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

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1. SCOPE:

This guide provides detailed information, guidance, and methods related to the Federal Aviation Administration Advisory Circular (AC)/Joint Airworthiness Authorities Advisory Material Joint (AMJ) 20-XXX, "Certification of Aircraft Electrical/Electronic Systems for Operation in the High Intensity Radiated Fields (HIRF) Environment" (draft). The AC/AMJ provides acceptable means, but not the only means, of compliance with Parts 23, 25, 27, and 29 of the Federal Aviation Regulations (FAR)/Joint Aviation Regulations (JAR) to prevent hazards to aircraft electrical and electronic systems due to HIRF produced by external transmitters.

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 Federal Aviation Administration (FAA) or Joint Aviation Authorities (JAA).

1.1 Purpose:

This document provides technical guidance to demonstrate compliance with aircraft high intensity radiated field (HIRF) certification regulations. This guide may be applied to new designs, significant modification of existing designs, and application of existing (off-the-shelf) equipment on an aircraft that has not previously used that equipment. The scope of the subsystems included in the HIRF certification are, but are not limited to, power distribution systems, electrical generating systems, electronic engine control systems, electronic flight control systems, and instrument flight rule (IFR) navigation and flight reference systems. The term 'systems' refers to black box equipment; interconnecting power, signal, and control wiring; indicators; control panels; and dependencies on other systems for input or output.

The HIRF regulations are applicable to any aircraft (i.e., transport aircraft, helicopters, single engine aircraft, etc.). The more specific area of applicability to each aircraft is the continued availability of functions related to safe takeoff, flight, and landing during and after exposure to HIRF. It must be demonstrated and certified that aircraft systems that perform functions related to safe takeoff, flight, and landing are not adversely affected when the aircraft is exposed to the Normal HIRF Environment. Furthermore, these functions must not be lost when the aircraft is exposed to the Severe or Certification HIRF Environment. 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 an environment derived from the Normal HIRF environment. The approach to achieving HIRF certification is through proper selection of equipment, qualification, and installation integration.

1.1 (Continued):

The discipline of Electromagnetic Environmental Effects (E^3) encompasses a broad number of electromagnetic phenomena. The E^3 discipline includes the following:

a. Intrasystem Electromagnetic Compatibility (EMC)
b. Intersystem Electromagnetic Compatibility (EMC)
c. Subsystem Electromagnetic Interference (EMI)
d. Grounding
e. Bonding
f. Lightning
g. Precipitation Static
h. Electrostatic Discharge (ESD)
i. Electromagnetic Pulse (EMP)
j. Emission Control
k. TEMPEST
l. Hazards of Electromagnetic Radiation to Ordnance (HERO)
m. Hazards of Electromagnetic Radiation to Fuel (HERF)
n. Hazards of Electromagnetic Radiation to Personnel (HERP)
o. High Intensity Radiated Fields (HIRF)

This guide is only concerned with one area - HIRF. The HIRF discipline deals with the ability of aircraft to withstand high intensity radiated fields. The HIRF field is a specialized subset of intersystem electromagnetic compatibility (EMC), similar to HERO. Intersystem EMC is the discipline of providing compatible operation of all systems, in all phases of operation, in all possible external radio frequency (RF) fields. Furthermore, since lightning, precipitation static, electromagnetic pulse (EMP), and electrostatic discharge (ESD) are all external electromagnetic phenomena, the technology used in these areas is applicable to the HIRF discipline and may be referenced for additional information.

To avoid confusion with other electromagnetic disciplines 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.

This document incorporates information and relevant details on the anticipated external electromagnetic environment for aircraft, design approaches for protection to HIRF, certification approaches to HIRF, and verification methods contained in the HIRF AC/AMJ.

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, integrated circuit (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 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 shield against HIRF and hence electronic circuits are provided inherent protection. However, some composites are poor shields and HIRF can irradiate the electronic systems on such aircraft with relatively little attenuation.

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:

Whenever a reference document appears in this guide, it implies the minimum revision level of the reference document acceptable to meet the intended requirements. Later versions of the reference document are also acceptable but earlier versions are not acceptable. In all cases, other documents shown to be equivalent to the referenced document are also acceptable. Should there be a conflict of requirements between documents the following is the order of precedence:

a. FAR/JAR
b. HIRF AC/AMJ 20-XXX
c. This guide
d. DO-160/ED-14
e. Other documents

2.1 Applicable Documents:

2.1.1 Federal Aviation Administration Documents: The following documents can be obtained from the US Department of Transportation; Subsequent Distribution Office; Ardmore East Business Center; 3341 Q 75th Avenue; Landover, MD 20785.

US Code of Federal Regulations 14 CFR Parts 23.901, 23.903, 23.1301, 23.1308, 23.1309, 23.1431, 23.1529, 25.901, 25.903, 25.1301, 25.1309, 25.1317, 25.1431, 25.1529, 27.901, 27.903, 27.1301, 27.1309, 27.1317, 27.1529, 29.901, 29.903, 29.1301, 29.1309, 29.1317, 29.1431, 29.1529.

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

2.1.2 Joint Airworthiness Authorities Documents: The following documents may be obtained from the Civil Aviation Authority (CAA), Printing and Publication Services, Greville House, 37 Grafton Road, Cheltenham, Glostershire GL50 2BN, England.

Joint Airworthiness Requirements, Sections 23.901, 23.903, 23.1301, 23.1309, 23.1317, 23.1431, 23.1529, 25.901, 25X899, 25.903, 25.1301, 25.1309, 25.1317, 25.1431, 25.1529, 27.901, 27.903, 27.1301, 27.1309, 27.1317, 27.1529, 29.901, 29.903, 29.1301, 29.1309, 29.1317, 29.1431, 29.1529.

Advisory Material/Joint 20-XXX, "Certification of Aircraft Electrical/Electronic Systems for Operation in the High Intensity Radiated Fields (HIRF) Environment", (draft).

2.1.3 RTCA, Inc. Documents: The following document can be obtained from RTCA, Inc., 1140 Connecticut Avenue, NW, Suite 1020, Washington, DC 20036-4001.

RTCA/DO-160D, "Environmental Conditions and Test Procedures for Airborne Equipment", dated July 29, 1997.

2.1.4 EUROCAE Documents: The following document can be obtained from EUROCAE, 17 rue Hamelin, 75116 Paris, FRANCE.

EUROCAE ED-14D, "Environmental Conditions and Test Procedures for Airborne Equipment", dated July 1997.

2.2 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.

2.2.1 U.S. Government Documents: The following documents can be obtained from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

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.

MIL-STD-461E, "Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility", dated 20 August 1999.

MIL-STD-464, “Electromagnetic Environmental Effects Requirements for Systems”, dated 18 March 1997.

MIL-DTL-38999K, "Connector, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded and Breech Coupling) Environment Resistant, Removable Crimp and Hermetic Solder Contacts General Specification"

MIL-STD-882D, "System Safety Program Requirements", dated 19 January 1993.

MIL-STD-1344A, "Test Methods for Electrical Connectors"

2.2.2 SAE Publications: The following documents can be obtained from Society of Aeronautical Engineers (SAE), 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP4754, “Certification Consideration for Highly Integrated or Complex Aircraft Systems”, issued November 1996.

ARP4761, “Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment", issued December 1996

2.3 Abbreviations:

A	Amperes
AC	Alternating Current
C	Capacitance
cm	Centimeters
dB	Decibel
DC	Direct Current
f or F	Frequency
I	Current
K	Constant
kHz	Kilohertz
L	Inductance
mA	Milliamperes
MHz	Megahertz
mH	Microhenry
ms	Microseconds
mm	Millimeters
nH	Nanohenry
P	Power
ps	Picoseconds
Q	Resonance characteristics
R	Resistance
V	Voltage
W	Watts
Z	Impedance

2.4 Acronyms:

AC	Advisory Circular
ARP	Aerospace Recommended Practice
AWG	American Wire Gauge
BCI	Bulk Current Injection
CMOS	Complementary Metal Oxide Semiconductor
CMR	Common Mode Rejection
CW	Continuous Wave
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EUROCAE	European Organization for Civil Aviation Equipment
EUT	Equipment Under Test
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Regulation
FBW	Fly-By-Wire
FHA	Functional Hazard Assessment
HIRF	High Intensity Radiated Fields
IFR	Instrument Flight Rules
JAA	Joint Airworthiness Authority
JAR	Joint Airworthiness Requirements
LLSC	Low Level Swept Coupling
LRU	Line Replaceable Unit
MIL-STD	Military Standard
MTBF	Mean Time Between Failures
MTBUR	Mean Time Between Unscheduled Removals
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NTIS	National Technical Information Service
PRF	Pulse Repetition Frequency
RF	Radio Frequency
RTCA	Radio Technical Committee on Aeronautics
SAE	Society of Aeronautical Engineers
STC	Supplemental Type Certificate
TC	Type Certificate
VFR	Visual Flight Rules
WG	Working Group

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 aviation certification 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 initially established two environments:

a. The Severe HIRF environment is based on the worst case estimate of electromagnetic field strengths that a civil aircraft might encounter.

b. 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.

3.1 (Continued):

ICAO flight standards allow flight to within 500 feet of the ground under visual flight rules (VFR) for fixed wing aircraft. Although this is uncommon for many aircraft, it is permissible. At such an altitude, aircraft have the potential to come extremely close to terrestrial-based emitters that produce RF field levels at the aircraft in excess of 7,000 volts/meter. The aircraft, on the other hand, may have been qualified only for an equipment electromagnetic environment of 0.5 volts/meter. The difference between equipment qualification and the estimated electromagnetic environment the aircraft will operate in, resulted in concern over HIRF. Another consideration that needed to be taken into account was the flight profiles used by rotorcraft. The ICAO fixed wing standard on height above the ground no longer applies. In addition, they can hover. This resulted in the committee establishing two Severe HIRF environments, one for fixed wing aircraft and one for rotorcraft.

It is recognized that some civil fixed wing aircraft perform special operations, however, the material in this guide deals only with flights above 500 feet except during landing and takeoff at civil airports.

Because of the very high field strengths estimated in the Severe HIRF environment, the committee developed a reduced environment suitable for the certification of Part 23 and 25 aircraft. This new environment is called the Certification HIRF Environment (HIRF Environment I). 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 aircraft categories. The Certification HIRF environment was only deemed to be suitable for rotorcraft IFR Level A functions. For rotorcraft VFR Level A functions the Rotorcraft Severe HIRF environment (HIRF Environment III) is appropriate.

The field strength level in each band of the Certification HIRF environment was the higher of the US and the European environments. This section of the Users 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. However, the entire band is proclaimed to require protection to that level because there are no guarantees that the most severe signal would not be found at a future date to be operating at any arbitrary frequency within that band.

3.2.1 Licensed Emitter Databases: The emitter data selected was from the licensing database. The information provided was the maximum operating characteristics of the emitter. These characteristics did not consider that the actual emitter may never achieve the maximum allowable effective radiated power (ERP). The degree to which a practical installation achieves the advertised maximum or licensed ERP depends upon both the frequency band and the power of the system. The committee was unable to develop a rational basis for reducing the effective environment emitter signal levels to reflect the maximum that was likely to be encountered in a real environment.

3.2.2 General Assumptions: In calculating the environment, both specific and general assumptions were made. The specific assumptions deal with aircraft to transmitter distance criteria and are discussed later. The general assumptions are as follows:

a. The envelope was divided into the frequency bands 10-100 kHz; 100-500 kHz; 500 kHz-2 MHz; 2-30 MHz; 30-70 MHz; 70-100 MHz; 100-200 MHz; 200-400 MHz; 400-700 MHz; 700 MHz-1 GHz; 1-2 GHz; 2-4 GHz; 4-6 GHz; 6-8 GHz; 8-12 GHz; 12-18 GHz; and 18-40 GHz.

b. Maximum main beam gain of a transmitter antenna was used.

c. Modulation of a transmitted signal was not considered. However, the duty cycle was used to calculate the average power for pulsed transmitters.

d. Constructive ground reflections of High Frequency (HF) signals, i.e. direct and reflected waves, were assumed to be in phase.

e. Non-cumulative field strength was calculated. Simultaneous illumination by more than one antenna was not considered.

f. Near field corrections for aperture and phased array antennas were used.

g. Field strengths were calculated at minimum distances that were dependent upon the location of the transmitter and aircraft.

h. Field strength for each frequency band was the maximum for all transmitters within that band.

i. Peak and average:

1. Peak field strength was based on the maximum authorized peak power of the transmitter, maximum antenna gain, and system losses.

2. Average field strength was based on the maximum authorized peak power of the transmitter, maximum duty cycle, maximum antenna gain, and nominal/actual system losses. Duty cycle is the product of pulse width and pulse repetition frequency. This applies to pulsed systems only.

3. The field strength values are expressed in volts per meter and were calculated from the power density.

3.2.2 (Continued):

j. The terms slant range and adjusted slant range are defined as follows:

1. Slant range is the line-of-sight distance between the transmitter and the aircraft.

2. Adjusted slant range is the distance between the transmitters and the aircraft taking into account the aircraft altitude and the maximum antenna elevation angle of the transmitter. If the maximum elevation angle was not available, 90 degrees was assumed, which is slant range of 500 feet.

In Figure 1, the aircraft is flying 500 feet above the ground-based transmitter. The height of the emitter is assumed to be insignificant. The transmitter antenna main beam elevation is limited to a maximum angle of 30°. At 1000 feet from the transmitter, the aircraft encounters the maximum illumination (main beam) of the transmitter antenna. As it flies closer, the aircraft will only encounter much lower side lobe illuminations. The distance at which the aircraft encounters the maximum illumination from an elevation-limited antenna main beam is called adjusted slant range.

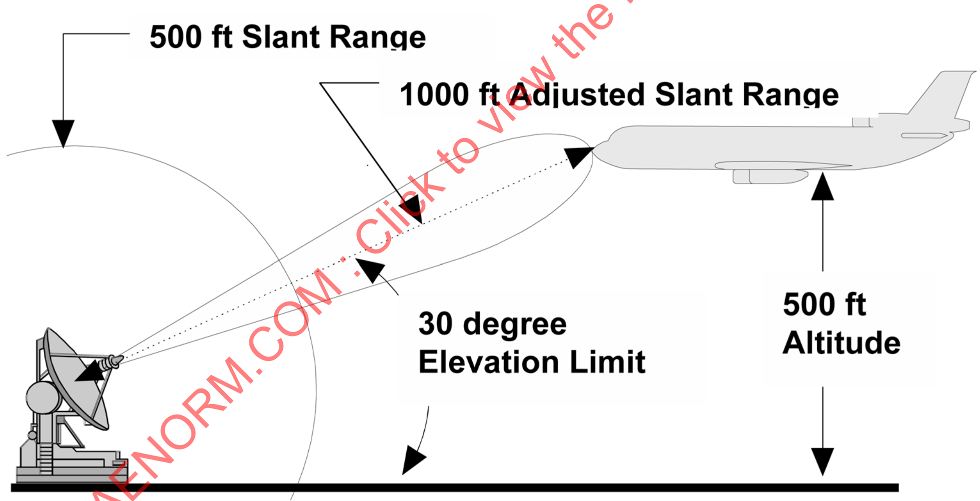

FIGURE 1 - Illustration of Slant Range

Many ground-based transmitters have limited elevation angle; for all these emitters it was appropriate to use the adjusted slant range from the transmitter, rather than 500 feet slant range, to estimate the power densities.

k. Transmitters located in Prohibited, Restricted, or Danger areas were not included in the environment.

3.2.2 (Continued):

l. For the US element of the environment, selected high power transmitters were placed in Special Use Airspace (SUA), which will be marked on the aeronautical charts. The size of an SUA would be derived from transmitter data and would therefore vary from transmitter site to transmitter site. Altitude and radius, as marked on the aeronautical charts, would specify the SUA size. For transmitters located within an area of SUA, the transmitter field strength was assessed at the boundary of the SUA.

m. Transmitters with experimental licenses were excluded.

n. Non-airport mobile tactical military transmitters were excluded.

o. Transmitter co-operative operation with aircraft procedures was used to calculate illumination and power density.

p. The US HIRF environment included estimated 3 dB transmitter losses into the antenna, unless transmitter data was available.

q. Antenna heights above ground due to antenna towers that are not part of the basic equipment package were not considered. Flat earth is assumed, i.e., terrain was not included.

r. Emitter data was extracted from authorized or licensed transmitters as of 1997.

s. Emitter data for the U.S. HIRF environment included Contiguous United States (CONUS), Alaska, Hawaii, and Puerto Rico. Emitter data for the European HIRF environment included France, Germany, United Kingdom, Netherlands, and Sweden.

t. Both the U.S. and European HIRF environments were based on mathematical modeling of the transmitter characteristics and sample in-flight validations.

u. Modulation was not considered for the non-pulsed emitters, therefore peak field strength and average field strength were set to be the same.

v. High impedance fields ($E > 120\pi H$) were found to exist in the frequency range of 10 to 100 kHz. These fields were excluded from the HIRF envelopes because they do not propagate and are more likely to be a problem on airframes that are predominantly non-conducting. Manufacturers intending to install equipment in such airframes should consult the cognizant Aircraft Certification Office. However, a note has been added stating the HIRF strength values for these frequency regions and is for information only.

3.2.3 Field Strength Values: The emitter databases, together with the designated minimum distances, were used to calculate the values of field strength for the environments. The peak field strength is based on the maximum authorized power level of the transmitter and antenna gain for the frequency range. The average field strength is based on the maximum average field strength (peak output power of the transmitter times the maximum duty cycle times the antenna gain) for the frequency range. The field strengths used in the environments for peak and average may or may not be from the same driver emitter.

For emitters that used amplitude modulation such as AM broadcast radio and TV, the continuous carrier output level (without modulation) was used for the calculation of both peak and average field strengths. Furthermore, for CW emitters, the duty cycle is unity and the peak and average powers are the same. It is more complex to define peak amplitudes when the signal is amplitude modulated (see Figure 2). The true peak field strength could be calculated from the product of continuous carrier output level, the percent of AM modulation, and the frequency of the modulation. In most cases the percent of AM modulation, and the modulation frequency varies greatly. Therefore it was not used for HIRF calculations.

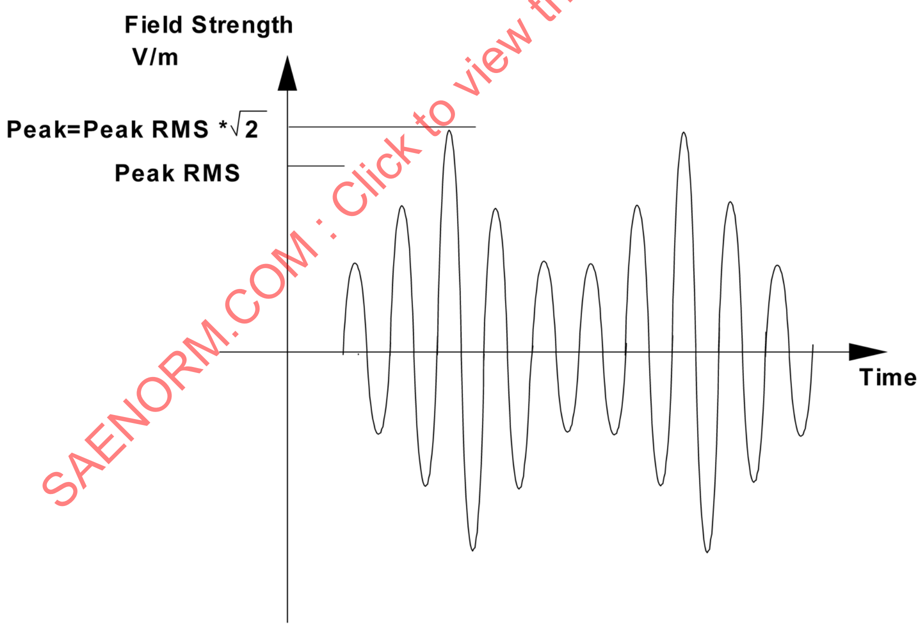

FIGURE 2 - Amplitude Modulated Signal

Pulse modulated signals, such as from a radar, have differences between peak and average power density. The ratio between the peak and average values is a function of the duty cycle with pulse modulated or gated signals. The peak field is the value of the electric field for the time that the signal is on (Figure 3). When the signal is off, the field strength is zero.

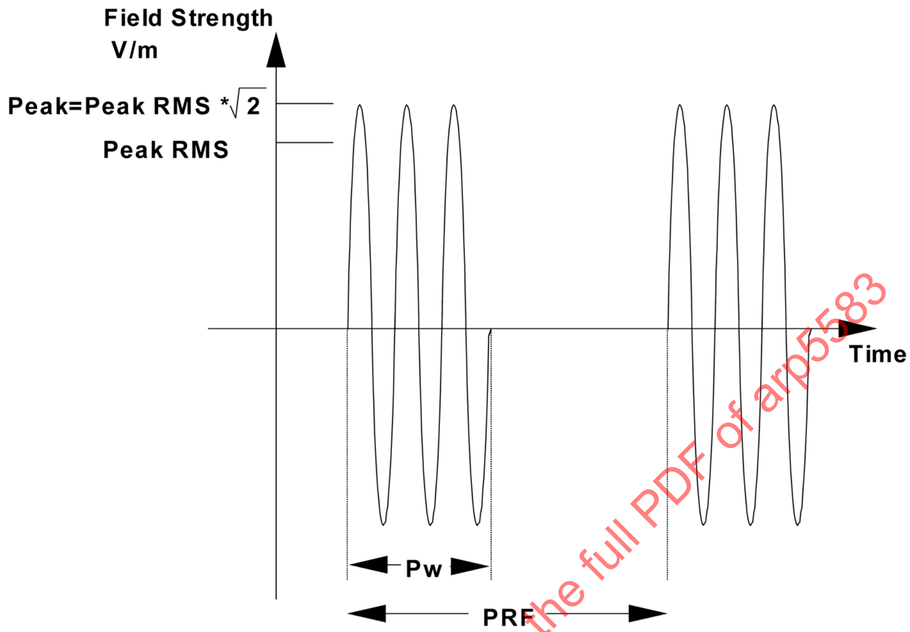

FIGURE 3 - Pulse Modulated or Gated Signal

3.2.3 (Continued):

The antenna pattern and rotation rate was not used for any of the calculations. Only the 3 dB beamwidth gain was used.

The units used to define the field strength of the HIRF environment are in terms of rms. All measurements or calculations of the field strength are derived in terms of the power density, either average or peak, then converted to volts per meter (v/m_{rms}). The root mean square (rms) units for peak electric field or peak power density are usually omitted since they are assumed to be understood without restatement. In all cases, the rms values, as in all forms of electrical engineering, have always been true electrical peak divided by root 2.

The term known as peak rms is the normal parameter measured during equipment and aircraft EMC tests, and the way the HIRF environment is expressed. The measurement of modulated RF signals during HIRF testing and the terms peak and peak rms cause significant confusion. For all HIRF measurements of modulated signals a peak detector must be used. By tradition, RF spectrum analyzers and measuring receivers are calibrated with a sine wave such that in peak mode a 1 $volt_{rms}$ sine wave input will give an indicated measurement of 1 volt. This will not change if the signal is switched on and off, the peak reading will still be 1 volt hence the term peak rms. Figure 2 shows the relationship between peak and peak rms for an amplitude modulated sine wave. Figure 3 shows the relationship between peak and peak rms for a pulse modulated or gated sine wave.

3.2.3 (Continued):

All measurements relating to HIRF are made using the peak detector function of the measuring receiver/spectrum analyzer. This is calibrated in terms of the equivalent rms value of a sine wave. What does this mean? When measuring a modulated signal, the bandwidth of the measuring receiver should be set wide enough to capture the total energy of the signal. The amplitude reading as measured by the peak detector function is noted. The unknown signal is disconnected and a sine wave signal at the same frequency fed in. Its amplitude is adjusted until the same reading is produced on the measuring receiver. This amplitude is expressed in terms of the rms value of the sine wave.

For calculating peak or average power, use the following engineering conventions:

Start with the average output power of the emitter (usually measured with an average reading power meter):

P_A = Average Power expressed in watts (rms)
G = Gain of antenna system (including near field correction factor), no units
r = distance from antenna aperture expressed in meters

From these values, the radiated power is calculated:

Pd_A = Average Power Density expressed in watts/meter^2 (rms)
$Pd_A = (P_A * G)/(4 \pi r^2)$

For main beam illumination by simple pulse emitters, the peak power density is calculated:

T_W = Pulse Width expressed in seconds
F_R = Pulse Repetition Frequency (PRF) expressed in Hertz
D = Duty cycle (ratio) = $T_W * F_R$
Pd_p = Peak Power Density expressed in watts/meter^2 (rms) = Pd_A/D

The power density is converted to electric field using the impedance of free space air (120 π or 377 ohms):

E_A = Average Electric Field Intensity expressed in Volts/meter (rms)
$= (Pd_A * 377)^{(1/2)}$
E_P = Peak Electric Field Intensity expressed in Volts/meter (rms)
$= (Pd_P * 377)^{(1/2)}$
or
$= E_A * D^{(-1/2)}$
or
$= (377/4\pi)^{(1/2)} * (P_A * G)^{(1/2)}/r$
or
$= (Pd_A * 377/D)^{(1/2)}$

3.2.3 (Continued):

The true electric peak field (which is ET = EP * √2) is not used because it does not relate to common measurements.

To convert from watts/meter^2 to mw/cm^2 a (10^3 W/mW) / (10^4 m^2/cm^2) conversion factor (1/10) is needed, e.g., 100 W/m^2 =10 mW/cm^2.

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
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. 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 - RBS interrogators
   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
   6. ATC transponder

3.3 (Continued):

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
6. Command and control facilities

d. Shipboard emitters

1. HF, VHF, and UHF communications
2. Navigation and tracking radars
3. IFF/SIF

e. Air-to-air (interceptor) emitters

1. Tracking radars
2. Various on-board radars
3. HF, VHF, and UHF communications

f. Air-to-air (non-interceptor) emitters:

1. Weather radars
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, adjusted 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 foot, adjusted slant range distance was used.

2. 50 feet, slant range, for mobile transmitters, including transmitters on other aircraft, and 150 feet slant range for aircraft weather radar.

3.3.1 (Continued):

b. Non-airport ground environment: These sources include the following emitters:

1. 500 feet, ajdusted 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 adjusted 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 slant range for non-interceptor aircraft with all transmitters operational.
2. 100 feet slant 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.

3.4 Rotorcraft Severe HIRF Environment (HIRF Environment III):

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

a. Airport/heliport
b. Non-airport/non-heliport ground
c. Shipboard
d. Off-shore platforms
e. 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.

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-100 kHz. Research shows that these fields induce negligible currents onto aircraft wiring and can be ignored.

3.4 (Continued):

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
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
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
6. Command and control facilities

d. The shipboard emitters

1. HF, VHF, and UHF communications
2. Navigation and Tracking radars
3. IFF/SIF

e. The off-shore platform emitters

1. HF, VHF, and UHF communications
2. Navigation and Tracking radars
3. ATC transponder

3.4.1 Assumptions for the Calculation of the Rotorcraft Severe HIRF Environment: The Rotorcraft Severe HIRF environment is derived from a worst case estimate of the electromagnetic field strength levels in the airspace in which rotorcraft flight operations are permitted. 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 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 300 foot adjusted slant range was used.

50 feet slant range for mobile transmitters, including transmitters on other aircraft, and 150 feet slant range for aircraft weather radar.

b. Non-Airport/Non-Heliport Ground environment: These sources include airport emitters while the rotorcraft is in flight:

All transmitters, 100 feet slant 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 take off or landing on a ship.) The resulting minimum separation is 500 feet slant 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 slant 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) Tables: The HIRF Environment III (Rotorcraft Severe) 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 - 100 kHz. Research shows that these fields induce negligible currents onto rotorcraft wiring and can be ignored.

3.5 Certification HIRF Environment (HIRF Environment I):

The certification levels are established from the 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 foot 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.

The Certification HIRF environment (HIRF Environment I) 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 Certification HIRF Environment: The Certification HIRF environment (HIRF Environment I) 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 adjusted 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. Adjusted slant range was calculated using the maximum elevation angle for the transmitters. Where maximum elevation angle was not known, 45° 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 slant range for non-interceptor aircraft with all transmitters operational.
   2. 100 feet slant range for interceptor aircraft with only non-hostile transmitters operational.

3.5.2 Certification HIRF Environment (HIRF Environment I) 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 - Certification HIRF Environment (HIRF Environment I)

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 Normal HIRF Environment (HIRF Environment II):

The normal HIRF environment (HIRF Environment II) 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 Normal HIRF environment.

The Normal HIRF environment 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 Normal HIRF environment 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 Certification HIRF environment, would be inappropriate.

3.6.1 Assumptions for the Calculation of the 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 Certification HIRF environment. For aircraft weather radar systems, a slant 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

3.6.1 (Continued):

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

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

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

3.6.2 Normal HIRF Environment (HIRF Environment II) 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 - Normal HIRF Environment (HIRF Environment II)

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.

The local fields that surround the aircraft are a combination of the incident HIRF (Normal, Rotorcraft Severe, and Certification) environment, and reflected (scattered) fields caused by induced surface currents and charges. These local fields are nonuniform 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, that drive the fields internal to the aircraft. These local fields may have a higher level than the incident field.

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. As noted, the local environment, not the incident environment, drives points of entry. The internal field levels are dependent on both the details of the point of entry and the internal cavity. The resulting internal fields 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. In some internal zones, internal field strength may exceed the incident field strength.

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. The field cannot be considered as uniform and homogeneous. This field will not necessarily allow a single point measurement to accurately determine of the internal field for use as the system test level. 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. For apertures small with respect to wavelength, measurements of the fields within the aperture would yield fields much larger than those farther inside the aircraft because the fields fall off inversely proportional to the radius cubed. For apertures on the order of a wavelength in size or larger, the fields may penetrate unattenuated.

3.7 (Continued):

The HIRF spectrum of RF energy that couples into aircraft wiring and electrical/electronic systems can be summarized into three basic ranges:

a. HIRF energy below 1 MHz - Induced coupling at these frequencies is inefficient and thus will be of lesser concern.

b. HIRF energy between 1 and 400 MHz - Induced coupling is of major concern since aircraft wiring acts as a highly efficient antenna at these frequencies.

c. HIRF energy above 400 MHz - Coupling to aircraft wiring drops off at frequencies above 400 MHz. At these higher frequencies the EM energy tends to couple through equipment apertures and seams and to the quarter wavelength of wire attached to the line replaceable unit (LRU). In this frequency range, aspects of equipment enclosure construction become important.

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, at frequencies below 400 MHz, 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 flight deck of the aircraft is an example of an open zone. The flight deck windows present almost no attenuation to an incoming field at and above the frequency for which its perimeter is one wavelength. Some enhancement above the incident field level generally exists in and around the aperture at this resonance condition.

