# SUMMARY OF MILITARY AND AEROSPACE EMC TESTS


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# SUMMARY OF MILITARY AND AEROSPACE EMC TESTS

Military and aerospace EMC tests cover a wide range of products. While the standards, including limits and test methods, may differ, all EMC test standards share a few commonalities. The most basic are the limits for emissions, and the types and levels of susceptibility testing.

Emissions tests (and their associated limits) are put in place for military and aerospace equipment primarily to protect other systems from interference. These other systems may or may not include radio equipment. There are examples abound showing the effect of inadequate EMC design; the Interference Technology 2016 Military EMC Guide (*Reference 1*) provides 3 such examples on page 11.

While many military and aerospace EMC issues may be addressed by operational changes, testing is still required to find weaknesses.

Military and aerospace EMC testing is performed at the system and subsystem levels. MIL-STD-464C provides requirements at the system or platform level. The latest version, MIL-STD-461G, provides requirements at the equipment or subsystem level. Reference 1 provides details on both of the standards, but this article will highlight some key tests, particularly as they relate to MIL-STD-461G.

MIL-STD-461G divides test requirements into 4 basic types. Conducted Emissions (CE), Conducted Susceptibility (CS), Radiated Emissions (RE) and Radiated Susceptibility (RS). There are a number of tests in each category; the following table, taken from MIL-STD-461G Table IV, shows these test methods.

| Table 1: MIL-STD-461G Emission and Susceptibility Requirements | |
|---|---|
| **Requirement** | **Description** |
| CE101 | Conducted Emissions, Audio Frequency Currents, Power Leads |
| CE102 | Conducted Emissions, Radio Frequency Potentials, Power Leads |
| CE106 | Conducted Emissions, Antenna Port |
| CS101 | Conducted Susceptibility, Power Leads |
| CS103 | Conducted Susceptibility, Antenna Port, Intermodulation |
| CS104 | Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals |
| CS105 | Conducted Susceptibility, Antenna Port, Cross-Modulation |
| CS109 | Conducted Susceptibility, Structure Current |
| CS114 | Conducted Susceptibility, Bulk Cable Injection |
| CS115 | Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation |
| CS116 | Conducted Susceptibility, Damped Sinusoidal Transients, Cables & Power Leads |
| CS117 | Conducted Susceptibility, Lighting Induced Transients, Cables & Power Leads |
| CS118 | Conducted Susceptibility, Personnel Borne Electrostatic Discharge |
| RE101 | Radiated Emissions, Electric Field |
| RE102 | Radiated Emissions, Antenna Spurious and Harmonic Outputs |
| RE103 | Radiated Susceptibility, Magnetic Field |
| RS103 | Radiated Susceptibility, Electric Field |
| RS105 | Radiated Susceptibility, Transient Electromagnetic Field |

A brief description of each these tests will be provided below. These are summarized from a more detailed introduction to MIL-STD-461G, which is found in the *References 1, 2, and 3*. Keep in mind that a complete copy of MIL-STD-461G is 280 pages, so any information here is brief and the standard must be read and understood. A copy of MIL-STD-461G may be obtained free. See *Reference 4*.

**CE101 Conducted Emissions, Audio Frequency Currents, Power Leads:**
CE101 is applicable from 30 Hz to 10 kHz for leads that obtain power from sources that are not part of the EUT. There is no requirement on output leads from power sources. Emission levels are determined by measuring the current present on each power lead. There is different intent behind this test based on the usage of equipment and the military service involved. The specific limits are based on application, input voltage, frequency, power, and current.

**CE102 Conducted Emissions, Radio Frequency Potentials, Power Leads:**
CE102 is applicable from 10 kHz to 10 MHz for leads that obtain power from sources that are not part of the EUT. There is no requirement on output leads from power sources. The lower frequency portion is to ensure EUT does not corrupt the power quality

(allowable voltage distortion) on platform power buses. Voltage distortion is the basis for power quality so CE102 limit is in terms of voltage. The emission levels are determined by measuring voltage present at the output port of the LISN. Unlike CE101, CE102 limits are based on voltage. The basic limit is relaxed for increasing source voltages, but independent of current. Failure to meet the CE102 limits can often be traced to switching regulators and their harmonics.

