



AEROSPACE INFORMATION REPORT

AIR5060™**REV. B**Issued 1997-10
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Superseding AIR5060A

(R) Electronic Engine Control Design Guide
for Electromagnetic Environmental Effects

RATIONALE

This document is being updated to incorporate policy and guidance changes made in the last 5 years in the area of electromagnetic and lightning environments.

FOREWORD

This SAE Aerospace Information Report (AIR) provides information and guidance on the nature of, protection against, and compliance with requirements relating to the effects of the electromagnetic environment upon electronic aircraft engine control systems. It is intended for use by the engineer who is responsible for specifying or designing equipment to function within the environment, but whose knowledge of the subject may be superficial. It is intended to allow the reader to progress to the technical depth necessary to accomplish the specification or design task, and provides references for those desiring detail beyond that provided herein.

This material is advisory in nature; it is not mandatory. Methods for compliance (FAA or military) are discussed. However, applications for government agency approval may elect to demonstrate compliance through alternative methods found acceptable to the appropriate agencies.

Due to continual technological advancements and the evolving nature of standards and specifications, it is acknowledged that some material may be outdated at the time of publication.

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1. SCOPE

The purpose of this document is to provide reference material for establishing compatibility of electronic gas turbine engine control systems and associated components with the electromagnetic environment and achieving compliance with associated airworthiness requirements.

1.1 Introduction

The modern gas turbine engine used for aircraft propulsion is equipped with an ever increasing variety of electrical and electronic systems which provide for engine control, instrumentation, and auxiliary functions.

Today's aircraft engines currently in service or in development employ full authority digital engine control (FADEC) systems. The criticality of the electronics employed in these systems, with regard to continued safe operation of the aircraft, has led to a greater emphasis on ensuring that the equipment is immune to both natural and man-made electromagnetic environments.

Some engine control systems employ electronics in a less than full authority role in the form of "supervisory" or "trimming" controls or limiters. Such systems are still required to be compatible with the electromagnetic environment although the allowable effects on the system and the pass/fail criteria for system testing may differ.

In addition to the control system itself, typical aircraft gas turbine equipment includes many other electronic or electrical devices; these include solenoid operated valves to control anti-icing or environmental air supplies, position indicating and pressure operated switches, ignition systems, permanent magnet alternators, etc. Many engines are also equipped with engine monitoring systems or data concentrator units which provide a digital data bus interface to other aircraft electronic systems.

Signal control and power levels range from a small fraction of a milliwatt to several hundred thousand watts during ignition discharges. Acquiring, understanding, and efficiently applying the assortment of specifications, both civil and military, can be a daunting prospect for the engine component supplier or the equipment designer. Applying stringent electromagnetic compatibility (EMC) requirements to individual components and subsystems may result in unnecessary size, cost, and weight penalties; however, if sufficient margin is not included in early requirements before actual threat levels can be known, the design may not meet final engine level EME requirements. The project engineer or engineering manager is frequently called upon to make decisions and judgments for which some basic knowledge of electromagnetic environmental effects and associated design, test, and certification compliance is essential.

This document aims to be a central source of information, providing reference and guidance material into each electromagnetic phenomenon. The electromagnetic environment is divided into its main constituents, these being:

- a. Electromagnetic interference (EMI), including high intensity radiated fields (HIRF)
- b. Lightning
- c. Electromagnetic pulse (EMP)

Within each chapter, the topic is broken down further into the following main sections:

- a. Introduction
- b. Description of the environment
- c. Certification/qualification requirements
- d. Design considerations
- e. Compliance methods

A bibliography is provided for those seeking a more detailed treatment of any given topic, and references are made to any appropriate industry specification where applicable.

Electromagnetic compatibility is essentially an air vehicle issue; for a subsystem, such as the engine control, compatibility must be established with other equipment in the aircraft, but it is the complete air vehicle which is exposed to, and must be certified/qualified for, the external HIRF or lightning/EMP threat. A definition of requirements at the subsystem level is required in order to design and test the equipment, prior to the availability of the full-up aircraft, and/or to substitute for full-up aircraft testing. Testing and analysis at the subsystem level is also required in order to achieve engine certification (FAR Part 33 or EASA CS-E) or qualification. However, the subsystem levels are dependent upon other equipment electrically connected to the engine, cable routing and shielding, and the effectiveness of the aircraft structure as an electromagnetic shield.

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), <http://www.sae.org/>.

ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP5107	Guidelines for Time-Limited-Dispatch (TLD) Analysis for Electronic Engine Control Systems
ARP5412	Aircraft Lightning Environment and Related Test Waveforms
ARP5414	Aircraft Lightning Zone
ARP5415	User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning
ARP5416	Aircraft Lightning Test Methods
ARP5583	Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment
ARP60493	Guide to Civil Aircraft Electromagnetic Compatibility (EMC)

2.1.2 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

AMC 20-1	Certification of Aircraft Propulsion Systems Equipped with Electronic Control Systems
AMC 20-136	Aircraft Electrical and Electronic System Lightning Protection
AMC 20-158	Aircraft Electrical and Electronic System High-Intensity Radiated Field (HIRF)
AMC 20-3A	Certification of Engines Equipped with Electronic Engine Control Systems
AMC E 50	Engine Control System
AMC E 170	Engine Systems and Component Verification

CS-E	Certification Specifications and Acceptable Means of Compliance for Engines
CS-E 50	Engine Control System
CS-E 170	Engine Systems and Component Verification
CS-MMEL	Certification Specifications and Guidance Material for Master Minimum Equipment List

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

FAA AC 20-136B	Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning
FAA AC 20-53A	Protection of Airplane Fuel Systems against Fuel Vapor Ignition Due to Lightning
FAA AC 33.28-3	Compliance Criteria for 14 CFR 33.28, Aircraft Engines, Electrical and Electronic Engine Control Systems
FAA AC 33.4-3	Instructions for Continued Airworthiness, Aircraft Engine High Intensity Radiated Fields (HIRF) and Lightning Protection Features-September 16, 2005
FAA AC 20-155	Aircraft Lightning Protection Certification-April 28, 2008.
FAA AC 21-16G	RTCA, Inc. Document RTCA/DO-160-Environmental Conditions and Test Procedures for Airborne Equipment, June, 22, 2011.
FAA AC 20-158A	The Certification of Aircraft Electrical and Electronic System for Operation in the High-Intensity Radiated Field (HIRF) Environment, May 30, 2014.
DOT/FAA/CT-87/19	Avionics System Design for HIRF Energy Fields

2.1.4 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160G	Environmental Conditions and Test Procedures for Airborne Equipment
RTCA/DO-357	User Guide Supplement to DO-160G

2.1.5 EUROCAE Publications

Available from EUROCAE Secretariat, 102 rue Etienne Dolet, 92240 Malakoff, France, Tel: +33 1 40 92 79 30, www.eurocae.net.