The methodology for determining the internal environment for systems is found in Sections 5, 6, 7, and 8.

3.8 Aircraft Exposure to HIRF:

Aircraft fly by or over ground HIRF transmitters to within a specified minimum point of closest approach. The criterion used in developing the environment was generally considered to be 250 or 500 feet. 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. The time, at which the signal exposure falls to 10 dB less than at the maximum, at closest approach, can be calculated as:

$$t = 3d/v \qquad \text{(Eq. 1)}$$

where:

d = distance of closest approach in feet
v = velocity in ft/s

3.8 (Continued):

The time, t, equals 7.5 and 15 seconds for v = 100 ft/s and for d = 250 ft and 500 ft. In addition, t equals 1.9 and 3.8 seconds for v = 400 ft/s, for d = 250 ft and 500 ft.

Since 100 feet/sec and 400 feet/sec 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 feet/sec) 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° and a scan period of about 8 seconds. This scan sweeps over a 25-foot area of the aircraft in about 67 milliseconds, 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 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. The design should consider the increased gain in energy transfer when resonant conditions exist.

The RF environment that impacts system wiring is usually the result of either direct illumination of wiring in unprotected areas, or indirect RF field illumination influenced by the structure of the aircraft. If cavity and circuit resonances are not present, then some attenuation of the RF field may be assumed. The degree of attenuation depends upon the design practices employed.

The amount of airframe attenuation is dependent on the effect of airframe cavity resonances, the effect of constructive or destructive reflections of EM energy within the airframe cavities, and RF field coupling of the EM energy through airframe apertures and seams.

The internal aircraft fields present beyond the point of entry may not be uniform. 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.

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 50 MHz	300 m to 6 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.
50 MHz to 400 MHz	6 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 on wiring close to equipment. Coupling through A/C and equipment apertures low coupling.

4.1.1 (Continued):

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 Faraday cage or gross 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, i.e., wheel wells, cockpits, wings, and other apertures.

4.1.2 (Continued):

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. For example:

a. Wing/tail to fuselage fairings: Composite (glass fiber, carbon fiber, etc.) panels that provide little or no attenuation of the external field at low frequencies frequently enclose these areas.

b. Engine pylon to wing/fuselage fairings: While these are often metal, non conductive (e.g., silicon rubber) rubbing strips are used to allow relative movement. The slot so formed will resonate at its natural and harmonic frequencies causing RF energy to penetrate into the inner cavity.

c. Doors and hatches: Unless a good RF bond is formed around the whole periphery of the door, energy will penetrate.

d. Joints: Joints closed with non-conductive sealant will allow the ingress of RF energy since they will become resonant slots at some frequencies.

e. 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.

f. 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.

g. 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.

h. 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
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
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 (I/O) connector while others use a 1/2 meter wire to ground the power returns to chassis. If the LRU only provides filtering of the positive input power lead, then the 1/2 meter return lead will allow HIRF to couple. Had the return been grounded at the connector instead of via a 1/2 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 I/O 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.

4.1.4 (Continued):

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 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.

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.

4.1.5 Bonding: Bonding is the method used to reduce both the DC resistance (DCR) 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 $\lambda/20$.

4.1.5 (Continued):

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, composite aircraft cannot always provide such a bond. 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.

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. The best solution is to house equipment within shielded equipment bays with all cabling between the bays enclosed in overall shields with the shields decoupled at the points of entry.

Cockpit mounted equipment and equipment housed in other areas where airframe shielding cannot be provided must rely on case and wire bundle shielding. To improve Faraday shielding, conductive gaskets may be used around panels that are rarely opened but they may be impractical for many high usage access areas such as undercarriage doors or passenger/freight shielded equipment bays.

Honeycomb panels may be required to provide Faraday shielding where ventilation is required. The opening size of the individual honeycomb openings is limited by the highest frequency against which immunity is required. Display screens may require metallized coatings 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
h. Other plastics or composites of decreasing conductivity

4.1.6 (Continued):

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
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. 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 a coaxial fashion. The connector flange must 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). The use of pigtails or shield drain wires for terminating individual shields should be minimized since they allow HIRF induced currents to generate magnetic fields that often couple to internal leads of the wire bundle in the connector region. In general, overall wire bundle shields that terminate at a connector should be bonded in a 360° manner to EMI connector backshells; shield pigtails should not be employed.

Wire bundles routed in wing leading edges that are exposed to the full HIRF environment during takeoff and landing may require wire bundle overshields. The usual requirements for shields, such as high optical coverage (85 percent) should not be used to control wire shielding performance. Optical coverage is not directly linked to wire shielding. Wire shielding is dependent on carrier diameter, number of picks per unit length, overall wire bundle diameter, carrier plating, and longitudinal pressure and not optical coverage. Only actual wire bundle shielding performance data should be specified such as shield transfer impedance data and/or testing similar to that specified by MIL-DTL-38999K for connectors but adapted for wire bundle shields. Most major shield manufacturers have considerable test data on their products and this data should be requested and specified in the wire bundle shield performance specification.

4.1.7 (Continued):

Additional wire bundle shielding can be provided by wire bundle raceways. A raceway can be fabricated as part of the airframe by providing a partial (three sided) or fully enclosed metallic or metallically plated plastic raceway. The raceway may employ a top cover to permit access or be left open depending on the amount of protection needed. The raceway could route from one major avionics bay to another or from the major avionics bay to the engines, or from the cockpit to the avionics bay. Partitioning can be provided to separate sensitive wires from noisy wires within the raceway.

The preferred wire type for digital data buses that operate up to 2.0 Mbits is twisted shielded pair.

Routing or clamping wires close to aircraft metallic surfaces or within raceways will minimize inductive pick-up in the loop created by the wire bundle and the aircraft skin.

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 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 4) is desirable. The shielded compartment contains both the I/O connector and all the filter elements including feed through elements that penetrate the compartment wall providing maximum shield isolation.

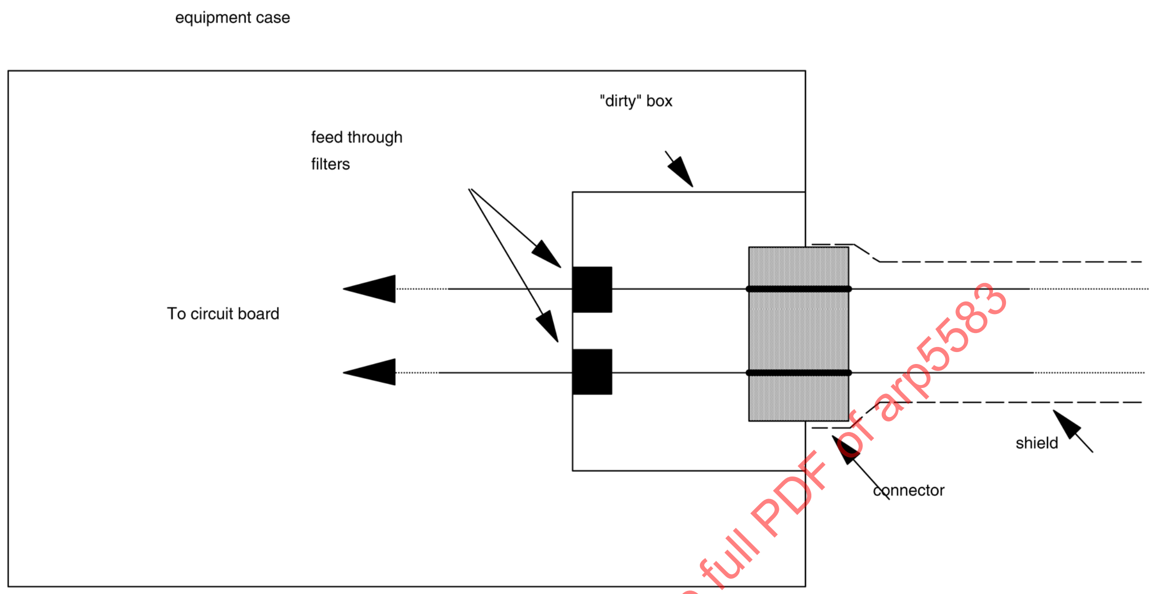

FIGURE 4 - Schematic Diagram Showing Filters Mounted in a Shielded Compartment Behind the I/O Connector

4.1.8 (Continued):

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 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 µf 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 contains 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.

4.1.8 (Continued):

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. Fiber optic (FO) transmission links do not respond to HIRF fields because of the nonconductive, dielectric nature of the fibers and because of the non-electrical nature of the signal (light) itself. FO links are available for the transmission of either analog or digital data. In terms of analog signal transmission, FO 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, FO links designed to operate as RS 232 serial buses, or IEEE 488/Hewlett Packard interface bus (HPIB) parallel buses are commonly available as standard commercial products.

The use of FO as a HIRF coupling 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.

4.1.9 (Continued):

The effectiveness of fiber optics in reducing EM transients on exterior or interior wires 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 major point of HIRF susceptibility for a fiber optic data link is at the input of the receiver amplifier, especially for a receiver using a PIN diode photodetector. Under normal operating conditions the signal level at this point is low. Input currents can be as small as 10^{-9} amps or less. Consequently, a very low HIRF signal injected at this point can produce system upset by increasing the signal to noise ratio or the bit error rate.

HIRF hardening measures for fiber optics electronics 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.

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 I/O connectors.

c. Place the power and data I/O lines in double braid shielded wire bundle or metal conduit with peripheral shields terminated at both ends to metallic enclosures. Route I/O lines to eliminate EMI coupling between power and signal lines.

d. Provide transient suppression or filtering on all lines where shielding is insufficient to prevent damage.

e. Use nonconductors such as aramid fibers for strengthening fiber optic cables where necessary. Do not include metal conductor power or signal lines in the fiber optic cable.

f. Use a high conductivity I/O connector or run the fiber through a small diameter metallic tube that is peripherally attached to the enclosure and has adequate length to attenuate the local exterior HIRF field.

g. Use a metal fiber optic connector to run the fiber through a small diameter metallic tube that is peripherally attached to the enclosure and has adequate length to attenuate the local exterior HIRF field.

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 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 an architecture:

a. Use of a non-electronic back-up system (optical or 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. All Level A functions must be immune to the HIRF 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
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. Experience indicates that analog circuitry usually is more susceptible to CW and AM modulated HIRF fields. However, digital circuitry tends to be more susceptible to pulsed HIRF. Keeping analog and digital signals zoned within I/O 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 I/O 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.

4.2.4 (Continued):

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 I/O 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 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
d. Sequence coded transition triggered signals, e.g., 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
h. Fault Tolerance

4.2.6 (Continued):

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 digitally averaging out the EMI effect. 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 buss 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 processing 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 unique processing environments for HIRF critical function.

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

4.2.6 (Continued):

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 the different processor can interface with the peripheral is dissimilar order to avoid being affected by a HIRF event at the same time. On a high level, the 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, 7, and 8.

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

Modeling of the coupling of external fields to wire bundle currents presently cannot be considered sufficiently accurate for complex system analysis. Reduction of the problem to a canonical geometric form may be suitable as an initial design tool, followed by more complex geometries and aircraft testing.

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.

4.4 (Continued):

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 possible reduction in test time.

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. Furthermore, 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.

4.4 (Continued):

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. At every opportunity throughout the development program, the design verification database can be expanded. This process identifies potential design weaknesses early in the development process. Corrective measures can be taken immediately thereby making rectification cheaper. 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 EMC analysis programs have been developed to predict electromagnetic coupling to electronic systems and to determine the effects on system operation. Many of these have been developed for assisting in the design of EMI control, EMP survivability, antenna design, etc. Some of these tools are suitable for aiding in the design and certification of HIRF control. These tools 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 tools appropriate and useful in determining the circuit level response to HIRF-induced interference have been developed. Some of these computer codes are suitable for use on microcomputers, such as desktop PCs. Some are only practical for more powerful work station or mainframe computers. Some of these codes represent commercial products and are available from the developer for a fee. The following is only a partial list of codes that are available. Some design consulting companies have in-house codes and tools that are available as a part of their services, but are not included in this list.

4.4.1 Three Dimensional Time Domain Codes: This group of codes represents the proven state-of-the-art in modeling entire complex aircraft electromagnetic features in three dimensions. All codes mentioned here solve Maxwell's equations directly via a numerical algorithm that employs finite difference techniques spatially and temporally. Models of aircraft may include both exterior and interior detail, accounting for both non-metallic (composite, dielectric, plastic, etc.) and metallic materials.

Mathematically, these codes model the aircraft as a spatial mesh, equivalent to a lattice of nodes. Electric fields, magnetic fields, and currents are computed anywhere within the mesh. This calculation is done for each time step specified. Mesh size determines the fidelity of the results, and also strongly influences computer run times and computing resources required. Small increases in model fidelity require significant increases in both computation time and required computer memory.

4.4.1 (Continued):

The models that are developed for these codes are top-down models, requiring only as much detail as desired by the user. Detail begins with exterior features and then includes varying degrees of detail as interior features are included. Therefore, models are built from the outside of the aircraft down to the interior. Typically, aircraft components or subassemblies are defined and assembled using a computer aided design (CAD) program. Interior layers are built independently from the exterior layers. These codes are suitable for work stations, minicomputers, and mainframe computers for modeling of whole aircraft. However, some of these codes are available for desktop PC computers.

Examples of these codes are listed below:

a. TSAR (Temporal Scattering and Response): TSAR uses a suite of modules to accomplish its modeling tasks. A CAD module is used to generate the shape of the aircraft, both exterior and interior. The CAD module can import data from other CAD models with IGES form. A finite difference mesh is generated from the CAD model and Maxwell's equations are solved directly in the time domain. Solutions are obtained in three dimensions. HIRF coupling in terms of fields and currents is obtained, both in the exterior and interior. Solutions account for penetrations through composite structures, apertures, seams, and exposed conductors. Solutions account for materials media that include dielectric, composite, metallic, and lossy. TSAR is a code that was developed by the government and is available for a nominal charge to qualified contractors from Lawrence Livermore Laboratories in Livermore, California. The code can be run on several operating systems (UNIX and VAX/VMS) and is suitable for use on work stations, minicomputers, mainframes, and supercomputers.

b. EMA3D (Three-Dimensional Finite Difference): EMA3D solves both the exterior and interior coupling problems simultaneously by directly meshing the entire aircraft. It has a graphical user interface (GUI) which can import data from CAD models with IGES file formats (such as exist with CATIA). Post-processing results visualization can be done in terms of 3D false color images and surface plots, animations, rotation, and single x-y plots. The code can account for anisotropic, lossy, frequency dependent, non-linear, or time-varying media. In particular, surface and transfer impedance representations of composite structures can be included. EMA3D can run on a variety of platforms, from UNIX workstations to supercomputers. Codes are available commercially from Electro Magnetic Applications, Inc., Denver, Colorado.

c. TLM (Transmission Line Modeling): TLM implements a numerical technique which is used for predicting electromagnetic fields, surface currents, and wire currents in a variety of problems. TLM models structure with a network of transmission lines and makes use of the equivalence between this network and Maxwell's equations. The solution of the network can be solved exactly, and gives a stable time-stepping numerical routing. The frequency range appropriate to the technique depends on the spatial separation used. At least six nodes/wavelength are required. Diakoptics is an extension of the TLM method and allows a large structure to be broken down into smaller substructures with differing grid sizes as required. The code is available from Timberly Communication Consultants, Nottingham, U.K.

4.4.1 (Continued):

d. ASERIS-FD: ASERIS-FD software was developed by Aerospatiale to manage a wide range of electromagnetic phenomena on complex geometries: EMC simulations, radar cross section (RCS) computations and antenna applications. It is based on the well-known mathematical Berenger's absorbing boundary conditions and the numerical scheme introduced by K. W. Yee. User-friendliness was a prime concern and it integrates a 3D and 2D Cartesian mesh generator plus an interactive Cartesian mesh viewer product. ASERIS-FD is currently used to simulate transient phenomena (e.g., lightning), on fully conductive or composite structures, as well as on homogeneous and inhomogeneous dielectric materials. Its design ensures a high level of performance on workstations and supercomputers (vectorial or parallel). It can be coupled with ASERIS-NET for complex electrical network analysis. Codes are available commercially from Aerospatiale, France (E-mail: as-soft@expace.aerospatiale.fr).

4.4.2 Three Dimensional Frequency Domain Codes: These codes implement the method-of-moments (MOM) algorithm for the solution to Maxwell's equations. Rather than directly solving Maxwell's equations in the time domain, either a frequency domain electric field integral equation (EFIE) form of Maxwell's equations, and/or a magnetic field integral equation (MFIE) form is solved using the MOM algorithm. Complex aircraft structures are modeled either as a structure of wires (in the case of the EFIE solution), as patches (in the case of the MFIE solution), or as a combination of the two. Solutions are provided at specific frequencies. Dielectric materials are difficult to account for with these codes. MOM codes are generally only appropriate for modeling external coupling.

a. NEC (Numerical Electromagnetic Code): This code implements the MOM technique to the solution of Maxwell's equations in the frequency domain. It can be used to predict EM fields and surface currents for a variety of problems. The frequency range the technique covers depends on the size of the model relative to the excitation wavelength. (The smaller the wavelength, the more model components required.) The code was developed by the government and is available for a fee from Lawrence Livermore Laboratories, Livermore, California to qualified contractors.

b. GEMACS (General Electromagnetic Analysis of Complex Systems): GEMACS is a hybrid analysis program comprised of a MOM module, a geometrical theory of diffraction (GTD) module, and a finite element/difference module. It is included in this category of codes, since it is often used as a MOM code that is augmented by the GTD module in the higher frequency regimes to alleviate the need for excessive MOM model elements. The code can model three dimensional structures with apertures. It has been developed by the government and is available from Rome Air Development Center, Rome AFB, NY to qualified U.S. companies in VAX and PC formats.

4.4.2 (Continued):

c. ASERIS-BE: ASERIS-BE software was developed by Aerospatiale and is widely used in EMC simulations, RCS computations and antenna optimizations. It is based on a finite boundary element method and can be interfaced with various modeling software and mesh generators. A high level of performance is obtained on workstations and supercomputers (vectorial or parallel). To efficiently analyze structures with complex electrical networks, it has been connected with ASERIS-NET. For antenna applications, radiation patterns can be sent to ASERIS-HF software that calculates the interaction with the structure (aircraft, helicopter, satellite) using a UTD asymptotic approximation. Codes are available commercially from Aerospatiale, France (E-mail: as-soft@expace.aerospatiale.fr).

4.4.3 Intrasystem Electromagnetic Interaction Modeling Codes: This group of codes do not model entire aircraft structure, but do model the complex interactions between the various subsystems, LRUs, and cabling. The code consists of an extensive package of analytical algorithms for different coupling and configuration situations and the relationships between individual models.

a. IEMCAP (Intrasystem EMC Analysis Program): This program models the complex HIRF coupling interactions between different intrasystem areas within the aircraft. The model developed by IEMCAP is a bottom-up model, in that extensive detail on internal aircraft configuration, i.e., wiring, boxes, structure are required to build up the model that then interacts with the internal HIRF environment. IEMCAP is not suitable for providing a flow down of HIRF environments from the outside of the aircraft to the inside. IEMCAP is available in VAX format. The code was developed by the US Air Force and is available from Rome Air Development Center, Rome AFB, NY or ECAC, Annapolis, Maryland.

b. AAPG (Antenna to Antenna Plus Graphic): AAPG is an interactive version of the antenna coupling portion of IEMCAP. The code is available from ECAC, Annapolis, Maryland.

4.4.4 Circuit Analysis Codes: Numerous circuit analysis codes exist for taking electromagnetically coupled HIRF-induced signals on wires and wire bundles and calculating their effects on a unit's electronic circuitry. Many of these codes are available commercially and are suitable for the PC environment.

a. SPICE (Simulation Program with Integrated Circuit Emphasis): SPICE was developed at the University of California at Berkeley and released in 1972. It has become the dominant analog circuit simulator for virtually every type of electronics application. Though upgraded several times, the core algorithm has remained essentially unchanged. Semiconductor devices are modeled using Gummel-Poon parameters. Circuit equations are solved both analytically and numerically.

b. IS_SPICE: IS_SPICE is a commercial version of SPICE offered by Intusoft, San Pedro, California. It operates in the PC (386 or higher) or Macintosh environment and offers advanced features including graphics output and post processing.

4.4.4 (Continued):

c. XSPICE: XSPICE is a version of SPICE developed under contract to the United States Air Force and is available through Georgia Tech Research Corp. XSPICE is an enhanced and extended version of SPICE version 3C1 and has both analog and digital simulation capabilities. The two advancements of XSPICE over SPICE are (1) The basic R, L, C, diode, and transistor library has been extended to include over 40 devices, including summers, integrators, digital gates, s-domain transfer functions, and digital state machines; and (2) a set of programming utilities allows model creation in the C programming language. System level simulation is possible with this program. The code is written for UNIX operating system and work station platforms.

d. ASERIS-NET: ASERIS-NET simulates the interference on an electrical or electronic network resulting from local injections (e.g., equipment circuit noise), or coupled on the wires by radiation. It works in both the time and frequency domains. It includes a tool to compute the RLCG matrix (electrical parameters) of complex wire bundles and a network analysis module including a connection to SPICE. This software currently handles applications on industrial networks with models of equipment (using SPICE libraries), local and distributed sources that can be produced by ASERIS-FD or ASERIS-BE. The code, with its user-friendly interfaces, runs on UNIX workstations. These developments are supported by Aerospatiale and codes are available commercially from Aerospatiale, France (E-mail: as-soft@expace.aerospatiale.fr).

4.4.5 Other Modeling Codes: These computer tools perform computerized implementation of specific engineering algorithms. These tools implement well-known canonical algorithms. These codes may be run on computers from PC-based and higher in complexity.

a. SEXCE (Shielding Effectiveness X Coupling Effectiveness): This is an interior coupling model developed at Lawrence Livermore National Laboratory. The program is described in IEEE Transactions on EMC, Vol. EMC-29, No. 1, Feb. 1986. It analyzes both shielding effectiveness and interior coupling for geometrical models which resemble aircraft.

b. EMCAD (Electromagnetic Compatibility and Design): EMCAD is a program that provides for analysis of radiated susceptibility, radiated emission, conducted susceptibility, conducted emission, detail filter analysis, and crosstalk problems. It is generally appropriate for the analysis of I/O wires (shielded and unshielded), LRU enclosures, power and signal filter designs, internal LRU interconnect, and printed circuit boards. This is an extensive set of programs that can be run on IBM PCs. It is available from CKC Laboratories, Inc., Mariposa, California.

4.5 Margins:

The term margin is liberally used to describe any amount of excess protection provided between the anticipated RF environment and the acceptable level of RF environment for the system. Examples of margins and their application are shown in Table 6.

TABLE 6 - Margins and Their Applications

Description	Application
Design Margin	An increase in the HIRF system requirement to provide system performance that exceeds the requirements to compensate for known uncertainties such as assumptions, aging, component variability etc.
Manufacturing Margin	An increase in the HIRF system requirement to provide system performance that compensate for variation in fabrication, assembly, and configurations during production of a system
Upset Margin	An increase in the HIRF system requirements to provide an upset of the system at a level in excess of the requirements
Damage Margin	An increase in the HIRF system requirements to cause damage or over-stress of the system at a level in excess of the HIRF performance requirements
Immunity Margin	An increase in the HIRF system requirement to provide system performance at a level in excess of the HIRF requirements
Test and Analysis Error Margin	An increase in the HIRF system requirement to provide system performance to compensate for tolerance in the test measurements, test methods, and numerical calculations
Environment Margin	An increase in the electromagnetic environment requirement to compensate for unknowns and assumptions in the environment collection, calculation and prediction

5. APPROACHES TO COMPLIANCE:

With the increasing use of electronics in performing operational control and display functions on civil aircraft, there is now a requirement during certification of civil aircraft to consider the effects of the external HIRF environment on such equipment. The following paragraphs outline possible approaches for demonstrating compliance per AC/AMJ 20-XXX. Details of the individual test procedures are defined in Sections 6, 7, and 8 of this document. This guide only considers the external HIRF environment and does not include the on-board environment generated by the aircraft emitters. Other approaches may be used but they should be agreed to in advance by the cognizant aviation certification authority.

5.1 HIRF Considerations in the Aircraft Hazard/Safety Analysis:

The continuous increase in the degree of complexity and the number of functions performed by electrical/electronic systems within an aircraft may give rise to the potential for failure conditions not identified in any standard aircraft Hazard/Safety analysis. It is therefore necessary to conduct a Hazard Assessment/Safety Analysis that is capable of identifying potential failures resulting from exposure to a HIRF environment.

5.1 (Continued):

The primary objective of the compliance verification process is to establish that the aircraft and its systems have been assessed and tested with respect to system effects which could contribute to a condition affecting the continued safe flight and landing of the aircraft as a result of its exposure to HIRF.

The effects must be assessed in a manner that allows determination of the degree to which they will influence the performance of the aircraft and its systems.

The operation of systems separately and in combination with and or in relation to other systems must be assessed with respect to HIRF influences.

The assessment should include all significant modes of operation, and of failures, as to their subsequent effect upon the aircraft, considering the stage of flight and operating conditions, the awareness of the crew to any failure or influence and the corrective action required to maintain a safe condition.

When analyzing function classification, consideration must be given to the unique effects of HIRF upon the function since the presence of HIRF environments may induce failures in ways not encountered under other operating conditions. Normally system redundancy reduces the probability of a functional failure, however the HIRF environment may cause redundant systems to suffer simultaneous effects (common mode failures).

HIRF is considered capable of common mode influences and a source of common mode failure in many redundant system architectures. Individual protection of all redundant elements within a system may therefore be required.

5.2 Requirement Considerations:

5.2.1 Level A Systems: Level A systems are further categorized into two groups. One group involves functions for which the pilot will not be part of the operational loop. These are classified as Level A Control systems, i.e., FBW, FADEC, etc. FADEC and FBW controls are classified as Level A systems for both IFR and VFR operation.

The second group involves functions for which the pilot will be within the loop through pilot/system information exchange. These are defined as Level A display systems, e.g., EFIS, EICAS, etc.

NOTE: Control system failures and malfunctions can more directly and abruptly contribute to a catastrophic event than display system failures and malfunctions. It is, therefore, appropriate to require a more rigorous HIRF verification method for Level A control systems than for Level A display systems.

5.2.2 Level B and Level C Systems: Level B and C systems usually include communication systems and navigational aid systems and displays that provide heading, position, and en route data. Although a failure of a Level B or C system by itself is not catastrophic, it may be a contributory factor when considered to exist in conjunction with other failures.

5.2.3 Automatic Flight Control Systems: The term “Automatic Flight Control” is commonly used to define systems that perform a controlling function with respect to one or more of the primary axes of pitch, roll, or yaw of the aircraft in flight. The main systems that perform these controlling functions are AFCS and FBW Flight Control Systems.

AFCS command control surface movements and/or power levels, closed loop, and can have catastrophic influences such as hard-over failures of the control. The primary requirement in validation testing of systems performing these control functions should be to demonstrate that any failure due to a HIRF encounter does not result in an undesired and unmonitored aircraft control surface movement or undesired and unmonitored change in power level.

For those AFCS performing an autoland function, the operating environment is the Normal HIRF environment, not the Certification. If it can be shown that the AFCS cannot cause a catastrophic event (as defined in AC 20.1329), then level B or C may be used.

In FBW installations the availability of the controlling function is rated at Level A since there are no mechanical links through which control of the aircraft can be maintained. Total loss of the function, therefore, causes catastrophic events. A FBW control system must survive a HIRF encounter without loss of function and remain operational in a manner that will safely control the aircraft. Deviations of control, during and following the encounter, must be shown to be within acceptable limits. In addition, excessive asymmetry of control surfaces such as flaps and slats may need to be shown to be extremely improbable.

When HIRF protection has been applied to the system of interest, partitioning may be used to aid in the immunity of the system against HIRF influences. Installations using wire and LRU separation for like systems can provide a lower probability of symmetrical HIRF response. Examples are where wire routing is disposed on opposite sides of the aircraft fuselage and LRU positioning is in different equipment bays.

5.2.4 Display Systems: The functions performed can vary over a wide range between aircraft types but there are a number of functions that are almost invariably performed as shown below:

a. Display of attitude, airspeed, vertical speed, barometric altitude, radio altitude, heading, flight director commands, flap and slat position, as well as other flight data.
b. Display of a pictorial representation of aircraft position.
c. Display of engine control parameters and alerts (EPR, N1, EGT, Fuel Flow, etc.)
d. Display of miscellaneous status.

These may be Level A, B, or C display systems, or may have no HIRF level.

5.3 HIRF Certification Compliance for Systems:

Compliance demonstration is required only for systems identified as performing, or contributing to, functions whose failure or malfunction could result in Catastrophic, Hazardous/Severe Major, or Major effects on the operation of the aircraft. The routes to compliance for all Level A Control systems are shown by the shaded boxed in the flow diagram of Figure 5 and the corresponding methods of demonstration are provided in Section 6. The routes to compliance for Level A Display systems are shown by the shaded boxed in the flow diagram of Figure 6 and the methods of demonstration are provided in Section 7 . The routes to compliance for level B and C Systems are shown by the shaded boxed in the flow diagram of Figure 7 and the methods of demonstration are provided in Section 8.

The testing of systems, equipment, or aircraft should address the requirements of the average and the peak amplitude levels defined within the characteristics of the appropriate environment definitions.

The flow diagrams of Figures 5, 6, and 7 outline the steps acceptable for the certification of systems with respect to HIRF.

Seven defined options are available embracing aircraft and/or system test application leading to HIRF vulnerability assessment (Step 15), and Certification (Step 17). The seven options are shown in Table 7.

