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Environmental Conditions and Test Procedures for Airborne Equipment

RTCA DO-160E
Supersedes DO-160D
December 9, 2004

Prepared by SC-135

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Foreword

This document was prepared by Special Committee 135 (SC-135) and approved by the RTCA Program Management Committee (PMC) on December 9, 2004. It supersedes RTCA DO-160D dated July 29, 1997; Change 1 dated December 14, 2000; Change 2 dated June 21, 2001; and Change 3 dated December 5, 2002.

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Federal Advisory Committee and develops consensus based recommendations on contemporary aviation issues. RTCA's objectives include but are not limited to:

- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;
- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunications Union and other appropriate international organizations can be based.

The organization's recommendations are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration technical Standard Orders.

Since RTCA is not an official agency of the United States Government, its recommendations may not be regarded as statements of official government policy unless so enunciated by the U.S. government organization or agency having statutory jurisdiction over any matters to which the recommendations relate.

These standards were coordinated by RTCA SC-135 with the European Organisation for Civil Aviation Equipment (EUROCAE) Working Groups (WGs) 14 and 31. EUROCAE concurs with RTCA on the environmental conditions and test procedures set forth herein. When approved by EUROCAE, this document will be identified jointly as RTCA DO-160E/EUROCAE ED-14E.

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RTCA/DO-160E

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Section 1

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Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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1 Purpose and Applicability

This document defines a series of minimum standard environmental test conditions (categories) and applicable test procedures for airborne equipment. The purpose of these tests is to provide a laboratory means of determining the performance characteristics of airborne equipment in environmental conditions representative of those which may be encountered in airborne operation of the equipment.

The standard environmental test conditions and test procedures contained herein may be used in conjunction with applicable equipment performance standards as a minimum specification under environmental conditions, which can ensure a sufficient degree of confidence in performance during operations.

Note: *In each of the test procedures contained herein, the following phrase will be seen several times:*

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The ∀applicable equipment performance standards∀ referred to are either:

a. EUROCAE Minimum Operational Performance Specifications (formerly Requirements) (MOPS/MOPR).

b. RTCA Minimum Performance Standards (MPS) and/or RTCA Minimum Operational Performance Standards (MOPS).

c. The manufacturers equipment specification(s), where applicable.

Some of the environmental conditions and test procedures contained in this document are not necessarily applicable to all airborne equipment. The selection of the appropriate and/or additional environmental conditions and test procedures is the responsibility of the writers (authors) of the performance standards for the specific airborne equipment.

Notes:

1. *There are several additional environmental conditions (categories), that specific airborne equipment may be subjected to, that have not been included in this document. These include, but are not limited to: hail, acceleration and acoustic vibration.*

2. *The procedures for testing airborne equipment for special environmental conditions that are usually uniquely related to that specific type of airborne*

equipment, should be the responsibility of the writer (author) of the performance standard for that specific equipment.

3. *The International System of Units (SI) is usually used throughout this document as the primary values. In certain instances, however, when the primary values were derived in English units, these units are used as the primary values.*

4. *Subject to the provisions of Subsection 3.2, it is permissible to use more than one test article.*

The words airborne equipment, as used within this document, have direct applicability to most airborne equipment. It is the responsibility of those who wish to apply the test conditions and procedures contained in this document to determine the applicability of these test conditions and procedures to a specific equipment intended for installation on, or within, a specific or general class or type of aircraft.

Minimum Operational Performance Standards (MOPS) prepared by RTCA, Inc. for airborne equipment contain requirements that the equipment must meet to ensure reliable operation in actual aeronautical installations. These equipment requirements must be verified in ambient and stressed environmental conditions. The MOPS typically contain recommended bench test procedures for ambient conditions**,** and refer to RTCA Document DO-160, “Environmental Conditions and Test Procedures for Airborne Equipment,” for the stressed environmental testing. The test categories defined in DO-160 are intended to encompass the full spectrum of environmental conditions that airborne equipment may experience – from benign to very hostile.

The environmental conditions and test procedures defined herein are intended to determine only the performance of the airborne equipment under these environmental conditions and are not intended to be used as a measure of service life of the airborne equipment subjected to these tests.

Any regulatory application of this document is the sole responsibility of appropriate governmental (regulatory) agencies.

1.1 Historical Note, and General Guidance to Users

DO-160 (or its precursor, DO-138) has been used as a standard for environmental qualification testing since 1958. It has been referenced in Minimum Operational Performance Specifications (MOPS) for specific equipment designs, and is referenced in FAA Advisory Circulars as a means of environmental qualification for TSO authorization. It has been subject to a continuous process of upgrade and revision as new needs arose within the aviation community, as improved test techniques have emerged, and as the realities of equipment operation of under actual environmental conditions has become better understood.

Environmental stresses can result from natural forces or man made effects, and may be mitigated by details of the equipment installation. The categories that have been developed over time reflect a reasonably mature understanding as to the severity of the stresses, the degrees of mitigation achievable in the design of an installation, and the robustness that must be designed into equipment in order to perform under the resultant stress. In order to fully reap the advantages of the maturity of this document, it is incumbent upon the designers of the installed equipment, as well as the designers of the host installation, to consider the categories defined herein as early in their programs as feasible. The categories defined within each environmental test procedure have proved to be a practical set of boundary conditions between the requirements of real world installations and the performance of installed equipment. Effective dialogue between the airframe and equipment designers is essential to ensure that correct categories are utilized.

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2 Definitions of Terms, General

This section contains the definitions of general terms that are utilized throughout this document. The definition of terms specific to a particular section may be found in the appropriate section.

2.1 Equipment Temperature Stabilization

a. Not Operating

The equipment is considered temperature stabilized when the temperature of the functioning parts of the test item considered to have the longest thermal lag are within three degrees Celsius of the specified test temperature. When temperature measurement of the largest internal mass is not practical, the minimum time considered applicable for temperature stabilization shall be three hours.

b. Operating

The equipment is considered temperature stabilized when the functioning parts of the test item considered to have the longest thermal lag do not vary by more than two degrees Celsius per hour. When temperature measurement of the largest internal mass is not practical, the minimum time considered applicable for temperature stabilization shall be two hours.

2.2 Maximum Duty Cycle

When operation of an equipment is periodic, the maximum duty cycle is the relationship between the maximum length of time for which the equipment is designed to operate at its rated capacity and the length of time during which the equipment is not operating; or when the operating capacity is at a defined minimum. The maximum duty cycle shall be established by the equipment specification.

2.3 Not Operating

Not operating is that condition wherein no power is applied to the equipment unless otherwise defined in the individual equipment specification.

2.4 Controlled or Partially Controlled Temperature Locations

A controlled or partially controlled temperature location is a space within an aircraft in which the temperature of the air is maintained by an environmental control system (see Table 4-1 of applicable category).

2.5 Total Excursion

Total excursion means the total displacement from positive maximum to negative maximum.

2.6 Equipment

The term Aequipment≅ includes the test items and all of the components or units necessary (as determined by the equipment manufacturer) for the equipment to properly perform its intended function(s). The equipment shall be representative of the production standard that will be utilized in service.

2.7 Altitude

Altitude represents the environmental pressure relative to sea level to which the equipment is exposed during the tests.

2.8 Category of Tests and Declarations

For each environmental condition addressed in this document, the equipment supplier shall select from categories defined within the particular sections that category which best represents the most severe environment to which the equipment is expected to be regularly exposed during its service life. The category selections thus determined are to be tabulated on the Environmental Qualification Form and/or the equipment nameplate in accordance with the guidelines presented in Appendix A.

Use of Category X on the environmental qualification form and/or equipment nameplate in association with any environmental test procedure of this document is reserved for the case where the equipment supplier wishes to indicate that compliance with equipment performance standards has not been demonstrated under the environmental conditions addressed by that particular procedure.

When the Statement "DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS" is found at the end of or during the test procedures, it should be understood that performance compliance and verification is considered to be the requirement that allows the equipment to be certified as to its ability to perform its intended function(s) during and/or after a specific test category.

3 Conditions of Tests

3.1 Connection and Orientation of Equipment

Unless otherwise stated, connect and orient the equipment (e.g. mechanically and electrically) as recommended by the equipment manufacturer for normal service installation, including any cooling provisions, as necessary to perform the tests and to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Interconnecting cable lengths, where not specified, shall be at least 1.50 m long and shall be configured so as to allow one common bundle of 1.20 m. Any inputs or outputs to or from other equipment(s) normally associated with the equipment(s) under test shall be connected or adequately simulated.

Note: Paragraphs 19.3, 20.3 and 21.5, if applicable, will require an interconnecting cable longer than these minimums.

3.2 Order of Tests, Multiple Test Articles

It is the responsibility of the equipment manufacturer to determine any requirements for cumulative or combined testing, and to reflect these requirements in the equipment specification and test plan. Insofar as any such requirements are not compromised, multiple test articles may be used, tests may be performed in any order, and separate test articles may be used for demonstrating compliance with the separate tests.

Note: In cases where cumulative testing is required, or multiple tests are to be performed upon a single test article, the following provisions shall apply:

a. The salt fog test shall not be conducted prior to the fungus resistance test.

b. The sand and dust test shall not be conducted prior to the fungus resistance, salt fog, or humidity tests.

c. The explosive atmosphere tests shall not be conducted prior to any other DO-160 tests.

d. The flammability tests shall not be conducted prior to any other DO-160 tests.

3.3 Combining Tests

It is acceptable to employ alternate procedures developed as combinations of the procedures described herein, provided it can be demonstrated that all applicable environmental conditions specified in the original procedures are duplicated or exceeded in the combined procedure. If alternate procedures are used, appropriate information should be provided along with the Environmental Qualification Form, (see Appendix A).

3.4 Measurement of Air Temperature in the Test Chamber

The temperature of the air in the test chamber shall be measured at a location where the air conditions are representative of that immediately surrounding the equipment. Measurement of chamber wall temperature is not suitable, due to temperature lag and heat transfer through the chamber wall.

A means of circulating air in the test chamber should be employed to assure an approximate uniform air temperature condition throughout the chamber. When such means are employed, the air movement shall not be directed on the equipment under test, and the equipment shall be tested at the minimum flow rate consistent with the purpose of maintaining a uniform temperature distribution in the chamber. The ambient air velocities surrounding equipment not requiring auxiliary cooling shall remain comparable to those air velocities that occur from natural convection.

For equipment that requires auxiliary cooling to assure proper operation, as defined in the equipment installation instructions, the following applies:

a. If air is the cooling medium, the supplied cooling air characteristics shall be the same as the specified chamber air characteristics, unless otherwise specified by the equipment manufacturer.

b. If the cooling medium is not air, the medium and its supply temperature shall be as specified by the equipment manufacturer.

Note: *For equipment whose installation location is known and defined relative to other equipment, sources of radiated heat and/or impediments to normal convection should be simulated in the test.*

3.5 Ambient Conditions

Unless otherwise specified, all tests shall be made within the following ambient conditions:

a. Temperature: +15 to +35 degrees Celsius.

b. Relative Humidity: Not greater than 85 percent.

c. Ambient Pressure: 84 to 107 kPa (equivalent to +5,000 to -1,500 ft) (+1525 to -460 m).

When tests are conducted at ambient conditions that differ from the above values, the actual conditions shall be recorded.

3.6 Environmental Test Condition Tolerances

Unless otherwise specified, tests made at environmental conditions other than ambient, as defined above, shall be conducted subject to the following tolerances:

a. Temperature: +/– 3 degrees Celsius.

b. Altitude: +/– 5 percent of specified pressure.

3.7 Test Equipment

All stimulus and measurement equipment used in the performance of the tests should be identified by make, model, serial number and the calibration expiration date and/or the valid period of calibration where appropriate. When appropriate, all test equipment calibration standards should be traceable to national and/or international standards.

3.8 Multiple Unit Equipment

If the equipment to be tested consists of several separate units, these units may be tested separately, provided the functional aspects are maintained as defined in the relevant equipment specification.

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 4

Temperature and Altitude

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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4.0 Temperature and Altitude

4.1 Purpose of the Tests

These tests determine the performance characteristics of equipment at the applicable categories for the temperatures and altitudes specified in Table 4-1 and at the pressures defined in Table 4-2.

4.2 General

Several temperature and altitude test procedures are defined, each to be selected according to the category for which the equipment is designed to be used when installed in an aircraft (see Subsection 4.3 and Table 4-1).

Note: The selection of a temperature/altitude category depends on the location in (or on) the aircraft, the maximum operating altitude of the aircraft and whether the equipment is located within a temperature and/or pressure controlled area. The above conditions must be taken into consideration by the equipment designer in evaluating these requirements, which are determined by the end application and use of the equipment.

4.3 Equipment Categories

The following categories cover the wide range of environments known to exist in the majority of aircraft types and installation locations. It should be recognized that not all possible combinations of temperatures and altitude limits are covered in these equipment categories. Categories for in-flight loss of cooling are defined in paragraph 4.5.5.

Category A1

Equipment intended for installation in a controlled temperature and pressurized location, on an aircraft within which pressures are normally no lower than the altitude equivalent of l5,000 ft (4,600 m) Mean Sea Level (MSL), is identified as Category A1. This category may also be applicable to equipment installed in temperature controlled but unpressurized locations on an aircraft that operates at altitudes no higher than 15,000 ft (4,600 m) MSL.

Category A2

Equipment intended for installation in a partially controlled temperature but pressurized location on an aircraft within which the pressures are normally no lower than the altitude equivalent of 15,000 ft (4,600 m) MSL is identified as Category A2. This category may also be applicable to equipment installed in partially controlled temperature but unpressurized locations on an aircraft that operates at altitudes no higher than 15,000 ft (4,600 m) MSL.

Category A3

Equipment intended for installation in a controlled or partially controlled temperature but pressurized location within an aircraft within which the pressures are normally no lower than the altitude equivalent of 15,000 ft (4,600 m) MSL, where the temperatures will be more severe than those for categories A1 and A2, is identified as Category A3.

Category A4

Equipment intended for installation in a controlled temperature and pressurized location, on an aircraft within which pressures are normally no lower than the altitude equivalent of 15,000 ft. (4,600m) Mean Sea Level (MSL), for which temperature requirements differ from category A1 as declared by the equipment manufacturer. This category may also be applicable to equipment installed in a temperature controlled but unpressurized locations on an aircraft that operates at altitudes no higher than 15,000ft. (4,600m) MSL, for which temperature requirements differ from category A1 as declared by the equipment manufacturer.

Category B1

Equipment intended for installation in a non-pressurized but controlled temperature location in an aircraft that is operated at altitudes up to 25,000 ft (7,620 m) MSL is identified as Category B1.

Category B2

Equipment intended for installation in non-pressurized and non-controlled temperature locations on an aircraft that is operated at altitudes up to 25,000 ft (7,620 m) MSL is identified as Category B2.

Category B3

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 25,000 ft (7,620 m) MSL is identified as Category B3.

Category B4

Equipment intended for installation in a non-pressurized location on an aircraft that is operated at altitudes up to 25,000 ft (7,620 m) MSL, for which temperature requirements differ from B1and B2, is identified as Category B4.

Category C1

Equipment intended for installation in a non-pressurized but controlled temperature location in an aircraft that is operated at altitudes up to 35,000 ft (10,700 m) MSL is identified as Category C1.

Category C2

Equipment intended for installation in non-pressurized and non-controlled temperature locations within an aircraft that is operated at altitudes up to 35,000 ft (10,700 m) MSL is identified as Category C2.

Category C3

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 35,000 ft (10,700 m) MSL is identified as Category C3.

Category C4

Equipment intended for installation on a non-pressurized aircraft that is operated at altitudes up to 35,000 ft (10,700 m) MSL, for which temperature requirements differ from C1and C2, is identified as Category C4.

Category D1

Equipment intended for installation in a non-pressurized but controlled temperature location on an aircraft that is operated at altitudes up to 50,000 ft (15,200 m) MSL is identified as Category D1.

Category D2

Equipment intended for installation in non-pressurized and non-controlled temperature locations on an aircraft that is operated at altitudes up to 50,000 ft (15,200 m) MSL is identified as Category D2.

Category D3

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 50,000 ft (15,200 m) MSL is identified as Category D3.

Category E1

Equipment intended for installation in non-pressurized and non-controlled temperature locations on an aircraft that is operated at altitudes up to 70,000 ft (21,300 m) MSL is identified as Category E1.

Category E2

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 70,000 ft (21,300 m) MSL is identified as Category E2.

Category F1

Equipment intended for installation in non-pressurized but controlled temperature locations on an aircraft that is operated at altitudes up to 55,000 ft (16,800 m) MSL is identified as Category F1.

Category F2

Equipment intended for installation in non-pressurized and non-controlled temperature locations on an aircraft that is operated at altitudes up to 55,000 ft (16,800 m) MSL is identified as Category F2.

Category F3

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 55,000 ft (16,800 m) MSL is identified as Category F3.

4.4 Definitions of Terms

Operating Low Temperature

Operating low temperature is the lowest temperature at which equipment will normally be exposed and be required to operate.

Operating High Temperature

The operating high temperature values given in Table 4-1 are the maximum levels that the equipment will be exposed to within the particular installation area, e.g. in an enclosed space behind an instrument panel, equipment racks, power plant areas, etc., under normal operating conditions.

Short-Time Operating Temperature

These are startup conditions where equipment is turned on following a ground soak. It is expected that these temperature conditions will occur infrequently and be of short duration, since cooling or heating air circulation or other means of controlling temperature would be enabled concurrent with equipment operation.

Ground Survival Temperatures

These are the lowest and highest ground temperatures that the equipment is normally expected to be exposed to during aircraft storage or exposure to climatic extremes. The equipment is not expected to operate within specification limits at these temperatures but is expected to survive without damage.

In-Flight Loss of Cooling

This condition represents the failure of the external or internal system that normally provides dedicated cooling for the equipment. Certain equipment must survive for a limited time in the absence of cooling. Test requirements for this type of equipment shall be specified in the equipment performance specification.

4.5 Temperature Tests

4.5.1 Ground Survival Low Temperature Test and Short-Time Operating Low Temperature Test

At the ambient pressure and with the equipment not operating, stabilize the equipment at the appropriate ground survival low temperature specified in Table 4-1 Maintain this temperature for at least three hours. Then with the equipment not operating, subject it to the short time operating low temperature specified in Table 4-1 for a period of not less than 30 minutes. Place the equipment into the operating state and maintain the test chamber air temperature at the appropriate short time operating low temperature specified in Table 4-1. Operate the equipment for at least 30 minutes. Verify equipment operation per note 1 during this operating period. The test profile is shown graphically in Figure 4-1.

Note: *1) This test simulates temperature conditions that may be encountered by equipment while the aircraft is on the ground. In determining the level of performance required during the period of this test, the operational requirements of the particular equipment or systems shall be stated in the test procedure and report or in the specific equipment performance standard*

2) *If the short time operating low temperature and operating low temperature are the same, the short-time operating low temperature need not be conducted. The ground survival low temperature test may not be deleted, even if the short-time operating low temperature is identical to the operating low temperature.*

4.5.2 Operating Low Temperature Test

With the equipment operating, adjust the test air chamber air temperature to the appropriate operating low temperature specified in Table 4-1 at ambient pressure. After the equipment temperature has become stabilized, operate the equipment for a minimum of the two hours while maintaining the temperature of the air in the test chamber at the operating low temperature. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this operating period. The test profile is shown graphically in figure 4-2.

4.5.3 Ground Survival High Temperature Test and Short-Time Operating High Temperature Test

At ambient pressure and with the equipment not operating, stabilize the equipment at the appropriate ground survival high temperature of Table 4-1. Maintain this temperature for at least three hours. Then with the equipment not operating, subject it to the short-time operating high temperature specified in Table 4-1 for a period of not less than 30 minutes. Place the equipment into the operating state and maintain the test chamber air temperature at the appropriate short-time operating high temperature specified in Table 4-1. Operate the equipment for at least 30 minutes. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this operating period. The test profile is shown graphically in Figure 4-3.

Note: *1) This test simulates temperature conditions that may be encountered by equipment while the aircraft is on the ground. In determining the level of performance required during the period of this test, the operational requirements of the particular equipment or systems must be considered.*

2) If the short-time operating high temperature and operating high temperature are the same, the short-time operating high temperature test need not be conducted. The ground survival high temperature test may not be deleted, even if the short-time high temperature is identical to the operating high temperature.

4.5.4 Operating High Temperature Test

With the equipment operating, adjust the test chamber air temperature to the appropriate operating high temperature specified in Table 4-1 at ambient pressure. After the equipment temperature has become stabilized, operate the equipment for a minimum of two hours while maintaining the temperature of the air in the test chamber at the operating high temperature. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the operating period. The test profile is shown graphically in Figure 4-4.

4.5.5 In-Flight Loss of Cooling Test

Categories of In-Flight Loss of Cooling Test Periods are defined by periods during which cooling is removed.

Category V - 30 minutes minimum
Category W - 90 minutes minimum
Category P - 180 minutes minimum
Category Y - 300 minutes minimum
Category Z - As defined in the equipment specification

With the equipment operating at ambient room pressure, and with cooling air supplied in accordance with the conditions specified in Subsection 3.4, adjust the test chamber air temperature to the value specified in Table 4-1 for the loss of cooling test, and allow the equipment temperature to stabilize. Turn off the equipment cooling air supply, and operate the equipment for the period of time specified for the applicable category while maintaining the temperature of the air in the test chamber at the value specified in Table 4-1. During this period DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. The test profile is shown graphically in Figure 4-5.

Note: This test applies to equipment that requires cooling for proper operation during the operating high temperature test, paragraph 4.5.4, and has functions whose failure following in-flight loss of cooling would contribute to or cause a failure condition that would prevent the continued safe flight and landing of the airplane.

4.6 Altitude, Decompression and Overpressure Tests

Refer to Table 4-1 for altitude and to Table 4-2 for pressure values.

4.6.1 Altitude Test

Conduct this test at ambient temperature. Operate the equipment at maximum duty cycle. Decrease the pressure in the test chamber to the appropriate maximum operating altitude specified in Table 4-1. Allow the equipment temperature to stabilize. Maintain this pressure for at least two hours. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the two-hour period or at the maximum duty cycle, whichever is longer. The test profile is shown graphically in Figure 4-6.

Note: When the equipment manufacturer requires that the equipment be tested for spark-producing conditions at altitude, Sections 9.6a and 9.6b may apply. If so, the *procedures of 9.7 shall be conducted at the maximum test altitude, and paragraph 3.3 (Combining Tests) may be applicable.*

4.6.2 Decompression Test

Conduct this test at ambient temperature. With the equipment operating, adjust the absolute pressure to an equivalent altitude of 8,000 ft (2,400 m) MSL and allow the equipment temperature to stabilize. Reduce the absolute pressure to the equivalent of the maximum operational altitude for the aircraft on which the equipment will be installed (see Table 4-1). This reduction in pressure shall take place within 15 seconds. Maintain this reduced pressure for at least 10 minutes or as specified in the equipment specification. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the period at maximum operating altitude. The test profile is shown graphically in Figure 4-7.

Note: The decompression test is intended for equipment as follows:

1) Equipment installed in pressurized areas on the aircraft required to operate during and following an emergency descent.

2) Equipment utilizing high voltage electrical/electronics circuits, i.e. displays etc...

Equipment intended for installation in areas that are subject to partial pressurization shall be tested in accordance with paragraph 4.6.1 above.

4.6.3 Overpressure Test

With the equipment not operating, unless otherwise specified in the equipment specification, subject the equipment to an absolute pressure equivalent to -15,000 ft altitude (170 kPa). Maintain this condition for at least 10 minutes. Return the equipment to the ambient atmospheric pressure and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. The test profile is shown graphically in Figure 4-8.

Note: 1) This test is for equipment installed in pressurized areas. The test determines whether the equipment will withstand cabin overpressures resulting from routine aircraft pressurization system testing.

2) Equipment installed in a pressurized area and whose internal sections are vented external to the pressurized area shall have these internal sections exposed to the pressure specified in the equipment specification during the overpressure test.

<u>Table 4-1</u> Temperature and Altitude Criteria

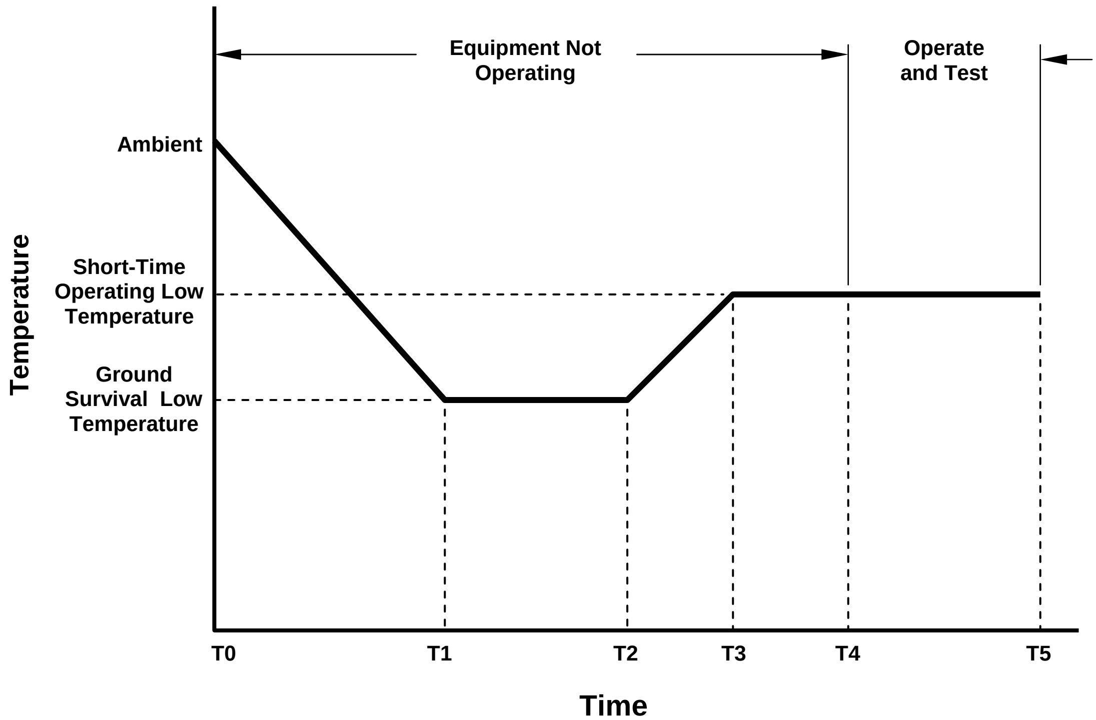
Environmental Tests	Category Paragraph 4.3																			
	A				B				C				D			E		F		
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	1	2	1	2	3
Operating Low Temp. Degrees C Paragraph 4.5.2	-15	-15	-15	-15	-20	-45	-45	Note (4)	-20	-55	-55	Note (4)	-20	-55	-55	-55	-55	-20	-55	-55
Operating High Temp. Degrees C Paragraph 4.5.4	+55	+70	+70	Note (3)	+55	+70	Note (3)	Note (4)	+55	+70	Note (3)	Note (4)	+55	+70	Note (3)	Note (3)	Note (3)	+55	+70	Note (3)
Short-Time Operating Low Temp. Degrees C Paragraph 4.5.1	-40	-40	-40	Note (3)	-40	-45	Note (3)	Note (4)	-40	-55	Note (3)	Note (4)	-40	-55	-55	-55	-55	-40	-55	-55
Short-Time Operating High Temp. Degrees C Paragraph 4.53	+70	+70	+85	Note (3)	+70	+70	Note (3)	Note (4)	+70	+70	Note (3)	Note (4)	+70	+70	Note (3)	Note (3)	Note (3)	+70	+70	Note (3)
Loss of Cooling Test Degrees C Paragraph 4.5.5	+30	+40	+45	Note (3)	+30	+40	Note (3)	Note (3)	+30	+40	Note (3)	Note (3)	+30	+40	Note (3)	Note (3)	Note (3)	+30	+40	Note (3)
Ground Survival Low Temperature Degrees C Paragraph 4.5.1	-55	-55	-55	Note (3)	-55	-55	Note (3)	-55	-55	-55	Note (3)	-55	-55	-55	-55	-55	-55	-55	-55	-55
Ground Survival High Temperature Degrees C Paragraph 4.5.3	+85	+85	+85	Note (3)	+85	+85	Note (3)	+85	+85	+85	Note (3)	+85	+85	+85	Note (3)	+85	Note (3)	+85	+85	Note (3)
Altitude Thousands of Feet Thousands of Meters Paragraph 4.6.1	15 4.6	15 4.6	15 4.6	15 4.6	25 7.6	25 7.6	25 7.6	25 7.6	35 10.7	35 10.7	35 10.7	35 10.7	50 15.2	50 15.2	50 15.2	70 21.3	70 21.3	55 16.8	55 16.8	55 16.8
Decompression Test Paragraph 4.6.2	Note (1) (4)	Note (1) (4)	Note (1) (4)	Note (1) (4)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Overpressure Test Paragraph 4.6.3	Note (2)	Note (2)	Note (2)	Note (2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note:

1) The lowest pressure applicable for the decompression test is the maximum operating altitude for the aircraft in which the equipment will be installed.
2) The absolute pressure is 170 kPa (-15,000 ft or -4,600 m).
3) To be declared by the equipment manufacturer relative to temperature extremes.
4) To be declared by the equipment manufacturer and defined in the manufacturer's installation instructions when specific critical criteria exist.

Table 4-2 Pressure Values for Various Pressure Altitude Levels

Pressure Altitude	Absolute Pressure			
	kPa	(mbars)	(in Hg)	mm Hg
-15,000 ft (-4,572 m)	169.73	1697.3	50.12	1273.0
-1,500 ft (-457 m)	106.94	1069.4	31.58	802.1
0 ft (0m)	101.32	1013.2	29.92	760.0
+8,000 ft (+2,438 m)	75.26	752.6	22.22	564.4
+15,000 ft (+4,572 m)	57.18	571.8	16.89	429.0
+25,000 ft (+7,620 m)	37.60	376.0	11.10	282.0
+35,000 ft (+10,668 m)	23.84	238.4	7.04	178.8
+50,000 ft (+15,240 m)	11.60	116.0	3.42	87.0
+55,000 ft (+16,764 m)	9.12	91.2	2.69	68.3
+70,000 ft (+21,336 m)	4.44	44.4	1.31	33.3



Note: *1) Temperature change rates from T0 to T1 and from T2 to T3 are not specified.*

2) T1 to T2 is time for equipment temperature stabilization time, plus a minimum of three hours.

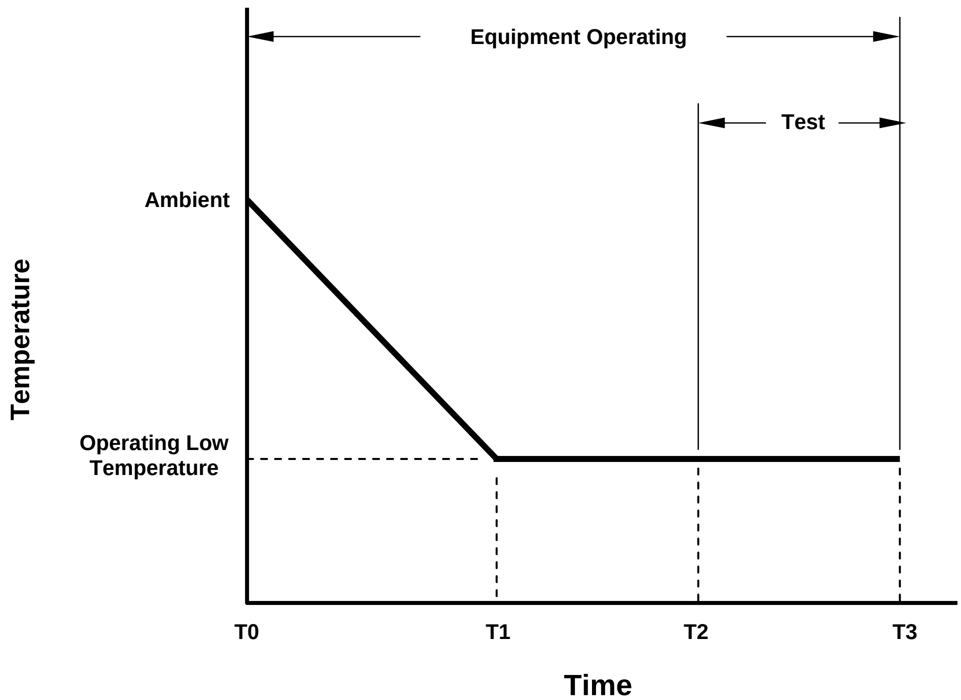
3) T3 to T4 is 0.5 hours, minimum.

4) T4 to T5 is 0.5 hours, minimum.

5) If the Short-Time Low and Ground Survival Low Temperatures are identical, the time from T2 to T4 is zero.

6) See Note 2 of the test procedure if the short-time low operating temperature is the same as the operating low temperature.

<u>Figure 4-1</u> **Ground Survival Low Temperature and Short-Time Operating Low Temperature Test**

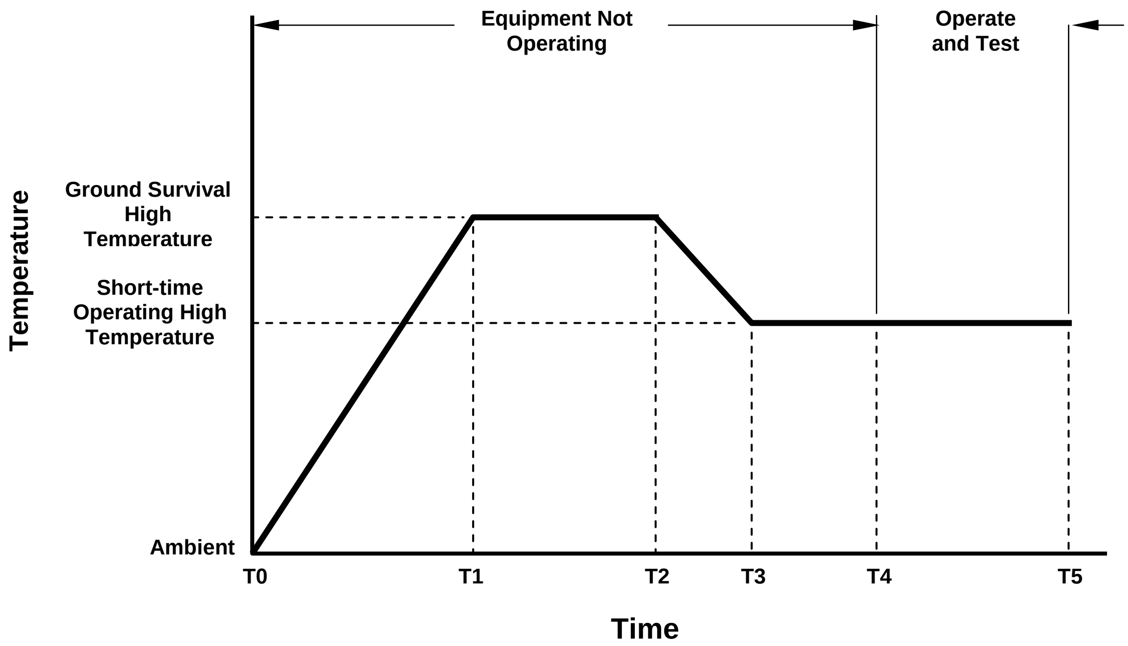


Note: *1) Temperature change rate from T0 to T1 is not specified.*

2) T1 to T2 is time for equipment temperature to stabilize.

3) T2 to T3 is 2.0 hours, minimum.

<u>Figure 4-2</u>   Operating Low Temperature Test



Note: *1) Temperature change rates from T0 to T1 and from T2 to T3 are not specified.*

2) T1 to T2 is time for equipment temperature stabilization time, plus a minimum of three hours.

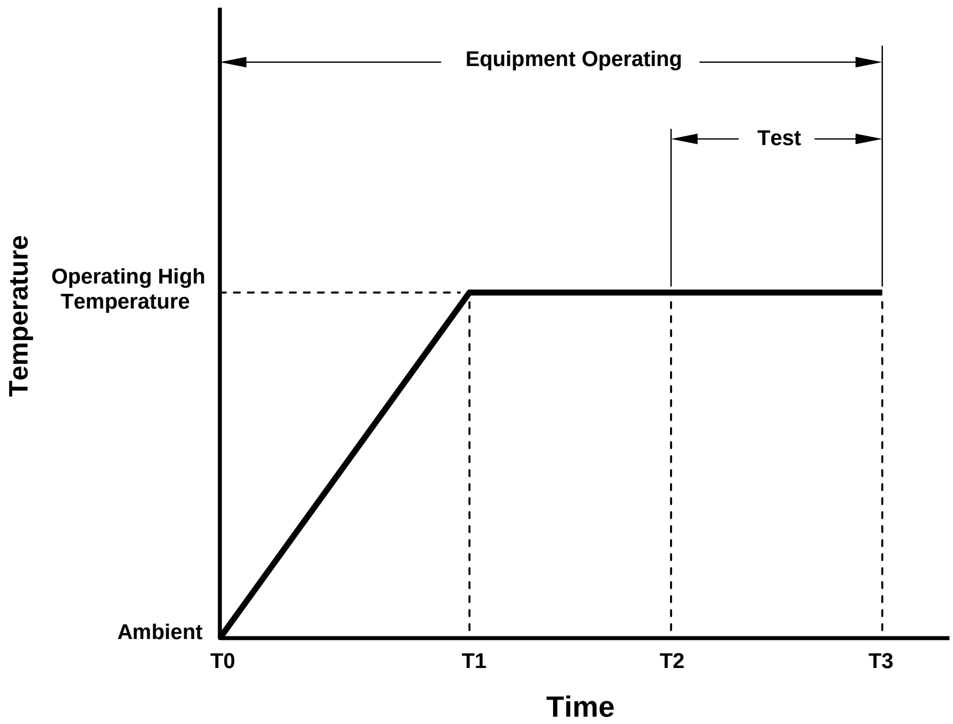
3) T3 to T4 is 0.5 hours, minimum.

4) T4 to T5 is 0.5 hours, minimum.

5) If the short-time high and ground survival high temperatures are identical, the time from T2 to T4 is zero.

6) See Note 2 of the test procedure if the short-time high operating temperature is the same as the operating high temperature.

Figure 4-3 Ground Survival High Temperature and Short-Time Operating High Temperature Test

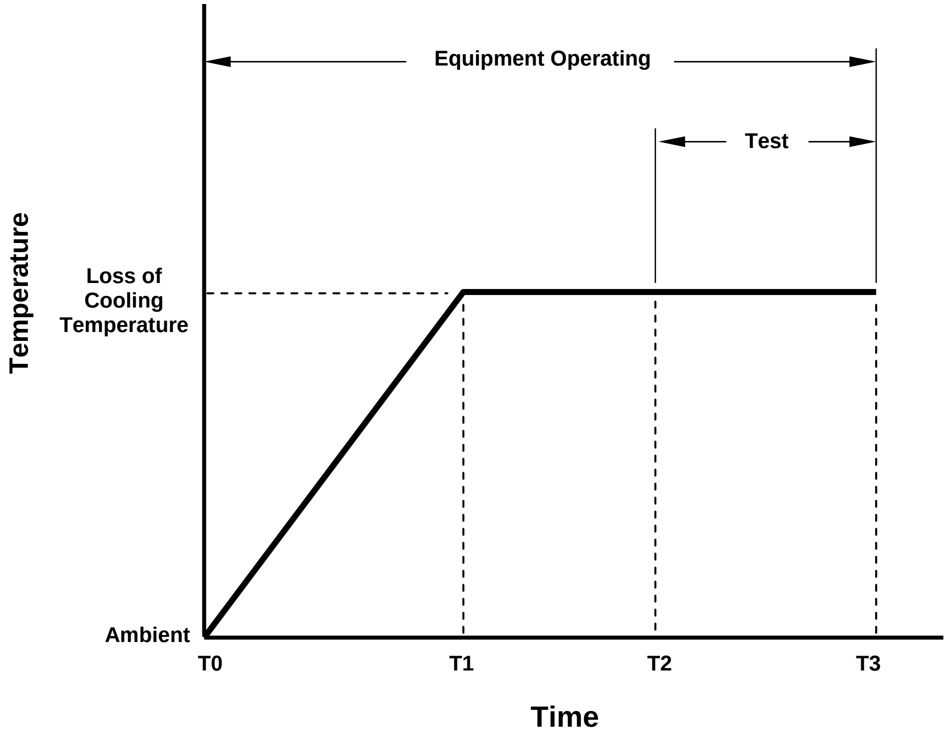


Note: 1) *Temperature change rate from T0 to T1 is not specified.*

2) *T1 to T2 is time for equipment temperature to stabilize.*

3) *T2 to T3 is 2.0 hours, minimum.*

Figure 4-4 Operating High Temperature Test

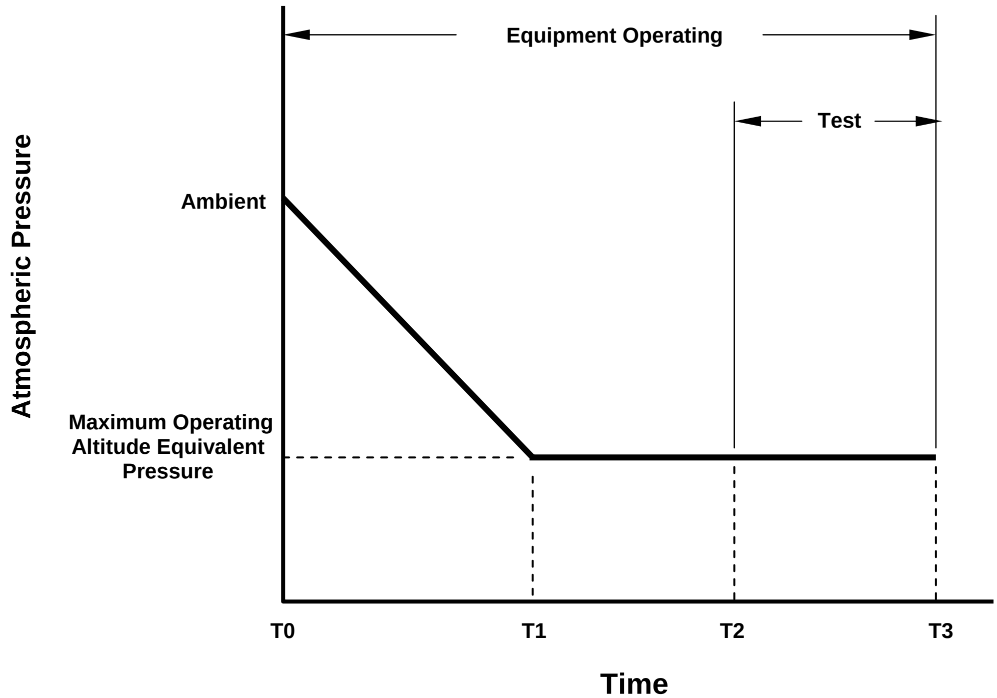


Note: 1) *Temperature change rate from T0 to T1 is not specified.*

2) *T1 to T2 is time for equipment temperature to stabilize.*

3) *See paragraph 4.5.4 for time duration T2 to T3.*

Figure 4-5 In-Flight Loss of Cooling Test

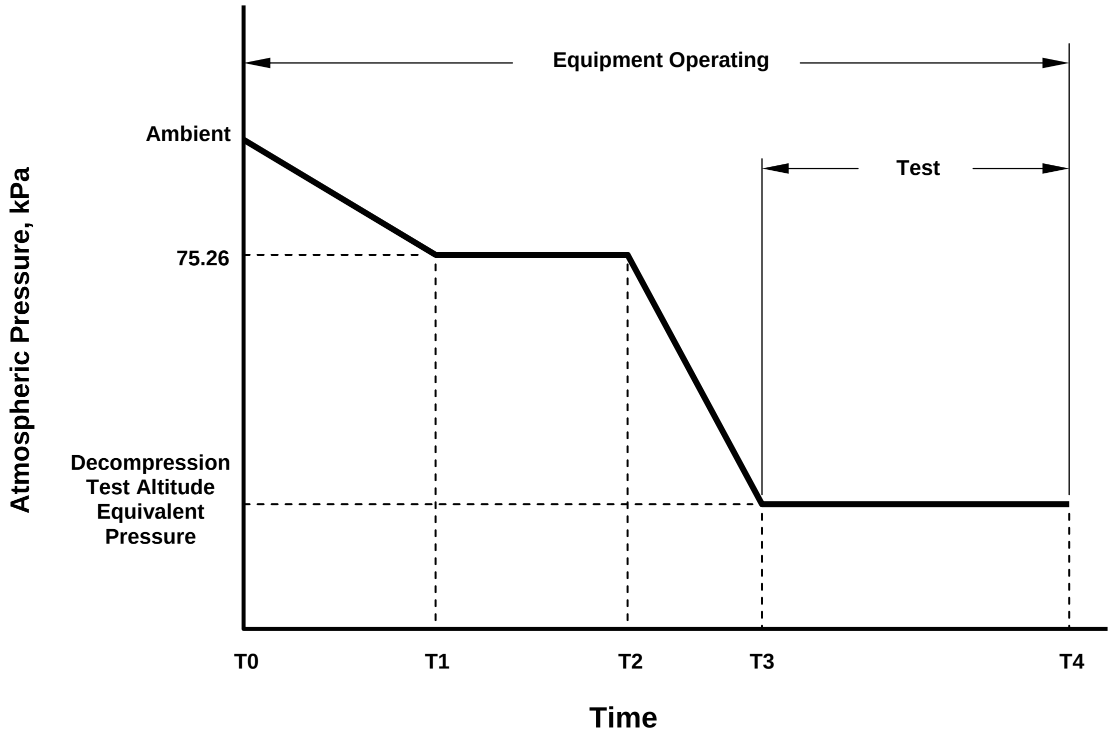


Note: *1) Pressure change rate from T0 to T1 is not specified.*

2) T1 to T2 is time for equipment temperature to stabilize.