EUROCAE/ED-14G	"Environmental Conditions and Test Procedures for Airborne Equipment," May 2011 [Corresponds to RTCA/DO-160G]
EUROCAE/ED-234	"User Guide Supplement to ED-14G," January 2015 [Corresponds to RTCA/DO-357]
EUROCAE/ED-84A	"Aircraft Lightning Environment and Related Test Waveforms," July 2013 [Corresponds to ARP5412]
EUROCAE/ED-91A	"Aircraft lightning zoning," January 2019 [Corresponds to ARP5414]

EUROCAE/ED-105A	"Aircraft lightning test methods," July 2013 [Corresponds to ARP5416]
EUROCAE/ED-107A	"Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment," July 2010 [Corresponds to ARP5583]
EUROCAE/ED-113	"Aircraft lightning direct effects certification," September 2002 [Corresponds to ARP5577]
EUROCAE/ED-248	"Guide to Civil Aircraft Electromagnetic Compatibility (EMC)," July 2010 [Corresponds to ARP60493]

2.1.6 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-C-38999/27	Connector, Electrical, Circular, Miniature, High Density, Quick Disconnect, "Bayonet, Threaded, and Breech Coupling," Environment, Removable Crimp and Hermetic Solder Contacts, General Specification for
MIL-HBK-217F	Military Handbook, Reliability Prediction of Electronic Equipment
MIL-HBK-237	Electromagnetic Compatibility Management, Guide for Platforms, Systems and Equipment
MIL-HBK-253	Guidance for the Design and Test of Systems Protected Against the Effects of Electromagnetic Energy
MIL-STD-202	Test Method Standard, Electronic and Electrical Component Parts
MIL-STD-461G	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 11 December 2015
MIL-STD-464C	DoD Interface Standard, Electromagnetic Environmental Effects Requirements for Systems
MIL-STD-704F	Aircraft Electrical Power Characteristics
MIL-STD-810	Military Standard Environmental Test Methods and Engineering Guidelines
MIL-STD-882	Systems Safety Program for Systems and Associated Subsystems and Equipment, Requirements for
MIL-STD-1310	Shipboard Bonding, Grounding and Other Techniques for Electromagnetic Interference and Safety
MIL-STD-1377	(NAVY); Effectiveness of Cable, Connector and Weapon Enclosure Shielding and Filters in Precluding Hazards of Electromagnetic Radiation to Ordnance, Measurement of
MIL-STD-3023	High-Altitude Electromagnetic Pulse (HEMP) Protection of Military Aircraft

2.1.7 Other Publications

F.A. Fisher, J.A. Plumer, and R.A. Peralá, "Aircraft Lightning Protection Handbook Report No. DOT/FAA/CT-89/22," FAA Technical Center, Atlantic City International Airport, NJ 08405, September 1989.

M. Dargi, E. Rupke, and K. Wiles, "Design of Lightning Protection for a Full-authority Digital Engine Control," International Aerospace and Ground Conference on Lightning and Static Electricity, 16-19 April 1991.

M. Dargi, E. Rupke, and K. Wiles, "Certification of Lightning Protection for a Full-authority Digital Engine Control" (ibid).

F.A. Fischer, R.A. Plumer, and R.A. Peralá, "Lightning Protection of Aircraft," July 2012.

Ghose, Dr. Rabindra N., EMP Environment and System Hardness Design, Don White Consultants, Inc., 1984.

Aeronautical Design Standard, ADS-37A-PRF, "Electromagnetic Environmental Effects (E³) Performance and Verification Requirements," U.S. Army, 28 May 1996.

RAE, RAE Defense Standard 59-41

National Telecommunications and Information Administration (NTIA) Manual of Regulations and Procedures for Federal Radio Frequency Management, "Radar Spectrum Engineering Criteria (RSEC)."

2.2 Bibliography

The following standards, handbooks, guides, etc., may be consulted for further guidance in specifying tests, test levels, and control practices for achieving electromagnetic compatibility.

- a. "Electromagnetic Compatibility Principles and Practices," National Aeronautics and Space Administration, Washington, D.C.; N66-16595 (NHB 5320.3).
- b. "Design Handbook Series 1-0, AFSC DH 1-4, Electromagnetic Compatibility," Third Edition; 5 January 1975; Department of the Air Force, Headquarters, Aeronautical Systems Division (AFSC), Wright-Patterson Air Force Base, Ohio 45433.
- c. "Interference Reduction Guide for Design Engineers," Volume 1; U.S. Army Electronics Laboratories, Fort Monmouth, New Jersey.
- d. "Interference Reduction Guide for Design Engineers," Volume 2; U.S. Army Electronics Laboratories, Fort Monmouth, New Jersey.
- e. "Prediction of Coupling, Shielding, and Grounds for Low Frequency Fields"; NUSC Report No. 4051; Naval Underwater Systems Center, Newport, Rhode Island 02840.
- f. "Electromagnetic Compatibility Design Guide for Avionics and Related Ground Support Equipment"; NAVAIR AD1115.
- g. SAE Aerospace Information Report, "Methods of Achieving Electromagnetic Compatibility of Gas Turbine Engine Accessories, for Self-Propelled Vehicles," SAE Standard AIR1425, Issued March 1978.
- h. SAE Aerospace Recommended Practice, "Corrosion Control and Electrical Conductivity in Enclosure Design," SAE Standard ARP1481A, Reaf. Aug. 2004.
- j. SAE Aerospace Recommended Practice, "Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety," SAE Standard ARP1870, Stab. Aug. 2012.
- m. SAE Aerospace Recommended Practice, "Aircraft Lightning Direct Effects Certification," SAE Standard ARP5577, Reaf. March 2008.

2.3 Abbreviations and Acronyms

A/C	Aircraft
AC	Alternating Current or Advisory Circular
ACARS	Communications Addressing and Reporting System
ACT	Active Control Technology
ADC	Air Data Computer
ADF	Automatic Direction Finder
AF	Audio Frequency
AFCS	Automatic Flight Control System
ALS	Advanced Low Power Schottky Logic
AMC	Acceptable Means of Compliance
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio Inc.
AS	Advanced Schottky Logic
ASW	Anti-Submarine Warfare
ATL	Actual Transient Level
BB	Broadband
BCI	Bulk Cable Injection
BITE	Built-in Test Equipment
BW	Bandwidth
CCF	Carbon Composite Fiber
CDU	Control Display Unit
CE	Conducted Emission
CLB	Closed Loop Bench
CM	Common Mode
CRT	Cathode Ray Tube
CS	Conducted Susceptibility
dB	Decibels
DC	Direct Current
DFDAU	Digital Flight Data Acquisition Unit

