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ELECTROMAGNETIC COMPATIBILITY REQUIREMENTS FOR SPACE SYSTEMS

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DEPARTMENT OF THE AIR FORCE
Washington, D.C. 20360

MIL-STD-1541A (USAF)

Electromagnetic Compatibility Requirements for Space Systems

1. This military standard is approved for use within the Department of the Air Force, and is available for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to:

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by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

The essential difference between this revision and the preceding issue of the standard is that both the intersystem and intrasystem requirements are stated more explicitly. It is structured to enable use of the DOD Intrasystem Analysis Program. Modifications to MIL-STD-461 have been minimized. New requirements have been added to provide for control of vehicle power system transients, the effects of composite vehicles, plus the potential intersystem interference due to spectral and orbital congestion.

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SECTION 1

SCOPE

1.1 PURPOSE

This standard establishes the electromagnetic compatibility requirements for space systems, including frequency management, and the related requirements for the electrical and electronic equipment used in space systems. It also includes requirements designed to establish an effective ground reference for the installed equipment and designed to inhibit adverse electrostatic effects. The purposes of this standard are:

a. To define minimum performance requirements for electromagnetic compatibility.

b. To identify the system relationships pertinent to electromagnetic compatibility.

c. To identify requirements for system and equipment engineering designed to enable achieving compatibility in a timely, predictable, and economical manner.

d. To define requirements for equipment and system tests and analyses to demonstrate compliance with this standard.

1.2 APPLICABILITY

The requirements covered by this standard apply to launch and space vehicles plus the associated ground, airborne, or spaceborne operational and support elements of the space system. It applies to new and modified or redesigned equipment or systems, and to existing equipment used in new applications. Equipment requirements are separately stated for vehicle and ground applications. Provisions for program peculiar compatibility requirements enable its use for systems which were originally developed and qualified to conform to other similar standards. This standard does not apply to the facilities which house the ground system segments of space systems (see MIL-STD-1542). Further information on the application of this standard is given in Appendix A.

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SECTION 2

REFERENCED DOCUMENTS

2.1 GOVERNMENT DOCUMENTS

2.1.1 Specifications, Standards, and Handbooks. Unless otherwise specified, the following specifications, standards, and handbooks of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DODISS) specified in the solicitation form a part of this standard to the extent specified herein.

SPECIFICATIONS

MIL-B-5087	Bonding, Electrical and Lightning Protection for Aerospace Systems
DOD-W-83575 (USAF)	Wiring Harness, Space Vehicle, Design and Testing

STANDARDS

MIL-STD-449	Radio Frequency Spectrum Characteristics, Measurement of
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-463	Definitions and System of Units, Electromagnetic Interference and Electromagnetic Compatibility Technology
MIL-STD-1539 (USAF)	Electrical Power, Direct Current, Space Vehicle Design Requirements
MIL-STD-1757	Lightning Qualification Test Techniques for Aerospace Vehicles and Hardware

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.1.2 Other Government Documents, Drawings, and Publications. The following other Government documents, drawings, and publications form a part of this standard to the extent specified herein.

NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

NTIA Manual	Manual of Regulations and Procedures for Federal Radio Frequency Management

(Application for copies should be addressed to Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA CR-135259	NASCAP Users Manual
NASA TP2361	Design Guidelines for Assessing and Controlling Spacecraft Charging Effects

(Application for copies should be addressed to the NASA Industrial Application Center/USC, 3716 South Hope St. #200, Los Angeles, CA 90007.)

2.2 OTHER PUBLICATIONS.

The following documents form a part of this standard to the extent specified herein. Unless otherwise specified, the issues of the documents which are DOD adopted shall be those listed in the issue of the DODISS specified in the solicitation. The issues of documents which have not been adopted shall be those in effect on the date of the cited DODISS.

AMERICAN NATIONAL STANDARDS INSTITUTE

ANSI/IEEE-STD-100	IEEE Standard Dictionary of Electrical and Electronic Terms

(Application for copies should be addressed to American National Standards Institute, 1430 Broadway, New York, NY 10018)

RAND CORPORATION

R-3046-AF	Techniques for the Analysis of Spectral and Orbital Congestion in Space Systems (DTIC # ADA140841)

(Application for copies should be addressed to the Defense Technical Information Center, DTIC-FDR, Cameron Station, Alexandria, VA 22304-6145.)

2.3 ORDER OF PRECEDENCE

In the event of a conflict between the text of this standard and the references cited herein, the text of this standard shall take precedence. Nothing in this standard, however, shall supersede applicable laws and regulations unless a specific exemption has been obtained from the acquisition activity.

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SECTION 3

DEFINITIONS

Terms are in accordance with the following definitions. Electromagnetic compatibility terms which are not otherwise defined are as given by MIL-STD-463. Electrical and electronic terms which are not otherwise defined are as given in ANSI/IEEE-STD-100.

3.1 ANOMALY

An anomaly is a response of the system to extraneous conducted or radiated electromagnetic energy that involves degradation of the intended input-output relationship, by an amount and for a time duration, which is not explicitly permitted by the item specification or provided for in the applicable error budget. An anomaly is also known as an improper response or a malfunction.

