - 3. ATC transponder.

3.4.1 Assumptions for the Calculation of the Rotorcraft HIRF Environment III

The Rotorcraft HIRF Environment III is derived from a worst case estimate of the electromagnetic field strength levels in the airspace in which rotorcraft flight operations are permitted, including special authorizations such as Police, EMS, etc. The worst case estimate considers transmitters in the following groups and rotorcraft to transmitter distances:

- a. Airport/Heliport environment: The rotorcraft on the ground may be subjected to emitters having unique separation distance and geometry due to local terrain and runway/taxiway layouts. Because of these conditions, minimum separation distances for each category of emitter were specified as follows:
 - 100 feet Direct range for fixed transmitters within a 5 nautical mile boundary around the runway, with the exception of airport surveillance radar and air route surveillance radar; for these two radar types a 300 feet Slant range was used.
 - 50 feet Direct range for mobile transmitters, including transmitters on other aircraft, and 150 feet Direct range for aircraft weather radar.
- b. Non-Airport/Non-Heliport Ground environment: These sources include all ground emitters outside a 5 nautical mile boundary around an airport runway:
 - All transmitters, 100 feet Direct range.
- c. Shipboard environment: The shipboard environment is the environment rotorcraft in flight may encounter from military or civil ships operating at sea or in port (This does not include takeoff or landing on a ship.) The resulting minimum separation is 500 feet Direct range for all shipboard transmitters.
- d. Offshore Platform environment: The offshore platform environment is the environment rotorcraft in flight may encounter during take-off and landing on offshore platforms. The resulting minimum separation is 100 feet Direct range for all platform based transmitters.
- e. Air-to-Air environment: Air-to-air interceptions of helicopters by fixed wing interceptors were not considered in the Rotorcraft Severe HIRF Environment. The scenario of air-to-air illumination of a helicopter by the airborne weather radar of an adjacent helicopter is covered in the Airport/Heliport transmitter group.

3.4.2 HIRF Environment III (Rotorcraft Severe Environment) Tables

The HIRF Environment III (Rotorcraft Severe Environment) in Table 2 is based on the available data representing all authorized transmitters in the United States and Western Europe.

TABLE 2 - ROTORCRAFT SEVERE HIRF ENVIRONMENT (HIRF ENVIRONMENT III)

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz - 100 kHz(1)	150	150
100 kHz - 500 kHz	200	200
500 kHz - 2 MHz	200	200
2 MHz - 30 MHz	200	200
30 MHz - 70 MHz	200	200
70 MHz - 100 MHz	200	200
100 MHz - 200 MHz	200	200
200 MHz - 400 MHz	200	200
400 MHz - 700 MHz	730	200
700 MHz - 1 GHz	1400	240
1 GHz - 2 GHz	5000	250
2 GHz - 4 GHz	6000	490
4 GHz - 6 GHz	7200	400
6 GHz - 8 GHz	1100	170
8 GHz - 12 GHz	5000	330
12 GHz - 18 GHz	2000	330
18 GHz - 40 GHz	1000	420
(1) High impedance fields of 1000 V/m have been found to exist in the frequency band of 10 kHz to 100 kHz. Research shows that these fields induce negligible currents onto rotorcraft wiring and can be ignored. (2) In the 6 GHz to 8 GHz range, a Level A VFR function would also have to be demonstrated in the HIRF Environment I and therefore the effective applicable average environment in that range is 200V/m.		

3.5 HIRF Environment I (Certification HIRF Environment)

The certification levels are established from the Fixed Wing Severe HIRF Environments by increasing the allowed distance between the aircraft and transmitters. The field strength associated with non-airport ground based transmitters was recalculated using a slant range based on a 1000 feet altitude above transmitters instead of 500 feet. For certification purposes these field strength levels are assumed to be incident on the external surface of an aircraft operating in the airspace.

HIRF Environment I (Certification HIRF Environment) has been established as an estimate of the electric field strength levels which could be encountered. This estimate considers the operational characteristics of the high peak power microwave transmitters, which typically do not operate continuously at the maximum output power levels. This estimate has also rounded the levels to the nearest single significant digit, given the known variability associated with the environment calculations. In the LF to UHF region the levels are greater than the fixed wing Severe HIRF Environment as a result of providing headroom to allow for future transmitter developments.

3.5.1 Assumptions for the Calculation of the HIRF Environment I (Certification HIRF Environment)

The HIRF Environment I (Certification HIRF Environment) considers the same transmitter groups as the Fixed Wing and Rotorcraft Severe HIRF Environments, but the aircraft to transmitter distances are re-assessed as follows:

- a. Airport environment: The distance assumptions for all fixed transmitters within the airport boundary remained unchanged from those used in the Fixed Wing Severe HIRF Environment. The distance assumptions for all mobile transmitters and aircraft weather radar systems remain unchanged from those used in the Fixed Wing Severe HIRF Environment.

b. Non-Airport Ground environment:

1. 500 feet Slant Range, for fixed transmitters within a wedge shaped area of airspace, originating at the departure and arrival end of the runway, over which aircraft would normally track, and extending for 3 nautical miles from the runway.
2. Aircraft were assumed to be at a minimum flight altitude of 1000 feet above local terrain, except for take-off and landing, and avoiding all obstructions, including transmitters, by 1000 feet. The Slant range was calculated using the maximum elevation angle for the transmitters. Where maximum elevation angle was not known, 45 degrees was assumed.

c. Shipboard environment: 1000 feet adjusted Slant range.

d. Offshore Platform environment: This group of transmitters was not considered in the Certification HIRF Environment.

e. Air-to-Air environment:

1. 500 feet Direct range for non-interceptor aircraft with all transmitters operational.
2. 100 feet Direct range for interceptor aircraft with only non-hostile transmitters operational.

In addition to the distances assumption described in this section the committee decided, for historical and practical reason, and in view to better cover possible future evolution at no cost, to maintain a 200 V/m minimum average environment in the whole radar frequency range for the Certification HIRF Environment (HIRF Environment I).

3.5.2 HIRF Environment I (Certification HIRF Environment) Tables

The electric field strengths shown in Table 3 serve as test and/or analysis levels to demonstrate that the aircraft and its systems meet the certification requirements.

TABLE 3 - HIRF ENVIRONMENT I (CERTIFICATION HIRF ENVIRONMENT)

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz - 100 kHz	50	50
100 kHz - 500 kHz	50	50
500 kHz - 2 MHz	50	50
2 MHz - 30 MHz	100	100
30 MHz - 70 MHz	50	50
70 MHz - 100 MHz	50	50
100 MHz - 200 MHz	100	100
200 MHz - 400 MHz	100	100
400 MHz - 700 MHz	700	50
700 MHz - 1 GHz	700	100
1 GHz - 2 GHz	2000	200
2 GHz - 4 GHz	3000	200
4 GHz - 6 GHz	3000	200
6 GHz - 8 GHz	1000	200
8 GHz - 12 GHz	3000	300
12 GHz - 18 GHz	2000	200
18 GHz - 40 GHz	600	200

3.6 HIRF Environment II (Normal HIRF Environment)

The HIRF Environment II (Normal HIRF Environment) is the electromagnetic field strength level in the airspace on and about airports in which routine departure and arrival operations take place and does not include the shipboard or air-to-air intercept environments.

Conditions such as reduced power take-offs and off-center landings were not considered in establishing the HIRF Environment II.

The HIRF Environment II is based on a representative maximum electromagnetic environment profile found in the vicinity of airports in the United States and other participating countries. This estimate considers the operational characteristics of the high peak power microwave transmitters, which typically do not operate continuously at the maximum output power levels. This estimate has also rounded the levels, given the known variability associated with the environment calculations.