TABLE 7 - Routes to Compliance

OPTION	ROUTE	DESCRIPTION	APPLICABILITY
1	Steps 1 through 8	Aircraft Coupling	Level A Control System
2	Steps 1 through 9	Aircraft Coupling and High Level Equipment/System Testing	Level A Control System
3	Steps 1 through 6 and 10	Aircraft High Level Testing	Level A Control System
4	Steps 1 through 5 and 11	Display System Rig Testing	Level A Display System
5	Steps 1 through 3 and 12	Equipment Test	Level B and C Systems
6	Steps 1, 2 and 13	Similarity	Level A, B, or C Systems
7	Steps 1, 2 and 14	Other Methods	Level A, B, or C Systems

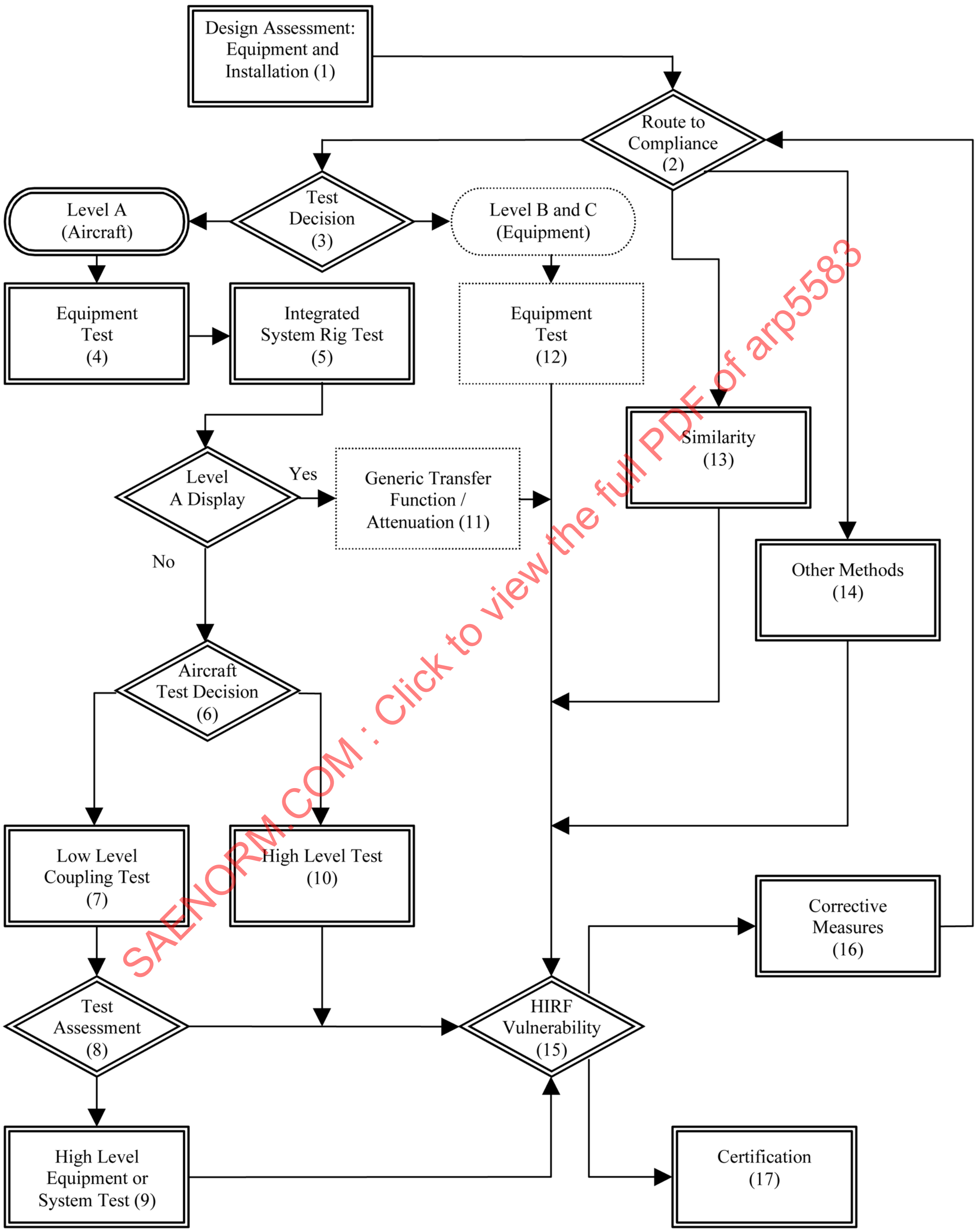

FIGURE 5 - Routes to Compliance for Level A Control Systems

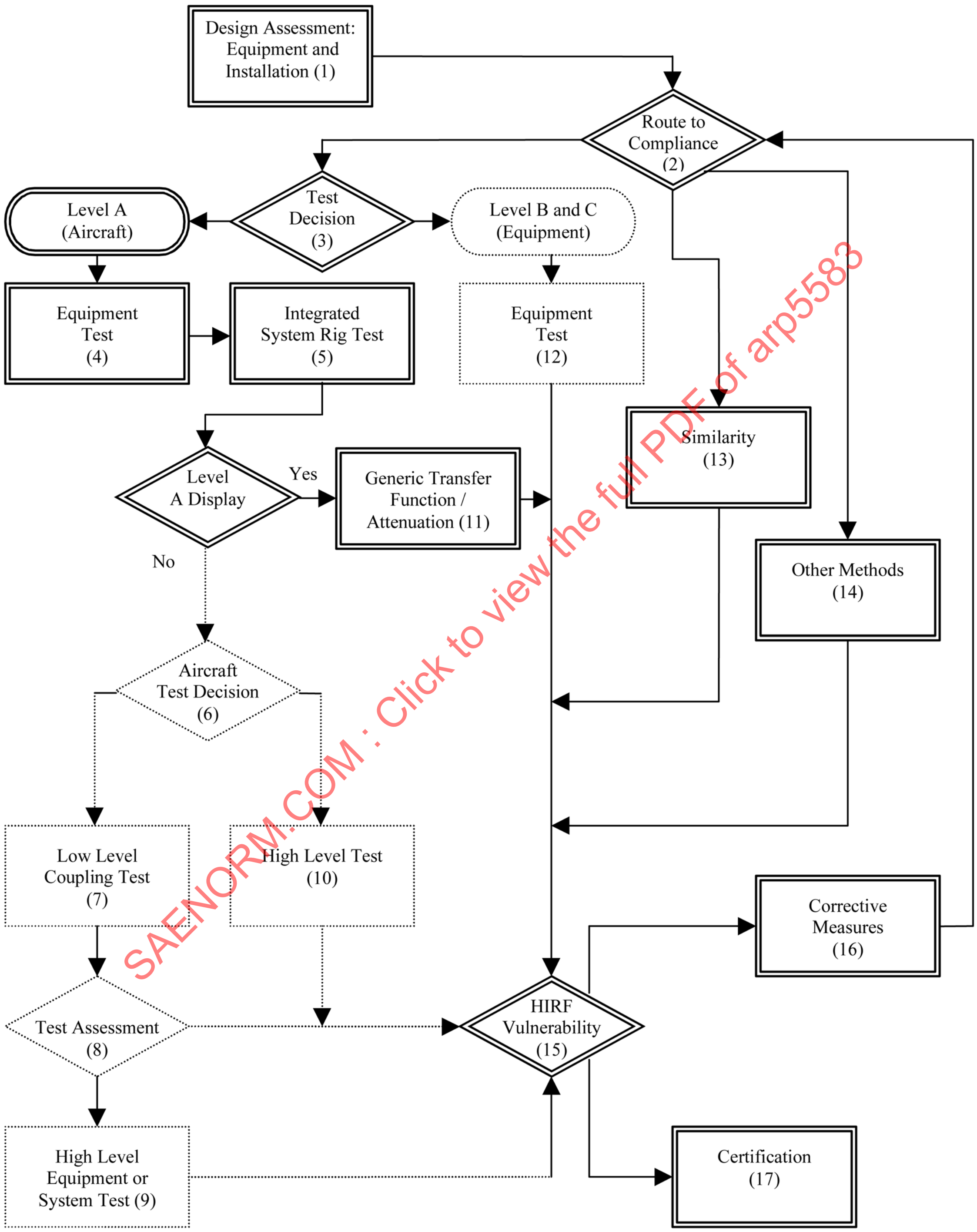

FIGURE 6 - Routes to Compliance for Level A Display Systems

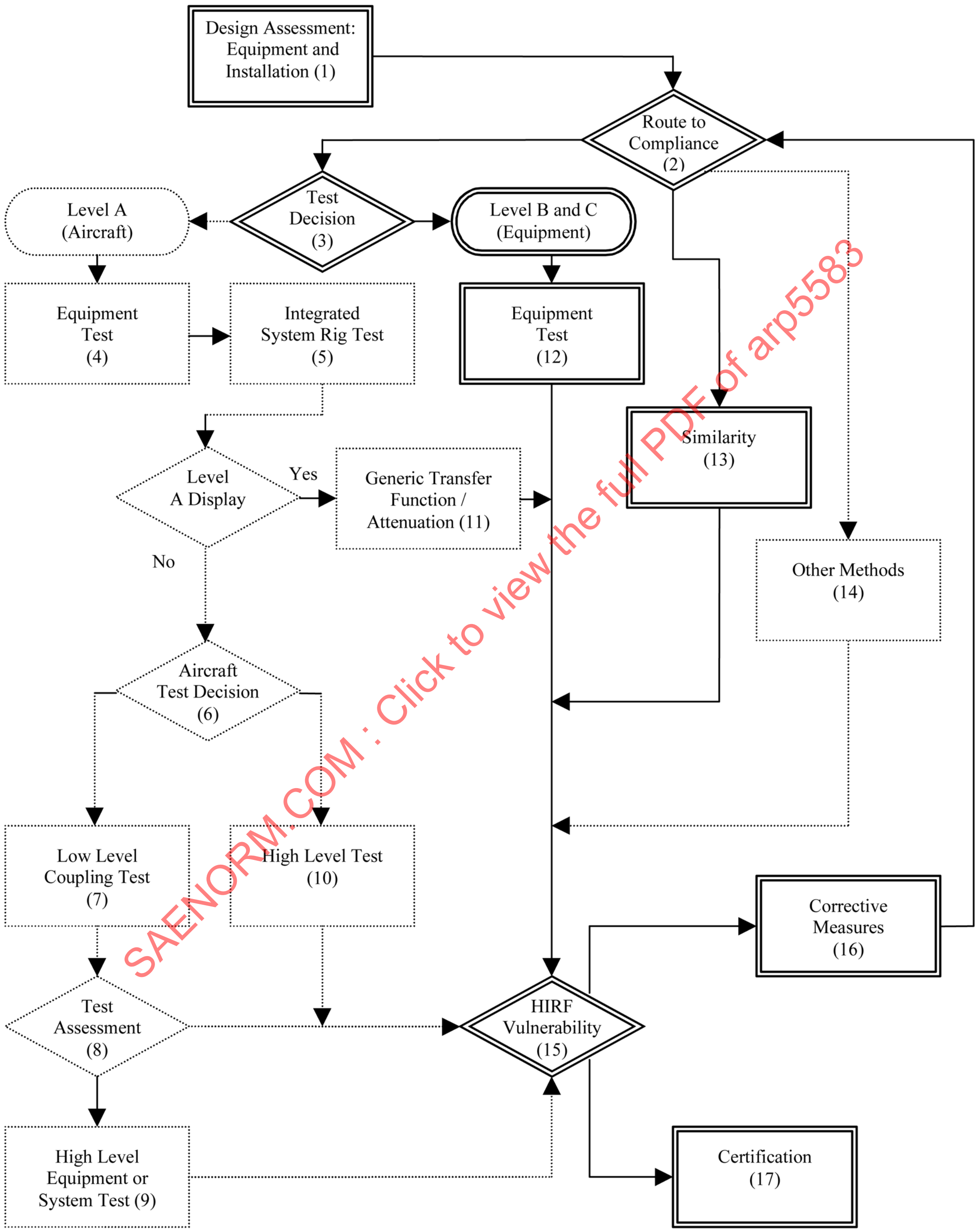

FIGURE 7 - Routes to Compliance for Level B and Level C Systems

5.3 (Continued):

Option 7 using Other methods was provided to recognize that in the future innovative means may come about permitting something not possible or practicable when this guide was developed. Concurrence from the cognizant aviation certification authority should be obtained before committing to this route for compliance.

5.4 Test Procedures Used in the Verification Process:

The verification process employed for compliance demonstration will inevitably require some testing and analysis phases that will involve mainly:

a. Equipment testing and/or
b. Integrated system rig testing and/or
c. Aircraft testing.

Developed and recommended procedures exist which have been accepted by the cognizant aviation certification authorities as being acceptable in the demonstration of HIRF compliance. These procedures are listed in Table 8 together with reference to their application to steps outlined in the routes to compliance.

Items 6, 7, and 8 are test procedures for the purpose of data acquisition in the development of test levels for items 1 through 5.

Details of the above listed test procedures and derivation of test levels to be applied relative to the categorization are provided in Sections 6, 7, and 8.

5.5 Routes to Compliance Definition:

5.5.1 Design Assessment Equipment and Installation (Step 1): The first step in a new/retrofit installation is to determine the HIRF environment for the equipment and wiring associated with an aircraft installation. This step establishes the test level(s) for the equipment or system test. DO-160C/ED-14C, Section 20, may be used as a general guide for procedures and test set-up when conducting equipment level testing. The selected test levels should be consistent with those levels derived from the aircraft level test and/or analysis.

5.5.2 Route to Compliance (Step 2): The route to compliance (Step 2) has three choices: Testing, Similarity, and Other Methods. The testing route covers three categories, namely Level A Control Systems(Steps 4 to 10), Level A Display Systems (Step 11), and Level B/C Systems (Step 12). The Similarity Route (Step 13) uses an existing certified system with sufficiently similar characteristics to the system to be certified. The Other Methods Route (Step 14) considers other potential methods to certification.

TABLE 8 - Test Procedure Application

Item	Test Procedure	Aircraft Testing	Integrated System Rig Testing	Equipment Testing
1	Radiated Susceptibility	Step 9	Step 5	Steps 4 and 12
2	Bulk Current Injection	Step 9	Steps 5 and 9	Step 4 and 12
3	High Level Equipment Test	Step 9	Step 9	
4	Aircraft High Level Test	Step 10		
5	High Level Direct Drive	Step 9		
6	Low Level Direct Drive	Step 7		
7	Low Level Swept Current	Step 7		
8	Low Level Swept Field	Step 7		

5.5.3 Test Decision (Step 3): The paths out of this decision block lead to aircraft testing, system testing, and equipment testing. These paths correspond to Level A Control (options 1 through 3 in Table 8), Level A Display (option 4 in Table 8), and Level B and C Systems (Option 5 in Table 8).

Compliance for Level A systems is based upon the ability to demonstrate satisfactory operation of the system when the aircraft is exposed to the RF field strengths defined for HIRF Environment II (Normal) and to maintain the function when the aircraft is exposed to the RF field strengths defined for HIRF Environments I (Certification) and III (Rotorcraft Severe).

If no system malfunctions are observed during testing of the system to levels appropriate to the aircraft exposure to HIRF Environments I (Certification) or III (Rotorcraft Severe), as appropriate, then there is no need to conduct further tests at levels appropriate to the aircraft exposure to HIRF Environment II (Normal) for Level A systems.

Compliance for Level A Display systems may perform a system level bench/rig test. This test places the system in an installation where interfaces with other equipment are a realistic simulation of equipment loads and harness. Possible choices for such an installation include iron birds, system integration laboratories, and aircraft system benches. Testing to 40 GHz should be required only if equipment under consideration operates in the 18 GHz to 40 GHz range or the equipment fails the pass/fail criteria in the 12 GHz to 18 GHz range.

5.5.3 (Continued):

Compliance for Level B and C systems is based upon the ability to demonstrate satisfactory operation of the system when the aircraft is exposed to HIRF Environment II (Normal). Testing is limited to an upper frequency of 8 GHz unless the system has a higher operating frequency.

Level B and C systems may be tested concurrently with Level A systems. However, box level testing of equipment is the minimum acceptable procedure to demonstrate compliance with HIRF requirements. There are a number of approaches that could be employed to demonstrate compliance as detailed in Section 8.

5.5.4 Equipment Test (Step 4): The test procedures of DO-160C/ED-14C, Section 20 or equivalent, should be used as a basis for the testing of electronic systems and equipment. This testing can be used to build confidence in the equipment performance prior to system integration testing and/or aircraft testing. DO-160/ED-14 standards define various levels of testing. The category (test level) appropriate to a particular item of equipment is dependent on the internal environment anticipated for that equipment and its associated wiring.

Equipment development testing may be used to augment the qualification test submission where appropriate.

If non-qualified equipment is used within the system to be the subject of compliance demonstration, then the qualification may be achieved by Step 5 of Figure 5 and the test in Step 4 may be bypassed.

DO-160/ED-14 details two test procedures designed to test the susceptibility of equipment to HIRF: bulk current injection (BCI) and radiated susceptibility (RS) Testing. The BCI test covers the band of 10 kHz to 400 MHz and the RS test covers the band of 100 MHz to 18 GHz depending upon equipment category.

5.5.5 System Integration Rig Test (Step 5): For Level A systems, further testing and evaluations at the system or sub-system level may be required.

System integration testing consisting of conducted and radiated tests may be performed on an integration rig. These tests may alleviate the need for high level equipment/system testing in Step 9 if it can be shown that the rig assembly adequately characterizes the final installation and the test levels reflect the predicted internal environment appropriate to the environment.

To take full advantage of these tests, the physical installation of the equipment in the rig assembly should be similar to that used on the aircraft i.e. the bonding and grounding of the system and the wiring harness detail (wire type, wire length, etc.) and the relative position of the elements to each other and the ground plane should closely match the aircraft installation in which the equipment is to be certified.

5.5.6 Aircraft Test Decision (Step 6): There are two main approaches to aircraft tests; Low Level Coupling (LLC) (Steps 7 through 9) or Aircraft High Level Test (Step 10). The decision should consider the maturity of the aircraft development program, the system design complexity, aircraft size, and technical risk. The decision should be addressed on an individual program basis. The approaches consist of whole aircraft tests or low level coupling test complemented with high level equipment/system test.

The low level coupling approach consists of two basic steps. First, the internal environment that would be produced when the aircraft is exposed to the appropriate HIRF environment is determined by measuring the transfer function of the aircraft (Step 7). Second, this internal environment is compared to the levels to which the system under evaluation has been tested during bench/rig or aircraft level system susceptibility testing (Steps 5 or 9). The advantages of the coupling approach are the relative low cost, portability and availability of test facilities and the potential for reduced live aircraft testing. The disadvantages of the coupling route include complex data reduction and the need to test each system's wire bundle and box individually.

The whole aircraft high level testing approach (Step 10) involves high RF field testing over the complete frequency range using either swept or discrete frequencies. With the aircraft systems operating, the aircraft is illuminated at the maximum field levels and the effects on the systems under consideration are observed. High RF field strength testing permits simultaneous irradiation of wire bundles, apertures, and all systems. The whole aircraft test may eliminate the need to address each system's wire bundle and box individually, providing the entire aircraft is illuminated. This aspect of whole aircraft immersion in the field is possible for small aircraft for test frequencies below 400 MHz. For a larger transport airliner, only portions of the aircraft may be illuminated. Other advantages of the radiation route are potentially shorter overall aircraft tests, and simplicity of test results for HIRF vulnerability assessment. The disadvantages of the high level test route are that the aircraft may have all systems operating during the test, therefore, the related systems that are not Level A may be subjected to the HIRF environment unnecessarily. Also, there are technical limitations of radiating over the full frequency range, and availability of facilities to test at high levels.

5.5.7 LLC Test (Step 7): The LLC test procedures provide options to use Low Level Swept Coupling (LLSC), Low Level Swept Fields (LLSF) and Low Level Direct Drive (LLDD) as means to characterize the internal HIRF environment.

The LLC option measures the transfer function relating the external RF fields to either equipment wire bundle currents (LLDD and LLSC) or internal fields (LLSF).

In the case of the LLSC and LLSF tests, the aircraft is illuminated with uniform swept frequency radiated fields and the induced wire bundle current (LLSC) measured or the internal bay fields (LLSF) are measured.

5.5.7 (Continued):

These tests are conducted for several aircraft orientations, configurations, and horizontal and vertical field polarizations as necessary, to produce worst case current profiles for the various wire bundles being measured (LLSC) or worst case attenuation figures for the bay being illuminated (LLSF). These coupling/attenuation figures can then be used to predict the internal environment when the aircraft is exposed to the appropriate HIRF environment by linear scaling.

An alternative to LLSC is LLDD for the low frequency portion of the spectrum where the LLSC test suffers from efficiency and practicality problems. The LLDD procedure can be used to measure the transfer function at low level between the skin current and individual equipment wiring bundles. The relationship between free field external radiation and skin current for all illumination angles and polarization is accurately determined by 3D mathematical modeling. Then the skin current can be simulated by direct injection into the airframe. Typically these currents are injected into various points on the aircraft wing, engine, nose, or tail. The resultant currents on the aircraft/equipment wire bundles are measured with a current probe and normalized to external unit field strength so that they can be scaled to the full field intensity. Direct drive current tests are extremely difficult for frequencies above the first full wavelength resonant frequency of the aircraft, but the continuing evolution of analysis and test techniques may make it usable at higher frequencies in the future.

5.5.8 Test Assessment (Step 8): The paths from the Test Assessment decision block are to HIRF Vulnerability or High Level Equipment/System Test. Which path to take is decided by the analysis of the data collected during the LLC Test and the Level A functional performance from the System Integration Rig testing (Step 5).

The worst case induced current profiles from the LLSC or LLDD test are compared with the System Integration Rig test (Step 5). If the worst case induced currents are all lower, then no further testing is required (providing the rig was electromagnetically representative of the aircraft installation). If, however, the induced currents are higher, then high level BCI tests are required on the installed system. The equipment wire bundle test currents should meet or exceed those current level established by the extrapolation of the LLSC or LLDD aircraft test data.

The LLSF test data should be reduced in the same way as the LLSC test data, except that the results will describe the shielding effectiveness as a function of frequency. The LLSF shielding effectiveness data should be subtracted from HIRF Environment I (Certification) or III (Rotorcraft Severe). The result will be the maximum anticipated internal RF fields for each area measured. The internal RF field strength is compared with the System Integration Rig testing (Step 5). If the Level A system was tested to a higher level, then further tests are not required for certification. If the Level A system was tested to a lower level, then further high level field tests are needed to demonstrate that the system is not susceptible to the internal electromagnetic environment defined by the extrapolated LLSF test data.

5.5.9 High Level Equipment/System Test (Step 9): High Level Equipment/System Test may be necessary where the test assessment (Step 8) indicates a short fall between the predicted internal environment and the system rig test (Step 5) or where a suitable system rig test has not been performed.

5.5.9 (Continued):

The possible tests include bulk current injection (BCI) at high levels, High Level Direct Drive, Equipment High Field Testing and whole Aircraft High Field Testing.

The BCI tests are performed on the Level A system either installed in the aircraft or a system rig. The high BCI levels are determined from the extrapolated LLSC tests. Every wire bundle associated with the Level A system is tested by injection and measurement of the induced current on the bundle. The Level A system is evaluated for susceptibility.

A high level Direct Drive (HLDD) test for injecting high level currents directly into the airframe in a manner similar to the LLDD is normally used only at frequencies below airframe resonance. It is essential that modeling predictions or LLSC measurements are made to determine the skin current distribution that will exist for different polarization and aircraft illumination angles so that these can be accurately simulated during this test. This procedure has the advantage of testing all systems simultaneously but at present is very restricted on usable frequency range.

When the internal RF field surrounding the equipment under evaluation has been measured using LLSF testing procedure and extrapolated to the HIRF environment, then the equipment can be illuminated with this field by localized internal illumination. The High Level Field Test consists of two possible options: high level field illumination of equipment or whole aircraft high field level test. (Step 10).

5.5.10 Aircraft High Level Test (Step 10): This step evaluates aircraft performance while the aircraft is being radiated with an RF field simulating the HIRF Environment I (Certification) or III (Rotorcraft Severe) over the frequency range of 10 kHz to 40 GHz. The test facility conducting these tests should have the capability to generate the appropriate HIRF environment over the entire frequency range and illuminate an aircraft, while operating on engine power.

The aircraft is placed at sufficient separation from the radiating antenna to ensure overall illumination. When field strength cannot be achieved at this distance, the radiating antenna is moved closer to the aircraft. Closer antenna positioning, may require multiple antenna positions to illuminate the aircraft adequately.

The aircraft is tested sequentially from all sides (typically all four sides and with horizontal and vertical polarization) to illuminate all apertures. The field strength is calibrated for the required illumination area prior to locating the aircraft in the test volume. The frequency steps and dwell time are selected to ensure that all aircraft and aperture resonances are adequately tested. This is especially important in the 500 kHz to 100 MHz band where high Qs in the coupling to aircraft skins and wiring are known to occur. Above 400 MHz, it becomes increasingly easier to generate high field levels.

5.5.11 System Integration Rig Test (Step 11): Step 11 is an acceptable means of demonstrating compliance for Level A display systems. This step is intended to alleviate the need for aircraft testing for Level A displays. It must not be used for Level A control systems.

The test procedure for Step 11 is:

a. Determine the internal environment by means of analysis, use of previous coupling/attenuation data from similar aircraft types or by using generic attenuation/transfer function curves (as defined in the AC/AMJ). The internal environment refers to the resultant local electromagnetic field to which the system/equipment is exposed, for a given external HIRF environment, and the interface stressing of equipment resulting from the total installation for which certification is sought.

b. Derive equipment/system test levels from (a.).

c. Conduct equipment/system testing on the systems integration rig.

A method of establishing the compatibility between the internal environment and the system/ equipment test levels must be derived as part of the verification process in the certification plan.

The substantiating evidence must show that the factors necessary to enable a direct comparison of the system/equipment test environment and the aircraft internal environment at the system/ equipment location, in terms of field strength (>100MHz) and current (<400MHz), have been taken into account when addressing these systems. These are defined in detail in Section 7.

5.5.12 Equipment Test (Step 12): For Level B & C systems, testing to appropriate test levels as defined in Section 8, using the procedures in DO160C/ED14C is the maximum required for certification.

5.5.13 Similarity (Step 13): Similarity is the process of using the verification documentation from a nearly identical system which as been qualified for an application in an aircraft of similar design and construction.

When using Similarity as a means to certification it should establish the commonality of the existing system with the methods and process in the user guide. Where there is a difference that may invalidate the similarity, then testing and analysis may need to be performed. The cognizant aviation certification authority should be coordinated with to obtain concurrence on the proposed approach before committing to the similarity route for compliance.

The requirements to demonstrate similarity depend on the functional criticality of the system being certified.

5.5.14 Other Methods (Step 14): Other Methods (Step 14) involves modelling, analysis, and combinations of any method given in the other routes. Comprehensive modelling and analysis for RF field coupling to the aircraft structure is an emerging technology. Therefore modelling and/or analysis on its own is not currently adequate for showing compliance to the HIRF requirements for Level A systems and will have to be augmented by testing.

5.5.14 (Continued):

Analytical models, representative of the aircraft and transfer characteristics of the installation, may be used in conjunction with supportive test data to provide the justification of compliance.

The data submitted should take account of the quality of the model and give full detail of the model accuracy assumed and the margins that are established by such an assessment. The margin required to be set will depend heavily on the quality of the data base utilized in the modelling and significant testing may be required to support the submission, even to the extent of some aircraft test.

The availability of models, capable of detailed system performance assessment related to Level A systems, is not generally accepted to exist at this time but accepted practices may develop in this field of compliance by modelling.

In addition “Other Methods” covers possible new procedures which are not covered in this document and may be suitable as offering an alternative route. In these cases, early discussions with the cognizant aviation certification authority would be appropriate.

5.5.15 HIRF Vulnerability (Step 15): The HIRF vulnerability assessment is the mechanism for evaluating test data and determining compliance with the HIRF requirement. The aircraft is certificated upon acceptable operation of the aircraft systems within the appropriate HIRF environment. Where effects are observed, the applicants and authorities may provide assessments and judgments on the acceptability of performance. The analysis is performed to verify all functional requirements of the system are met when subjected to the applicable HIRF environment.

The system test and aircraft test may result in detection of HIRF susceptibilities. The HIRF assessment requires an engineering judgment by the certifying authority to determine whether a susceptibility is acceptable or affects the continued safe flight and landing of the aircraft. If the susceptibility does affect the continued safe flight and landing of the aircraft, then it is an HIRF vulnerability.

The susceptibilities perceived as unacceptable should be fed back into the HIRF certification process for elimination. The susceptibilities that are acceptable may be declared as insignificant in the compliance statement.

The HIRF vulnerability assessment should include all effects observed and the assumptions and judgments used to show compliance with the HIRF requirements.

5.5.16 Corrective Measures (Step 16): Once it is determined that a susceptibility is a HIRF vulnerability, the next step is to implement corrective measures. Corrective measures may be taken at several levels, singularly or in combination. Examples of possible levels for corrective measures include:

a. Aircraft Level - i.e., changes in aircraft wiring, relocation of the equipment, replacement of the equipment, addition of equipment shielding, changes in equipment installation;

b. Equipment Level - i.e., changes in the equipment enclosures, changes in the equipment connectors, changes in the location of circuit boards in the equipment; and

c. Circuit Level - i.e., changes to the equipment interfaces, replacement of circuit components, and changes to the circuit design.

The selection of the appropriate level will be based on the impact of the corrective measure to the certification effort.

A consequence of a redesign in the aircraft or equipment will be the need to perform some level of testing to demonstrate that the corrective measure is effective. A change in the equipment may involve both equipment and aircraft testing. A change in the aircraft may involve aircraft testing. The testing, however, may be abbreviated to concentrate on showing that the HIRF vulnerability has been corrected. It may be possible to limit the testing to those frequencies where the HIRF vulnerability had occurred but this would need to be technically justified. In some cases, correction and analysis may be adequate to eliminate the HIRF vulnerability.

5.5.17 Certification (Step 17): The applicant shall demonstrate compliance with the requirements of FAR Sections 23.1308, 25.1317, 27.1317, and 29.1317. The requirements are summarized in Table 1 of the AC/AMJ. Any susceptibility detected and not corrected should be identified in the certification report and demonstrated not to be a problem.

6. COMPLIANCE FOR LEVEL A CONTROL SYSTEMS:

This section details test procedures suitable for use in aircraft HIRF certification of Level A control systems. The demonstration of compliance does not involve in-flight tests but rather a series of tests leading to certification. These tests can involve equipment, system, and aircraft level testing.

The various paths to achieving compliance are depicted in Figure 8 and Figure 9 for Level A control systems. The details of the test procedures for each of the paths are discussed in this section in greater detail. The procedures outlined in this section can of course be used for all categories of criticality although they are more onerous than other acceptable procedures. These are the currently acceptable procedures but alternative procedures may exist or be developed, which are equally valid and may be used as part of the aircraft certification following approval by the aviation airworthiness authorities.