3.2 COMPONENT

A component is a functional unit that is viewed as an entity for purposes of analysis, manufacturing, maintenance, or record keeping. Examples are hydraulic actuators, valves, batteries, electrical harnesses, and individual electronic boxes such as transmitters, receivers, or multiplexers.

3.3 EQUIPMENT

Equipment is a general term, as used in this standard, to denote electrical and electronic components or combinations of several interconnected components. In some cases this may be a subsystem.

3.4 ITEM

Item is a nonspecific term used to denote any unit of product that may be applicable, including a system, vehicle, subsystem, component, subassembly, part, or material.

3.5 LAUNCH VEHICLE

A launch vehicle is a composite of the initial stages, injection stages, space vehicle adapter, and fairing having the capability of launching and injection of a space vehicle or vehicles into orbit.

3.6 PORT

A port is a place of access to a device or network where energy may be supplied or withdrawn or where the device or network variables may be observed or measured.

3.7 RESISTIVITY, SURFACE

Surface resistivity is the resistance of a unit length and unit width of a thin conductive film, measured between parallel edges.

3.8 RESISTIVITY, VOLUME

Volume resistivity is the resistance in ohm-centimeter of a one centimeter cube of a material, measured between parallel faces.

3.9 SAFETY MARGIN, POINT

The point safety margin is the ratio of the receptor's susceptibility threshold to the level of the interfering emissions, evaluated at a single frequency.

3.10 SAFETY MARGIN, INTEGRATED

The integrated safety margin is the reciprocal of the integral of the ratio or of the square of the ratio of the level of interfering emissions to the receptor's susceptibility threshold, evaluated over the frequency range occupied by the interfering emissions.

3.11 SPACE VEHICLE

A space vehicle is a complete, integrated set of subsystems and components capable of supporting an operational role in space. A space vehicle may be an orbiting vehicle, a major portion of an orbiting vehicle, or a payload which performs its mission while attached to a recoverable launch vehicle. The airborne support equipment which is peculiar to programs utilizing a recoverable launch vehicle is considered a part of the space vehicle being carried by the launch vehicle.

3.12 SYSTEM

A system is the composite of equipment, skills, and techniques capable of performing or supporting an operational role. A system includes all operational equipment, related facilities, material, software, services, and personnel required for its operation. Examples of systems that include space

vehicles as a major subtier element are launch systems and on-orbit systems.

3.13 VEHICLE

The term vehicle is used without modifiers to denote both launch and space vehicles; it does not pertain to ground vehicles. For applications pertaining only to launch vehicles, or only to space vehicles, the appropriate modifier is included.

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SECTION 4

GENERAL REQUIREMENTS

4.1 ELECTROMAGNETIC COMPATIBILITY

Systems shall be compatible with defined safety margins. Systems shall be free of overstress and anomalies caused by either intentional or extraneous electromagnetic energy, whether originating within or outside the system from man-made or natural sources, subject to the limitations defined in this standard (4.2 and 4.3). Energy originating within a system shall be controlled as necessary to secure a compatible system. Extraneous energy emanating from a system shall be controlled to the extent needed to be compatible with the operation of other related or unrelated systems. Compatibility is required for all operating modes and mission phases.

4.2 ELECTROMAGNETIC ENVIRONMENT

Systems shall be compatible with respect to all defined environments to which they are intended to be exposed. For vehicles, this includes the assembly, test, storage, transportation, prelaunch preparation, and operational phases. Consideration shall be given to the operational radiated environment from both friendly and hostile emitters which the system may encounter during its life cycle.

4.3 INTERSYSTEM COMPATIBILITY

All conductive and radiative interfaces between systems shall be compatible, independently of whether the interfaces are intentional or incidental, and whether the systems are related or unrelated. Radio frequency receiving and transmitting subsystems are regarded as conforming if the frequency management and equipment requirements of this standard are satisfied.

4.4 FREQUENCY MANAGEMENT

System and equipment emission and susceptibility characteristics shall conform to established international, national, and military frequency management requirements, standards, procedures and policies to ensure that the systems neither causes nor receives harmful interference to or from other authorized spectrum users when placed in their intended operational environment. Frequency bands used shall conform to those allocated to the applicable radio service.

4.5 INTRASYSTEM COMPATIBILITY

The equipment composing a system shall be compatible at all conductive and radiative interfaces, independently of whether the interfaces are intentional or incidental.

4.6 LIGHTNING

Vehicle and equipment designs shall prevent overstress or damage induced by a lightning strike to the nearest facility lightning protective device, by a lightning strike just outside the zone of protection, or by a lightning strike near or above underground cables which are a part of the system.

4.7 TRIBOELECTRIC CHARGING

Disturbances in the performance of launch vehicles, which may arise from electrostatic charging of external surfaces by impact of atmospheric particles and which may lead to corona or streamer discharges and sparking, shall be prevented by bonding all conductive parts and by controlling the charge accumulation on external dielectric surfaces.

4.8 MAGNETOSPHERIC CHARGING

Disturbances in the performance of space vehicles, which may arise from differential charging of external surfaces and internal components by space plasma and which may lead to electrical discharges, shall be minimized by bonding all conductive parts and by controlling the charge accumulation on external dielectric surfaces and in bulk dielectrics.