As the HIRF Environment II considers only arrival and departure operations, the inclusion, within the environment of all the transmitter groups incorporated in the Fixed Wing and Rotorcraft Severe HIRF Environments and the HIRF Environment I, would be inappropriate.

3.6.1 Assumptions for the Calculation of the HIRF Environment II (Normal HIRF Environment)

The transmitter groups and the aircraft to transmitter distances considered in the Normal HIRF Environment (HIRF Environment II) are as follows:

a. Airport environment:

With the exception of aircraft weather radar systems, the distance assumptions for both fixed and mobile transmitters located within the airport boundary remain unchanged from those used in the Fixed Wing Severe HIRF Environment and the HIRF Environment I. For aircraft weather radar systems, a Direct range of 250 feet was used.

b. Non-Airport Ground environment:

Transmitters within a wedge shaped area of airspace, originating at each end of the runway, over which aircraft would normally track, were assessed at differing slant ranges according to the transmitter distance from the runway as follows:

0 - 3	Nautical Miles	500 feet adjusted Slant range
3 - 5	Nautical Miles	1000 feet adjusted Slant range
5 - 10	Nautical Miles	1500 feet adjusted Slant range
10 - 25	Nautical Miles	2500 feet adjusted Slant range

c. Shipboard environment: This group of transmitters was not considered in the HIRF Environment II (Normal HIRF Environment).

d. Offshore Platform environment: This group of transmitters was not considered in the HIRF Environment II (Normal HIRF Environment).

e. Air-to-Air environment: This group of transmitters was not considered in the HIRF Environment II (Normal HIRF Environment).

3.6.2 HIRF Environment II (Normal HIRF Environment) Tables

The electric field strengths shown in Table 4 serve as test or analysis levels for the Normal HIRF Environment (HIRF Environment II).

TABLE 4 - HIRF ENVIRONMENT II (NORMAL HIRF ENVIRONMENT)

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz - 100 kHz	20	20
100 kHz - 500 kHz	20	20
500 kHz - 2 MHz	30	30
2 MHz - 30 MHz	100	100
30 MHz - 70 MHz	10	10
70 MHz - 100 MHz	10	10
100 MHz - 200 MHz	30	10
200 MHz - 400 MHz	10	10
400 MHz - 700 MHz	700	40
700 MHz - 1 GHz	700	40
1 GHz - 2 GHz	1300	160
2 GHz - 4 GHz	3000	120
4 GHz - 6 GHz	3000	160
6 GHz - 8 GHz	400	170
8 GHz - 12 GHz	1230	230
12 GHz - 18 GHz	730	190
18 GHz - 40 GHz	600	150

3.7 Internal Aircraft Environment

The internal environment within an aircraft is different from the external environments (HIRF Environments I, II and III) that are given in previous sections. The internal environment is a result of complex electromagnetic interactions of the external electromagnetic field, the aircraft, and the systems installed in it.

Incident external fields reflect and scatter when they encounter the exterior of an aircraft. This interaction results in induced currents and charge on the structure which generate additional fields both inside and external to the aircraft.

Aircraft with composite external structure present an even more complex electromagnetic interaction with the incident field than do traditional all-metal skin aircraft.

Paths of electromagnetic wave entry from the exterior to the interior equipment regions are sometimes referred to as points of entry. Examples of points of entry may be joints, wire bundle entries, windows, etc. The local environment at points of entry, not the incident environment, drives the resulting internal RF environment.

The RF environment local to the equipment or system within the installation and the degree of attenuation or enhancement achieved for any region are the product of many factors such as materials, bonding of structure, dimensions and geometric form of the region, and the location and size of any apertures allowing penetration into the aircraft.

The internal field resulting from such influences, as noted above, will in most cases produce a non-uniform field in the system or equipment location. Several hot spots typically exist within any subsection of the aircraft. This is particularly true at cavity resonant conditions. Intense local effects are experienced at all frequencies in the immediate vicinity of any apertures for a few wavelengths away from the aperture itself. This internal field distribution will be changing fast during actual flight exposure due to the changes in the position and orientation of the aircraft relative to the HIRF source.

The extension of electrical/electronic systems throughout the aircraft ranges from highly distributed (e.g. flight controls) to relatively compact. Wiring associated with distributed systems penetrates several aircraft regions. Some of these regions may be more open to the electromagnetic environment than others and wiring passing through the more open regions is exposed to a higher environment. Thus the wiring of a highly distributed system could have a relatively wide range of induced voltages and currents that would appear at equipment interface circuits.

The methodology for determining the internal environment for systems is found in Sections 6 and 7.

The hazards related to radiated fields generated by T-PEDs are not considered part of the external HIRF environment encountered by an aircraft. Considerations of such effects are provided in DO-294C, "Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft", and DO-307, "Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance".

3.8 Aircraft Exposure to HIRF

Aircraft fly by or over ground HIRF transmitters to within a specified minimum point of closest approach. The criteria used in developing the environment have been identified in Section 3 of this guide, applicable to each environment. As the aircraft approaches the point of closest proximity, the external field rises steadily to the maximum and then subsides as the aircraft moves away. Example and discussion of exposure scenarios are presented below but Section 7.3.13 of this Guide includes further information on dwell time.

For omnidirectional transmitters, since 100 ft/s and 400 ft/s are typical limits of velocity in low altitude and approach flight, it can be seen that the total exposure time, for aircraft approaching and receding from continuously radiating emitters varies between 2 and 15 seconds. In this short time, the signal drops 10 dB. Therefore, for aircraft which are not orbiting around a strong emitter, the exposure time does not exceed one minute and may be as short as a few seconds, even for a continuous radiating omnidirectional emitter.

Radar transmitters, which are generally above 400 MHz, have narrow 3 dB beams of radiation that are between a few tenths of a degree and a few degrees.

If these radars are fixed in azimuth and beamed toward the point of closest approach (worst case geometry) this would further shorten the exposure time. At a closest approach of 500 feet significant antenna beamwidth signal reduction, 6 dB would be felt within 2 seconds, and 10 dB reduction would occur in about 4 seconds. This reduces the effective exposure time by a factor of about 7 as compared to the exposure from an omnidirectional emitter. If the radar antenna is rotating in azimuth, the total exposure may be reduced even further. The region of closest approach would be swept once per revolution. Since typical rotation rates are 3 to 30 RPM, this results in scan intervals of 2 to 20 seconds. Even slow aircraft (100 ft/s) at 500 feet from the emitter experiencing the fastest scan rate (30 RPM or 2 second period) would be exposed to 15 sweeps that were within 10 dB, either side, of the maximum. More typical air search radar scans of 8 seconds and aircraft velocities of 200 feet/sec result in 3 or 4 total exposures within 10 dB of peak in the encounter. Fly-bys within 250 feet instead of 500 feet, while increasing the signal level, reduce the number of exposures to between 1 and 7 per encounter. The duration of an individual exposure within an encounter depends on the beam width and scan rate of the radar. A typical high powered air search radar has a ± 3 dB beam width of 3 degrees and a scan period of about 8 seconds. This scan sweeps over a 25-foot area of the aircraft in about 67 ms, as the aircraft flies by 500 feet away. A tenth of a second would then seem a reasonable maximum duration of exposure for each rotation of the radar. Remember that only a maximum of 15 such exposures will occur within 10 dB of the maximum encounter during this fly-by. In summary, the worst case exposure to a typical rotating air search radar would be 15 sweeps each lasting less than 100 ms.

A separate but related issue is the duty cycle of the radar. Within each scanning exposure of the fly-by encounter, the radar will emit many short pulses. Typical pulse repetition periods are few milliseconds and exposure times may be a few microseconds. This is accounted for by the use of low duty cycle pulse test signals.

4. PRACTICAL DESIGN CONSIDERATIONS

Accounting for HIRF effects on electrical/electronic systems should be recognized as a total/overall aircraft issue that should be addressed at the aircraft level early in the aircraft design phase.