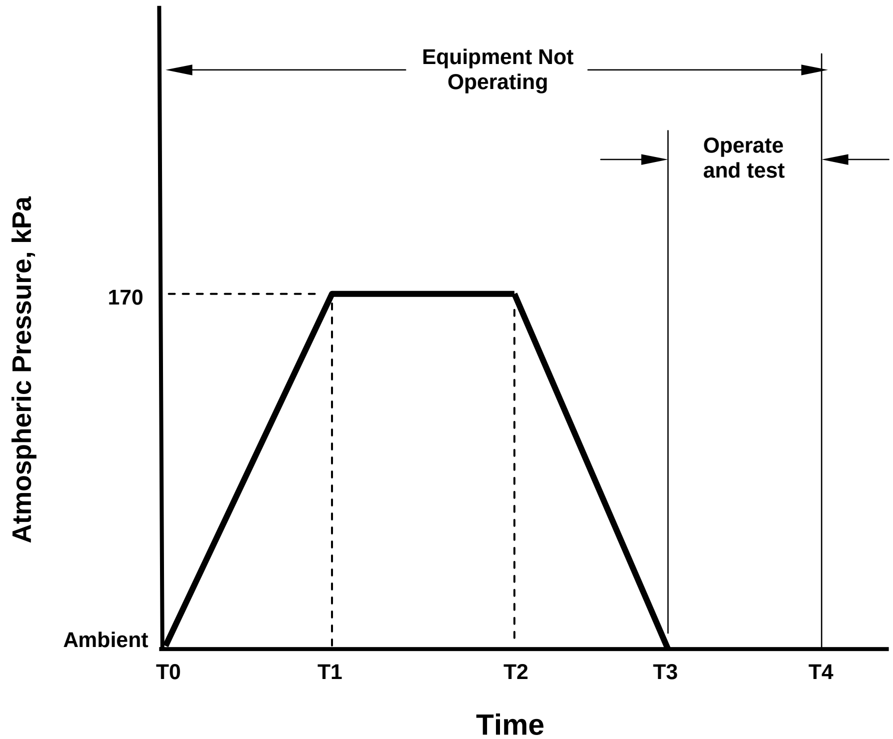
3) T2 to T3 is 2.0 hours, minimum.

Figure 4-6 **Altitude Test**



Note: *1) Pressure change rate from T0 to T1 is not specified*
2) T1 to T2 is time for equipment temperature to stabilize
3) T2 to T3 is 15 seconds, maximum
4) T3 to T4 is 10 minutes, minimum

Figure 4-7 Decompression Test



Note: *1) Pressure change rates from T0 to T1 and from T2 to T3 are not specified.*

2) T1 to T2 is 10 minutes, minimum.

3) T3 to T4 is minimum time necessary to operate and test equipment.

Figure 4-8 Overpressure Test

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 5

Temperature Variation

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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5.0 Temperature Variation

5.1 Purpose of the Test

This test determines performance characteristics of the equipment during temperature variations between high and low operating temperature extremes. The applicable categories for flight operations are shown in Table 4-1. For categories A, B, and C, it is required that the equipment be subjected to the temperature variation test in 5.3.1 when such equipment is tested according to the procedures contained in Paragraphs 4.5.1, 4.5.2, 4.5.3, and 4.5.4. For categories S1 and S2, it is required that the equipment be subjected to the temperature shock test per Paragraph 5.3.2 or 5.3.3.

5.2 Temperature Change Rates

The rates applicable to the temperature variation procedures defined in Subsection 5.3 are as follows:

Category A - For equipment external to the aircraft or internal to the aircraft:

10 degrees Celsius minimum per minute.

Category B - For equipment in a non-temperature-controlled or partially temperature controlled internal section of the aircraft:

5 degrees Celsius minimum per minute.

Category C - For equipment in a temperature-controlled internal section of the aircraft:

2 degrees Celsius minimum per minute.

Category S1 - For equipment external to the aircraft or internal to the aircraft:

Known rate of change greater than 10 degrees Celsius per minute. The rate of change shall be noted in the Qualification Form.

Category S2 - For equipment external to the aircraft or internal to the aircraft:

Unknown rate of change greater than 10 degrees Celsius per minute.

Note: 1) *Equipment qualified to Category B is considered to have met Category C.*

2) *Rates of change greater than 10 degrees Celsius minimum per minute are considered as temperature shocks. Categories S1 and S2 are intended to evaluate the effects of more rapid or sudden temperature changes to the equipment. The outer surfaces, regions, or interfaces of the equipment may be of primary interest during temperature shock as the internal regions can have comparatively long time constants to reach stabilization.*

3) *For Categories S1 and S2, Thermal Shock, Category S2 shall be used unless the temperature change rate is known, then Category S1 may be used.*

5.3 Test Procedures

5.3.1 Test Procedure Categories A, B, and C

The temperature variation test (except for Categories S1 and S2) can be combined to include the procedures of the ground survival low temperature test and short-time operating low temperature test, Paragraph 4.5.1, the operating low temperature test, Paragraph 4.5.2, the ground survival high temperature test short-time operating high temperature test, Paragraph 4.5.3, and the operating high temperature test, Paragraph 4.5.4. The following procedures shall apply:

a. If the test is a combined test, proceed in accordance with Paragraph 4.5.1, which describes the ground survival low temperature test and the short-time operating low temperature test, and Paragraph 4.5.2, the operating low temperature test. After completion of the test defined in Paragraph 4.5.1 and 4.5.2, proceed to Subparagraph c. If the test is not a combined test, commencing at ambient temperature with the equipment operating, lower the temperature in the chamber towards the operating low temperature level at the applicable rates specified in Subsection 5.2.

b. Stabilize the equipment in the operating mode at this operating low temperature level.

c. Raise the temperature in the chamber towards the operating high temperature at the applicable rate specified in Subsection 5.2. During this temperature change, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

d. Stabilize the equipment at the operating high temperature. If this is a combined test, proceed in accordance with Paragraph 4.5.3, the ground survival high temperature test and short-time operating high temperature test, and subsequently Paragraph 4.5.4, the operating high temperature test. Maintain the equipment in a non-operating state for a minimum of 2 minutes.

e. Turn the equipment on and lower the temperature in the chamber towards the operating low temperature level at the applicable rate specified in Subsection 5.2. During this temperature change DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

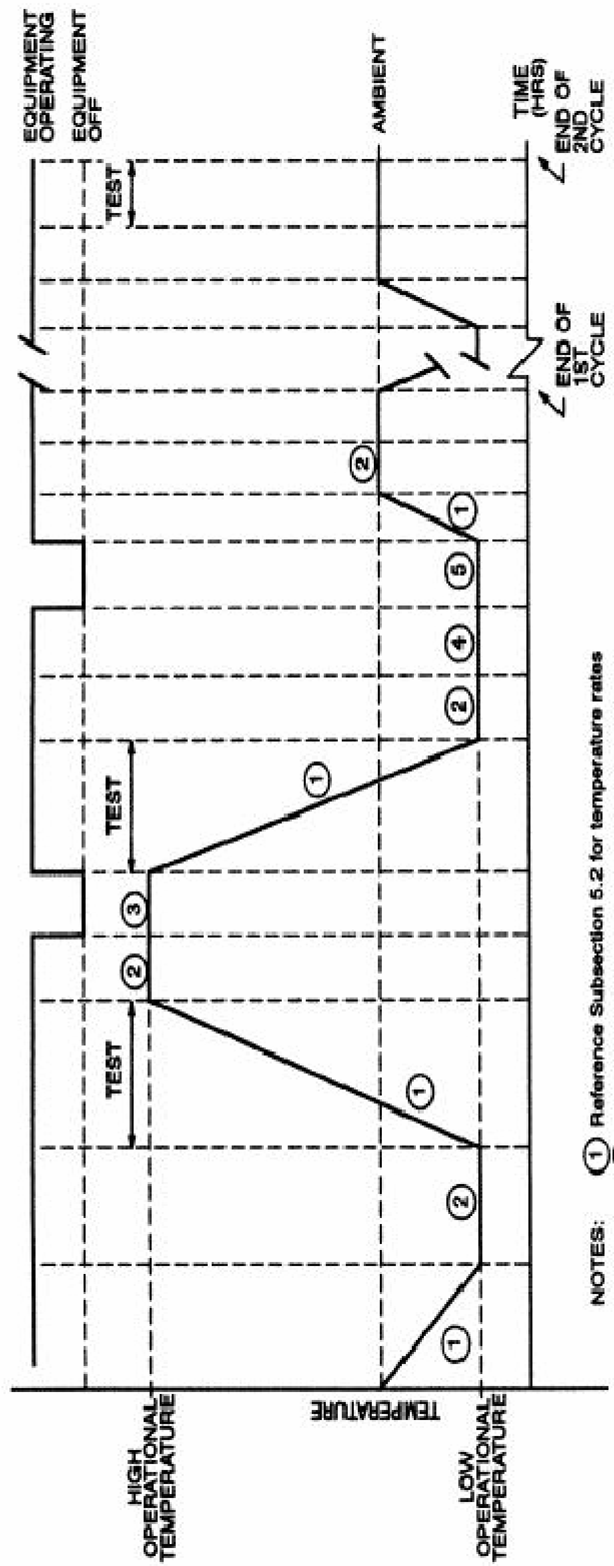
f. Stabilize the equipment temperature with the chamber at the operating low temperature, and then operate the equipment for at least one hour. Then turn off the equipment for 30 minutes, and restart the equipment while maintaining the chamber at the operating low temperature.

g. Change the temperature of the chamber towards the ambient temperature at the applicable rate specified in Subsection 5.2.

h. Stabilize the chamber and the equipment at ambient temperature. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

A minimum of two cycles (a. through h. above) shall be accomplished. If complete determination of compliance with applicable equipment performance standards can be accomplished during each temperature change period of a single cycle, then testing is required during the second cycle only. If the time during a temperature change period does not allow for complete determination of compliance with applicable equipment performance standards, a sufficient number of cycles shall be accomplished so that complete compliance can be determined. When temperature rise induces a potential risk of condensation on the equipment under test, the humidity level of the air in the chamber should be controlled to eliminate this condensation. The test profile is shown graphically in Figure 5-1.

Note: If this is a combined test, it is not necessary to repeat the Ground Survival Low Temperature, Short-Time Operating Low Temperature, Ground Survival High Temperature, and Short Time Operating High Temperature tests as defined in steps a. and d. above during the second cycle.



NOTES:

1. Reference Subsection 5.2 for temperature rates
2. Equipment temperature stabilization time
3. 2 minutes, minimum
4. 60 minutes, minimum
5. 30 minutes, minimum

FIGURE 5-1 TEMPERATURE VARIATION TEST

5.3.2 Test Procedure Category S1

The temperature variation test for Category S1 should not be combined with other temperature testing.

The following procedures shall apply:

a. Commencing at ambient temperature with the equipment operating, lower the temperature in the chamber towards the operating low temperature level at the applicable rates specified in Subsection 5.2.

b. Stabilize the equipment, if workable, at this operating low temperature level.

c. Raise the temperature in the chamber towards the operating high temperature at the applicable rates specified in Subsection 5.2. During this temperature change, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

d. Stabilize the equipment at the operating high temperature, if workable. Maintain the equipment in a non-operating state for a minimum of 2 minutes.

e. Turn the equipment on and lower the temperature in the chamber towards the operating low temperature level at the applicable rates specified in Subsection 5.2. During this temperature change DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

f. Stabilize the equipment temperature, if workable, with the chamber at the operating low temperature, and continue to operate the equipment for at least one hour. Then turn off the equipment for 30 minutes, and restart the equipment while maintaining the chamber at the operating low temperature.

g. Change the temperature of the chamber towards the ambient temperature at the applicable rates specified in Subsection 5.2.

h. Stabilize the chamber and the equipment at ambient temperature, if workable. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

A minimum of two cycles (a. through h. above) shall be accomplished. If complete determination of compliance with applicable equipment performance standards can be accomplished during each temperature change period of a single cycle, then testing is required during the second cycle only. If the time during a temperature change period does not allow for complete determination of compliance with applicable equipment performance standards, a sufficient number of cycles shall be accomplished so that complete compliance can be determined. When temperature rise produces condensation on the equipment tested, the humidity level of the air in the chamber should be controlled to eliminate this condensation.

5.3.3 Test Procedure Category S2

The temperature variation test for Category S2 shall not be combined with other temperature testing.

The required test apparatus shall consist of either one two-celled chamber or two separate chambers in which the test conditions can be established and maintained. Chamber 1 shall be set to the operating low temperature and chamber 2 shall be set to the operating high temperature. The insertion of equipment in test chambers can modify its environmental condition. In this case, the temperature shall be stabilized within five minutes after transfer of the test item.

The following test procedure shall apply:

a. Place the equipment into chamber 1, and turn the equipment on.

b. Stabilize the equipment, if workable, at the operating low temperature.

c. Transfer the equipment from chamber 1 to chamber 2 as rapidly as possible but in no more than five minutes. In the case of when separate chambers are used, it is permissible to turn the equipment on immediately after the equipment transfer. If the transfer requires more than five minutes, it shall be indicated in the qualification form.

d. Stabilize the equipment at the operating high temperature, if workable. During this temperature stabilization, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

e. Turn the equipment off, and keep it in a non operating state for a minimum of 2 minutes

f. Turn the equipment on, and transfer the equipment from chamber 2 to chamber 1 (from high to low temperature) as rapidly as possible but in no more than five minutes. In the case of when separate chambers are used, it is permissible to turn the equipment on immediately after the equipment transfer. If the transfer requires more than five minutes, it shall be indicated in the Qualification Form

g. Stabilize the equipment at the operating low temperature, if workable, and continue to operate the equipment for at least one hour. During the temperature stabilization, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

h. Turn off the equipment for 30 minutes and restart the equipment while maintaining the chamber 1 at operating low temperature

i. Transfer the equipment at ambient temperature, and after equipment temperature stabilization, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

A minimum of two cycles (a. through i. above) shall be accomplished. If complete determination of compliance with applicable equipment performance standards can be accomplished during each temperature change period of a single cycle, then testing is required during the second cycle only. If the time during a temperature change period does not allow for complete determination of compliance with applicable equipment performance standards, a sufficient number of cycles shall be accomplished so that complete compliance can be determined. When temperature rise induces a potential risk of condensation on the equipment under test, the humidity level of the air in the chamber should be controlled to eliminate this condensation.

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 6

Humidity

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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6.0 Humidity

6.1 Purpose of the Test

This test determines the ability of the equipment to withstand either natural or induced humid atmospheres. The main adverse effects to be anticipated are:

a. Corrosion.
b. Change of equipment characteristics resulting from the absorption of humidity. For example:

- Mechanical (metals).
- Electrical (conductors and insulators).
- Chemical (hygroscopic elements).
- Thermal (insulators).

Note: The humidity test shall not be conducted prior to the temperature/altitude tests and vibration tests (See Subsection 3.2, "Order of Tests").

6.2 Equipment Categories

<u>Category A - Standard Humidity Environment</u>

The standard humidity environment ordinarily provides an adequate test environment for equipment intended for installation in civil aircraft, non-civil transport aircraft and other classes, within environmentally controlled compartments of aircraft in which the severe humidity environment is not normally encountered.

<u>Category B - Severe Humidity Environment</u>

Equipment installed in zones not environmentally controlled may be required to be operated under conditions such that it is subjected to a more severe atmospheric humidity environment for periods of time in excess of that specified for the standard humidity environment.

<u>Category C - External Humidity Environment</u>

Equipment may be required to be operated under conditions such that it is subjected to direct contact with outside air for periods of time in excess of that specified for the standard humidity environment.

6.3 Test Procedures

Subject the equipment to an atmosphere in which the relative humidity (RH) is 95±4 percent (%), unless stated otherwise in the following steps. Moisture shall be provided by steam or by evaporation of water having a percent Hydroxide (pH) value between 6.5 and 7.5 or the water resistivity shall not be less than 250,000 ohm centimeters when measured at 25 degrees Celsius (^oC). The velocity of air throughout the exposure area shall be between 0.5 and 1.7 meters per second. The test chamber shall be vented to the atmosphere to prevent buildup of pressure, and provisions shall be made to prevent water from dripping onto the equipment.

6.3.1 Category A—Standard Humidity Environment

The test profile is shown graphically in Figure 6-1. The procedure shall be in accordance with the following steps:

Step 1: Install the test item in the test chamber, and ensure its configuration is representative of that used in actual service.

Step 2: Stabilize the test item at 30±2 ^oC and 85±4 % RH.

Step 3: Over a two-hour period, ±10 minutes, raise the chamber temperature to 50±2 ^oC and increase the RH to 95±4 %.

Step 4: Maintain the chamber temperature at 50±2 ^oC with 95±4 % RH for six hours minimum.

Step 5: During the next 16-hour period, ±15 minutes, decrease the temperature gradually to 38±2 ^oC or lower. During this period, keep the RH as high as possible and do not allow it to fall below 85 %.

Step 6: Steps 3, 4 and 5 constitute a cycle. Repeat these steps until a total of two cycles (48 hours of exposure) have been completed.

Step 7: At the end of the exposure period, remove the equipment from the test chamber and drain off (do not wipe) any condensed moisture. Within one hour after the two cycles are completed, apply normal supply power and turn on the equipment. Allow 15 minutes maximum following the application of primary power for the equipment to warm up. For equipment that does not require electrical power for operation, warm up the equipment for 15 minutes maximum by the application of heat not to exceed the short-time operating high temperature test as required by applicable equipment categories. Immediately following the warm-up period, make such tests and measurements as are necessary to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

6.3.2 Category B—Severe Humidity Environment

The test profile is shown graphically in Figure 6-2. The procedure shall be in accordance with the following steps:

Step 1: Install the test item in the test chamber, and ensure its configuration is representative of that used in actual service.

Step 2: Stabilize the test item at 30 ±2 ^{o}C and 85 ±4 % RH.

Step 3: Over a two-hour period, ± 10 minutes, raise the chamber temperature to 65 ^{o}C and increase the RH to 95 ±4 %.

Step 4: Maintain the chamber temperature at 65 ^{o}C with the RH at 95 ±4 % for six hours minimum.

Step 5: During the next 16-hour period, ±15 minutes, decrease the temperature gradually to 38 ^{o}C or lower. During this period, keep the RH as high as possible and do not allow it to fall below 85 %.

Step 6: Steps 3, 4 and 5 constitute a cycle. Repeat these steps until a total of 10 cycles (240 hours of exposure) have been completed.

Step 7: At the end of the exposure period, remove the equipment from the test chamber and drain off (do not wipe) any condensed moisture. Within one hour after the 10 cycles are completed, apply normal supply power and turn on the equipment. Allow 15 minutes maximum following the application of primary power for the equipment to warm up. For equipment that does not require electrical power for operation, warm up the equipment for 15 minutes maximum by the application of heat not to exceed the short-time operating high temperature test as required by applicable equipment categories. Immediately following the warm-up period, make such tests and measurements as are necessary to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

6.3.3 Category C—External Humidity Environment

The test profile is shown graphically in Figure 6-3. The procedure shall be in accordance with the following steps:

Step 1: Install the test item in the test chamber, and ensure its configuration is representative of that used in actual service.

Step 2: Stabilize the test item at 30 ±2 ^{o}C and 85 ±4 % RH.

Step 3: Over a two-hour period, ±10 minutes, raise the chamber temperature to 55 ±2 ^{o}C and increase the RH to 95 ±4 %.

Step 4: Maintain the chamber temperature at 55 ^{o}C with the RH at 95 ±4 % for six hours minimum.

Step 5: During the next 16-hour period, ±15 minutes, decrease the temperature gradually to 38 ^{o}C or lower. During this period, keep the RH as high as possible and do not allow it to fall below 85 %.

Step 6: Steps 3, 4 and 5 constitute a cycle. Repeat these steps until a total of six cycles (144 hours of exposure) have been completed.

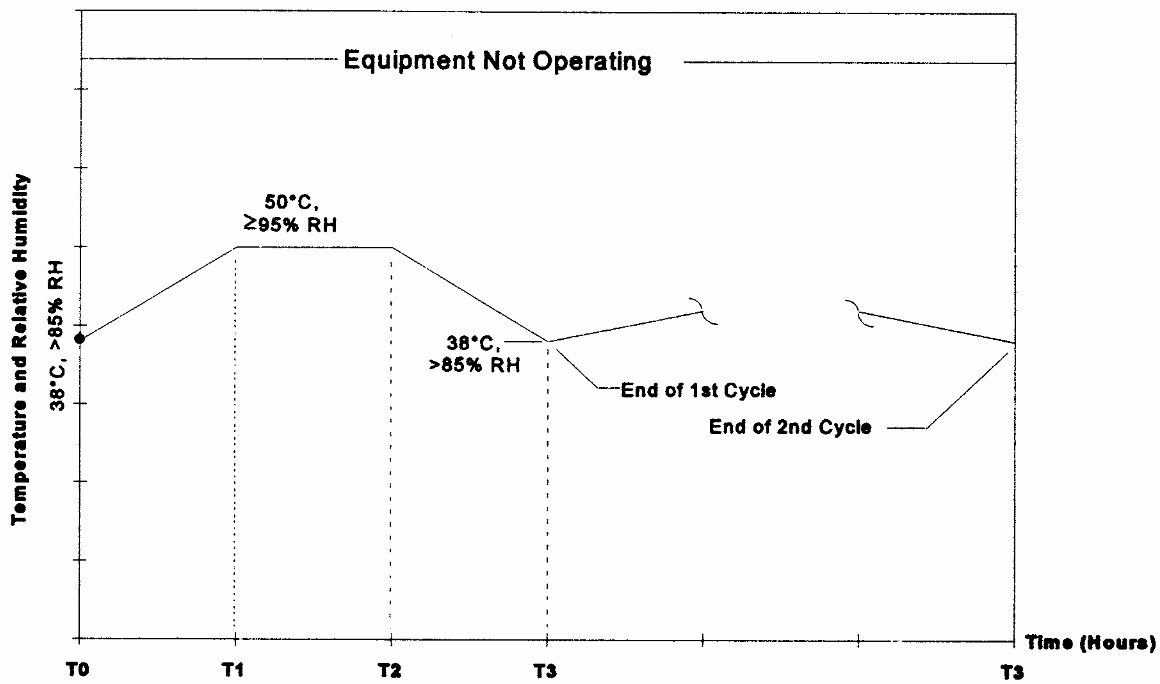
Step 7: At the end of the exposure period, remove the equipment from the test chamber and drain off (do not wipe) any condensed moisture. Within one hour after the six cycles are completed, apply normal supply power and turn on the equipment. Allow 15 minutes maximum following the application of primary power for the equipment to warm up. For equipment that does not require electrical power for operation, warm up the equipment for 15 minutes maximum by the application of heat not to exceed the short-time operating high temperature test as required by applicable equipment categories. Immediately following the warm-up period, make such tests and measurements as are necessary to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

6.3.4 Conducting Spot Checks

For conducting spot checks on the performance of the equipment under test, the equipment may be operated at the end of each of the 6 or 10 cycles as appropriate for a period not to exceed 15 minutes. If the equipment is removed from the test chamber to conduct a spot check, the period of removal shall not exceed 20 minutes, and the equipment shall not be operated for more than 15 minutes of this 20-minute period.

6.3.5 Other Specified Checks

If the applicable performance standard requires that other checks be made to determine compliance, these shall also be performed during this test.



<u>Figure 6-1</u> Category A - Standard Humidity Environment Test

*N*OTES:

1) T0 to T1 is 2 hours ±10 minutes.
2) T1 to T2 is 6 hours, minimum.
3) T2 to T3 is 16 hours ±15 minutes. During this period, relative humidity should not fall below 85%.
4) See paragraph 6.3.1, Step 7, for continuation of test after the end of the 2nd cycle.

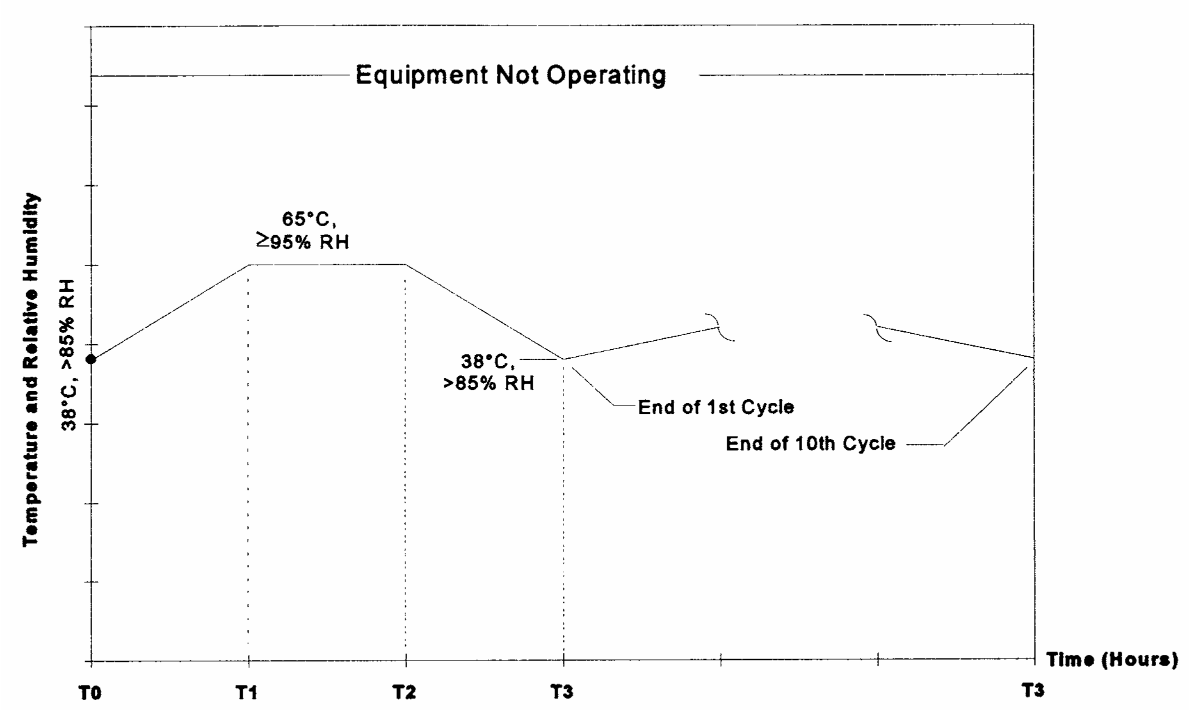


Figure 6-2 Category B - Severe Humidity Environment Test

NOTES:

1) *T0 to T1 is 2 hours ±10 minutes.*
2) *T1 to T2 is 6 hours, minimum.*
3) *T2 to T3 is 16 hours ±15 minutes. During this period, relative humidity should not fall below 85%.*
4) *See paragraph 6.3.2, Step 7, for continuation of test after the end of the 10th cycle.*

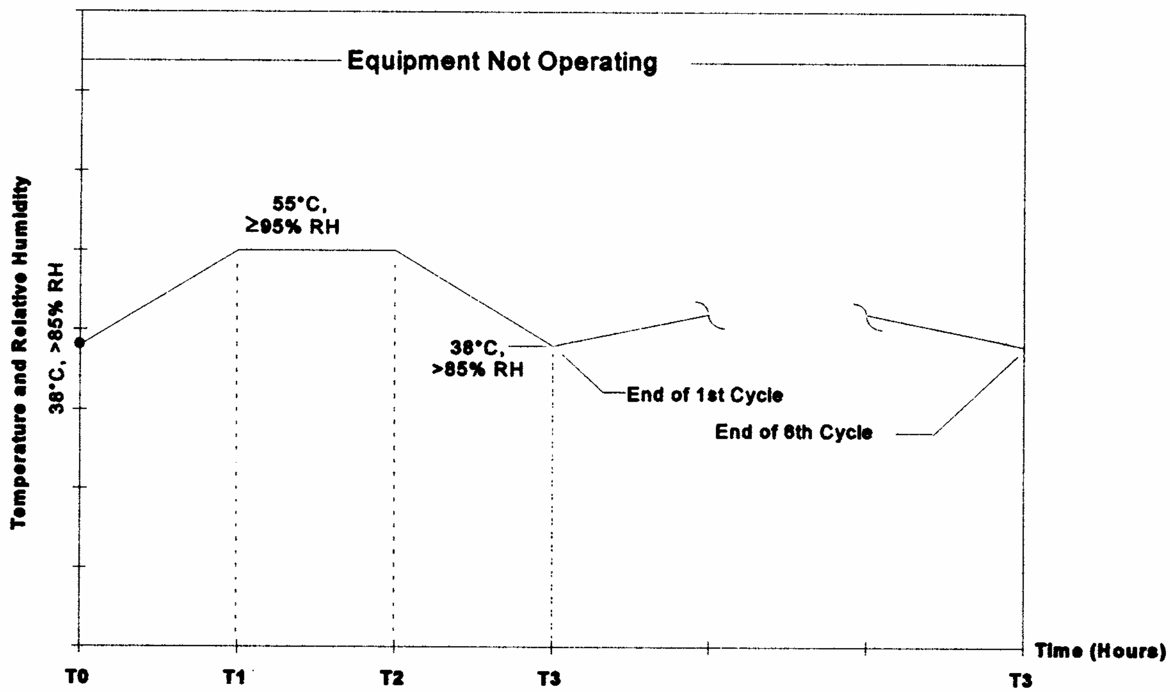


Figure 6-3 Category C - External Humidity Environment Test

NOTES:

1) *T0 to T1 is 2 hours ±10 minutes.*
2) *T1 to T2 is 6 hours, minimum.*
3) *T2 to T3 is 16 hours ±15 minutes. During this period, relative humidity should not fall below 85%.*
4) *See paragraph 6.3.3, Step 7, for continuation of test after the end of the 6th cycle.*

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 7

Operational Shocks and Crash Safety

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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7.0 Operational Shocks and Crash Safety

7.1 Purpose of the Tests

The operational shock test verifies that the equipment will continue to function within performance standards after exposure to shocks experienced during normal aircraft operations. These shocks may occur during taxiing, landing or when the aircraft encounters sudden gusts in flight. This test applies to all equipment installed on fixed-wing aircraft and helicopters. Two operational shock test curves are provided; a standard 11 msec pulse and a low frequency 20 msec pulse. The 20 ms pulse may not be adequate to test against the effect of longest duration shocks on equipment that have its lowest resonance frequency (as per section 8) below 100Hz.

The crash safety test verifies that certain equipment will not detach from its mountings or separate in a manner that presents a hazard during an emergency landing. It applies to equipment installed in compartments and other areas of the aircraft where equipment detached during emergency landing could present a hazard to occupants, fuel systems or emergency evacuation equipment. These tests do not satisfy FAR requirements for all equipment, e.g. seats and seat restraints.

Note: For fixed-wing aircraft: a complete installation demonstration, i.e. including aircraft acceleration loads (such as flight manoeuvring, gust and landing) in addition to the crash safety loads, may be accomplished by using the "Unknown or Random" orientations for the "sustained" test procedure.

Using a dummy load on the shock test apparatus may be necessary to ensure that the recorded shock pulse will be within the specified tolerances of Figure 7-2.

7.1.1 Equipment Categories

Category A
Equipment tested for standard operational shocks.

Category B
Equipment tested for standard operational shock and crash safety.

Category D
Equipment tested for operational low-frequency shock.

Category E
Equipment tested for operational low-frequency shock and crash safety.

7.2 Operational Shocks

Performance compliance requirements are normally required following application of the shocks. If equipment requires monitoring during the application of the shock pulses, the monitoring requirements must be stated in the relevant equipment specification.

7.2.1 Test Procedure

Secure the equipment to a shock table by means of a rigid test fixture and mounting means intended for use in service installations. The mounting of the equipment should include those non-structural connections that are a normal part of the installation. The accelerometer used to measure or control the input shock pulse shall be placed as close as practicable to an equipment attachment point. The test system accuracy to measure acceleration shall be within ±10 percent of standard reading. With the equipment operating and with its temperature stabilized, apply to the test item three shocks in each orientation having a terminal saw-tooth wave shape with an acceleration peak value of six (6) g's. The nominal pulse duration shall be 11 ms for standard shock testing and 20 ms for low frequency shock testing. The characteristics of instrumentation used to demonstrate compliance and the shock pulse tolerance limits are shown in Figures 7-1 and 7-2, respectively. An equivalent shock response spectrum may replace the terminal saw-tooth wave shape.

After application of the shocks, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

When using a conventional drop shock machine, the equipment shall be shock tested in the following orientations:

a. Normal upright.

b. Suspended upside down.

c. At orientations such that the first major orthogonal axis of the equipment successively forms angles of +90 degrees and -90 degrees (two orientations) with the plane of the table.

d. At orientations such that the second major orthogonal axis of the equipment successively forms angles of +90 degrees and -90 degrees (two orientations) with the plane of the table.

7.2.2 Alternate Test Procedure

It is permissible to apply the shocks specified in paragraph 7.2.1 with the equipment mounted in its normal operating orientation (i.e., as spatially oriented in its customary aircraft installation), provided that three shocks are applied in both directions of the three orthogonal axes.

7.3 Crash Safety

If the crash safety test is applicable, both the impulse and sustained test procedures shall be performed.

During the impulse tests of paragraphs 7.3.1 or 7.3.2, an equivalent weight (dummy load) may be substituted for electrical-mechanical components normally mounted within or on the equipment case. Such equivalent weight shall approximate the weight of the components that it replaces and shall be so located that the center of gravity of the equipment is essentially unchanged. The equivalent weight shall not contribute to the strength of the equipment case or its mounting fastenings to a greater extent than the components it replaces.

7.3.1 Test Procedure 1 (Impulse)

Secure the equipment or dummy load to a shock table by means of a rigid test fixture and mounting means intended for use in service installations.

In each of the six equipment orientations listed in paragraph 7.2.1, apply one shock having a wave shape identical to that specified in paragraph 7.2.1. After application of the six shocks, bending and distortion shall be permitted. There shall be no failure of the mounting attachment and the equipment or dummy load shall remain in place.

7.3.2 Alternate Test Procedure (Impulse)

It is permissible to apply the shocks specified in paragraph 7.3.1 with the equipment mounted in its normal operating orientation provided that these shocks are applied in both directions of the three (3) orthogonal axes.

7.3.3 Test Procedure 2 (Sustained)

It is expected that the sustained test procedure below will normally be carried out using a centrifuge or sled. In certain cases, however, it is acceptable to simulate the effects of inertia by applying forces statically through the center of gravity of the equipment under test, providing it can be determined that other parts within the equipment can be contained within the casing of the equipment should they break loose.

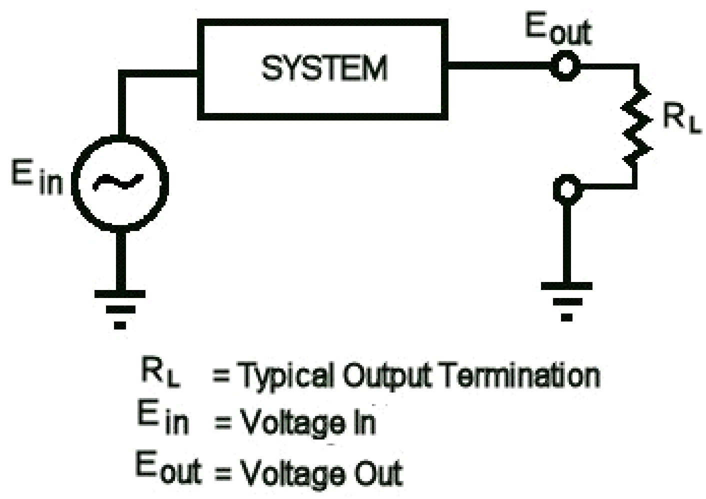
Secure the equipment or dummy load to test facility by means of a rigid test fixture and mounting means intended for use in service installation. Apply the appropriate test loads for a minimum of three seconds in each direction of load. "Direction of load" in Table 7-1 applies to the aircraft's major orthogonal axes. The applicable test levels are given in Table 7-1 (*). Where the orientation of the equipment to the aircraft axes is known, then the required load and direction of load relative to the equipment can be determined. If the orientation of the equipment under test is unknown or not fixed in relation to the aircraft axes, then the random orientation is required along each direction of the equipment's three orthogonal axes (Figure 7-3). After application of the six loads, bending and distortion shall be permitted. There shall be no failure of the mounting attachment and the equipment or dummy load shall remain in place.

Table 7-1 Crash Safety Sustained Test Levels

Aircraft Type	Test Type (5)	Sustained Test Acceleration (g Minimum) Direction of Load for Equipment Orientation				
		Up	Down	Forward	Aft	Side (4)
1. Helicopters (1)	F R	4.0 20.0	20.0 20.0	16.0 20.0	NA 20.0	8.0 20.0
2. Fixed-Wing Transport (2)	F R	3.0 9.0	6.0 9.0	9.0 9.0	1.5 9.0	4.0 9.0
3. Fixed-Wing Non-Transport (3)	F R	3.0 18.0	NA 18	18.0 18.0	NA 18.0	4.5 18.0
4. All Fixed-Wing	F R	3.0 18.0	6.0 18	18.0 18.0	1.5 18.0	4.5 18.0
5. Helicopter and All Fixed-Wing	F R	4.0 20.0	20.0 20.0	18.0 20.0	1.5 20.0	8.0 20.0

NOTES: *(1) Reference FAR 27.561*
(2) Reference FAR 25.561
(3) Reference FAR 23.561
(4) Side includes both left and right directions
(5) "F" is known and Fixed orientation. "R" is unknown or Random orientation.