DFDR	Digital Flight Data Recorder
DITS	Digital Information Transfer System
DM	Differential Mode
DME	Distance Measuring Equipment
DoD	Department of Defense
DWV	Dielectric Withstanding Voltage
E/E	Electrical/Electronic
E3	Electromagnetic Environmental Effects
EADI	Electronic Attitude Director Indicator
EASA	European Union Aviation Safety Agency
ECS	Environmental Control System
EEC	Electronic Engine Control
EED	Electro-Explosive Device
EEHWG	Electromagnetic Effects Harmonization Working Group
E-FIELD	Electric Field
EFIS	Electronic Flight Instrument System
EGT	Exhaust Gas Temperature
EHSI	Electronic Horizontal Situation Indicator
EICAS	Engine Indication and Crew Alerting System
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment
EMI	Electromagnetic Interference
EMIC	Electromagnetic Interference/Compatibility
EMICP	Electromagnetic Interference Control Procedures
EMITP	Electromagnetic Interference Test Procedures
EMITR	Electromagnetic Interference Test Report
EMP	Electromagnetic Pulse
EMV	Electromagnetic Vulnerability
EPR	Engine Pressure Ratio

ESD	Electrostatic Discharge
ESE	Electric (field) Shield Effectiveness
ETDL	Equipment Transient Design Level
EUROCAE	European Organization for Civil Aviation Electronics
EUT	Equipment Under Test
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Regulation
FCC	Federal Communication Commission
FCC	Flight Control Computer
FDEP	Flight Data Entry Panel
FMC	Flight Management Computer
GAMA	General Aviation Manufacturers Association
GPS	Global Positioning System
Gr/Ep	Graphite/Epoxy
H-Field	Magnetic Field
HIRF	High Intensity Radiated Field
HMC	Hydromechanical Control
Hz	Hertz (oscillations per second)
IEEE	Institute of Electrical and Electronic Engineers
IEMP	Internal EMP
IF	Intermediate Frequency
JSC	Joint Spectrum Center
kHz	Kilohertz (10^3 Hz)
LISN	Line Impedance Stabilization Network
LLC	Low Level Coupling
LRU	Line Replaceable Unit
MHz	Megahertz (10^6 Hz)
NIST	National Institute of Standards and Technology
NPA	Notice of Proposed Amendment

NPRM	Notice of Proposed Rulemaking
OATS	Open Area Test Site
PEDS	Portable Electronic Devices
PMA	Permanent Magnetic Alternator
PRF	Pulse Repetition Frequency
RAE	Royal Air Force Establishment
RE	Radiated Emissions
RF	Radio Frequency
RFM	Radio Frequency Modulation
RMS	Root Mean Square
RS	Radiated Susceptibility
RTCA	Radio Technical Commission for Aeronautics
SCD	Source Control Drawing
SGEMP	Space Generated EMP
SIL	Systems Integration Laboratory
TCL	Transient Control Level
TD	Type Design
TLD	Time Limited Dispatch
TRA/TLA	Throttle Resolver Angle/Throttle Lever Angle
TSO	Technical Standard Order
TVS	Transient Voltage Suppressor
TWT	Traveling Wave Tube

2.4 Glossary

ABSORPTION LOSS: Attenuation or retention of electromagnetic energy passing through a material, a shield. Absorption loss and reflection loss contribute to total shielding effectiveness (SE).

AC NOISE IMMUNITY: The relative immunity of a device to noise pulses. As pulse width increases, AC noise immunity approaches the DC noise margin. As the pulse width is reduced toward the propagation delay time, the circuits become less able to respond and a larger signal voltage is required. See noise-energy immunity; DC noise margin.

ANODIZE: A preparation by electrolytic process that deposits a protective oxide, insulating film on a metallic surface (aluminum). The oxide defeats electrical bonding. Alodine and iridite finishes on aluminum are conductive.

APERTURE: An opening, such as a nonconductive panel joint, slot, or crack, allowing electromagnetic energy to pass through a shield.

ATTENUATION: Attenuation is the general term used to denote a decrease in magnitude in transmission from one point to another. It may be expressed as a ratio or by extension of the term in decibels.

AUDIO FREQUENCY (AF): The spectrum (20 to 20000 Hz) of human hearing, often defined as extending from approximately 20 Hz to 50 kHz and sometimes to 150 kHz. Audio noise is nuisance hum, static, or tones from powerline 400 Hz, switching regulator and digital clock harmonics.

B-Field: See magnetic flux density.

BACKSHELL: Metal shell connecting circuit shields or overbraid to an electrical connector.

BALANCED CIRCUIT: A signal, acting line to line, between two conductors having symmetrical voltages identical and equal in relation to other circuits and to ground, "differential mode" is line to line; "common mode" is line to ground.

BANDPASS FILTER: A bandpass filter is a wave filter which has a single transmission band, neither of the cutoff frequencies being zero or infinite.

BANDWIDTH (BW): Frequencies bounded by an upper and lower limit in a given band associated with electronic devices, filters, and receivers.

BONDED: Electrically connected by means of welding, brazing, compressing or other mechanical means not likely to be affected by heat or corrosion and which will give a good low-resistance (example $<0.1 \Omega$) electrical path.

BONDING: Electrically connecting two mechanical parts together, providing a low resistance path.

BRAID, OVERBRAID: Fine metallic conductors woven to form a flexible conduit or cableway and installed around insulated wires to provide protection against electric fields and radio frequencies. Best when peripherally connected to backshells. A grounding strap/jumper may be made of braid.

BROADBAND EMISSIONS: Term used to describe emissions which have a bandwidth greater than some reference bandwidth.

CABLE OR HARNESS: A bundle of separate, insulated, electrical circuits, shielded or unshielded, usually long and flexible and having breakouts, terminations, overbraid, and mounting provisions completely assembled.

CABLEWAY: A solid metallic housing (liner, foil, and coating) surrounding and shielding insulated electrical conductors. Also called conduit, tray, or raceway. Crosswise or transverse openings or breaks in the metallic cableway cause noise voltages to be transferred to internal wire circuits.

CHARACTERISTIC IMPEDANCE: The purely resistive ratio between the amplitudes of the voltage and current of a wave propagating in one direction along a transmission line that is terminated in a resistance equal to the characteristic impedance, such that there are no reflections of the wave. The characteristic impedance is a function of the geometry and materials of the transmission line.

CIRCULAR MILS (ABBR. CIR MIL): The diameter of a cylinder squared. 1 mil = 0.001 inch. When multiplied by $\pi/4$ (or $\pi/4$), equals the area of the circle in square mils.

COMMON IMPEDANCE COUPLING: The means by which two or more circuits sharing common impedance share a common voltage drop across the impedance, thereby coupling it to the secondary source(s). Conducted interference.

COMMON MODE (CM) IMPEDANCE: Impedance or resistance shared by two or more circuits so that noise voltages/currents generated by one are impressed on the others.