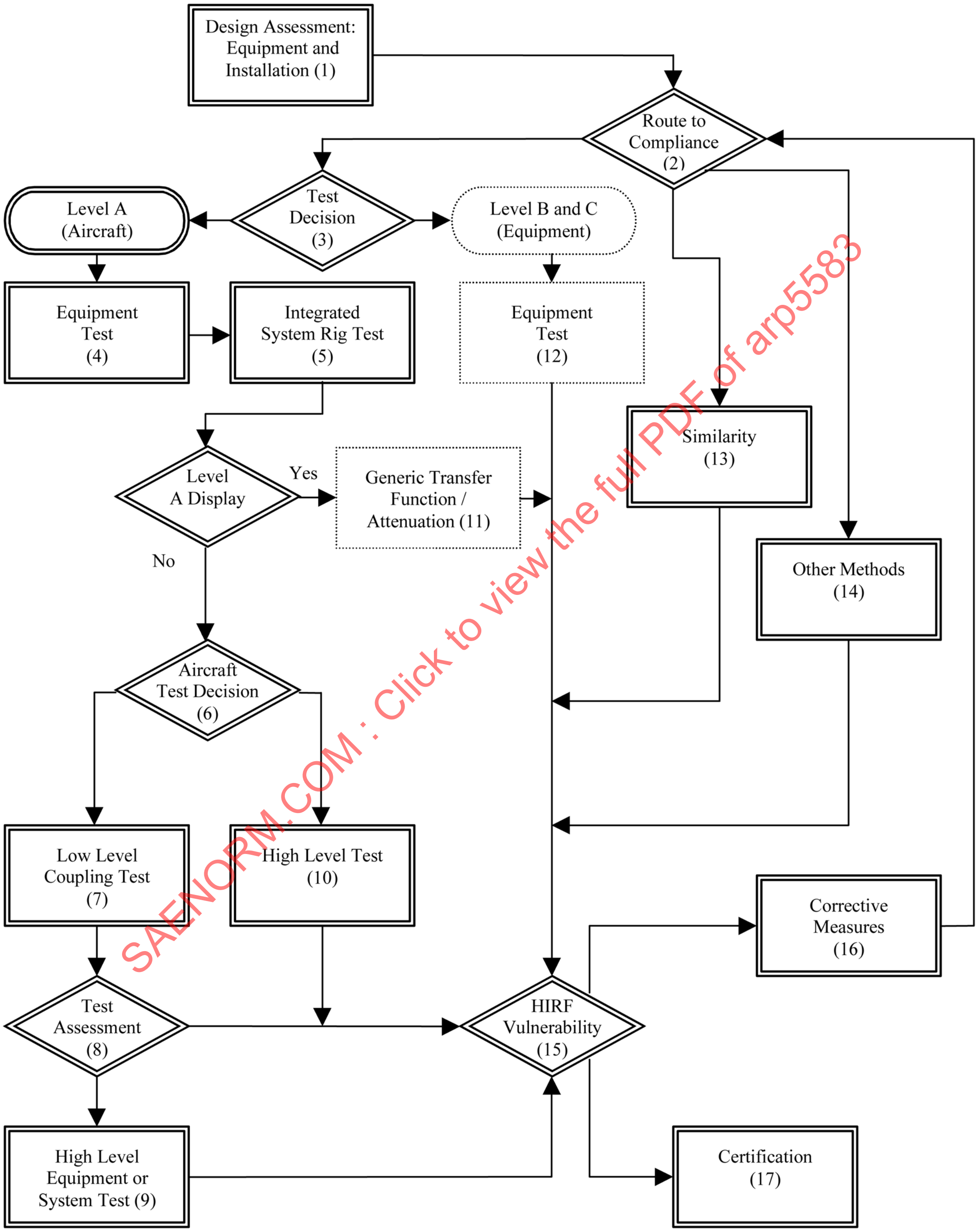

FIGURE 8 - Routes to Compliance for Level A Control Systems

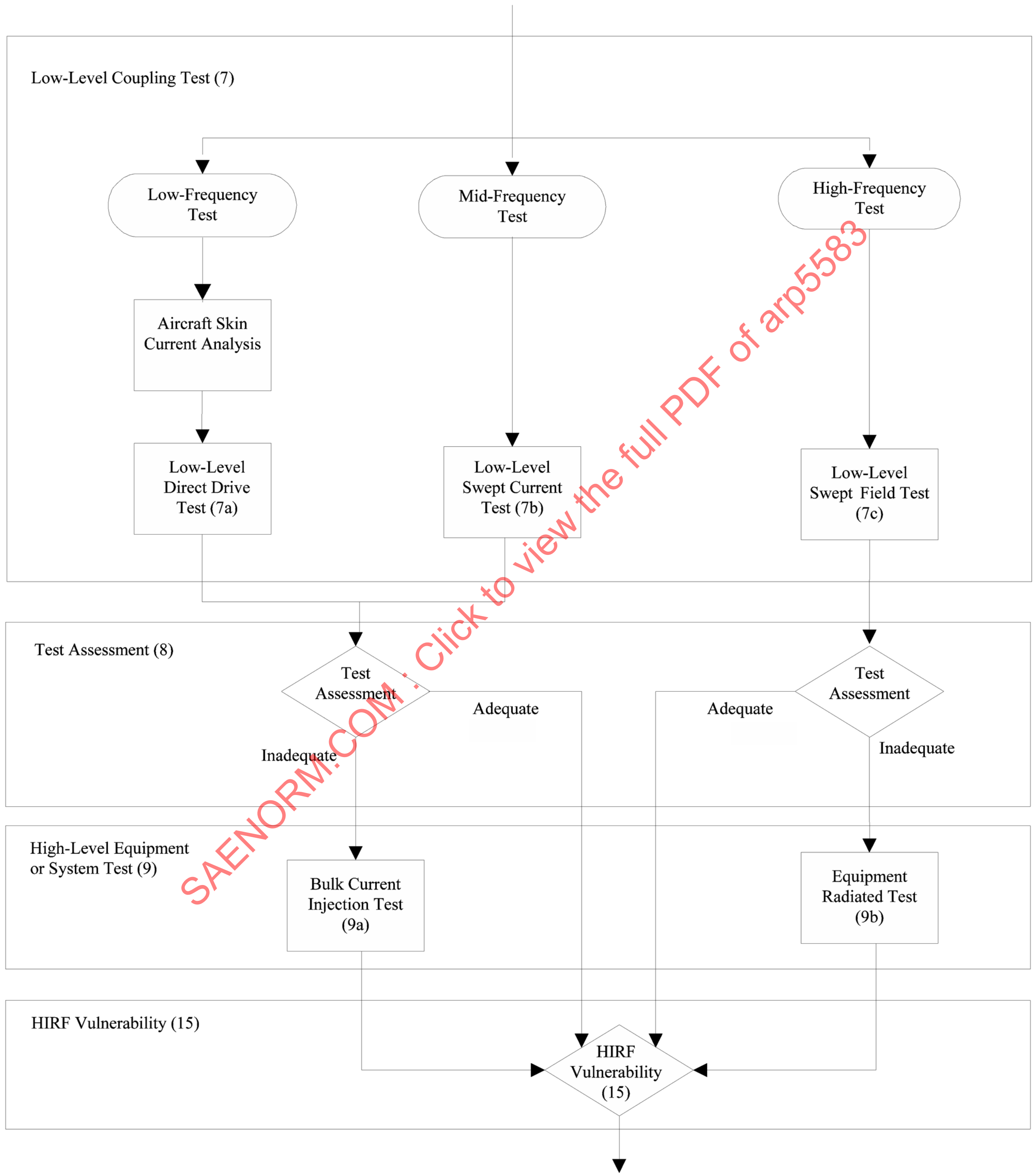

FIGURE 9 - Routes to Compliance - Expanded View Steps 7 to 9

6. (Continued):

This section only discusses the certification of aircraft to the external HIRF environment and does not include certification to the on-board environment generated by the aircraft transmitters which is not covered by this document.

Unless Similarity applies, at some stage some form of aircraft test is required for this category of system. Effective equipment or system testing can reduce the degree of aircraft testing required.

The HIRF compliance demonstration uses a system approach to conducting tests and analysis to support HIRF certification. The tests and analysis involve a combination of equipment test, system bench tests, low level coupling tests and high level tests, all complimented by an HIRF vulnerability analysis. Depending on the test combination, whole aircraft testing may be required for low level coupling or high field tests on installed systems.

6.1 Compliance Procedure Overview for Level A Control Systems:

Unless Similarity applies (Step 13, 6.7.8), the path to certification for Level A control systems can be summarized:

a. The revised testing procedures (Step 4) of DO-160/ED-14, Chapter 20 (version D or later issues), can be of assistance in the qualification of electronic systems and equipment in this category. The equipment should be qualified by these techniques to levels commensurate with the expected levels from the analysis of the aircraft and installation for the given external environment. The equipment testing may be used to augment the qualification test submission where this is appropriate to the demonstration of aspects of compliance. During the BCI test, the current and resonances which are generated on the equipment wiring should be measured and recorded as a potential aid in the cross comparison with those values acquired from possible aircraft installed test procedures.

b. Selection of test levels for system integration rig testing (Step 5). The test plan will define the extent of the system to be tested. The test levels should be supplied by the aircraft manufacturer and can be based on (in descending order of reliability) actual aircraft measurement, analysis of previous aircraft data, or the use of generic curves. Confirmation of the adequacy of the levels chosen should be provided by step (c.).

c. Testing of the equipment on a system integration rig (Step 5) providing an accurate representation of the final aircraft installation. The following items should be accomplished to provide this accuracy:

   1. Wire length, composition, branching, and shielding policy should all be as in the final installation to achieve similar electromagnetic performance.

   2. Bonding strap dimensions and composition should all be as in the final installation to achieve similar electromagnetic performance.

6.1 (Continued):

3. Actual racks should be used where appropriate.

4. Equipment wire bundles (apart from primary power) should be terminated with the actual hardware to be used in the aircraft.

5. The layout of the wiring with respect to the ground plane should be similar to that used in the aircraft.

d. Measurement of the internal aircraft environment (Step 7) using the procedures defined in this section, if not already conducted for step (a.) or (b.), to confirm the adequacy of the levels used in (a.) or (b.).

e. Susceptibility testing at system integration rig or aircraft level (Step 9) if the levels used in (b.) were inadequate or the test representation inaccurate.

f. In all cases the test levels used should be derived from actual aircraft measurements as conducted in (d.).

g. As an alternative to Steps 7 through 9 in the flow charts, high level field illumination of the complete aircraft (Step 10) can be used as adequate evidence of proof of compliance with the HIRF requirements.

h. Specific test techniques described in this document follow practices currently accepted as state of the art. However, alternative techniques, particularly those offering technical improvement, may be employed where validated (Step 14).

NOTE: (a.) and (b.) are optional when using Step 10 - whole aircraft field illumination test or if (e.) is to be applied.

6.2 Test Aircraft and Equipment:

The test aircraft and equipment or systems should be described in the compliance plan. The following description of the aircraft and equipment is provided to guide in planning the demonstration tests.

The aircraft used for the test should be representative of the configuration to be certificated. The aircraft should have all systems installed and operational. The reason for this is that RF current on wiring which forms part of a non-essential system can cross couple to wiring of Level A systems. Systems submitted for compliance demonstration should be operational. When differing configurations of avionics systems are to be offered, then each configuration should be considered in the test program. In some cases the aircraft program will involve only minimum changes such as an update to the propulsion or flight instrument systems. These aircraft updates need to be addressed. For further guidance see 6.7.8.

6.2 (Continued):

The equipment and system description should include the EUTs, the characteristics of its intended operation and relevance to Level A control systems. Any HIRF protection methods designed into the EUTs (which might need to be emphasized during the testing) need to be identified and summarized.

6.3 System Integration Rig Test Level Determination (Step 5):

The test limits to be used for Level A systems should be based on measurements of the internal aircraft environment on the aircraft to which the equipment is to be fitted. Early in the life of the program this information may not be available. Test limits based on data obtained from similar aircraft could be used to enable initial testing to be performed.

The required test levels can be derived from the generic transfer function and attenuation curves developed for Level A display systems (Section 7). The levels chosen, however, will have to be demonstrated as being adequate by on-aircraft measurements later in the program. Suitable transfer function curves (10 kHz - 400 MHz) for calculating the BCI test levels are provided in the Advisory Circular. In addition, suitable generic attenuation curves are provided in the Advisory Circular that can be used for predicting the internal environment at the location of the equipment. This predicted internal environment then provides the test level for the equipment/system integration rig Radiated Susceptibility test. The attenuation curves are defined in terms of equipment location.

6.3.1 Bulk Current Injection (BCI) Test Limits: Suitable generic transfer function curves for calculating the BCI test levels are given in the Advisory Circular. These show the envelope of the maximum currents (in mA) that might be expected to be induced on aircraft wiring bundles in an external HIRF environment of 1 V/m. An example of a generic transfer function is given in Figure 10. These currents need to be linearly multiplied by the appropriate external HIRF environment (normally the Certification) to provide the test level induced current envelope. For example, for an external HIRF field of 100 V/m the induced wire bundle current limit for the BCI test is 100 times the transfer function curve.

The Advisory Circular also provides a composite worst case transfer function (normalized to 1 V/m) produced by overlaying all the generic curves. A manufacturer whose product is to be fitted to a wide range of aircraft using common installation policy could use this curve as the test limit. This would alleviate the need to conduct several tests.

The envelope of the maximum currents induced during the BCI test should be compared with this envelope extrapolated to the appropriate environment and demonstrated to be at least equal to it.

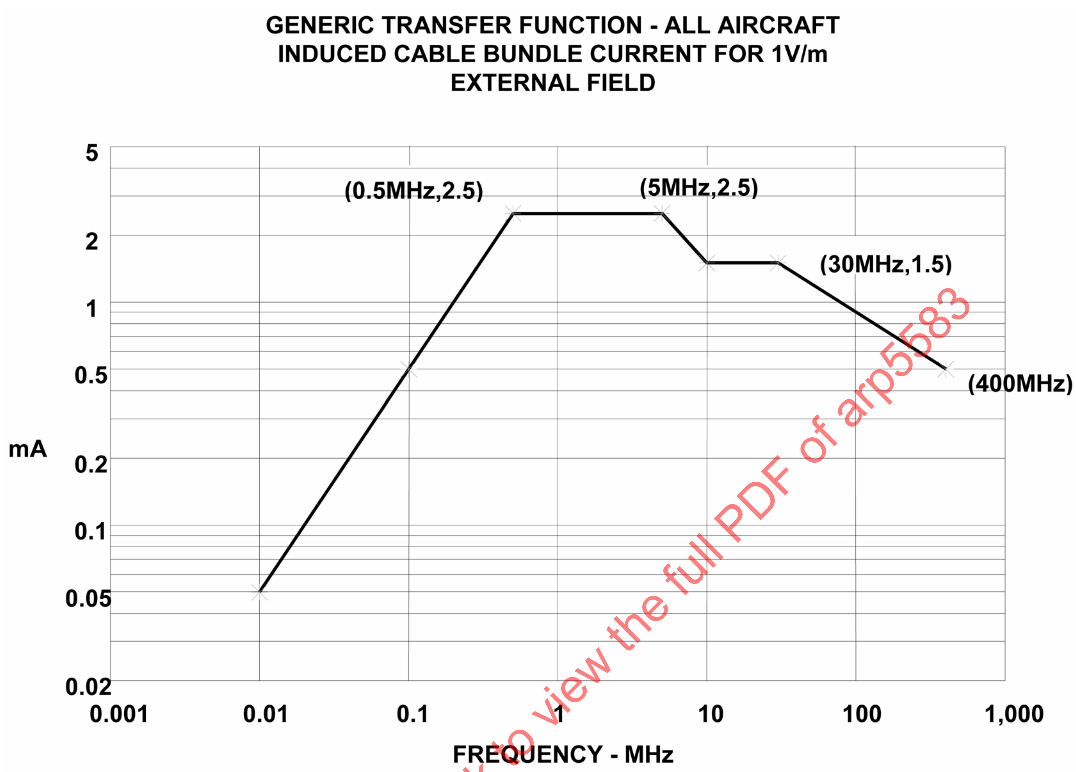

FIGURE 10 - Typical Generic Induced Bundle Current Transfer Function Normalized to 1 V/m

6.3.1 (Continued):

The generic transfer function curves provided in the Advisory Circular provide both the generic curves for fixed wing aircraft categorized by fuselage length and a generic curve for helicopters. These curves have been derived from a statistical analysis of some 700 spectra from 16 civil aircraft. These spectra were split into some 400 frequency bands with a cumulative probability curve being calculated for each band. In each band the induced current for a given population probability figure was calculated. These induced currents were plotted and an envelope of the peaks produced to provide the transfer function plots. Break points in the envelope were determined based on the fuselage maximum and minimum dimensions for each category. For example, for the 25 to 50 m category, the low frequency break point is when 50 m = $\lambda/4$ i.e., 1.5 MHz and the high frequency break point is when 25 m = $\lambda/4$ i.e., 6 MHz. The induced current level at 95 percent probability was used as the basis for the data.

Figures 11 and 12 show the composite Generic Transfer Function for all aircraft types extrapolated to various peak environments. The latest environments as specified in the Advisory Circular should be used. These extrapolated curves can form the limits for the BCI test.

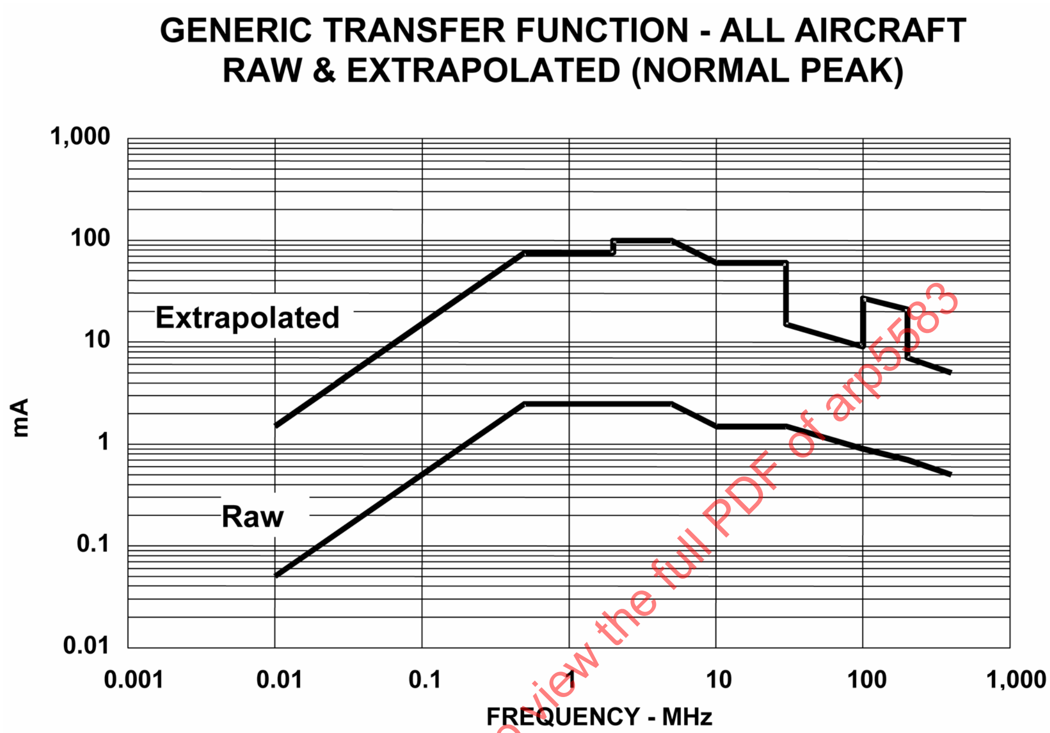

FIGURE 11 - Generic Transfer Function for all Aircraft Types Extrapolated to Normal Peak HIRF Environment

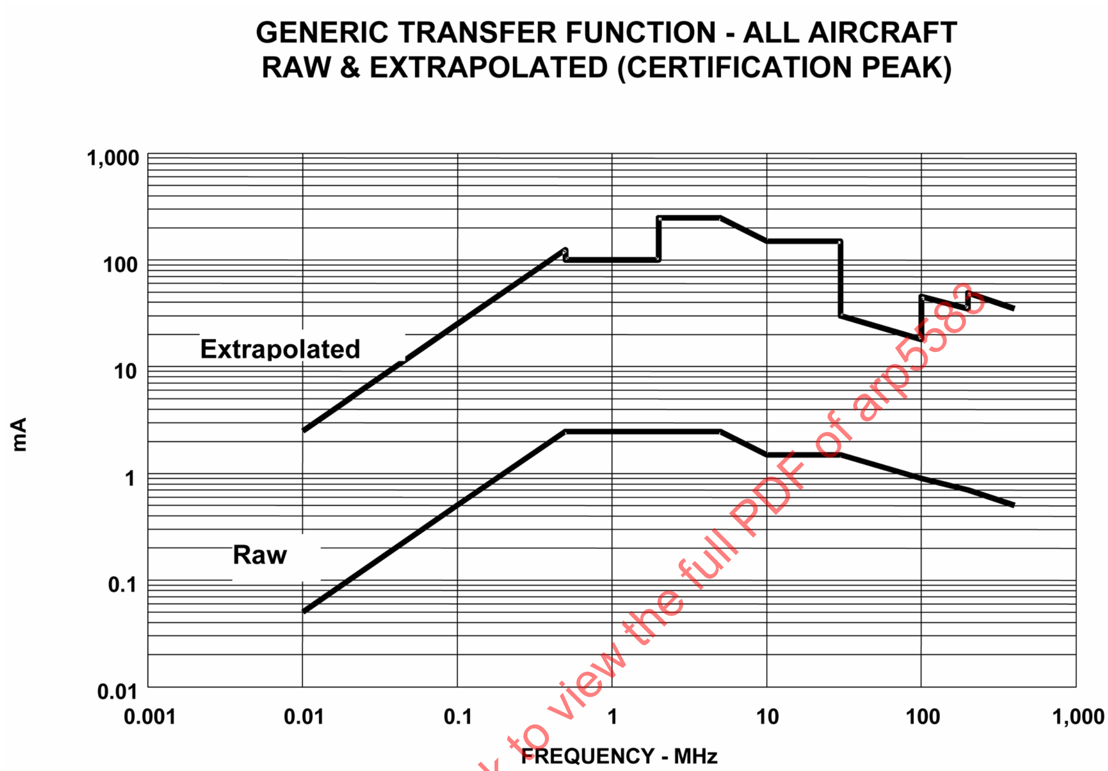

FIGURE 12 - Generic Transfer Function for All Aircraft Types Extrapolated to Certification Peak HIRF Environment

6.3.1 (Continued):

Figure 13 shows a generic transfer function, extrapolated to a typical external HIRF environment, overlaid on the currents induced during a BCI test. This shows a satisfactory result with the envelope of the induced current peaks being equal to or greater than the extrapolated generic transfer function curve. It is assumed that the power limit described in 6.5.3.3 (f) was also met.

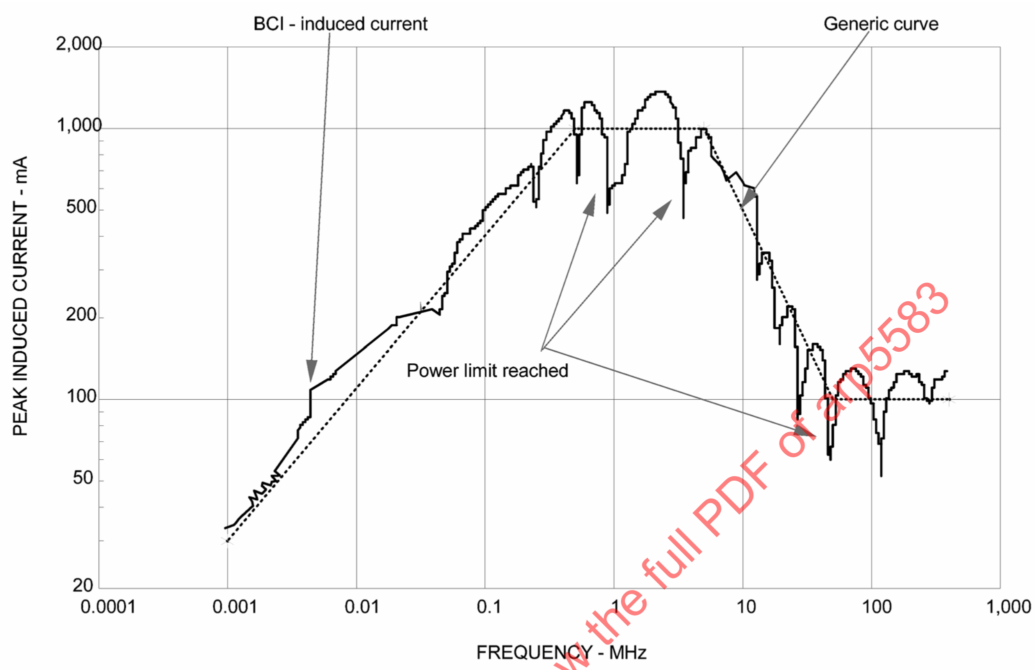

FIGURE 13 - Comparison of BCI Induced Current With Generic Transfer Function Extrapolated to a HIRF Environment

6.3.1 (Continued):

The generic transfer function curves provided in the Advisory Circular are for wiring bundles running within the airframe with no additional protection such as that provided by conduit or raceways. In the compliance submission, the added protection such measures provide should be demonstrated if a lower test level is considered more representative.

Airframe manufacturers can produce their own product specific generic curves and use these in their compliance submission. This would be advantageous as they will provide a more accurate reflection of the true environment.

6.3.2 Radiated Susceptibility Test Limits: The Advisory Circular provides generic attenuation curves that can be used for predicting the internal environment in terms of field strength at the location of the equipment for Level A display systems for the frequency band 100 MHz to 18 GHz.

In the absence of actual aircraft measured data, the generic curves can be used for estimating the system test levels for Level A control systems. The levels chosen, however, will need to be demonstrated as being adequate by aircraft measurement later on.

6.3.2 (Continued):

This predicted internal environment then provides the test level for the Radiated Susceptibility test. The attenuation curves are defined in terms of the following equipment location categories:

Category Y: This attenuation curve can be used when the equipment under consideration is located in very severe electromagnetic environments, which are defined as areas with unprotected non-conductive composite structures, areas where there is no guarantee of structural bonding, and other open areas where no shielding is provided. This attenuation curve may also be used when a broad range of installations is to be covered.

Category W: This attenuation curve can be used when the equipment under consideration is located in severe electromagnetic environments, which are defined as areas outside the fuselage such as wings, fairings, wheel wells, pylons, control surfaces, etc. where minimal shielding is provided. This attenuation curve is not appropriate for equipment installations more appropriately described by the definition of Cat Y Location.

Category V: This attenuation curve can be used when the equipment under consideration is contained entirely within a moderate electromagnetic environment, which is defined as the fuselage of a metallic aircraft or composite aircraft demonstrating equivalent shielding effectiveness. Examples of such an environment are avionics bays not enclosed by bulkheads, cockpit areas, and locations with large apertures, i.e. doors without EMI gaskets, windows, access panels, etc. Current carrying conductors in this environment such as hydraulic tubing, control cables, wire bundles, metal wire trays, etc. are not necessarily electrically grounded at bulkheads. This attenuation curve is not appropriate for equipment installations more appropriately described by the definitions of CAT W and CAT Y Locations.

Category U: This attenuation curve can be used when the equipment under consideration is contained entirely within a partially protected environment, which is defined as the fuselage of a metallic aircraft or composite aircraft demonstrating equivalent shielding effectiveness. Wire bundles in this environment passing through bulkheads should have shields terminated at the bulkhead connector. Wire bundles should be installed close to the ground plane and take advantage of other inherent shielding characteristics provided by metallic structures. Current carrying conductors such as hydraulic tubing, control cables, metal wire trays, etc., should be electrically grounded at all bulkheads. This attenuation curve is not appropriate for equipment installations more appropriately described by the definition of CAT V, W, and Y Locations.

Category T: This attenuation curve can be used when the equipment under consideration, all interfaces to/from equipment, and the wire bundles are contained entirely within a well protected environment, which is defined as an electromagnetically enclosed area. This attenuation curve is not appropriate for equipment installations more appropriately described by the definitions of levels Category U, V, W and Y Locations.

6.3.2 (Continued):

The test levels that should be applied therefore are:

Test Level = (Certification HIRF Environment / Appropriate Attenuation).

For example: 20 dB attenuation means the Test Level is lower by a factor of 10 than the Certification HIRF environment.

Further details of test procedures are given in 6.6.

6.4 Modulation:

It is important when conducting susceptibility tests for the applied RF to be modulated with representative modulations.

The test levels when applying modulated signals are in terms of the peak of the test signal as measured by a spectrum analyzer's peak detector which is capable of responding to the peak of the signal. The spectrum analyzer is calibrated in terms of the equivalent rms value of a sine wave thus giving a reading of peak rms.

The following modulation types are an attempt to define a baseline modulation:

10 kHz to 400 MHz — 1 kHz square wave modulation of depth >90 percent.

cw

The peak of the test signal must meet the requirements based on the peak environment.

400 MHz to 18 GHz — 1 kHz pulse modulation of at least 90 percent depth. The pulse width shall be as defined in Table 9. The peak of the test signal must meet the requirement based on the peak environment.

1 kHz square wave modulation of at least 90 percent depth. The peak of the test signal must meet the requirement based on the average environment.

cw. The peak of the test signal must meet the requirement based on the average environment.

TABLE 9 - Modulations

HIRF Environment III (Rotorcraft Severe)
For Frequencies less than 1 GHz: Pulse Width 4 µsec, PRF 1 kHz For Frequencies greater than 1 GHz: Pulse Width 1 µsec, PRF 1 kHz
HIRF Environment I (Certification)
For Frequencies less than 4 GHz: Pulse Width 4 µsec, PRF 1 kHz For Frequencies greater than 4 GHz: Pulse Width 1 µsec, PRF 1 kHz
HIRF Environment II (Normal)
For Frequencies less than 4 GHz: Pulse Width 4 µsec, PRF 1 kHz For Frequencies greater than 4 GHz: Pulse Width 1 µsec, PRF 1 kHz

6.4 (Continued):

Consider switching the signal on and off at a 1 to 3 Hz rate and 50 percent duty cycle for an EUT which may have a low frequency response (e.g., flight control equipment). When using 1 Hz to 3 Hz modulation, ensure that sweeping and/or frequency stepping is suspended during the “off” period of the modulation.

The dwell time shall be one second minimum at each particular test frequency, unless the system characteristics dictate an increase in dwell time. The maximum dwell time shall be 5 seconds. The minimum sweep rate shall be equal to the number of discrete frequencies per decade multiplied by 1 second, i.e., 100 discrete frequencies per decade times 1 second equals 100 seconds per decade sweep rate. In the case of helicopters, which by their nature can hover in the field for longer durations, dwell times would have to be set so as to cover the longest response time of the EUT.

If a system is considered to be more sensitive to a modulation type not covered by the above but which may be expected to occur in practice, this modulation type should be tried during testing. Also consider using additional modulations associated with the EUT, such as clock, data, IF, internal processing or modulation frequencies. For further information, the reader is referred to DO-160/ED-14.

Determining the modulations to which the system under evaluation is most sensitive can minimize the test time. If the system under test is most sensitive to only one type of modulation over the complete frequency band, use only this modulation for the test rather than running the tests with all the modulations listed above.

6.5 System Integration Rig Tests (Step 5):

Step 5 specifies two test procedures designed to test the vulnerability of equipment to RF BCI and RS testing. The former covers the band to 400 MHz and the latter the band up to 18 GHz.