4.9 ELECTROMAGNETIC COMPATIBILITY CRITICALITY CATEGORIES

System and equipment designs shall provide electromagnetic interference safety margins in accordance with the worst case potential criticality of the effects of interference induced anomalies. The following categories shall be used:

a. Category I: Serious injury or loss of life, damage to property, or major loss or delay of mission capability

b. Category II: Degradation of mission capability, including any loss of autonomous operational capability

c Category III: Loss of functions not essential to mission

4.10 SAFETY MARGINS

Electromagnetic interference safety margins shall incorporate allowances for the effects of failures of redundant items, variations in characteristics due to ageing and between like units. Other system requirements are as follows:

a. Category I: 12 dB for qualification; 6 dB for acceptance

b. Category II: 6 dB

c. Category III: 0 dB

Category I and II safety margins shall be increased by 6 dB if the only practicable method of verification is entirely by analysis based on estimated emission or susceptibility characteristics (4.11).

4.10.1 Degradation Criteria. Safety margins shall be related to definite degradation criteria depending upon whether the appropriate requirement is freedom from overstress or damage due to continuous or aperiodic interference, autonomous recovery to the state prior to the occurrence of aperiodic interference, or continuous operation within specification limits.

4.10.2 Superposition. The specified safety margins shall be obtained with the combined effects of conducted and radiated broadband and narrowband emissions.

4.11 SYSTEM REQUIREMENTS EVALUATION.

System analyses shall be performed to validate reductions in the requirements of this standard, to define certain requirements which are commonly peculiar to a system (such as those pertaining to signal and control circuits), and to identify the need for requirements which must be more restrictive or severe than those in this standard. The resulting program peculiar requirements are subject to the approval of the contracting officer.

4.11.1 Intersystem Analysis. Global compatibility with the radiations of all communications-electronics activities, whether earth or space based, shall be evaluated using the techniques described in the NTIA manual and Rand Report R-3046-AF, or equivalent. Intersystem compatibility analysis for conductive interfaces shall be done using the methods specified by this standard for intrasystem analysis (4.11.2).

4.11.2 Intrasystem Analysis. Electromagnetic compatibility calculations entail finding the peak response of the potentially susceptible circuits in the time domain to several or more extraneous emissions which may be coupled through one or more transfer functions. For steady state conditions, analyses based on the direct and inverse Fourier transforms, plus the convolution theorem, are appropriate and shall be used. Either amplitude or power spectral density functions may be used. (See Appendix A for suitable and well documented analysis programs.)

4.11.2.1 Frequency and Time Domain. Steady state emissions shall be stated in the frequency domain for the same frequency ranges as for the corresponding requirements of MIL-STD-461 as modified by this standard. Oscillatory load switching transients shall be defined in both the time and frequency domain; nonoscillatory transients may be defined only in the time domain.

4.11.2.2 Reference Requirements. The evaluation shall include all the emission and susceptibility requirements specified in MIL-STD-461, as modified by this standard, for the classes of equipment under consideration. It shall include the applicable technical standards specified in the NTIA manual.

4.11.2.3 Interference Coupling Modes. The analyses shall incorporate mathematical models to account for the following:

a. Transverse and common-mode effects in signal and power circuits, including the effects of power source voltage ripple.

b. Coupling between circuits in interconnecting cables.

c. Bilateral coupling between the system antennas and circuits in interconnecting cables.

d. Bilateral coupling between the system antennas, between the equipment enclosures, and between antennas and enclosures.

4.11.2.4 Susceptibility Requirements. Susceptibility requirements shall be shown to be sufficient to provide the required integrated safety margins for the applicable frequency range and point safety margins at all frequencies in that range.

4.11.2.5 Simplifications. Circuits within an interconnecting cable may be represented by only one of each distinct signal classification, as determined by similarity of signal characteristics and the terminations.

4.11.3 Signal and Control Interface Circuits. Emission and susceptibility requirements for signal and control circuits shall be developed and specified as program peculiar limits. Values suitable for the signal levels and impedances characteristic of the applicable circuits shall be established.

4.11.4 Lightning Analysis. Susceptiblity to lightning and lightning protection shall be addressed in the analysis.

4.11.5 Magnetospheric Charging Analysis. Magnetospheric charging susceptibility and protection shall be addressed in the analysis. The program described in NASA CR-135259 shall be used. NASA TP2361 shall be used as a guide in determining applicable design requirements.

4.11.6 Triboelectric Charging Analysis. For launch vehicles, triboelectric charging shall be addressed.

4.12 NONSTANDARD LIMITS

Changes in the detailed emission and susceptibility limits of this standard shall be justified by analysis.

4.13 CONSOLIDATED EQUIPMENT REQUIREMENTS

A single set of compatibility requirements shall be established for each equipment. If more than one set is needed (e.g., for items which operate only in orbit, as contrasted with those which also operate in the launch and ascent environment), the differences shall be covered by a special classification method similar to that used in MIL-STD-461. Emission and susceptibility requirements shall be stated directly and explicitly. Susceptibility requirements shall not be specified indirectly in terms of an operating environment.