*** CAUTION : These test levels may not satisfy the installation requirement in the FAR**s.



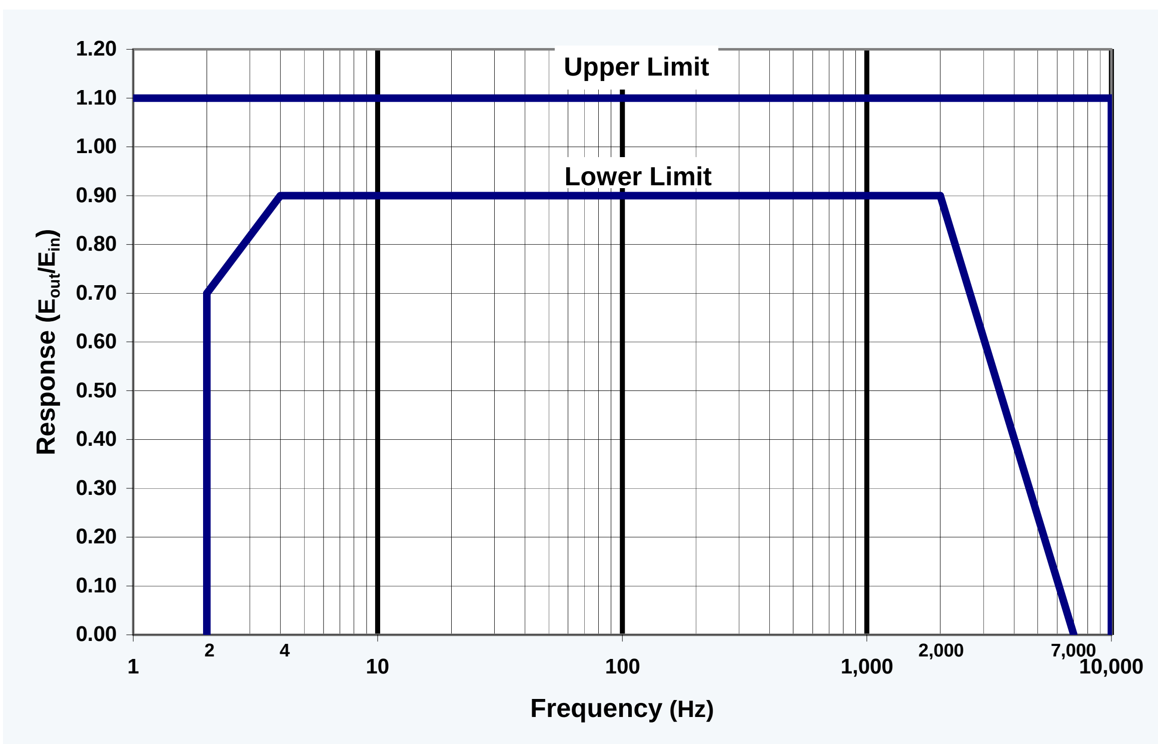
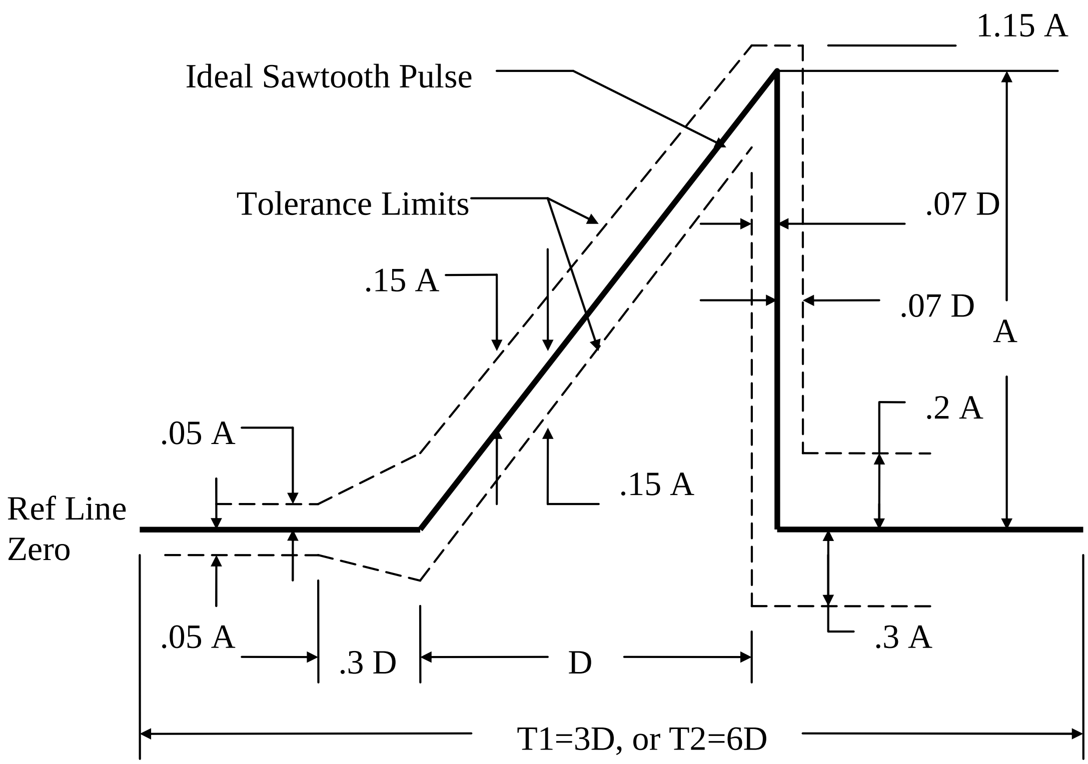


Figure 7-1 **Shock Measuring System Frequency Response**

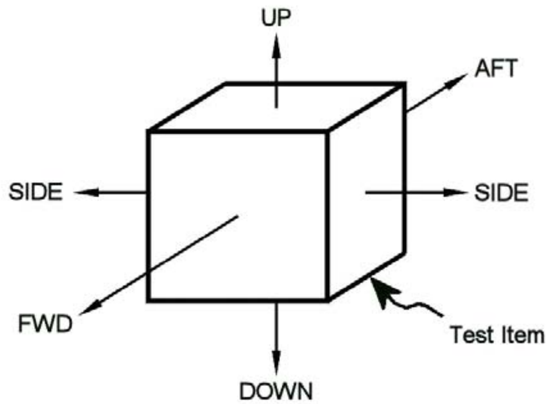


D = Duration of nominal pulse.
A = Peak acceleration of nominal pulse.
T1 = Minimum time during which the pulse shall be monitored for shocks produced using a conventional shock testing machine.
T2 = Minimum time during which the pulse shall be monitored for shocks produced using a vibration generator.

Test (impulse)	Peak value (A) (g)	Nominal duration (D) (ms)
Operational Standard	6	11
Operational Low-frequency	6	20
Crash safety	20	11
Crash safety low frequency	20	20

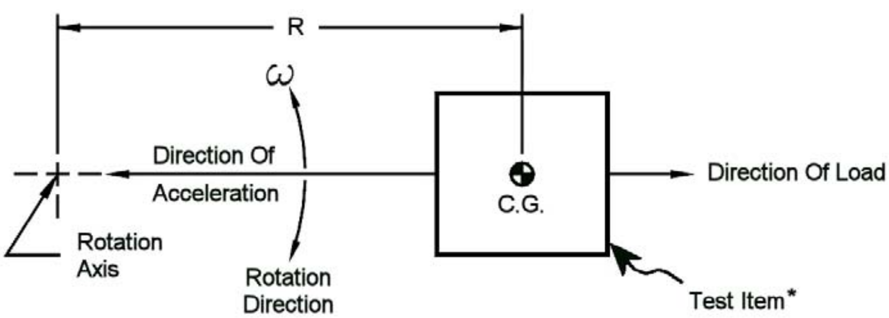
Note: The oscillogram shall include a time duration T_1 or T_2 with a pulse located approximately in the center. The acceleration amplitude of the terminal saw-tooth pulse is A and its duration is D. The measured acceleration pulse shall be contained within the dashed line boundaries and the measured velocity change (which may be obtained by integration of the acceleration pulse) shall be within the limits $V_i \pm 0.1\ V_i$, where V_i is the velocity change associated with the ideal pulse which equals 0.5 DA. The integration to determine velocity change shall extend from 0.4 D before the pulse to 0.1 D after the pulse.

<u>Figure 7-2</u> Terminal Saw Tooth Shock Pulse Configuration & Its Tolerance Limits



Aircraft Directions

Note: If a centrifuge is used, the effects of rotational acceleration and rate of acceleration on the specimen should be considered.



Looking Down On The Plane of Rotation

* Align test item so the direction of acceleration aligns with the appropriate aircraft direction, and apply the test acceleration specified for that aircraft direction.

$$\text{Acceleration (G's)} = \frac{R(\omega)^2}{9.81} = 0.001118 * R * (\text{RPM})^2$$

R = Radius, Meters
ω = Angular Rotation, Radians/Second
RPM = Revolutions Per Minute

Centrifuge Definitions

Figure 7-3 Definitions for Crash Safety Sustained Test

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 8

Vibration

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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8.0 VIBRATION

8.1 Purpose of the Tests

These tests demonstrate that the equipment complies with the applicable equipment performance standards (including durability requirements) when subjected to vibration levels specified for the appropriate installation.

8.2 Applicability

The vibration tests described below apply to equipment installed on fixed-wing propeller aircraft, fixed-wing turbojet, turbofan, and propfan aircraft and helicopters.

The specific vibration tests to be performed to show compliance with the performance standards are defined in this paragraph and are dependent upon three identifiers: (1) aircraft type, (2) test category and (3) aircraft zone location The requirements and procedures to accomplish these tests are specified in subsequent paragraphs herein.

8.2.1 Vibration Test Category Definitions

The appropriate category (or categories) selected from the categories defined below should be based upon the level of assurance required for the equipments demonstration of performance. For equipment on fixed wing aircraft, either a standard or a robust vibration test may be performed. The need to do the high level short duration test is dependent upon the equipment performance requirements. For equipment on helicopters, only a robust test may be performed.

8.2.1.1 Standard Vibration Test (Category S)

The standard vibration test for fixed wing aircraft demonstrates that equipment will meet its functional performance requirements in the vibration environment experienced during normal operating conditions of the aircraft.

8.2.1.2 Robust Vibration Test (Categories R, U, U2)

The robust vibration test demonstrates that equipment will operate satisfactorily while being subjected to vibration and that it will continue to operate satisfactorily after being subjected to endurance vibration levels. It combines a demonstration of the equipment functional performance and structural integrity. This test should be performed on all equipment where its resistance to effects of long duration exposure to vibration must be demonstrated. The necessity for conducting this test in lieu of the standard vibration test shall be determined by the relevant equipment specification. Categories U and U2 are for equipment to be installed in helicopters with unknown rotor related frequencies.

8.2.1.3 High Level-Short Duration Vibration Test (Categories H, Z)

High-level short duration transient vibration levels are encountered during abnormal fixed wing aircraft vibration conditions that occur during an engine fan blade loss. This test should be applied to equipment in which a functional loss of performance can hazardously affect the aircraft's performance. The Category H test is a generalized test that encompasses all applications. The Category Z test covers restricted low fan frequency applications. These tests do not replace the standard or robust tests. Also see following **CAUTION** note.

CAUTION: A full analysis of vibration levels related to some specific engine imbalance conditions has not been evaluated against these limits. Therefore this test alone may not be sufficient for some applications without additional test or analysis.

8.2.2 Test Curve / Test Level Selection

8.2.2.1 Test Description

The data in Table 8-0 below provides a brief description of the test for each of the test categories. See the procedures for a more detailed description.

Table 8-0 Test Description

Category	Aircraft Type	Standard Vibration	High Level - Short Duration Vibration	Robust Vibration
S	Fixed-Wing	1 Hr/Axis sine or random at perf. Level	NA	NA
H or Z	Fixed-Wing	NA	High g / low f sine sweep each axis	NA
R	Fixed-Wing	NA	NA	Sine of 3 Hrs/Axis less 30 min/dwell (max 4 dwells) or Random at 30 min perf. Level and 3 Hrs Endurance level (repeat in all 3 axes)
R or U	Helicopter	NA	NA	Sine-On-Random; 1 Hr at Endurance levels plus dwells (max of 4) and EUT 30 min performance test at beginning and end of test period (repeat in all 3 axes). Test repeated 3 times for Category U.
U2	Helicopter	NA	NA	Random ; 30 min at perf level, 3 hrs at Endurance level and 30 min at perf level (repeat in all 3 axes)

8.2.2.2 Test Curves

Table 8-1 specifies the appropriate test curves to be used for the applicable category and aircraft zone for each aircraft type. The test levels for the categories of Table 8-1 are shown in Figures 8-1 to 8-5 for fixed-wing aircraft and Tables 8-2a and 8-2b for helicopters.

Note that the zone for "instrument panel, console and racks" includes interior items attached to the galley interior partitions and cabin floor and is separate from the "fuselage" zone. The "fuselage" zone applies to all equipment not installed in multiple slot equipment racks but that is attached to frames, stringers, skin and other fuselage structure or brackets.

Weight Allowance – For equipment items weighing greater than 22.7kg (50 lbs), a reduction in standard and robust test levels for frequencies above 60 Hz is allowed using the following schedule: The random and sinusoidal standard and robust test levels may be reduced by 0.10 dB for each 0.454 kg (1.0 lb) equipment weight increment above 22.7 kg (50 lb) to a maximum reduction of 6.0 dB. (Note that a 6.0 dB reduction would reduce the APSD level to 1/4 and the sinusoidal level to 1/2 of the original level.)

8.3 Vibration Test Requirements

The following general requirements apply for all vibration tests:

a. Install the equipment under test so the input vibratory motion is parallel to one of its three major orthogonal axes. Any test fixture used shall be as rigid and symmetrical as practicable. The equipment shall be attached to the fixture or vibration table by the means specified in the equipment specification. Equipment that is mounted on external vibration/shock isolators shall be tested with the isolators.

b. Where applicable, accelerometers shall be attached to the equipment item undergoing vibration to measure and record the equipment's vibration response in the axis of vibration to determine resonant frequencies and amplification factors. Locations selected may include principal structure, printed circuit boards, large components and modules, where practicable.

c. The control accelerometer(s) shall be attached to the test fixture as near as practicable to the equipment mounting location for each axis of test. When more than one accelerometer is employed for test level control, the average of the accelerometer control signals for sinusoidal tests or the average of the acceleration power spectral densities (APSDs) for random tests shall be used as the test level control. For all vibration input types, spectrum or APSD plots as appropriate shall be made to demonstrate that the control levels meet the test level requirements.

d. The random vibration signal should have a Gaussian distribution, and the instantaneous vibration acceleration peaks of the control signal may be limited to three times the g rms acceleration level.

e. The accuracy of the instrumentation system for measuring sinusoidal acceleration shall be ±10 percent for acceleration and ±2 percent for frequency.

f. If the random vibration test requirements exceed the power capability of the vibration test system, the test may be performed in separate frequency bands of 10 to 600 Hz and 600 to 2000 Hz. The specified test time shall be applied to each frequency band.

8.4 Vibration Test Level Requirements

8.4.1 Control Level Tolerance Requirements

8.4.1.1 Sinusoidal Control Input

The acceleration test level control, as defined in 8.3c, for any sinusoidal input curve, shall be within ±10 percent of the specified level over the specified frequency range.

8.4.1.2 Random Control Input

The acceleration power spectral density (APSD) of the test control signal, as defined in 8.3c, shall not deviate from the specified requirements by more than +3 dB or -1.5 dB below 500 Hz and ±3.0 dB from 500 to 2,000 Hz. The overall g rms level of the control signal shall be within +20 and -5 percent of the overall rms value for the specified APSD curve.

8.4.2 Measurement of Acceleration Power Spectral Density

Analysis and control systems shall use a bandwidth-time (BT) product greater than or equal to 50. Specific analyzer characteristics or their equivalent shall be as specified below. Discrete FFT analysis methods are preferred for APSD measurements.

8.4.2.1 Analog Analyzer Requirements

a. On-line contiguous filter, equalization/analysis system having a bandwidth, B, less than or equal to 50 Hz.

b. Swept frequency analysis systems characterized as follows:

(1) Constant bandwidth analyzer.

(a) Filter bandwidths.

B = 10 Hz, maximum from 10 to 200 Hz. B = 50 Hz, maximum from 200 to 2,000 Hz.

(b) Analyzer averaging time = T = 2τ = 1 s minimum, where T = true averaging time and τ = analyzer time constant.

(c) Analysis linear sweep rate = R = B/4τ or B^2/8 Hz/s maximum, whichever is smaller.

(2) Constant percentage bandwidth analyzer.

(a) Filter bandwidth = Pf_c = one third octave maximum. (where P = percentage ≤ 0.23 and f_c = analyzer center frequency).

(b) Analyzer averaging time = T = 50/Pf_c minimum.

(c) Analysis logarithmic sweep rate = R.

$$R = \frac{Pf_c}{4\tau} \text{ or } \frac{(Pf_c)^2}{8} \text{ Hz/s maximum, whichever is smaller}$$

8.4.2.2 Digital Analyzer Requirements

Digital power spectral density analysis system employing discrete frequency analysis techniques shall have a minimum of 400 lines of frequency resolution (i.e., Δf equal to or less than five Hz). The bandwidth-time product is equal to the number of records used to obtain one APSD (i.e., the number of ensemble averages should be 50 or greater when measuring an APSD).

8.5 Standard Vibration Test Procedure-Fixed Wing Aircraft

The standard vibration test curves to be used in Table 8-1 for the specified category and zone are given in Figures 8-1 through 8-3. For most aircraft type / zone applications either a sinusoidal or a random test vibration curve is defined . For Aircraft Type 6 Zone 7, the user can choose between sinusoidal and random vibration testing. The procedures for both sinusoidal and random tests are defined below. (note: only the applicable sinusoidal or random test needs to be performed).

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING AND AT THE CONCLUSION OF STANDARD VIBRATION TESTING.

8.5.1 Sinusoidal Test Procedure

In each of the equipment's three orthogonal axes perform the following tests using the appropriate test curves of Figure 8-2 or Figure 8-3.

With the equipment operating, perform sine frequency sweep cycles varying the vibration frequency over the appropriate frequency range from lowest to the highest (up-sweep) to the lowest (down-sweep) specified frequencies with a logarithmic sweep rate not exceeding 1.0 octave/minute. During the initial up-sweeps, record plots of the accelerometers at the response locations selected and identify the critical frequencies. Critical frequencies are defined as those frequencies where: (1) mechanical vibration resonances have peak acceleration amplitudes greater than twice the input acceleration amplitude, or (2) a change in performance or behavior is noticeable whether or not performance standards are exceeded.

Continue the vibration sine frequency sweep cycling and operation for one hour minimum to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Any changes in the critical frequencies that occur during the test shall be noted on the Environmental Qualification Form (see Appendix A). At the completion of the test, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

Any difficulty in reading any display feature of the test item, when the total displacement of applied input vibration exceeds 0.5 mm, shall not be a cause for failing the test.

8.5.2 Random Test Procedure

In each of the equipment's three orthogonal axes, perform the following test sequence:

a. Perform a 0.5 g-PK sinusoidal scan from 10 Hz to 2000Hz at a sweep rate not exceeding 1.0 octave/minute. Record plots of response accelerometers at selected position on the equipment to determine resonant frequencies and amplification factors. Resonant frequencies are defined as response peaks that are greater than twice the input acceleration amplitude.

b. With the equipment operating, apply the appropriate performance level test APSD of Figure 8-1 for a minimum of one-hour-per-axis to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. During this vibration period, also perform an APSD analysis of the vibration response measurements on the equipment.

c. Repeat the sinusoidal scan of subparagraph 8.5.2.a. Any changes in vibration resonant frequencies shall be noted on the environmental Qualification form (see Appendix A).

At the completion of the test, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

8.6 High Level-Short Duration Vibration Test Procedure

With the equipment operating, apply sinusoidal vibration at the levels shown in Figure 8-5 for the appropriate equipment zone location. For general Category H applications, perform one sinusoidal linear frequency sweep in each of the equipment's three orthogonal axes from 10 to 250 Hz at a sweep rate not to exceed 0.167 Hz/sec. For restricted Category Z applications, the maximum frequency can be reduced. For this application, the maximum frequency shall be equal to or greater than 2 times the maximum fan rotor speed. For Category Z, the maximum frequency tested to shall be reported on the Environmental Qualification Form (see Appendix A). DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARD. Operational performance requirements during and after the test shall be defined by the equipment specification.

8.7 Robust Vibration Test Procedure-Fixed-Wing Aircraft

The robust vibration test curves to be used in Table 8-1 for the specified category and zone location are given in Figure 8-1 to Figure 8-4. For most aircraft type / zone applications either a sinusoidal or a random vibration curve is defined. For Aircraft Type 6 Zone 7, the user can choose between sinusoidal and random vibration tests. The procedures for both sinusoidal and random tests are defined below. (note: only the sinusoidal or random test needs to be performed).

8.7.1 Sinusoidal Test Procedure

In each of the equipment's three orthogonal axes, perform the following test using the appropriate sinusoidal test levels of Figure 8-2.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING AND AT THE CONCLUSION OF VIBRATION TESTING.

a. With the equipment operating, unless otherwise specified in the equipment specification, perform sine frequency sweep cycles, varying the vibration frequency over the appropriate frequency range from the lowest to the highest (up-sweep) to the lowest (down-sweep) specified frequencies with a logarithmic sweep rate not exceeding 1.0 octave/minute. The time spent performing these sweeps may be included in the total sweep time of subparagraph 8.7.1.c. During the initial up-sweeps, record plots of the accelerometers at the selected response locations and identify the critical frequencies. Critical frequencies are defined as those frequencies where: (1) mechanical vibration resonance have peak acceleration amplitudes greater than twice the input acceleration amplitude, or (2) a change in performance or behaviour is noticeable whether or not performance standards are exceeded.

b. Select the four most severe frequencies from the critical frequencies identified in 8.7.1a. Dwell at each of these selected frequencies for 30 minutes. During each resonance dwell, the applied frequency shall be adjusted, if necessary, to maintain the maximum acceleration response at the vibration resonance being dwelled. If fewer than four critical frequencies are identified, dwell at each one for a 30-minute period. If no critical frequencies are identified, then no dwells need be performed.

c. Following the vibration dwell test, complete the vibration testing by sine frequency sweep cycling. The time spent at frequency cycling will be three hours minus any time spent at testing resonances in 8.7.1.b.

   Any changes in the critical frequencies that occur during the test shall be noted on the Environmental Qualification Form (see Appendix A). If no change occurs, a statement to that effect shall be included in the declaration. Any difficulty in reading any display feature of the test item, when the total excursion of applied input vibration exceeds 0.5 mm, shall not be a cause for failing the test.

d. At the completion of the tests, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

8.7.2 Random Test Procedure

In each of the equipment's three orthogonal axes, perform the following test sequence:

a. Perform a 0.5 g-PK sinusoidal scan from 10 Hz to 2000Hz at a sweep rate not exceeding 1.0 octave/minute. Record plots of response accelerometers at selected position on the equipment to determine resonant frequencies and amplification factors. Resonant frequencies are defined as response peaks that are greater than twice the input acceleration amplitude.

b. With the equipment operating, apply the appropriate performance level test APSD of Figure 8-1 for a minimum of 30 minutes to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. During this vibration period, also perform an APSD analysis of the vibration response measurements on the equipment.

c. Apply the appropriate endurance level test APSD of Figure 8-4 for three hours. Unless otherwise defined in the equipment specification, the test item shall be operating during vibration. Near the beginning and again near the end of the vibration period, perform an APSD analysis of the vibration response measurements on the equipment and DETERMINE COMPLIANCE WITH

APPLICABLE EQUIPMENT PERFORMANCE STANDARDS**.** If the test item is not operating during the endurance level vibration test, testing to show compliance with the applicable equipment performance standards shall be performed following completion of the endurance level vibration test.

d. Repeat the sinusoidal scan of subparagraph 8.7.2.a. Any changes in vibration resonant frequencies shall be noted on the environmental Qualification form (see Appendix A).

e. At the completion of the tests, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

8.8 Vibration Test for Helicopters

The tests described herein are default tests that can be performed on equipment installed on helicopters in which no measured vibration data is available. For helicopters where data have been measured, "tailored" tests may be applied using accepted standard procedures for helicopter test standards. The test procedures cover both known and unknown helicopter frequency cases. For the unknown helicopter frequency case, two optional procedures are provided.

Caution should be exercised regarding wear / damage occurring during the tests to Zeus or other flexible mounting devices.

8.8.1 Sine-on-Random Test Procedure – Known Helicopter Frequencies

The test frequencies, test levels and test procedure for performing a sine-on-random vibration test are defined below. Equipment that have passed the test are considered qualified for installation on any helicopter whose frequencies as defined in Table 8-2a are included in the Sine Frequency ranges fn* 0.90 to fn*1.10 defined in 8.8.1.3.

8.8.1.1 Test Frequencies

The one-per-revolution frequencies of the four primary rotational sources are defined as:

FM = Main rotor one/rev frequency, Hz
FT = Tail rotor one/rev frequency, Hz
FE = Engine one/rev frequency, Hz
FG = Main gearbox one/rev frequency, Hz

The blade passage frequencies of the rotor blades are defined using the number of blades for the main and tail rotors:

NM = Number of blades on the main rotor
NM*FM = First blade passage main rotor frequency, Hz
NT = Number of blades on the tail rotor
NT*FT = First blade passage tail rotor frequency, Hz

The test frequencies to be used for each helicopter zone can be determined using the formulae provided in Table 8-2a.

8.8.1.2 Sine and Random Test Levels

Using the appropriate sinusoidal test frequencies as determined in 8.8.1.1, the sinusoidal test levels, An, can be calculated for each frequency from the formulae given in Table 8-2b. The random levels are also given in Table 8-2b. The combined sinusoidal and random curves appear (generically) as a total test curve in Figure 8-6.

8.8.1.3 Procedure

The applied controlled input vibration level shall have a frequency content of the sum of the sinusoidal frequencies and the wide-band random test levels determined above.

The sinusoidal frequencies shall be varied at a logarithmic sweep rate not exceeding 1 Oct/min from fn*(0.9) to fn*(1.1) (where fn are the sinusoidal frequencies of the test spectrum).

A performance and endurance vibration test shall be performed in each of the equipment's three orthogonal axes using the test procedure defined below.

a. Perform a 0.5 g-PK sinusoidal scan from 10 Hz to 2000Hz at a sweep rate not exceeding 1.0 octave/minute. Record plots of response accelerometers at selected position on the equipment to determine resonant frequencies and amplification factors. Resonant frequencies are defined as response peaks that are greater than twice the input acceleration amplitude.

b. With the equipment operating, apply the appropriate performance test level curve of Table 8-1 as defined by Tables 8-2a and 8-2b for a minimum of 30 minutes to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING VIBRATION.

c. With the equipment non-operating, unless otherwise specified in the applicable equipment specification, apply the appropriate endurance test level curve of Table 8-1 as defined by Tables 8-2a and 8-2b for a minimum of 1 hour. If one or several of the equipment resonant frequencies determined in 8.8.1.3a. are within the +/- 10% bandwidth of the sinusoidal test frequencies, select the most severe frequencies (maximum of 4). Perform sinusoidal dwells at each of these frequencies for 30 minutes. The dwell tests may include multiple frequencies. During each resonance dwell, each of the applied frequencies shall be adjusted, if necessary, to maintain the maximum acceleration response at the resonance being dwelled. The complete non-operating test time at the endurance levels will be two hours plus the time spent at dwells.

d. After completion of 8.8.1.3.c, repeat the test of subparagraph 8.8.1.3.b. Any change in the performance shall be noted on the Environmental Qualification Form (see Appendix A).

e. Repeat the sinusoidal scan of subparagraph 8.5.2.a. Any changes in vibration resonant frequencies shall be noted on the Environmental Qualification Form (see Appendix A). If no change occurs, a statement to that effect shall be included in the declaration. Any difficulty in reading any display feature of the test item, when the total excursion of applied input vibration exceed 0.5 mm, shall not be a cause for failing the test.

f. At the completion of the tests, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

8.8.2 Sine on Random Test Procedure for Category U – Unknown Helicopter Frequencies

This unknown helicopter frequency test procedure utilizes the known helicopter frequency sine-on-random test procedures of 8.8.1 with the test frequencies being as defined below. The following test sequence may be applied to Table 8-2a Zone 1a and Zone 2 equipment only. This includes the fuselage, instrument panel, console and equipment rack.

Perform three tests per 8.8.1.3 (the tests may be performed using 1, 2 or 3 units) using the following values for the sinusoidal test frequencies:

Test 1: f_1= 11 Hz, f_2= 19.9, f_3= 35.5, f_4= 63.9

Test 2 : f_1= 13.4 Hz, f_2= 24, f_3= 43.4, f_4= 77.8

Test 3: f_1= 16.3Hz, f_2= 29.2, f_3= 52.5, f_4= 94.9

The equipment resonance sine dwells can be done on any one of the tests / test units.

8.8.3 Random Test Procedure for Category U2 – Unknown Helicopter Frequencies

The following random test procedure may be used as an alternate to the sine-on-random test procedure of 8.8.2 for Table 8-2A Zone 1a and Zone 2 equipment. It may also be used for Zone 1b (tail boom) equipment.

In each of the equipment's 3 orthogonal axes, perform the following tests using the test curve and test levels of Figure 8-7.

a. With the equipment operating, apply the performance level test APSD for a minimum of 30 minutes to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING VIBRATION.

   During this time period, also perform an ASPD analysis of the vibration acceleration response at selected positions on the equipment.

b. Apply the endurance level test ASPD for 3 hours. During this period, unless otherwise specified, the equipment need not be operating.

c. After the three hour test, repeat the test of subparagraph 8.8.2.a. Any change in the performance or the vibration resonance's shall be noted on the Environmental Qualification Form (see Appendix A).

d. At the completion of the tests, the equipment shall be inspected and shall no evidence of structural failure of any internal or external component.

<u>Table 8-1</u> Categorization and Vibration Tests by Aircraft Types and Equipment Locations

AIRCRAFT TYPE	TEST CATEGORY	AIRCRAFT ZONE 1 FUSELAGE	2 INSTRUMENT PANEL, CONSOLE & EQUIPMENT RACK	3 NACELLE & PYLON	4 ENGINE & GEAR BOX	5 WING & WHEEL WELL	6 LANDING GEAR	7 EMPENNAGE & Fin Tip
		VIBRATION TEST CURVES (2)						
1. Helicopters (Reciprocating & Turbojet Engines)	R or U (1)	G	G	H	I			J
	U2 (1)	F & F1	F & F1					
2. Fixed Wing Turbojet or Turbofan Engines (Subsonic & Supersonic)	S	C (3)	B, B2 or B3 (4)	D	W	E	W	E
	H or Z	R	R	P	P	P	P	P
	R	C & C1 (3)	B & B1, B2 & B12, or B3 & B4 (4)	D & D1	W	E & E1	W	E & E1
3. Fixed Wing Reciprocating & Turboprop Engines Multi Eng over 5,700 KG (12,500 lbs)	S	L(3)	M	T	U	T		
4. Multi Eng Less than 5,700 KG (12,500 lbs)	S	M(3)	M	L	L	L		
5. Single Eng Less than 5,700 KG (12,500 lbs)	S	M	M	M	L	M		
6. Fixed Wing Unducted Turbofan Engines (Propfan)	S	Y (3)	B, B2 or B3 (4)	D	W	E	W	E or Z
	H or Z	R	R	P	P	P	P	P
	R	Y (3)	B & B1, B2 & B12 or B3 & B4 (4)	D & D1	W	E & E1	W	E & E1 or Z

<u>Notes:</u>

1. *U applies to zones 1a and 2 only: (1a is fuselage - 1b is tail boom). U2 is an alternate to U and applies to 1a, 1b and 2 only*
2. *Curves B to E are random; curves G to J are Sine-on-Random; all others are sinusoidal.*
3. *Does not include equipment mounted on structure directly affected by jet efflux.*
4. *Curves B2 and B12 are the same as those found in EUROCAE ED-14C/RTCA DO-160C as B and B′, respectively. They are representative of levels expected on many fixed wing aircraft but are not sufficient for many others. Curves B and B1 contain higher levels and reflect the expected environment for all cases. Curves B3 and B4 are representative of large aircraft.*

Table 8-2a Sine-on-Random Vibration Test Frequencies for Helicopters

Helicopter Zone Vibration Test Frequencies						
Zone / Test Curve	1a / G	1b / G	2 / G	3 / H	4 / I	7 / J
(1) Test Frequencies f_n	Fuselage	Tail boom	Instrument Panel Console & Equipment Rack	Nacelle & Pylon	Engine & Gear Box	Empennage, & Fin Tip
f_1	NMxFM	NMxFM	NMxFM	NMxFM	NMxFM	NMxFM
f_2	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM
f_3		NTxFT		FE	FE	NTxFT
f_4		2xNTxFT		FG	FG	2xNTxFT

Note: (1) FM, FT, FE, FG, NM and NT are defined in Paragraph 8.8.1.

Table 8-2b Sine-on-Random Vibration Test Levels for Helicopters

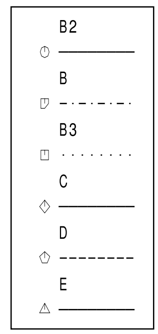
HELICOPTER VIBRATION TEST CURVE TEST LEVELS (PERFORMANCE)				
Test (1) Frequency Range, Hz	**Sinusoidal Test Levels, An, (g-PK) (2)**			
	G	H	I	J
$3 < f_n < 10$	$0.04 \times f_n$	$0.05 \times f_n$	$0.08 \times f_n$	$0.17 \times f_n$
$10 < f_n < 20$	$0.04 \times f_n$	$0.05 \times f_n$	$0.08 \times f_n$	4.2
$20 < f_n < 40$	$0.04 \times f_n$	$0.05 \times f_n$	$0.08 \times f_n$	4.2
$40 < f_n < 200$	1.6	2.5	$0.08 \times f_n$	4.2
$200 < f_n < 2000$			16.7	
PSD	**Random curve level (g^2/Hz)**			
W_0	0.01	0.01	0.01	0.01

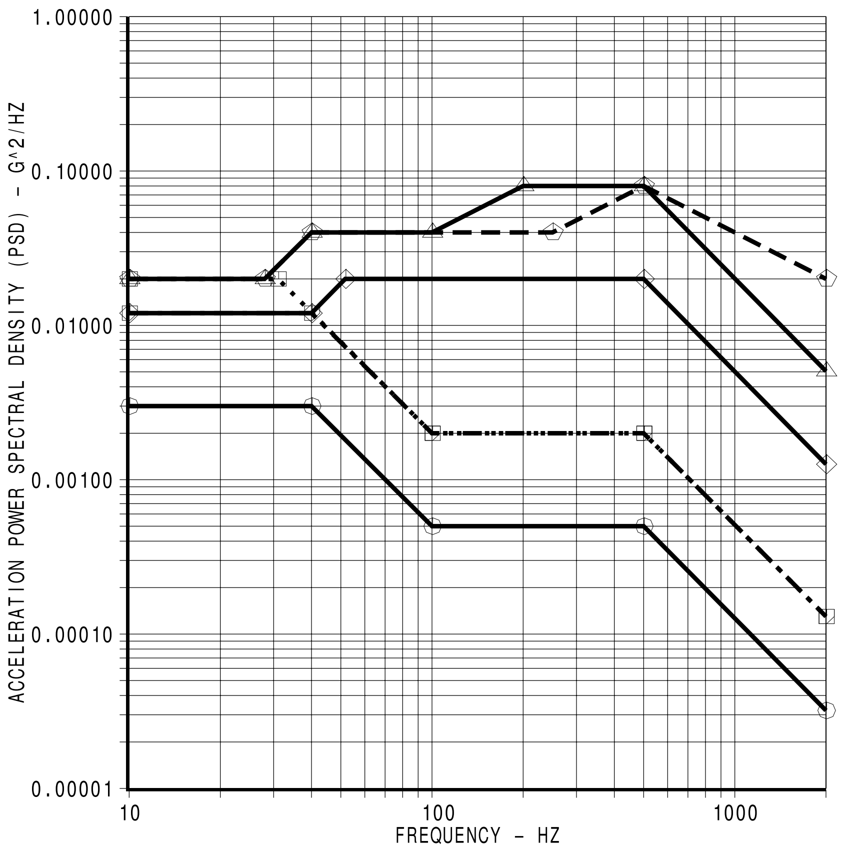
HELICOPTER VIBRATION TEST CURVE TEST LEVELS (ENDURANCE)				
Test (1) Frequency Range, Hz	**Sinusoidal Test Levels, An, (g-PK) (2)**			
	G	H	I	J
$3 < f_n < 10$	$0.05 \times f_n$	$0.07 \times f_n$	$0.1 \times f_n$	$0.2 \times f_n$
$10 < f_n < 20$	$(0.2 \times f_n)-1.5$	$(0.28 \times f_n) - 2.1$	$(0.3 \times f_n) - 2$	$(0.3 x f_n) - 1$
$20 < f_n < 40$	2.5	3.5	4.00	5.00
$40 < f_n < 200$	2.5	3.5	$(0.1 \times f_n)$	5.00
$200 < f_n < 2000$			20.00	
PSD	**Random curve level (g^2/Hz)**			
W_0	0.02	0.02	0.02	0.02

(1) _Note 1_: *The four sinusoidal frequencies f_1, f_2, f_3 and f_4 for each zone are determined in Table 8.2a.*

(2) _Note 2_: *For equipment located externally on the airframe and exposed to the external airflow, the sinusoidal levels shall be increased by a factor 1.5.*

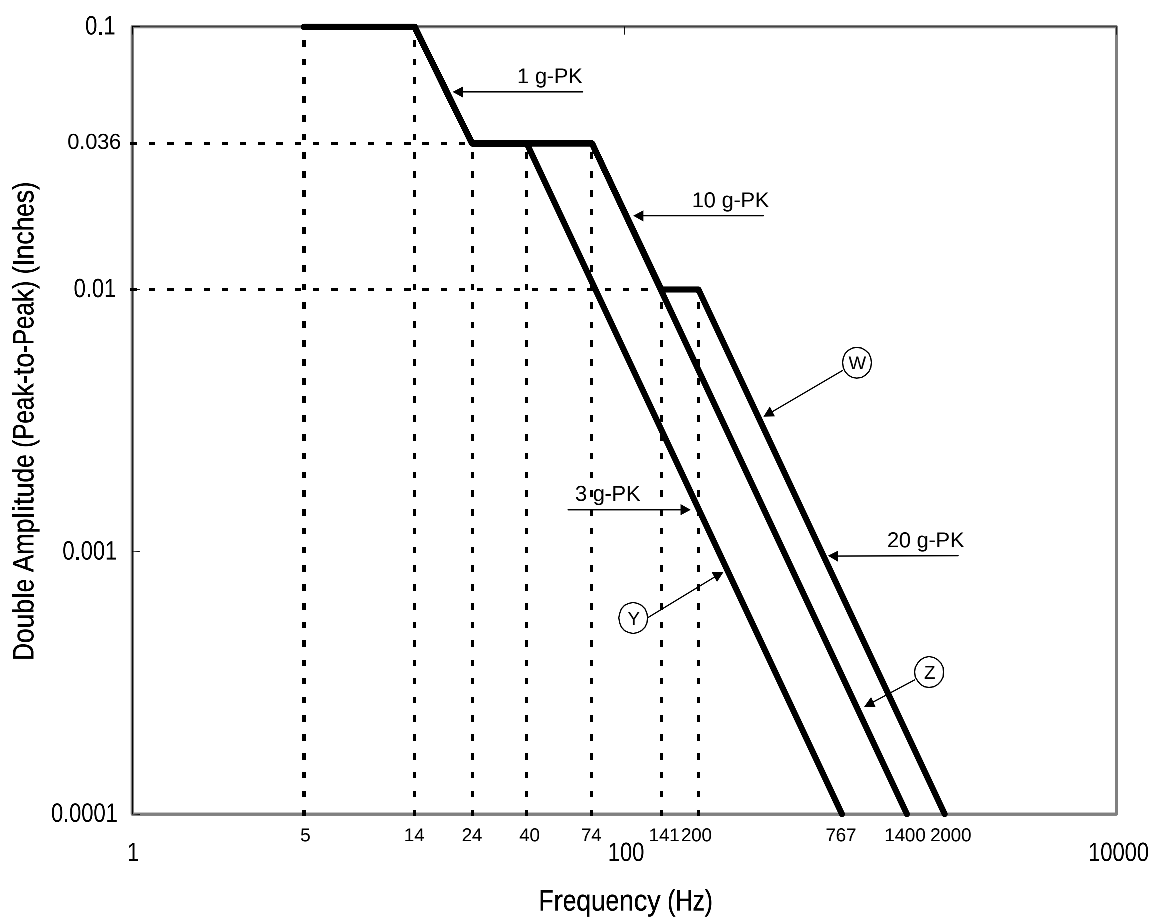
Curves	G_{rms}
B2	0.74
B	1.48
B3	1.55
C	4.12
D	8.92
E	7.94





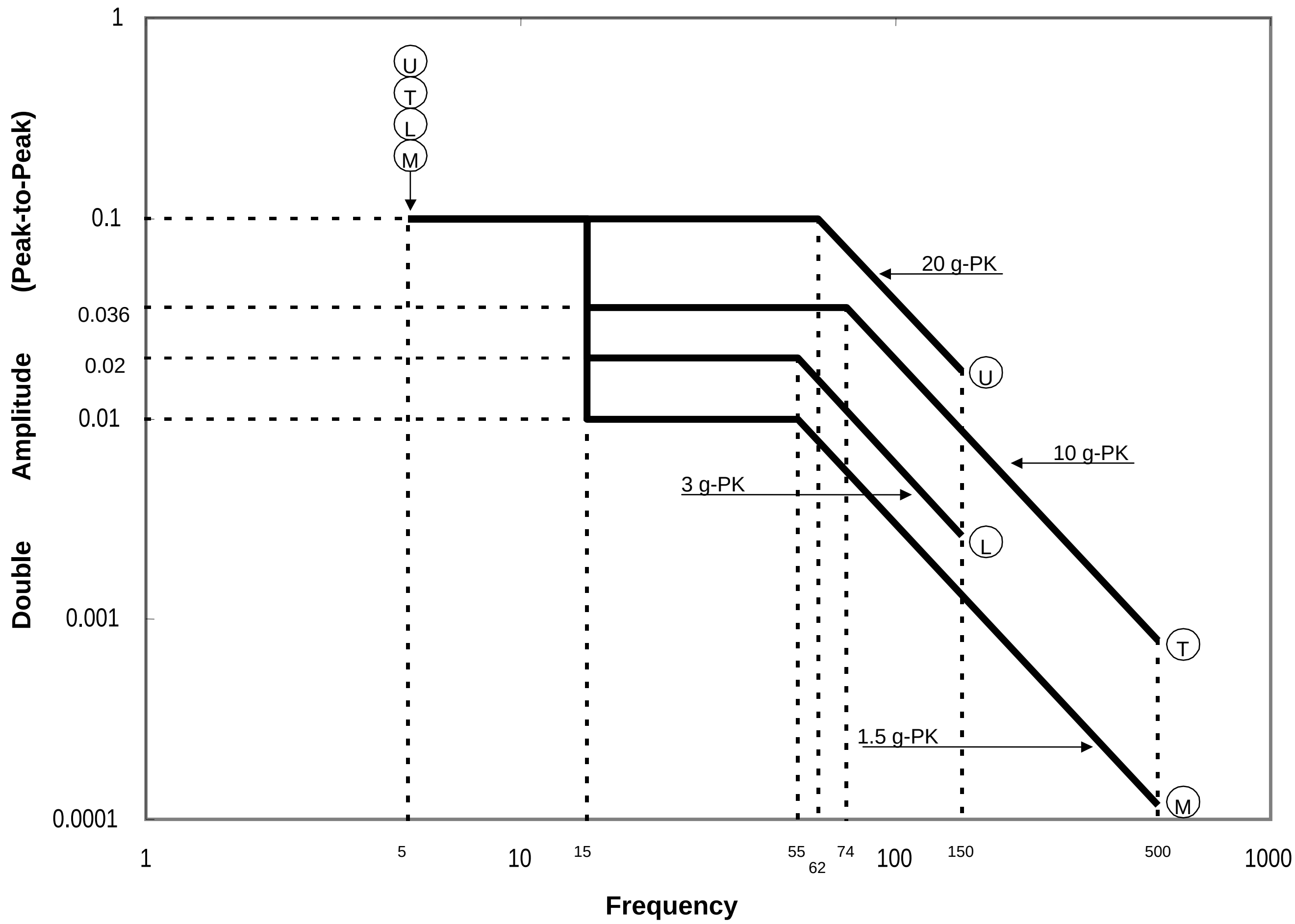
Test Levels at test curve frequency break points										
	10	28	31	40	51.7	100	200	250	500	2000
B2	0.003			0.003		0.0005			0.0005	0.000032
B	0.012			0.012		0.002			0.002	0.00013
B3	0.020		0.020			0.002			0.002	0.00013
C	0.012			0.012	0.020				0.020	0.00126
D	0.020	0.020		0.040				0.040	0.080	0.020

<u>Figure 8-1</u> Standard Random Vibration Test Curves for Equipment Installed in Fixed Wing Aircraft with Turbojet or Turbofan Engines



Note: In this figure the use of English units was retained because the graphs were derived units

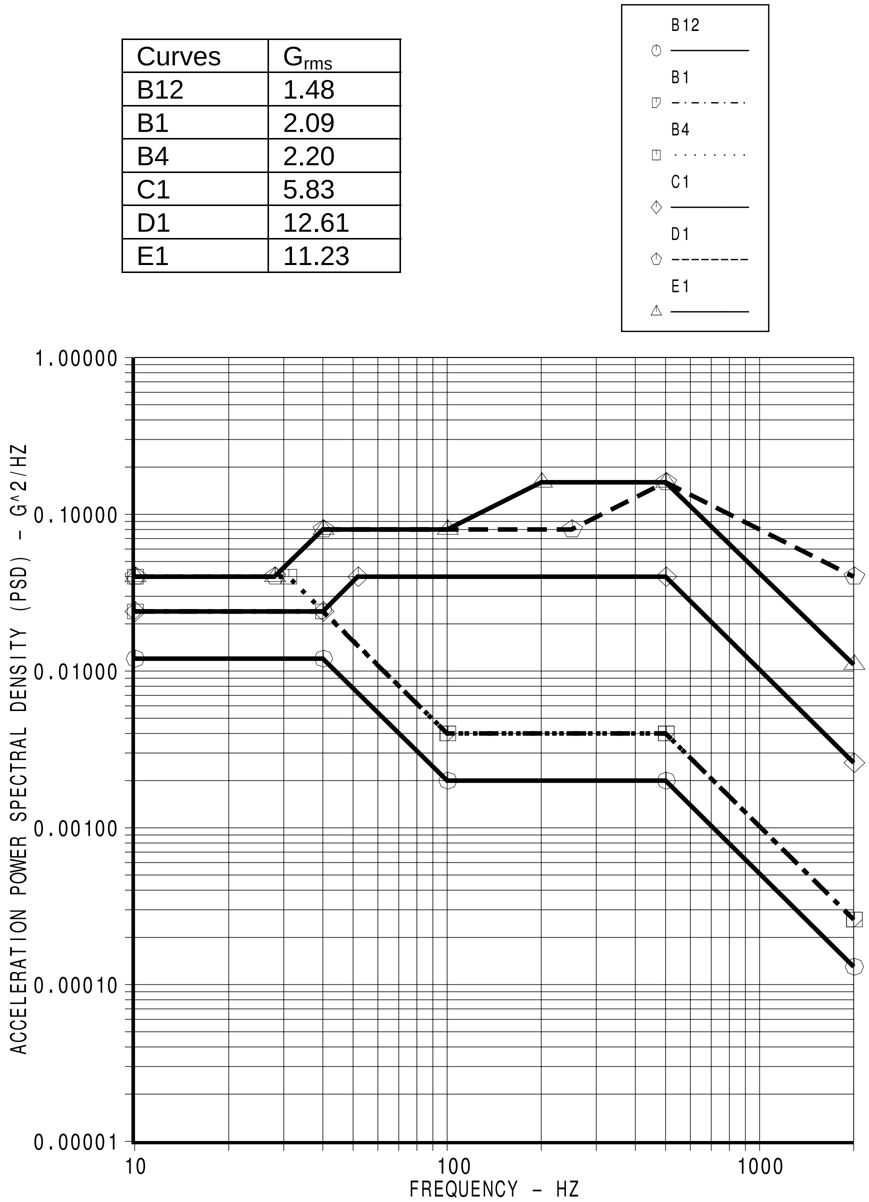
<u>Figure 8-2</u> Standard and Robust Sinusoidal Vibration Test Curves for Equipment Installed in Applicable Zones in Fixed-Wing Aircraft with Turbojet or Turbofan Engines and Unducted Fan Engines



Note: In this figure the use of English units was retained because the graphs were derived from these units originally.