COMMON MODE REJECTION: The ability of wiring or an electronic device to reject common mode (line-to-ground) signals and maintain fidelity of differential mode (line-to-line) signals.

COMMON MODE SIGNAL: Identical and equal signals on input conductors or at the terminals of a device relative to ground.

CONDUCTED EMISSION (CE) OR INTERFERENCE: Voltage/current noise signals entering or leaving a unit on interface conductors. Emission is the general term; interference is undesired noise.

CONDUCTED SUSCEPTIBILITY: The response of a system to the presence of noise on the power and signal lines or cables. The noise can be either line-to-line (differential mode) or line-to-ground (common mode).

CROSSTALK: The interference energy transferred from a source to an unintentional load by conductive, inductive or capacitive coupling. Usually of concern when source and susceptor are less than 1/6 wavelength apart. Referred to as near end or far end crosstalk depending on relation of where it is measured, with respect to the source.

CULPRIT: Signal or circuit that is the source of interference.

COUPLING: The transfer of energy between wires or components of a circuit electrostatically, electromagnetically, or directly.

CROSS COUPLING (CROSSTALK): Transfer of signals from one channel, circuit, or conductor to another as an undesired or nuisance signal or the resulting noise.

DAMAGE: The irreversible failure of a component.

DECIBEL (dB): Decibel expresses the ratio between two amounts of power, P_1 and P_2 . By definition, the number of dB = $10 \log$ to the base 10 of (P_1/P_2) . For special cases, when a standard power level $P_2 = 1 \text{ mW}$ or 1 W or 1 kW , then the ratio is defined as "dBm," "dBw," or "dBkW." Moreover, because $P = V^2/R$ and also I^2R , decibels express voltage and current ratios. Ideally, the voltages and currents are measured at two points having identical impedances. By definition, $\text{dB} = 20 \log V_1/V_2$ and $\text{dB} = 20 \log I_1/I_2$. For convenience, V_2 or I_2 are often chosen as $1 \mu\text{V}$ or $1 \mu\text{A}$ and the ratio is defined as dB above a μV or dB above a μA when graphing emission or susceptibility limits.

DC NOISE MARGIN: The difference between the maximum input voltage [$V_{IL}(\text{max})$] that will still be interpreted as a "0" and the maximum output voltage that can be provided by the source in the "0" state [$V_{OL}(\text{max})$]. Referred to as the low-level signal line noise margin, $V_{OL}(\text{min}) = V_{IL}(\text{max}) - V_{OL}(\text{max})$.

DECOUPLING: Filtering, the removing of the coupling effect usually referring to conductive coupling. Decoupling capacitors are used on the power supply to isolate the effects of the load on the distribution system or vice-versa (also bypass capacitor).

DIELECTRIC: An electrical insulator that can be polarized by an applied electric field. The applied field displaces charges within the insulator in a way that counteracts the applied field and stores energy within the dielectric.

DIELECTRIC STRENGTH: Voltage withstand capability that an insulating material sustains before destructive arcing and current flow, usually, in cases such as the PC board conducting layers or conformal coating, it is expressed as volts per mil. For assemblies such as a sensor or actuator it is an overall maximum voltage withstand level. Dielectric withstand voltage is the voltage level at which insulation breakdown occurs.

DIFFERENTIAL MODE (DM) SIGNAL: The signal in a two wire circuit measured from line to line.

DUAL GROUND: Equipment case ground/return through two independent circuit paths to structure implemented in flammable zones and water leakage areas, each path meeting electrical conductivity (resistance) requirements.

DUAL IN-LINE PACKAGE (DIP): A pin configuration, common on integrated circuits, where the pins are aligned in two parallel and opposing rows.

EARTH: With respect to charge, the earth is considered an infinite sink; therefore, the lowest possible zero potential reference.

ELECTRIC FIELD: High-impedance, radiated voltage field, positive or negative, from a voltage source as contrasted to a low-impedance magnetic field from a current source.

ELECTROMAGNETIC COMPATIBILITY (EMC): The capability of electronic equipment to be operated as designed in the intended operational electromagnetic environment.

ELECTROMAGNETIC INTERFERENCE (EMI): Degradation of the electromagnetic environment by an unwanted disturbance.

ELECTROSTATIC DISCHARGE (ESD): Arc discharge across an air gap caused by the electric potential across the gap exceeding the dielectric breakdown voltage of air in the gap.

EMITTER: Source of electromagnetic signal.

FAR FIELD RADIATION: Electromagnetic radiation that occurs at a distance greater than approximately 1/6 wavelength from the source of interference. At these distances the electromagnetic field decreases at a rate inversely proportional to the distance from the source and the ratio of E-Field to H-Field = 377Ω in free space.

FAULT CURRENT: The maximum current (magnitude and duration) flowing through a fault point; equal to the supply voltage divided by the DC resistance of powerline leads, circuit breakers, and the current return in wire or structure.

FILTERING: Device or unit that passes or rejects a frequency band and designed to block noise from entering or leaving a circuit or unit.

GROUND: (1) Voltage reference which is eventually related back to the potential of the earth. Because of path resistance, usually not at earth potential. Ground is usually of "local" value such that all grounded equipment in immediate area is the "same" potential, irrespective of earth. (2) Low impedance return path for signal or power currents. Deprecated version of "return." (3) Electron source or sink for the dissipation of electrostatic discharge (ESD) currents.

GROUND PLANE: An equipotential voltage reference to which electronic units are referenced so that the voltage potential between interconnected units is less than or equal to an acceptable noise level.

IMMUNITY: Capability of a circuit or unit to operate within performance specification in a specified electromagnetic interference environment.

INDUCTIVE COUPLING: The detrimental effect which one circuit or subsystem has on another by means of the mutual inductance that exists between them. The amount of coupling is a function of the frequency, the loop area of the systems, and the length and proximity of parallel interacting wiring runs.

ISOLATION: Electrical separation and insulation of circuits from ground and other circuits or arrangement of parts to provide protection and prevention of uncontrolled electrical contact.

JUMPER/STRAP: A short wire, strip, strap, or braid conductor installed to make a safety ground connection, to dissipate electrostatic charge, or establish continuity around a break in a circuit.

LIMITING: VOLTAGE/CURRENT: Semiconductor components, diodes, avalanche devices, or filters designed to clip and shunt to ground an applied transient or steady-state voltage. Used to protect against noise frequencies, faults, lightning, and inductive switching transients.

LOOP: The current caused by a difference in voltage between two points. Occurs only when there are two or more paths between the two points.

LOW FREQUENCY: Those frequencies whose wavelength is 16 times greater than the largest circuit dimension (rule of thumb). Also 0 to 10 kHz. (Use whichever is smaller.)

MAGNETIC FIELD: A radiated, low-impedance field having lines of "flux" or magnetomotive force associated with an electrical current.