Designing aircraft electrical/electronic system immunity to HIRF effects from the beginning is the optimum approach to achieving certification of such systems. The design objectives should be the foundation for compliance demonstration, proving that system immunity was designed in from the beginning.

As a general rule, optimum immunity to HIRF effects will result from the use of the various aircraft/ architecture system installation options. At the aircraft level, the design objective is to reduce the HIRF internal environment adjacent to the installed electric/electronic equipment. At the system level, a robust design of the system and installation is the objective.

This would involve employing system measures (hardware and software) that are robust to HIRF effects. The design application of structural protection/protective devices should be such that operational deterioration is minimized.

4.1 HIRF Environment Reduction

The shielding requirement for each area of the aircraft containing electric/electronic systems or wire bundle installation should be established. Protection to achieve the required level of attenuation should be the basis of structural protection design.

4.1.1 Coupling Mechanism/Frequency Bands

The local fields that surround the aircraft are a combination of the incident HIRF (Normal, Rotorcraft Severe, or Certification) environment, and reflected (scattered) fields caused by induced surface currents and charges. These local fields are non-uniform and are dependent on the frequency of the incident field and the size, shape, and composition of the aircraft. It is these local fields, not the incident fields, which drive the fields internal to the aircraft. These local fields may have a higher level than the incident field.

The internal field levels are dependent on both the details of the point of entry and the internal cavity. The resulting internal fields are also non uniform and can vary over a wide range of intensity, wave shape, and wave impedance. Below 10 MHz within a metal aircraft, magnetic fields predominate due to the electric field shielding properties of metal skins.

The basic phenomena of electromagnetic coupling experienced by installed electronic systems are that the interconnecting wires of the installation act as receiving antennas (see Table 5) and penetration of equipment apertures.

TABLE 5 - SIGNALS COUPLING EFFECTS

Frequency	Wavelength	Type of Radiation	Effects/Threat
10 kHz to 100 kHz	30 km to 3 km	VLF CW with AM	A/C and wiring - very low coupling.
100 kHz to 1 MHz	3 km to 300 m	Low frequencies CW with AM	A/C and wiring - low coupling.
1 MHz to 100 MHz	300 m to 3 m	MF/HF CW with AM or SSB/DSB	A/C and wiring - maximum coupling at aircraft/wiring resonance. Frequency dependent on A/C size and wire length.
100 MHz to 400 MHz	3 m to 75 cm	VHF CW with AM or FM	A/C, wiring, LRU - moderate coupling.
400 MHz to 40 GHz	75 cm to 7.5 mm	UHF, SHF CW with AM Radar Pulsed	Coupling through A/C apertures. Coupling on wiring close to equipment and then coupling through equipment box while frequency is increasing.

Wire orientation relative to the field is an important factor in HIRF coupling. Wires routed near multiple apertures see a coupling effect that is a composite from each aperture.

When the airframe and/or wiring dimensions are multiples of the RF wavelength fractions then the coupling is at a maximum due to resonances. Normally the maximum coupling occurs when the airframe and/or wiring dimensions are quarter or half wavelengths. At higher frequencies, coupling decreases proportionally with the wavelength squared. For higher frequencies, transmission line losses become significant. This means that the primary coupling path is at the box/connector/wire interface or at box apertures.

4.1.2 Entry Points

In practical aircraft designs shielded compartments provide only limited amounts of shielding due to apertures, wire penetrations, joints, and other points of entry. HIRF energy may be transferred from one area to another by mechanisms such as wire coupling, raceway coupling, and other coupling paths.

Care must be taken not to compromise the shielding effectiveness of the structure when the wire bundles and mechanical linkages including hydraulic lines are exposed to the external environment in areas of minimal protection, e.g. wheel wells, cockpits, wings, and other apertures.

Location of these main areas of concern may be readily identifiable such as windows but the coupling survey should also look for less obvious coupling paths.

The following are examples of coupling paths into the interior of the aircraft.

Radiated coupling directly through dielectric materials:

- a. Passenger windows: The most obvious point of entry for radiated coupling, passenger windows can be the most dominant source of radiated coupling, if lacking metallic coatings.
- b. Flight Deck windows: If flight deck windows lack metallic coatings, it can be expected that flight deck internal fields will not exhibit any attenuation.
- c. Glass fiber composite fairings and panels (Radiated coupling directly through carbon fiber composite structure is much less of a concern).

Radiated coupling around dielectric slots between metallic surfaces:

- d. Passenger windows with metallic coatings.
- e. Flight Deck windows with metallic coatings.
- f. Carbon fiber and metallic fairings.
- g. Engine cowl slots.
- h. Doors and hatches without RF gaskets: Unless a good RF bond is formed around the whole periphery of the door, energy will penetrate.
- i. Joints: Joints closed with non-conductive sealant will allow the ingress of RF energy since they will become resonant slots at some frequencies.

Conductive coupling to wire bundles:

- j. Wing trailing/leading edge devices: When these devices (e.g. flaps and slats) are extended, an unprotected area is often opened. Any wire bundles in this area may require individual protection.
- k. Wire conduit/raceway: Unless well bonded at both ends and frequently down their length, these items can resonate and allow energy to couple into the bundles they are meant to protect.
- l. Wires running parallel to the sensitive bundles: Non-sensitive wires (e.g. from navigation or logo lights) which enter the fuselage or other shielded space from an unshielded area will carry noise currents. Should these wires run parallel to sensitive wire bundles then the noise will be inductively coupled into the sensitive bundles. Care should be taken to guarantee good separation of sensitive wires over their whole length.

m. General:

1. Although the basic design may be satisfactory for initial certification, the deterioration of the electromagnetic barrier with use over time may compromise HIRF protection in the future (See Section 9).
2. Entry point analysis should consider the effects of such a deterioration on the level of protection.
3. In general, the total contribution of the aircraft structure to the propagation of electromagnetic waves into areas containing the installed system must be assessed. The penetration of energy into the LRUs through joints and connectors must be assessed in the higher frequency regime.

4.1.3 Design Options for HIRF Environment Reduction

The design protection applied normally will be specific to the integrated system under review, but the most commonly applied hardening techniques are within the categories of:

- a. Structural attenuation,
- b. Installation protection techniques of subsystems,
- c. Specific circuit protection, and
- d. Common and differential mode impedance control of wires with their source and load impedances.

Subsystem and circuit protection typically is applied by the following hardening design practices:

- a. Circuit design measures,
- b. Bonding and grounding,
- c. Shielding,
- d. Cabling, and
- e. Filtering.

The verification of any protective design will usually be by equipment (DO-160/ED-14), system, and/or aircraft tests.

4.1.4 Grounding

An overall grounding method should be developed for new aircraft. The method should specify the grounding requirements for both power and signal interfaces. It is important that equipment used on the aircraft comply with the aircraft grounding requirements even if it means a given piece of equipment that already has a Technical Standard Order (TSO) will have to be retested. The purpose of grounding extends beyond both lightning and HIRF considerations. Selected power and signal grounding during DO-160/ED-14 testing may produce entirely different susceptibility profiles than during actual aircraft installation. Some aircraft ground the power return including phase neutral to chassis just outside the input/output connector while others use a ½ meter wire to ground the power returns to chassis. If the LRU only provides filtering of the positive input power lead, then the ½ meter return lead will allow HIRF to couple. Had the return been grounded at the connector instead of via a ½ meter wire, the entire HIRF profile would be different. A controlled grounding concept must be implemented and LRUs must be compatible with the selected scheme. An alternate method would be to have the aircraft grounding approach modified to reflect the LRU. This generally is difficult for the aircraft manufacturer.