Equipment may have been tested in accordance with DO-160/ED-14 and categorized with respect to the appropriate limits.

However, DO-160/ED-14 are minimum performance standards with respect to equipment testing and as such do not provide the degree of thoroughness that should be used for Level A control systems. The procedures outlined in this section are derived from those in DO-160/ED-14 but are more rigorous. If the test arrangement is representative of the final aircraft installation, the use of the procedures may alleviate the need for system integration/aircraft susceptibility testing (Step 9) as discussed in 6.6.

The substantiating evidence to demonstrate this should show that the factors necessary to enable a direct comparison of the Equipment Test Environment and the Aircraft Internal Environment at the equipment location have been taken into account. The environment is considered in terms of field strength at frequencies >100 MHz and induced wire bundle current at frequencies <400 MHz. Field strength may have to be considered at lower frequencies for large equipment where the equipment case may be an appreciable fraction of a wavelength. In this situation, the effect of field penetration at these lower frequencies cannot be ignored.

The following conditions should be met:

a. The systems integration rig is an accurate representation of the final aircraft installation, i.e., the recommended installation policy should be followed, and the same equipment modification state should be used.

b. The system should be tested in an operational state including input sensors. Passive input sensors (RTDs, etc.) can be simulated by test sets providing that the test set accurately represents the terminating impedances of the sensor.

c. The test procedures used and test levels employed should be selected to simulate the conditions imposed by the aircraft internal environment when operating in the appropriate HIRF environment for Level A control systems. Suitable test procedures are described in this section. BCI testing is used from 10 kHz to 400 MHz and RS testing from 100 MHz to 18 GHz.

During testing, antenna ports should be protected from the RF either by mounting the antenna outside the test room or by terminating the antenna port in a dummy load.

6.5.1 System Installation Requirements: It may be argued that the most accurate test is one conducted on an installed system. However, in many instances, this simply is not practical nor possible, especially in small aircraft. However it is essential in all cases to reproduce as accurately as possible the aircraft installation in so far as it affects the electromagnetic characteristics of the system under test.

The system under test shall be set up on a representative systems rig or, for a simple system, over a ground plane, in accordance with the general criteria in DO-160/ED-14 Section 20.3.a. However, if these criteria conflict with the aircraft installation, then the aircraft installation criteria should be used. The following criteria should be applied in addition to the general criteria in DO-160/ED-14 Section 20.3.a.

a. Ground Plane - In all cases where a shielded enclosure is employed, the ground plane shall be bonded to the shield at intervals no greater than 0.91 m and at both ends of the ground plane. This is not applicable if a representative rig is used.

b. Shock and Vibration Isolators - Any equipment racks used in the aircraft installation should be used during the test.

c. Bonding - The bonding straps should be of the same construction and dimensions as will be used in the final installation.

d. External Ground Terminal - When an external terminal is available for a ground connection on the EUT, this terminal shall be connected to the ground plane, if the terminal is normally grounded in the installation.

e. Interconnecting Wires - All equipment interconnecting wire bundles and RF transmission lines shall be in accordance with the manufacturer's installation wiring diagram. Shielded or twisted wires shall be used only where specified by the equipment manufacturer. When dealing with long wire bundles, these should be zig-zagged on the bench. The zig-zag should not be tight so as to cancel radiation from the wire bundle.

f. Power Leads - Within the system under test, power leads should be run and terminated as on the aircraft. Where they leave the rig or system under test they need to be fed from a defined impedance which is representative of the aircraft. The easiest solution is to feed the power lines via a line impedance stabilization network (LISN) as specified in DO-160/ED-14 to minimize test variation caused by varying test house supply impedance.

g. Dummy Antennas - The dummy antenna shall have electrical characteristics that closely simulate those of the normal antenna and should be shielded.

6.5.2 Instrumentation Requirements: Test instruments shall be set up and operated in accordance with DO-160/ED-14 Section 20.3.b., with the following additional criteria:

a. Bonding Test Equipment - Test equipment shall be physically grounded with only one connection. When a dipole antenna, loop antenna, or current probe is utilized, the test equipment shall be connected to ground with only the power cord ground terminal. If a bonding strap is used on either the test equipment or the antenna, neither the power cord ground nor the test equipment ground terminals shall be used.

b. Impedance Stabilization Network - One line impedance stabilization network (LISN) that satisfies DO-160/ED-14 Section 20.3.b. shall be inserted in each ungrounded primary input power lead of the EUT. The network enclosure shall be bonded to the ground plane. The length of the line between the stabilization network and the EUT should simulate the lengths used in the aircraft installation. An acceptable default length is 1 meter. The measurement terminal on the LISN shall be terminated in a 50 ohm non-inductive high power load for the tests in this section.

c. Radiating Antenna Position - When planning for a radiated susceptibility test, special consideration should be given to the placement of the transmitting antenna relative to the EUT. The placement will drive the size of the area needed to conduct the testing. The placement is determined by setting the separation distance between the antenna and the EUT at distances equal to or greater than the far field boundary of the antenna. The most common distance is 1 meter. The far field boundary is calculated by the formula $(2*D)^2/\lambda$, where D is the largest dimension of the antenna, and λ is the wave length of the lowest frequency of interest for that antenna. If the test is to be conducted in shielded enclosures with anechoic material, then the antenna should be at least 0.3 m away from the absorber surfaces.

d. The desire during the test is to illuminate the EUT with a uniform field. This is impractical for large systems. The solution is to expose each equipment in turn complete with $\lambda/2$ of wiring. The antenna could be moved farther way, which will increase the illumination area and decrease the number of antenna placements required for large EUT configuration.

e. Shielded Enclosures If a shielded enclosure is used, then consideration should be given to the impact of field measurements to the size of the room. The accurate calibration of the radiated field for RS testing in a shield enclosure requires that the room be relatively free of standing waves. The standing waves are minimized by the extensive use of anechoic material. The anechoic lining should be effective over the total frequency rage of the test. As a minimum the anechoic lining should be placed around the transmitting antenna, along the rear of the test bench and on the ceiling and floor between the transmitting antenna and the bench/rig.

f. Mode Stirred Chambers An alternative radiated susceptibility test method is presented in 6.6.5 Reverberation Chamber. This section should be consulted to determine test equipment requirements on such topic as size of the room, stirring paddles, and impact on the EUT.

6.5.3 Bulk Current Injection (BCI) Test: The BCI test was specifically developed in its present form to provide information to aid aircraft certification, and make equipment level electromagnetic susceptibility tests more accurately simulate the real environment.

For the results of the BCI test to be of use in the Route to Compliance, two parameters should be measured during the test. First, provide a loop impedance or correlation plot of the wire bundles. Figure 14 shows a sample test arrangement for producing such a plot. Second, measure the level of induced current on the equipment's wire bundles.

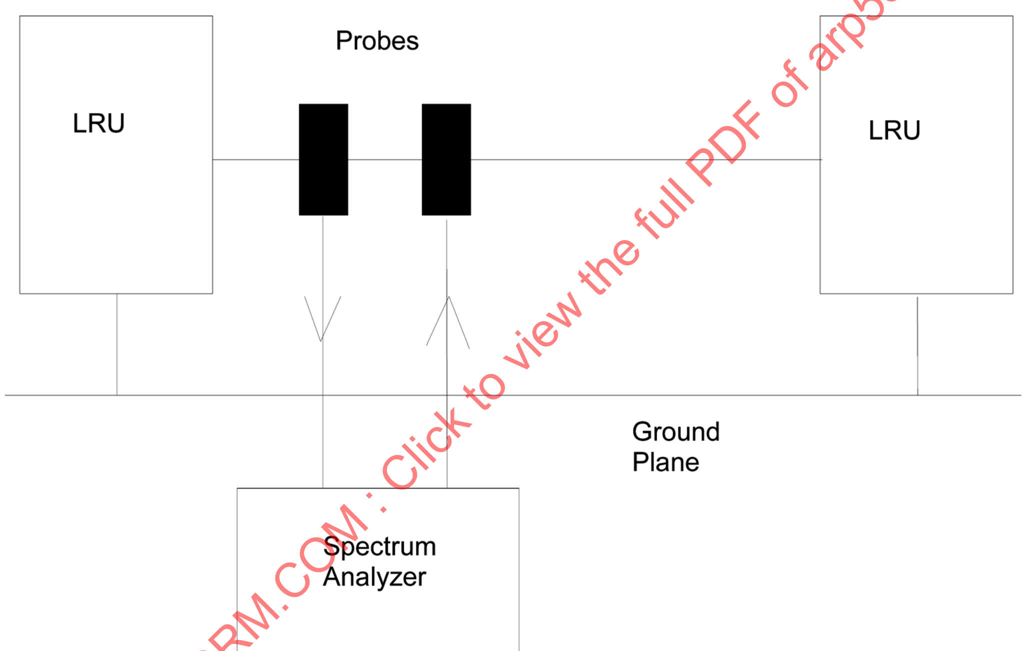

FIGURE 14 - Correlation Plot: Test Arrangement

This correlation plot (insertion loss measurement, normalized to 1 watt forward power into the injection probe) provides a measure of the loop impedance for each wire bundle formed by the wiring, LRU bonding straps, and ground plane. The same measurement can be repeated when the equipment is installed in the aircraft. Comparison of the two gives an indication of the validity of the laboratory measured signature. It would, for example, show any strong resonances that could have given unrepresentative results during equipment testing.

It should be remembered that this measurement does not provide the actual impedance value as it is a comparative insertion loss measurement only.

6.5.3 (Continued):

The equipment is tested using the bulk current test method described next, to enable the electrically weak wire bundles to be highlighted and possible failure modes to be determined. During testing the current at the selected test level for each frequency on each bundle is measured and recorded for later comparison with the LLSC results from the whole aircraft tests. The power required by the injection probe to achieve the limits chosen or that caused malfunction is recorded. It is also suggested, but not required, that the equipment might be subjected to increasing power up to a fail safe level (in terms of power) or until malfunction, whichever is sooner, in order to establish malfunction thresholds above the pass/fail level.

The purpose of this test is to confirm that RF signals in the range 10 kHz to 400 MHz, when coupled on to EUT interconnecting wire bundles and power supply lines, will not cause either degradation of performance or malfunction. In addition, the test will provide an amplitude/frequency signature for the system. The signature may be compared with the levels of current on the wiring bundles due to the effects of on-board and external transmitting sources. The currents on the wire bundles may be measured during system/aircraft high level testing.

6.5.3.1 Test Setup: Wire bundles that connect the system under test to other equipment in the aircraft (including primary power lines) or those interconnecting units of the system under test are subject to this test. Wire bundles or individual wires can be tested. The bundles or individual wires to be tested will be defined in the equipment test plan but some basic ground rules are:

a. All bundles will be tested as a whole, connector by connector.

b. Primary power lines shall, in addition, be tested individually by injecting and monitoring on each line in turn.

c. On equipment performing a critical control function, individual wire bundle branches should be selected for testing in addition to (a) and (b) above.

d. Simultaneous injection on several bundles may be required by the Certification Authority for systems with built-in redundancy, e.g., a quadruplex flight control system.

Figure 15 shows the layout for a test on a simple system over a ground plane. Variation from this may be applicable to ensure the test setup is representative of the aircraft installation.

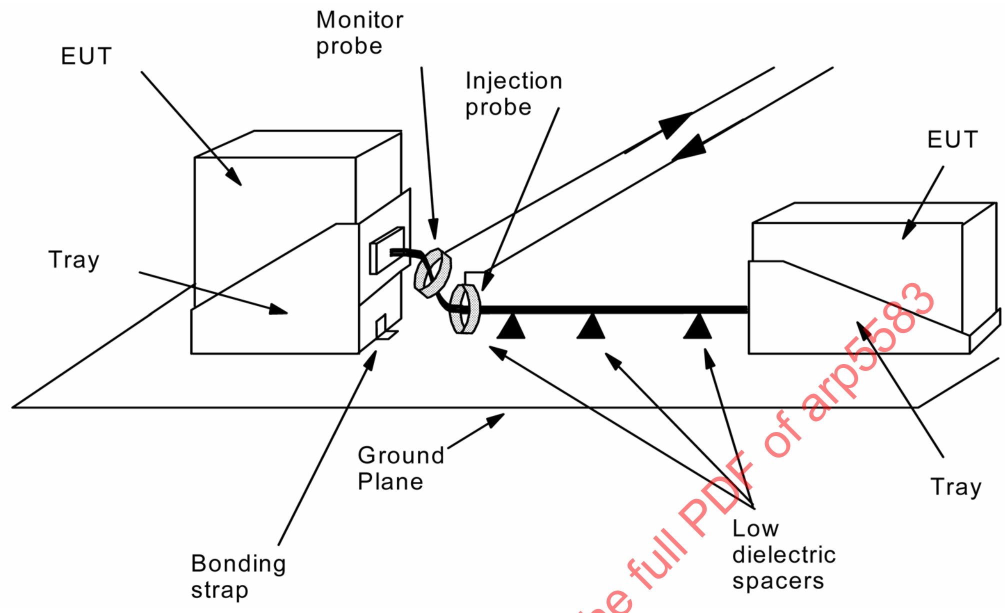

FIGURE 15 - Typical Test Configuration for a Simple Systems

6.5.3.1 (Continued):

The following test equipment is used.

a. Current injection probes: The probes should have the insertion loss shown in DO-160/ED-14 Section 20.3.b.(4) and be capable of handling the power required to meet the test limits.

b. Calibration jig for the current injection probes: The calibration jig standing wave ratio (VSWR) should meet the limit of DO-160/ED-14 Section 20.4.b. when terminated in 50 ohms with no probe fitted.

c. Current monitoring probes: 10 kHz to 400 MHz

d. Signal source: 10 kHz to 400 MHz

e. Power amplifier: 10 kHz to 400 MHz. This amplifier should be capable of supplying the full rated power into the current injection probes (which have a high VSWR) with a harmonic content of less than 10 percent.

f. Spectrum analyzer or measuring receivers: 10 kHz to 400 MHz

g. Directional coupler: 10 kHz to 400 MHz

6.5.3.2 Injection Probe Calibration Procedure: Unlike the standard DO-160/ED-14 test, the test limits are primarily based on the actual currents induced in the wiring bundle rather than calibration jig current because the induced current is being compared with actual aircraft measurement. The calibration should be done prior to each equipment test or series of consecutive tests if actual measured aircraft data is not being used.

The following calibration procedure shall be performed prior to the test or series of tests using the same test equipment layout, measurement and feeder wires, and injection/measurement probes as will be used for the test. The feeders to the injection probe and the measurement wires should have ferrite loading on their outer shields to minimize RF current flow (on the outside of their shields) which could affect test accuracy. The injection probe shall be installed in the calibration jig. Figure 16 shows a schematic of the calibration jig that is commercially available.

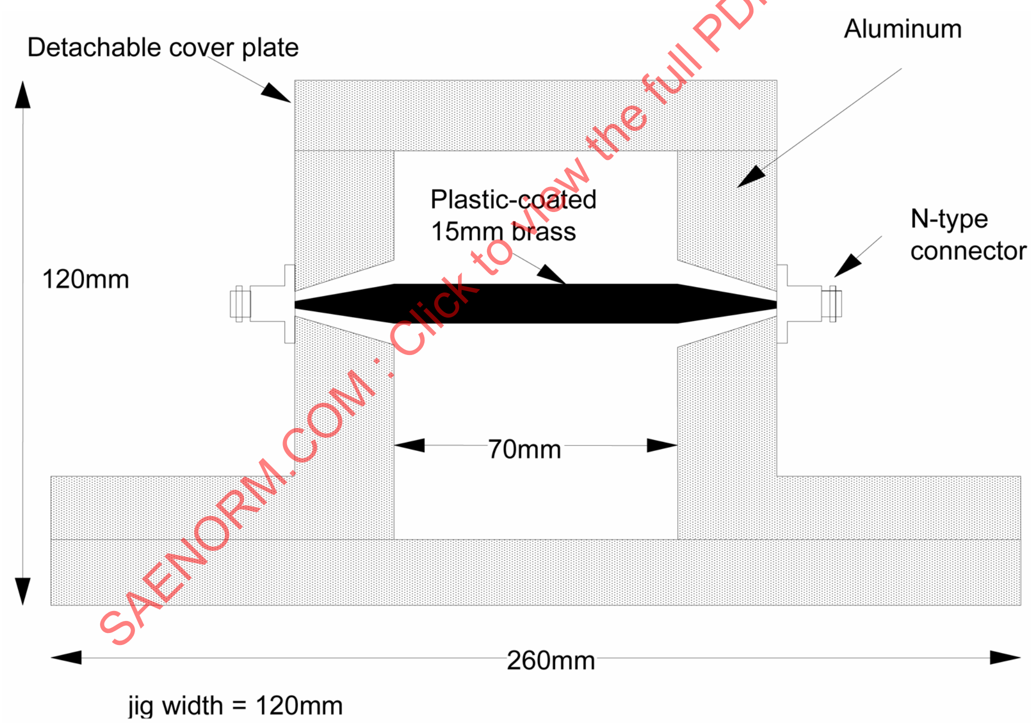

FIGURE 16 - BCI Calibration Jig

The cover plate may need to be removed for calibrating the 10 kHz to 2 MHz probe because of the physical dimensions of the probe, but must be fitted for calibrations in the 2 to 400 MHz band to prevent spurious calibration jig resonances.

6.5.3.2 (Continued):

The calibration jig shall be terminated in a 50 ohm 500 W RF coaxial load at one end and a 50 ohm spectrum analyzer or RF voltmeter at the other (see Figure 17.) A 500 W power attenuator will be required to protect the spectrum analyzer. The VSWR of the terminations at both ends of the calibration jig shall be less than 1.2:1 over the frequency range of the test. The injection probe is fed with power from the signal source via the power amplifier. The limits specified for this test method are in terms of current induced in the calibration jig. A pass/fail level up to which the performance of the system should not be affected.

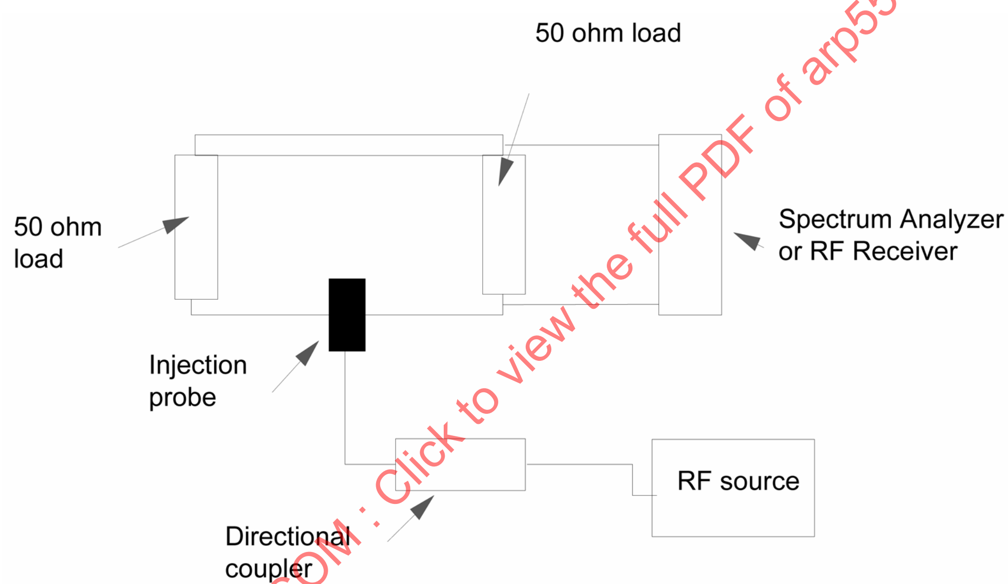

FIGURE 17 - Configuration for Calibrating Injection Probes

The test signal supplied to the injection probe shall be increased until the voltmeter or spectrum analyzer indicates that the required accept/reject level of current is flowing in the calibration jig. The forward power flow to the probe shall be increased until required test level current is reached, and the forward power flow again recorded. Details on the test limits are given in 6.3.1. These measurements are to be made over the frequency range 10 kHz to 400 MHz, with a minimum of 100 test frequencies per decade, equally spaced on a logarithmic scale. Greater spacing between measurement points may be used if the amplitude variation between test frequencies is less than 1 dB.

Care should be taken to minimize the time for which power is applied to the injection probes, to prevent overheating.

The calibration curves shall be shown in the test report. The forward power to the current injection probes to give the two levels of current shall become the pass/fail level and the test level respectively for the equipment test.

6.5.3.3 Test Procedure:

a. This test may be applied to whole wire bundles or individual conductors as defined in the equipment test plan. As a minimum requirement, the injection probe shall be connected around the complete wire bundle and subsequently around any branches of that bundle. In all cases the current monitor probe shall be connected around the complete wire bundle 50 mm from the connector (see (c) below).

b. The calibration procedure described above shall be performed prior to the commencement of the tests.

c. A current monitor probe is used to measure the current actually induced on the bundle or conductor under test. This probe shall be fitted around the bundle or conductor under test such that the face of the monitor probe nearest the EUT connector is 50 mm from that connector (Figure 18). If the overall length of the connector and backshell exceeds 50 mm, the monitor probe shall be placed as close to the connector's backshell as possible and its position noted in the test report.

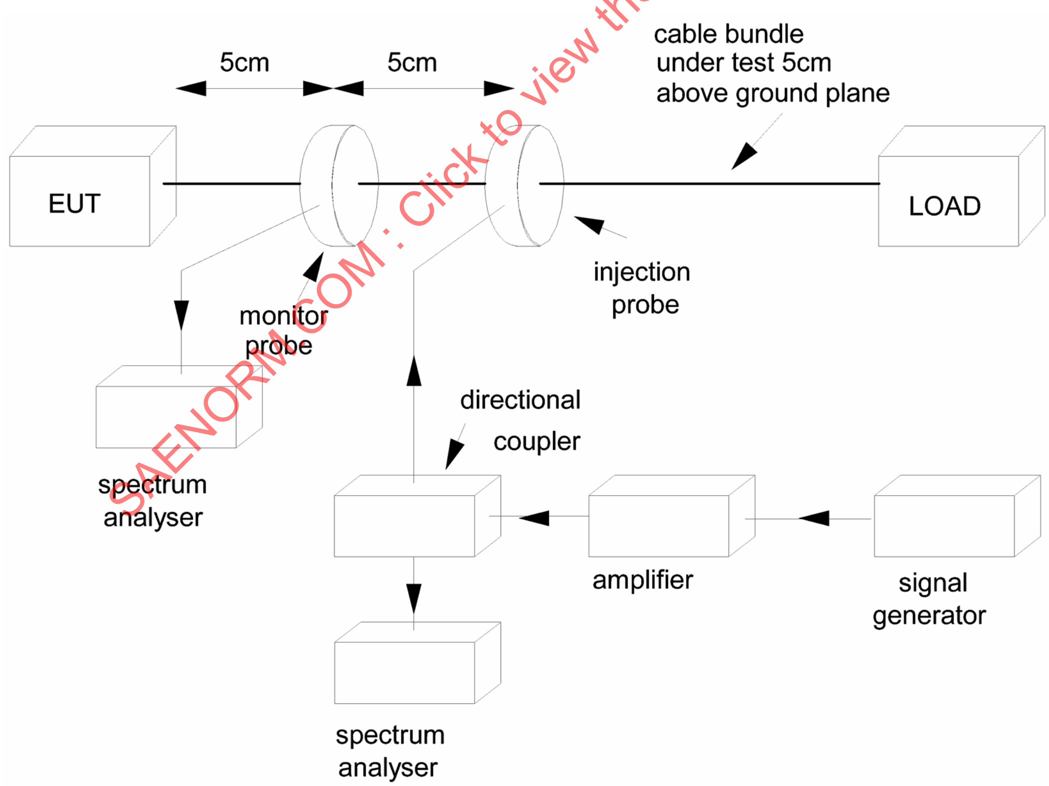

FIGURE 18 - Detailed BCI Test Configuration

6.5.3.3 (Continued):

d. The current injection probe shall be fitted around the bundle or conductor under test such that the separation of the adjacent faces of it and the current monitor probe is 50 mm. However, if the length of the bundle is less than 0.5 m then the injection probe shall be placed in the center of the bundle and the induced current measured 50 mm from each connector's backshell.

e. Prior to commencement of the test on each bundle as defined under (a), a swept measurement of induced current per unit forward power to the injection probe shall be made (loop impedance test). The power level to the injection probe should be of the order of 1 mW. This test can be accomplished using the test setup (shown in Figure 14) which uses a spectrum analyzer with tracking generator as the signal source. The measurements shall be graphically recorded in the test report, with the induced current normalized for a forward power of 1 watt. This information will aid the aircraft certification authority in assessing how well the test installation simulated the aircraft installation. These results should also be referred to when measuring to the pass/fail level in (f) to ensure resonances in the coupling are covered.

f. At each test frequency, the signal amplitude may have to be gradually increased, up to the pass/fail level in terms of induced current, to check for window effects as described in (g). If the required current cannot be induced in the wiring bundle under test, two different procedures apply depending on the derivation of the limits:

   1. If the limit is based on actual measured aircraft coupling data on the system installed in the aircraft then the actual measured induced current extrapolated to the appropriate environment shall be induced during the test. If the rig installation is an accurate representation, this is feasible. Minor discrepancies in the rig simulation may mean that resonances on the wire bundle under test occur at different frequencies and this may prevent the required current being reached without excessive power being applied. In this case the injection probe may be moved away from the monitor probe to attempt to gain better coupling into the wire.

   2. If the limit is based on previous experience or generic curves then it is very likely at many frequencies that the limit in terms of induced current can not be met with realistic power levels even if the injection probe is moved. In this case the applied power should be limited to realistic levels to avoid damaging the equipment. A "rule of thumb" suggestion would be to limit the power to 10 dB above that which gave the test level in the calibration jig.

   During the test, two parameters shall be recorded: the induced current in the bundle or wire (50 mm from the connector under test as measured by the monitor probe) and the forward power to the injection probe. The induced current will be used to provide information in support of the compliance submission by comparison with the aircraft measured induced currents and the forward power will demonstrate the severity of the test.

6.5.3.3 (Continued):

Complete frequency coverage should be obtained by slowly sweeping across the frequency band to ensure the lowest susceptibilities have been found. Where the signal source sweeps in discrete steps, such as a signal synthesizer, the minimum number of test frequencies shall be as defined in DO-160/ED-14, that is 100 frequencies per decade, equally spaced on a logarithmic scale.

g. Window effects is the term for system susceptibility observed during immunity testing that occurs at a certain test level, but then apparently disappears at a higher level. An example of this is a system that utilizes a solid state switch and the upset is defined as inadvertent operation of the switch. As the level of applied RF is increased, a threshold level is reached where the controlling circuitry changes state, thus operating the switch. At higher levels, the controlling circuitry is saturated, thus no longer changing the state of the switch. If in this case the test level was just applied at the higher level then the susceptibility would not have been found. Equipment should be reviewed for circuits which may exhibit window effects to determine the system response and necessity to conduct window effect tests.

   To check window effects the signal source should be programmed to reduce its output by 20 dB at a minimum of 5 frequencies per decade, logarithmically spaced. At these frequencies, the output is then gradually increased to the pass/fail level. If it is intended to sweep across the frequency band at the test level, to reduce test time it should be demonstrated that window effects are not applicable to the system under test.

h. It is important that the system under test should be exercised during testing to make sure it is operating normally and has not been inhibited from performing some of its tasks.

i. Care should be taken to minimize the time for which power is applied to the injection probes, to prevent overheating.

6.5.3.4 Special Precautions: The System Integration Rig installation should mirror the final aircraft installation for the BCI test results to be meaningful. Therefore, factors such as wire shielding policy, grounding, rack mounting, wire bundle composition and length need to be taken into account; these also affect the radiated susceptibility test accuracy.

In addition, certain equipment installation practices can cause susceptibility characteristics of the equipment obtained during the BCI test to be significantly different than the susceptibility characteristics of the equipment installed on the aircraft. Precautions need to be taken to ensure that the performance of the equipment during these tests mirrors that which will be obtained in practice. Some of these precautions are discussed below.

6.5.3.5 Grounding Wires: An aspect of installations often overlooked that can cause significant errors is shown in Figure 19.

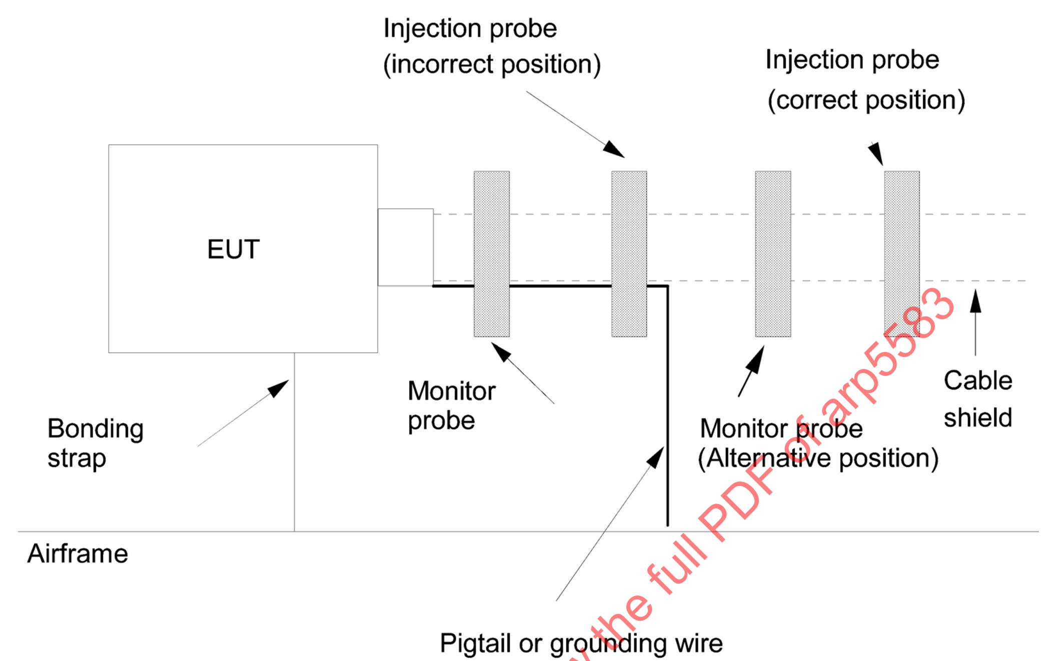

FIGURE 19 - BCI Test Problem Caused by Pigtail or Ground Wire

6.5.3.5 (Continued):

In many installations a short wire is run either from the connector backshell to ground, or from a grounding point inside the box, through a pin to ground. If the test is only conducted when the injection probe is placed around this lead as well as the total bundle, misleading results at lower frequencies (<100 MHz) will be obtained as this wire acts as a short circuit carrying most of the induced current. The induced currents to the equipment during the BCI test with the grounding wire included in the injection probe can be typically an order of magnitude higher than those that would be produced by a radiated field to an aircraft wire bundle. The injection probe should be placed around the bundle excluding this wire as shown in Figure 19. This will happen providing the statement above that "each branch is also tested" is followed. At VHF and UHF frequencies this wire may contribute to the susceptibility of the equipment and should therefore also be tested as part of the total bundle. It is important that the monitor probe should be placed in the same position as for the aircraft LLSC measurement. If this wire grounds the wire shields, and is not bonded to the equipment case or connector, then it should be excluded from both the monitor and injection probe when using generic curves. This is because it can cancel out the induced currents on the shield, giving low induced current readings, and result in over-testing.