4.14 EXISTING DESIGNS AND MODIFICATIONS

To the extent they are complete and suitable, prior analyses and test data shall be used to satisfy the requirements of this standard for new applications or modifications of existing items. The additional system and component analyses and tests shall be centered on defining similarities and differences and evaluating compatibility for the new situation.

4.15 GOVERNMENT FURNISHED EQUIPMENT

The system emission and susceptibility characteristics shall be such that compatibility, with safety margins, is secured if the government furnished equipment satisfies the requirements of MIL-STD-461 as supplemented and modified by the equipment

requirements of this standard (5.3). If the primary system performance requirements depend on having more restrictive requirements, or if the government furnished equipment does not conform to this standard, the contractor shall advise the Government indicating the system impact of such deficiencies and the recommended remedial steps for establishing compatibility.

SECTION 5

DETAILED REQUIREMENTS

5.1 INTERSYSTEM REQUIREMENTS

The system shall conform to the standards and requirements of the NTIA manual pertaining to the performance characteristics listed in Table I. Relaxation of these requirements is subject to special restrictions (Appendix A, 50.4.1).

5.2 VEHICLE REQUIREMENTS

5.2.1 Structural Materials. The requirements of this standard are applicable independently of whether the vehicle structure is composed of conductive, semiconductive, or nonconductive materials.

5.2.2 Electrical Ground Network. The conductive and semiconductive parts of vehicle structures and component enclosures shall be electrically connected to form a vehicle ground network (potential reference). These conductive connections may be provided by separate bonding conductors or by the bundle shields for interconnecting cables. A suitable terminal shall be provided for connection to the facility ground network during assembly and test activities.

5.2.3 Electrical Power Subsystem Referencing. The return or neutral conductor of each isolated segment of the power subsystem shall be conductively connected to the ground network so as to control the differential voltage between the circuits and metallic elements of the vehicle. Primary power circuits shall be so connected near the source. The connection location for secondary power shall be selected so as to minimize common-mode effects on signal circuits.

5.2.4 Bonding. Bonding between the conductive parts of the vehicle structure, component enclosures, and cable shields shall conform to the requirements for Class R of MIL-B-5087. Conductive films on dielectric materials (such as thermal blankets) shall be bonded to the ground network with a resistance equal or less than 10 ohms. Bonding resistance between the conductive and semiconductive items of the vehicle system shall be less than 1 ohm. Other applications of bonds shall conform to MIL-B-5087.

5.2.5 Lightning Protection. Vehicles shall satisfy the lightning requirement (4.6) when exposed to a lightning current

TABLE I. Performance Requirements Relating to Communications by Satellites

Subject	NTIA Manual Paragraph
Definitions	6.1 & 8.3.2
Frequency Bands	4.1
Spurious emissions and frequency tolerances	5.2.3
Control of emission from space-stations	8.2.32
Power flux density limits	8.2.36
Station keeping of space-stations	8.2.38
Pointing accuracy of antenna on geostationary-satellites	8.2.39
Selection of sites and frequencies for earth-stations	8.2.33
Minimum angle of earth-station antenna elevation	8.2.35
Earth-station antenna performance standards	8.2.36.4
Power and direction of maximum radiation of earth stations	8.2.35
Earth-station coordination	8.4.13
Satellite network coordination	8.4.14
Frequency assignments to transportable earth-station	8.2.43
Intra-military coordination of frequency applications	8.4.5
Basic coordination arrangement between the IRAC and the FCC	8.4.1

waveform of 200,000 amperes peak, a width of 5 to 10 microseconds at the 90 percent point, not less than 20 microseconds width at the 50 percent point, and a rate of rise of at least 100,000 amperes per microsecond (MIL-B-5087).

5.2.6 Surface Finish for Control of Electrostatic Charging. Differential electrostatic charging shall be minimized by avoiding the use of near ideal dielectric materials at the outer surface of vehicles. Grounded semiconductive surface coatings or other forms of charge leakage paths shall be provided if practicable.

a. For a grounded semiconductive coating over an insulating material, the surface resistivity shall not exceed 10^8 ohms per square.

b. For a painted surface over a grounded semiconductive material over a dielectric, the surface resistivity of the semiconductive material shall not exceed 4.6×10^7 ohms per square. The paint thickness shall not exceed 0.005 inches, and the volume resistivity shall not exceed 10^{12} ohm-centimeter.

c. The volume resistivity of a coating over a grounded metal conductor shall not exceed $(2.5/t) \times 10^{10}$ ohm-centimeters, with t equal to the coating thickness in centimeters.

5.2.7 Interconnecting Cables. External interconnecting cables shall conform to the circuit categorization, wiring, and shielding requirements of DOD-W-83575.

5.2.8 Vehicle Electrostatic Susceptibility. The integrated vehicle (without electroexplosive devices installed) shall conform to the electrostatic arc discharge susceptibility requirement of 5.3.3.10.

5.2.9 Power Bus Impedance and Transient Recovery Time. The source impedance and the transient recovery time for the power sources and distribution networks of vehicles shall be such that the following conditions are satisfied: The required safety margins shall exist with the combined effects of the steady state time varying components of source voltage, load currents and normal transients. Worst case transients shall be assumed for load switching, or changes in the operating mode of utilization equipment. This requirement applies at the power input terminals of all connected loads.