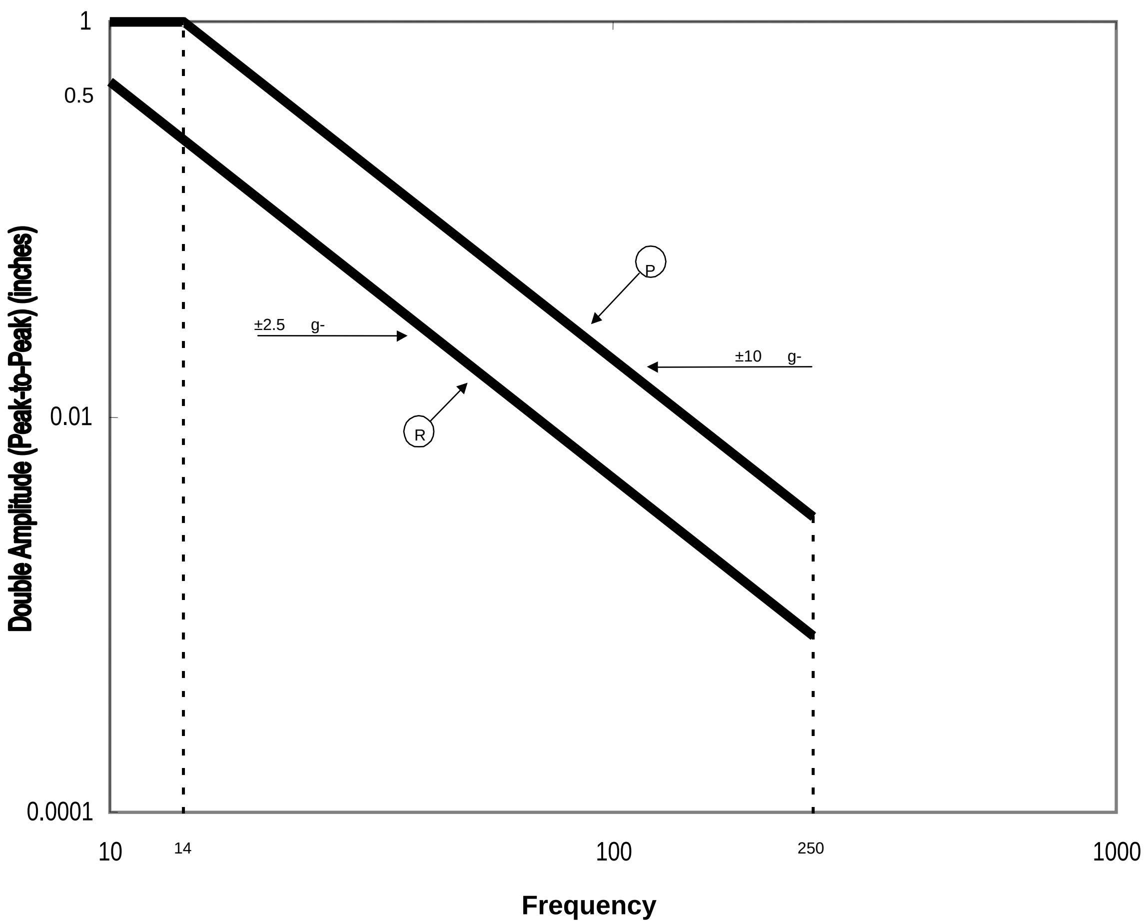
<u>Figure 8-3</u> Standard Sinusoidal Vibration Test Curves for Equipment Installed in Fixed-Wing Aircraft with Reciprocating or Turbopropeller Engines

Curves	G_{rms}
B12	1.48
B1	2.09
B4	2.20
C1	5.83
D1	12.61
E1	11.23



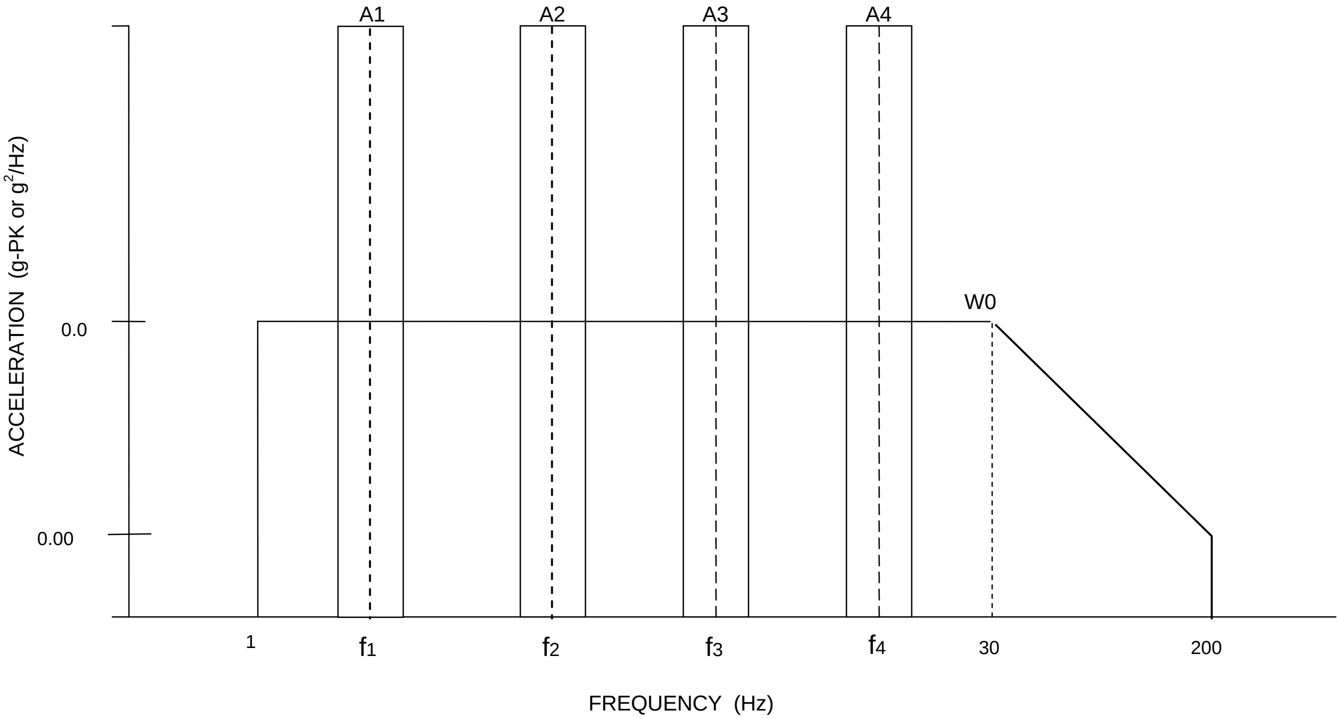
Test Levels at test curve frequency break points										
	10	28	31	40	51.7	100	200	250	500	2000
B12	0.012			0.012		0.002			0.002	0.00013
B1	0.024			0.024		0.004			0.004	0.00026
B4	0.040		0.040			0.004			0.004	0.00026
C1	0.024			0.024	0.040				0.040	0.0026
D1	0.040	0.040		0.080				0.080	0.160	0.040
E1	0.040	0.040		0.080		0.080	0.160		0.160	0.011

Figure 8-4 Robust Random Vibration Test Curves for Equipment Installed in Fixed Wing Aircraft with Turbojet or Turbofan Engines



Note: In this figure the use of English units was retained because the graphs were derived from these units originally.

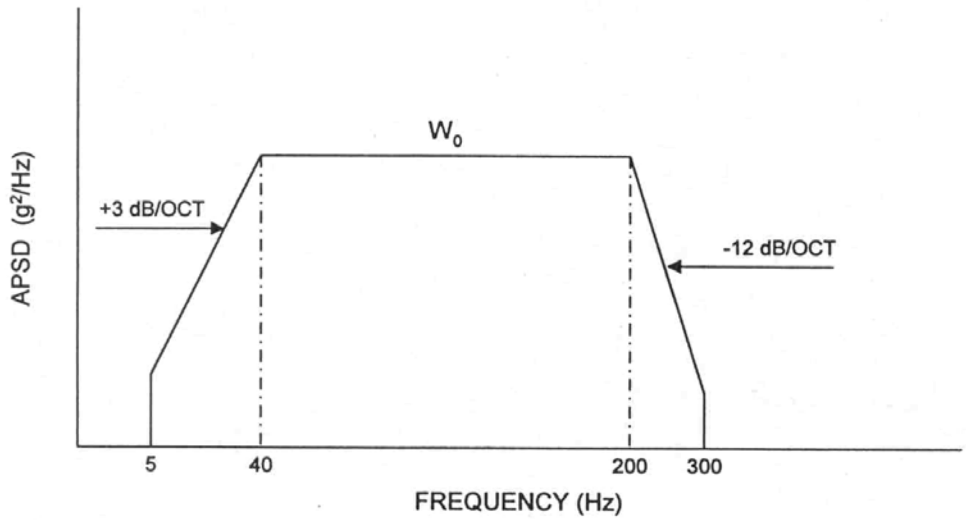
<u>Figure 8-5</u> High-Level Short Duration Sinusoidal Vibration Test Curves for Equipment Installed on Fixed-Wing Aircraft with Turbojet or Turbofan Engines



<u>Figure 8-6</u> Sine-On-Random Vibration Test Curve for Helicopters

Note: W0 is a random PSD curve, g^2/Hz ; A1- A4 are Sinusoidal Curves, g-PK.
The vibration frequencies are determined using the equations in Table 8-2a,. Use these frequencies together with the equations in Table 8-2b to determine the vibration levels.

TEST	TEST CURVES	W_0	grms
Performance	F	0.05	2.97
Endurance	F1	0.10	4.20



<u>Figure 8-7</u> Random Test Curves for Helicopters Fuselage, Instrument Panel, and Tail Boom (Unknown Frequencies)

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RTCA/DO-160E

Environmental Conditions and Test Procedures for Airborne Equipment

Section 9

Explosive Atmosphere

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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Prepared by: SC-135

9.0 Explosive Atmosphere

9.1 Purpose of the Test

This test specifies requirements and procedures for aircraft equipment that may come into contact with flammable fluids and vapors such as those specified herein. It also refers to normal and fault conditions that could occur in areas that are or may be subjected to flammable fluids and vapors during flight operations.

The flammable test fluids, vapors or gases referred to in this section simulate those normally used in conventional aircraft and that require oxygen for combustion (e.g., monofuels are not included).

These standards do not relate to potentially dangerous environments occurring as a result of leakage from goods carried on the aircraft as baggage or cargo.

Note: *The explosive atmosphere tests shall be conducted after the article being tested has been subjected to other environmental tests of this document (see Subsection 3.2, "Order of Tests").*

9.2 Explosion Proof

Equipment is explosion proof when it has been determined that there is negligible risk that it will cause an explosion of a flammable gas or vapor within the declared environment.

9.3 Environment Definitions and Equipment Requirements

Equipment Environments and related requirements shall be as follows (See Table 9-1).

9.3.1 Environment I

Environment I is an atmosphere in a space in which uncovered flammable fluids or vapors exist, or can exist, either continuously or intermittently (e.g., in fuel tanks or within fuel systems). Installed equipment shall meet the standards and test procedures of explosion containment.

9.3.2 Environment II

Environment II is an atmosphere in which flammable mixtures can be expected to occur only as a result of a fault-causing spillage or leakage. Installed equipment shall meet the standards and test procedures for any one of the explosive atmosphere categories (paragraphs 9.4.1, 9.4.2 or 9.4.3).

9.3.3 Environment III

Environment III is an atmosphere within a designated fire zone. The equipment test requirements are the same as for Environment II except that fault conditions in Category A equipment need not be considered.

9.4 Equipment Categories

9.4.1 Category A Equipment

Category A equipment is designed so that:

a. Ignition of an explosive mixture is contained within the equipment without igniting an explosive atmosphere surrounding it and so that it meets the Category A tests specified in paragraph 9.7.1.

b. During normal operation, or as a result of any fault, the temperature of any external surface will not rise to a level capable of causing ignition (subparagraph 9.7.1.4).

Hermetically sealed equipment meeting subparagraph 9.4.1 b. shall be identified as Category A equipment.

9.4.2 Category E Equipment

Category E equipment is not hermetically sealed and not contained in cases designed to prevent flame and explosion propagation. Category E equipment is not intended for installation in Environment I.

Such equipment shall be designed so that in normal operation the temperature of any external surface will not rise to a level capable of causing ignition, nor will any operating part cause ignition.

9.4.3 Category H Equipment

Category H equipment, including those hermetically sealed, contain hot spot surfaces (external or internal) and are non-spark producing under normal operating conditions (see paragraph 4.6.1).

Such equipment shall be designed so that in normal operation the temperature of any external surfaces will not rise to a level capable of causing ignition.

9.5 General Test Requirements

9.5.1 General

The test requirements specified below are necessary to assure that the equipment, when tested in accordance with the applicable test procedure, will comply with the standards established in Subsection 9.3.

9.5.2 Test Specimen

The test specimens selected shall be representative of production equipment.

9.5.3 Fuel

Unless otherwise specified, the fuel used may be propane, normal hexane and associated equations.

9.5.4 Fuel Mixtures

a. For propane, a 1.05 stoichiometric mixture of 3.85% to 4.25% by volume of propane to 96.15% to 95.75% by volume of air. For an example of test apparatus see Figure 9-1.

b. For hexane, a 1.80 stoichiometric fraction of normal hexane shall be calculated according to the following equations:

(1) Volume (ml) of 95% normal hexane (metric units) =

$$(4.27 \times 10^{-4}) \frac{[\text{net chamber vol (liters)}][\text{chamber pressure (pascals)}]}{[\text{Chamber temp (K)}][\text{Relative density of n-hexane}]}$$

(2) Volume (ml) of 95% normal hexane (english units) =

$$(150.41) \frac{[\text{net chamber vol } (\text{ft}^3)][\text{chamber pressure (psia)}]}{[\text{Chamber temp (R)}][\text{Relative density of n-hexane}]}$$

Note: *K = the thermodynamic temperature and is C + 273.15*
R = the thermodynamic temperature and is F + 459.67
The relative density of normal hexane can be determined from Figure 9-2.

The equipment used to vaporize the fuel for use in the explosive atmosphere test should be so designed that a small quantity of air and fuel vapor will be heated together to a temperature such that the fuel vapor will not condense as it is drawn from the vaporizer into the chamber.

When the test facility is designed for fuel vaporization inside the explosion chamber, the fuel may be introduced at the ambient temperature of the test site.

9.6 Equipment Design and Installation Information

Equipment specifications should detail any design constraints applicable to the particular category of equipment enclosure. Such design constraints should include the following as appropriate:

a. Equipment that may come into contact with flammable fluids or vapors and that in normal operations may produce arcs, sparks or hot surfaces shall be designed, considering its likely manner of installation, to be explosion proof.

b. Equipment that may come into contact with flammable fluids or vapors, and that under fault conditions may produce arcs, electrical sparks, friction sparks or hot surfaces shall be designed and installed to reduce to an acceptable minimum the overall risk of a fault occurring that will ignite the flammable vapors.

c. In designing the air supply system for forced air ventilated equipment, the possibility of contamination of the air by flammable vapors shall be taken into account. If the equipment and its ducting, including joints, are in an area that can be so contaminated, they shall be capable of meeting the conditions appropriate to the environment.

d. The specification for Category A equipment, paragraph 9.4.1, should consider the design requirements of flange and hole dimensions or other equivalent means, such as flame traps, for adequate safety from flame propagation. This information is contained in national documents.

9.7 Test Procedures

9.7.1 Category A Test

9.7.1.1 Preparation for Test

a. Preparation of Test Case or Enclosure – The purpose of this procedure is to intentionally fill the case or enclosure under test with a volatile gas mixture then ignite it. Drilling and tapping openings in the case or enclosure for inlet/outlet hose connections to the fuel-vapor-air mixture circulation system and for mounting a spark gap device may be required. The case volume shall not be altered by more than ±5 percent by any modification to facilitate the introduction of explosive vapor.

b. Hose Installation - When inserting a hose from a blower, adequate precaution shall be taken to prevent ignition of the ambient mixture by backfire or the release of pressure through the supply hose.

c. Spark Gap Device - A spark gap device for igniting the explosive mixture within the case or enclosure shall be provided. The case or enclosure may be drilled and tapped for the spark gap device, or the spark gap device may be mounted internally.

d. Case Installation - The case or enclosure with either the test item or a model of the test item of the same volume and configuration in position within the case or enclosure shall be connected and oriented in the explosion chamber mechanically and electrically, as recommended by the manufacturer for normal service installation. This shall include any cooling provisions, as necessary to perform the tests described herein.

e. Test Facility – The required apparatus consists of a chamber or cabinet together with auxiliary instrumentation capable of establishing, maintaining and monitoring the specified test conditions. Use a chamber with a means of igniting the fuel-air mixture such as a spark-gap device, as well as a means of determining the explosiveness of a sample of the mixture such as a spark gap or glow plug ignition source. An alternative method of determining the explosive characteristics of the vapor is by using a calibrated explosive gas meter which verifies the degree of explosiveness and the concentration of the fuel-air mixture.

9.7.1.2 Performance of Test

The following test sequence shall be performed three times as follows:

Step 1: The chamber shall be sealed and the internal pressure maintained at site level pressure. The ambient chamber temperature shall be at least 25°C. An explosive mixture within the chamber shall be obtained by using the mixture defined in paragraphs 9.5.3 and 9.5.4. Circulate (by blower or pump) fuel/air mixture through test unit to insure explosive mixture within test unit.

Step 2: The internal case ignition source shall be energized in order to cause an explosion within the case. The occurrence of an explosion within the case may be detected by use of a thermocouple inserted in the case and connected to an appropriate temperature recorder outside the test chamber. If ignition of the mixture does not occur immediately, the test shall be considered void and shall be repeated with a new explosive charge.

Step 3: At least five internal case explosions shall be performed. If the case tested is small (not in excess of 1/50 of the test chamber volume) and if the reaction within the case upon ignition is of an explosive nature without continued burning of the mixture as it circulates into the case, more than one internal case explosion, but not more than five, may be produced without recharging the entire chamber. Ample time shall be allowed between internal case explosions for replacement of burnt gases with fresh explosive mixture within the case. If the internal case explosions produced did not cause a main chamber explosion, the explosiveness of the fuel-air mixture in the main chamber shall be verified by igniting a sample of the mixture with a spark plug or glow plug. If the air-vapor mixture in the main chamber is found not to be explosive, the test shall be considered void and the entire procedure repeated.

9.7.1.3 Failure Criteria

If the internal case explosion causes a main chamber explosion, the test item shall have failed the test and no further tests need be conducted.

9.7.1.4 External Surface Temperature Tests

If required, test procedures shall be specified in the individual equipment specification (subparagraph 9.4.1 b.).

9.7.2 Category E Test

9.7.2.1 Preparation for Test

a. The test item shall be connected and oriented mechanically and electrically as recommended by the manufacturer for normal service installation. This shall include any cooling provisions as necessary to perform the tests described herein so that normal electrical operation is possible and mechanical controls may be operated through the pressure seals from outside the chamber. External covers of the test item shall be removed or loosened to facilitate the penetration of the explosive mixture. Large test items may be tested one or more units at a time by extending electrical connections through the cable port to the balance of the associated equipment located externally.

b. The test item shall be operated to determine that it is functioning properly.

c. Mechanical loads on drive assemblies and servomechanical and electrical loads on switches and relays may be simulated if proper precaution is given to duplicating the normal load in respect to torque, voltage, current, inductive reactance, etc. In all instances, it is preferable to operate the test item as it normally functions in the installed environment.

9.7.2.2 Performance of Test

The test shall be conducted at site level pressure.

Step 1: The test chamber shall be sealed and the ambient temperature within shall be raised to the Operating High Temperature, given in Table 4-1, for which the equipment is designed to operate. The temperature of the test chamber and the chamber walls shall be permitted to rise to within 11°C of the chamber ambient air, prior to the introduction of the explosive mixture, to prevent condensation of the explosive medium.

Step 2: The required quantity of fuel (paragraph 9.5.4) shall be introduced into the chamber. Circulate the test atmosphere for at least three minutes to allow for complete vaporization of fuel and the development of a homogenous mixture.

Step 3: At this time all electrical contacts of the test item shall be actuated. The operation of the test item shall be continuous throughout this period and all making and breaking of electrical contacts shall be conducted as frequently as deemed practicable.

Step 4: If no explosion has occurred as a result of the test item operation, the potential explosiveness of the air-vapor mixture shall be verified by igniting a sample of the mixture with a spark gap or glow plug. If the air-vapor mixture is not found to be explosive, the test shall be considered void and the entire procedure repeated.

9.7.2.3 Failure Criteria

If the item causes an explosion, it shall have failed the test and further tests need not be conducted.

9.7.3 Category H Test

9.7.3.1 Preparation for Test

The test item shall be placed in the test chamber in accordance with subparagraph 9.7.2.1. the suspected components or surfaces to be tested for thermal ignition shall be instrumented with thermocouples operating in a range of 65 to 260°C.

9.7.3.2 Performance of Test

The test shall be conducted as follows:

Step 1: The test chamber shall be sealed and the ambient temperature within shall be raised to the Operating High Temperature, given in Table 4-1, for which the equipment is designed to operate. The temperature of the test chamber and the chamber walls shall be permitted to rise to within 11°C of the chamber ambient air.

Step 2: The equipment shall be turned on and operated in its normal mode until thermal stabilization of the equipment has been attained. The maximum temperatures attained at the suspected components or surfaces shall be recorded. If a temperature in excess of 204°C is attained, the test shall be terminated.

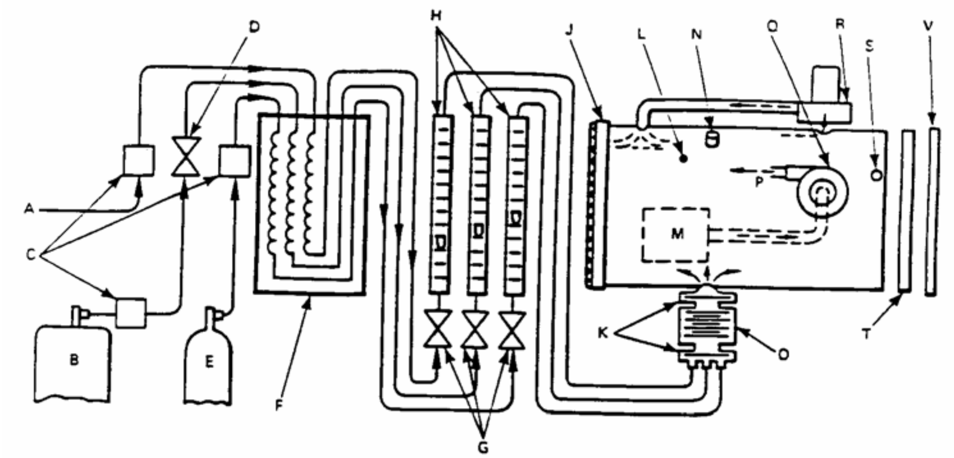
9.7.3.3 Failure Criteria

In Step 2 above, if the item exceeds 204°C, the test item shall have failed the test and further tests need not be conducted.

Table 9-1 Equipment Categories and Test Requirements

Environment	Equipment Categories	Requirements and Tests	Notes
I	A A (hermetically sealed)	See paragraph 9.7.1 See paragraph 9.7.1.2	1/
II	A E H	See paragraph 9.7.1 See paragraph 9.7.2 See paragraph 9.7.3	2/
III	A E H	Same as for Environment II, but fault cases are not applicable	3/

Notes: 1/ *Paragraph 9.3.1 applies*
2/ *Paragraph 9.3.2 applies*
3/ *Paragraph 9.3.3 applies*



Legend

A AIR
B PROPANE GAS CONTAINER
C REDUCING VALVES
D GAS CUT-OFF VALVE OPERATED BY MICRO-SWITCHES ON EXPLOSION CHAMBER
E OXYGEN BOTTLE
F HEAT EXCHANGER TO BRING THE GASES TO STANDARD TEMPERATURE
G NEEDLE VALVES
J BOTH ENDS COVERED BY DIAPHRAGMS (E G PAPER, POLYETHYLENE) HELD ON BY RUBBER BANDS

K DIAPHRAGM CHECK VALVES
L CYLINDRICAL EXPLOSION CHAMBER
M UNIT UNDER TEST
N VENT
O MIXING CHAMBER
P WASTE TO ATMOSPHERE
Q EXTRACTOR FOR CHARGING UNIT UNDER TEST
R STIRRING BLOWER
S MICRO-SWITCH (ONE T EACH END) RELEASED WHEN H FLOW METERS RUBBER BAND IS DISPLACED BY EXPLOSION
T DIAPHRAGM
V RUBBER BAND

Figure 9-1 Example of Apparatus for Testing in Explosive Atmospheres

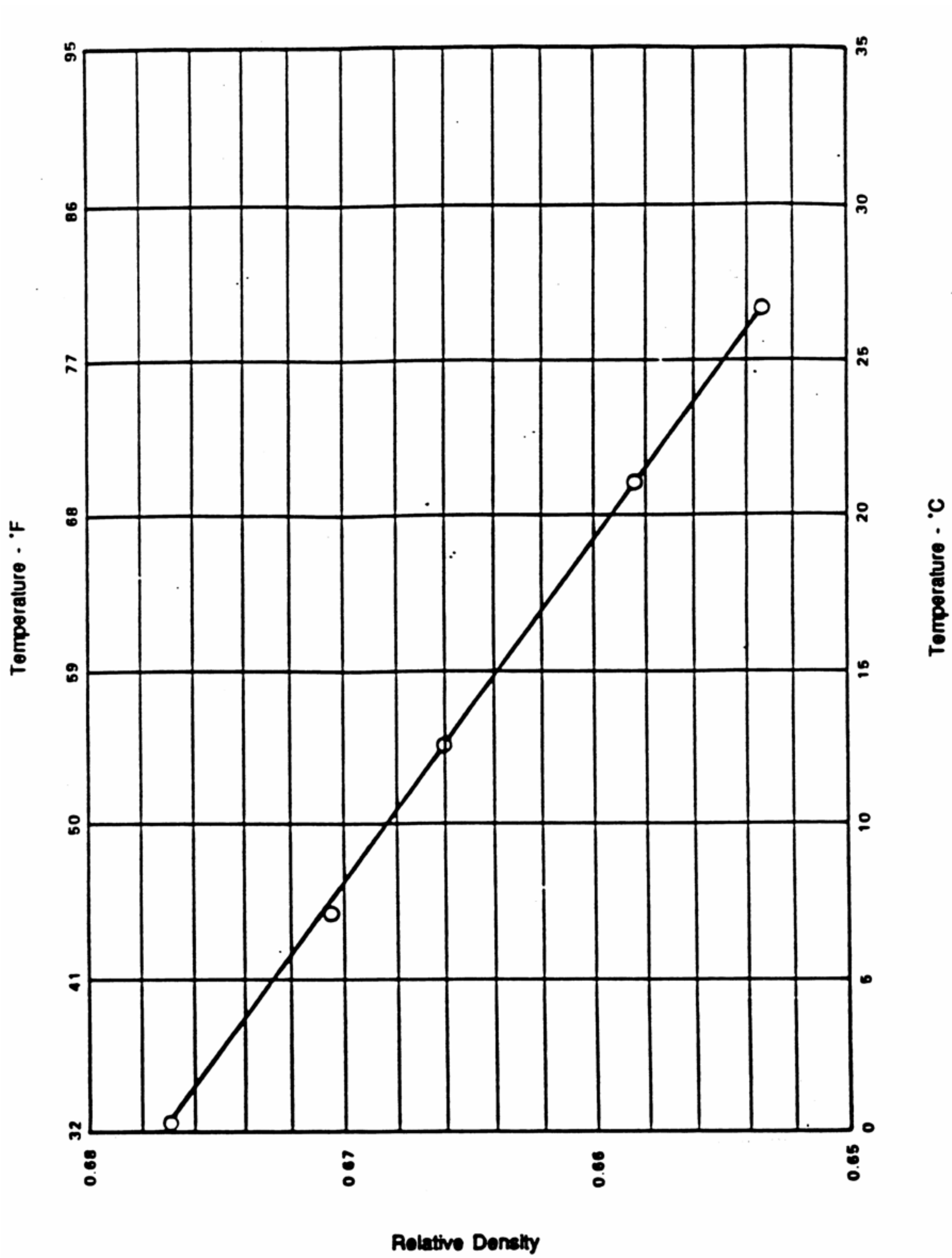
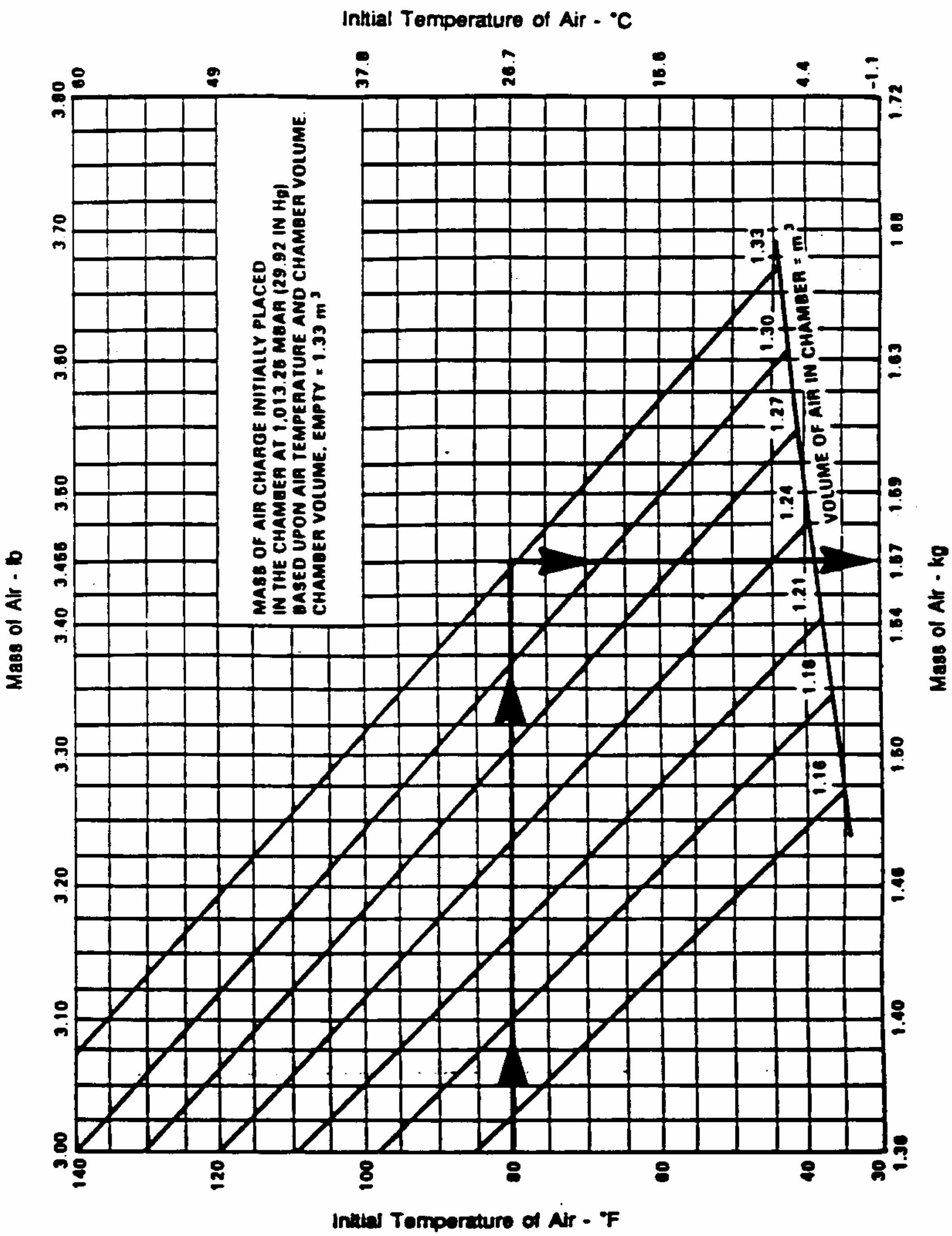


FIGURE 9-2 RELATIVE DENSITY OF N-HEXANE



<u>Figure 9-3</u> Mass of Air Charge vs Temperature

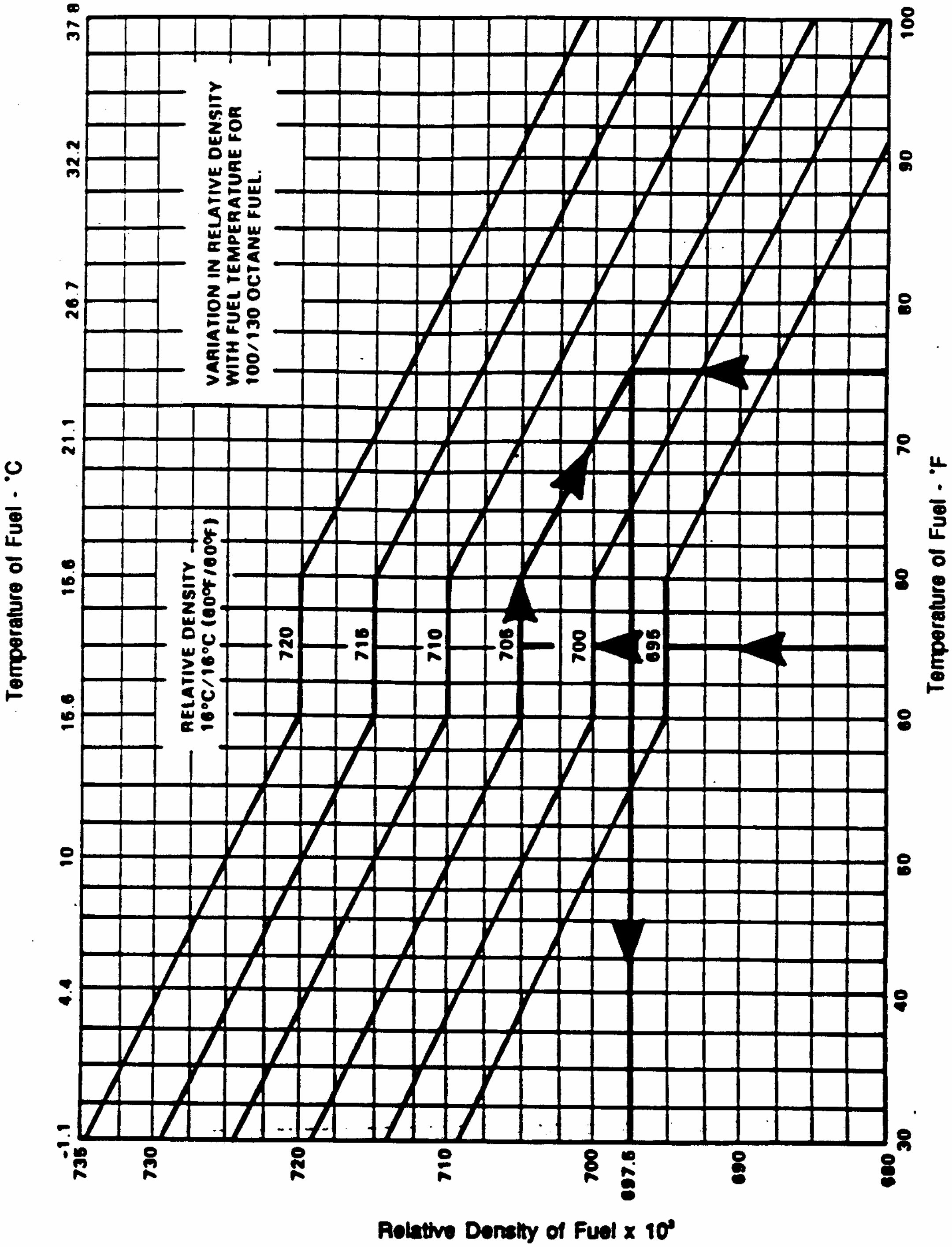


FIGURE 9-4 RELATIVE DENSITY VS TEMPERATURE

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 10

Waterproofness

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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10.0 Waterproofness

10.1 Purpose of the Test

These tests determine whether the equipment can withstand the effects of liquid water being sprayed or falling on the equipment or the effects of condensation.

These tests are not intended to verify performance of hermetically sealed equipment. Therefore, hermetically sealed equipment may be considered to have met all waterproofness requirements without further testing. Equipment shall be considered hermetically sealed when the seal is permanent and airtight.

10.2 Equipment Categories

<u>Category Y</u>

Equipment that is installed in locations where it is subjected to condensing water in the course of normal aircraft operations is identified as Category Y. For equipment intended for installation in such locations, the condensing water proof test procedure applies and the equipment is identified as Category Y.

<u>Category W</u>

Equipment that is installed in locations where it is subjected to falling water (generally the result of condensation) in the course of normal aircraft operations is identified as Category W. For equipment intended for installation in such locations, the drip proof test procedure applies and the equipment is identified as Category W.

<u>Category R</u>

Equipment installed in locations where it may be subjected to a driving rain or where water may be sprayed on it from any angle is identified as Category R. For equipment intended for installation in such locations, the spray proof test procedure applies. Equipment that has passed the Category R requirements may be considered to meet the Category W requirement without further testing.

<u>Category S</u>

Equipment installed in locations where it may be subjected to the forces of a heavy stream of fluid such as would be encountered in aircraft de-icing, washing or cleaning operations is identified as Category S. For equipment intended for installation in such locations the continuous stream proof procedure applies. Water is used in this test to simulate the actual fluid forces. Equipment that has passed the Category S requirements may be considered to meet the Category W requirements without further testing.

10.3 Test Procedures

10.3.1 Condensing Water Proof Test

Two temperature chambers will be used for this test. Chamber 1 will be set to -10°C, while chamber 2 will be set to 40°C and 85% RH. Mount the equipment under test according to the manufacturer's specifications with all connectors and fittings engaged into chamber 1. With the equipment not operating let the equipment stabilize for a minimum of three hours. Chamber 2 shall be stabilized at 40°C and 85% humidity during this same time. After the three-hour stabilization, transfer the equipment to chamber two within a five minute transition time. Mount the equipment according to the manufacturer's specifications with all connectors and fittings, Including ventilation, engaged into chamber 2 within a maximum delay of 5 minutes. Turn the equipment on and let it operate for 10 minutes (+1 minute, - 0 minutes). Following the 10 minute operating period DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

10.3.2 Drip Proof Test.

Prior to the start of the Drip Proof test, with the equipment under test not operating, stabilize the equipment to a temperature of at least 10 degrees Celsius above the temperature of the water to be used for the drip test. Place equipment according to the manufacturer's specifications with all connectors and fittings engaged. With the equipment not operating, subject it to water falling at a uniform rate from a minimum height of one meter above the top surface of the equipment under test for a minimum of 15 minutes. The test equipment shall emit a volume of water greater than 280 $l/m^2/hr$ dripping from a dispenser with 0.33 mm nominal diameter drip holes on a 25 mm pattern as shown in Figure 10-1. The drip hole pattern shall be sufficiently large to meet or exceed the horizontal cross sectional area of the equipment under test when installed in its normal position. At the conclusion of the test DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

10.3.3 Spray Proof Test

Mount the equipment according to the manufacturer's specification with all connectors and fittings engaged. With the equipment operating, subject it to a shower of water from a shower head nozzle as depicted in Figure 10-2. The water shall be directed perpendicular to the most vulnerable area(s) of the equipment as stated in the applicable equipment performance standards.