**CE106 Conducted Emissions, Antenna Port:**
CE106 is applicable from as low as 10 kHz to as high as 40 GHz (depending on the operating frequency) for antenna terminals of transmitters, receivers, and amplifiers. It is designed to protect receivers on and off the platform from being degraded by antenna radiation from the EUT. CE106 is not applicable for permanently mounted antennas.

**CS101 Conducted Susceptibility, Power Leads:**
CS101 is applicable from 30 Hz to 150 kHz for equipment and subsystem AC and DC power input leads. For DC powered equipment, CS101 is required over the entire 30 Hz to 150 kHz range. For AC powered equipment, CS101 is only required from the second harmonic of the equipment power frequency (120 Hz for 60 Hz equipment) to 150 kHz. In general, CS101 is not required for AC powered equipment when the current draw is greater than 30 amps per phase. The exception is when the equipment operates at 150 kHz or less and has an operating sensitivity of 1 µV or better. The intent is to ensure that performance is not degraded from ripple voltages on power source waveforms.

**CS103, CS104 and CS105 Conducted Susceptibility, Antenna Port, Intermodulation, Rejection of Undesired Signals and Cross-Modulation:**
This series of receiver front-end tests includes test methods for Intermodulation (CS103), Rejection of Undesired Signals (CS104) and Cross Modulation (CS105). These methods were designed for traditional tunable super-heterodyne type radio receivers. Due to the wide diversity of radio frequency subsystem designs being developed, the applicability of this type of requirement and appropriate limits need to be determined for each procurement. Also, requirements need to be specified that are consistent with the signal processing characteristics of the subsystem and the particular test procedures to be used to verify the requirement.

**CS109 Conducted Susceptibility, Structure Current:**
CS109 is a highly specialized test applicable from 60 Hz to 100 kHz for very sensitive Navy shipboard equipment (1 µV or better) such as tuned receivers operating over the frequency range of the test. Handheld equipment is exempt from CS109. The intent is to ensure that equipment does not respond to magnetic fields caused by currents flowing in platform structure. The limit is derived from operational problems due to current conducted on equipment cabinets and laboratory measurements of response characteristics of selected receivers.

**CS114 Conducted Susceptibility, Bulk Cable Injection:**
CS114 is applicable from 10 kHz to 200 MHz for all electrical cables interfacing with the EUT enclosures.

**CS115 Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation:**
CS115 is applicable to all electrical cables interfacing with EUT enclosures. The primary concern is to protect equipment from fast rise and fall time transients that may be present due to platform switching operations and external transient environments such as lightning and electromagnetic pulse.

**CS116 Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads:**
CS116 is applicable to electrical cables interfacing with each EUT enclosure and also on each power lead. The concept is to simulate electrical current and voltage waveforms occurring in platforms

from excitation of natural resonances with a control damped sine waveform.

**CS117 Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads:**
CS117 is one of two new test methods added to MIL-STD-461G. CS117 is applicable to safety-critical equipment interfacing cables and also on each power lead. Applicability for surface ship equipment is limited to equipment located above deck, or which includes interconnecting cables that are routed above deck. The concept is to address the equipment-level indirect effects of lightning as outlined in MIL-STD-464 and it is not intended to address direct effects or nearby lightning strikes.

**CS118 Conducted Susceptibility, Personnel Borne Electrostatic Discharge:**
CS118 is applicable to electrical, electronic, and electromechanical subsystems and equipment that have a man-machine interface. It should be noted that CS118 is not applicable to ordnance items. The concept is to simulate ESD caused by human contact; test points are chosen based on most likely human contact locations. Multiple test locations are based on points and surfaces which are easily accessible to operators during normal operations. Typical test points would be keyboard areas, switches, knobs, indicators, and connector shells as well as on each surface of the EUT.

**RE101 Radiated Emissions, Magnetic Field:**
RE101 is applicable from 30 Hz to 100 kHz and is used to identify radiated emissions from equipment and subsystem enclosures, including electrical cable interfaces. RE101 is a specialized requirement, intended to control magnetic fields for applications where equipment is present in the installation, which is potentially sensitive to magnetic induction at lower frequencies.

**RE102 Radiated Emissions, Electric Field:**
RE102 is applicable from 10 kHz to 18 GHz and is used to identify radiated emissions from the EUT and associated cables. It is intended to protect sensitive receivers from interference coupled through the antennas associated with the receiver.