5.2.10 Electrical Power Quality.

Electrical power quality applies to both AC and DC electrical power subsystems. For DC, the vehicle shall conform to MIL-STD-1539 as modified by this standard.

5.2.10.1 Voltage Ripple. At any distribution point for a DC electrical power subsystem, the total source generated and load induced ripple, including repetitive spikes, shall not exceed 500 millivolts peak-to-peak as measured in the time domain.

5.2.10.2 Spikes. Short duration (less than 50 microseconds) aperiodic transients and short duration components of long-duration aperiodic transients shall be limited to a peak value less than three times the nominal load voltage and an impulse strength less than 0.14×10^{-3} volt-seconds.

5.2.10.3 Surges. Positive and negative voltage surges shall decay to within steady-state limits in less than 5 and 100 milliseconds, respectively.

5.2.10.4 Load Switching and Load Faults. Exclusive of spikes, the instantaneous surge amplitude produced at the main distribution point by load switching and the clearing of faults within connected loads shall remain between 65 and 130 percent of the nominal load voltage. The instantaneous surge amplitude produced at the output of a branch circuit supplying two or more loads, by the clearing of faults within one of those loads, shall remain between 0 and 175 percent of the nominal load voltage.

5.2.10.5 Power Subsystem Faults. Exclusive of spikes, the instantaneous surge amplitude produced at any distribution point during faults within the electrical power subsystem shall remain between 0 and 175 percent of the nominal load voltage.

5.3 EQUIPMENT REQUIREMENTS

5.3.1 NTIA Requirements. The equipment shall conform to the standards and requirements of the NTIA manual pertaining to the performance characteristics listed in Table I. Relaxation of these requirements is subject to special restrictions (Appendix A, 50.4.1).

5.3.2 Ground Equipment.

5.3.2.1 Interface Safety Margins. The characteristics of the ground segments of launch and space systems shall be such as to yield electromagnetically compatible performance. Safety margins shall be established at all mission critical interfaces between space vehicles and ground equipment.

5.3.2.2 Ground Power Sources. The power output circuit of ground sources for vehicle power shall be isolated from the power input circuit, control circuits, and the equipment enclosure by an insulation resistance of at least 1 megohm.

5.3.2.3 Performance Criteria. The requirements of MIL-STD-461 shall be used to establish performance criteria and for design guidance. The applicable parts of MIL-STD-461 are as follows:

a. Class A3; ground facilities: Parts 1 and 4

b. Class B ; support equipment: Parts 1 and 7

c. Class C2; power equipment: Parts 1 and 8

5.3.3 Vehicle Equipment. Vehicle equipment shall conform to Parts 1 and 3 of MIL-STD-461 except as supplemented and modified by this standard.

5.3.3.1 Independence From Conductive Vehicle Structures. Subsystems and equipment shall satisfy the requirements of this standard when operating with a ground network consisting only of the power return conductors, the conductive parts of the component enclosures, and any bundle shields for interconnecting cables. Satisfactory performance shall not depend upon having low impedance bonds between component enclosures and a highly conductive ground plane.

5.3.3.2 CE01 Applicability. This requirement is applicable.

5.3.3.3 CE06 and RE03. The frequency range specified in MIL-STD-462 shall be extended to the thirtieth harmonic or 100 gigahertz, whichever is less, for equipment operating frequencies greater than 30 megahertz. Relaxation of these requirements is subject to special restrictions (Appendix A, Tailoring limitations).

5.3.3.4 CS01 Limit. This requirement shall be satisfied under conditions such that the instantaneous voltage applied to the equipment is respectively equal to the maximum and minimum instantaneous voltage limits specified for the load equipment under steady state operating conditions .

5.3.3.5 CS02 and RS03. Susceptibility signals shall have modulation characteristics (for example, amplitude, type, degree, frequency, and waveform) which have the maximum effect on the test sample as shown by analysis. Standard signal generator modulation characteristics may be utilized if there is no reason to expect test sample sensitivity to a unique modulation type.

5.3.3.6 CS06 Limits. The following spike shall be used:

Spike #1 E_1 = 200 volts; t_1 = 10 microseconds +/- 20 percent

5.3.3.7 Electrical Power Surges. Equipment shall withstand positive and negative input voltage surges which are sustained for at least 10 and 200 milliseconds, respectively.

5.3.3.7.1 General Surge Response. Equipment shall remain undamaged when subjected to step changes of the input voltage from 0 to 175 percent and from 120 to 0 percent of the nominal load voltage. With step changes from 0 to 100 percent of the nominal load voltage the instantaneous inrush current shall not exceed 10 times the average steady-state input current.

5.3.3.7.2 Surge Response of Essential Equipment. Essential subsystems and components shall satisfy their performance requirements when subjected to input voltage step changes from 100 to 65 percent and from 100 to 130 percent of the nominal load voltage.

5.3.3.8 Signal and Control Circuits. Signal and control circuits shall conform to the program peculiar emission and susceptibility limits.