MAGNETIC FLUX DENSITY: The field intensity integrated over the area in question.

MATCHED TRANSMISSION LINE: A transmission line is said to be matched at any transverse section if there is no wave reflection at that section (i.e., the line impedance equals the load impedance).

MULTILAYER: Referring to a printed circuit board which is constructed by laminating two or more layers of etched conductor and substrate together, and connecting layers by plated holes. The conductive layers have dedicated functions such as power, ground, signals laid out in the "X" or "Y" direction, or shield.

MULTISTACKED: Multistacked PCBs are complete double- or single-sided PCBs which are riveted together through holes intended to conduct current. Rivets replace plated through-holes and hold board layers together. These boards may be repaired (where multilayer cannot) by removing the rivets. Not used very often in commercial electronics.

MULTIWIRE (TM): A PCB fabrication technique where power and ground are etched on a single- or double-sided PCB then coated with adhesive; wire is laid onto the adhesive using a computer numerical controlled wiring machine. The holes are then drilled and plated to make connection to the wires. Multiwire can achieve higher density than multilayer boards and it is simple to make changes. It is relatively expensive and not usually economical for production applications.

NEAR FIELD RADIATION: Electromagnetic radiation that occurs at a distance less than approximately $1/6$ wavelength from the source of interference. Electric fields (E-fields) in the near field attenuate inversely proportional to the cube of the distance for high-impedance sources and $1/r^2$ for low-impedance sources. Near field magnetic (H-fields) attenuate as the inverse square of the distance from the source for high impedance sources and $1/r^3$ for low-impedance sources.

NOISE: Conducted or radiated emission causing circuit upset, performance disorder, or undesired sound.

NOISE ENERGY IMMUNITY: EN, equals the noise voltage required to cause a circuit to malfunction squared $(V_n)^2$, times the noise pulse-width (PW), divided by the parallel equivalent of the input under evaluation and the impedance of the wiring and circuit connected to it (R_o). $EN = [(V_n)^2(PW)]/R_o$. Not usually applied to power and ground leads.

NOISE IMMUNITY: See AC noise immunity; noise-energy immunity.

NOISE MARGIN: See DC noise margin; AC noise immunity.

PCB: Printed circuit board. A substrate with conductors etched out of a conductor bonded to it, used to support and interconnect circuit components. May also refer loosely to multiwire and wire wrap boards.

PICKUP: Interference from a nearby circuit or system. Also known as crosstalk.

PRECIPITATION STATIC (P-STATIC): Electrostatic discharge, corona, arcing, and streamering, steady state or impulsive, which may cause circuit upset, receiver noise or component damage.

PROPAGATION DELAY: The delay in moving a signal from Point A to Point B through a medium or circuit. The delay is caused by the energy storing characteristics of the medium (such as capacitance or inductance) that need to be satisfied before the next increment of medium in the path can be excited. Each increment requires a finite delay.

RADIATED EMISSION (RE): Electromagnetic energy transmitted and propagated in space usually considered as audio frequency or radio frequency noise.

RADIO FREQUENCY (RF): Frequencies in the electromagnetic spectrum used for radio communications extending from kilohertz to gigahertz.

RADIO FREQUENCY INTERFERENCE (RFI): Electromagnetic interference in the radio frequency range.

RADIATED SUSCEPTIBILITY: The response of a system to the presence of electromagnetic waves.

RECEPTOR: Signal or circuit which responds to electromagnetic noise.

RETURN: The low impedance conductor(s) used to direct current from the load back to the source. Does not have to be ground or earth potential (i.e., balanced line). See earth; ground.

SCHOTTKY LOGIC: Logic circuits whose transistors have a metal-semiconductor diode built in between the collector and base. This diode prevents the transistor from saturating, thereby greatly increasing its switching speed.

SEALANT: An applied substance enclosing and protecting the integrity of a joint, fastener, or electrical bond from moisture, contaminants, oxidation, and acid or alkaline corrosion.

SHIELD: A conductive material, opaque to electromagnetic energy, for confining or repelling electromagnetic fields. A structure, skin panel, case, cover, liner, foil, coating, braid, or cableway that reduces electric and magnetic fields into or out of circuits or prevents accidental contact with hazardous voltage.

SHIELDING: Reducing EMI by interposing a conductive or absorptive and/or reflective medium (shield) between a noise and a receptor.

SHIELD EFFECTIVENESS (SE): The ability of a shield to reject electromagnetic fields. A measure of attenuation in field strength at a point in space caused by the insertion of a shield between the source and the point.

SIGNAL RETURN: A wire conductor between a load and the signal or driving source. Structure can be a signal and power return. Commonly, it is the low voltage side of the closed loop energy transfer circuit.

SINGLE-ENDED CIRCUIT: A circuit with source and load ends grounded to case and structure and using structure as return.

SKIN DEPTH: The distance from a conductor's outside surface to where the current density in the conductor falls to 1/e of its surface value.

STRUCTURE: Basic members, supports, spars, stanchions, housing, skin panels, or coverings that may or may not provide conductive return paths and shields for electrical/electronic circuits.

SUSCEPTIBILITY: Upset behavior or characteristic response of an equipment when subjected to specified electromagnetic energy; identified with the point, threshold, or onset of operation outside of performance limits. Conducted susceptibility (CS) applies to energy on interface conductors; radiated susceptibility (RS) to radiated fields.

SYSTEM: A group of components, circuits, or equipment connected together to provide a complementary function, and thereby having to operate without interference in a mutual electromagnetic environment.

THRESHOLD, NOISE: The lowest electromagnetic interference signal level that produces onset of susceptibility.

TRACE: The conductor bonded to a printed circuit board substrate that conducts current between two or more points.

TRANSIENT VOLTAGE STAND-OFF: The maximum voltage measured relative to aircraft structure at which there is no significant current conduction for a circuit loop.

TRANSMISSION LINE: A combination of conductors arranged in a mutual field, having the characteristics of distributed reactance, and uniform impedance along its length when properly terminated.

UPSET: Temporary interruption of performance that is self-correcting or reversible by manual or automatic process.

UNACCEPTABLE RESPONSE: Upset, malfunction, or degrading of performance beyond the tolerances defined in the certification test plan.

UNDESIRABLE RESPONSE: Change of performance and output, not designated a malfunction or safety hazard, that is evaluated as acceptable as is because of minimum nuisance effects and excessive cost burdens to correct.

VALIDATION: Demonstration and authentication that a final product operates in all modes and performs consistently and successfully under all actual operational and environmental conditions founded upon conformance to the applicable specifications. The determination that the requirements for a product are correct and complete.

VERIFICATION: The evaluation of an implementation of requirements to determine that they have been met.

3. GENERAL TOPICS

This chapter is provided to present general topics which are applicable to any of the electromagnetic environmental effects which are discussed in subsequent chapters.