6.5.3.6 In-line Connectors: Alternative positions for probes should also be considered when the wiring configuration includes in-line connectors close to the equipment. When the wire bundles with shields terminated to the equipment connector and to the in-line connector close by, it is more realistic to either float the in-line connector bracket when the probes are in the standard position. Or the probes should be positioned on the other side of the in-line connectors while leaving the connector bracket grounded. The intent is to avoid a test configuration that limits the injected current to a short shielded loop between the equipment and the in-line connector.

6.5.3.7 Discontinuous Shields: Where a discontinuous shield is used in the installation, consideration should be given to injecting on the unshielded wires to a level commensurate with the area of the aircraft where the unshielded portion of the wire bundle is situated. This will require the use of break-out boxes with the induced current also being measured at the equipment terminals underneath the shield. This induced current measurement will also have to be made on the aircraft using a breakout box during the LLSC testing for Level A systems.

6.5.3.8 Multiple Bonds on Shielded Wires: Where wire shields are regularly bonded on the aircraft, the results from the BCI test may be in error as injection is only taking place on one segment of the wire bundle. In these circumstances, a breakout box is required for the LLSC test and the BCI test or for the BCI test the shield is removed during testing and allowance for it made in the test levels used.

6.5.3.9 Wire Lengths: Where non representative wire lengths are used, incorrect information may be obtained as to the hardness of the equipment. The wire length determines the frequencies where the maximum energy is coupled into the EUT. Therefore, during testing these frequencies may occur where the limits are relaxed which may not be so in the final installation. If the correct wire lengths cannot be used, then a "worst case assumption" will have to be employed, where the highest test level is used across the frequency band. This approach will need to be validated when the aircraft is available to confirm the test levels employed.

6.5.4 Radiated Susceptibility Test 100 MHz - 18 GHz: The radiated susceptibility test provides information on the field strength at which malfunctions of the equipment were observed. This information is of use at frequencies greater than 100 MHz where wire bundle current measurements become less accurate. At these higher frequencies penetration of RF through the equipment case becomes increasingly important. This mode of coupling is not covered by the current injection test.

The lower frequency limit depends on when the equipment cases become a significant fraction of a wavelength and hence cannot be ignored as a route for interference into the system. Some overlap with the BCI test should be provided and thus the lower frequency limit was set at 100 MHz. Less overlap may be used (such as a lower limit of 200 MHz) if agreed upon by the cognizant certification authorities.

The system/equipment under test including interconnecting wiring is subject to this test method.

6.5.4.1 Test Set-Up: DO-160/ED-14 Section 20.3 should be studied before commencement of the test. Figure 20 shows a typical test set-up.

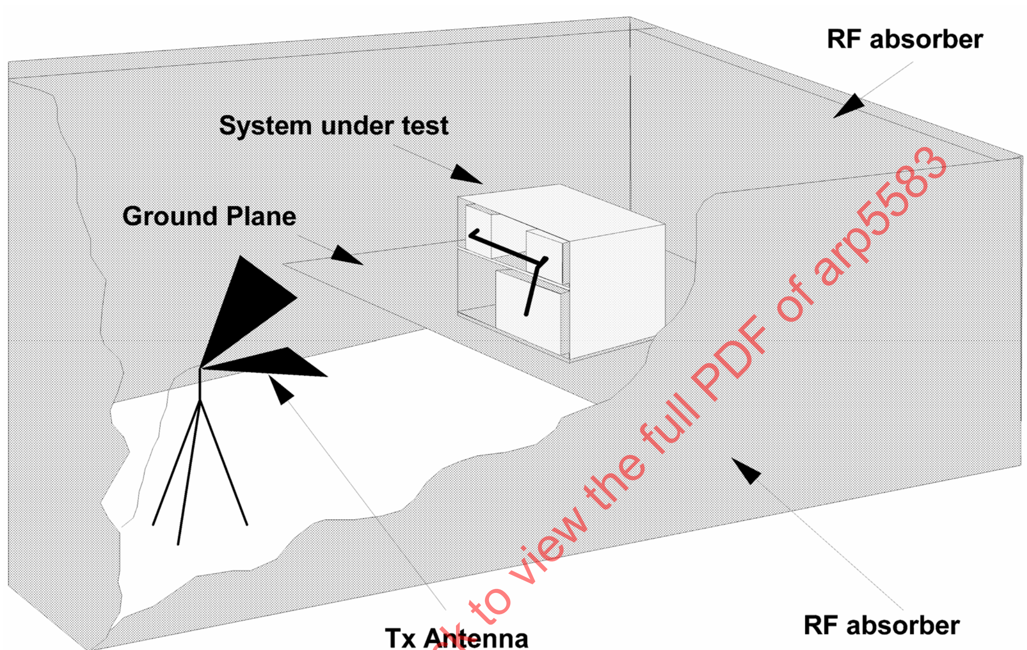

FIGURE 20 - Typical Radiated Susceptibility Test Setup for a Simple System

Care should be taken to ensure isolation of the test equipment outside the shielded enclosure from the RF electric field environment. Special attention should be given to filtering wires at the shielded enclosure bulkhead before exiting the shielded enclosure to the test equipment. It is recommended that fiber-optic interfaces should be provided at the EUT to give susceptibility-free monitoring of the EUT performance. The fiber-optic interfaces should be designed such that they could be utilized to monitor equipment performance during the whole aircraft tests.

RF absorber material should be used to reduce screened room reflection whenever possible.

The antennas, power amplifiers, and signal generators in the test set-up should be selected to produce the required field intensities at the specified frequencies to cover the area of the EUT with single or multiple areas (see DO-160/ED-14 Section 20.3.b.(3)). The antennas may be either linearly polarized or circularly polarized. Linear antennas are preferred because they will permit separate investigation of the effects of horizontal and vertical fields to the EUT.

6.5.4.2 Test Method: The test method is split into two parts: Calibration of the field and the equipment/ system test. The field calibration should be completed first to be able to transmit the correct field to the EUT during the equipment/system test.

6.5.4.3 Field Calibration: The field at the location of the EUT to be tested is calibrated prior to the equipment installation (see Figure 21). The transmit antenna is placed out in front of the EUT at a distance that is equal to or greater than the far field distance for the antenna (see DO-160/ED-14 Section 20.3.b.(3) for more details). A small isotropic field sensor is placed horizontally in the center of the transmitting antenna beam, vertically at a height that is the mid height of the EUT (30 cm may be used as a default) and at the location where the side of the EUT would be closest to the transmitting antenna. A reference antenna may be used depending upon the transmit power measurement device used. The forward power to the transmitting antenna is adjusted until the required resultant field strength as measured by the probe is achieved. The power transmitted and corresponding field are recorded. Only the power transmitted is used during the test of the EUT to set the field for the RS test. It is normally convenient to leave the probe in the test area during testing of the EUT. The probe permits monitoring of the field and confidence that no malfunction of the transmit antenna or feeder has occurred. It should be remembered that the probe does not provide in its own right an absolute measurement of the field strength at the location of the EUT without the EUT present.

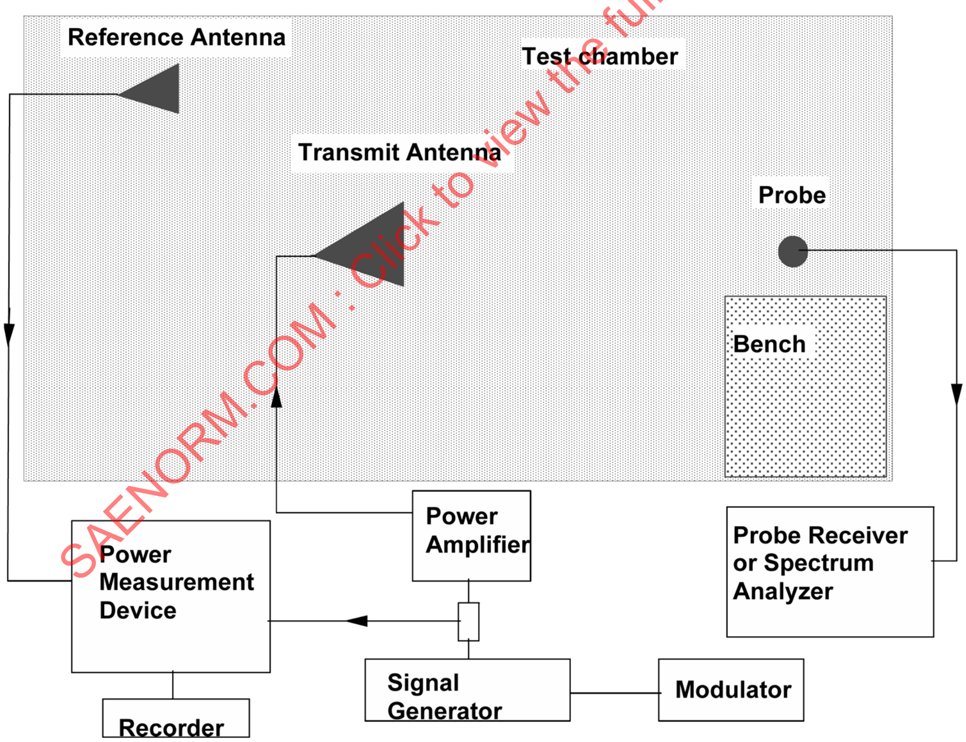

FIGURE 21 - Field Calibration Test Arrangement

6.5.4.3 (Continued):

The field over the area of the EUT (at the height used to calibrate the reference point described above) for the given transmit antenna position should be mapped to ensure that the resultant field does not vary by more than 6 dB. If it does, for example for large systems, the additional antenna positions are required and each position should be calibrated. If a shielded enclosure is used, then extensive uses of RF anechoic material may be required to achieve this uniformity.

NOTE: The resultant field is calculated to be:

$$E_T = \sqrt{E_x^2 + E_y^2 + E_z^2} \quad \text{(Eq. 2)}$$

where:

E_T = total resultant E-field
E_x = total resultant E-field
E_y = total resultant E-field
E_z = total resultant E-field

When linear antennas such as biconical, log periodic, and horn are used for the transmitting antenna, both polarizations should be calibrated, unless it can be proven than the fields radiated in both polarization orientations have similar beamwidth and illumination of the EUT.

The field calibration is made with no modulation (CW). The small isotropic field sensors normally give erroneous results when measuring modulated fields.

The power transmitted is determined by measurement of the forward and reflected power from a directional coupler fed to a spectrum analyzer or a power meter set to peak detection. The power transmitted is calculated by using the standard formula for a directional coupler.

If the field to be measured exceeds the range accuracy of the probe, then the field strength at the location of the EUT can be determined by linear extrapolation of the transmitted power. First, the field is measured for several lower field values (within the range of the probe) with corresponding the power transmitted values. The lower field values should determine the linearity of the RS system and the function of power transmitted to radiated field. Then, during the testing of the EUT the probe can be removed from the test area or placed in an area of acceptable fields. The required field is radiated based on the extrapolated calibration values of transmitted power. Care should be taken using extrapolation, so that the high power RF amplifier does not go into compression causing large harmonics and resulting in misleading field extrapolation.

6.5.4.4 Equipment/System Test: The EUT is installed in the system integration rig and radiated with the test environment (Figure 20). As stated in the calibration procedure the field level is set based on the transmitted power not the monitor probe. See DO-160/ED-14 Section 20.3 for guidance regarding the EUT and the test instrumentation requirements. The test environment should include the modulation described in 6.5 at the limits from 6.4.2. When using AM modulation, most signal generators increase the peak rms level as a function of modulation for the same CW setting on the signal generator output. Therefore, the signal generator output will have to be lowered to ensure the peak-rms value with modulation is equal to the CW power transmitted during calibration for the desired field on the EUT. Pulse modulation does not usually suffer from this instrumentation phenomenon.

The field should be swept over the complete frequency band from 100 MHz to 18 GHz. Where the signal source sweeps in discrete steps the minimum number of test frequencies should be at least 100 frequencies per decade, equally spaced on a logarithmic scale. Window effects may be checked as detailed in 6.6.3.7(g).

The EUT should be evaluated for proper function while being subjected to the test environment. At each test frequency there should be sufficient dwell time allotted to allow full functional assessment before proceeding to the next test frequency. The dwell time requirements are described in 6.5.

At frequencies above 400 MHz, holes and discontinuities in the shield of the EUT shall be directly illuminated by the transmitting antenna (i.e., the numerical displays, CRT screen, LRU connectors, etc. on the EUTs should be normal to the main lobe of the radiating antenna.

When polarized antennas are used for the transmitting antenna, then the test should be either completed for both vertical and horizontal orientation or a 45 degree orientation may be used with a single sweep. (There is a 3 dB reduction of field to the normal polarizations.)

6.5.5 Alternate Radiated Susceptibility Test - Reverberation Chamber: Reverberation chamber tests provide an alternative to 6.5.4 for susceptibility testing at frequencies greater than 100 MHz. (Note the chamber size will determine the lowest usable frequency for a particular facility.) An aircraft compartment is a heavily loaded resonant cavity while a reverberation chamber is a lightly loaded resonant cavity. A reverberation chamber test generates a complex electromagnetic environment similar to that in an aircraft compartment whereas an anechoic chamber or open field site test generates far-field plane waves.

The advantages of a reverberation chamber are:

a. During one rotation of the paddle wheel, the peak field will occur at all points in the room;

b. Multiple configurations are not necessary since the mechanical stirrer moves the fields through all angles and polarizations throughout the chamber;

c. Less RF input power is required to generate a given test field due to the high Q of the reverberation chamber than is required in an absorber-loaded chamber or at an open site.

6.5.5 (Continued):

The limitations of a reverberation chamber are:

a. The mode density at frequencies below a calculable limit based on chamber size is too low to provide adequate mode mixing and hence insufficiently randomized fields.

b. For light loading conditions, the time constant of a reverberation chamber may be too slow for tests requiring short duration waveforms.

c. The directivity characteristics of antennas or EUTs are not preserved.

The thoroughness of exposure in a reverberation chamber is difficult to achieve in practice with any other test method. The time required for testing an EUT depends on the response time of the EUT, as in other methods, but additional care is needed for reverberation chamber testing since the test fields vary with time as the tuner rotates.

The reverberation chamber radiated susceptibility test procedure in DO-160/ED-14 Section 20.6 may be used for these tests.

6.5.6 Optional Procedure for Testing Below Reverberation Chamber Frequency Limit: This section addresses a test option that may be applied to the RS test procedure of 6.6.4 to reduce localized field variations or to the RS procedure of 6.5.5 when the lowest usable frequency is greater than 100 MHz. The low frequency limit on this procedure is the first chamber resonance. If this procedure is implemented there should be a frequency overlap of at least 200 MHz with the test procedures of 6.5.4 or 6.5.5.

Although it utilizes a tuner, this procedure is not equivalent to reverberation chamber operation. The procedure does not provide the field uniformity, isotropicity, and polarization randomization of reverberation chamber operation. The procedure is, in fact, a modification of the RS test method of 6.5.4.

This test method utilizes the concept of varying the modal structure with a tuner. As the tuner in a shielded enclosure rotates, the electromagnetic boundary conditions are changed. This results in changes to the peaks and nulls of the modal structure of the unperturbed enclosure. Available field characterization data shows a substantial reduction in the spatial and frequency dependent field variability when the tuner is operating.

To maximize the effectiveness of this procedure the tuner should be as large as possible and, as for reverberation chamber operation, should be asymmetric. Available data indicates that a tuner with a maximum dimension of eight feet will provide adequate performance to below 100 MHz. Method 3008 of MIL-STD-1344A Notice 3 describes an acceptable approach to tuner design.

The tuner should be operated at 12 rpm or greater to provide the maximum variation in the modal structure during the specified five second exposure time.

6.5.6 (Continued):

The test setup should be the same as in 6.5.4 except that no absorbing material should be used. Note in this procedure, as opposed to the reverberation chamber procedure, the transmit antenna directly illuminates the EUT. Note also that unlike the reverberation chamber procedure, the EUT should be exposed to both vertical and horizontal polarizations and the EUT may have to be exposed at multiple orientations.

6.6 Aircraft Test (Steps 6 through 10):

6.6.1 Test Decision (Step 6): Depending on the aircraft size and the RF environmental requirements a suitable route to compliance is selected. A mixture of test procedures from Steps 7 through 10 may be used.

Step 10, which involves high level HIRF testing over the complete frequency band, presents a major technical problem because of the difficulty in generating adequate uniform RF fields over the complete volume of the aircraft below 400 MHz. In such a case, use low amplitude RF fields to measure the coupling from the external field onto the aircraft wiring, and then use BCI techniques to inject worst case currents determined from the low level RF tests onto the wiring bundles (Steps 7 through 9).

It is important that the aircraft should be illuminated uniformly over its total volume in the lower part of the frequency band (less than 400 MHz) to ensure that the airframe/wiring resonances are correctly excited. Unfortunately, at these frequencies, it is difficult to generate the worst case field. Above this frequency it becomes easier to generate the required fields as high gain antennas become small enough to be practical.

Above 400 MHz only the last $\lambda/2$ length of the EUT connector and associated wiring along with direct case penetration of the equipment are the dominant coupling paths. Thus localized illumination of the sensitive areas becomes a valid technique although overall illumination is preferable and quicker.

Steps 7 through 9 comprises the following general test philosophy:

a. Assessment of the internal environment using LLDD and LLSC free field illumination. Below 400 MHz the tests assess the induced bulk current on wiring referenced to unit external electric field. Above 400 MHz the internal fields at the location of the equipment being assessed are measured and referenced to unit external field.

b. Extrapolation of this internal environment to the specified external electric field,

c. Comparison of this internal environment to the equipment test or system test environment with on-aircraft (or fully representative rig) system testing using BCI and high level equipment field testing.

6.6.1 (Continued):

The procedures proposed in these steps are split into two: below 400 MHz and above 400 MHz. The procedures below 400 MHz rely on low level field testing to measure the coupling factor, complemented by simulated high level bulk current injection. Above 400 MHz the low level field coupling measurements are complemented by high field equipment testing. The break-point of 400 MHz is not clear cut. The radiated field testing should be conducted below this frequency to provide some overlap with current measurements and to ensure testing at frequencies where equipment case penetration starts becoming significant.

A typical test procedure when using Steps 7 through 9 could be:

a. Modeling and LLDD injection from 10 kHz to 10 MHz - Measure the coupling from the external field to the internal wiring.

b. LLSC free field coupling test from 5 MHz to 18 GHz. Frequency band overlaps (a.) to provide greater confidence in the results from (a.).

c. BCI test from 10 kHz to 400 MHz. Applied to systems installed in the aircraft.

d. Equipment level high field test from greater than 100 MHz to 18 GHz.

A combination of Steps 7 through 9 and 10 can also be used, e.g., substituting Step 8 from 100 MHz or higher to 18 GHz instead of (d.).

6.6.2 Aircraft Low-Level Test Approach (Steps 7 through 9): It is sensible during the aircraft certification procedure to make maximum use of the information provided by the equipment qualification tests, and to assess different aircraft orientations and configurations rapidly.

The BCI test results give two items of information that can be utilized during the certification testing. The first is the signature of the equipment in terms of the level of induced current on the various wire bundles. The second is an indication of the validity of the laboratory qualification test arrangement by providing an impedance plot of the wire bundles. This impedance plot provides a measure of the loop impedance for each wire bundle formed by the wiring, LRU bonding straps, and ground plane. The same measurement can be repeated when the equipment is installed in the aircraft and comparison of the two gives an indication of the validity of the laboratory measured signature. It would show any strong resonances that could have given unrepresentative results during equipment testing.

6.6.2 (Continued):

The LLSF and LLDD techniques are used to measure the transfer function relating the external RF fields to equipment wire bundle currents for frequencies below 400 MHz. Since the transfer function relates wire bundle currents to the external field, then the bulk currents to certify the equipment can be related to the field value used to certify the aircraft. Above 400 MHz, the LLSF test is used to determine the transfer function relating the external field to the internal bay fields at the location of the equipment under evaluation. The scaled internal bay field can be compared with the results of the RS testing of the equipment to determine the certification level of the equipment. RS testing on a system integration rig or equipment bench in a shielded room have technical limitations below 100 MHz, therefore, BCI testing is the preferred method. Above 400 MHz, the uncertainties currently associated with BCI testing makes RS test the preferred method.

The techniques in Steps 7 through 9, if used without significant high field testing, assumes that non-linearity due to scaling and synergism of a complete aircraft test are covered by a margin.

The procedures outlined in Steps 7 to 9 require significantly less expensive facilities than those required for Step 10. The procedures in Steps 7 to 9 can also provide more comprehensive testing of the aircraft by virtue of the more extensive frequency coverage if performed with care with appropriate allowance made for test errors.

6.6.2.1 Test Approach: The approach used in Steps 7 through 9 consists of three parts. The objective of the first part is to determine the hardness of the equipment to a predetermined high level of RF over the complete frequency range. The objective of the second part is to determine the coupling between external electromagnetic fields and wire bundle currents or fields inside the aircraft. The objectives of the third part are to determine the high level wire bundle currents or internal bay fields and then to determine the equipment's susceptibility to these levels.

The three parts involve testing as shown below:

a. The system is tested using the bulk current test method described in Step 5. This test will enable the electrically weak wire bundles to be highlighted and possible failure modes to be determined. During testing the maximum current or current at malfunction for each frequency on each bundle is measured and recorded for later comparison with the results from the whole aircraft tests. This enables equipment testing and hardening to be undertaken during the development phase and before an aircraft is available. The power required by the injection probe to obtain the maximum current is recorded and compared with the limits set by the analysis of the external HIRF environment to the current coupled to selected wire bundles. The loop impedance of the wire bundles is also measured.

   In addition, under Step 5, radiated susceptibility testing covering the frequency band up to 18 GHz is performed on the system.

6.6.2.1 (Continued):

b. The coupling of the external RF field to the aircraft on-board systems is measured. Three test techniques can be used depending on the frequency band being covered:

1. LLDD Injection (from 10 kHz to first airframe resonance). RF current is injected directly into the airframe at various locations. The worst case currents induced onto the wire bundles are determined and related to an external free field by modeling. The reason to use this technique is to give improved measurement sensitivity in this frequency band over LLSC. Instead of measuring coupling at these low frequencies, a worst case assessment can be made where a 20 dB/decade roll off is assumed for frequencies below the point where the first airframe resonance is equal to or greater than $\lambda/10$.

2. LLSC (from 1 MHz or higher to 400 MHz). The aircraft is placed in a uniform low level swept RF field as described in 6.6.2.3 and the bundle currents are measured on the system under test over the required frequency band. The currents measured can be scaled to the full threat field, including safety margins. This testing is conducted for several aircraft orientations and configurations, using both horizontal and vertical field polarizations, to produce worst case current profiles for the various wire bundles being measured.

3. LLSF (from 100 MHz or higher to 18 GHz). The aircraft is placed in a uniform low level swept RF field and the fields inside the equipment bays in the location of the equipment are measured (see 6.6.2.6).

c. Below 400 MHz - The installed system is tested using BCI with the test levels determined from (B). Every bundle is tested by injection and measurement of the induced current on that bundle in accordance with the procedures already described for Step 5. If a bundle branches, each branch is also tested. This test can be conducted on a fully representative systems integration rig. If Step 5 was conducted on a fully representative rig and the test levels used are demonstrated to have been adequate then this step may not be required.

d. Above 100 MHz - The installed equipment and $\lambda/2$ of the associated wire bundles are simultaneously and uniformly illuminated with the predicted internal RF field. This step can be conducted on a fully representative systems integration rig. If Step 5 was conducted on a fully representative rig and the test levels used are demonstrated to have been adequate then this step may not be required.

Test a. could be performed during equipment development. Tests b. and c. could be performed by the aircraft manufacturers, requiring relatively low cost portable facilities.

The low level swept techniques described are complex but only need to be applied to systems performing a critical control function. The techniques give comprehensive coverage of the frequency spectrum. The LLSC, LLDD, and LLSF tests with the BCI test and equipment high field test enable certifications for high HIRF levels. The LLSC, LLDD, and LLSF tests enable fast evaluation of several aircraft configurations.

6.6.2.1 (Continued):

The techniques described offer several advantages:

a. They enable certification to the HIRF environment to be made by a combination of aircraft illumination and bulk current testing/system level high field testing.

b. As very low level swept techniques can be used, a more thorough frequency coverage is possible, compared with only spot frequency testing in the existing high field facilities.

c. They enable the effect of field polarization and illumination angle to be rapidly assessed.

The low level swept techniques enable rapid assessment of the worst case illumination angle and aircraft configuration. Without this technique under-testing may result. In addition the low level swept techniques cause less RF interference to the surrounding area, only requiring sufficient field to enable the induced currents to be measured.

There are of course concerns as to the validity of basing certification on scaled results. Experience to date has shown that over the range used here, scaling is valid.

6.6.2.2 Low Level Direct Drive Skin Injection (Step 7a): This procedure can be used to measure the transfer function at low level between the skin current and individual wiring bundles. The skin current can be set up by direct injection into the aircraft providing the relationship between free field external radiation and skin current is known for all illumination angles and polarizations, either by accurate modeling such as TLM (see Section 4) or by use of the LLSC test. At present the technique is in its infancy and is normally only used below first airframe resonance. However with care it is possible to extend the technique up to about 100 MHz depending on the size of the aircraft. The larger the aircraft the lower the upper frequency. Below first resonance, single point injection techniques can readily be used. This is the procedure outlined below.

A ground plane of wire mesh is laid under the aircraft to increase the aircraft capacitance to ground. The injection points chosen are selected on the basis of the modeling and normally consist of:

a. Nose to tail
b. Wing tip to wing tip

The former simulates side illumination of the aircraft and the latter end illumination.

At each injection point the surface of the aircraft is cleaned to bare metal. The inner core of the coaxial feed cable is connected to the fuselage at these points in turn. The outer shield is connected to the ground plane. Figure 22 shows the test layout for direct injection.

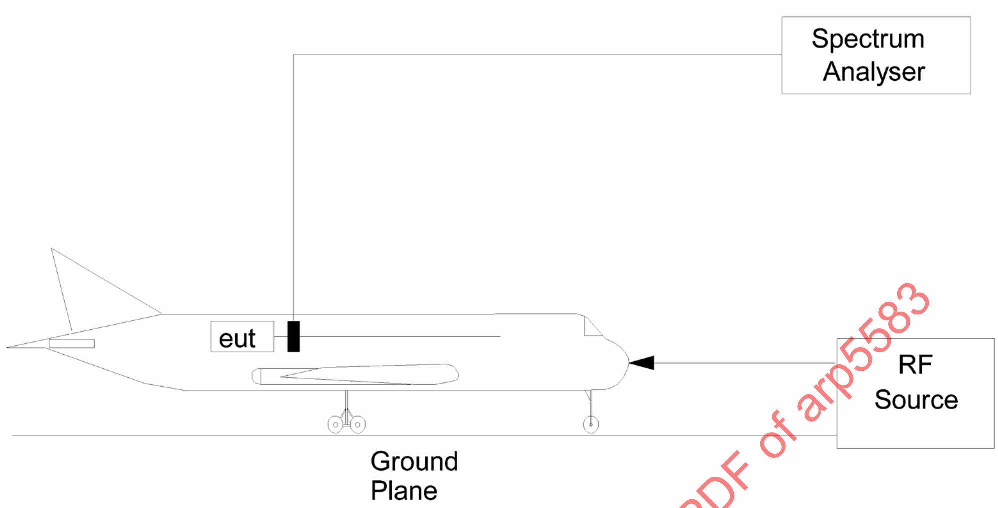

FIGURE 22 - Typical Direct Injection Test Layout

6.6.2.2 (Continued):

Constant drive current is fed to the airframe. The surface skin current is measured at the drive point, center point of the fuselage, and at the center of the wings for comparison with the predictions. The currents induced on the wire bundles of the systems under evaluation at the connectors are measured. Fiber optics are used to connect the current measurement probes to the spectrum analyzer. The measured skin current is compared with the predicted skin current from modeling the aircraft exposed to plane waves, and a scaling factor is calculated. This scaling factor is applied to the measured wire bundle currents to estimate the currents that would be induced on the wire bundles for a given plane wave illumination of the aircraft.

6.6.2.3 LLSC Tests <400 MHz (Step 7b): The test consists of two phases. First, the field generated over the measurement frequency range at the location of the aircraft (prior to its installation) is measured. Then the currents induced in the aircraft wire bundles by the field are determined and normalized to a unit field strength. The aircraft should be illuminated from four separate positions.

The four radiating antennas are placed as far from the intended location of the aircraft as possible so as to provide uniform illumination over the required test area. There will be a trade off between having a high enough signal to produce measurable current flow on the aircraft wiring and yet not so high as to cause interference to other spectrum users. With the system described here, the separation distance of the antennas from the center of the test site should be at least 1.5 times the length of the aircraft. The aim is to produce less than a 3 to 4 dB variation over the length of the aircraft. A measuring antenna is placed at the location of the aircraft prior to its placement (Figure 23).