5.3.3.9 DC Electrical Power Equipment. The source generated ripple voltage at the output of electrical power subsystems measured in the time domain, shall not exceed 250 millivolts peak-to-peak including periodic spikes. This requirement applies for a resistive load at rated full-load current. The equivalent source impedance shall conform to the vehicle system requirement (5.2.9).

5.3.3.10 Equipment Electrostatic Susceptibility. The operation of logic level circuits shall not be disturbed by the arc discharge described in 6.7.2. The discharge voltage shall be 10 kilovolts for synchronous satellites. Test values for other conditions shall be determined as part of the system requirements evaluation (4.11).

SECTION 6

TEST AND EVALUATION

6.1 VERIFICATION METHODS

Compliance with system requirements shall be satisfied by a combination of system tests and analyses based on equipment electromagnetic compatibility characteristics. Definite equipment characteristics shall be established by test.

6.2 MEASURING INSTRUMENTS

Measuring instruments shall conform to MIL-STD-462.

6.2.1 Instrumentation Errors. Requirements of this standard shall be satisfied with additional margin appropriate to instrumentation accuracy.

6.2.2 Time Domain Measurements. The instrumentation bandwidth used for time domain measurements shall be at least 50 megahertz.

6.3 SYSTEM VERIFICATION

A detailed description of the tests, test methods, and analyses by which the requirements of this standard are to be satisfied shall be prepared before performing system verification.

6.3.1 Radiated Susceptibility. Except for radio frequency receivers, system safety margins with respect to radiated emissions may be established by analyses based on measured equipment susceptibility data.

6.3.2 Partitioning. System segments shall be verified individually. Combinations of segments shall then be proven compatible by tests at conductive signal and control interfaces, including tests for common-mode effects. The specified sensitivity of radio frequency receivers shall be proven by test at every level of system integration.

6.3.3 Lightning. Unless otherwise specified, the requirements for compatibility with lightning shall be satisfied by analysis. Tests, if required, shall be conducted in accordance with MIL-STD-1757.

6.3.4 Superposition Effects. Compliance with the requirement pertaining to superposition (4.10.2) may be shown by analysis.

6.4 SYSTEM QUALIFICATION TESTS

Qualification tests shall be designed to secure all data necessary to establish the specified safety margins with respect to known equipment susceptibility characteristics. The simplifications applicable to analysis (4.11.2.5) are also acceptable for demonstrating compatibility.

6.4.1 Selection of Test Points. Test points used for the validation of the electromagnetic compatibility safety margins (4.10) during the system test shall be selected from the circuits involved in all mission critical functions. Tests and analyses shall be performed to determine the applicable degradation criteria. (4.10.1). The points selected shall be the minimum number that adequately demonstrate the required margins for subsystems of the system, and shall be subject to the approval of the contracting officer.

6.4.2 Category I and II Functions. Safety margins for category I and II functions shall be established by direct measurement of extraneous emissions at conductive interfaces, including those introducing common-mode effects. Freedom from extraneous responses by radio frequency receivers shall be shown directly by test.

6.4.3 Category III Functions. Category III safety margins may be demonstrated by freedom from anomaly for all system operating conditions.

6.4.4 Test Conditions. The system test configuration shall be as nearly identical to the operational configuration as is practical, while yet providing for access to the ports at which measurements are required. The test shall include all operating modes. The effect of departures from the operational configuration shall be addressed by analysis.

6.4.5 Acceptance Criteria. Acceptance criteria shall be established for each category I and II function. If the safety margin cannot be demonstrated by the results of a single direct measurement, that allowable for each of the several or more ports involved shall be allocated and defined.

6.5 SYSTEM ACCEPTANCE TESTS

Acceptance tests shall establish compliance with the requirements for bonding (5.2.4), electrical power subsystem referencing (5.2.3), plus the limits on power quality (5.2.10). Additional tests shall be performed to reverify the safety margin for any category I or II function for which the margin required for qualification has not been demonstrated.

6.6 EQUIPMENT TESTS

Conformance to the requirements of this standard shall be demonstrated by test. Test methods and the allocated performance degradation limits shall be defined before performing equipment tests.

6.6.1 Acceptance Criteria. Equipment shall conform to the performance requirements for ground or vehicle equipment, as applicable (5.3.1, 5.3.2 or 5.3.3). Equipment shall not exhibit anomalous behavior or part degradation when subjected to the specified susceptibility tests.

6.6.2 Equipment Qualification Tests. Qualification tests shall cover all equipment performance requirements .

6.6.3 Equipment Acceptance Tests. Equipment which fail to conform to any qualification requirement, and for which a waiver was granted, shall be retested to that requirement as a part of acceptance tests to ensure that production variations do not invalidate the justification for granting the waiver.