3.1 Specification Guidelines

As the most general guideline, over-specification should be avoided. This may involve analysis and perhaps preliminary testing at the aircraft and sub-system levels at a stage as early in the development program as possible. This approach should enable threat or emission levels to be tailored to practical, necessary levels at the aircraft engine interface, i.e., avoiding the imposition of "blanket" specification limits which would result in unnecessary cost, weight and reliability penalties resulting from over design. If relaxation can be tolerated it should be included in the procurement document. Obviously insusceptible components should be exempted from any specific requirements.

Requirements which apply only to appropriate interfaces should be specified. For example, conducted emission power circuit requirements on aircraft engine interface leads should be specified only where power is actually supplied by the aircraft source.

3.2 Criticality Assessment

The FAA presently considers all EEC (electronic engine control) systems for primary propulsion to be critical, whether they are supervisory or full authority types, and therefore requires that they be tested as critical systems. Due to the integrated nature of EEC systems with other aircraft systems there may be functions performed by the EEC which are not classified as critical to engine or aircraft system operation. If a susceptibility occurs during EME testing, the impact of the upset shall be evaluated based on the classification of the function which is affected. If the specific signal upset is associated with more than one function, then it shall be evaluated against the more critical functional classification.

APU requirements may differ somewhat from those for the primary propulsion control system, in that the equipment may be considered essential or critical. Some greater level of upset than is the case for the propulsion system may be permissible; e.g., switchover to a backup control function or even shutdown.

3.3 General Pass/Fail Criteria

In the certification of civil primary propulsion control systems, the following general pass/fail criteria are usually applied in the testing for compliance with electromagnetic environmental effects. In addition to the general criteria below, there may be other customer specific requirements, or different criteria for military applications. Different certification authorities may have criteria which vary from the FAA 33.28 criteria stated in this document.

- a. No permanent damage results.
- b. No false indications which could cause the pilot or crew to take inappropriate and potentially hazardous action.
- c. No unacceptable change or effect in thrust or power during the test event, and complete recovery afterwards (e.g., $\pm 1\%$ for greater than 1 second is often used; however, AC 33.28 defines "Adverse Effect" as a power or thrust perturbation of greater than $\pm 3\%$ of most sensitive operating point or $\pm 1\%$ of take-off power or thrust, whichever is greater, for a period of more than 2 seconds, for civil certifications).
- d. No lane or channel change or reversion to a back-up system is permissible, unless you can demonstrate both channels are not affected by common mode failures (i.e., channels with dissimilar architectures).
- e. No anomalous operation of overspeed or thrust reverser circuits.
- f. No anomalous operation of propeller control.

Determination of thrust or power variations that may result in an adverse effect is application dependent. In general, thrust variations exceeding 1% of the take-off power or thrust or greater than 3% of the most sensitive operating point, whichever is greater, for a period greater than 2 seconds have been considered as adverse for turbine engine applications. For additional guidance refer to AC 33.28-3.

3.4 System Test Configuration

During the pre-qualification phase of the engine control system development, it will be necessary to compile test plans for each electromagnetic environmental effects test to be performed. Each test plan should declare the intended system test configuration, i.e., how the EEC will be interfaced to any supporting equipment, and in which mode(s) it is to be operated during the test. To avoid redundancy, it is often more convenient to combine multiple plans into one overall E3 test plan with subsections for each test. This raises several points regarding the many options which are possible for configuring a certain system test. These are broadly divided into two sub-categories for further discussion:

- a. "Full up" system test versus "component" test.
- b. Open loop versus closed loop configuration.

3.4.1 "Full Up" System Test versus "Component" Test

A "full up" system is defined as one featuring the EEC components connected to a full complement of production actuators and sensors, production engine cables and airframe cables and interface equipment which may be conformed facsimiles. A "component" test is defined as the simplest configuration which would allow functionality and electromagnetic characteristics of the component to be measured.

Clearly, the closer the test configuration resembles the actual installation (i.e., the full up configuration) the more meaningful the test. Also, test credit may be sought for the other installation components if they are included with the system test. However, there are usually practical reasons why a complete full up test is not feasible, so the actual test configuration may lie between the two extremes. Care should be taken to replicate and document relevant production features in facsimiles where ever conformed production parts are not available. For example, a single error in grounding or sensor duplication can invalidate related testing.

a. Wiring Harnesses:

It is generally recognized that the wiring harness plays an important role in the electromagnetic performance of the EEC system. Engine cables should be conformed production components. In some cases, especially in the case of the airframe cables, these components may be conformed facsimiles in which the relevant construction details (shielding, terminations, bundled, grounding, etc.) must be replicated. These production engine cables and facsimiles airframe cables may be "modified" (example removal of an overbraid on double shielded cables to demonstrate margin during a certification test). However, modifications must be documented and must be conformed to get regulatory approval prior to test.

b. Engine Sensors and Actuators:

Nothing loads the EEC as representatively as the real system sensors and actuators. However, practical limitations may arise depending upon the intended operating mode during the test. Some sensors are easily adapted for realistic signal simulation (e.g., frequencies can be induced magnetically onto speed sensors). However, certain sensors are not so readily adaptable without invasive methods (thermocouples, pressure sensors, etc.) so a judgment must be made as to whether the ambient conditions experienced by the sensors during the test represent a useable operating condition. This may also be affected by the decision to operate in open loop or closed loop mode.

c. Airframe Interfaces:

Again, a judgment is necessary depending upon the complexity of the interface equipment and the impact of simulating the device. Airframe data busses are more readily simulated by external bus transceivers, and it would usually be infeasible to feature, for example, an Air Data Computer in the EEC test. However, in the case of a device such as a power demand resolver, it may be somewhat straightforward and would make good sense to use the real device.

3.4.2 Open Loop versus Closed Loop Configuration

An open loop test is defined to be an arrangement whereby preset simulated conditions may be set up onto the EEC inputs, but these do not vary in response to the outputs of the EEC. Conversely, a closed loop test is a configuration which features some type of inputs to the EEC that are used by the simulation to generate responsive outputs to the actuators, etc. In this manner, the EEC can operate in at least one control mode as it would in the installation. Each type of test has advantages and limitations, and each type has its proponents. Therefore, the type of test method proposed should receive suitable consideration, and be declared for customer and certification authority approval well in advance of the test date. In either case the operating mode should be chosen to be the most sensitive to the applied environment. This may result in different set points for EMI, Lightning and HIRF or differing set points for emissions versus susceptibility tests. A single operating mode may be used to adequately address all applied environments and operating modes provided sufficient analysis is provided in the test plan. The following is intended to outline some of the advantages and drawbacks associated with each test configuration.

a. Open Loop Testing:

It is to be expected that during open loop testing, the action of the control software within the EEC would be to drive the actuator demand onto a minimum or maximum software limit. It is then argued that any susceptibility on, say, an input, which would tend to drive the output demand in the direction to exceed the software limit would now be masked by the action of the limit. This is cited as unacceptable by those opposed to this method of test. However, the much simpler test arrangement afforded by the open loop test makes a solution to the above problem attractive.