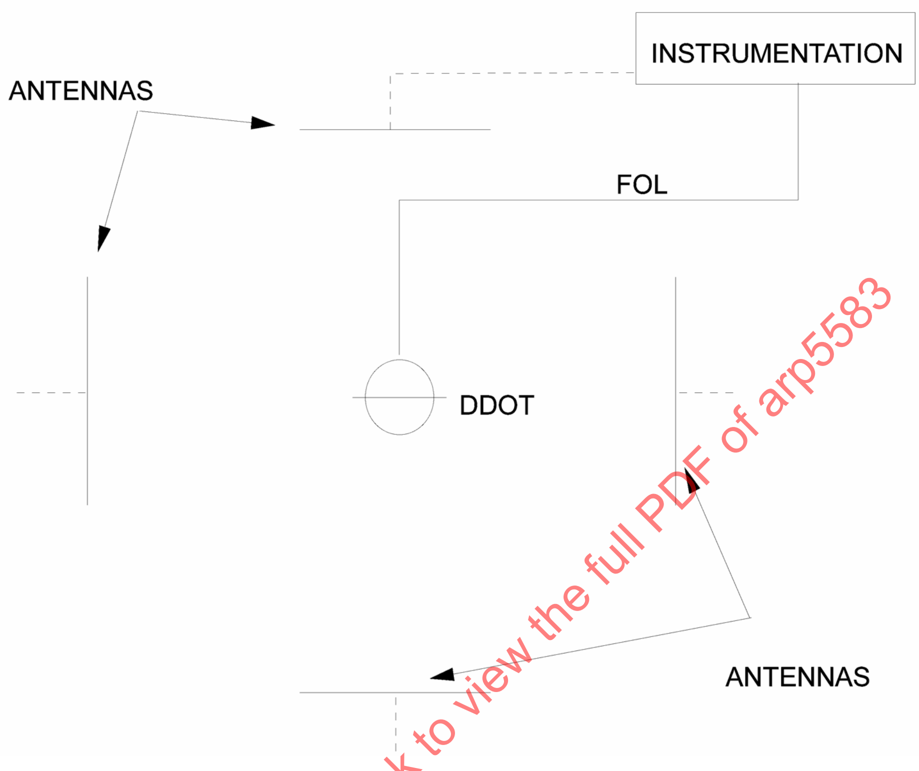

FIGURE 23 - Test Setup for LLSC Calibration

6.6.2.3 (Continued):

The antenna normally used is a D-dot sensor that is effectively a broadband short dipole; a B-dot sensor is also used to measure the magnetic field. The received signal is fed via a 1 GHz bandwidth fiber optic link to the input of a computer controlled spectrum analyzer; the whole measurement is under computer control. The fiber optic link is essential to provide isolation and prevent stray pick-up problems. The head of the fiber optic link is placed as close to the receive antennas as possible to keep the length of interconnecting wire short. This lead is ferrite loaded to prevent spurious resonances.

Antennas that are appropriate for the frequency range transmit the test field.

Antennas that have been used for these measurements are shown in Table 10.

TABLE 10 - Antennas

Frequency Range	Antenna
0.5-25 MHz	Dipole of length 15 m and diameter 3 cm at the center tapered to 1.5 cm at each end for horizontal polarization. For vertical polarization the length is shortened to 7.5 m. A 50:600 ohm balun is used to feed the antenna.
25-200 MHz or 25-400 MHz	Biconical, Log Periodic, or Log Conical antenna Bilog antenna
200-400 MHz	Log periodic antenna.

6.6.2.3 (Continued):

Other antennas can be used but it is important that the field generated is free from deep resonances (Figure 24). It does not need to be flat over the frequency band as the variation will be normalized out by the calibration. The field pattern over the volume of the aircraft should be free from nulls caused by the main lobe from the antenna splitting up.

The antenna should be fed via a broadband balun to maintain polarization fidelity. It is important to maintain balanced drive to the dipole antenna or the antenna feeder will radiate affecting the polarization fidelity of the field. A linearly polarized antenna should be used to measure the field in both the vertical and horizontal polarizations.

The signal to the transmitting antennas is derived from the tracking generator output of the spectrum analyzer and amplified to the required level by means of a linear power amplifier. The power required depends on the coupling to the aircraft wire bundles - the higher the coupling, the less the transmitted power to produce a measurable signal. The output power from the amplifier is measured and recorded via an in-line directional coupler. This information is used to ensure that the same power is used for all the test runs. It is essential that the same power used for calibrating the test volume is used for measuring the induced current. The computer measures the field induced at the test site over the frequency range of the test (with antenna changes as necessary) and stores this calibration data on disk. This data is used to normalize the induced bundle currents to any required reference field strength.

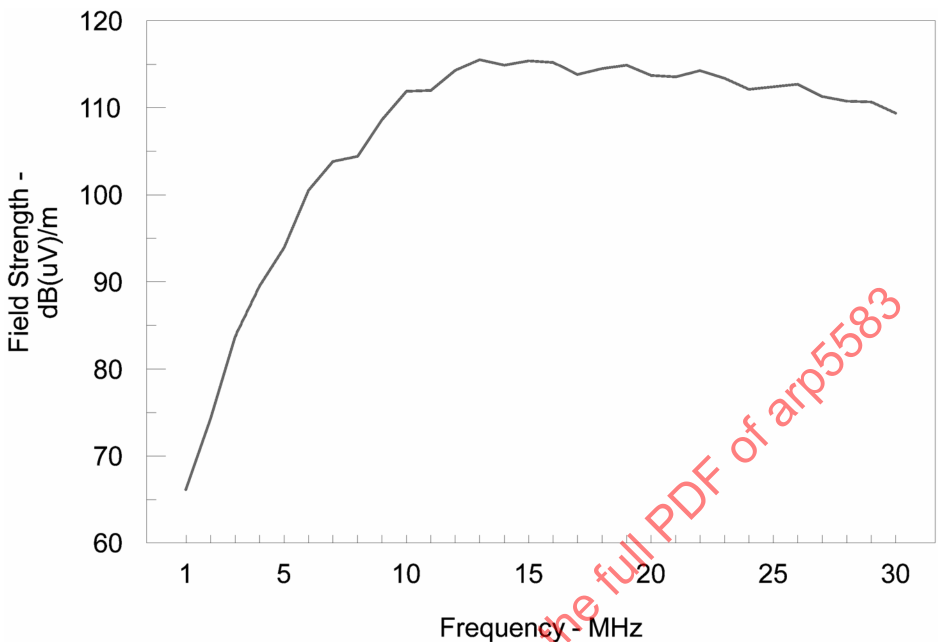

FIGURE 24 - Typical Field Calibration for Horizontally Polarized Fields in the HF Band

6.6.2.3 (Continued):

Reference antennas should also be placed at opposite sides of the test arrangement at locations where reflections from the test aircraft will not affect them. The fields measured by these antennas during calibration are recorded and used to compare with the fields generated during the aircraft test. This acts as a quality check on the transmitting antenna/feeder/amplifier chains.

It is important to minimize interference to other spectrum users. Test planning documents should address licensing requirements to operate a HIRF test system in an open-field test site. Frequency management agencies (e.g. FCC and FAA) impose low limits on radiated levels in certain frequency bands in which HIRF test data are required. Section 6.7.7 discusses how test limitations or frequency exclusions imposed by licensing authorities on open-field tests can be addressed. The fields should therefore be kept to a minimum and the measurement is made by sweeping the band as fast as the spectrum analyzer allows for the required sensitivity with a maximum of five sweeps being made to allow signal averaging for improved sensitivity.

After calibrating the test site, the measuring antenna is replaced by the aircraft and current probes are placed on the wire bundles to be monitored (Figure 25 and Figure 26).

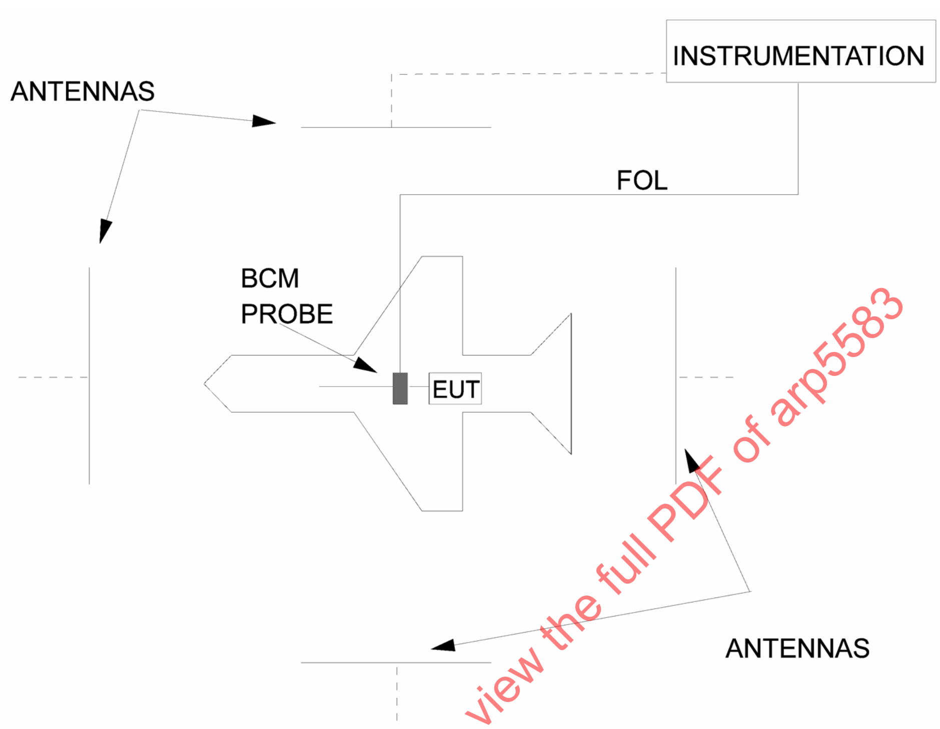

FIGURE 25 - LLSC Test Arrangement

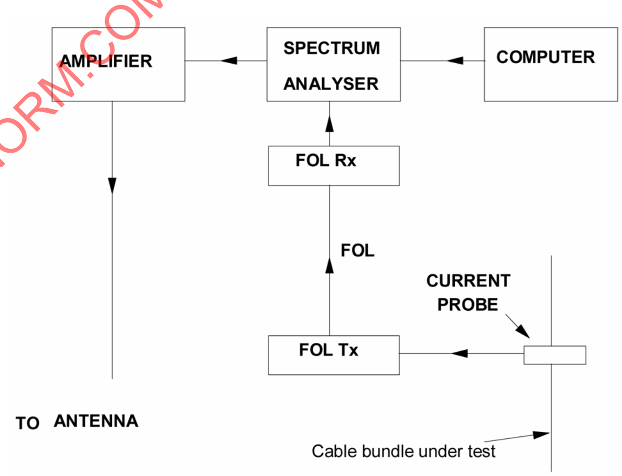

FIGURE 26 - Detailed LLSC Test Configuration

6.6.2.3 (Continued):

Multiple fiber optic links are used to connect the current probes to the spectrum analyzer and the software sequentially measures the currents induced onto the bundles. The fiber optic link connection to the aircraft is essential in order to preserve the aircraft shielding and to provide isolation.

To maintain isolation the aircraft is usually tested while unpowered. The connection of ground power and hydraulics to the aircraft produces an undesired aircraft configuration due to the coupling of the field into these systems and hence to the aircraft. It could be argued that the system should be powered for these measurements to give the normal impedances at each end of the line. However, if the bundle under test is a multi-wire type, this effect is not as significant as having extraneous wires connected to the aircraft. If the bundle under test is of only 1 or 2 wires going, say, to a relay, then being un-powered could produce significant errors. The optimum is to use aircraft engine power but this is expensive and hazardous and hence is only performed as a confirmatory test.

With the probes in place the currents induced on the wire bundles by the low level swept field are measured and normalized to the desired field strength using the calibration figures stored previously. The results can be plotted or stored for later evaluation.

Because of the inherent noise floor of the fiber optic link, miniature pre-amplifiers may be required to improve sensitivity below 5 MHz. These pre-amplifiers are positioned between the current probes and the fiber optic link transmitter.

The test is repeated for four orientations of the aircraft (nose, tail, left and right side) and for other aircraft configurations if applicable, to obtain a worst case value of induced current. The time required for each run over the complete frequency range is of the order of 2.5 to 5 minutes per bundle.

Although the horizontally polarized field usually produces the highest currents this is not always true. Generally, below 20 MHz, horizontally polarized fields produce the highest currents in fixed wing aircraft. Above this frequency either polarization can produce the highest currents. The break frequency depends on aircraft size and geometry. It is therefore important to test both polarizations.

Predictions can be made using various modeling tools to enable the effect of the ground on the measured induced currents to be calculated and calibrated out. This enables a closer prediction of the in-flight induced currents to be made.

The results for the various orientations and configurations are superimposed (see Figure 27) to enable a worst case current profile to be produced for each bundle for comparison with the BCI results.

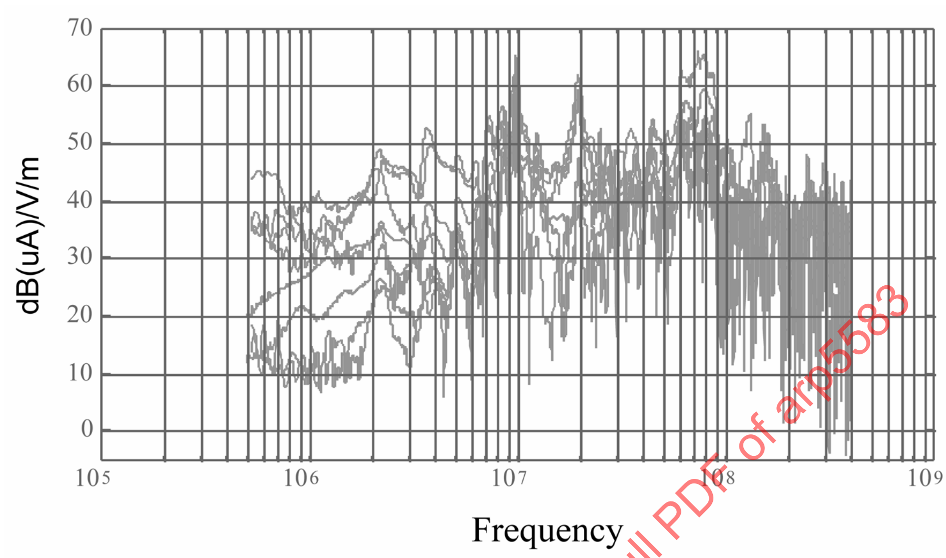

FIGURE 27 - Overlay of Typical LLSC Results

6.6.2.3 (Continued):

The whole test should be computer controlled to provide rapid testing , data reduction and evaluation of test results. The computer program should automate the process of the measurement of power to the transmitter antenna, the resultant fields and the induced current to the EUT wire bundles. In addition, the program should include the storage, and interpolation of correction factors for the various sensors used. The results of the measurement should be available on hard copy in both graphical and tabular format as well as in digital format for further numerical analysis and automated document preparation

Currents induced by high level illumination have been compared with those determined by extrapolation from low level illumination to determine whether the extrapolation was valid. In all cases, for multi-wire bundles this extrapolation has been found to be accurate. The range of this scaling test was 1000:1.

6.6.2.4 Test Level Assessment (Step 8): The worst case induced current profiles from Step 7 are compared with the BCI signatures from Step 5 or Step 9 (Figure 28 shows a typical result). Where the test limits for Step 5 were initially derived from analysis or generic transfer function curves, this worst case current profile is compared with the test limits used to assess their adequacy. When comparing with the BCI test results the comparison is made for discrete frequency bands, for example:

10 kHz - 0.5 MHz
0.5 MHz - 30 MHz
30 MHz - 100 MHz
100 MHz - 200 MHz
200 MHz - 400 MHz

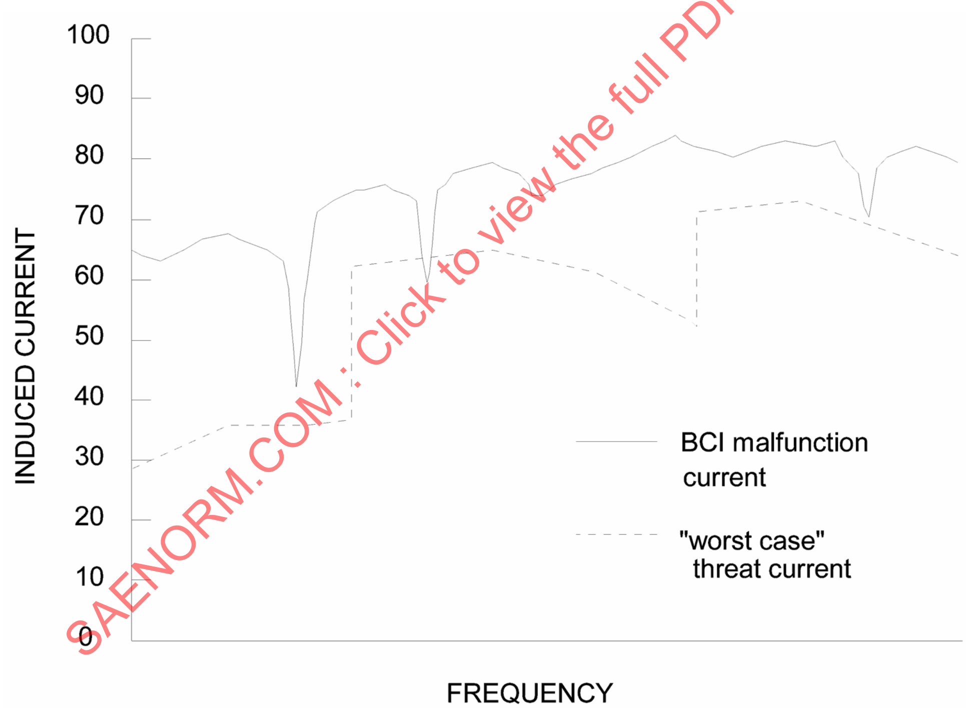

FIGURE 28 - Comparison of LLSC Worst Case Envelope with BCI Test Results

6.6.2.4 (Continued):

The comparison is done in coarse bands to allow for differences in wiring lengths and installation between equipment level test and aircraft level test. The choice of bands is dependent on the primary resonances in the airframe/wiring. For aircraft, the main aircraft dependent resonances are usually where the airframe dimensions are multiples of $\lambda/4$. The bands covering these resonances should be selected such that the resonance falls in the center of the appropriate band. It is important that major coupling resonances or resonances in the results depicting equipment weakness should fall in the center of the appropriate bands.

If the difference between the predicted-environment-induced worst case current and the BCI current signature for the equipment is greater than the margin allowed for measurement error, further testing may not be required. Further testing can be avoided, however, only if the BCI tests fulfilled the requirements of Step 5 described in 6.4. If, however, the difference between the two plots is less than this, or the requirements of Step 5 were not met, BCI is required on the installed system (Step 9).

The loop impedance measurement made in the equipment BCI test can be repeated on the aircraft to help in determining how representative the laboratory test was. If there is a significant difference then the BCI test is again required on the installed system.

6.6.2.5 Problem Areas: In any installation there will be wire bundles where the results from the LLSC test may be misleading.

If a wire bundle is only partly shielded along its length and if the LLSC measurements are made on the outside of the shield, a true indication of the RF affecting the equipment will not be made. The RF currents induced on the unshielded portion will not be measured, but will affect the equipment.

An example of this type of installation is often to be found on engine electronics where the wiring runs in a shield from the engine pod to the wing or airframe and then is unshielded for the rest of its run. As the LLSC measurement has to be made at the engine electronics, a breakout box may have to be used to enable the currents induced on the wires under the shield to be determined.

In these circumstances care will also have to be taken with the BCI tests when conducted on the aircraft or rig and a breakout box will have to be used.

A similar problem exists with wire shields bonded at multiple points to the airframe along their length. A BCI test conducted on one segment may give misleading answers. Simultaneous injection using multiple injection probes may be used on all the segments. Or, the LLSC and the BCI test may be conducted directly on the wires underneath the shield by using a breakout box, or for the BCI test, by removing that segment of the shield where the BCI is to be conducted.

6.6.2.6 LLSF Tests from 100 MHz or Higher: The test procedure is similar to that outlined in 6.7.2.3 but with the internal bay fields being measured instead of wire currents. At these higher frequencies it is not necessary to illuminate the total aircraft. However, it is important to ensure that all leakage points into the bay where the equipment is installed are illuminated with the field. The radiating antenna has to be far enough away to ensure that all these leakage points are included in the antenna beam width. The radiating antenna has to be far enough away to ensure that all these leakage points are covered. In addition a variety of incident angles should be used to ensure that the worst case is measured. Leakage around a bay door may be greater for a glancing illumination angle than normal to the bay door.

The field from the transmitting antenna is measured at the required distance without the aircraft present and the power to the antenna recorded. The antennas for this test should be capable of providing a uniform field over the required illumination area. Linearly polarized broadband horn antennas can be used but both polarizations need to be measured.

After completing the reference (open field) measurements, the aircraft is place inside the test volume; the same power is fed to the radiating antenna(s); and the fields inside the equipment bays (cavities) are measured. The airframe attenuation is defined as the ratio of the reference measurement to the field measurement made inside the aircraft cavity.

It is essential that the maximum field within the equipment bay be measured. Since most airframe cavities are electrically large over the majority of the frequency range for this test, a single measurement is statistically insignificant since the resulting answer would indicate a peak, null, or most likely, a value in between. The maximum field should be determined statistically by thoroughly mapping the test volume, or by mechanically or electronically mixing the modes within the cavity.

Placing an electrically large metallic paddle or stirrer inside the equipment bay along with the stationary field sensor accomplishes mechanical mode mixing. The boundary conditions of the cavity are changed as the paddle rotates through one revolution at each test frequency, resulting in the field sensor measuring the maximum field value at some point during the paddle revolution. Mode stirring is only valid at frequencies where the cavity is large enough to be considered multimoded.

Alternatively, the cavity mode structure may also be excited electronically by modulating the carrier frequency with band limited, white Gaussian noise (BLWGN). This test technique provides for real time field homogeneity by using a frequency agile transmitter to vary the test frequency over a narrow bandwidth (e.g., 10 to 50 MHz) about the center test frequency. The eigenmodes within the noise bandwidth are stimulated simultaneously and randomly by power at the same magnitude across the agility bandwidth. The agility bandwidth should be sufficiently wide to excite a large number of modes yet narrow enough to measure high-Q airframe resonances. If a wide-band receiver is used for electronic mode stirring, care should be taken to ensure that results are not affected by unwanted signals from nearby transmitters.

6.6.2.6 (Continued):

The advantage of this technique is that it reduces the test field requirement from that needed for illuminating the outside of the aircraft as it takes into account the shielding provided by the airframe. It is used in conjunction with high field equipment illumination testing (Step 9, 6.7.3). The lowest frequency of the test is dependent on the size of the equipment being evaluated. As a minimum it should be 400 MHz. The lowest frequency depends on when the size of the equipment case becomes significant relative to a wavelength such that it can no longer be predicted that coupling of RF through the wires is the dominant mechanism for susceptibility to RF.

Figures 29 and 30 are examples of illumination angles that can be used for this test. When irradiating the cockpit area, the height of the transmit antenna should be equal to the height above ground of the horizontal center line of the fuselage.

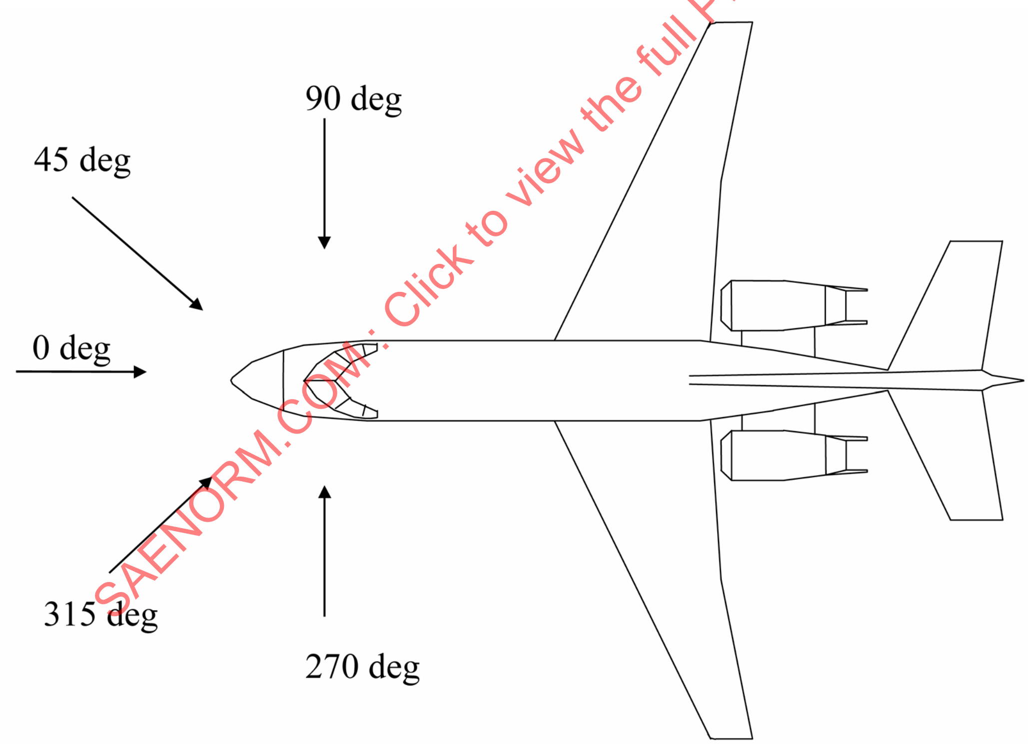

FIGURE 29 - Measurement Positions for Cockpit Area

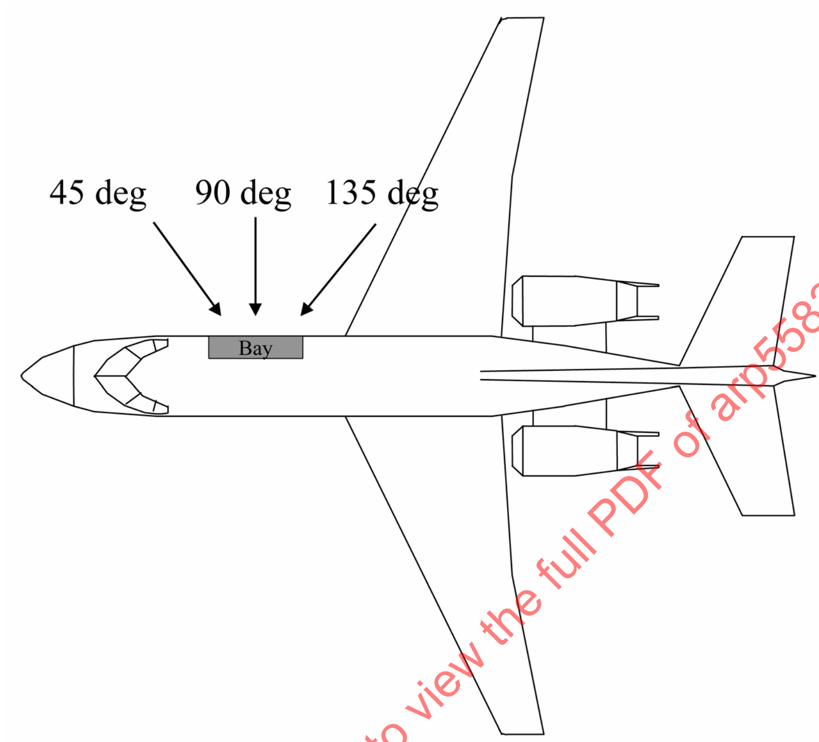

FIGURE 30 - Electronics Bay Measurement Positions

6.6.3 High Level Equipment/System Testing (Step 9):

6.6.3.1 Direct Bulk Current Injection - Aircraft or Full System Level (Step 9b): Bulk current injection is applied to systems installed on the aircraft or on a fully representative "iron bird" rig when following Step 7 through 9 where:

a. BCI testing in Step 5 was not performed on a fully representative rig or the loop impedance was not measured.

b. The loop impedance when measured on the aircraft differed significantly (>6 dB) from that measured in Step 5.

c. The BCI test levels used in Step 5 were shown to be too low when compared to the aircraft measured induced currents.

d. Assessment in Step 8 indicates potential vulnerability.

6.6.3.1 (Continued):

The installed system is tested using BCI with the test levels determined from the LLSC measurements. The procedures used should be based on those described in Step 5 for rig testing, but require modification for on-aircraft testing as described below. Every bundle in the system is tested by injection and measurement of the induced current on that bundle. If a bundle branches, each branch is also tested. The problem area of short grounding wires is equally applicable for testing on the aircraft. Section 6.6.3.9 should be reviewed.

Shielded wires whose shields are bonded at multiple locations or where the shields are discontinuous along their length may have to use break out boxes. This will allow the currents induced on the inner cores to be measured for comparison with the LLSC tests.

During the BCI testing, the systems should be fully operational and the aircraft placed in various simulated operating phases, to ensure systems are operating at their maximum sensitivity.

It is possible to apply the test to a full system rig providing it is fully representative of the aircraft installation as regards wiring lengths/composition and equipment fit and mounting. In addition the rig should be capable of operating in all the simulated flight modes to ensure systems are tested at their maximum sensitivity as for the aircraft test. Successful rig testing has been applied in the past to rigs driving flight simulators that enable the effect of malfunctions to be assessed by a pilot.

The test is similar to the equipment level BCI test but smaller specialized injection probes may be required in confined areas. Since the worst case currents are known for the bundles to be tested, the calibration procedure is not required; the test limits will be related to injecting these worst case currents. Figure 31 shows the layout for the equipment level test that is still valid in this case.

One shortcoming of this technique is that the BCI test in (A) and (C) of 6.6.2.1 until recently has been applied to wire bundles individually, which was not the same condition as when the whole aircraft is illuminated. If required, it is feasible to inject on several bundles at once. If during aircraft illumination the currents at the various connectors on an LRU are measured, it is possible, if required, under computer control, to inject the same ratio on each bundle simultaneously using multiple injection and monitoring probes. It is probably easier to do this on a full system rig than on the aircraft since accessibility is much better. Multiple injection is essential for systems having a built in redundancy capability. For example single bundle injection tests on a full authority fly-by-wire aircraft showed that the faulty channel was voted out allowing the system to continue normal operation - in an external field all the channels could be affected simultaneously.

Figure 32 shows the test layout of the multi-bundle injection techniques that have been developed and used successfully on aircraft.