6.7 EQUIPMENT TEST METHODS.

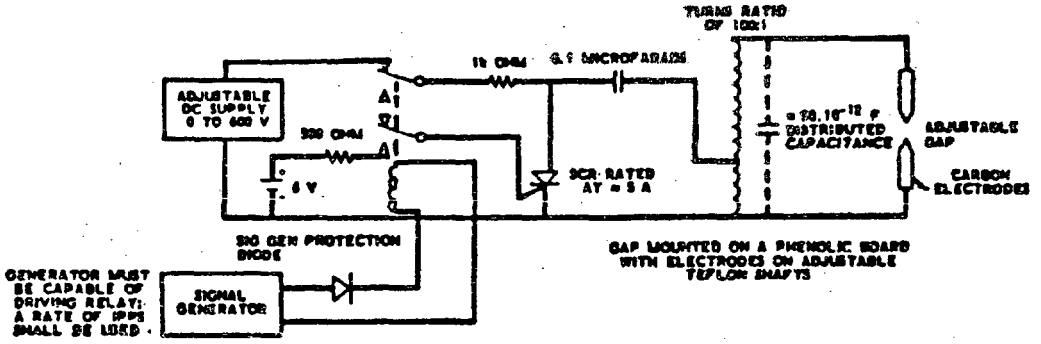
6.7.1 General. Test methods for requirements in the NTIA manual shall conform to the methods of the NTIA manual, MIL-STD-449, or MIL-STD-462. Test methods for requirements specified by MIL-STD-461 shall be in accordance with MIL-STD-462. The test method for electrostatic arc discharge susceptibility (5.3.3.10) shall conform to this standard (6.7.2). Test methods for other equipment requirements (5.3.3.7, 5.3.3.8, and 5.3.3.9) shall be established by the contractor.

6.7.2 Electrostatic Arc Discharge Susceptibility. The test setup shall simulate the operational wiring and grounding scheme. The equipment under test shall be bonded to the ground plane by the same method used for the vehicle installation. For synchronous orbits, a pulsed discharge, at a pulse rate of 1 per second for a period of 30 seconds, shall be established at a level of 10 kilovolts and at a distance of 30 centimeters from each exposed face of the test sample. The test shall be repeated by one of the following methods:

a. Using a direct discharge from one test electrode to each top corner of the test sample for equipment exposed to the direct space environment: e.g., external to a shielded space vehicle.

b. Impressing the series current from the arc-discharge through the mounting surfaces of the test sample for equipment installed within a shielded space vehicle.

If test sample failures are observed at 10 kilovolts, the voltage level shall be decreased to the point where satisfactory equipment operation is obtained, and that level noted. For orbits other than geosynchronous, the applicable test voltage shall be determined as part of the system evaluation of 4.11. Figure 1 contains a suggested arc source schematic capable of establishing the minimum required voltage and arc discharge. Any other equivalent type of circuitry may be used and shall be fully described in the applicable electromagnetic compatibility test plan. The energy dissipated should be equivalent to the maximum energy storage capacity of storage elements subject to electrostatic charging. The energy levels in Figure 1 are given only as minimum values for equipment testing, and may not be adequate for full system level testing.



TYPICAL GAP-SPACING AND VOLTAGE BREAKDOWN LEVEL		
GAP (mm)	VOLTAGE BREAKDOWN (kV)	APPROX ENERGY DISSIPATED (W-s)
1	1.5	36.5×10^{-6}
2.5	2.5	300×10^{-6}
5	5	900×10^{-6}
7.5	9	$2,500 \times 10^{-6}$

Figure 1. Schematic Diagram of Arc Source

Custodian:
Air Force - 19

Preparing Activity:
Air Force - 19

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APPENDIX A

APPLICATION INFORMATION

10. SCOPE

This appendix contains information for use in the application of this standard by an acquisition activity. Its use is optional.

20. REFERENCED DOCUMENTS

The following documents are technical references which may be useful during the implementation of this standard:

20.1 Government Documents, Drawings, and Publications.

SPECIFICATIONS

MIL-E-6051	Electromagnetic Compatibility Requirements, Systems

HEADQUARTERS, AIR FORCE SYSTEMS COMMAND

AFSC DH 1-4	Electromagnetic Compatibility (Design Handbook Series 1-4)

(This document is available from ASD/ENES, Wright-Patterson AFB, OH 45433-6503.)

ROME AIR DEVELOPMENT CENTER, AIR FORCE SYSTEMS COMMAND

RADC-TR-73-217	Method of Moments
RADC-TR-73-324	Analysis of Nonlinear Systems with Multiple Inputs
RADC-TR-74-342	Intrasystem Electromagnetic Compatibility Program, Dec. 1974, (3 volumes)
RADC-TR-76-101	Application of Multiconductor Transmission Line Theory to the Prediction of Cable Coupling, (8 volumes)

RADC-TR-82-20 Intrasystem Electromagnetic Compatibility Program, Feb. 1982, (IAP) Model Improvement

(These documents are available from the Defense Technical Information Center, DTIC-FDR, Cameron Station, Alexandria, VA 22304-6145.)

SPACE DIVISION, AIR FORCE SYSTEMS COMMAND

SAMSO-TR-75-44 Static-Electricity Analysis Program, Oct. 1974

SD-TR-85-26 The Aerospace Spacecraft Charging Document, 3 June 1985

(These documents are available from the Defense Technical Information Center, DTIC-FDR, Cameron Station, Alexandria, VA 22304-6145.)