**RE103 Radiated Emissions, Antenna Spurious and Harmonic Outputs:**
RE103 may be used as an alternative for CE106 when testing transmitters with their intended antennas. CE106 should be used whenever possible. However, for systems using active antenna or when the antenna is not removable or the transmit power is too high, RE103 should be invoked. RE103 is applicable and essentially identical to CE106 for transmitters in the transmit mode in terms of frequency ranges and amplitude limits. The frequency range of test is based on the EUT operating frequency.

**RS101 Radiated Susceptibility, Magnetic Field:**
RS101 is a specialized test applicable from 30 Hz to 100 kHz for Army and Navy ground equipment having a minesweeping or mine detection capability, for Navy ships and submarines, that have an operating frequency of 100 kHz or less and an operating sensitivity of 1 µV or better (such as 0.5 µV), for Navy aircraft equipment installed on ASW capable aircraft, and external equipment on aircraft that are capable of being launched by electromagnetic launch systems. The requirement is not applicable for electromagnetic coupling via antennas. RS101 is intended to ensure that performance of equipment susceptible to low frequency magnetic fields is not degraded.

**RS103 Radiated Susceptibility, Electric Field:**
RS103 is applicable from 2 MHz to 18 GHz in general, but the upper frequency can be as high as 40 GHz if specified by the procuring agency. It is applicable to both the EUT enclosures and EUT associated cabling. The primary concern is to ensure that equipment will operate without degradation in the presence of electromagnetic fields generated by antenna transmissions both onboard and external to the platform. The limits are platform-dependent

and are based on levels expected to be encountered during the service life of the equipment. It should be noted that RS103 may not necessarily be the worst case environment to which the equipment may be exposed.

**RS105 Radiated Susceptibility, Transient Electromagnetic Field:**
RS105 is intended to demonstrate the ability of the EUT to withstand the fast rise time, free-field transient environment of EMP. RS105 applies for equipment enclosures which are directly exposed to the incident field outside of the platform structure or for equipment inside poorly shielded or unshielded platforms and the electrical interface cabling should be protected in shielded conduit.

Not all tests are required for each type of device or intended use environment. MIL-STD-461G provides a matrix in *Table 2* showing how these tests are used based on the intended use of the device.

| Equipment and Subsystems Installed In, On, or Launched From the Following Platforms or Installations | Type of Product/Service | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CE101 | CE102 | CE106 | CS101 | CS103 | CS104 | CS105 | CS109 | CS114 | CS115 | CS116 | CS117 | CS118 | RE101 | RE102 | RE103 | RS101 | RS103 | RS105 |
| Surface Ships | A | A | L | A | S | L | S | L | A | S | A | L | S | A | A | L | L | A | L |
| Submarines | A | A | L | A | S | L | S | L | A | S | L | S | S | A | A | L | L | A | L |
| Aircraft, Army, Including Flight Line | A | A | L | A | S | S | S | | A | A | A | L | A | A | A | L | A | A | L |
| Aircraft, Navy | L | A | L | A | S | S | S | | A | A | A | L | A | L | A | L | L | A | L |
| Aircraft, Air Force | | A | L | A | S | S | S | | A | A | A | L | A | | A | L | | A | |
| Space Systems, Including Launch Vehicles | | A | L | A | S | S | S | | A | A | A | L | A | | A | L | | A | |
| Ground Army | | A | L | A | S | S | S | | A | A | A | S | A | | A | L | L | A | |
| Ground Navy | | A | L | A | S | S | S | | A | A | A | S | A | | A | L | L | A | L |
| Ground, Air Force | | A | L | A | S | S | S | | A | A | A | | A | | A | L | | A | |

Legend:
A: Applicable (in green)
L: Limited as specified in the individual sections of this standard. (in yellow)
S: Procuring activity must specify in procurement documentation. (in red)

Table 2: MIL-STD-461G Requirement matrix

Again, the reader is referred to *References 1* through *3* for more details, or to MIL-STD-461G for the details of the standard (*Reference 4*). This guide also provides a list of standards that apply to various military equipment.

A popular and common aerospace EMC requirement set by the FAA for commercial aircrafts is RTCA/DO-160, Environmental Conditions and Test Procedures for Airborne Equipment.