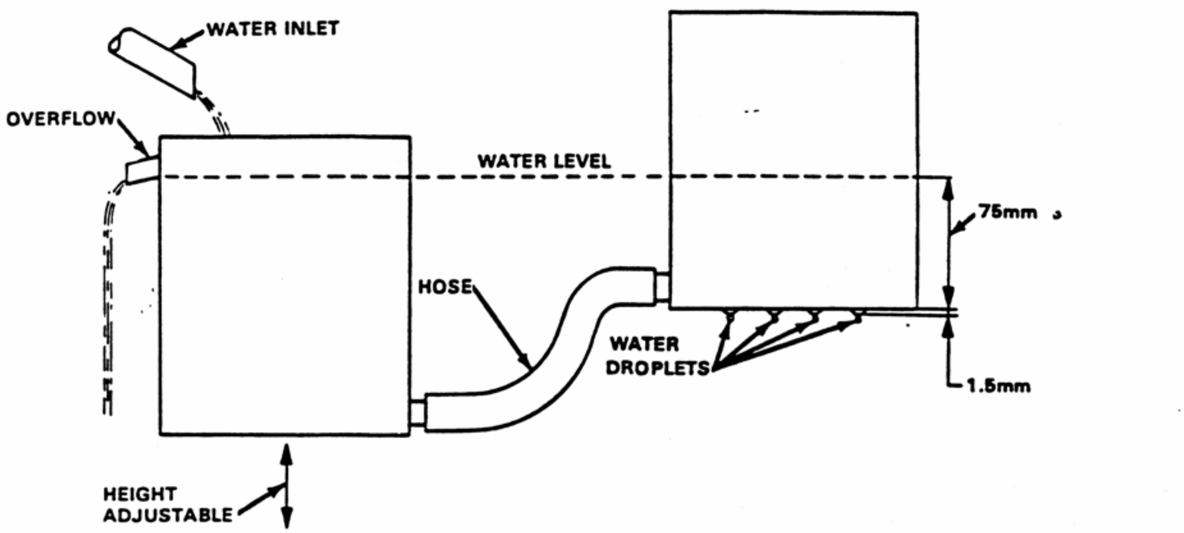
Each of the areas under test shall be subjected to the spray for a minimum of 15 minutes. If desired, the test may be applied simultaneously to more than one area at a time by using an appropriate number of showerheads. The showerhead shall be located not more than 2.5 m from the area under test and shall emit a volume of water greater than 450 liters per hour. At the conclusion of the test DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

10.3.4 Continuous Stream Proof Test

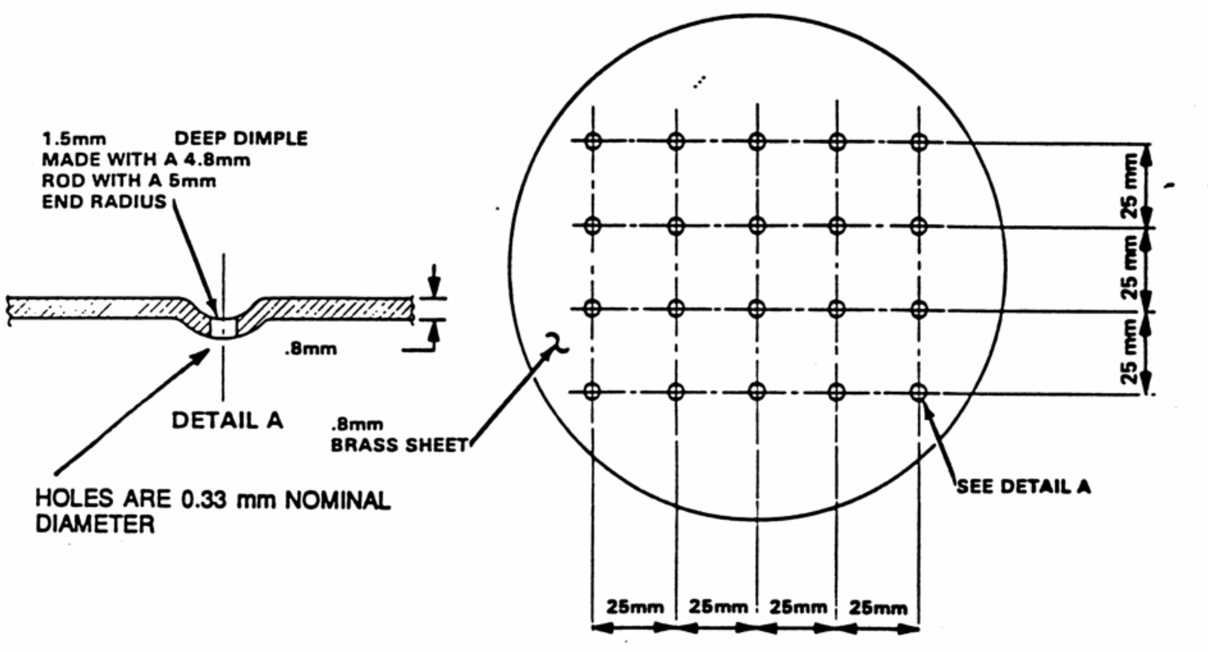
This test is used to supplement the fluids susceptibility test in Section 11.0. Susceptible materials such as gaskets shall be subjected to the appropriate tests of Section 11.0 prior to the performance of this test. This test shall be performed with water at a temperature of 50 degrees C.

Mount the equipment according to the manufacturer's installation instructions in a manner that simulates the aircraft installation. Connectors or other fittings shall be connected as in normal operation. The equipment need not be operated during this test.

Subject the equipment, particularly in areas where parts are mated with a resilient gasket, to a continuous stream of water on all sides for a minimum five minutes on each side. The stream of water shall be of sufficient pressure to produce, through a 6.4-mm diameter nozzle, at least a six-meter vertical stream of water. The equipment shall be subjected to this stream of water from a distance of one to two meters. At the conclusion of the test DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.



(A) TEST SETUP FOR WATER PROOFNESS TEST



(B) DISPENSER DETAILS

AL02638

NOTE: Container size and number of holes as required to meet the flow rate requirement of paragraph 10.3.1.

FIGURE 10-1 DRIP PROOF TEST DETAILS

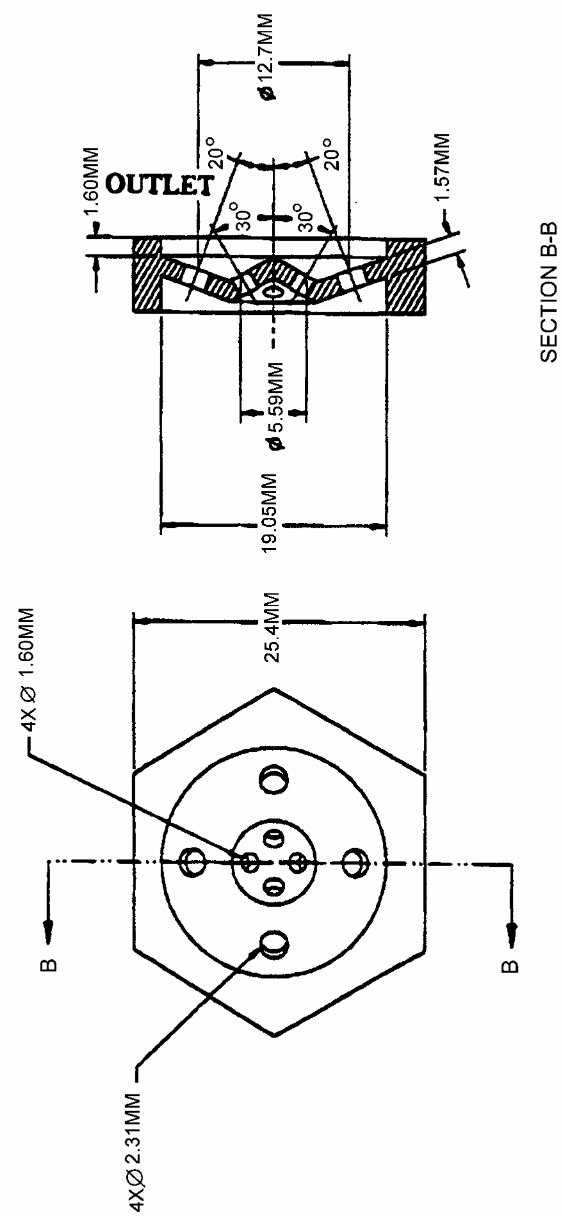


FIGURE 10-2 SHOWER HEAD DETAILS

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 11

Fluids Susceptibility

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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11.0 Fluids Susceptibility

11.1 Purpose of the Test

These tests determine whether the materials used in the construction of the equipment can withstand the deleterious effects of fluid contaminants. Fluids susceptibility tests should only be performed when the equipment will be installed in areas where fluid contamination could be commonly encountered. The fluids are representative of those commonly used fluids encountered in airborne and ground operations. Fluids not listed herein and for which susceptibility tests are indicated shall be included in the relevant equipment specification.

11.2 Precautions

Since many contaminants may have flash points within the test temperature range, care should be taken to ensure that adequate safety measures are taken to limit the possibility of fire or explosion.

Some contaminants may themselves or in combination with other contaminants or with the test sample be toxic. Due consideration should be given to this possibility before commencing the tests.

11.3 Equipment Categories

Category F

Equipment that has passed the tests covered in this section is identified as Category F. Details of the test fluids involved and the methods used shall be provided in the Environmental Qualification Form (See Appendix A).

Note: Sections 10.0 and 14.0 of this document cover waterproofness and salt spray tests, respectively. Section 11.0 covers seven general classes of other contaminating fluids. In addition there are 23 specific fluids that are used to test these classes. Table 11-1 contains the class of fluids, the specific fluids and the temperatures required in these tests.

11.4 Test Procedures

11.4.1 Spray Test

Connect the equipment mechanically and electrically as defined in the relevant equipment specification. The equipment is not required to operate during this test and shall be at room ambient.

Spray the equipment with the appropriate fluid one or more times per day as necessary to maintain a wetted condition for a minimum of 24 hours. If it is difficult to maintain a wetted condition and the equipment specification requires the spray test rather than the immersion test, it shall be acceptable to thoroughly spray the equipment at intervals of four hours maximum. The spray shall be a fine mist maintained at the temperatures in Table 11-1 and shall be directed toward every major surface, seal and connector of the equipment sample under test. At the end of 24 hours, operate the equipment for at least 10 minutes.

Following this period, and without removing the excess fluid, the test specimen shall be placed in an appropriate chamber and subjected to a constant temperature of +65 degrees C for a minimum of 160 hours. At the end of this period, the test specimen shall be returned to room temperature and operated for a minimum of two hours.

Note: If the equipment is to be tested with more than one class of contaminating fluid, it should normally be tested with each fluid separately. However, simultaneous testing is permitted if fluids are of the same base (Example: oil base should not be followed by water base fluid). Fluids should not be pre-mixed prior to spraying, and the order of application should be as specified in the equipment specification. Unless otherwise noted in the equipment specification, the total exposure time for simultaneous application of fluids should be the same as the exposure time for a single fluid. The precautions noted elsewhere in this section should be observed.

Following the two-hour period, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

At the completion of the test, the equipment shall be inspected and shall show no evidence of damage of any internal or external component.

11.4.2 Immersion Test

Connect the equipment mechanically and electrically as defined in the relevant equipment specification. The equipment is not required to operate during this test and shall be at ambient temperature. Do not pre-mix any solution.

Immerse the equipment in the appropriate fluid for a minimum of 24 hours. The fluid temperature shall be maintained at the temperature shown in Table 11-1 and shall cover the test specimen completely.

At the end of 24 hours, operate the equipment for at least 10 minutes while it is completely immersed in the fluid.

Following this period, remove the test specimen, place in an appropriate chamber and subject it to a constant temperature of +65 degrees C for minimum of 160 hours. At the end of this period, the test specimen shall be returned to room temperature and operated for a minimum of two hours.

Following the two-hour period, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
At the completion of the test, the equipment shall be inspected and shall show no evidence of damage of any internal or external component.

11.5 Use of Material Specimens

Material specimen test may be used in place of equipment tests. The results of these tests shall assure that the material will protect the equipment from deleterious effects after being exposed to the relevant fluid in the manner defined in the equipment test procedures (Subsection 11.4).

Note: Material specimen tests are not permitted if the equipment is to be subsequently subjected to the continuous stream proof test (paragraph 10.3.3).

Table 11-1 Classes of Test Fluids and Fluid Temperatures

Class of Contaminating Fluid	Test Fluid	Fluid Temperature Degrees C
Fuels	Aviation Jet A Fuel Aviation Piston Engine Fuel	40 1/ 40 1/
Hydraulic Fluids	Mineral-Based Non-mineral Based Phosphate Ester-Based (Synthetic), Type IV 2/ Silicate Ester-Based (Synthetic) Silicone-Based (Synthetic) Synthetic Hydrocarbon Base	80 50 70 70 70 70
Lubricating Oils	Mineral-Based Ester-Based (Synthetic) Internal Combustion Engine 15W40	70 150 70
Solvents and Cleaning Fluids	Isopropyl Alcohol Denatured Alcohol Cleaning compound for aircraft surfaces	50 1/ 23 1/ 23
De-Icing Fluid	Ethylene Glycol Propylene Glycol AEA Type 1 3/ AEA Type 2 3/ SAE Type 1 SAE Type 2 SAE Type 4	50 50 50 50 23 23 23
Insecticides	Dichlorvos (DDVP) (commercially available min 0.92% concentration by volume) Pyrethroid Pesticide (commercially available min 0.92 concentration by volume)	23 23
Sullage	To be defined by the equipment specification	23
Disinfectant (Heavy duty Phenolics)	Clear, soluble phenolics, e.g., phenol or its derivatives dissolved in surfactant and diluted with water to give a clear solution. Black fluids, e.g., refined tar products dissolved in a carrier oil and emulsified with detergent. White fluids, e.g., colloidal emulsions of refined coal tar products in water, usually containing a small amount of surfactant.	23 23 23
Coolant dielectric fluid	PAO dielectric	70
Fire extinguishants	Protein Fluoroprotein	23 23

Notes:

1/ *This temperature exceeds the critical flash point temperature. Testing should always be performed in a suitable pressure vessel.*

2/ *These fluids are electrically conductive. Suitable precautions should be taken after exposure to the fluids before operating the equipment.*

3/ *Association of European Airlines.*

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 12

Sand and Dust

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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12.0 Sand and Dust

12.1 Purpose of the Test

This test determines the resistance of the equipment to the effects of blowing sand and dust where carried by air movement at moderate speeds. The main adverse effects to be anticipated are:

a. Penetration into cracks, crevices, bearings and joints, causing fouling and/or clogging of moving parts, relays, filters, etc.

b. Formation of electrically conductive bridges.

c. Action as nucleus for the collection of water vapor, including secondary effects of possible corrosion.

d. Pollution of fluids.

Note: Consideration must be given in determining where in the sequence of environmental tests to apply this test procedure, as dust residue from this test procedure, combined with other environmental synergistic effects may corrode or cause mold growth on the test item and adversely influence the outcome of succeeding test procedures. Sand abrasion may also influence the results of the salt spray, fungus or humidity test procedures.

12.2 Categories of Equipment

<u>Category D</u>

Equipment installed in locations where the equipment is subjected to blowing dust in the course of normal aircraft operations is identified as Category D and should be tested as recommended in the following paragraphs.

<u>Category S</u>

Equipment, possibly with moving parts, installed in locations where the equipment is subjected to blowing sand and dust in the course of normal aircraft operations is identified as Category S and should be tested as recommended in the following paragraphs. Such equipment includes cockpit equipment or equipment at any other location not intentionally protected against sand and dust exposure.

12.3 Agent

12.3.1 Dust

Dust used in a suitable test chamber vented to the atmosphere shall be raised and maintained at a concentration of 3.5 to 8.8 g/m3 and shall be 97% to 99% silicon dioxide.

Dust to be used can be Red china clay or Silica Flour and must meet size distributions of 100% by weight less than 150 µm, with a median diameter (50 ±2 % by weight) of 20 ±5 µm. This dust is readily available as a 140 mesh Silica Flour (about 2% retained on a 140 mesh (108 microns) sieve) and should provide comparable results to prior test requirements. National documentation may contain other more specific distributions.

12.3.2 Sand

Sand shall be at least 95±2 % silicon dioxide and shall meet the following characteristics:

The recommended particle size distribution for the sand particles is :

a. 1% +/- 0.5% shall be retained by a 20 mesh screen, i.e diameter 0.85mm
b. 1.7% +/- 0.5% shall be retained by a 30 mesh screen, i.e diameter 0.59mm
c. 14.8% +/- 2% shall be retained by a 40 mesh screen, i.e diameter 0.42mm
d. 37.0% +/- 2% shall be retained by a 50 mesh screen, i.e diameter 0.30mm
e. 28.6% +/- 2% shall be retained by a 70 mesh screen, i.e diameter 0.21mm
f. 12.7% +/- 2% shall be retained by a 100 mesh screen, i.e diameter 0.15mm
g. 5.2% +/- 2% shall pass 100 mesh screen

12.4 Dust Test Procedure

The equipment shall be submitted to the dust test along each direction of each major orthogonal axis in succession. The air velocity shall be maintained between 0.5 and 2.4 m/second.

Note 1: Unless otherwise required in the relevant specification, the equipment is not required to operate during the exposure period.

Note 2: Health and safety regulations regarding the use dust should be observed.

12.4.1 First Cycle

With the internal temperature of the test chamber maintained at +25 ±2 degrees Celisus (°C) and the relative humidity at not more than 30 percent, submit the equipment to a minimum exposure period of one hour along each direction of each major orthogonal axis in succession.

12.4.2 Second Cycle

With the internal temperature of the test chamber raised and stabilized at +55 ±2 °C and the relative humidity at not more than 30 percent, submit the equipment to a minimum exposure period of one hour along each direction of each major orthogonal axis in succession.

At the end of this exposure period, the equipment shall be removed from the chamber and cooled to room temperature. Externally accumulated dust only on surfaces of the equipment required to verify proper operation (e.g. displays, connectors, keyboards, test ports etc.) shall be removed by brushing, wiping or shaking with care being taken to avoid introducing additional dust into the equipment. Under no circumstances shall dust be removed by either air blast or vacuum cleaning. After removing the excess dust, manipulate the mechanical moving features of the equipment ten times and check for clogging or binding of movement. <u>DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS</u>.

12.5 Sand Test Procedure

The test item shall be submitted to the sand test at wind velocities ranging from 18-29 m/s, with the exposed surface positioned 3-m from the sand injection point - to allow sand particles to reach terminal wind velocities before impacting the test item. If the test item will not directly see wind velocities of this magnitude during normal service life (cockpit screen displays) then the test item shall be submitted to air velocities of 0.5 and 2.4 m/second. A vertical chamber may be utilized to preserve the uniformity of sand distribution.

Note 1: Unless otherwise required in the relevant specification, the equipment is not required to operate during the exposure period.

12.5.1 First Cycle

With the internal temperature of the test chamber maintained at +25 ±2 °C and the relative humidity at not more than 30 percent, submit the equipment to a minimum exposure period of one hour along each direction of each major orthogonal axis in succession.

12.5.2 Second Cycle

With the internal temperature of the test chamber raised and stabilized at +55 ±2 °C and the relative humidity at not more than 30 percent, submit the equipment to a minimum exposure period of one hour along each direction of each major orthogonal axis in succession.

At the end of this exposure period, the equipment shall be removed from the chamber and cooled to room temperature. Externally accumulated sand only on surfaces of the equipment required to verify proper operation (e.g. displays, connectors, keyboards, test ports etc.) shall be removed by brushing, wiping, or shaking with care being taken to avoid introducing additional sand into the equipment. Under no circumstances shall sand be removed by either air blast or vacuum cleaning. After removing the excess sand, manipulate the mechanical moving features of the equipment ten times and check for clogging or binding of movement. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 13

Fungus Resistance

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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13.0 Fungus Resistance

13.1 Purpose of the Test

These tests determine whether equipment material is adversely affected by fungi under conditions favorable for their development, namely, high humidity, warm atmosphere and presence of inorganic salts.

Notes:

A. Fungi proximity to other materials, exposure to daily susceptible contaminants such as fluids during routine operation and maintenance, or equipment exposure to solar actinic effects - may break molecular bonds and reduce the item to sub-compositions which may be fungus nutrients.

B. This test shall not be conducted after Salt Spray or Sand and Dust. A heavy concentration of salt may effect the fungal growth, and sand and dust can provide nutrients, which could compromise the validity of this test (see Subsection 3.2, "Order of Tests").

13.2 General Effects

Typical problems caused by fungi growing on equipment are:

a. Microorganisms digest organic materials as a normal metabolic process, thus degrading the substrate, reducing the surface tension and increasing moisture penetration.

b. Enzymes and organic acids, produced during metabolism, diffuse out of the cells and onto the substrate and cause metal corrosion, glass etching, hardening of grease and other physical and chemical changes to the substrates.

c. The physical presence of microorganisms produces living bridges across components that may result in electrical failures.

d. The physical presence of fungi can also cause health problems and produce aesthetically unpleasant situations in which users will reject using the equipment.

The detrimental effects of fungal growth are summarized as follows:

a. Direct attack on materials. Nonresistant materials are susceptible to direct attack as fungus breaks these materials down and uses them as nutrients. This results in deterioration affecting the physical properties of the material. Examples of nonresistant materials are:

(1) Natural material. Products of natural origin (carbon based) are most susceptible to this attack.
(a) Cellulose materials (e.g., wood, paper, natural fiber textiles, and cordage).
(b) Animal- and vegetable-based adhesives.

(c) Grease, oils, and many hydrocarbons.
(d) Leather.
(2) Synthetic materials.
(a) PVC formulations (e.g., those plasticized with fatty acid esters).
(b) Certain polyurethanes (e.g., polyesters and some polyether).
(c) Plastics that contain organic fillers of laminating materials.
(d) Paints and varnishes that contain susceptible constituents.

b. Indirect attack on materials. Damage to fungus-resistant materials results from indirect attack when:

(1) Fungal growth on surface deposits of dust, grease, perspiration, and other contaminants (that find their way onto materiel during manufacture or accumulate during service) causes damage to the underlying material, even though that material may be resistant to direct attack.
(2) Metabolic waste products (i.e., organic acids) excreted by fungus cause corrosion of metals, etching of glass, or staining or degrading of plastics and other materials.
(3) The acidic waste products of fungus on adjacent materials that are susceptible to direct attack come in contact with the resistant materials.

13.3 Categories of Equipment

Category F

Equipment that is installed in an environment where it will be exposed to severe fungus contamination is identified as Category F and shall be subjected to the fungus resistance test. If all materials used in the construction of the equipment can be shown to be non-nutrients for the growth of fungi, either through their composition or through previous testing, this test is not required. If non-nutrient material certification is u tilized for this verification, this fact shall be declared on the Environmental Qualification Form (see Appendix A).

13.4 Apparatus

The apparatus required to conduct this test consists of chambers or cabinets together with auxiliary instrumentation capable of maintaining the specified condition of temperature and humidity. Provisions shall be made to prevent condensation from dripping on the test item. There shall be free circulation of air around the test item and the contact area of fixtures supporting the test item shall be kept to a minimum. When forced air is employed, the flow should not exceed one meter per second over the surface of the test specimen.

13.5 Test Procedures

13.5.1 Preparation of Mineral-Salts Solution

The solution shall contain the following:

Potassium dihydrogen orthophosphate	0.7 g
Potassium monohydrogen orthophosphate	0.7 g
Magnesium sulfate heptahydrate	0.7 g
Ammonium nitrate	1.0 g
Sodium chloride	0.005 g
Ferrous sulfate heptahydrate	0.002 g
Zinc sulfate heptahydrate	0.002 g
Manganous sulfate monohydrate	0.001 g
Distilled Water	1000 ml

Sterilize the mineral salts solution by autoclaving at 121 degrees C for 20 minutes. Adjust the pH of the solution by the addition of 0.01 normal solution of sodium hydroxide so that after sterilization the pH level is between 6.0 and 6.5. Prepare sufficient salt solutions for the required tests.

13.5.1.1 Purity of Reagents

Reagent grade chemicals shall be used in all tests. Unless otherwise specified, it is intended that all reagents shall conform to the specification of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.

13.5.1.2 Purity of Water

Unless otherwise specified, references to water shall be understood to mean distilled water or water of equal purity.

13.5.2 Preparation of Mixed Spore Suspension

The following test fungi shall be used:

Fungi	ATCC[1]
Aspergillus niger	9642
Aspergillus flavus	9643
Aspergillus versicolor	11730
Penicillium funiculosum	11797
Chaetomium globosum	6205

[1] American Type Culture Collection, 12301 Parklawn Drive, Rockville, Maryland, 20852.

Maintain cultures of these fungi separately on an appropriate medium such as potato dextrose agar. However, the culture of chaetomium globosum shall be cultured on strips of filter paper on the surface of mineral salts agar. (Mineral salts agar is identical to the mineral salts solution described in paragraph 13.5.1, but contains in addition 15.0 g of agar/liter.) The stock cultures may be kept for not more than four months at 6 ±4 degrees C, at which time subcultures shall be made and new stocks shall be selected from the subcultures. If genetic or physiological changes occur, obtain new cultures as specified above. Subcultures used for preparing new stock cultures or the spore suspension shall be incubated at 30 degrees C for seven to ten days. Prepare a spore suspension of each of the five fungi by pouring into one subculture of each fungus a 10 ml portion of a sterile solution containing 0.05 g/liter of a non-toxic wetting agent such as sodium dioctyl sulfosuccinate or sodium lauryl sulfate. Use a sterile platinum or nichrome inoculating wire to scrape gently the surface growth from the culture of the test organism. Pour the spore charge into a sterile l25 ml glass-stoppered Erlenmeyer flask containing 45 ml of sterile water and 10 to 15 solid glass beads, five millimeters in diameter. Shake the flask vigorously to liberate the spores from the fruiting bodies and to break the spore clumps. Filter the dispersed fungal spore suspension through a six millimeter layer of glass wool, contained in a glass funnel, into a sterile flask. This process should remove large mycelial fragments and clumps of agar that could interfere with the spraying process. Centrifuge the filtered spore suspension aseptically and discard the supernatant. Resuspend the residue in 50 ml of sterile water and centrifuge. Wash the spores obtained from each of the fungi in this manner three times. Dilute the final washed residue with sterile mineral-salts solution in such a manner that the resultant spore suspension shall contain 1,000,000 ±200,000 spores/milliliter as determined with a counting chamber. Repeat this operation for each organism used in the test and blend equal volumes of the resultant spore suspension. The spore suspension may be prepared fresh each day and maintained at 6 ±4 degrees C not more than fourteen days.

13.5.3 Viability of Inoculum Control

With each daily group of tests, place each of three pieces of sterilized filter paper, 2.54 cm square on hardened mineral-salts agar in separate Petri dishes. Inoculate these with the spore suspension by spraying the suspension from a sterilized atomizer[1] until initiation of droplet coalescence. Incubate these at 30 degrees C at a relative humidity not less than 85 percent, and examine them after seven days of incubation. There shall be copious growth on all three of the filter paper control specimens. Absence of such growth requires repetition of the test.

13.5.4 Control Items

In addition to the viability of inoculum control, known susceptible substrates shall be inoculated along with the test item to insure that proper conditions are present in the incubation chamber to promote fungus growth. The control items shall consist of (unbleached) cotton duck 234 g strips that are 3.2 cm wide, that have been dipped into a solution containing 10% glycerol, 0.1% potassium dihydrogen orthophosphate, 0.1% ammonium nitrate, 0.025% magnesium sulfate, and 0.05% yeast extract (pH level 5.3), and from which the excess liquid has been removed. The strips should be hung to air dry before being inoculated and placed into the chamber.

13.5.5 Inoculation of Test Control

a. Mount the test and control items on suitable fixtures or suspend from hangers.

b. Precondition the chamber and its contents at 30 degrees C and 97 ±2% relative humidity for at least four hours.

c. Inoculate the test and control items with the mixed fungus spore suspension (paragraph 13.5.2) by spraying it on the test and control items in the form of a fine mist from a previously sterilized atomizer or nebulizer. In spraying the test and control items, care should be taken to cover all surfaces. If the surfaces are non-wetting, spray until initiation of droplet coalescence. Incubation is to be started immediately following the inoculation.

13.5.6 Incubation

a. Maintain the test chamber at 30 degrees C and 97 ±2% relative humidity (minimum) during the life of the test. Keep the test chamber closed during the incubation period, except during inspection or for addition of other test items.

b. After seven days, inspect the growth on the control items to be assured that the environmental conditions are suitable for growth. If inspection reveals that the environmental conditions are unsuitable for growth, the entire test shall be repeated.

c. If the control items show satisfactory fungus growth, continue the test for a period of 28 days from the time of inoculation or as specified in the equipment specification.

---

[1] An atomizer capable of providing 15,000 ±3,000 spores/cm^2.

13.5.7 Inspection

At the end of the incubation period, inspect the test item immediately. If possible, inspect the item within the chamber. If the inspection is not completed in eight hours, return the test item to the humid environment for a minimum of twelve hours. Except for hermetically sealed equipment, open the equipment enclosure and examine both the interior and exterior for evidence of deterioration. The equipment shall then be tested to <u>DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS</u>.

13.5.7.1 Analysis of Results.

The following information is provided to assist in the evaluation of the test results.

a. Any fungal growth on the test item must be analyzed to determine the species, and if the growth is on the test item material(s) or on contaminants.

b. Any fungal growth on the test item material(s), whether from the inoculums or other sources, must be evaluated by qualified personnel for:

(1) The extent of growth on susceptible components or materials. Any growth must be completely described.

(2) The immediate effect that the growth has on the physical characteristics of the materiel.

(3) The long-range effect that the growth could have on the materiel.

(4) The specific material (nutrient(s)) supporting the growth.

c. Evaluate human factors effects (including health risks).

13.5.8 Precautions

The fungi specified for this test are not normally considered a serious hazard for human handling. It is possible for an individual to be allergic to one of them, and for this reason it is wise to exercise care when performing the test. Surgical gloves may be worn to protect the hands, and care should be taken not to splash the suspension on other areas of the skin or on clothes. Additionally, an advisory prior to fungus inoculation should be issued instructing personnel possibly entering the vicinity where fungus spray inoculations or test preparations are taking place, to wear surgical masks and gloves as precautions to prevent adverse health reactions from fungus exposure.

It is also possible, during the incubation period in the test chamber, for a foreign spore, present as an unintentional intruder, to develop; some of these fungi thus present as native to some testing locations, may be injurious to the human system. For this reason there is a possibility that the specimen after exposure may be a hazard, and it should be handled with care.

The greatest danger, if some hazardous foreign spore is present on exposed specimens, is that small, dry, detached particles may become airborne and be carried into the lungs. This is only likely to happen after the specimen has dried out. If the specimen is carried quickly from the test chamber to a normal chemical fume hood before it has time to dry, the flow of air does not reach the operator and detached fragments cannot enter the nasal passages.

Detached portions of growth may be so small that no protection is offered by wearing a gauze mask and only a special respirator for sub-micron particles is effective. The use of a fume hood as suggested above, however, is considered an adequate precaution when performing this test.

Where the test location may contain such a harmful fungus, vestiges of it may remain in the test chamber and present a similar danger when it is being cleansed. High temperature steam, the preferred cleansing treatment, will render the chamber completely harmless. Where, however, fumigation with propylene oxide is adopted, it will be noted that fumigation prior to washing will ensure that all residues washed from the chamber are completely harmless.

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 14

Salt Fog

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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14.0 Salt Fog

14.1 Purpose of the Test

This test determines the effects on the equipment of prolonged exposure to a salt atmosphere or to salt fog experienced in normal operations.

The main adverse effects to be anticipated are:

a. Corrosion of metals.
b. Clogging or binding of moving parts as a result of salt deposits.
c. Insulation fault.
d. Damage to contacts and uncoated wiring.

Note: The salt fog test shall not be conducted prior to the fungus resistance test (see Subsection 3.2, “Order of Tests”).

14.2 Categories of Equipment

Category S

When the equipment is installed in locations where it is subjected to a corrosive atmosphere in the course of normal aircraft operations, the equipment is identified as Category S and the salt spray test is applicable.

Category T

When the equipment is installed in locations where it is subjected to a severe salt atmosphere, such as equipment exposed directly to external unfiltered air on hovering aircraft that may operate or be parked near the sea, the equipment is identified as category T and the severe salt spray test is applicable..

14.3 Apparatus

The apparatus used in the salt spray test shall include the following:

a. Exposure chamber with racks for supporting test items.

b. A salt solution reservoir with means for maintaining an adequate level of solution.

c. A means for atomizing the salt solution, including suitable nozzles and compressed air supply.

d. A means of heating and controlling chamber temperature.

e. A means for humidifying the air at temperatures above the chamber temperature.

14.3.1 Chamber

The chamber and all accessories shall be made of material that will not affect the corrosiveness of the fog, e.g. glass, hard rubber, plastic or kiln-dried wood other than plywood. In addition, all parts that come in contact with test items shall be made of materials that will not cause electrolytic corrosion. The chamber and accessories shall be constructed and arranged so that there is no direct impingement of the fog or dripping of the condensate on the test items; the fog circulates freely about all test items to the same degree, and no liquid that has come in contact with the test item returns to the salt-solution reservoir. The chamber shall be properly vented to prevent pressure build-up and allow uniform distribution of the salt fog. The discharge end of the vent shall be protected from strong drafts to prevent strong air currents in the test chamber.

14.3.2 Atomizers

The atomizers shall be designed and constructed to produce a finely divided, wet, dense fog. Atomizing nozzles shall be made of materials that are non-reactive to the salt solution.

14.3.3 Air Supply

The compressed air entering the atomizers shall be essentially free from all impurities, such as oil and dirt. Means shall be provided to humidify and warm the compressed air as required to meet the operating conditions. The air pressure shall be suitable to produce a finely divided dense fog with the atomizer or atomizers used. To avoid clogging the atomizers with salt deposition, the air should have a relative humidity of at least 85 percent at the point of release from the nozzle. A satisfactory method is to pass the air in very fine bubbles through a tower containing heated water that is automatically maintained at a constant level. The temperature of the water should be at least 35 degrees C. The permissible water temperature increases with the increasing volume of air and with the decreasing heat insulation of the chamber and the chamber’s surroundings. However, the temperature should not exceed a value above which excessive moisture is introduced into the chamber (for example 43 degrees C at an air pressure of 84 kPa) or a value that makes it impossible to meet the requirements for operating temperature.

14.3.4 Preparation of Salt Solution

The salt shall be sodium chloride containing on the dry basis not more than 0.1 percent sodium iodide and not more than 0.5 percent of total impurities. Unless otherwise specified, a five ±l percent solution shall be prepared by dissolving five parts by weight of salt in 95 parts by weight of distilled or demineralized water. The solution shall be adjusted to and maintained at a relative density between the limits shown on Figure 14-1 by utilizing the measured temperature and density of the salt solution.

14.3.4.1 Adjustment of pH

The pH of the salt solution shall be maintained and measured daily so that the solution atomized at $35^{o}C$ and collected by the method specified in subparagraph 14.3.6.3 will be in the pH range of 6.5 to 7.2. Only diluted chemically pure hydrochloric acid or chemically pure sodium hydroxide shall be used to adjust the pH. The pH measurement shall be made electrometrically, using a glass electrode with a saturated potassium chloride bridge, by a colorimetric method such as bromothymol blue or other measuring instruments or litmus paper, provided the results are equivalent to those obtained with the electrometric method. The pH shall be measured when preparing each new batch of solution and as specified in subparagraph 14.3.6.4.

14.3.5 Filter

A filter fabricated of noncorrosive materials similar to that shown in Figure 14-2 shall be provided in the supply line and immersed in the salt solution reservoir as illustrated in Figure 14-2.

14.3.6 Test Procedure

14.3.6.1 Temperature

The test shall be conducted with a temperature in the exposure zone maintained at 35 degrees C. Satisfactory methods for controlling the temperature accurately are by housing the apparatus in a properly controlled constant temperature room, by thoroughly insulating the apparatus and preheating the air to the proper temperature prior to atomization or by jacketing the apparatus and controlling the temperature of the water or of the air used in the jacket. The use of immersion heaters within the chamber for the purpose of maintaining the temperature within the exposure zone is prohibited.

14.3.6.2 Atomization

Suitable atomization has been obtained in chambers having a volume of less than 0.34 m^3 with the following conditions:

a. Nozzle pressure shall be as low as practical to produce fog at the required rate.

b. Orifices shall be between 0.5 mm and 0.8 mm in diameter.

c. Atomization of approximately three liters of salt solution per 0.28 m^3 of chamber volume per 24 hours.

When using large size chambers having a volume considerably in excess of 0.34 m^3, the condition specified may require modification to meet the requirements for operating conditions.

14.3.6.3 Placement of Salt Fog Collection Receptacles

The salt fog conditions maintained in all parts of the exposure zone shall be such that a clean fog-collecting receptacle placed at any point in the exposure zone will collect from 0.5 to three milliliters of solution per hour for each 80 cm^2 of horizontal collecting area (10 cm diameter) based on an average test of at least 16 hours. A minimum of two receptacles shall be used, one placed at the perimeter of the test item nearest to the nozzle, and the other also at this perimeter of the test item but at the farthest point from the nozzle. Receptacles shall be placed so that they are not shielded by test items and so that drops of solution from test items or other sources will not be collected.

14.3.6.4 Measurement of Salt Solution

The solution, collected in the manner specified in subparagraph 14.3.6.3, shall have the sodium chloride content and pH specified in paragraph 14.3.4 when measured at a temperature of 35 degrees C. The salt solution from all collection receptacles used can be combined to provide the quantity required for the measurements specified.

14.3.6.4.1 Measurement of Sodium Chloride Content

The solution, maintained at the specified temperature, can be measured in a graduate of approximately 2.5 cm inside diameter. A small laboratory type hydrometer will be required for measurement within this volume.

14.3.6.4.2 Measurement of pH

The pH shall be measured as specified in paragraph 14.3.4.1.

14.3.6.4.3 Time of Measurements

The measurement of both sodium chloride and pH shall be made at the following times:

a. For salt fog chambers in continuous use, i.e., used within five days, the measurements shall be made following each test.

b. For salt fog chambers that are used infrequently, more than five days since use or if nozzles have been clogged, a 24-hour test run shall be accomplished followed by the measurements. The test item shall not be exposed to this test run.

14.3.6.5 Preparation of Test Item

The test item shall receive minimum handling, particularly on the significant surfaces, and shall be prepared for test immediately before exposure. Unless otherwise specified, uncoated metallic or metallic-coated devices shall be thoroughly cleaned of oil, dirt and grease as necessary until the surface is free from water break. The cleaning methods shall not include the use of corrosive or protective films, nor the use of abrasives other than a paste of pure magnesium oxide. Test items having an organic coating shall not be cleaned with a solvent. Those portions of test items which come in contact with the support and, unless otherwise specified in the case of coated devices or samples, cut edges and surfaces not required to be coated, shall be protected with a suitable coating of wax or similar substance impervious to moisture.

14.3.6.6 Performance of Normal Salt Fog Test (Category S)

Step 1: Continuously atomize a salt solution of a composition as given in 4.4.1.1b into the test chamber for a period of 24 hours or as specified in the test plan. During the entire exposure period measure the salt fog fallout rate and pH of the fallout solution at least at 24-hour intervals[1/]. Ensure the fallout is between 1 and 3 ml/80cm^2/hr.

Step 2: Dry the test item at standard ambient temperatures and a relative humidity of 50% or less for 24 hours. Do not disturb the test item or adjust any mechanical features during the drying period.

Step 3: At the end of the drying period and unless otherwise specified, replace the test item in the salt fog chamber and perform one repeat of steps 1 and 2.

Step 4: At the end of the drying period, operate the test item and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The test item shall then be inspected for corrosion. If necessary, a gentle wash in running water not warmer than 28 degrees C may be used. Any corrosion must be analyzed for its immediate or potential effect on proper functioning of the test item.

14.3.6.7 Performance of the Severe Salt Fog test (Category T)

The test item shall be placed in the chamber and exposed to the salt fog for a period of a minimum of 96 hours or as specified in the equipment test specification.

Within an hour of removing the equipment from the chamber, power the equipment and allow to dry for 24 hours. Then DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The test item shall then be inspected for corrosion. Before any dismounting or washing operation, measure and record the insulation or bonding values as defined in the equipment specification. Then, if necessary, a gentle wash in running water not warmer then 28 degrees C may be used. Any corrosion must be analyzed for its immediate or potential effect on proper functioning of the test item.

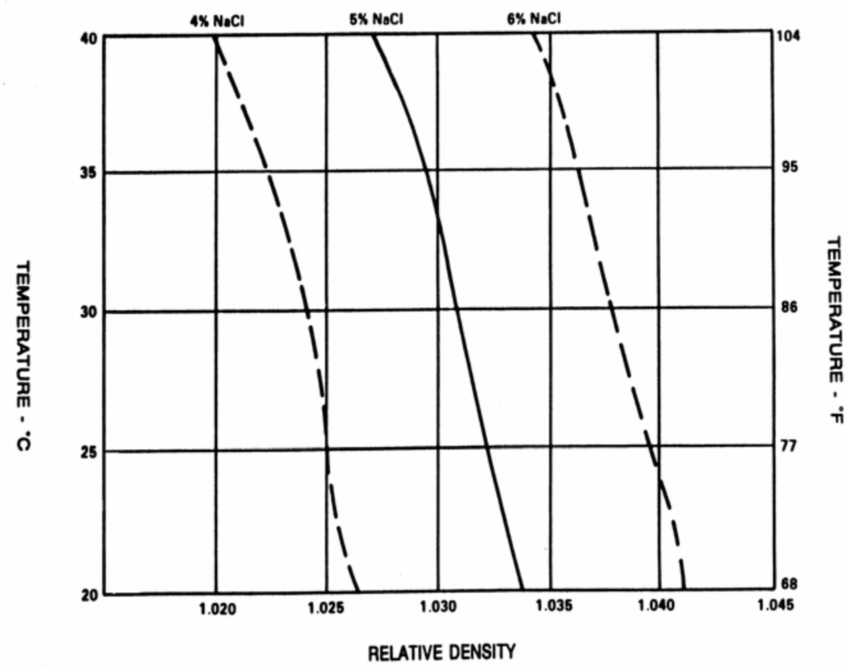
[1/] Recommend more frequent intervals. Repeat the interval if fallout quantity requirements are not met.

14.3.6.8 Failure Considerations

a. Physical. Salt deposits can cause clogging or binding of mechanical components and assemblies. The extent of any deposits resulting from this test may be representative of those induced by anticipated environments.

b. Electrical. Moisture remaining after the 24-hour drying period could cause electrical malfunctions. If so, attempt to relate the malfunctions to that possible in service.

c. Corrosion. Analyze any corrosion for its immediate and potential long-term effects on the proper functioning and structural integrity of the test item.