AIR FORCE GEOPHYSICS LABORATORY, AIR FORCE SYSTEMS COMMAND

AFGL TR-79-0082 Spacecraft Charging Technology (1978)

AFGL TR-81-0270 Spacecraft Charging Technology (1980)

(These documents are available from the Defense Technical Information Center.)

NAVAL RESEARCH LABORATORY

Reduction of Spacecraft Charging Using Highly Emissive Surface Materials; Effect of the Ionosphere on Space and Terrestrial Systems, by A. G. Rubin, P. L. Rothwell, and G. K. Yates. (Naval Research Laboratory, p. 313, 1978) (DTIC # ADA068291)

(This document is available from the Defense Technical Information Center, DTIC-FDR, Cameron Station, Alexandria, VA 22304-6145.)

20.2 Nongovernment Documents, Drawings, and Publications.

A. B. Carlson "Communications Systems," McGraw-Hill, New York, 1968.

G. R. Cooper and C. D. McGillem "Methods of Signal and System Analysis," Holt, Rhinehart and Winston, New York, 1967.

R. Morrison — "Grounding and Shielding Techniques In Instrumentation," Wiley, New York, 2nd edition, 1977.

H. W. Ott — "Noise Reduction Techniques in Electronic Systems," Wiley, New York, 1976.

P. R. Satnnard, I. Katz, L. Gedeon, J. C. Roche, A. G. Rubin, and M. F. Tautz — Validation of the NASCAP Model Using Spaceflight Data; AIAA Meeting Paper (Reno, Nevada), Jan. 1982.

40. GENERAL INFORMATION

40.1 General Description. This standard is intended primarily to identify the requirements which describe the technical characteristics of the end item. Since tailoring of the quantitative performance requirements is often necessary or desirable, it also includes requirements for the analyses needed to validate those changes.

40.2 Intrasystem Analysis Program. This standard has been structured to make best use of the developments which have been realized from the DOD Intrasystem Analysis Program. These benefits include improved analytical methods and programs for computer analysis. The analysis programs described in RADC-TR-74-342 and RADC-TR-82-20 are suitable and well documented.

40.3 Analytical Methods. The methods presented in the applicable and the referenced documents are representative of the current art pertaining to the topics covered. Accordingly, they may be used as criteria for determining the adequacy and acceptability of any methods used.

50. DETAILED INFORMATION

50.1 Open Requirements. The following items are not specified in this standard:

a. Uninterrupted operation during lightning strikes (4.6).

b. Lightning testing (6.3.3)

50.2 Equipment Requirements. Vehicle equipment developed for different programs may be inherently incompatible because of the long standing practice of establishing program peculiar EMC

requirements. When acquiring equipment intended for use in a space system, but to be supplied as government furnished equipment, relaxation of standard equipment requirements should be avoided. For some space vehicles, reduced radiated emission limits (RE02) may be required. These reduced limits must be specified for such acquisitions.

50.3 Computer Programs. The best available analytical methods may be secured by a contract requirement for use of the Air Force standard Intrasystem Analysis Program (IAP). To preserve the benefits of standardization, the contract requirement should prohibit unauthorized changes in that program.

50.4 Tailoring Guidance.

50.4.1 Tailoring Limitations. Certain provisions of this standard (5.1) and MIL-STD-461 (CE06) cannot be modified below the limits specified by the National Telecommunications and Information Administration (NTIA) unless a written waiver of those limits is obtained from NTIA.

50.4.2 Self Tailoring. Comprehensive self tailoring is incorporated within this standard in the following ways:

a. Requirements to be met only if specified by the contracting officer (50.1).

b. Requirements of limited applicability (4.7, and 4.8)

c. Equipment requirements in accordance with the classifications of MIL-STD-461.

d. Provision for program-peculiar compatibility limits (4.11).

50.4.3 Tailoring for Cost Effectivity. In its complete form, the standard is designed to systematically limit the risk involved in developing an acceptable system design: one characterized by definite and reliable safety margins. Further tailoring to reduce these requirements introduces uncertainties, in both the development and operations phases and may or may not be cost effective. Tailoring should be based on the mission criticality of the system to which it is applied, with recognition of the attendant risk.

50.4.4 Tailoring Based On Criticality of Function. The applicability of the standard may be reduced by applying strict limits to the definition of mission critical functions (4.9), or by omitting one or more of the requirements for safety margins.

60. DATA REQUIREMENTS

This standard does not require the preparation of any plans or reports. MIL-E-6051 should be used to require an electromagnetic compatibility program. The data normally required for delivery under an electromagnetic compatibility program include:

a. Frequency allocation and assignment

b. System EMC Plan

c. Subsystem EMC Plan

d. System EMC Test Plan

e. Subsystem EMC Test Plan

f. Test reports, general

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE
MIL-STD-1541A(USAF)	Electromagnetic Compatibility Requirements for Space Systems

3a. NAME OF SUBMITTING ORGANIZATION	4. TYPE OF ORGANIZATION *(Mark one)*
	☐ VENDOR
	☐ USER
b. ADDRESS *(Street, City, State, ZIP Code)*	☐ MANUFACTURER
	☐ OTHER *(Specify)*: _____

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional	b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional
c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional	8. DATE OF SUBMISSION *(YYMMDD)*

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