In a sensibly designed system, the software actuator drive limits do not represent the absolute electrical limits of the actuator drive itself. Therefore, susceptibility of the output circuitry will not be masked in either direction by operating on the software limit. In this case the pass/fail criteria for these outputs must be below the limits of the hardware output capability. Alternatively, special test software could be used which disables the normal control logic connection from input(s) to output(s) and inserts either fixed position commands or constant output commands depending on whether closed loop inner loop actuator control is possible within the test environment. Any position feedback devices should be representative of the actual hardware used in the application and set to a position(s) relevant to the test conditions being evaluated. Test equipment will then be necessary to monitor the control outputs for any test induced disturbances. The problem is then reduced to exposing susceptibility on signal inputs (especially difficult if susceptibility is assessed purely by monitoring the response of the actuator drives). One solution would be, in addition to the electrical monitoring of outputs, to monitor digitized sensor data over a diagnostic data port. Each input parameter could have a predefined pass/fail limit, computed from the overall power/thrust limit, and continuously compared to that limit by a diagnostic computer. Any input excursion could then be logged, and possibly analyzed off line for the expected effect upon the power/thrust limit. Time histories of each input and output should be recorded for use in applying resultant test induced disturbances to the normal operating conditions of the model. Care should be taken to ensure that the update rate of input parameters is adequate to avoid missing short duration susceptibility. In effect, the input update rate should be as fast as that used in the application software.

In considering the effects of input disturbances on power/thrust in establishing limits on each input, the cumulative effect on engine thrust due to disturbances on each input should be considered. As these cumulative effect criteria generally lead to restrictive pass/fail criteria, it is common to evaluate power/thrust response by biasing the inputs of an off-line closed-loop engine system model with the recorded digital input disturbances. These input disturbances are often applied at a variety of operating conditions (not just the operating conditions being simulated during the open-loop testing) to determine worst-case effects.

b. Closed Loop Testing:

Closed loop testing usually involves a much more complicated and expensive test set up, but as it more accurately represents the installed system, it is usually favored by the certification authorities. However, there are limitations associated with this method which should be appreciated and accommodated.

The closed loop test is usually arranged so that the most common control loop is utilized. Any susceptibility of those input parameters associated with that control mode would indeed be exposed by an unwanted response of the output parameter. However, there may also be other input parameters which are only used in other control modes and are consequently tolerant of large upsets when operating in the chosen mode. Plans must therefore be made to accommodate this problem; one possible solution would be to monitor digitized input parameters as outlined for the open loop testing. This can also prove useful in providing the capability for evaluating future control software modifications. Another solution would be to arrange to test in every control mode, but this would usually be prohibitively expensive and time consuming.

Another practical drawback to the closed loop test is the potential for test gear/simulation susceptibility, even though the test gear is usually placed in a control room and not directly exposed to the environment, and the problems involved in discerning this from real EEC susceptibility. Resolving this problem usually involves time consuming, detailed investigation at the test site. However, similar problems occur with data acquisition systems in open loop tests. The engine simulation should be valid for small perturbation inputs and validated using actual engine data. The model should have sufficient accuracy, at least to within 10% of the actual engine response, to simulate a 2% power/thrust change. A full non-linear engine simulation is not required if acceptable small signal transient accuracy can be shown with a linearized model. Model validation for small changes should be shown. It is preferable to define a test condition where the control loops for all EEC control actuators are modulating instead of at the maximum stop position. It is recommended to choose an operating condition to maximize the number of actuators that are modulating.

3.5 Degraded Mode Operation

Some EEC systems are approved for Time limited dispatch (TLD) when the applicant demonstrates compliance with the Guidelines for Time-Limited-Dispatch Analysis for Electronic Engine Control Systems provided in ARP5107 (see 2.1.1). TLD procedures permit dispatch of engines with degraded redundancy, provided it can be demonstrated that the system complies with this criteria. One of the TLD criteria is that any dispatchable configuration must continue to meet all of the applicable FARs. Another criterion for TLD is that all dispatchable configurations must continue to meet the certification environment, which includes the electromagnetic environment. In order to demonstrate compliance with this latter criterion, the applicant may be required to repeat the electromagnetic test program with the system in the worst-case dispatch configuration. This requires that the applicant perform an analysis to determine the worst-case dispatch configuration relative to EMC and demonstrate that the system continues to meet the electromagnetic environmental requirements.

4. ELECTROMAGNETIC INTERFERENCE (INCLUDING HIRF)

4.1 Introduction

The interaction between information carrying signals and undesirable electrical energy, commonly referred to as noise, in electrical and electronic system is the basis for electromagnetic interference (EMI). Aircraft electrical and electronic systems offer unique challenges in their need to tolerate a wide array of noise threats. Additionally, EMI also encompasses propulsion engine control system generated emissions, conducted or radiated, which may result in aircraft system interference. This section provides an overview for the aircraft and its electromagnetic noise environment as it pertains to propulsion electronic control systems.

4.2 Environment

Both the internal and external aircraft environments directly impact the aircraft engine electronic control system relative to EMI. The engine control system must contend with a diverse array of noise emitters while components such as the engine control itself is a noise emitter relative to surrounding electronic equipment in or on the aircraft. Radar and transmitter systems provide a radio frequency (RF) noise environment (HIRF) of prime concern to an engine control system. The natural lightning environment provides a further noise environment of prime concern. Of military concern is the nuclear electromagnetic pulse (EMP) noise environment (lightning and EMP are discussed generally in separate sections of this document). These threats, in addition to noise from other electrical or electronic equipment in or near the aircraft, form the bulk of noise sources that may affect engine controls.

Historically, the requirements placed upon a system regarding the RF electromagnetic environment were prescribed by the civil or military "general" EMI specification. However, in more recent years, due mainly to the changing picture of terrestrial, ship-based and airborne transmitters, a subset of the EMI environment, namely HIRF, has warranted closer attention. The proliferation of high power radar and transmitter systems has necessitated the development of high intensity radiated field (HIRF) requirements. These high intensity radiated fields and the certification requirements are defined in AC 20-158 and Section 20 of RTCA DO-160. Due to the complexity of the certification requirements and procedures as evidenced by the expansion of RTCA DO-160, Section 20, the certification or qualification requirements for HIRF are discussed separately within Section 4.3.3. Similarly, RTCA DO-160, Section 22, details the certification or qualification requirements for induced lightning effects and are discussed separately within Section 5 of this document.