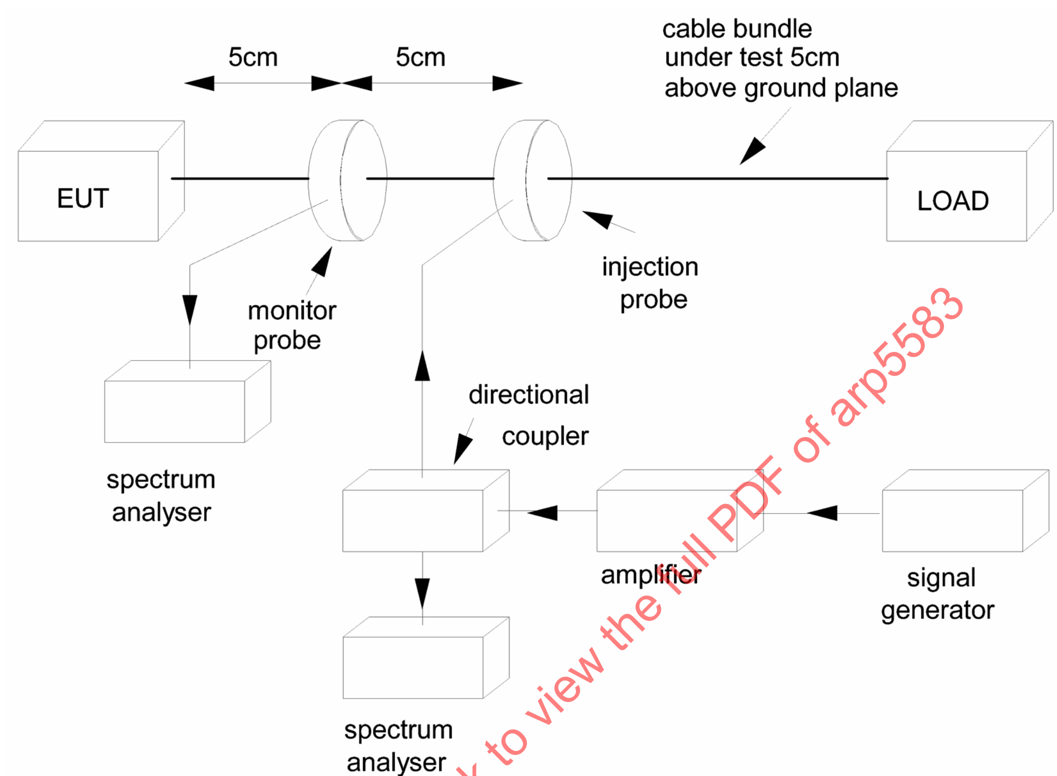

FIGURE 31 - Equipment Level Test Layout

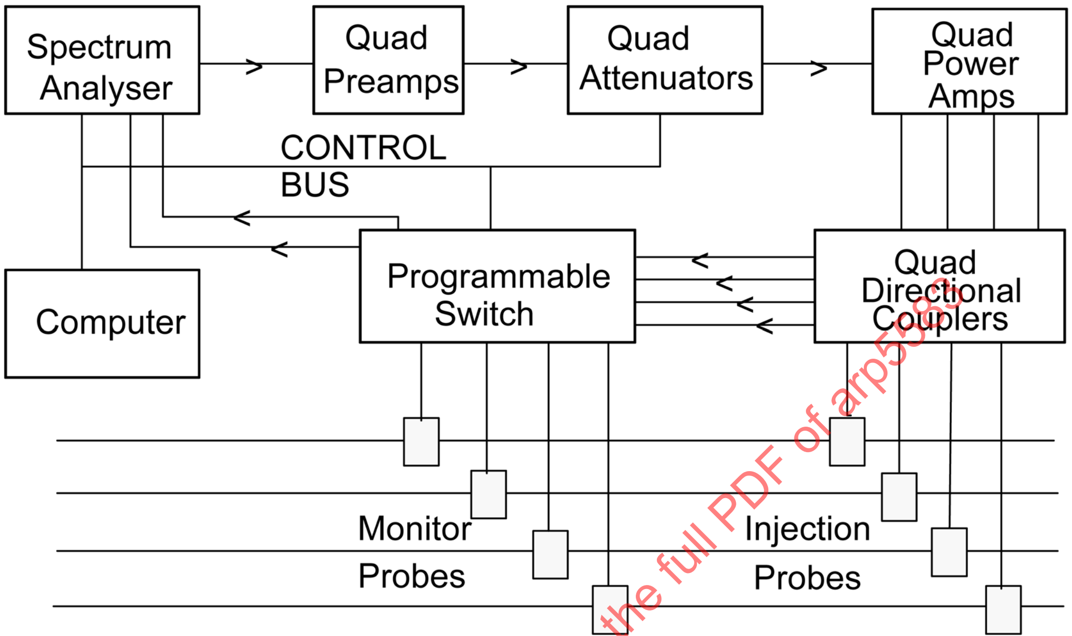

FIGURE 32 - Test Setup for Multiple Bundle BCI

6.6.3.1 (Continued):

The current injection technique is very efficient in terms of power required to give the desired injection current. Typically between 5 and 50 watts (depending on the bundle location) are required to produce the currents that would be induced in an external field of 200 V/m in the HF band. By comparison, the existing high field generation facilities would require several hundred kilowatts of power into an antenna to generate the same field intensity uniformly over the aircraft. Since BCI couples the electromagnetic energy where it is required there is no interference to airfield or other equipment. Also the cost of the equipment is much less than that required to produce the equivalent high power fields.

For aircraft injection tests, special small clip-on injection probes have been developed.

In conducting the tests, the applied RF may be modulated with the default representative modulations as defined in 6.5.

6.6.3.2 BCI Test Limitations: During the BCI tests, the current divisions on the wire bundle wires are not necessarily the same as those produced by the external field, since the method of producing the wire currents is not the same in the bench test as for the whole aircraft illumination. There is no unique external field configuration and the possible ratio of currents induced in the bundles by the action of an external field is probably infinite. It is expected that this procedure will cover the worst case situation with adequate safety margins, since it involves injection on defined bundles and branches over the complete frequency range to limits derived from a worst case coupling profile for four illumination angles and two polarizations.

6.6.3.3 Equipment/System High Field Test (Step 9c): Field Testing is applied to systems installed on the aircraft or fully representative systems integration rig, when following Steps 7 through 9 where any of the following conditions apply:

a. Field testing in Step 5 was not conducted on a representative rig.

b. The test levels used in Step 5 were shown to be too low when compared to the aircraft measured internal fields.

c. Assessment indicates potential vulnerability.

The equipment under evaluation is illuminated at the peak field strength levels measured at the aircraft location of the equipment. Figure 33 shows a typical test arrangement, with the illumination being applied to an equipment bay with the bay door open. The lower frequency of this test should overlap the rig/aircraft BCI test described above for enhanced confidence.

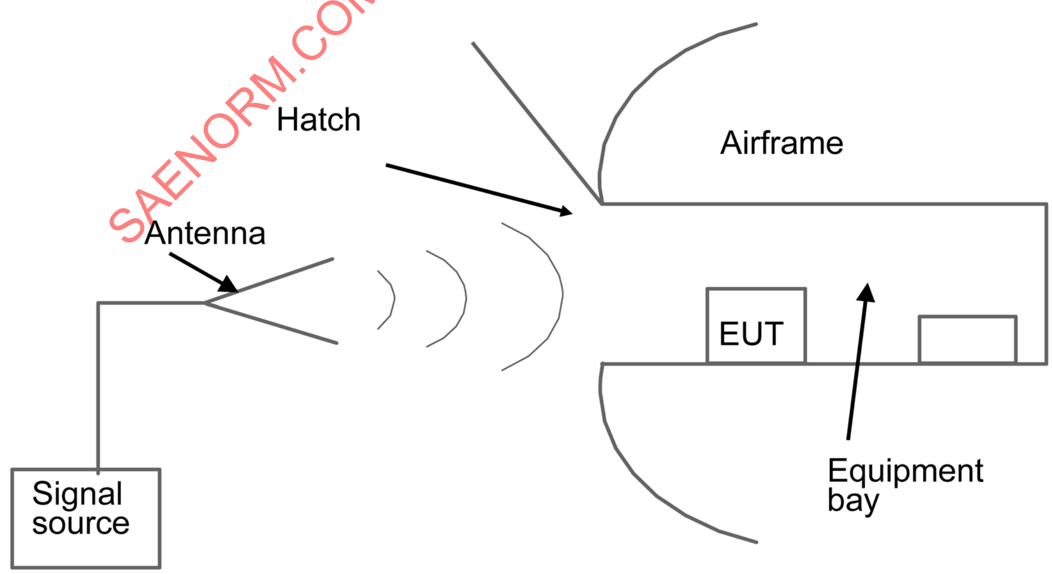

FIGURE 33 - Typical On-Aircraft Radiated Susceptibility Test Setup

6.6.3.3 (Continued):

The field is monitored by means of a small isotropic sensor placed near the location of the EUT.

The test can also be applied to a representative system rig or iron bird providing the installation is representative. If the required field strengths are too high to be generated by the available facilities and it can be shown conclusively that the primary coupling route for the RF is through the equipment case and not via the wiring, then the following procedures can be adopted:

a. The protection afforded by the equipment case is determined by measuring the ratio of external to internal fields using an empty equipment case.

b. The equipment minus the case covers is illuminated in the laboratory at a field strength equivalent to the calculated internal HIRF determined by reducing the level of the equipment threat by the degree of protection determined in (i).

This approach is likely to be valid only at frequencies above 1 GHz and should be used with caution.

Where RF coupling is via the wiring and the case, the equipment wiring HIRF protection should be degraded to the same level accomplished by removing the case covers. The test should now simultaneously and uniformly illuminate the total volume of the equipment and a minimum of $\lambda/2$ of the associated wire bundle.

In conducting the tests, the applied RF should be modulated with representative modulations as defined in 6.5.

6.6.4 Aircraft High Level Tests (Step 10): The Aircraft High Level Testing relies on the exposure of the aircraft to an externally radiated RF test environment. The test environment is selected to represent the applicable HIRF environment for the Level A Control (or optionally the Level A Display and Level B and C) systems to be certified. The results of the aircraft high level field tests are then analyzed to determine whether the aircraft systems are compatible with the HIRF environment.

The methodology for the aircraft high level field testing involves the following steps:

a. Develop a unique test environment tailored to the aircraft, test facility, and HIRF environment

b. Select the antenna position that optimizes coupling of the environments to the Level A systems equipment.

c. Calibrate (measure) the high level test environment without the aircraft present.

d. Illuminate the aircraft with the high level test environment and evaluate systems functions under test for susceptibilities

e. Perform a HIRF vulnerability analysis to determine impact of the detected susceptibilities.

6.6.4 (Continued):

Step 10 relies on the test facility having the capability of generating fields of adequate level and adequate uniformity to simulate the severe or certification HIRF environments.

If desired the Level A system may have the induced currents and the internal equipment bay field measured during illumination with the high level HIRF environments. These levels can be compared with the equipment test, and System Rig tests for additional confidence. Also, the coupling data could be used in the future for certification similarity. The on aircraft induced current measurements and equipment bay field measurements can be adapted from the technical discussion for Step 7. They are not discussed in this section.

The details on the Aircraft High Level Test methodology are described in the following sections.

6.6.4.1 HIRF Test Environment: The development of the test HIRF environment should include the following:

a. Emitter Characteristics (frequency, modulation, antenna gain, polarization, etc.)

b. Laboratory Signal Sources (transmitter power, frequency, modulation)

c. Timing of the radiated test signal with test of the system so that RF is present when the system is being tested. Compensate for rotating antennas, varying pulse widths, and pulse repetition frequencies (PRF), for example.

d. Available test time

e. Cost of conducting the test on a per test frequency basis factored by the time it takes to conduct the test for all the test frequencies

f. Avionics equipment characteristics should be reviewed to incorporate parameters such as clock rates and synchro frequencies.

g. If personnel must be present during radiation testing, then the parameters need to be adjusted to avoid excessive RF exposure. The appropriate national RF safety standard should be consulted for definition of safe levels of exposure.

h. The test site must be considered. Outdoor facilities are authorized to transmit on limited frequencies. Also ramp space may preclude use of large antennas to radiate low frequencies.

i. Since peak and average field strengths were derived independently from the emitter characteristics, it may be necessary to test two separate test emitters, one for the peak field strength and a second for the average field strength.

6.6.4.1 (Continued):

j. The frequency coverage should be sufficient to ensure that all resonant effects are adequately measured. This is especially important in the 0.5 to 100 MHz band where high Qs in the coupling signature have been observed. Above 400 MHz, the high peak levels may be tested using spot frequencies. The test frequencies used to simulate the peak levels above 400 MHz should be selected to sufficiently cover the HIRF frequency bands and test the coupling through all apertures and shield discontinuities in the airframe shield for the area being illuminated and the function under test. A minimum of 3 test frequencies per band distributed across the band should be used. For the average, levels should be swept across the band or at least 100 frequencies per decade, equally spaced on a log scale should be used.

k. Consideration should be given to the overall system response times to ensure that the modulation frequency is below the cut-off for the loop under evaluation.

l. A margin may be desired to allow for such factors as measurement error, and spread over the fleet. The test HIRF level used to illuminate the aircraft will be increased by that margin resulting in a HIRF test environment higher than the applicable HIRF environment.

However, if a rotating radar is used for the source, (typically radars are 6 to 10 revolutions per minute, with illumination times of 1 second) then the 1 Hz modulation at microwave frequencies is not appropriate.

Optimizing the above areas results in a HIRF test environment that should be satisfactory for the test. However, in some cases other adjustments may be required in order to correlate the test emitter to the operational emitter. For example, a magnetron source can match frequency and PRF but cannot adapt to various pulse widths. Also the antenna revolution rate can be increased to 60 RPM verses 6 RPM in order to observe EMI quickly rather than every ten seconds.

6.6.4.2 Antenna Positioning: The placement of the antenna is the second most important aspect of the test. Below 400 MHz overall uniform illumination of the aircraft is essential to properly excite airframe/wiring resonances. The aircraft is illuminated on all four sides sequentially. Above this frequency, more localized illumination is allowed providing the total bay area where the equipment is housed is illuminated to ensure all leakage routes into the area are included in the test. In this circumstance, when positioning antennas, the following items should be considered to identify those areas where radiation will affect the system under test.

a. The point of entry where, if the aircraft were flying, RF could penetrate the aircraft surfaces and cause EMI with aircraft systems. The most likely areas are windows, access panels, air vents, and flexible environmental seals.

6.6.4.2 (Continued):

b. The anticipated coupling modes to the system under test are a function of the frequency. At low frequencies the RF couples to the aircraft skin and then to the wiring and ultimately to the equipment interface. At high frequencies the RF couples directly to the equipment interface. Therefore, antenna positioning at low frequencies concentrates on aircraft structure excitation and high frequency antenna positions concentrate on illumination of the equipment.

c. The location of the aircraft avionic systems to be tested needs to be evaluated. Some systems are single boxes and other systems have multiple units that are split up all over the aircraft from the cockpit to the wings to the engine compartments. The ability and need to radiate each box is considered. Also, if the test involves engine operation or rotor blades turning, then the antenna needs to be placed to avoid the engine blast and moving surfaces.

d. The anticipated aspect angle at which a high power emitter might illuminate the aircraft during the flight envelope should be considered. Ground-based emitters might not ever be able to directly radiate the top of an aircraft. Emitters that are used for precision approach only radiate the front of the aircraft. The airborne emitters can radiate all over the aircraft.

e. The emitter field polarization can also help guide antenna placement. The typical HF field is horizontal while the typical radar field is vertical. However, the best practice is to radiate both horizontal and vertical polarization. For frequencies above 400 MHz circular polarization may be used. Occasionally a 45 degree orientation of a linear antenna can be used, but there is a 3 dB reduction of the field to the normal polarizations.

f. When radiated into enclosed areas, the RF field may result in fields, which might be hazardous to test personnel. Therefore, proper steps should be taken to ensure personnel safety.

g. The available test time and funding may dictate the number of antenna positions that can be practically accomplished. The factoring of antenna positions, test frequencies, and systems under test determines the extensiveness and thoroughness of the test. An extensive and thorough test takes a long time and is expensive.

h. The test facility may be space-limited in the ability to site antennas all around the aircraft. The large antenna and large aircraft require compromising placement of the antenna and movement of the aircraft to radiate all desired areas.

i. RF reflectors may be used to illuminate inaccessible areas such as the top or bottom of the aircraft.

6.6.4.2 (Continued):

j. For frequencies below 400 MHz, uniform illumination of the aircraft would be ideal. This should be the priority where the airframe and wire resonances dominate. Above 400 MHz spot illumination is practical. The priority in the upper range is to ensure all leakage points into the bay housing the equipment performing function under test are uniformly illuminated. The various portions of the aircraft are then illuminated by sequential antenna positions over the length of the aircraft. In either case care should be taken not to pick an antenna positions that will expose the aircraft extremities to field greater than the test level. This could happen to a wing mounted engine system and trying to use a side position off the wing tip to illuminate the fuselage with the desired field.

k. The separation distance from the aircraft should be equal to or greater than the far field boundary of the transmitting antenna (see DO-160/ED-14 Section 20.3.b(3)). As the separation distance is increased to allow the antenna beamwidth to illuminate the test area there will be a decrease in the field which will have to be compensated by an increase in transmitter output (this may or may not be possible for the sites equipment).

The minimum antenna positions to consider for frequency below 400 MHz are four quadrants around the aircraft. Shown in Figure 34 shows possible positions for a fixed wing aircraft and a rotorcraft for test frequencies below 400 MHz.

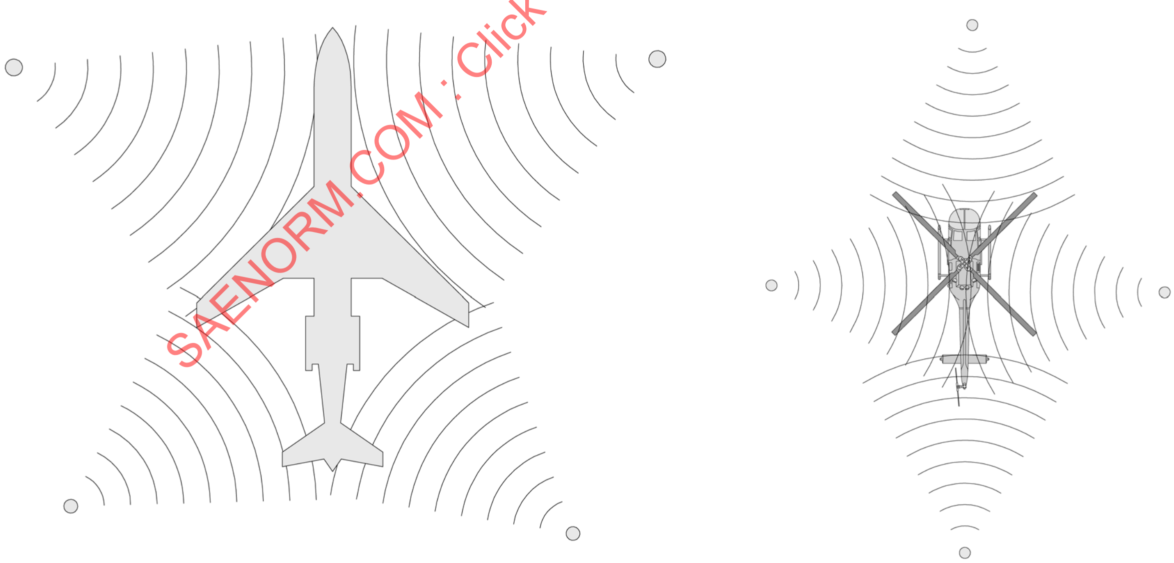

FIGURE 34 - Fixed Wing Aircraft and Rotorcraft Antenna Positions <400 MHz

The minimum antenna positions for frequencies above 400 MHz are the four quadrants and the tail, cockpit, nose and engines. Figure 35 shows possible positions for frequencies above 400 MHz for a fixed wing aircraft and a rotorcraft.

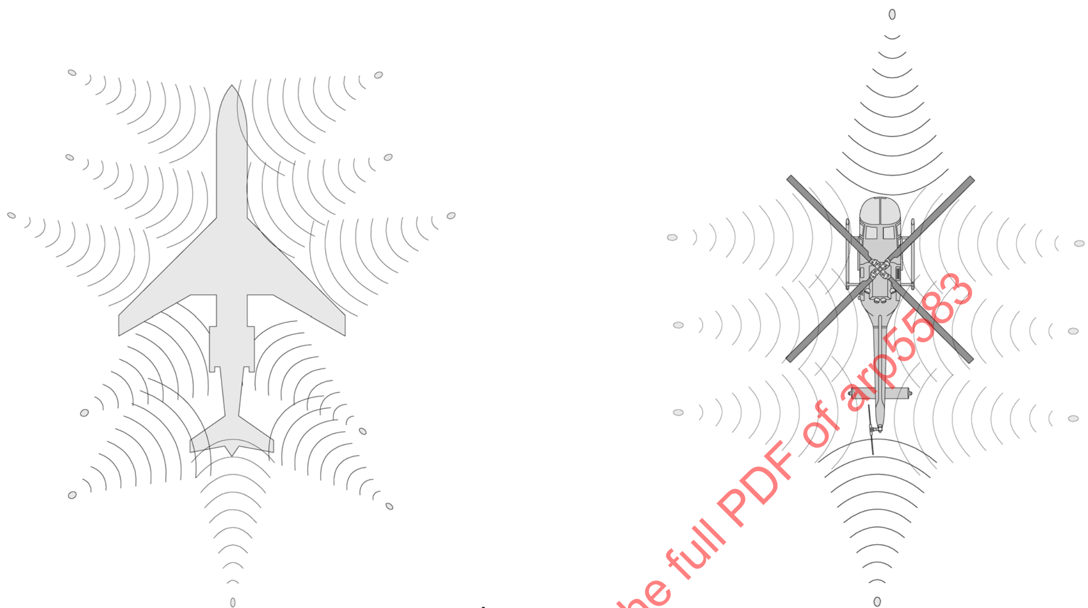

FIGURE 35 - Fixed Wing Aircraft and Rotorcraft Antenna Positions >400 MHz

6.6.4.3 Test Procedure: The test procedure for conducting a radiated test involves three phases: field calibration, aircraft illumination, and susceptibility threshold measurements. The following discussion will detail each of these phases. The approaches to operating the aircraft systems during the test are covered in 7.10.5.4.5.

6.6.4.4 Field Calibration: The field calibration is done without the aircraft present. This is necessary because it is impossible to have the aircraft located in the same physical location as the measurement probe, and the aircraft structure adds multipath signals that preclude repeatable field measurements.

For large antennas the field is calibrated at a point relative to where the aircraft will eventually be parked. The transmitter is keyed with no modulation and the field is measured with a field probe. The probes typically used are monopole whips or dipoles connected to a spectrum analyzer or a three-axis probe connected to a microprocessor augmented DC meter.

Where modulated signals are used both peak and average field strengths will need to be determined.

The data recorded for the test in all cases are the transmitter settings required to produce the desired field at a measured distance from the antenna.

6.6.4.5 Aircraft Illumination: The aircraft is placed in the test area and the radiating antennas are located at the antenna positions (Figures 33 or 34). In many cases only one antenna can be set up, while the other antennas stay clear of the illumination area.

Then before radiating, the test procedures for each system are performed by the aircraft operator to establish normal indications. This is the base line used for comparison during illumination with the RF. The baseline need only be done once during a test. However, changes in weather and equipment repair may necessitate reruns of the test procedure to establish a baseline for the change of conditions. The next step is to transmit at a level 12 dB, for example, below the maximum test level for the frequency. For this phase of the test, the field will be created by the basic transmitter modulation of pulse width and pulse repetition frequency and antenna simulation as described by the test plan. With the aircraft now being radiated with RF from the transmitter's antenna, the test procedure is again executed and any anomalies differing from the baseline are recorded. The field is increased in 3 or 6 dB steps until the full field is reached. At each increase in field strength, the test procedure is executed and any anomalies are recorded. When there is reason to believe that system damage would occur at the next higher level, then power increases should be avoided.

The test should be done first using external ground power, filtered at the aircraft. This will allow maximum flexibility in conducting the test without incurring the difficulties of engine operation. Systems that show problems during the ground power test, along with systems that only operate with engine power are tested during a second test phase with internal power. The internal power can be provided by an on-board auxiliary power unit or from the main engines. At the present time, no practical means is available to conduct an airborne version of the radiated test.

6.6.4.6 Susceptibility Threshold Measurements: After the system is exposed to the full field, anomalies that are related and are susceptibilities to the HIRF test environment can be identified. At this point, the field can be lowered in 1 to 3 dB steps to locate a field level where the anomalies do not occur, and a small increase in field level makes the anomalies reoccur. Check for hysteresis of the susceptibilities by decreasing and then increasing the field level through the susceptibility threshold. The lesser of the two will be the susceptibility threshold. For additional information, the antenna scan simulation may be removed simulating continuous main beam illumination. The susceptibility threshold for this emission should be recorded also. Other modulation parameters can be varied to characterize the susceptibility. This includes switching to CW, or changing PW, PRF, modulation level, modulation frequency, and antenna scan simulation.

In conjunction with susceptibility threshold measurements it may be desirable to determine the points of entry. Although it is tempting to investigate at the first signs of a problem, it is wiser to wait and complete all of the HIRF tests levels and all of the systems tests. The result will be a complete picture of the HIRF test levels that cause the problems and changes in susceptibility levels. This information is vital to deciding whether to tape up a door seal, cover a wire bundle with foil, improve bonding, or install extra filtering. Since the iterations of test, analysis, and fix associated with point-of-entry investigations can also be very time consuming, completion of the test may be in jeopardy if it is not made the first priority. The only time point of entry investigations take priority is when an event occurs such that no further testing can be accomplished without correction of the problem.

6.6.4.7 Data Logging During Test: A test matrix should be established listing the key HIRF test parameters (frequencies, antenna positions, polarization, etc.) versus the aircraft states, systems, and modes. The HIRF tests should start at the low frequency end and finish at 18 GHz. As the test progresses the matrix can be filled in to track the HIRF susceptibilities and systems evaluated. Any anomalies noted during the test procedure should be logged on separate data sheets where full details on the HIRF susceptibility, system, and description of the problem can be recorded with no restraint on information.

6.6.5 Aircraft Operating Modes During Test: The aircraft operating modes during test are common to both the Steps 4 to 9 and Step 10 test methods. The test procedures should simulate airborne operation and provide a means to quantitatively or qualitatively evaluate system performance. The use of self test, built-in-test (BIT), or on-board-check (OBC) are good ways to evaluate performance. The simulation of airborne operation can become very complicated when unhardened ground support equipment is used. Therefore, the use of such test equipment should be minimized. The simulated airborne operation test should concentrate on maximum system workload (take-off power versus idle for example) and system-to-system dependencies during operation.

6.6.6 Degradation Criteria: The test procedure for each system to be evaluated should include degradation criteria and unacceptable responses. The degradation criteria should state qualitative conditions and quantitative methods of establishing susceptibilities. The qualitative conditions need to reflect flight crew impressions of normal and abnormal operation. The quantitative methods are engineering measures of the system response that can be related to performance and later used in the vulnerability analysis.

6.6.7 RF Spectrum Limitations: National regulations and international agreements control emission of RF energy for all purposes, including testing. The radiated and conducted test approaches described in 6.7.2 through 6.7.4 require coordination with the cognizant spectrum management authority to comply with the applicable regulations. This applies to LLDD, LLSC, BCI, and high field tests performed on an aircraft or equipment in a system integration rig/bench.

The applicable spectrum management regulations may limit the frequency ranges available for test, the allowed radiated RF power, frequency sweep times, modulations, or test sites. Early coordination between the certification applicant, test conductor, aircraft certification authorities, and the spectrum management authorities is needed to ensure that the aircraft HIRF tests can be performed with the appropriate power levels, frequency coverage, and excluded frequencies.

If the cognizant spectrum management authority will not authorize test operations over all frequencies in the HIRF environment, the certification applicant should provide analysis or rationale for the acceptability of the aircraft HIRF protection over frequency ranges where tests are not allowed.

6.6.8 Certification Based on Similarity (Step 13): Certification by Similarity is the process of using the verification documentation from a nearly identical item of equipment or system that has been qualified for an application in an aircraft of demonstrably equivalent design and construction. It is not applicable for a combination of a new aircraft design and a new equipment design.

6.6.8 (Continued):

This section refers to a certification based on a previous demonstration (here after referred to as the baseline demonstration) which was performed with one of the recommended procedures other than Similarity. This can be applied where either of the following applies:

a. The airframe is modified or differs in role from the one used during the baseline demonstration.
b. One or more systems are different or modified.

The baseline demonstration cannot be automatically transferred to the new certification procedure. A difference in requirements also exists for systems performing functions of differing criticalities which leads to different approaches in demonstrating compliance using similarity.

The procedure is only completely valid if the baseline demonstration takes into account further modifications. Particular data is required for demonstration based on similarity and thus this data should be obtained during the baseline demonstration for use in future certification submissions based on similarity.

Certification based on similarity as the baseline demonstration should be avoided, as in these circumstances the correct procedure will be to refer back to the baseline demonstration and to identify modifications between the baseline version and the present one. The demonstration is then applied to the original version with all the modifications previously identified.

6.6.8.1 Aircraft Modifications: Aircraft modifications can be:

a. Modifications on a given airframe.
b. Installation of a system previously certified in a similar aircraft type.

The following parameters act as a pointer as to whether a full test procedure or a partial one will suffice. It should be noted that changes in electrical installation procedures can dramatically affect the system's EM susceptibility.

a. The system should comprise the same LRUs with an equivalent standard (from the EM susceptibility viewpoint).

b. All system interfacing should be identical.

c. All wire bundles should be of identical construction and layout as the previous installation. Special attention should be paid to wire shields.

d. The system grounding and bonding philosophy should be identical.

6.6.8.2 Level A Control System Modifications: Similarity assessments for modifications to Level A control systems are generally supported by demonstration based on two distinctive phases:

a. The first step is to determine the impact of the modification on the system's environment. This can be done by analysis (computer codes), by partial retest, by complete retest, or by a mixture of analysis and dedicated tests.

b. The second step is to conduct tests at system level with the new environment, where the new environment is more severe than the basic one.

This demonstration can be based on a minimum of tests if the basic environment is known in detail and if the modifications do not reduce the shielding effectiveness of the airframe and in general do not increase the system's environment.

If the demonstration is conducted purely by analysis in both steps (a.) and (b.), some spot checks still need to be conducted to verify the analysis especially below 400 MHz.

6.6.8.3 Aircraft Stretchs: The impact of major airframe changes such as stretching will need careful assessment to support the case for certification on the grounds of similarity and each case will have to be discussed on its merits with the relevant aviation authorities. Analysis may be adequate if the changes are expected to be minor in terms of EM characteristics.

The most common case of stretching is a change in fuselage length. In this case, the change in system environment is not in terms of level but more in terms of a shift in resonant frequencies. If the transfer function can be analyzed and shown to correlate to the fuselage dimensions in the particular case being assessed, then the shift in these frequencies can be predicted and the standard procedures followed.

6.6.8.4 System Modifications: These modifications can be modifications to a system previously installed and certified on the same or similar airframe, or installation of a system certified in a similar aircraft type.

A demonstration by similarity can only be performed if the system's environment is accurately known. If not, a complete retest at system level (including boxes, installation layout, and peripherals) is needed unless analysis shows that the immunity of the system has not been degraded. In some cases, a DO-160 test can be sufficient, i.e. if the modification involves only one box without repercussion on the other components of the system, especially on wiring and installation.

6.6.8.5 Practical Use of Demonstration by Similarity: The demonstration of compliance by similarity is not always the shortest and cheapest route to certification in view of the restrictions outlined above. The demonstration is typically longer or more expensive if the basic certification is performed without taking into account further modifications or using full aircraft tests. The demonstration is also more complicated if the level of modification exceeds box changes or fuselage stretching, or includes re-assessment of Level A control systems.