<u>Figure 14-1</u> Relative Density Variations of the Salt Solution with Temperature

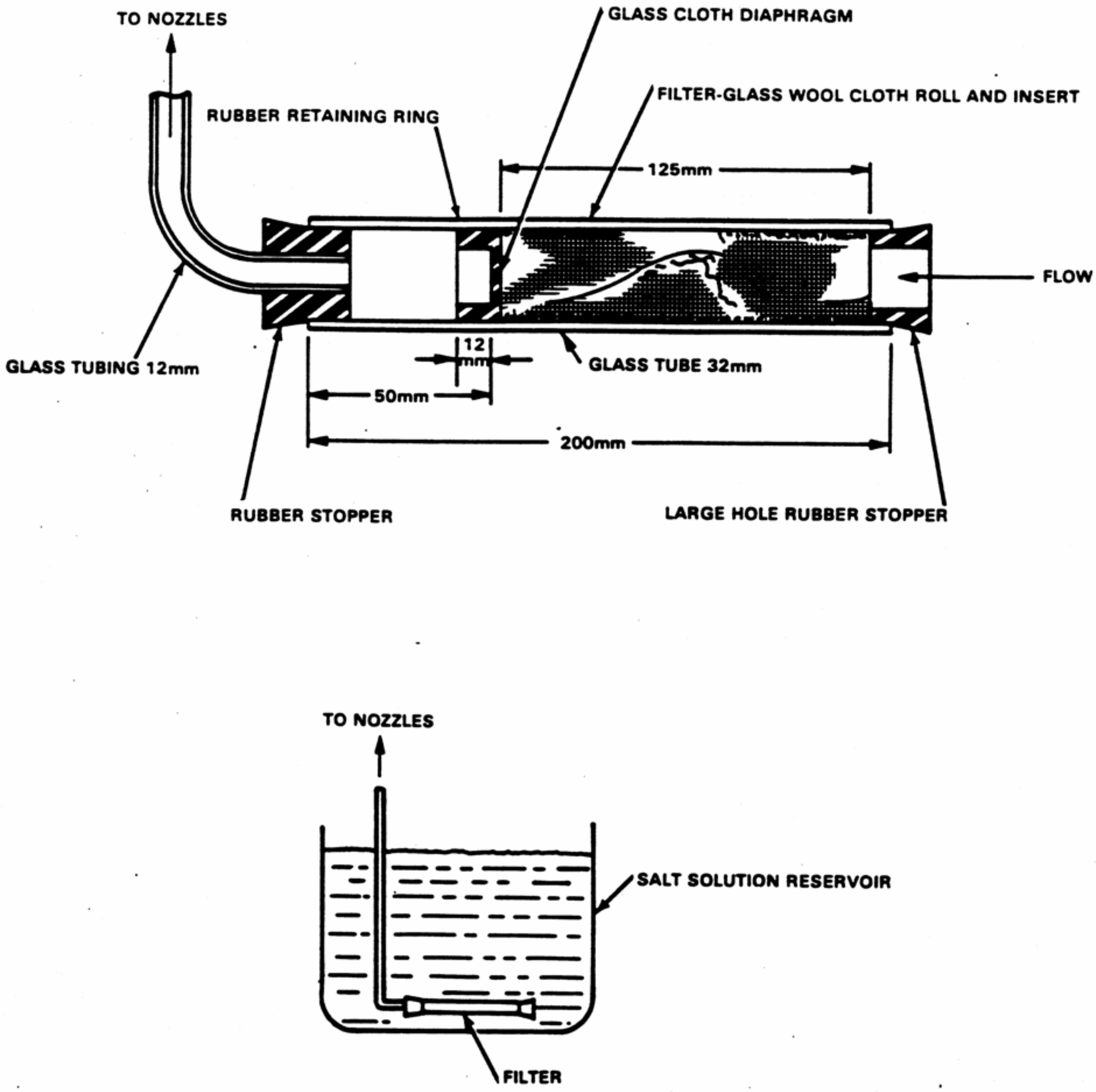


FIGURE 14-2

LOCATION OF SALT SOLUTION FILTER

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 15

Magnetic Effect

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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15 Magnetic Effect

15.1 Purpose of the Test

This test determines the magnetic effect of the equipment. This test ensures that equipment can operate properly without interference which may affect the nearby equipment, determining equipment compliance with the applicable equipment performance standard or assisting the installer in choosing the proper location of the equipment in the aircraft.

15.2 Test Description

The magnetic effect of the equipment shall be determined in terms of the deflection of a free magnet (e.g., uncompensated compass) in a uniform magnetic field (as produced by the earth) having a horizontal intensity of 14.4 A/m ±10% when the equipment under test is positioned on the east-west line through the pivot of a magnet.

Note 1: If the horizontal component of the magnetic field produced by the earth at the location of the test lab is within the tolerance stated above, the angular deflection used to determine equipment category in paragraph 15.3 shall be one degree (Dc = 1).

Note: 2: If the horizontal component of the magnetic field produced by the earth at the location of the test lab exceeds the tolerance stated above, the angular deflection used to determine the equipment category in Subsection 15.3 shall be adjusted using the following formula:

$$\text{Dc} = \frac{14.4\ \text{A/m}}{\text{Horizontal Component of Ambient Field Strength}}$$

where,

Dc is the equivalent deflection angle to be used in determining equipment category.

15.3 Test Procedure

The EUT is to be powered with the same or an identical cable harness used for section 20 testing. All cables and extended power leads for the EUT are to be placed in one bundle for the test. This bundle is to be routed along the east to west axis of the compass.

1) If HCAFS (HCAFS = Horizontal Component of Ambient magnetic Field Strength produced by the earth) at the location of the test lab without EUT is unknown, measure it (with magnetometer for instance).

2) If HCAFS is within the tolerances described in paragraph 15.2, then Dc = 1 ° per paragraph 15.2, NOTE 1.

If HCAFS is not within the tolerances described in paragraph 15.2, adjust the value of the deflection angle (Dc) by inserting the measured HCAFS into the formula given in paragraph 15.2, NOTE 2.

3) Place the EUT cable on the east - west line through the pivot of a magnet as shown in Figure 15-1.

4) With the EUT operating, choose the steady state mode that produces the maximum magnet deflection.

5) With the EUT cable maintained on the east-west line through the pivot of a magnet, choose the orientation of the EUT that produces the maximum magnet deflection.

6) Reduce the distance between the EUT and the magnet to obtain Dc.

If the test is performed by moving the compass towards the EUT rather than moving the EUT towards the compass, then a field uniformity test is necessary. This test is performed as follows:

> With the EUT removed from the test area, the compass shall not deflect by more than +/- 0.5 degrees with the compass moved linearly along the planned path to the EUT location.

7) Measure and record the minimum distance between the magnet pivot and the nearest part of the EUT obtained for Dc.

8) Using the measured distance for a deflection of Dc from step 7, select the category from the table below:

Equipment Category	Distance for a Deflection of Dc
Z	less than 0.3 m
A	between 0.3 m and 1.0 m
B	between 1.0 m and 3.0 m
C	greater than 3.0 m

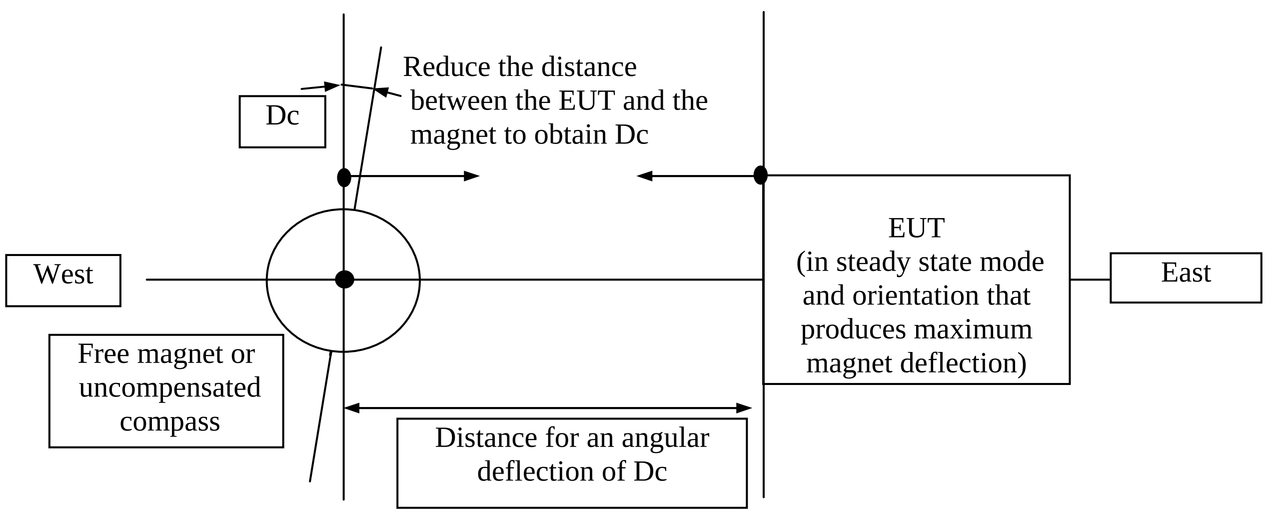

Figure 15-1 TEST INSTALLATION AND PROCEDURE

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 16

Power Input

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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16 Power Input

16.1 Purpose of the Test

This section defines test conditions and procedures for ac and dc electrical power applied to the terminals of the equipment under test. It covers the following electrical power supplies:

- 14 Vdc and 28 Vdc
- 115 Vrms ac and 230 Vrms ac at either a nominal 400 Hz frequency or over a variable frequency range which includes 400 Hz.

Equipment categories and frequency classes, test conditions and procedures for equipment using other electrical power supplies must be defined in applicable equipment performance standards.

16.2 Equipment Categories

Test designation for equipment consists of:

Category reference:

- For ac equipment: A(CF), A(NF) or A(WF)
- For dc equipment: A, B, or Z

Followed by an additional letter for ac equipment only to indicate if the equipment has to be submitted to ac harmonic tests (letter H) or not (letter X).

<u>Categories A(CF), A(NF), A(WF) and A</u>

Equipment intended for use on aircraft electrical systems where the primary power is from a constant or variable frequency ac system and where the dc system is supplied from transformer-rectifier units, is identified as:

- for ac equipment: Category A(CF), A(NF) or A(WF),
- for dc equipment: Category A.

A battery may be floating on the dc bus.

A(CF) designates ac equipment intended for use on aircraft electrical systems where the primary power is from constant frequency (400 Hz) ac system.

Note: A(CF) designates the same equipment as the ac ones designated by Category A in the previous DO-160 / ED14 issues.

A(NF) designates ac equipment intended for use on aircraft electrical systems where the primary power is from narrow variable frequency (360 to 650 Hz) ac system.

A(WF) designates ac equipment intended for use on aircraft electrical systems where the primary power is from wide variable frequency (360 to 800 Hz) ac system.

A designates dc equipment intended for use on aircraft electrical systems where the dc is generated from primary power supplied from either a constant or variable frequency ac system.

Category B

Dc equipment intended for use on aircraft electrical systems supplied by engine-driven alternator/rectifiers, or dc generators where a battery of significant capacity is floating on the dc bus at all times, is identified as Category B.

Category Z

Dc equipment that may be used on all other types of aircraft electrical systems applicable to these standards is identified as Category Z. Category Z shall be acceptable for use in lieu of Category A or Category B. Examples of this category are dc systems supplied from variable speed generators where:

a. The dc supply does not have a battery floating on the dc bus, or

b. The control or protective equipment may disconnect the battery from the dc bus, or

c. The battery capacity is small compared with the capacity of the dc generators.

AC Distortion Tests: Designation H

This test designation relates to equipment with an individual maximum power consumption greater than 35 VA or installations where the combined power consumption of multiple units (of the same equipment type) is greater than 150 VA. For such equipment, the current distortion tests of section 16.7.1 have to be performed if required by the equipment performance standards.

16.3 Emergency Electrical System Operation

Emergency electrical system operation is defined as the condition of the electrical system during flight when the primary electrical system becomes unable to supply sufficient or proper electrical power, thus requiring the use of an independent source(s) of emergency power which is limited in power output capabilities.

16.4 Standard Electrical Power Input Parameters (ac)

Certain electrical parameters are considered standard, i.e., not varying from nominal limits throughout the requirements of this section. All tests shall be conducted with the following standard parameters:

CAUTION: **All mentioned voltage values are for 115 Vrms ac equipment. Multiply them by 2 for 230 Vrms ac equipment.**

a. Phase Sequence

The voltage of the individual phases of a three phase supply are mutually displaced from each other by 120 electrical degrees; they are designated A, B, and C, and reach their respective peak values in that sequence.

b. Phase Displacement

This is the relative displacement between the zero voltage points on the waveforms of the three phases. The phase displacement will be within the following limits:

- A(CF) and A(NF) category equipment: 120 ± 4 electrical degrees
- A(WF) category equipment: 120 ± 6 electrical degrees

c. Phase Voltage Unbalance

c.1. A(CF) and A(NF) Category Equipment

For normal electrical system operation, the maximum spread in phase voltages will not exceed 6 volts root-mean-square (rms) between the phase with the highest voltage and the phase with the lowest voltage for all aircraft operations. This spread will not exceed 8 volts rms when the source of power is the emergency power system.

c.2. A(WF) Category Equipment

For normal electrical system operation, the maximum spread in phase voltages will not exceed 8 volts root-mean-square (rms) between the phase with the highest voltage and the phase with the lowest voltage for all aircraft operations. This spread will not exceed 10 volts rms when the source of power is the emergency power system.

d. Voltage waveform crest factor and harmonic content

The voltage waveform will have a crest factor 1.41 ± 0.15 and an harmonic content as specified in the table below.

Equipment category	Maximum voltage total harmonic distortion (*)	Maximum voltage individual harmonic content (*)
A(CF) and A(NF)	8 %	6 %
A(WF)	10 %	8 %

(*) For related definition, refer to section 16.5.1.8.1.

e. Voltage waveform dc content

For normal electrical system operation, the voltage waveform dc content will be within the following limits: 0 ± 0.1 V

f. Requirement

Compliance with subsequent requirements in this section infers compliance under these standard conditions.

16.5 Electrical Power Input Parameter Limits (ac)

The following defines quantitatively those parameters of electrical power input that are variable and the related test conditions where applicable, and are divided into those associated with NORMAL and ABNORMAL electrical system operation.

Note: The power source used should be able to supply the maximum current required by the EUT.

16.5.1 Normal Operating Conditions (ac)

The following conditions and tests are applicable to Category a(CF), A(NF) and A(WF) equipment.

CAUTION: All mentioned voltage values are for 115 Vrms ac equipment. Multiply them by 2 for 230 Vrms equipment.

16.5.1.1 Voltage and Frequency (ac)

a. Definition

	EQUIPMENT CATEGORY		A(CF)	A(NF)	A(WF)
MAX	VOLTAGE (Vrms)	Highest phase	122	122	122
		Average of three phases	120.5	120.5	120.5
	FREQUENCY (Hz)	Normal	410	650	800
		Emergency	440	650	800
MIN	VOLTAGE (Vrms)	Lowest phase	100	100	100
		Average of three phases	101.5	101.5	101.5
	FREQUENCY (Hz)	Normal	390	360	360
		Emergency	360	360	360

Notes:

1. *The above mentioned voltage values are at equipment terminals.*
2. *For ac networks:*
   - *Nominal voltage is 115 Vrms*
   - *Nominal frequency is 400 Hz (A(CF) category only)*

b. Requirement for Single Phase Equipment

(1) Operate the equipment at maximum duty cycle for at least 30 minutes for each test. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltage to be applied at equipment terminals:

TEST	VOLTAGE (Vrms)	FREQUENCY (Hz)		
		A(CF)	A(NF)	A(WF)
1	122	410	650	800
2	100	410	650	800
3	122	390	360	360
4	100	390	360	360

(2) For A(CF) category equipment designated to operate under emergency electrical system conditions, operate it at maximum duty cycle for at least 30 minutes for each test. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at A(CF) category equipment terminals:

TEST	VOLTAGE (Vrms)	FREQUENCY (Hz)
1	122	440
2	100	440
3	122	360
4	100	360

c. Requirement for Three Phase Equipment

c.1 Requirement for A(CF) and A(NF) Category Three Phase Equipment

(1) Operate the equipment at maximum duty cycle for at least 30 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)	
	Phase A	Phase B	Phase C	A(CF)	A(NF)
1	120.5	120.5	120.5	410	650
2	101.5	101.5	101.5	410	650
3	120.5	120.5	120.5	390	360
4	101.5	101.5	101.5	390	360
5	122	122	116	410	650
6	100	100	106	410	650
7	122	122	116	390	360
8	100	100	106	390	360

(2) For equipment designated to operate under emergency electrical system conditions, operate it at maximum duty cycle for at least 30 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)	
	Phase A	Phase B	Phase C	A(CF)	A(NF)
1	120.5	120.5	120.5	440	N/A
2	101.5	101.5	101.5	440	N/A
3	120.5	120.5	120.5	360	N/A
4	101.5	101.5	101.5	360	N/A
5	122	122	114	440	650
6	100	100	108	440	650
7	122	122	114	360	360
8	100	100	108	360	360

c.2 Requirement for A(WF) Category Three Phase Equipment

(1) Operate the equipment at maximum duty cycle for at least 30 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)
	Phase A	Phase B	Phase C	
1	120.5	120.5	120.5	800
2	101.5	101.5	101.5	800
3	120.5	120.5	120.5	360
4	101.5	101.5	101.5	360
5	122	122	114	800
6	100	100	108	800
7	122	122	114	360
8	100	100	108	360

(2) For equipment designated to operate under emergency electrical system conditions, operate it at maximum duty cycle for at least 30 minutes for each test with the primary power adjusted for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)
	Phase A	Phase B	Phase C	
1	122	122	112	800
2	100	100	110	800
3	122	122	112	360
4	100	100	110	360

16.5.1.2 Voltage Modulation (ac)

a. Definition

Voltage modulation is the cyclic variation, random variation, or both, about the mean level of the ac peak voltage that may be encountered during steady state electrical system operation caused by voltage regulation variations and speed variations. The voltage modulation will be 3.5 volts maximum peak-to-valley difference between the minimum and the maximum voltage reached on the modulation envelope applied for at least two minutes, or as indicated in the equipment specification.

The frequency components of the voltage modulation envelope waveform will not exceed the limits of Figure 16-1.

b. Requirement

The equipment, when subjected to this condition, shall operate within the applicable equipment performance standards. Any test requirement, if applicable, will be specified in the individual equipment performance standard. This test shall be performed with a frequency of :

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

16.5.1.3 Frequency Modulation (ac)

a. Definition

Frequency modulation is the cyclic or random variation, or both, of instantaneous frequency about a mean frequency during steady-state electrical system operation. The frequency modulation is normally within narrow frequency limits and occurs as a result of speed variations in a generator coupling and/or drive speed regulation. The variations of primary system frequency due to frequency modulation during any two-minute period or as specified in the equipment specification will be within a band about the mean frequency defined by Figure 16-2.

b. Requirement

The equipment, when subjected to this condition, shall operate within the applicable equipment performance standards. This test shall be performed with a frequency of :

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

16.5.1.4 Momentary Power Interruptions (ac)

Definition

Transfer of power sources can result in power interruptions for periods up to 200 ms.

b. Requirement for Equipment with Digital Circuits (Applicable to all ac Equipment)

This test is applicable only to equipment that incorporates digital circuitry and/or memory devices, including equipment with delay circuits.

This type of equipment is sensitive to momentary power interruptions that can cause aberrations in performance. Such transient power interruptions may be of any function of V-transient and T-transient where V_t may have any value between V-steady state and zero, and T_t may be any value from 0 to 200 milliseconds. Since there are a multitude of such combinations, this test procedure selects discrete values that are considered effective for determining equipment performance.

Test Procedures

The equipment shall be fully operational.
Nominal voltage shall be applied prior to each test condition.

Concerning frequency:

- A(CF) category equipment: nominal frequency shall be applied prior to each test condition.
- A(NF) and A(WF) category equipment:

  First, all tests will be performed with 360 Hz +5/-0 Hz applied prior to each test condition.

  Then, all tests will be rerun with:

  - A(NF) category equipment: 650 Hz +0/-5 Hz
  - A(WF) category equipment: 800 Hz +0/-5 Hz

  applied prior to each test condition.

Data shall have been entered, either manually or automatically, and all related displays functioning prior to each test condition.

For each operating mode of the equipment, apply each of the test conditions of Table 16-1 at least twice.

The second successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test.

After exposure, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards.

c. Requirement for Other Equipment (Applicable to all ac Equipment)

This test is applicable to all equipment that does not incorporate digital circuitry and/or memory devices as defined in subparagraph 16.5.1.4 b.

Test Procedures

With the equipment operating at its design voltage(s) and nominal frequency, interrupt the power for a minimum of five times; each interrupt period shall last 50 ms. Repeat this procedure with interrupt periods of 200 ms. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Manual or automatic reset is permitted if allowed by the individual specification.

Each successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test.

d. Additional Requirement (A(NF) and A(WF) Category Equipment Only)

The equipment shall be fully operational.
Nominal voltage shall be applied prior to each test condition.
For each operating mode of the equipment, apply each of the test conditions of Table 16-2 at least twice.

The second successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test.

After exposure, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards.

16.5.1.5 Normal Transients (ac)

16.5.1.5.1 Normal Surge Voltage

a. Definition

A normal surge is a variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system in response to disturbances imposed by normal system operations, such as load switching and remedial action by the regulator.

b. Requirement

(1) Operate the equipment for five minutes with a voltage of 115 Vrms ± 1 Vrms at equipment terminals. Then cycle the voltage three times as

indicated below:

Increase the voltage to:
- A(CF) and A(NF) category equipment: 160 Vrms ± 2 Vrms for 30 ms.
- A(WF) category equipment: 170 Vrms ± 2 Vrms for 30 ms.

Return the voltage to 115 Vrms ± 1 Vrms for five seconds.

Decrease the voltage to 70 Vrms ± 1 Vrms for 30 ms. Return the voltage to 115 Vrms ± 1 Vrms for five seconds.

(2) The supply frequency shall be as follows:

- A(CF) category equipment: 400 Hz ± 5 Hz.
- A(NF) category equipment: test to be run first with 360 Hz +5/-0 Hz, then rerun the test with 650 Hz +0/-5 Hz.
- A(WF) category equipment: test to be run first with 360 Hz +5/-0 Hz, then rerun the test with 800 Hz +0/-5 Hz

The voltage surges should be applied and monitored in a manner similar to that in Figure 16-3.

(3) During the normal electric system surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Unless so stated in the equipment performance standard, equipment may have degraded performance during the surge and must meet the specified performance when returned to nominal voltage and frequency.

(4) Following application of the voltage surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: If the equipment performance standard requires that performance be met during the abnormal surge voltage test of subparagraph 16.5.2.3.1 and momentary undervoltage test of subparagraph 16.5.2.2, it is not necessary to run the above test.

16.5.1.5.2 Normal Frequency Transients (A(CF) Category Equipment Only)

a. Definition

A normal transient is a momentary variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system in response to disturbances imposed by normal system operations, such as engine speed changes and remedial action by the regulator.

b. Requirement

(1) Operate the equipment for five minutes with a voltage of 115 Vrms ±1 Vrms at equipment terminals and a frequency of 400 Hz ± 5 Hz.

Then cycle the frequency three times as indicated below:

Increase the frequency to 440 Hz ± 5 Hz for 150 ms. Then lower the frequency to 420 Hz for 1.5 second. Return the frequency to 400 Hz ± 5 Hz for five seconds.

Decrease the frequency to 350 Hz ± 5 Hz for 150 ms. Then increase the frequency to 380 Hz for 1.5 second. Return the frequency to 400 Hz ± 5 Hz for five seconds.

(2) During the normal frequency transients, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: U*nless so stated in the equipment performance standard, equipment may have degraded performance during the transients and must meet the specified performance when returned to nominal voltage and frequency.*

(3) Following application of the frequency transients, DETERMINE COMPLIANCE WITH APPLICABLE EQUIMENT PERFORMANCE STANDARDS.

Note: If the equipment performance standard requires that performance be met during the abnormal frequency transients test of subparagraph 16.5.2.3.2, it is not necessary to run the above test.

16.5.1.6 Normal Frequency Variations (A(NF) and A(WF) Category Equipment Only)

a. Definition:

Frequency variations up to 200 Hz/sec, unless otherwise specified in the applicable equipment performance standards, can occur in normal operating conditions as a result of quick engine speed changes more particularly during aircraft take-off and engine shutdown sequences.

b. Requirement:

(1) Operate the equipment for five minutes with a voltage of 115 Vrms ± 1 Vrms at equipment terminals and a frequency of 360 Hz +5/-0 Hz.

Then, cycle the frequency three times as indicated below:

Increase the frequency to:

- A(NF) category equipment: 650 Hz +0/-5 Hz

- A(WF) category equipment: 800 Hz +0/-5 Hz

with a constant frequency rate of change of 100 Hz/s, then return the frequency to 360 Hz +5/-0 Hz with the frequency rate of change at 200 Hz/s and maintain the frequency at 360 Hz +5/-0 Hz for five seconds.

(2) During the normal frequency variations, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS

Note: Unless so stated in the applicable equipment performance standards, equipment performance shall not be degraded during normal frequency variations.

16.5.1.7 Voltage DC Content (ac)

a. Definition:

A voltage dc content up to ± 0.1 volt may be encountered during normal steady state electrical system operation.

b. Requirement:

Operate the equipment at maximum duty cycle with a voltage of 115 Vrms ± 1 Vrms at its terminals and a frequency as specified in the note below. Apply to each of the primary input leads a voltage dc offset of – 0.1 V.

The equipment shall operate in these conditions for at least 30 minutes. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the 30-minute test period.

If the equipment is a three-phase unit, test each phase individually and then all phases simultaneously.

Repeat, with a voltage dc offset of + 0.1 V.

The voltage dc offset may be produced as shown in Figure 16-9 for single-phase equipment and Figure 16-10 for three-phase equipment.

Note: These tests shall be performed with a frequency of:

- *400 Hz for A(CF) category equipment*
- *360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.*

16.5.1.8 Voltage distortion (ac)

Current draw from non-linear ac loads will cause distortion in the ac voltage waveform under normal conditions (for detailed definitions, refer to paragraph 16.5.1.8.1). All ac equipment are expected to operate correctly with this distortion present.

16.5.1.8.1 Definitions

16.5.1.8.1.1 Total Harmonic Distortion

The total harmonic distortion of the ac waveform is the ratio of the rms value of the harmonics to the rms value of the fundamental. The formula defining total harmonic distortion (THD) is provided below. The variable ‘X’ may represent voltage or current, and may be expressed as an rms value or a peak value.

$$THD_X = 100 \cdot \frac{\sqrt[2]{\sum_{n=2}^{\infty} X_n^2}}{X_1}$$

X_1 = Fundamental value of current or voltage;

X_n = n^{th} harmonic value of current or voltage.

Note: The frequency of the n^{th} harmonic (F_n) is an integer multiple of the fundamental frequency F_1 : $F_n = n.F_1$

16.5.1.8.1.2 Individual Harmonic Content

The individual harmonic content is the voltage or current, as applicable, at a given harmonic frequency, expressed as a percentage of the fundamental. The formula defining individual harmonic content (IHC_n) is provided below. The variable 'X' may represent voltage or current, and may be expressed as an rms value or a peak value. The fraction expresses the amount of distortion at the n^{th} harmonic.

$$IHC_n = 100 \cdot \frac{X_n}{X_1}$$

where: X_1 = Fundamental value of current or voltage;

X_n = nth harmonic value of current or voltage.

16.5.1.8.2 Requirement

Operate the equipment at maximum duty cycle with minimum voltage (as per table in subparagraph 16.5.1.1 a.) at its terminals and a frequency as specified below. The voltage distortion may be produced via a full-wave rectifier bridge as shown in Figure 16-8. The level of voltage distortion can be controlled by varying the load on the rectifier(s), and insertion of source impedance in the line. Alternatively, input voltage to the EUT may be distorted by clipping the supply voltage. The equipment shall operate in these conditions for at least 30 minutes.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the 30-minute test period.

This test shall be performed with a frequency of:

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

This test shall be performed with a voltage total distortion level (THD_v) as follows:

- 8 % +2/-0 % for category A(CF) and A(NF) equipment
- 10 % +2/-0 % for category A(WF) equipment

16.5.2 Abnormal Operating Conditions (ac)

The following conditions and tests are applicable to all ac equipment.

CAUTION: **All mentioned voltage values are for 115 Vrms ac equipment. Multiply them by 2 for 230 Vrms ac equipment.**

16.5.2.1 Abnormal Voltage and Frequency Limits in Steady State (ac)

a. Definition

	EQUIPMENT CATEGORY		A(CF)	A(NF)	A(WF)
MAX	VOLTAGE (Vrms)	Highest phase	134	134	134
		Average of three phases	132.5	132.5	132.5
	FREQUENCY (Hz)		430	N/A	N/A
MIN	VOLTAGE (Vrms)	Lowest phase	97	97	97
		Average of three phases	98.5	98.5	98.5
	FREQUENCY (Hz)		370	N/A	N/A

Notes: (1) The above mentioned voltage values are at equipment terminals.

The following power supply frequency shall be applied for the requirements included in the paragraphs b. and c. hereafter:

- *A(CF) category equipment: 400 Hz*
- *A(NF) category equipment: tests to be performed first with 360 Hz then with 650 Hz*
- *A(WF) category equipment: tests to be performed first with 360 Hz then with 800 Hz*

(2) Any requirement for performance of the equipment during application of the abnormal voltage and/or abnormal frequency (refer to the paragraphs b. to e. below) will be specified in the equipment performance standard.

b. Requirement for Single Phase Equipment

Operate the equipment at maximum duty cycle for at least 5 minutes for each test with the voltage at equipment terminals adjusted as mentioned in the table below. At the end of each test and with the equipment still energized, adjust this voltage to 115 Vrms and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

TEST	VOLTAGE (Vrms)
1	134
2	97

c. Requirement for Three Phase Equipment

Operate the equipment at maximum duty cycle for at least 5 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. At the end of each test and with the equipment still energized, adjust the average voltage at equipment terminals to 115

Vrms and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS

Voltages to be applied at equipment terminals:

TEST	EQUIPMENT CATEGORY	PHASE A/B/C VOLTAGE (Vrms)		
		Phase A	Phase B	Phase C
1	All	132.5	132.5	132.5
2	All	98.5	98.5	98.5
3	A(CF) and A(NF)	134	134	128
3	A(WF)	134	134	126
4	A(CF) and A(NF)	97	97	103
4	A(WF)	97	97	105

d. Additional Requirement for Single Phase Equipment (A(CF) Category Equipment Only)

Operate the equipment at maximum duty cycle for at least 5 minutes for each test. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 5-minute test period.

Frequency and voltage to be applied at equipment terminals:

TEST	VOLTAGE (Vrms)	FREQUENCY (Hz)
1	122	430
2	100	430
3	122	370
4	100	370

e. Additional Requirement for Three Phase Equipment (A(CF) Category Equipment Only)

Operate the equipment at maximum duty cycle for at least 5 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 5-minute period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)
	Phase A	Phase B	Phase C	
1	120.5	120.5	120.5	430
2	101.5	101.5	101.5	430
3	120.5	120.5	120.5	370
4	101.5	101.5	101.5	370
5	122	122	116	430
6	100	100	106	430
7	122	122	116	370
8	100	100	106	370

16.5.2.2 Momentary Undervoltage Operation (ac)

a. Definition

Momentary voltages in the range from zero to 97 Vrms may occur for any duration up to seven seconds.

b. Requirement

The equipment, when exposed to this condition, shall operate within the applicable equipment performance standards when returned to its normal operating voltage range.

With the equipment operating with a voltage of 115 Vrms ± 1 Vrms at its terminals and a frequency as specified in the note below, decrease the input ac voltage to 60 Vrms, or as otherwise specified in the equipment specification, for seven seconds. With the equipment still energized, adjust the input ac voltage to 115 Vrms and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat with 10 Vrms instead of 60 Vrms.

Note: These tests shall be performed with a frequency of:

- *400 Hz for A(CF) category equipment*
- *360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.*

16.5.2.3 Abnormal transients (ac)

16.5.2.3.1 Abnormal Surge Voltage

a. Definition

An abnormal surge is a variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system and remedial action by the regulator, such as during fault clearance. The abnormal ac surge voltage characteristics shall be within the limits defined by Figure 16-5.

b. Requirement

With the equipment operating with a voltage of 115 Vrms ± 1 Vrms at its terminals and a frequency as specified in the note below, apply to each of the primary input leads, voltage surges of 180 Vrms for 100 ms and 148 Vrms for one second. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-3.

Apply each surge three times at ten-second intervals. Following application of voltage surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: These tests shall be performed with a frequency of:
- *400 Hz for A(CF) category equipment*
- *360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.*

16.5.2.3.2 Abnormal Frequency Transients (A(CF) Category Equipment Only)

a. Definition

An abnormal frequency transient is a variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system and remedial action by the regulator in response to fault condition such as abnormal engine speed change.

b. Requirement

Operate the equipment for five minutes with a voltage of 115 Vrms ± 1 Vrms at equipment terminals and a frequency of 400 Hz ± 5 Hz.
Then, perform the following tests.

Test 1:
Cycle the frequency three times as indicated below:

- Decrease the frequency to 350 Hz ± 5 Hz in less than 1 ms and operate the equipment for 5 seconds.
- Decrease the frequency to 320 Hz ± 5 Hz in less than 1 ms and operate the equipment for 200 ms.
- Decrease the voltage to 0 Vrms in less than 1 ms and operate the equipment for 200 ms.
- Return the voltage to 115 Vrms ± 1 Vrms and the frequency to 400 Hz ± 5Hz in less than 1 ms and operate the equipment for 10 seconds.

Test 2:
Cycle the frequency three times as indicated below:

- Increase the frequency to 480 Hz ± 5 Hz for 200 ms.
- Decrease the frequency to 440 Hz ± 5 Hz in less than 1 ms and operate the equipment for 5 seconds.
- Decrease the voltage to 0 Vrms in less than 1 ms and operate the equipment for 200 ms.
- Return the voltage to 115 Vrms ± 1 Vrms and the frequency to 400 Hz ± 5 Hz in less than 1 ms and operate the equipment for 10 seconds.

Following application of the above tests, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

16.6 Electrical Power Input Parameter Limits (dc)

The following defines quantitatively those parameters of electrical power input that are variable and the related test conditions where applicable, and are divided into those associated with NORMAL and ABNORMAL electrical system operation.

Note: The power source used should be able to supply the maximum current required by the EUT.

16.6.1 Normal Operating Conditions (dc)

The following conditions and tests are applicable to Category A, Category B and Category Z equipment.

CAUTION: All mentioned voltage values are for 28 Vdc equipment. Divide them by 2 for 14 Vdc equipment.

16.6.1.1 Voltage (Average Value dc)

a. Definition:

Voltage (at equipment terminals)	All categories
Maximum:	30.3 V
Minimum:	22.0 V
Emergency Operation:	18.0 V

Note: Nominal dc network voltage is with regards to:
- *Category A and Z equipment: 28 V*
- *Category B equipment: 28 V or 14 V*

b. Requirement

(1) Operate the equipment at maximum duty cycle for at least 30 minutes with voltage at its terminals adjusted to the appropriate maximum voltage. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this 30-minute period. The test may be run at the abnormal voltage levels to satisfy both normal and abnormal operating conditions.

(2) Operate the equipment for at least 1 minute with nominal voltage at its terminals, then adjust voltage at equipment terminals to the appropriate minimum voltage and operate the equipment at maximum duty cycle for at least 30 minutes. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this 30-minute period. The test may be run at the abnormal voltage levels to satisfy both normal and abnormal operating conditions.

(3) For equipment designated to operate under emergency electrical system conditions, operate the equipment at maximum duty cycle for at least 30

minutes with voltage at its terminals adjusted to the appropriate emergency voltage. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this 30-minute period.

16.6.1.2 Ripple Voltage (dc)

a. Definition and ripple maximum level:

Ripple is the cyclic variation about the mean level of the dc voltage during steady state dc electrical system operation. The cyclic peak to peak dc ripple voltage will be less than 4 volts if voltage at equipment terminals is above or equal to 22 V; if not, ripple voltage will be less than 2 V.

b. Requirements related to ripple frequency components:

Refer to the paragraph 18.3.1 of subsection 18.3.

N*ote: Categories R, B and Z defined in section 18 correspond respectively to categories A, B and Z defined in section 16*

16.6.1.3 Momentary Power Interruptions (dc)

a. Definition

Transfer of power sources can result in power interruptions for any period up to 200 ms for Category A and 50 ms for Category B equipment, and 1.0 second for Category Z equipment.

b. Requirement for Equipment with Digital Circuits

This test is applicable only to equipment that incorporates digital circuitry and/or memory devices, including equipment with delay circuits.

This type of equipment is sensitive to momentary power interruptions that can cause aberrations in performance. Such transient power interruptions may be of any function of V-transient and T-transient where V_t may have any value between V-steady state and zero, and T_t may be any value from 0 to 1 second. Since there are a multitude of such combinations, this test procedure selects discrete values that are considered effective for determining equipment performance.

Test Procedures

The equipment shall be fully operational.
Nominal voltage shall be applied prior to each test condition.

Data shall have been entered, either manually or automatically, and all related displays functioning prior to each test condition.

For each operating mode of the equipment, apply each of the test conditions of Table 16-3 at least twice.

The second successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test.

After exposure, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards.

c. Requirement for Other Equipment

This test is applicable to all equipment that does not incorporate digital circuitry and/or memory devices.

Test Procedures

With the equipment operating at its design voltage(s), interrupt the power for a minimum of five times; each interrupt period shall last 50 ms whatever the category of equipment. Repeat this procedure with interrupt periods of 200 ms for Category A equipment, and 1 second for Category Z equipment.
Each successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Manual reset is permitted if allowed by the individual specification.

16.6.1.4 Normal Surge Voltage (dc)

a. Definition

A normal surge is a variation from the controlled steady-state level. It results from the inherent regulation of the electrical power supply system in response to disturbances that are imposed by normal system operations, such as load switching and remedial action by the regulator.

b. Requirement

(1) Operate the equipment for five minutes with a voltage of 28 Vdc ± 0.5 Vdc at its terminals, then cycle the voltage three times as indicated below:

Increase the voltage to 47 Vdc ± 0.5 Vdc for 5 ms then decrease the voltage to 40 Vdc ± 0.5 Vdc for 30 ms for Category A and Category B equipment. Increase the voltage to 50 Vdc ± 0.5 Vdc for 50 ms for Category Z equipment. Return the voltage to 28 Vdc ± 0.5 Vdc for five seconds. The voltage change from a level to another should be done within 1 ms.

Decrease the voltage to 17 Vdc ± 0.5 Vdc for Category A and Category B equipment, and to 12 Vdc ± 0.5 Vdc for Category Z equipment for 30 ms. Return the voltage to 28 Vdc ± 0.5 Vdc for five seconds. The voltage change from a level to another should be done within 1 ms.

(2) The voltage surge should be applied and monitored in a manner similar to that in Figure 16-4. (These voltage values are halved for 14.0 Vdc

nominal equipment.)

(3) During the normal electrical system surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Unless so stated in the individual equipment performance standard, equipment may have degraded performance during the surge and must meet the specified performance when returned to nominal voltage.

(4) Following application of the voltage surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: If the equipment performance standard requires that performance be met during the abnormal surge voltage test of subparagraph 16.6.2.4 and momentary undervoltage test of subparagraph 16.6.2.3, it is not necessary to run the above test.

16.6.1.5 Engine Starting Under Voltage Operation (dc)

a. Definition

This requirement applies to Category Z and 28 volt Category B equipment. During engine starting, momentary voltages in the range from 10.0 to 20.5 Vdc may occur for any duration up to 35 seconds or as indicated in the equipment specification.

b. Requirement

With the equipment energized at nominal rated voltage, decrease the input voltage to 10.0 Vdc and increase 0.30 volts per second for 35 seconds, then return to rated voltage or as indicated in the equipment specification. During this period the equipment performance can fall to a level stipulated in the equipment specification. Return the voltage to its nominal value and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

16.6.2 Abnormal Operating Conditions (dc)

The following conditions and tests are applicable to Category A, Category B, and Category Z equipment.

CAUTION: All mentioned voltage values are for 28 Vdc equipment. Divide them by 2 for 14 Vdc equipment.

16.6.2.1 Voltage Steady State (dc)

a. Definition

Abnormal voltage limits that may be encountered are:

Voltage (at equipment terminals)	All categories
Maximum:	32.2 V
Minimum:	20.5 V

Note: Nominal dc network voltage is with regards to:
- *Category A and Z equipment: 28 V*
- *Category B equipment: 28 V or 14 V*

b. Requirement

(1) Operate the equipment for at least five minutes with voltage at its terminals adjusted to the appropriate maximum voltage. With the equipment operating, reduce this voltage to nominal voltage and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

(2) Operate the equipment for at least one minute with nominal voltage at its terminals, then adjust voltage at equipment terminals to the appropriate minimum voltage and operate the equipment for at least five minutes. With the equipment still energized, increase voltage at its terminals to nominal voltage and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Any requirement for performance of the equipment during application of the abnormal voltage will be specified in the equipment performance standard.

16.6.2.2 Low Voltage Conditions (dc) (Category B Equipment)

a. Definition

Voltages in the range from zero to the appropriate minimum voltage may occur for any duration up to ten minutes.

b. Requirement

Operate the equipment for at least one minute with nominal voltage at its terminals then adjust the input power voltage(s) to the appropriate minimum voltage and operate the equipment for at least one minute. With the equipment still energized, decrease the input power voltage(s) linearly to zero over a period of 10 minutes. With the equipment still connected, adjust the input power voltage(s) to the equipment's appropriate nominal voltage and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: For this test, equipment which derives ac power from an inverter shall be considered as dc-operated equipment.

16.6.2.3 Momentary Undervoltage Operation (dc)

a. Definition

Voltages may momentarily vary below nominal for any duration up to seven seconds.

b. Requirement

The equipment, when exposed to this condition, shall operate within the applicable equipment performance standards when returned to normal operating voltage range.

With the equipment energized at nominal rated voltage, decrease the input dc voltage to 12.0 V for seven seconds. With the equipment still energized, adjust the input dc voltage to nominal rated value and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

16.6.2.4 Abnormal Surge Voltage (dc)

a. Definition

An abnormal surge is a variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system and remedial action by the regulator, such as during fault clearance. The transient surge voltages that may be encountered are shown in Figure 16-6.

b. Category Z requirement

With the equipment operating at its appropriate nominal voltage, apply to the positive (dc) input lead voltage surges of 80 Vdc for 100 ms and 48 Vdc for one second. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-4. Apply each voltage surge three times at ten-second intervals. Following this test, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

c. Category A requirement

With the equipment operating at its appropriate nominal voltage, apply to the positive (dc) input lead voltage surges of 46.3 Vdc for 100 ms and 37.8 Vdc for one second, unless otherwise specified in the equipment specifications. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-4. Apply each voltage surge three times at ten-second intervals. Following this test, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

d. Category B requirement

With the equipment operating at its appropriate nominal voltage, apply to the positive (dc) input lead voltage surges of 60 Vdc for 100 ms and 40 Vdc for one second, unless otherwise specified in the equipment specifications. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-4. Apply each voltage surge three times at ten-second intervals. Following this test, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

16.7 Load Equipment Influence on Aircraft Electrical Power System

16.7.1 Current Harmonic Emissions from Loads (ac)

16.7.1.1 Definitions

Refer to section 16.5.1.8.1

16.7.1.2 Current Distortion

The following requirements shall be met for equipment with test designation H (as defined in section 16.2).

1. When supplied with a voltage waveform of low Total Harmonic Distortion (THD_V at the EUT input less than 1.25 % according to Test Condition 1, Verification Requirements, paragraph 16.7.1.3), the equipment shall not demand harmonic current components greater than 1.25 % above that already specified in Tables 16-4 and 16-5 for every 1 % of distortion in the corresponding individual voltage harmonic.

   Notes:

   a. If the EUT power is greater than 2 kVA, the THD_V may be greater than 1.25 % but shall not exceed 4 %.

   b. For example of calculation of the harmonic current component limits, refer to Table 16-6.