In terms of signal grounding, discrete signals often prove difficult to control. Discrete signals often use the airframe as return. HIRF-induced standing waves often enter through signal return leads that tie to chassis. Properly specified signal grounding to the LRU chassis at the input/output connection can prevent HIRF penetration. Non-discrete digital and analog signals should be provided with a dedicated signal return lead for controlling the effective signal loop area.

In the case of digital signals, the return wire provides loop control even when both ends are terminated to chassis ground inside their respective LRUs. For example, rather than using a single wire to connect an output driver to an input device, a twisted wire pair should be used with the ground wire preferably connected to a signal reference at the output driver and signal reference at the input device.

When a safety ground is required for each power connector, this wire can be a point of HIRF entry if it is not grounded immediately to the LRU chassis at the point of entry. If the LRU only provides filtering of the positive input power lead then the separate ground wire will contribute to the HIRF coupling effects in an entirely different manner than that resulting from the ground at the connector.

The chassis or safety ground pin should either remain disconnected in the aircraft wire harness or be connected to chassis within $\frac{1}{2}$ meter distance of the LRU. In either case, the ground must be tied to the LRU chassis immediately upon LRU entry to prevent it from becoming a HIRF entry point.

4.1.5 Bonding

Bonding is the method used to reduce both the DC resistance and RF impedance between two metallic surfaces or assemblies. This limits the voltage build up across them. Good bonding practices ensure low impedance paths for all RF currents induced in cabling and equipment cases.

Typical electrical bonding practices may not be adequate for HIRF. HIRF requirements usually demand low impedance bonds over broader frequency range than conventional bonding. The frequency range generally required is from DC to 3 GHz but can be greater depending on the susceptibility response of the internal LRU circuitry. Because of the RF currents induced by the HIRF, it is of utmost importance to minimize the bonding impedance of the RF bonds through such methods as grounding the equipment case (not relying on "green wire" safety grounds).

Equipment bonding to a mounting tray or airframe should be accomplished by direct metal to metal contact rather than a bond strap. Even a one inch long bond strap becomes half wave resonant at 6 GHz. All bonding straps should be as short as possible and of low impedance throughout the frequency range where the equipment can adversely respond to HIRF-induced voltages. Long bonding straps cannot be used. These may be adequate at low frequencies but represent high impedances at quarter wave lengths and odd multiples of the quarter wavelength. (The impedance of a bond strap is the summation of four impedance factors: DC resistance, inductance, skin effect, and standing wave impedance.) A length to width ratio of 5 to 1 will fix the inductance per unit length of the strap. However, to control the standing wave impedance, the total strap length should be less than about $\lambda/20$.

The LRU design should provide a low impedance bonding of its chassis to the aircraft. A low impedance bond is a bond whose resistance measured at DC or 1000 Hz is less than 2.5 milliohms. However, for HIRF the important factor is the establishment of a low impedance bond between the wire bundle shields and the shielded LRU even if the LRU to airframe impedance cannot be kept low.

Insuring a good and reliable bond of the equipment case to a composite structure may require the use of embedded conductive material inside the structure. Main techniques are foil, mesh or expanded foil inserted in the structure during its manufacturing. Expanded foil may be preferred to mesh for manufacturing aspects. Usually the protection for HIRF effects is the driving parameter for most of the grounding and bonding concept applied for a composite aircraft.

4.1.6 Shielding

Shielding of both the airframe and LRU cases is discussed in this section. Shielding is mainly driven by apertures, seams, and ungrounded conductive penetrations through a compartment or case wall. Maximum compartment/case shielding is achieved when the shield totally encloses the equipment. This is often called Faraday shielding or overall shielding. Partial shielding can result from locating circuits on a ground or image plane. For equipment that would require very high level of protection, the best solution is to house equipment within shielded equipment bays with all cabling between the bays enclosed in overall shields with the shields electrically bonded at the points of entry. To improve Faraday shielding, conductive gaskets should be used around panels that are opened and for high usage access areas such as undercarriage doors or passenger/freight shielded equipment bays. For high access areas conductive gaskets should be designed in the frame, panel, or door such that damage is minimized but can be accessible for cleaning.

Equipment housed in areas where airframe shielding is not provided must rely on case and/or wire bundle shielding.

Metal honeycomb panels with an integrated shielding gasket may be required to provide Faraday shielding where ventilation is required. The opening size of the individual honeycomb cells and honeycomb thickness is determined by the highest frequency against which immunity is required. Increased shielding is achieved with thickness and smaller openings of the honeycomb. Display screens may require metalized coatings or a shielded window made of fine wire mesh with an integrated shielding gasket to minimize RF penetration.

Traditional aircraft design employed a skin material comprised of continuous sheets of metal bonded to the metal frame. This provided good shielding of the interior from the external HIRF. More recent aircraft designs incorporate the use of non-conductive materials and techniques that are less effective as shields to HIRF. Listed below are materials in approximate descending order of effectiveness as shields against RF entry:

- a. Copper - solid sheet,
- b. Aluminum - solid sheet,
- c. Titanium - solid sheet,
- d. Other structural metals - solid sheet,
- e. Graphite-Epoxy - solid sheet,
- f. Fiberglass - solid sheet,
- g. Aramid fiber composite - solid sheet, and
- h. Other plastics or composites of decreasing conductivity.

Openings in airframe compartments and other enclosures can be covered to provide shielding. Choices for such covers in descending order of their shielding effectiveness are:

- a. Metal panels,
- b. Conductively coated or plated composite,
- c. Conductively filled composite,
- d. Conductively filled plastic, and
- e. Vacuum deposited metal coated glass.

The shielding effectiveness of a panel is degraded when either the panel material conductivity decreases or when the seam or joint conductivity between the panel and the compartment decreases. Such a decrease in conductivity may be caused by deterioration of a conductive coating or deterioration of a metal surface due to oxidation, corrosion, or loss of contact pressure between the surfaces due to loss or looseness of fasteners. Metal surface contact also may be lost or impaired electrically due to manufacturing processes such as anodizing and paint overspray. Openings in the aircraft metal skin, such as points at which wiring, tubing (fuel, hydraulic, pneumatic, etc.) or other mechanisms penetrate a metal surface such as a wing spar or bulkhead also permit RF entry.

4.1.7 Wire Shielding

One of the main HIRF coupling routes into equipment is via its wiring. Wiring acts as an antenna or collector of HIRF energy. The wiring type selected impacts the immunity of the equipment.

Shield pigtails (shield ground wires) that terminate individual shields generally provide sufficient HIRF protection for systems and wire bundles exposed to low to moderate HIRF fields, or with less stringent performance criteria.

Many types of shield connections that are not ideal exist for practical reasons, such as pig-tails bonded to aircraft structure by ground blocks, or connections using Signal or Power Ground. The main aspect with regards to shield terminations is that the system passes the certification tests without using shield terminations that would be of better efficiency than the production type used, however such shield terminations should be avoided as they may create some of the following undesirable effects.

Connection to signal ground induces risk of coupling any HIRF onto an associated system's input and output circuitry, especially if an electrical bonding issue develops at the ground point.

Connection to Power Ground induces additional risk of losing the shield's electrical bond (electrical bond degradation) due to heating-cooling effects of the electrical bond joint. Issue tends to manifest more as aircraft systems are modified as the system design matures after initial aircraft Type Certificate (TC).

The aircraft integrator should avoid carrying a shield through equipment connectors and terminating the shield inside the equipment chassis, even in the case where such a pin is provided, unless such connection is specifically necessary to achieve manufacturer's specified performance.

In general, all wire shields should be terminated at the connector in such a manner that shield currents return to the aircraft structure without penetrating the equipment chassis. This also applies to wire bundles penetrating bulkheads, such as wing and body disconnects. If the wire bundle has an overall shield, it is acceptable for the interior signal wire shields to be carried through the bulkhead if the overall shield is peripherally terminated at the bulkhead.