The latest version is RTCA/DO-160 G, published on December 8, 2010, with Change 1 published on December 16, 2015. DO-160 covers far more than just EMC issues, but the EMC subjects covered include:

- Input power conducted emissions and susceptibility, transients, drop-outs and hold-up
- Voltage spikes to determine whether equipment can withstand the effects of voltage spikes arriving at the equipment on its power leads, either AC or DC
- Audio frequency conducted susceptibility to determine whether the equipment will accept frequency components of a magnitude normally expected when the equipment is installed in the A/C
- Induced signal susceptibility to determine whether the equipment interconnect circuit configuration will accept a level of induced voltages caused by the installation environment
- RF emissions and susceptibility
- Lightning susceptibility
- Electrostatic discharge susceptibility

This document can be purchased from RTCA on their website (*Reference 5*).

A manufacturer producing products subject to the requirements in RTCA/DO-160 should obtain a copy and ensure they have a complete understanding of the content of the document, and that any laboratory testing to it is properly accredited.

**Examples of Differences in Test Equipment Between Commercial and Military Standards**

There are differences in test equipment used compared with commercial EMC tests. Some examples are provided below.

Where 50 µH LISNs are universally required for commercial EMC tests, there are specific cases for CE01 and CE02 tests where a 5 µH LISN is called out. Limits for CE101 tests are provided in dBµA. LISNs are only used for line impedance stabilization. The measurements are taken with current probes.

Limits for CE102, on the other hand, are given in dBµV and measurements are taken in much the same way as for commercial standards with the receiver connected to the RF output port of one of the LISNs and the other RF output port(s) terminated in 50 Ohms. It should be noted that MIL-STD-461G calls out a 20 dB pad on the output of the LISN to protect the receiver from transients. This is not a requirement in the commercial standards, but is worth considering when setting up a laboratory for commercial testing.

Military EMC standards, such as MIL-STD-461G, will require the use of different antennas for radiated emissions testing. Commercial equipment standards, such as CISPR 32 and ANSI C63.4, require the use of linearly polarized antennas and do not contain requirements for magnetic field testing. MIL-STD-461G, RE101, requires the use of a 13.3 cm loop sensor, not required in the commercial standards. A receiver capable of tuning from 30 Hz to 100 kHz is needed.

MIL-STD-461G, RE102, requires testing of radiated emissions to as low as 10 kHz. From 10 kHz to 30 MHz a 104 cm (41 inch) rod antenna is used. This frequency range is not covered in CISPR 32 or the FCC Rules for radiated emissions. Thus, the antenna and receiver requirements are different. From 30 MHz to 200 MHz a biconical antenna is used—this is also commonly used in commercial testing. From 200 MHz to 1 GHz, a double ridge horn antenna is called out in 461G. This is different than the tuned dipole or log periodic dipole array antennas used for commercial testing.

The test procedures are also different for radiated emissions testing, requiring different laboratory setups and test facility types. No turntable is needed for MIL-STD-461G, nor is an antenna mast capable of moving the antenna over a range of heights.

MIL-STD-461G, RS103, can require significantly higher field intensities for radiated susceptibility testing. Where CISPR 35 requires 3 V/m from 80 MHz to 1 GHz, and at a few discrete frequencies up to 5 GHz (with the option of testing a few discrete frequencies at up to 30 V/m), MIL-STD-461G requires testing from 20 V/m to as high as 200 V/m over the range of 2 MHz to 40 GHz for certain equipment. Additional test equipment (signal generators, amplifiers, antennas, etc.) is required over that needed for commercial testing.

Each test in MIL-STD-461G requires its own unique test equipment. Some may be usable for commercial testing, others may not. If testing to MIL-STD-461G, ensure that the equipment is appropriate for the tests being performed. A detailed understanding of the requirements in MIL-STD-461G is required to ensure that the proper equipment is being used and the laboratory is following the correct processes.

**References**

1. 2016 Military EMC Guide, Interference Technology
2. Ken Javor, MIL-STD-461G: The “Compleat” Review, Interference Technology, April 2016
3. Ken Javor, Why Is There AIR (in MIL-STD-461G)?, Interference Technology, April 2016
4. MIL-STD-461G, December 2015, Defense Acquisition System
5. RTCA/DO-160G, RTCA, December 2010

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