2. When supplied with a distorted voltage waveform (Test Condition 2, Verification Requirements, paragraph 16.7.1.3), the equipment shall not demand harmonic currents greater than 1.25% above that already specified in Tables 16-4 and 16-5 for every 1% of distortion in the corresponding individual voltage harmonic.

   Note: For example of calculation of the harmonic current component limits, refer to Table 16-6.

   C*ommentary: Distorted voltage waveform requirements are required to ensure the EUT is stable when exposed to realistic power system conditions (Refer also to section 16.5.1.8).*

16.7.1.3 Current Distortion Verification Requirements

CAUTION: All mentioned voltage values are for 115 Vrms equipment. Multiply them by 2 for 230 Vrms equipment.

The following data shall be supplied as part of the qualification test procedure to verify compliance with distortion requirements in the design requirements under all operating modes:

1. A description of the operating mode of equipment when the measurement was taken;

2. A description of the test setup, a copy of the test procedure, and a description of test equipment used and their settings;

3. Plot of current and voltage waveforms, with scaling information, for each phase of the equipment;

4. For A(CF) category equipment:

   - Tabulation of equipment input current and voltage harmonic components magnitude and phase (optional) for integral frequencies between 400 Hz and 16 kHz for each phase of the equipment;

   - Spectrum analysis plot of equipment input current (magnitude only) with a resolution of less than 20 Hz for each phase of the equipment.

5. For A(NF) category equipment:

   - Tabulation of equipment input current and voltage harmonic components magnitude and phase (optional) for integral frequencies of 360 Hz to 14.4 kHz and 650 Hz to 26 kHz for each phase of the equipment;

   - Spectrum analysis plot of equipment input current (magnitude only) with a resolution of less than 20 Hz for each phase of the equipment.

6. For A(WF) category equipment:

   - Tabulation of equipment input current and voltage harmonic components magnitude and phase (optional) for integral frequencies of 360 Hz to 14.4 kHz and 800 Hz to 32 kHz for each phase of the equipment;

   - Spectrum analysis plot of equipment input current (magnitude only) with a resolution of less than 20 Hz for each phase of the equipment.

7. True RMS of input current for each phase of the equipment; and

8. Total harmonic distortion of input current and voltage for each phase of the equipment.

All equipment shall be tested with their intended load and in minimum and maximum steady state operating modes. (For example, ballasts for fluorescent and other discharge lamps shall be tested with their intended lamp combination(s) for bright, dim, off and other modes of operation.)

Current harmonic measurements shall be performed in accordance with Figure 16-7. Current measuring devices shall have an amplitude error of less than 3% and phase error (if reported) of less than 5 degrees for all frequencies up to 50 kHz.

Current harmonic components less than 5 mA, or less than 0.25 % of the fundamental, whichever is greater, shall be disregarded.

Spectrum analyzers or other harmonic analysis equipment shall be selected so that the resulting error in harmonic current measurement is less than 5% of the permissible limit, and the resulting frequency spectrum shall have a resolution of less than or equal to 20 Hz. Harmonic analysis equipment shall have capability of sufficiently high sampling rate, sufficiently long time window, appropriate window functions and anti-aliasing filters. As a guideline, the following test features should be considered:

a. A sampling rate of 100 kHz or higher should be used.

b. A time window of 0.05 seconds or longer should be used.

c. An anti-aliasing filter with a corner frequency within 25 kHz to 50 kHz should be used.

d. Either Rectangular, Hanning, Hamming, or Blackman-Harris windowing should be used.

Test conditions:

The equipment shall be tested under two conditions of input voltage distortion. In both cases, the equipment shall be supplied by a source having a voltage of 115 Vrms ± 2% and a frequency as follows:

- A(CF) category equipment: frequency of 400 Hz ± 1%.
- A(NF) category equipment: frequency of 400 Hz ± 1%, then 360 Hz ± 1% then 650 Hz ± 1%.
- A(WF) category equipment: frequency of 400 Hz ± 1%, then 360 Hz ± 1% then 800 Hz ± 1%.

The supply voltage and frequency shall remain constant within these limits while measurements are made.

Test Condition 1:

For the first test condition, the THD of the voltage (THD_V) at the input terminals of the equipment shall be less than 1.25% during the whole test.

Note: If the EUT power is greater than 2 kVA, the output impedance of the source may not be sufficiently low to keep THD_V at the input of the EUT below 1.25%. In this case, THD_V may be greater than 1.25 % but shall not exceed 4%.

Test Condition 2:

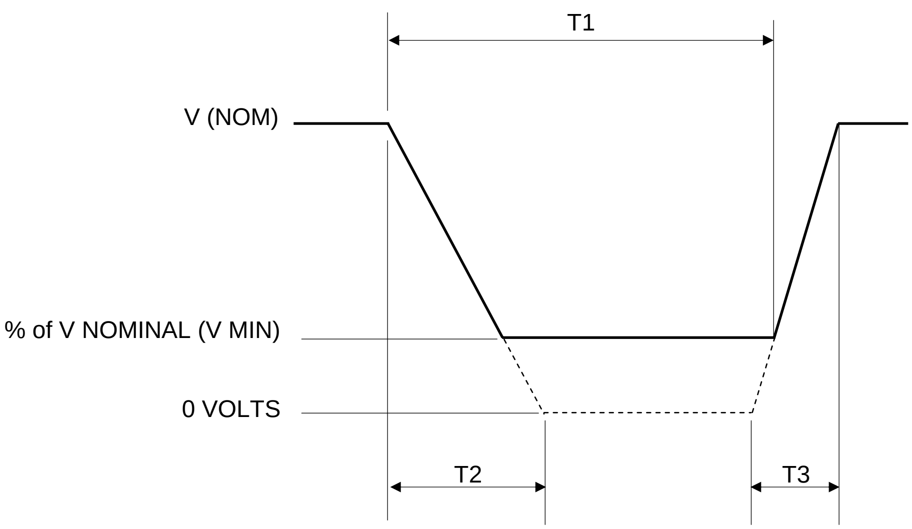
For the second test condition, the THD of the voltage (THD_V) at the input terminals of the equipment shall be greater than or equal to:

- 8% for A(CF) and A(NF) category equipment
- 10 % for A(WF) category equipment

during the whole test.

The voltage distortion may be produced via a full-wave rectifier bridge as shown in Figure 16-8. The level of voltage distortion can be controlled by varying the load on the rectifier(s), and insertion of source impedance in the line. Alternatively, input voltage to the EUT may be distorted by clipping the supply voltage.

Table 16-1 Test Conditions for AC Equipment with Digital Circuits



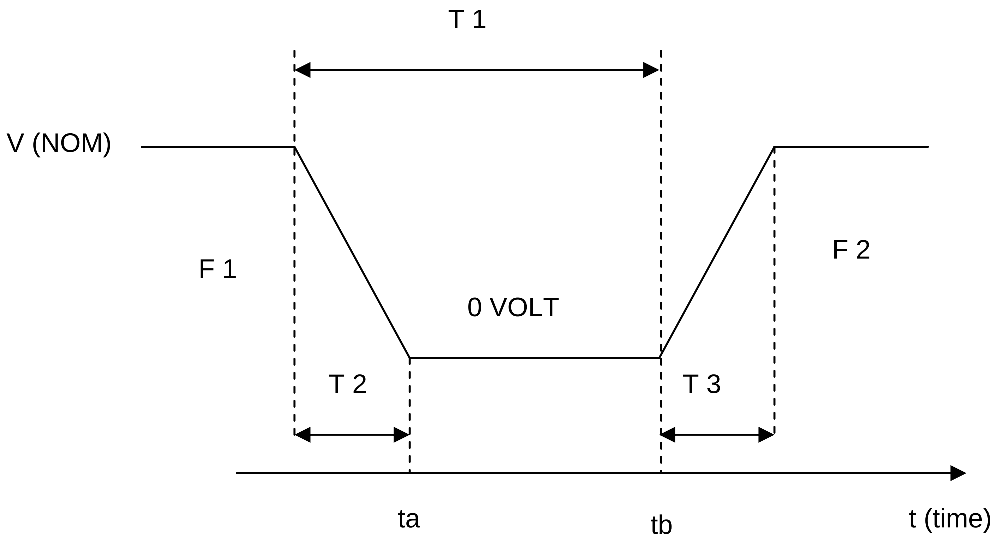
Notes:

1. *Definitions:*
   - *T1* *Power interrupt time.*
   - *T2* *Time it would take for the applied voltage to decay from V (nom) to zero volts.*
   - *T3* *Time it would take for the applied voltage to rise from zero to V (nom) volts.*
   - *V MIN* *The minimum level (expressed as a percentage of V NOMINAL) to which the applied voltage is permitted to decay.*
2. *Tolerance to T1, T2, T3 = ± 10%.*

Test Condition No.	1	2*	3	4	5	6	7	8*	9*	10	11	12	13	14*	15*	16*	17
T1 (Milliseconds)	2	10	25	50	75	100	200	10	25	50	75	100	200	30	35	40	25
T2 (Milliseconds)	<1	20*	20	20	20	20	20	50*	50*	50	50	50	50	50*	50*	20*	5
T3 (Milliseconds)	<1	5	5	5	5	5	5	20	20	20	20	20	20	20	5	20	5
% of Vnominal (V min)	0	50	15	10	5	0	0	80	50	0	15	5	0	65	60	35	0

* Voltage will not reach zero in this test condition.

Table 16-2 Additional Test Conditions for A (NF) and A(WF) Category Equipment



Notes:

T1 = power interrupt time

T2 = 20 ms and T3 = 5 ms

Tolerance to T1, T2, T3 = ±10 %

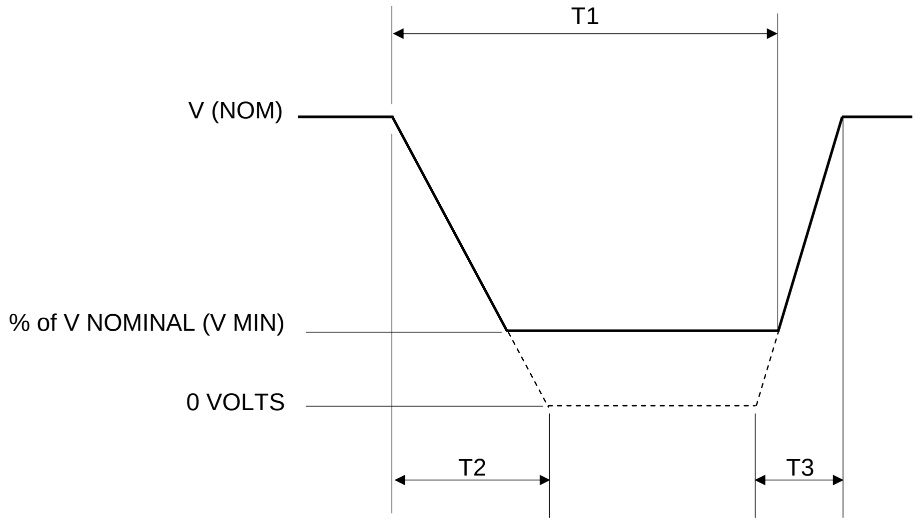
F1 = frequency of equipment voltage supply when t ≤ ta

F2 = frequency of equipment voltage supply when t ≥ tb

Test condition number	**I**	**II**	**III**	**IV**	**V**	**VI**
T1 (ms)	50	50	100	100	200	200
F1 (Hz)	360	F_{MAX}	360	F_{MAX}	360	F_{MAX}
F2 (Hz)	F_{MAX}	360	F_{MAX}	360	F_{MAX}	360

With F_{MAX} = 650 Hz for A(NF) category equipment
F_{MAX} = 800 Hz for A(WF) category equipment

Table 16-3 Test Conditions for DC Equipment with Digital Circuits



Notes:

1. *Definitions:*

   T1 *Power interrupt time.*

   T2 *Time it would take for the applied voltage to decay from V (nom) to zero volts.*

   T3 *Time it would take for the applied voltage to rise from zero to V (nom) volts.*

   V MIN *The minimum level (expressed as a percentage of V NOMINAL) to which the applied voltage is permitted to decay.*

2. *Tolerance to T1, T2, T3 = ± 10%.*

Applicable Category	A, B, Z				A, Z			Z	A, B, Z		A, Z				Z	A, B, Z			
Test Condition No.	1	2*	3	4	5	6	7	8	9*	10*	11	12	13	14	15	16*	17*	18*	19
T1 (mS)	2	10	25	50	75	100	200	1000	10	25	50	75	100	200	1000	30	35	40	25
T2 (mS)	<1	20*	20	20	20	20	20	20	50*	50*	50	50	50	50	50	50*	50*	20*	5
T3 (mS)	<1	5	5	5	5	5	5	5	20	20	20	20	20	20	20	20	5	20	5
% of Vnominal (V min)	0	50	15	10	5	0	0	0	80	50	0	15	5	0	0	65	60	35	0

* Voltage will not reach zero in this test condition.

Table 16-4 Current Harmonic Limits for Single-Phase Electrical Equipment

Harmonic Order	Limits
Odd Non Triplen Harmonics (h = 5, 7, 11, 13,…, 37)	$I_h = 0.3\ I_1 / h$
Odd Triplen Harmonics (h = 3, 9, 15, 21, ..., 39)	$I_h = 0.15\ I_1 / h$
Even Harmonics 2 and 4	$I_h = 0.01\ I_1 / h$
Even Harmonics > 4 (h = 6, 8, 10, ..., 40)	$I_h = 0.0025\ I_1$

Table 16-5 Current Harmonic Limits for Balanced Three-Phase Electrical Equipment

Harmonic Order	Limits
3rd, 5th, 7th	$I_3 = I_5 = I_7 = 0.02\ I_1$
Odd Triplen Harmonics (h = 9, 15, 21, ..., 39)	$I_h = 0.1\ I_1 / h$
11th	$I_{11} = 0.1\ I_1$
13th	$I_{13} = 0.08\ I_1$
Odd Non Triplen Harmonics 17, 19	$I_{17} = I_{19} = 0.04\ I_1$
Odd Non Triplen Harmonics 23, 25	$I_{23} = I_{25} = 0.03\ I_1$
Odd Non Triplen Harmonics 29, 31, 35, 37	$I_h = 0.3\ I_1 / h$
Even Harmonics 2 and 4	$I_h = 0.01\ I_1 / h$
Even Harmonics > 4 (h = 6, 8, 10, ..., 40)	$I_h = 0.0025\ I_1$

I_1 = maximum fundamental current of the equipment that is measured during the maximum steady-state power demand operating mode condition, at a single test frequency (*). This maximum current shall be used to calculate the current harmonic limits for all modes of operation, at that test frequency (*).

(*) For test frequency values, refer to section 16.7.1.3

h = order of harmonic.

I_h = maximum harmonic current of order h obtained for all normal steady state modes of operation.

Table 16-6 Example of Determination of Single Phase Equipment Compliance Under Testing with a Distorted Input Voltage Waveform

A Harmonic Order	B Current Harmonic Reqmt's (%)	C Harmonics in Voltage Waveform (%)	D= (B + C*1.25) Revised Current Harmonic Reqmt's (%)	E Current Harmonics Emitted by Unit Under Test (%)	F Test Results
2	0.50	0.04	0.55	0.51	P
3	5.00	3.49	9.36	11.72	F
4	0.25	0.03	0.28	0.25	P
5	6.00	2.99	9.73	7.53	P
6	0.25	0.12	0.40	0.15	P
7	4.29	1.67	6.37	13.20	F
8	0.25	0.02	0.27	0.10	P
9	1.67	0.21	1.93	0.98	P
10	0.25	0.01	0.26	0.05	P
11	2.73	0.72	3.63	3.00	P
12	0.25	0.03	0.28	0.12	P
13	2.31	0.64	3.11	5.20	F
.					
.					
40	0.25	0.0017	0.2521	0.0065	P

Column A identifies the harmonic order; for example, row 1, for A(CF) category equipment, is associated with the 800-Hz components of voltage and current (2 * 400 Hz). (For actual determination of load compliance with the harmonic requirements, the table should include data up to, and including, the 40th harmonic.)

Column B lists the current harmonic requirements for a single phase load as determined from Table 16-4.

Column C is an example of what the voltage harmonic components may be for an applied voltage whose total harmonic distortion is greater than five percent (as specified in the test condition 2). It is stressed that column C are example numbers only, in practice this column would contain the actual harmonic components of the applied voltage.

Column D represents the allowed current harmonics for the EUT.

Column E provides an example of current harmonic data for an item of equipment tested under the distorted voltage condition.

Column F expresses whether the equipment has passed or failed the requirements for each specific harmonic. This is determined by the relationship between the current harmonics measured at the equipment input (column E) and the allowed current harmonics under distorted voltage input conditions (column D).

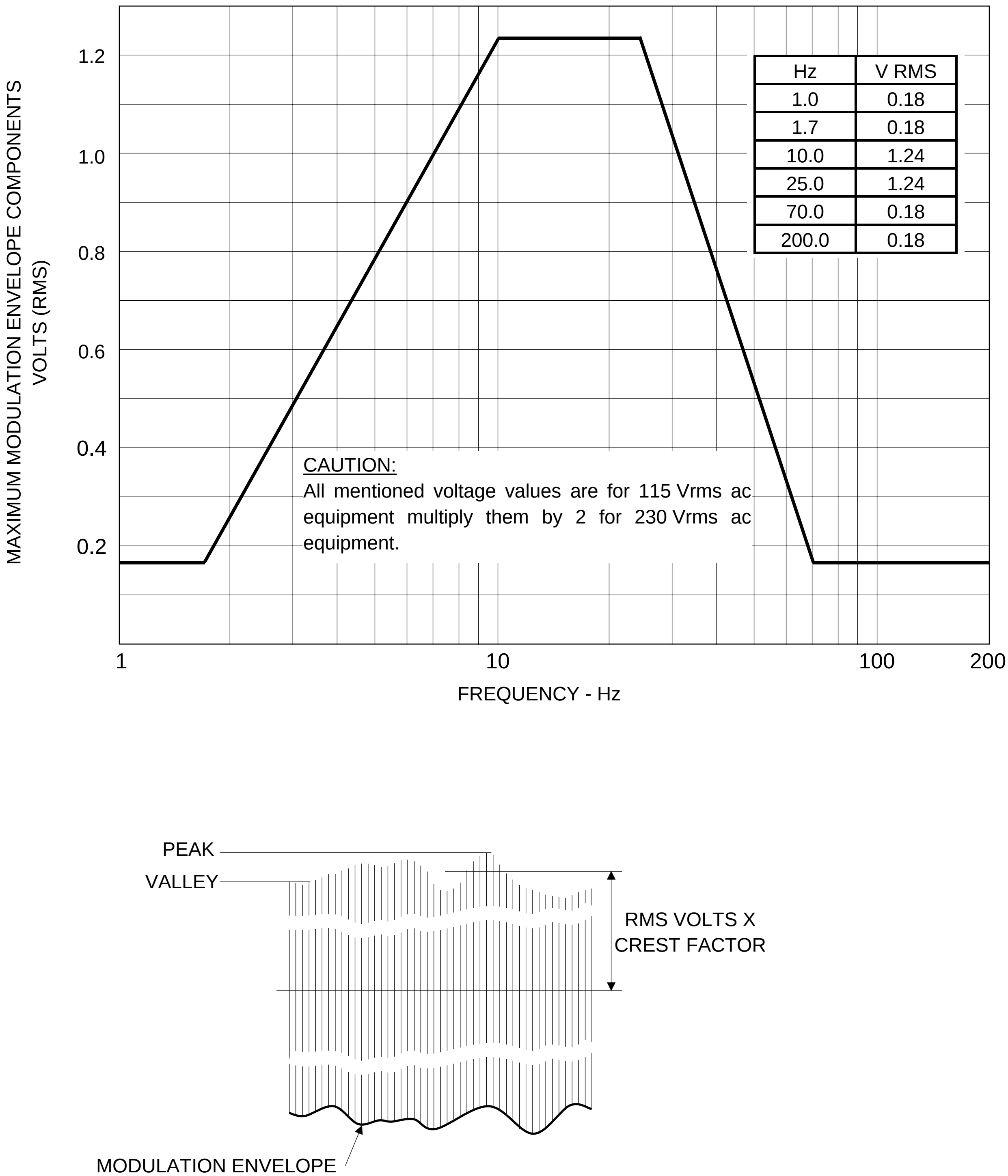
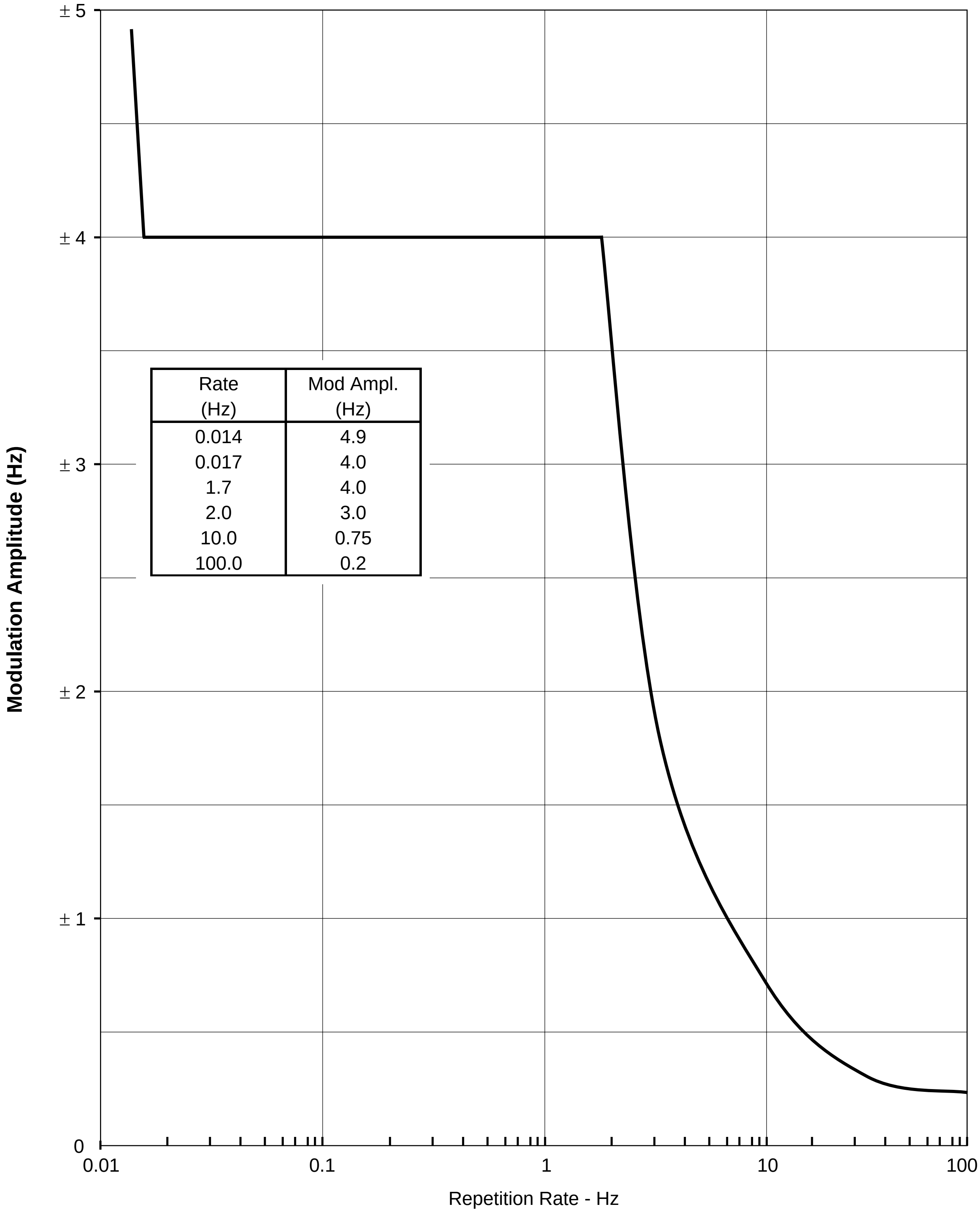
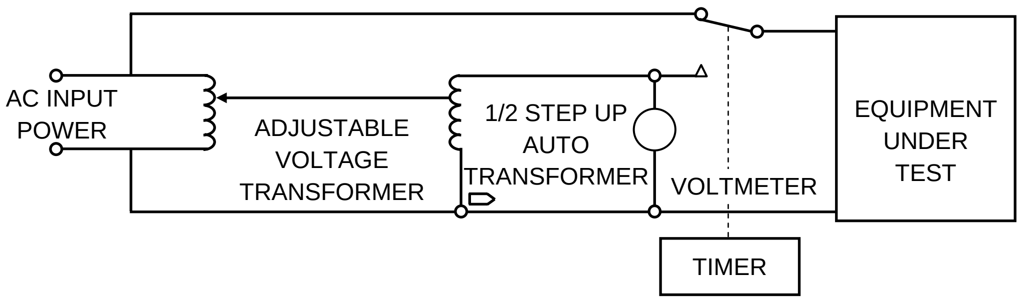


Figure 16-1 Frequency Characteristics of AC Voltage Modulation Envelope



Rate (Hz)	Mod Ampl. (Hz)
0.014	4.9
0.017	4.0
1.7	4.0
2.0	3.0
10.0	0.75
100.0	0.2

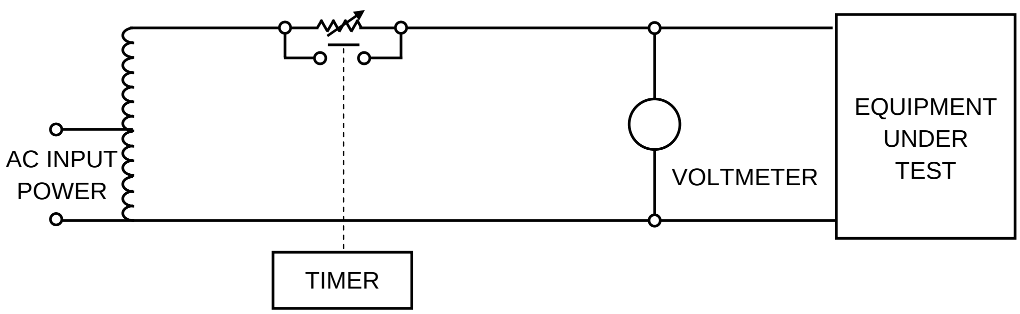
Figure 16-2 Characteristics of AC Frequency Modulation



Must be of sufficient volt-ampere capacity for equipment under test

CIRCUIT A

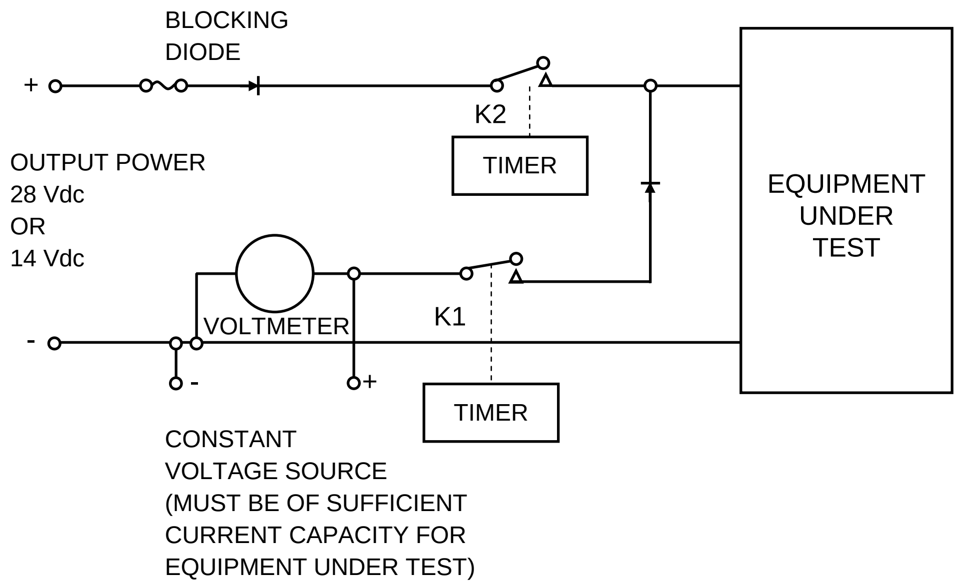
Note: Equipment under test will receive zero power during timer switching.



CIRCUIT B

Note: Circuit B is optional and can only be used when the source impedance is not critical to the equipment performance.

Figure 16-3 AC Equipment Surge Voltage Test

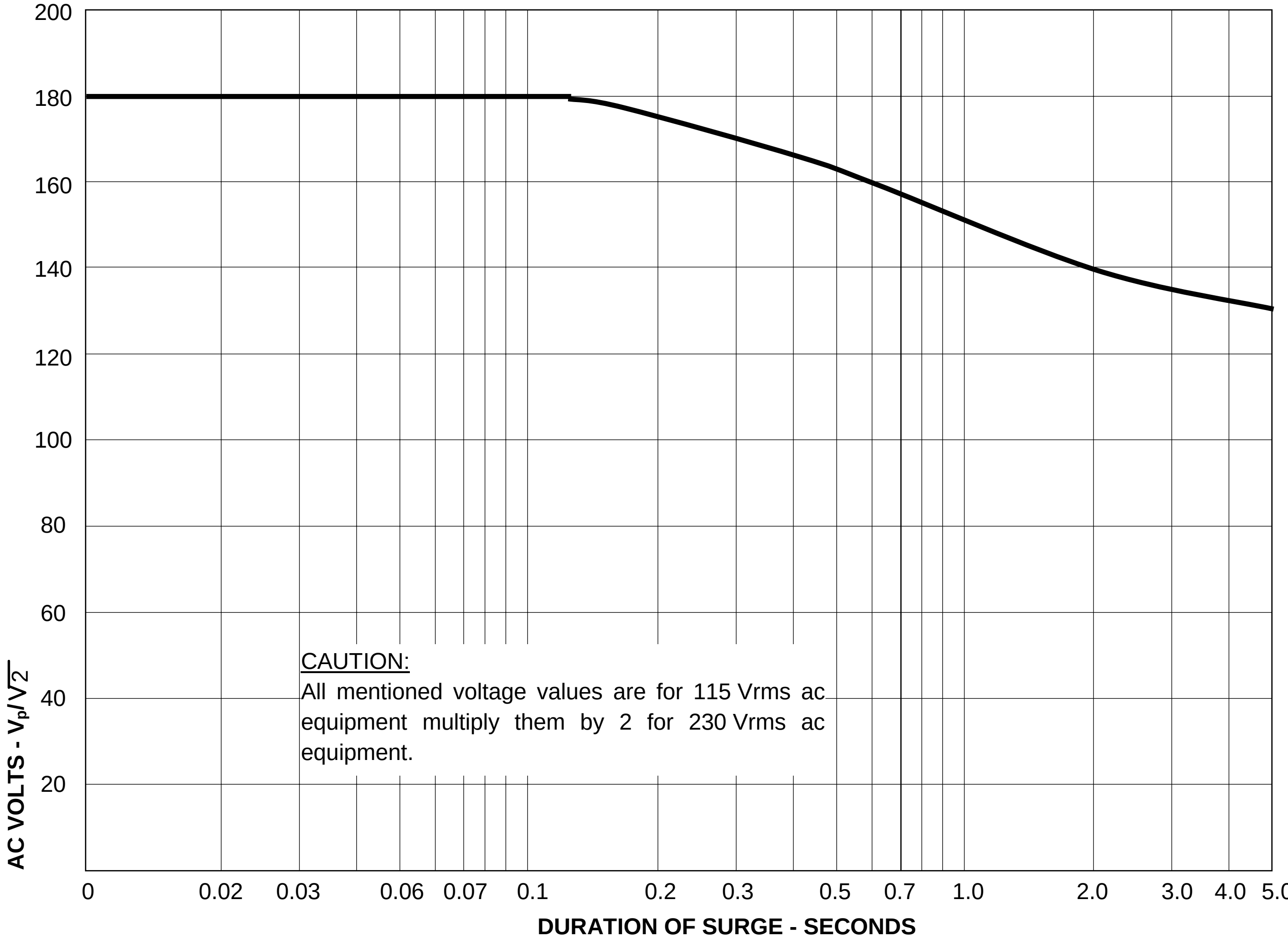


		VOLTAGE TO BE APPLIED TO EUT		
		ABOVE NOMINAL VOLTAGE	BELOW NOMINAL VOLTAGE	NOMINAL VOLTAGE
K1 AND K2 STATE	K1	CLOSED	CLOSED	OPEN
	K2	CLOSED	OPEN	CLOSED
		See note 1	See note 1	

Notes: 1. *The duration of this K1/K2 state configuration is equal to the duration of the voltage surge according to paragraph 16.6.1.4 (normal surge voltage) or paragraph 16.6.2.4 (abnormal surge voltage)*

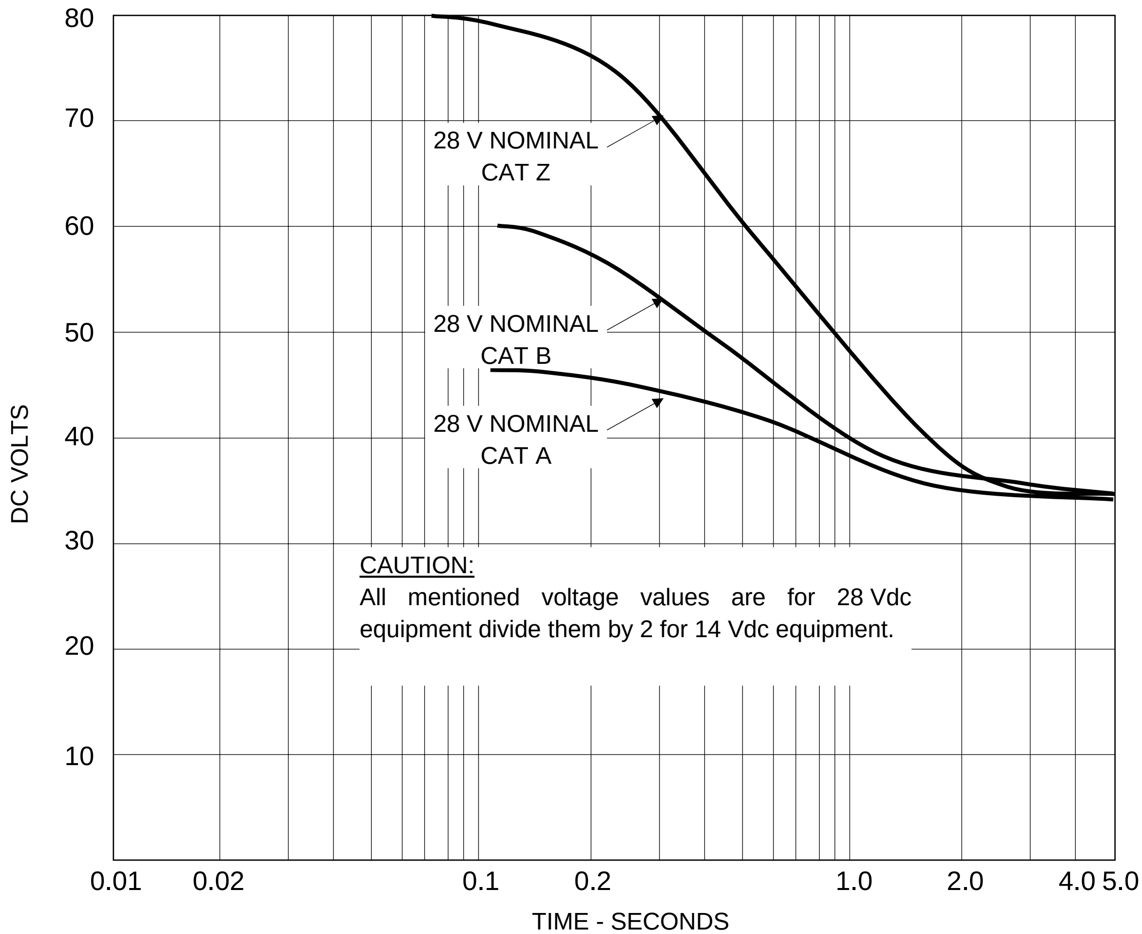
2. *K1 and K2 have to be actuated so that no power off condition is applied to EUT*

Figure 16-4 DC Equipment Surge Voltage Test



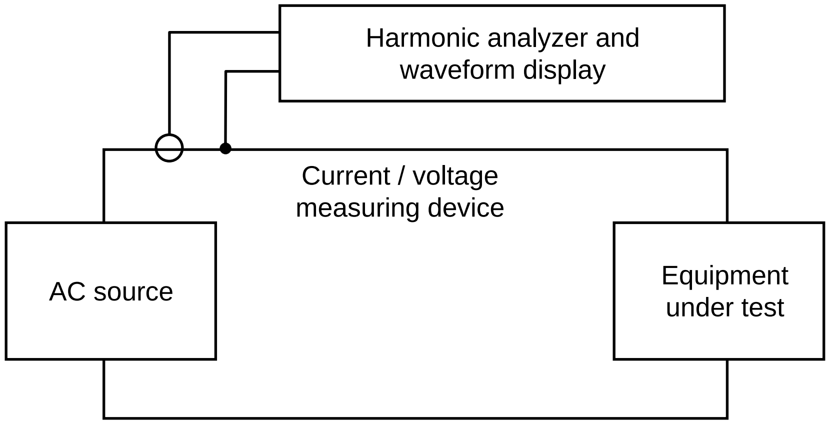
SURGE LIMIT	
Sec.	$V_p / \sqrt{2}$
5.0	134
3.0	135
1.0	148
0.4	168
0.2	178
0.1	180
0.01	180

Figure 16-5 Envelope of AC Abnormal Voltage Surges

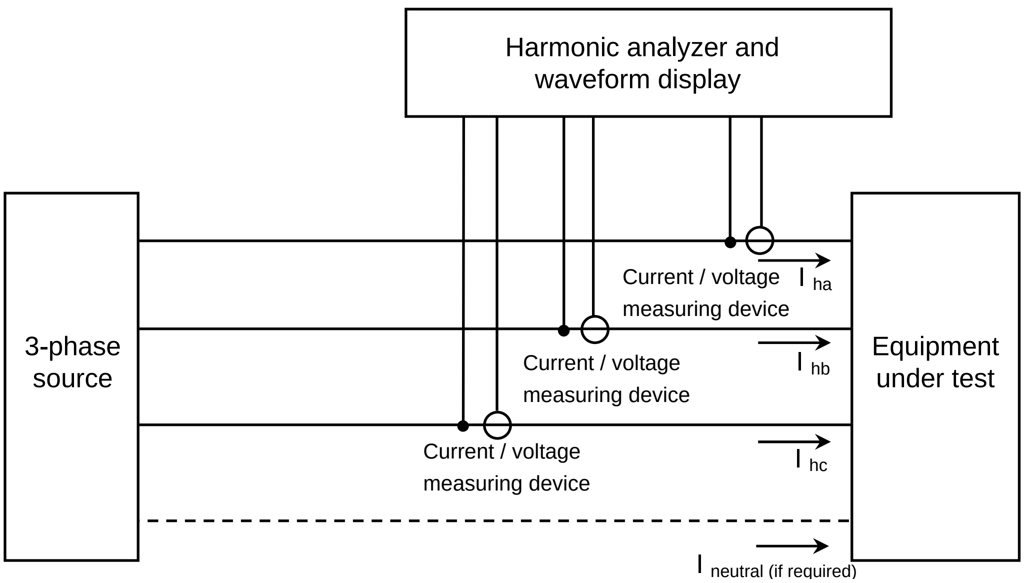


SURGE LIMITS			
Sec.	Cat A	Cat B	Cat Z
5.0	32.2	32.2	32.2
1	37.8	40	48
0.5	42.5	47	60
0.1	46.3	60	80

Figure 16-6 Typical Abnormal DC Surge Voltage Characteristics

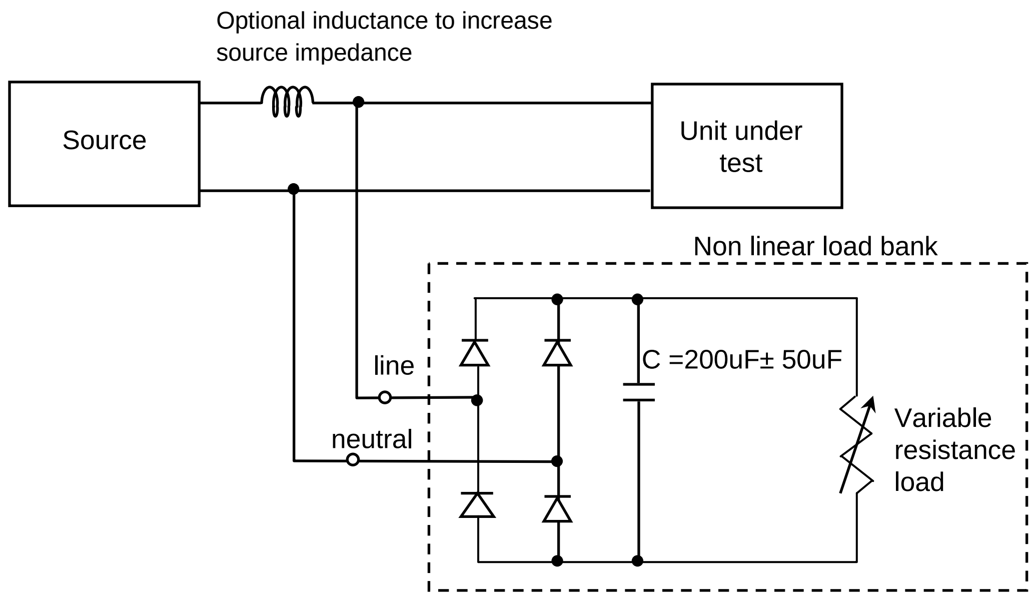


Current Harmonic Measurement for Single Phase Equipment

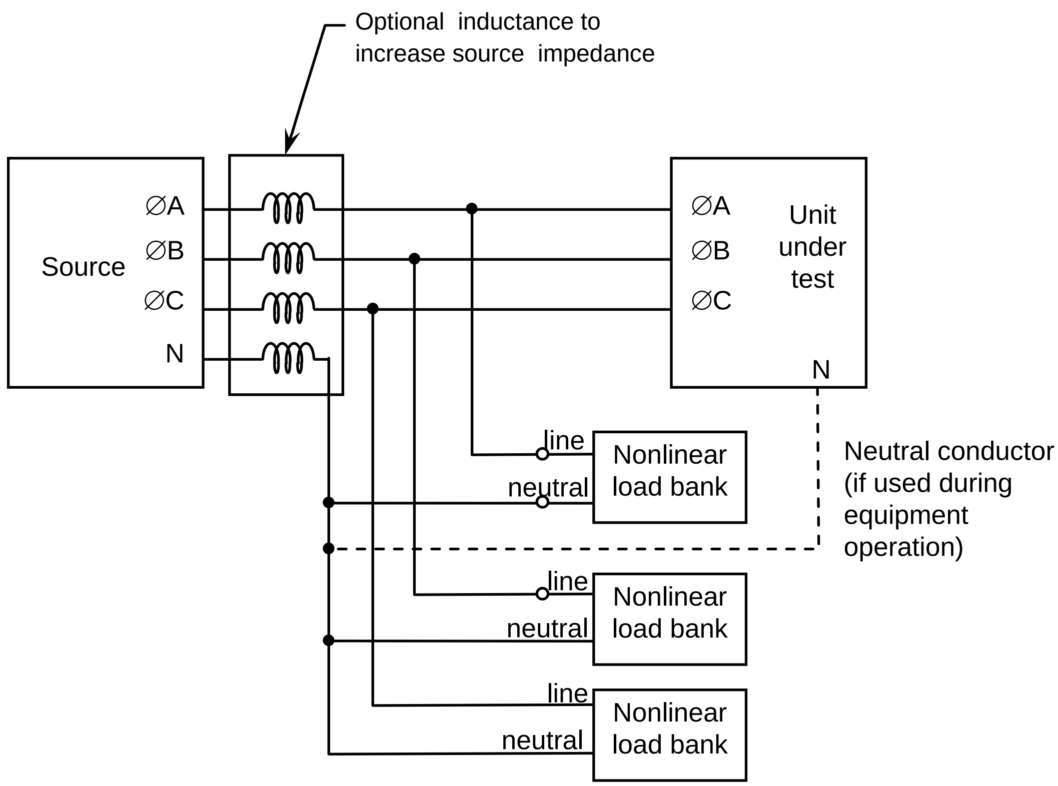


Current Harmonic Measurement for Three Phase Equipment

Figure 16-7 Typical Current Harmonic Measurement Diagrams

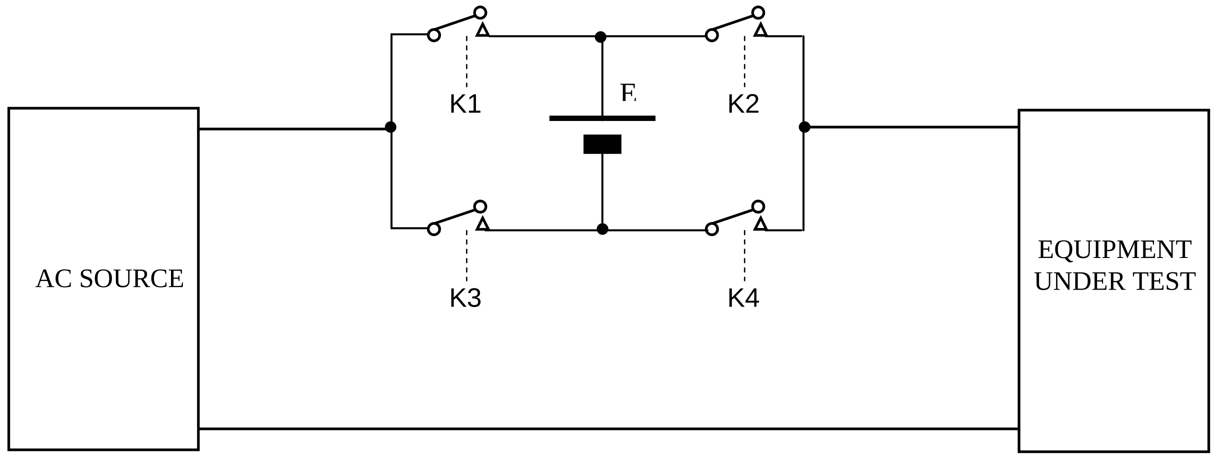


Voltage Distortion Production for Single Phase Equipment



Voltage Distortion Production for Three Phase Equipment

Figure 16-8 Typical Voltage Distortion Circuits for Harmonic Testing



DC VOLTAGE OFFSET PRODUCTION FOR SINGLE-PHASE EQUIPMENT

“E” corresponds to an adjustable DC voltage source. This source:

- Shall be compatible with the EUT maximum steady-state rms current obtained for all normal modes of operation.