For systems that have stringent performance requirements when exposed to high HIRF fields, more robust protection may be achieved by implementing an improved bonding of the shields to EMI connector or backshell.

Significant protection can be achieved by individual (all leads individually shielded) and overall wire bundle shields if the shields are terminated at both wire bundle ends to the connector backshell in an efficient fashion. The connector flange should be bonded to the LRU case and both mating surfaces of the connector must achieve good RF bonding when mated together (see MIL-DTL-38999K).

4.1.8 Filtering

In some designs filtering may be a more practical solution to the HIRF problem than shielding. Typical filtering can consist of discrete filter assemblies, actual filter pin connectors, or Surface Mount Technology (SMT) type capacitive filter boards whose internal ground plane provides both a shield barrier wall and ground planes for the filter capacitors.

A prime example is the generator feed lines between the aircraft fuselage and wing-mounted engine-driven generators. During a portion of the flight profile, these power feeders may be exposed to the full HIRF threat. It is impractical, from the point of view of heat buildup and weight, to shield these large gauge wires. These feeders, typically four wires (one for each phase plus neutral) and a shorter safety ground wire, can pick up significant amounts of energy when exposed to the HIRF fields. The induced HIRF power can be directly conducted to equipment, interfere with equipment performance, and provide an entry path into the aircraft fuselage, significantly degrading the fuselage shielding effectiveness.

A potential solution is filtering of the power lines at the feeder entry point to the fuselage. The power line filter may consist of a non-polarized 0.1 μF feed-through capacitor. The capacitors can be bulkhead mounted either in the wing body disconnect or in the fuselage skin (preferred). Such a filter, working against the characteristic impedance of the power feeder transmission line can provide 20 dB or more filtering above 1 MHz. Such filtering might well be considered for all low frequency power and signal lines emanating from a protected zone (fuselage) to an exposed area (wing or leading edge).

The use of low pass feed-through filter circuits mounted directly behind the equipment connectors within a shielded compartment (Figure 1) is desirable. The shielded compartment contains both the input/output connector and all the filter elements including feed through elements that penetrate the compartment wall providing maximum shield isolation.

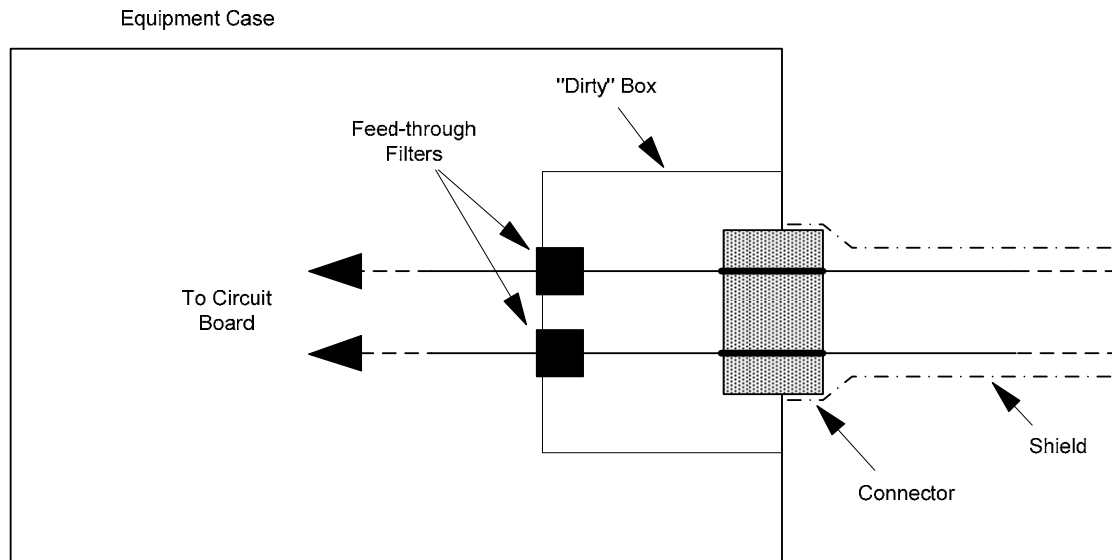


FIGURE 1 - SCHEMATIC DIAGRAM SHOWING FILTERS MOUNTED IN A SHIELDED COMPARTMENT BEHIND THE INPUT/OUTPUT CONNECTOR

A filter pin connector can be used instead of the filter shielded compartment approach. The main advantage of the filtered connector is volume and weight reduction. In general, the filter pin connector is more expensive than the shielded filter compartment approach. The most reliable filter pin connector designs employ a discoidal monolithic substrate. It is important to specify a copper ground plane for the substrate for maximum filter action at microwave frequencies. For combined AC power and signal filtering, separate non-ceramic AC rated filter capacitors are recommended for the AC leads. For HIRF purposes a single stage capacitive-only discoidal filter can provide the needed suppression. Multi-pole filter stages only add cost, volume, and weight to the filter pin connector. The inductor stage only consists of ferrite beads that add very little benefit. The filter capacitance available for typical connectors can be as high as 1.0 μf . The typical values for HIRF are 0.001 to 0.0001 μf . It is strongly suggested that the maximum to minimum value ratio not exceed 10 to 1. The filter pin connector works best at frequencies greater than 1 MHz.

Lossy line wires can also provide filtering. Lossy line wires containing a ferrite embedded layer over the wire or wires that form the wire bundle plus a shielded jacket and another ferrite layer. Some concern regarding cost, weight, and conductivity of the outer layer exists with lossy line wires. The lossy line ferrite material provides a distributed common mode choke to the wire. The wire is interchangeable with normal wire but provides RF attenuation (as a function of length) at frequencies above 10 MHz.

Filters are effective in reducing induced HIRF power levels when the low pass cut off frequency is about ten times higher than the fundamental frequency being transmitted by the wire. Low pass filtering of high speed data lines (~1.0 Mbits and higher) for HIRF protection is usually not recommended since data skewing problems can occur. In some cases, like analog video signals, the standard type video drivers cannot drive filter capacitance. The necessary amount of capacitance needed for video lines (~1000 pF) also limits the effective video bandwidth.

Some concern exists for filtering differential lines in terms of unbalancing the line-to-ground differential impedance. Holding the tolerance on the filter capacitance to ± 5 percent and limiting the capacitance to 0.001 μf usually solves the problem. A key factor when designing filter pin or connector filtering is all connectors pins must be filtered or shunted to the filter ground plane. Not even one signal lead including signal ground leads should go unfiltered when connector filtering is being used to meet the HIRF environments. For this reason it is important NOT to mix shielded signals with unshielded signals in the same connector. Signals going to connectors should be grouped such that only shielded (and therefore not filtered) leads enter one connector while all unshielded leads (which all will require filtering) go to another connector. The filters must be specified to meet the current and voltage requirements for each signal or power application.

Non-linear clamping devices can also be added to filter pin connectors and internal filter assemblies. It is acceptable to place the transient clamping device on the load side and adjacent to the filter capacitor since it will protect both the filter capacitor and the circuit due to its parallel location. No appreciable series inductance should exist between the capacitor and the shunting clamp.

4.1.9 Fiber Optic Cables

Fiber optics is a method of transmitting optical (light) signals over glass/silica or plastic fibers for the purpose of communication or power transmission. Fiber Optic transmission links do not respond to HIRF fields because of the non-conductive, dielectric nature of the fibers and because of the non-electrical nature of the signal (light) itself. Fiber optic links are available for the transmission of either analog or digital data. In terms of analog signal transmission, fiber optic links are available off-the-shelf to transmit signal frequencies as high as 1 GHz (and somewhat higher as custom state-of-the-art units). As far as digital data is concerned, fiber optic links designed to operate as Ethernet (10BaseF), RS232 serial buses, or Institute of Electrical and Electronics Engineers (IEEE) 488/Hewlett Packard Interface Bus (HPIB) parallel buses are commonly available as standard commercial products.