An overview of the flow of EMI, lightning, and HIRF requirements from certification authority regulations down to specific methods and guidance is detailed in Figure 1. Although Figure 1 specifically uses FAA certification requirements as a starting point, the flow is similar for other certification authorities.

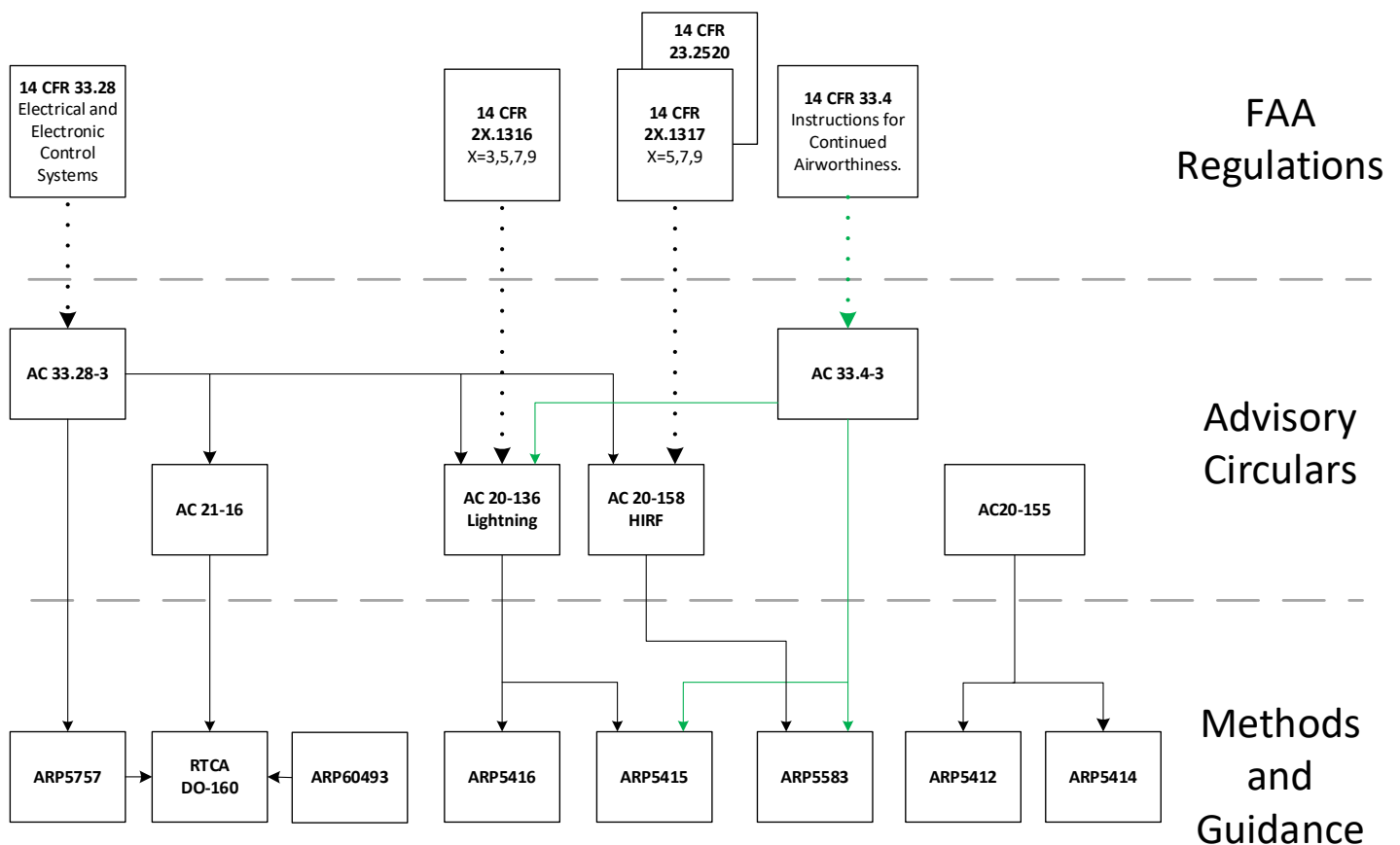


Figure 1 - Certification requirements flow

4.2.1 Fundamentals of EMI

The EMI community has distinguished between a noise emitting source and a noise susceptible victim by grouping electrical noise measurement into two categories:

1. Emissions (or interference)
2. Susceptibility

Both categories are further divided into two groups, based on the propagation method:

- a. Radiated
- b. Conducted

This provides a set of four categories into which electrical noise measurement falls today.

- 1a. Radiated emissions (or interference)
- 1b. Conducted emissions (or interference)
- 2a. Radiated susceptibility
- 2b. Conducted susceptibility

4.2.1.1 Radiated Emissions/Susceptibility

Electrical/electronic engine control systems are a natural source of emissions which can be radiated from a component enclosure/housing or more predominately from engine and engine to airframe cables. In the former case, metallic housings usually provide more than adequate shield effectiveness (attenuation). However, housing discontinuities such as access plate interfaces, drain holes, pressure ports, etc., must be addressed to maintain necessary attenuation. The use of non-metallic (composite) housings require more in depth consideration to produce adequate shield effectiveness. In the second case, cable/wiring configurations can result in less than desired attenuation and ultimately significant emissions. System to system coupling, inductive or capacitive, can occur with collinear routed cables and increased emissions due to inadequate cable attenuation and can also adversely affect radiated emissions.

One of the most significant problems, which mandates emissions limits, is radiated coupling to aircraft receivers. Such emissions, if in-band, can disrupt aircraft communications and result in a reduction of reception range. Such emissions can adversely affect GPS, TCAS, transponder, etc., operation. In low frequency emissions, cables are usually the predominant source of emissions, in high frequency cases aperture leakage is typically prevalent. Even in these cases, cables are usually the predominant source of emissions. When adequate shields cannot be deployed on cables, filtering may have to be used on input/output interfaces. Radio frequency radiated emissions are normally determined over a broad frequency range. Often the measurements are made so as to distinguish between broadband and narrowband emissions. Radiated emissions can also take the form of pulse or spike emissions in real time and are not necessarily periodic but may be random in characteristic. Typical sources of potential noise in an engine control are switching power supplies, processor clocks, and data busses.

Radiated susceptibility focuses on the potential of on board transmitters or external sources (radar, other aircraft, etc.) immersing the engine control system in the radiated fields. Such radiated fields can couple to the control system, again primarily through the cable coupling media, and result in system susceptibility. It should be noted that aperture coupling is a potential path for radiated field susceptibility and should not be ignored. High intensity radiated fields have been confirmed and defined as an environment and form the basis of the radiated susceptibility requirements. To ensure compliance to these requirements, utilize a layered scheme comprised of:

- Designing the electronics for high immunity (levels as high as practically possible).
- Producing enclosures which are effective shields.