The use of fiber optic as a HIRF mitigation solution introduces a new set of engineering problems in dealing with electro-optical components in an aircraft design. Fibers are fabricated of silica, various glasses, and plastics as well as composite fibers consisting of plastic-clad glass or silica. Each has certain advantages and disadvantages. Pure silica fibers, which usually have a core doped with materials in order to increase the index of refraction, have the lowest signal attenuation values. Glasses and plastic fibers fabricated of acrylic or polystyrene have high signal attenuation. Composite fibers usually have a silica core with a suitable plastic cladding and have moderate signal attenuation. A disadvantage of plastic or plastic clad fibers is a limited temperature range. Plastic fibers should be avoided, as they are not stable over temperature and will flow at high temperatures and the severe environments found in aircraft.

There are two types of glass fibers: single mode, and multimode. The "modes" refer to the electromagnetic mode of propagation in the fiber. Single mode is best suited for very high speed, long distance communications, with low losses (in the 'couple of dB' per kilometer range). Single mode fiber is responsible for the backbone of the country's major network communications links.

Multimode fiber is higher loss but well suited for typical aircraft applications. The shorter the range, the higher the frequency multimode can be pushed. For short range (300 ft) aircraft applications, multimode is well suited to the low gigabit range. Physically, single mode fibers have a much smaller core (10 μm), and thus are much more critical in connector preparation and less forgiving in mated connections. Multimode typically has a 50 to 62.5 μm and sometimes larger cores, simplifying connector preparation. Overall diameters of the bare fiber are similar to single mode, about 125 μm . Graded Index Multimode are essentially multimode fibers, but utilize a radially graded index of refraction fiber instead of a two glass stepped index construction. Graded index provides a useful improvement over step index multimode but retains all the user friendly features of the latter. Fibers can be purchased as glass fiber only (125 μm), buffered tube (1 mm), or jacketed fiber with Kevlar strength members (can be purchased off the shelf connectorized). There are also 'tactical' graded fiber cables, which are one or more fibers with Kevlar high strength plastic jacket and sometimes metal covering for use in military applications.

The effectiveness of fiber optics in reducing susceptibility or emissions, as compared to a similar speed wire communications link, can be greater than 100 dB. This, however, does not imply that the entire data link is immune. The electronics associated with the link have a susceptibility threshold similar to any electronic system operating at a comparable signal level. The weak point of HIRF susceptibility for a fiber optic data link is at the fiber connector input of the receiver amplifier. The entrance point for the HIRF is the ceramic 1 mm diameter nose of the fiber optic connector and the corresponding mating hole in the receptacle (directly behind this ceramic nose is the photodiode receptor). This is especially true for a receiver using a PIN diode photodetector. Under normal operating conditions the signal level at this point is extremely low and input currents can be as small as 10^{-9} amperes or less. Consequently, a very low HIRF signal injected at this point can produce system upset by decreasing the signal to noise ratio or increasing the bit error rate.

HIRF hardening measures for fiber optics electronics is no different than hardening for any other electronics module. Measures for fiber optics include many general electronics hardening measures, such as:

- a. Install the fiber optic transmitter and fiber optics receiver components in a high conductivity metal enclosure with good bonding and conductive gaskets. Keep in mind, the wavelength for a 40 GHz HIRF signal is 7.5 mm.
- b. Eliminate all enclosure apertures except those that are absolutely necessary, such as that for the fiber optics, the seams due to the access cover, and the input/output connectors. Typical apertures for the fiber connectors are in the order of 1 mm in diameter.
- c. Use a high conductivity input/output connector and metal fiber optic connector in conjunction with above.

- d. Use nonconductors such as aramid fibers (Kevlar) for strengthening fiber optic cables where necessary.
- e. For extreme HIRF environments, the fiber connector can be eliminated. After securing the fiber jacket via a small metal tube (similar to the crimp style of coax connectors), bring the core fiber through a bent metal tube (or a coil of tubing) and terminate the fiber to the photodiode away from the fiber entrance. This bent tube can be the same tube used in the exterior, brought through a hole in the case. The tube can be then soldered or welded to the case. The smaller the diameter the better. Alternately, a separate compartment can be used where the bare fiber can pass through a hole sized for the bare fiber diameter, and then the bare fiber can be connectorized to a receptacle. Then a standard connectorized fiber can be mated to the receptacle externally.

4.1.10 Maintenance and Design

HIRF maintenance considerations should begin when the design and architecture is being developed in support of certification activity. Care should be taken to develop designs that will withstand the environment in which they are installed, without excessive degradation, over the life of the aircraft. As with all designs there are trade-offs, design engineers must consider system functionality, weight, manufacturability, service experience of components, maintenance, and cost, as typical contributions to the design of the HIRF protection of the aircraft. In assessing trade-offs in the various design architectures care should be taken to ensure data from surveillance programs and any other relevant in-service source is considered in design decisions. In-service data can be more valuable than laboratory or accelerated aging test data on components as it provides a better representation of the true effects of the environment in which a component resides. See Section 9 of this document for further detail on maintenance and assurance activities.

4.2 Electrical/Electronic System Robustness

The overall system design should minimize the vulnerability of the system to high RF fields. Special attention must be paid to system integration techniques. The layout of a system should be constrained to avoid low level signaling over long distances in the airframe. Signal waveforms that are required to be transmitted around the airframe must be carefully considered for their integrity in harsh EM environments. The design of the overall system architecture for the computers and software can have significant influence on the hardness of the system.

4.2.1 System Architecture Considerations

At the system level, one HIRF protection technique is the use of dissimilar designs between redundant parts of the system. In all cases, any failure of a system component must not adversely affect the function of the system. Two main techniques are used in producing such architecture:

- a. Use of a non-electronic back-up system (optical, electromechanical, or pure mechanical).
- b. Use of redundant systems that have differing frequency susceptibilities. If the most susceptible frequencies for the various channels are different, then exposure to HIRF will only affect one channel.

Some restrictions apply to the above techniques. There cannot be any adverse effects for any systems providing inputs to Level A functions, with exposure to Environment II (Normal). The various frequency bands where the different channels are susceptible should be at least one frequency octave apart.

The concept of different malfunction signatures can be used as a margin in the design and development process. Techniques for achieving this are:

- a. Dissimilar hardware (technology, electronic devices, circuit design, etc.),
- b. Dissimilar software,
- c. Different data sources,
- d. Different LRU locations,
- e. Different wire routing and lengths, and
- f. Avoiding common points or paths between channels or components.

4.2.2 Hardware Design

In general the hardware design is the most sensitive and cost effective step of the system design. It is important to separate analog components from digital ones. Keeping analog and digital signals zoned within input/output connectors and interconnect routing is of value. Analog signals often utilize filter capacitors for hardening while digital signals often rely on wire bundle shielding.

4.2.3 Circuit Design Measures

Circuit design is important because good design minimizes requirements for additional protection methods, reducing weight and cost. Retrofit hardening is difficult and costly to achieve and should be avoided by considering HIRF at the initial aircraft and/ or equipment design phase. Typical design methods are:

- a. Signal levels should be sufficiently high to provide adequate signal-to-noise ratios in the presence of HIRF, but not so high as to cause interference in their own right to other equipment.
- b. The spectral content of the required signal should be the minimum required for correct circuit operation. In addition, the circuitry should be designed to respond only to the frequency range of the required signal and should be band limited outside this range to minimize undesired response to interfering signals.
- c. Circuit interface impedance levels should be kept reasonably low to minimize crosstalk coupling from interfering signals.
- d. Balanced input circuitry should be used, where practical, to minimize common mode interference problems.

4.2.4 Analog Devices

The two major ways HIRF-induced effects interfere with analog circuits are through RF rectification and modulation detection. Any non-linear device including diodes can cause rectification and/or demodulation. RF rectification causes a DC offset in the circuitry. If the induced level is strong enough it can fully saturate an amplifier. In the case of modulation detection, the RF carrier is separated from the signal modulation. When the modulation frequency falls within the circuit's response bandwidth the modulation is processed along with the intended signal resulting in circuit functional upset. The following design precautions may be taken:

- a. Restrict the pass band of the system by low pass common mode filtering at the point of input/output entry to the LRU.
- b. Locate analog devices such as sensors or actuators as close as possible to their supporting control electronics (use short wires usually less than 1 meter in length) whenever possible.
- c. Employ twisted shielded wires between the sensor/actuator and the control electronics unit with shield grounded coaxially at both ends for high HIRF levels. The twisted shielded wire allows the shield to be non-current carrying. The inner conductors carry the entire signal current.
- d. Where redundancy is used, care must be taken with the devices used to exclude erroneous data; use virtual voters (no hardware) if a suitable voting algorithm can be produced.

The usual techniques for achieving data coherence verification for analog signals are:

- a. DC offset and scale limitation.
- b. AM and FM signals (if possible the carrier or center frequency is different from the HIRF modulation frequencies, or from internal aircraft modulations such as 400 Hz, 1 kHz, etc.).
- c. Monitoring of the signal reference.

4.2.5 Digital Devices

The source and load impedance, effective bandwidth, and characteristic impedance of the selected data wire of the technology to be employed are the most important factors. Each logic type has different circuit impedance, bandwidth, and noise threshold, e.g. Transistor/Transistor Logic (TTL), Complementary Metal Oxide Semiconductors (CMOS), or Very Large Scale Integration (VLSI). The same design precautions used for analog circuitry are generally used for digital circuits.

Internal wiring and printed circuit board trace isolation segregation is important especially between input/output signals and sensitive internal analog and/or high speed digital circuits. Separating shielded wires from unshielded leads such as discrete leads among connectors is an important technique. Internal interconnect wires should not be routed over or near Integrated Circuit (IC) devices since that could result in direct coupling between them.

The following design techniques for discrete data signals and data buses can be classified in decreasing susceptibility:

- a. Level triggered signals,
- b. Edge triggered signals,
- c. Transition triggered signals such as Manchester bi-phase code, and
- d. Sequence coded transition triggered signals, i.e. a transition is electrically encoded with a particular sequence such as ARINC 629.

Bi-phase signals are inherently more immune than single phase signals.

4.2.6 Software Design

Standard software design techniques may increase the system immunity to HIRF. Such techniques include:

- a. Data Link Communication,
- b. Interrupts,
- c. Timers,
- d. Multi-processor,
- e. Redundancy,
- f. Dissimilar Programs,
- g. Processing Sequencing, and
- h. Fault Tolerance.

Generally, all the above mentioned techniques could be applied at the equipment level and/or the system level. The HIRF influence should be considered when redundancy is being implemented to improve reliability and availability. Incorporation of EMI-tolerant software techniques may lead to an improved system.

The CPU software interface with various input, control and display devices may use data link communication techniques for maintaining data integrity in the presence of a HIRF environment. The data may be verified with the peripheral device.

The data may be evaluated to determine if it is consistent with the previous and subsequent data communicated to or from the peripheral device. The data may be obtained over different interface channels with the same peripheral and compared for consistency. Likewise, the data may be obtained from different peripherals, but of similar capability and compared for consistency. The data shared with a peripheral may be sampled over a period of time and integrated or compared to derived consolidated data effectively averaging out the EMI effect by digitally filtering. Re-send tactics may be used if interference is detected. Error correction algorithms may also be used.

Computer interrupts may be used for treating unexpected malfunction like EMI errors and equipment malfunction due to EMI. The computer interrupt along with the device on the bus would be polled to locate and diagnose the failure. A decision would be made by the CPU to use either a secondary/backup function or alert the pilot.

Watch dog or time-outs are used frequently on communication links to detect problems with peripheral devices. These timers are also means of identifying systems that have failed due to HIRF, reporting to the CPU for corrective action.

In a multi-processor architecture, one processor can monitor critical software functions and software flow in order to detect HIRF induced anomalies of the other processor. Programs that are devoid of loops and software without deterministic behavior are better at detecting HIRF anomalies.

The use of redundancy for multi-channel computers and or parallel-processing computer systems provides another option. The redundant processing power may be capable of tolerating HIRF effect on a single channel or processor with minimum software sophistication.

Another approach is to use dissimilar software programs in redundant computers. Alternatively, dissimilar CPU types could host the software program resulting in two different processing environments for HIRF critical function.

The techniques of fault tolerant software systems provide another good means to design systems that are immune to the effects of HIRF. The critical function could be program to fail in a passive or non-catastrophic mode.

The sequence in which the software executes its process may be structured in such a manner to minimize the impact of the HIRF. In a redundant system, different processors can interface with peripherals in a dissimilar order to avoid being affected by a HIRF event at the same time. On a high level, multiple processing methods may be used. For instance, two or more of the following may be used: real time, monitored, background, foreground, sequential, prioritized or interrupt driven.

The above discussion is not exhaustive. The reader is referred to such organizations as RTCA, SAE, EUROCAE, etc., for further information on software technologies that might mitigate HIRF effects. Many more techniques exist and more will be developed. The primary point is that software can mitigate some effects of HIRF. HIRF tolerant software techniques could be applied at the equipment level and or the system level. Incorporation of HIRF tolerant software techniques may lead to a simpler system with less dependence on unique hardening hardware that requires surveillance and or maintenance.

4.3 Empirical Methods

Methods for performing experimental testing associated with research in support of design and engineering testing in support of design are provided in Sections 6 and 7.

Installed systems and interconnecting wiring will in most cases be subject to a complex field distribution which can be simulated by a combination of analysis and aircraft testing.

General transfer functions may be used as a result of database information from representative testing. However, unique effects in a given structural design may defy an accurate assessment based on general transfer functions.

4.4 Analytical Methods

The testing of a complete aircraft containing complex, flight-safety electronics in various HIRF environments can be time consuming. An aircraft trial carried out over many weeks is likely to investigate only a small number of possible combinations of system modes, HIRF illumination angles, and frequencies. It is unusual for a complete aircraft to be made available for many weeks of ground testing prior to production certification. A more complete assessment can be accomplished using analysis of the HIRF hazards. An analytical approach can mitigate undesirable impacts on the aircraft certification program.

In addition to allowing more comprehensive assessments than testing alone, analysis can directly support testing. Two examples of such direct support are:

- a. Defining and selecting the test methodologies

- b. Assessing the completeness and validity of the test results (i.e. assessing the impact of the approximations made during testing).

The simulation of the HIRF hazards is complex and involves a detailed understanding of the electromagnetic interactions involved. The design of test arrangements to provide required excitation of the aircraft is heavily dependent on being able to analyze the simulation in detail. Furthermore, a quantitative assessment of impact of the unavoidable approximations in the test setup can be achieved using detailed analyses. In general, airworthiness certification should be achieved through a combination of test and analysis.

Analytical methods aimed at the problem of protecting the aircraft against external RF environments primarily involve calculation of electromagnetic field coupling to the aircraft structure and wires (radiated susceptibility) and calculation of circuit level response (conducted susceptibility). Emission analysis methods also can be used to predict and resolve design problems. The HIRF-induced RF currents on wires from the environment are viewed as emission sources requiring control.

Detailed analyses can identify problem areas of system installation and electrical design. The measurement program during the airworthiness testing can be planned to concentrate on those areas. High quality measurement data can be obtained for these areas and used to validate the analysis. If validation is achieved, then many of the combinations of system modes and frequencies can be considered by analysis only. In this way, a more thorough EM hazard protection certification is achieved as well as a possible reduction in test time.

The trend towards the extensive use of non-metallic airframe materials (lower shielding), coupled with the increasing reliance on electronic systems for Level A functions (sensitive circuits), has made the task of HIRF design very difficult and expensive to accomplish. The level of confidence required in the modern aerospace industry for system installation design, airframe design, and airworthiness certification cannot be easily accomplished without using analytical methods. In general, errors in analysis are comparable to test errors in size. Efficient design processes offload expensive testing with less expensive analysis. This process identifies potential design weaknesses early in the development process. Corrective measures can be taken immediately thereby making rectification cheaper.

Until recently, detailed modeling and analyses of induced currents and voltages in wires, conduits, LRU cases, and various structural components were not feasible. However, the development of three-dimensional computer codes that can be run on machines of increasing speed and efficiency now has made such analyses viable.

Modeling of the coupling of external fields to the aircraft has been proven to be quite easy and efficient when the analysis is limited to surface current distribution on the aircraft skin.

Analytical methods that evaluate RF field penetration through the aircraft skin, windows and doors must consider the complex effects related to the field interaction with the aircraft materials and configuration. These effects include:

- the diffusion in the skin,
- the diffraction through aperture,
- the effects of the inner distribution of materials, and
- the effects of complex harnesses.

Of course, these effects depend on the characteristics of a given aircraft in a given frequency range.

Modeling coupling to aircraft wire bundles directly with 3D modeling is difficult. This is because the physical dimensions of features in wire bundles, such as connectors and shield terminations are very small relative to the dimensions of the aircraft. It is therefore more effective to use 3D modeling in combination with network analysis codes. The 3D modeling can provide the internal RF field at the wire bundle location, and network analysis codes can calculate the currents on the wire bundles.

Such an approach is able to provide accurate results but in all cases one key aspect is the know-how of the operator that provides the input to the codes. This input is the electrical and geometrical model data that needs to be simplified from the Computer Aided Design (CAD) model in order to allow the codes to handle it. There are many possibilities to introduce major error during these simplifications and therefore the results can be considered reliable only after it has been validated with dedicated aircraft test results, typically Low Level Swept Current (LLSC) or Low Level Swept Fields (LLSF), or thanks to previous acquired database of coupling measurement.

Consequently, when no validation is available, at early stage of a new project representing a technological step, such a model can be used to compare various design configurations and will give relative information to support designer choices but also to support the test engineer in preparing the most effective test campaign.

The process of validation of the analysis methods employed should be confirmed by test as soon as there is a complete airframe available with some systems installed. The model may be helpful in analyzing and consolidating the test results. Consistent results from the analysis and test provide confidence in both the analysis method and the test method. At every opportunity throughout the development program, the design verification database can be expanded.

When robust validation data is available, such a model can be used to extend the coupling database to some new path, evaluate coupling on actual scenarios for which test is unpractical and evaluate limited aircraft design evolutions without the need for major retesting. The body of evidence to support certification is developed. Testing of the final standard production aircraft should be little more than a confirmatory check to ensure that there have been no significant changes between prototype and production.

Detailed and high quality analysis of the EM hazard protection has a significant part to play in the design and development of modern aircraft. However, testing will always be required in order to ensure that the very early assumptions were correct. In addition, the many features of the airframe and system that are not deliberately designed to have HIRF protection must be investigated for their impact on EM hazard protection performance.

Various analysis methods have been developed to predict electromagnetic coupling to aircraft and their electrical and electronic systems and to determine the effects on system operation. Many of these have been developed for assisting in the design of EMI control, Electromagnetic Pulse (EMP) survivability, antenna design, etc. Some of these methods are suitable for aiding in the design and certification of HIRF protection. These methods range in complexity from large state-of-the-art numerical simulations suitable for modeling entire aircraft to more simple numerical implementations of specific analytical models of HIRF and EMI coupling. In addition, circuit analysis methods appropriate and useful in determining the circuit level response to HIRF-induced interference have been developed. In general, no single analysis method can evaluate aircraft HIRF protection over the entire HIRF frequency range of 10 kHz to 40 GHz. Therefore multiple analysis methods may be used, or analysis methods may be used in combination with tests.

Analysis methods may use time domain or frequency domain to solve the electromagnetic Maxwell's equations. The methods may be implemented in two dimensions or three dimensions. Some analysis methods convert the electromagnetic field problem into a circuit analysis problem. The characteristics, advantages and disadvantages of these methods are described in detail in Clemson University report CVEL-08-011.2. [T. Hubing, C. Su, H. Zeng and H. Ke, "Survey of Current Computational Electromagnetics Techniques and Software", Clemson University Technical Report CVEL-08-011.2, September 21, 2008; <http://www.cvel.clemson.edu/pdf/CVEL-08-011.2.pdf>]

Commonly used electromagnetic analysis methods include method of moments, finite difference time domain, finite element, transmission line matrix, and geometrical theory of diffraction. These methods may be used to model HIRF interaction with aircraft and associated structure, materials, doors and windows. With these methods the aircraft structure and materials are modeled in three dimensions. Typically these methods are combined with digital aircraft design data to develop the electromagnetic model.

Circuit analysis and transmission line analyses may be useful to evaluate HIRF protection related to aircraft wiring and equipment.

4.5 HIRF Protection Main Contributors

In assessing the efficiency of the various protections implemented on the system, attention must be paid to the evolution of their performance that can result from later modifications, changes in production techniques and ageing.

4.5.1 Structure

As a summary of Section 4, the elements that are of primary importance in the design of the HIRF protection of an aircraft structure are at least:

- a. The intrinsic attenuation of the fuselage, including material and the technology used for joining parts, in view of the apertures present in each area of concern and in the corresponding HIRF frequency range.

- b. The apertures, including those due to composite panels, in each areas of concern of the aircraft, including their shielding and sealing techniques. Aperture analysis shall also include apertures between internal areas.
- c. The techniques used for a conductive linear part, such as hydraulic pipes or any other structural or mechanical part, to cross from two areas with different attenuation.
- d. Structural protection of the wiring such as conduit/raceway.

4.5.2 Harness

As a summary of Section 4, the elements that are of primary importance in the design of the HIRF protection of an aircraft harnesses are at least:

- a. The techniques used for harnesses to cross from two areas with different attenuation. The shielding of individual lines including the shield bonding concept (one end, two ends, intermediate points...).
- b. The global shielding of wire bundle including the shield bonding concept (one end, two ends, intermediate points...).

4.5.3 System Hardware

As a summary of Section 4, the elements that are of primary importance in the design of the HIRF protection of an aircraft architecture are at least:

- a. The system architecture concept: redundancy and dissimilarity.
- b. The overall grounding concept including signal, power lines, shields (individual or global) and safety ground if applicable.
- c. The bonding rules.
- d. LRU locations including sensors.
- e. Wire routing and segregation as a function of systems criticality or between routes that come from area of different severity of HIRF exposure.
- f. Type of links such as structural return, differential lines, and optical lines.
- g. Filtering, internal or external to the equipment, including lossy lines wires and components not specifically addressing HIRF such as surge suppressor.
- h. Interface components up to the first active component, type of input circuit balanced/unbalanced, band pass, impedance and audio rectification effect.
- i. Signal type, level and spectral content.
- j. Internal Printed Circuit Board (PCB) routing and filter implementation.
- k. Internal components, especially when directly in contact with power lines.

4.5.4 System Software

As a summary of Section 4, the elements that are of primary importance in the design of the HIRF protection of an aircraft system software are at least:

- a. Communication protocol (interrupt, timer...).
- b. Dissimilar software for redundant systems.