- Shall create the following DC voltage offset on the AC source:
  - ◊ For 115V AC equipment: -0.1 V and +0.1 V ± 0.03V
  - ◊ For 230V AC equipment: -0.2 V and +0.2 V ± 0.06V

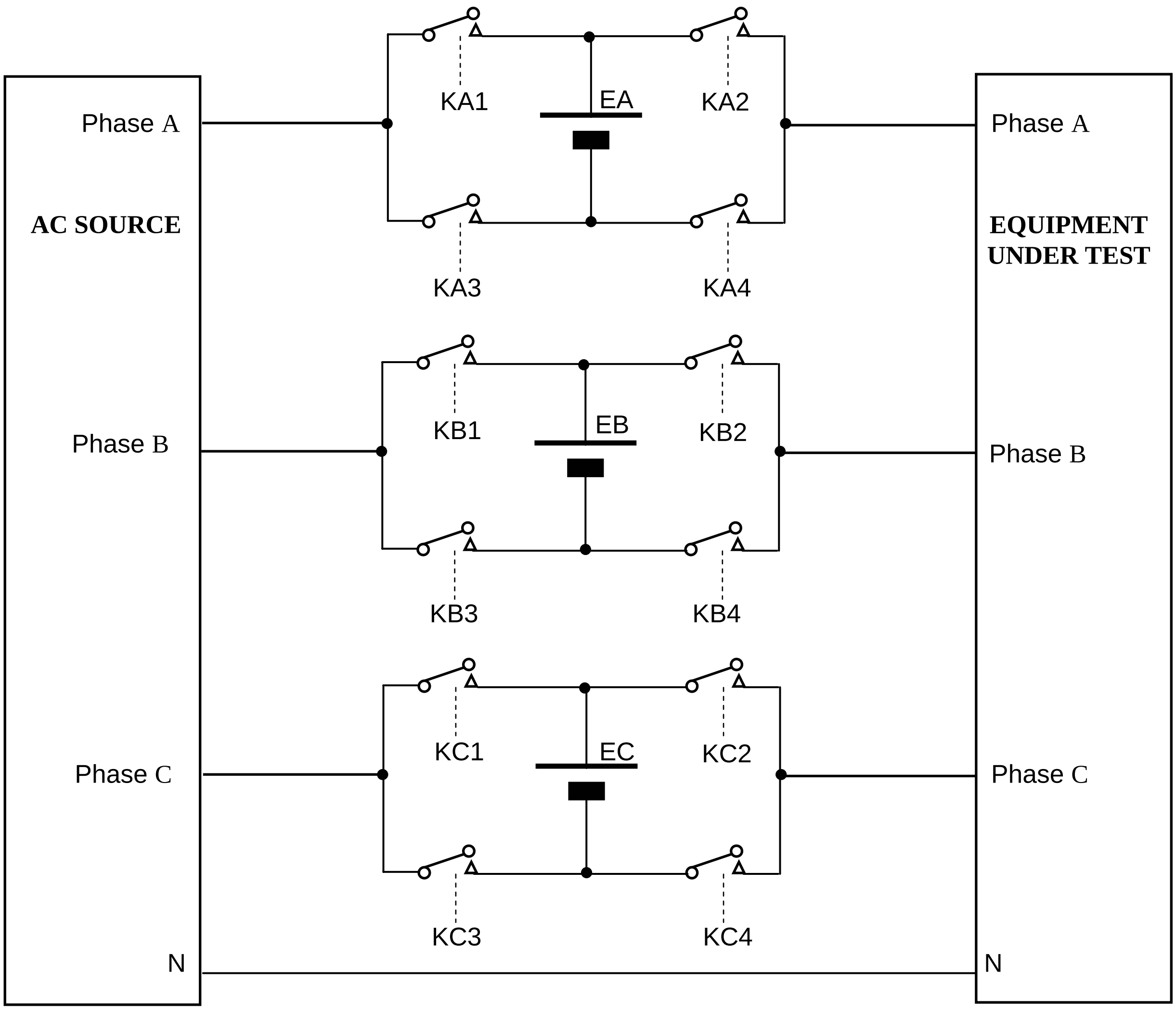
State of switches K1 to K4

- Initial power-up of EUT:
  - ◊ K1 and K2 (or K3 and K4) are closed in order not to submit E to the EUT inrush current.

- Test Condition: Application of negative DC content on the AC source
  - ◊ K1 and K4 are closed
  - ◊ K2 and K3 are open

- Test Condition: Application of positive DC content on the AC source
  - ◊ K1 and K4 are open
  - ◊ K2 and K3 are closed

Figure 16-9 AC Single-Phase Equipment DC Offset Test



DC Voltage Offset Production for Three-Phase Equipment

"EA", "EB", and "EC" correspond to adjustable DC voltage sources. These sources:

- Shall be compatible with the EUT maximum steady-state rms current obtained for all normal modes of operation.
- Shall create the following DC voltage offset on the AC source:
  - ◊ For 115V AC equipment: -0.1 V and +0.1 V ± 0.03V
  - ◊ For 230V AC equipment: -0.2 V and +0.2 V ± 0.06V

State of switches KA1 to KA4, KB1 to KB4 and KC1 to KC4

- Initial power-up of EUT:
  - ◊ KA1, KB1, KC1 and KA2, KB2, KC2 (or KA3, KB3, KC3 and KA4, KB4, KC4) are closed in order not to submit EA, EB and EC to the EUT inrush current
- Test Condition: Application of negative DC content on the AC source
  - ◊ KA1, KB1, KC1 and KA4, KB4, KC4 are closed
  - ◊ KA2, KB2, KC2 and KA3, KB3, KC3 are open
- Test Condition: Application of positive DC content on the AC source
  - ◊ KA1, KB1, KC1 and KA4, KB4, KC4 are open
  - ◊ KA2, KB2, KC2 and KA3, KB3, KC3 are closed

Figure 16-10 AC Three-Phase Equipment DC Offset Test

RTCA, Inc.

1828 L Street, NW Suite 805

Washington, DC 20036

RTCA/DO-160E

Environmental Conditions and Test Procedures for Airborne Equipment

Section 17

Voltage Spike

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

Date of Issue:
December 9, 2004

Supersedes: RTCA/DO-160D
Prepared by: SC-135

Page

17.0 Voltage Spike

17.1 Purpose of the Test

This test determines whether the equipment can withstand the effects of voltage spikes arriving at the equipment on its power leads, either ac or dc. The main adverse effects to be anticipated are:

a. Permanent damage, component failure, insulation breakdown.

b. Susceptibility degradation, or changes in equipment performance.

17.2 Equipment Categories

Category A

Equipment intended primarily for installation where a high degree of protection against damage by voltage spikes is required is identified as Category A.

Category B

Equipment intended primarily for installations where a lower standard of protection against voltage spikes is acceptable is identified as Category B.

17.3 Test Setup and Apparatus

The transient generator used shall produce the waveform shown in Figure 17-1. A typical test setup is shown in Figure 17-2. Any method of generating the spike may be used if the waveform complies with Figure 17-1.

17.4 Test Procedure

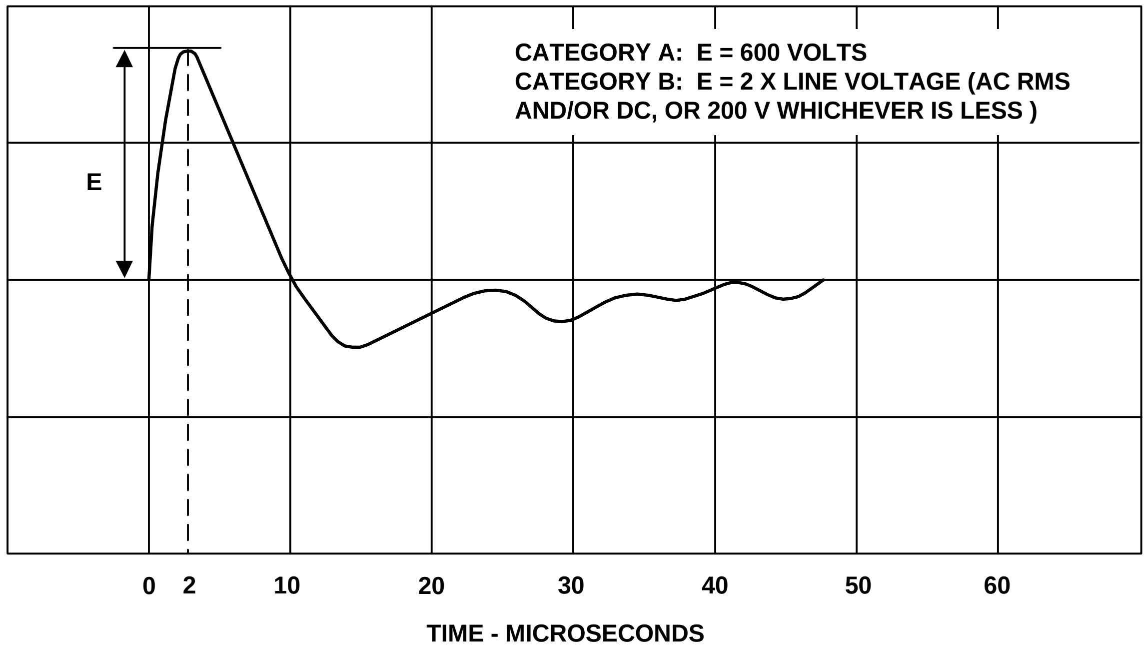
With the equipment under test disconnected, the transient wave shape shall be verified to be in accordance with Figure 17-1.

With the equipment operating at its design voltage(s), apply to each primary power input a series of positive and negative spikes described in Figure 17-1. Apply a minimum of 50 transients of each polarity within a period of one minute.

Repeat the test for each operating mode or function of the equipment.

After application of the spikes, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

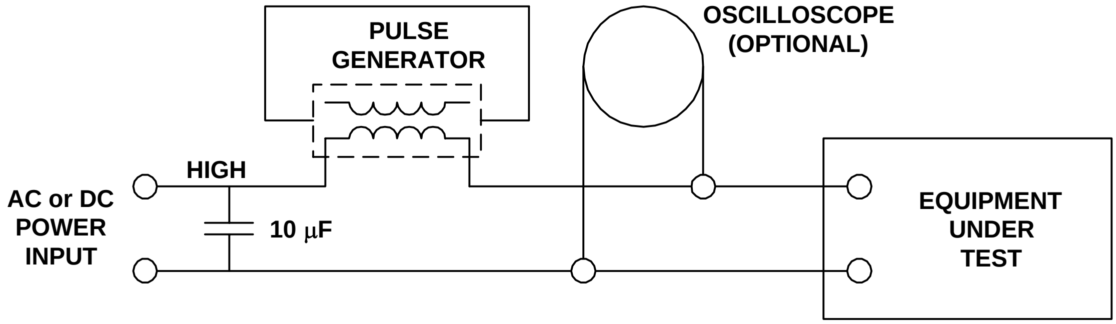
Note: If performance is measured during the application of this test, then the performance requirements contained in the applicable equipment performance standard apply.



THE WAVEFORM SOURCE IMPEDANCE SHALL BE 50Ω ±10%. THE SPECIFIED VOLTAGE AND DURATIONS ARE FOR OPEN CIRCUIT CONDITIONS ONLY. THE PEAK VOLTAGE MAY BE SUBSTANTIALLY LOWER WITH THE EQUIPMENT CONNECTED. THE TESTER SOURCE IMPEDANCE CAN BE VERIFIED BY TESTING WITH A 50Ω LOAD RESISTOR AND SHOULD PRODUCE ONE HALF OF THE SPECIFIED VOLTAGE ±10%.

Note: The waveform shown above is typical. The waveform requirement is accomplished if the pulse rise time is less than or equal to 2µsec and the total pulse duration is at least 10µsec.

Figure 17-1 Voltage Spike Waveform



Note: For equipments drawing high currents,alternate test methods may be required (To avoid saturating transformer etc.).

<u>Figure 17-2</u> Voltage Spike Test Setup

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 18

Audio Frequency Conducted Susceptibility — Power Inputs

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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Prepared by: SC-135

18.0 Audio Frequency Conducted Susceptibility - Power Inputs (Closed Circuit Test)

18.1 Purpose of the Test

This test determines whether the equipment will accept frequency components of a magnitude normally expected when the equipment is installed in the aircraft. These frequency components are normally harmonically related to the power source fundamental frequency.

18.2 Equipment Categories and Frequency Classes

18.2.1 Equipment Categories

Section 18 utilizes the same designators (CF, NF, and WF) as Section 16: The designator (CF) refers to electrical systems where the primary power is from a constant frequency (400 Hz) ac system, the designator (NF) refers to electrical systems where the primary power is from a narrow variable frequency (360 to 650 Hz) ac system, and the designator (WF) refers to electrical systems where the primary power is from a wide variable frequency (360 to 800 Hz) ac system.

Category reference:

- For ac equipment: R(CF), R(NF), R(WF), K(CF), K(NF) or K(WF)
- For dc equipment: R, B, or Z

Categories R(CF), R(NF), R(WF) and R

Equipment intended for use on aircraft electrical systems where the primary power is from a constant or variable frequency ac system and where the dc system is supplied from transformer-rectifier units, is identified as:

- for ac equipment: Category R(CF), R(NF) or R(WF),
- for dc equipment: Category R.

<u>Category B</u>

Dc equipment intended for use on aircraft electrical systems supplied by engine-driven alternator/rectifiers, or dc generators where a battery of significant capacity is floating on the dc bus at all times, is identified as Category B. Unless otherwise specified, tests levels for 14 Vdc equipment are half those shown for 28 Vdc equipment.

<u>Category </u>K(CF), K(NF) or K(WF)

Equipment intended for use on aircraft electrical systems where the primary power is from a constant or variable frequency ac system and characterized by a voltage distortion level higher than the one for the ac supplies applied on category R equipment.

Category K shall be acceptable for use in place of Category R for ac equipment.

Category Z

Dc equipment that may be used on all other types of aircraft electrical systems applicable to these standards is identified as Category Z. Category Z shall be acceptable for use in place of Category R or B. Examples of this category are dc systems supplied from variable-speed generators where:

a. The dc power supply does not have a battery floating on the dc bus, or

b. Control or protective equipment may disconnect the battery from the dc bus, or.

c. The battery capacity is small compared with the capacity of the dc generators.

18.3 Test Procedures

18.3.1 DC Input Power Leads

For Categories R, B, and Z, connect the equipment under test as shown in Figure 18-1. While the equipment is operating, apply a sine wave audio frequency signal successively in series with each ungrounded dc input power lead. While varying the audio frequency of the applied signal and with the peak-to-peak amplitude of this signal at the value specified in Figure 18-2 or Figure 18-3, (as appropriate) and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

18.3.2 AC Input Power Leads

a. For R(CF) and K(CF) category Equipment

Connect the equipment under test as shown in Figure 18-1. While the equipment is operating, apply a sine wave audio frequency signal successively in series with each ungrounded ac input power lead, while varying the frequency of the applied signal between 700 Hz and 16 kHz.

For R(CF) Category equipment, maintain the rms amplitude of this signal at not less than 6% of the maximum normal ac input voltage and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

For K(CF) Category equipment, maintain the rms amplitude of this signal at not less than 8% of the maximum normal ac input voltage up to 7.6 kHz and 6% above 7.6 kHz, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3

b. For R(NF) and K(NF) category equipment:

(1) Connect the equipment under test as shown in Figure 18-1. While equipment operating with a power source frequency of 360 Hz +5/-0 Hz, apply a sine wave audio frequency signal successively in series with each ungrounded ac input power lead, while varying the frequency of the applied signal between 700 Hz and 26 kHz.

For R(NF) Category equipment, maintain the rms amplitude of this signal at not less than 6% of the maximum normal ac input voltage, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

For K(NF) Category equipment, maintain the rms amplitude of this signal at not less than 8% of the maximum normal ac input voltage up to 12.4 kHz and 6% above 12.4 kHz, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

2) Repeat test (1) with a power source frequency of 650 Hz +0/-5 Hz while varying the frequency of the applied signal between 1100 Hz and 32 kHz.

c. For R(WF) and K(WF) category equipment:

(1) Connect the equipment under test as shown in Figure 18-1. While equipment operating with a power source frequency of 360 +5/-0 Hz, apply a sine wave audio frequency signal successively in series with each ungrounded ac input power lead, while varying the frequency of the applied signal between 700 Hz and 32 kHz.

For R(WF) Category equipment, maintain the rms amplitude of this signal at not less than 6% of the maximum normal ac input voltage, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

For K(WF) Category equipment, maintain the rms amplitude of this signal at not less than 8% of the maximum normal ac input voltage up to 15.2 kHz and 6 % above 15.2 kHz, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

(2) Repeat test (1) with a power source frequency of 800 Hz +0/-5 Hz while varying the frequency of the applied signal between 1400 Hz and 32 kHz.

18.3.3 Frequency Scan Rates

For test equipment that generate discrete frequencies the minimum number of test frequencies shall be 30 frequencies per decade. The test frequencies shall be logarithmically spaced. As an example, a formula that can be used to calculate these frequencies for 30 steps per decade in ascending order is:

$$F_{n+1} = f_1 * 10^{(n/30)} \pm 1\%$$

Where f_n is a test frequency and n = 1 to m
f_1 is the start frequency
f_m is the end frequency
$m = 1 + 30 * \log(f_m/f_1)$.

The dwell time at each test frequency shall be at least one minute, exclusive of test equipment settling time. If the last test step for F_{n+1} yields a frequency greater than f_m, round down to f_m.

For test equipment that generate a continuous frequency sweep, the minimum (i.e., fastest) sweep rate shall be equal to the number of discrete frequencies per decade (m) multiplied by the dwell time, i.e., 30 discrete frequencies per decade times 1 minute dwell time equals 30 minutes per decade sweep rate.

These tests shall be performed for the equipment operating modes that draw maximum steady state current and minimum steady state current from the prime power system. Where the ratio between maximum steady state current to minimum steady state current is 2:1 or less, then only one test at maximum steady state current is required.

18.4 General Remarks

a. If the impedance of the test power leads is such that excessive power will be required to generate the specified audio signal voltage level, the test conditions will be adequately satisfied by the use of an audio amplifier with a maximum output of 100 W. The impedance of the output of the transformer shall be 0.6 Ohm ±50%.

b. For dc input power leads, paragraph 18.3.1, a large capacitor (100 microfarads or more) shall be connected across the dc power source. For ac input power a 10 microfarad capacitor shall be connected across the power source.

c. When a transformer is used to couple the audio frequency energy into the power lead, it must be capable of performing adequately when the ac or dc load current drawn by the equipment under test flows through its secondary winding.

d. On ac lines, a phase shifting network may be used to eliminate the power frequency component at the signal monitor.

e. Caution must be exercised so that reflected voltages developed by input power current do not damage the audio power source generation system.

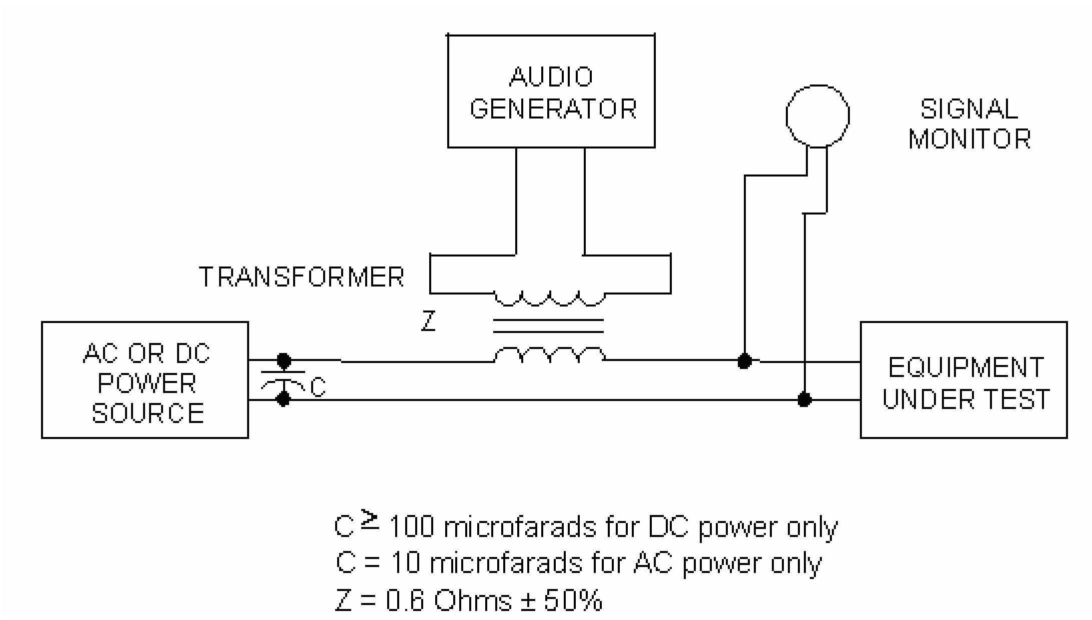
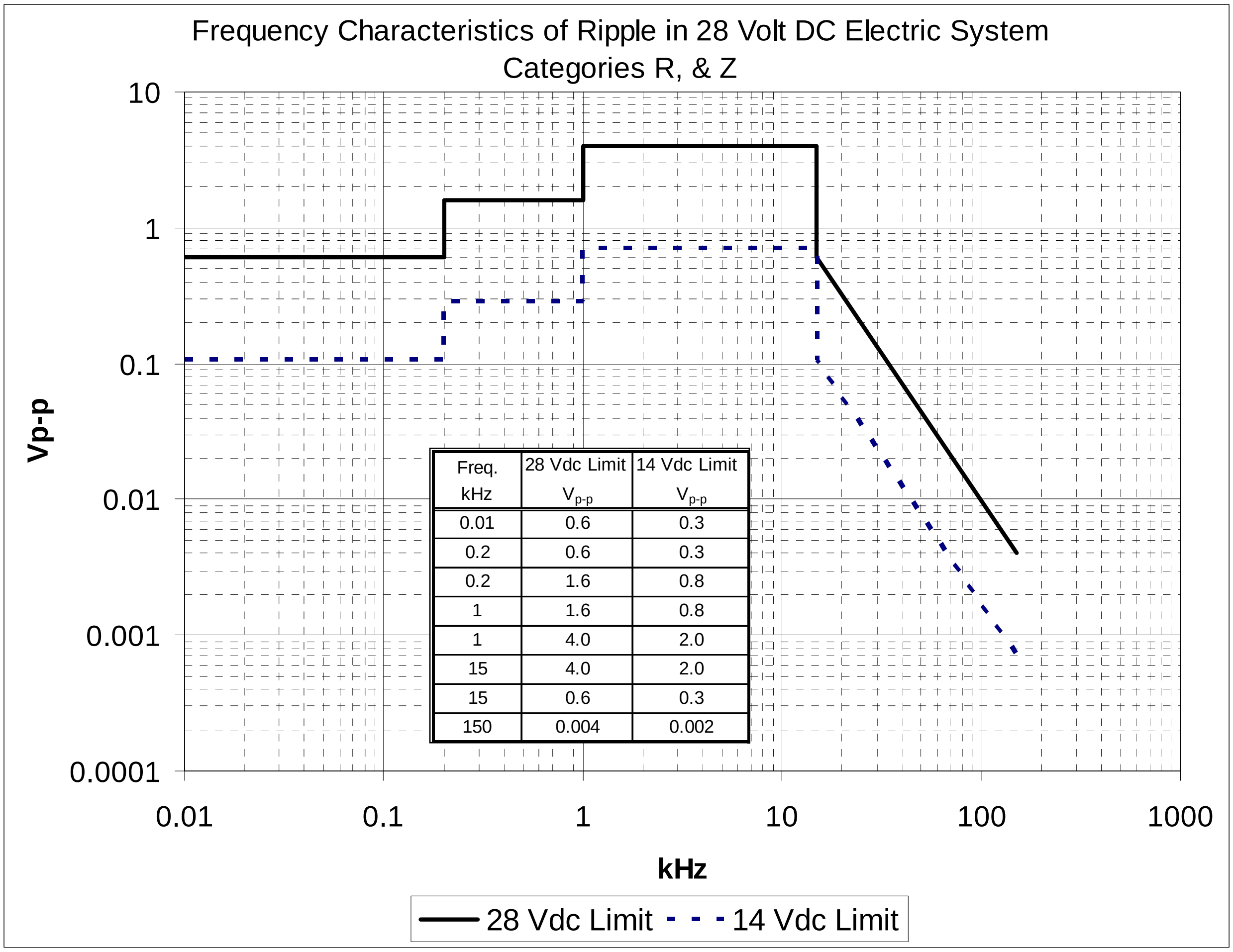


Figure 18-1 Test Setup for Audio Frequency Conducted Susceptibility Test (For AC and DC Power Lines)



Freq. kHz	28 Vdc Limit V_{p-p}	14 Vdc Limit V_{p-p}
0.01	0.6	0.3
0.2	0.6	0.3
0.2	1.6	0.8
1	1.6	0.8
1	4.0	2.0
15	4.0	2.0
15	0.6	0.3
150	0.004	0.002

Figure 18-2 Frequency Characteristics of Ripple in 28 Volt DC Electric System — Categories R, & Z

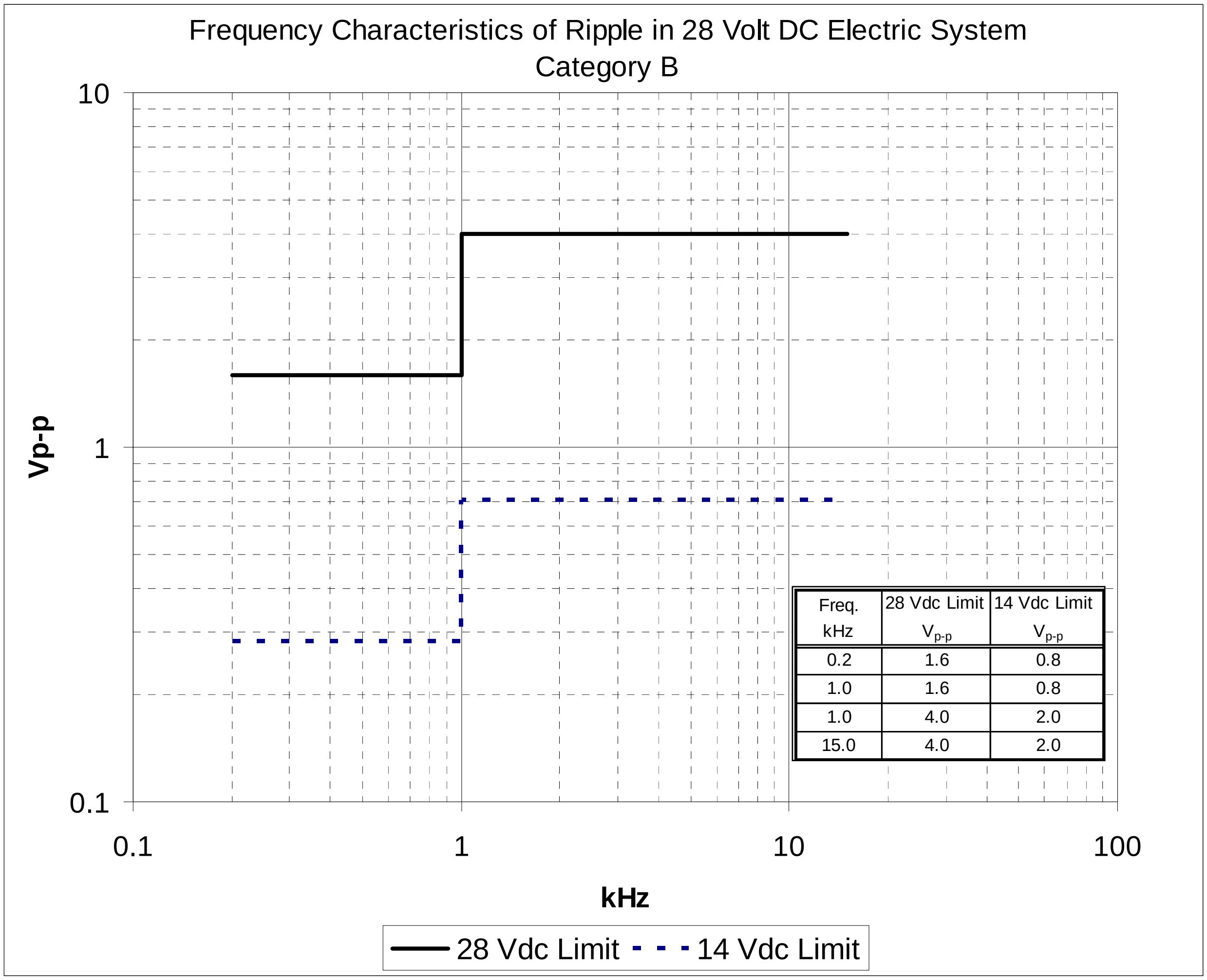


Figure 18-3 Frequency Characteristics of Ripple in 28 Volt DC Electric System — Category B

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Environmental Conditions and Test Procedures for Airborne Equipment

<u>Section 19</u>

Induced Signal Susceptibility

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, <u>Appendix A</u> is applicable for identifying environmental tests performed.

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19.0 Induced Signal Susceptibility

19.1 Purpose of the Test

This test determines whether the equipment interconnect circuit configuration will accept a level of induced voltages caused by the installation environment. This section relates specifically to interfering signals related to the power frequency and its harmonics, audio frequency signals, and electrical transients that are generated by other on-board equipment or systems and coupled to sensitive circuits within the EUT through its interconnecting wiring.

19.2 Equipment Categories

The induced signal susceptibility tests category is defined with two letters. The first letter (C, Z, A or B) refers to the test level and the second letter (C, N or W) refers to the type of primary power supply installation.

Category C_
Equipment intended primarily for operation in systems where interference-free operation is required and where severe coupling occurs due to long wire runs or minimum wire separation is identified as Category C_.

Category CC: Equipment is installed on aircraft whose primary power is constant frequency (e.g. 400 Hz) or DC

Category CN: Equipment is installed on aircraft whose primary power is variable over a narrow frequency range (e.g. 350 Hz – 650 Hz)

Category CW: Equipment is installed on aircraft whose primary power is variable over a wide frequency range (e.g. 350 Hz – 800 Hz)

Category Z_
Equipment intended primarily for operation in systems where interference-free operation is required is identified as Category Z_.

Category ZC: Equipment is installed on aircraft whose primary power is constant frequency (e.g. 400 Hz) or DC

Category ZN: Equipment is installed on aircraft whose primary power is variable over a narrow frequency range (e.g. 350 Hz – 650 Hz)

Category ZW: Equipment is installed on aircraft whose primary power is variable over a wide frequency range (e.g. 350 Hz – 800 Hz)

Category A_
Equipment intended primarily for operation where interference-free operation is desirable is identified as Category A_.

Category AC: Equipment is installed on aircraft whose primary power is constant frequency (e.g. 400 Hz) or DC

Category AN: Equipment is installed on aircraft whose primary power is variable over a narrow frequency range (e.g. 350 Hz – 650 Hz)

Category AW: Equipment is installed on aircraft whose primary power is variable over a wide frequency range (e.g. 350 Hz – 800 Hz)

Category B_
Equipment intended primarily for operation in systems where interference would be controlled to a tolerable level is identified as Category B_.

Category BC: Equipment is installed on aircraft whose primary power is constant frequency (e.g. 400 Hz) or DC

Category BN: Equipment is installed on aircraft whose primary power is variable over a narrow frequency range (e.g. 350 Hz – 650 Hz)

Category BW: Equipment is installed on aircraft whose primary power is variable over a wide frequency range (e.g. 350 Hz – 800 Hz)

19.3 Test Procedures

19.3.1 Magnetic Fields Induced Into the Equipment

Subject the equipment under test to an audio frequency magnetic field, generated by the current specified in Table 19-1, in a straight wire radiator located within 0.15 m of the periphery of the unit of equipment under test. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

During this test, the radiator shall be oriented with respect to each external surface of each unit to cause maximum interference. The length of the radiator shall extend a distance of at least 0.6 m (laterally) beyond each extremity of the unit under test. The leads applying current to the radiator shall be routed at least 0.6 m away from any part of the unit under test and from the radiator itself. All units of the equipment under test shall be individually tested. The magnetic field power source shall not be synchronized with the power source of the equipment supply.

19.3.2 Magnetic Fields Induced Into Interconnecting Cables

Subject the interconnecting wire bundle of the equipment under test to an audio frequency magnetic field as illustrated in Figure 19-2. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS when the field is of the value specified in Table 19-1.

During this test, all equipment interconnecting cables shall be installed in accordance with the applicable installation and interface control diagrams. Any inputs or outputs from or to other equipment(s) normally associated with the equipment under test shall be adequately simulated. The magnetic field power source is not to be synchronized with the power source of the equipment power supply. Frequency scan rates and dwell times shall be in accordance with section 19.3.5

19.3.3 Electric Fields Induced Into Interconnecting Cables

Subject the interconnecting wire bundle of the equipment under test to an audio frequency electric field as illustrated by Figure 19-3. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS when the field is of the value specified in Table 19-1.

During this test, all equipment interconnecting cables shall be in accordance with the applicable installation and interface control diagrams. Shielded or twisted wires shall be used only where specified by the equipment manufacturer. Any inputs or outputs from or to other equipment(s) normally associated with the equipment under test shall be adequately simulated. The electric field power source shall not be synchronized with the power source of the equipment power supply. Frequency scan rates and dwell times shall be in accordance with section 19.3.5

19.3.4 Spikes Induced Into Interconnecting Cables

During this test, all equipment interconnecting cables shall be in accordance with the applicable installation and interface control diagrams. Shielded or twisted wires shall be used only where specified by the equipment manufacturer. Any inputs or outputs from or to other equipment normally associated with the equipment under test shall be adequately simulated.

Subject the interconnecting wire bundle of the equipment under test to both positive and negative transient fields using the test setup shown in Figure 19-4. Table 19-1 defines the desired cable lengths for categories of section 19.2. The timer shown in Figure 19-4 shall be adjusted to yield a pulse repetition rate of eight to ten pulses each second. The waveform present at point A, Figure 19-4, should be similar to that described in Figure 19-5. For both positive and negative polarities of the transient, the pulsing for each polarity shall be maintained for a period of not less than two minutes or for a longer period of time if specified in the relevant equipment specification.

After exposure, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Any requirement for performance of the equipment during application of the tests will be specified in the equipment performance standard.

The inductive switching transient generated when the contact opens should be very similar to the illustration in Figure 19-5, when monitored at point A on Figure 19-4. When the contact opens, the voltage at Point A drives from +28 V dc to large negative voltages in about two microseconds. (The capacitance, 250 to 3,000 picofarad typically, between windings of the coil is charged negatively during this time.) When the voltage reaches the ionizing potential, arc-over occurs at the contact and the voltage drives rapidly toward 28 V dc through the ionized path at the contact. The voltage at Point A usually overshoots +28 V dc because of the wire inductance between Point A and the coil. At this time, the arc extinguishes and the cycle is repeated. In a typical case, the repetition period is 0.2 to 10 microseconds and the number of repetitions is often 5 to 1,000 before the energy of the inductive load ($E = 1/2\ LI^2$) is dissipated.

19.3.5 Frequency Scan Rates

For test equipment that generate discrete frequencies, the minimum number of test frequencies shall be 30 frequencies per decade. The test frequencies shall be logarithmically spaced. As an example a formula which can be used to calculate these frequencies for 30 steps per decade in ascending order is:

$$f_{n+1} = f_n * 10^{(1/30)}$$

where f_n is a test frequency and n = 1 to m,
f_1 is the start frequency
f_m is the end frequency
$m = 1+30*\log(f_m/f_1)$

The dwell time at each test frequency shall be at least 10 seconds, exclusive of test equipment settling time.

For test equipment that generate a continuous frequency sweep, the minimum (i.e., fastest) sweep rate shall be equal to the number of discrete frequencies per decade (m) multiplied by the dwell time, i.e., 30 discrete frequencies per decade times 10 second dwell time equals 5 minutes.

Table 19-1 Applicability of Categories to Induced Signal Susceptibility

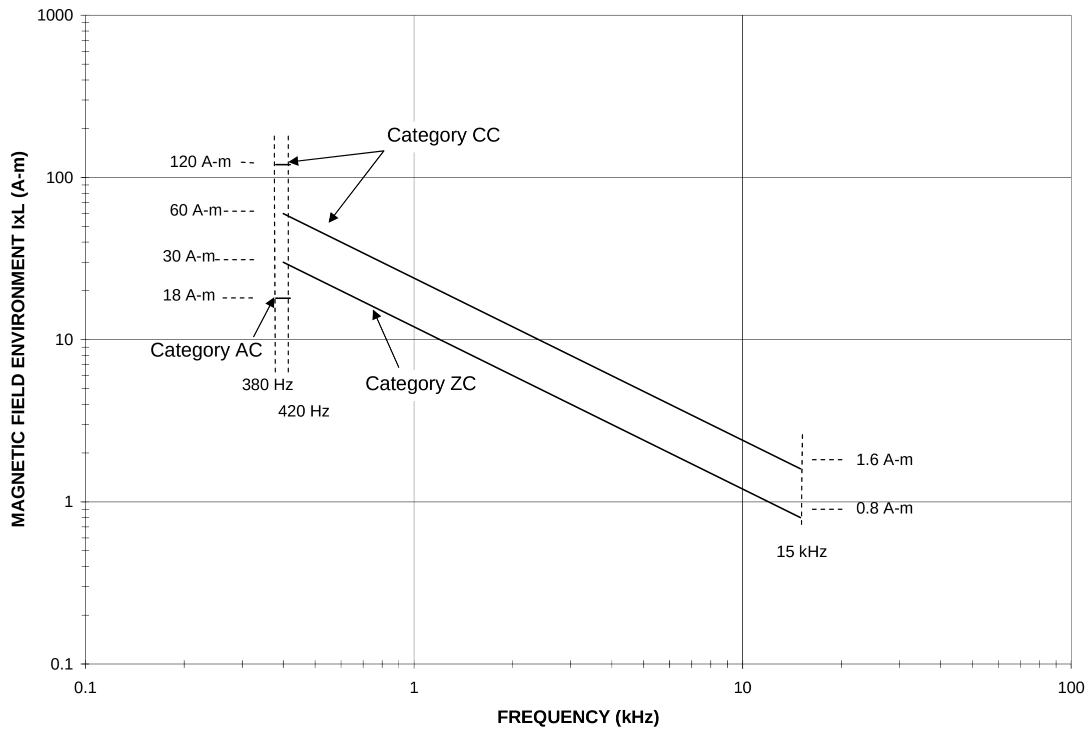
Paragraph	Test	Category ZC	Category AC	Category BC	Category CC
19.3.1	Magnetic Fields induced into the equipment	20 A rms at 400 Hz	20 A rms at 400 Hz	20 A rms at 400 Hz	20 A rms at 400 Hz
19.3.2	Magnetic fields induced into interconnecting cables	IxL=30 A-m at 400 Hz reducing to 0.8 A-m at 15 kHz	IxL=18 A-m from 380 to 420 Hz	Not Applicable	IxL=120 A-m from 380 to 420 Hz and 60 A-m at 400 Hz reducing to 1.6 A-m at 15 kHz
19.3.3	Electric Fields induced into interconnecting cables	VxL=1800 V-m from 380 to 420 Hz	VxL=360 V-m from 380 to 420 Hz	Not Applicable	VxL=5400 V-m from 380 to 420 Hz and 5400 V-m at 400 Hz reducing to 135 V-m at 15 kHz
19.3.4	Spikes induced into interconnecting cables	Figure 19-4 L=3.0 m	Figure 19-4 L=3.0 m	Figure 19-4 L=1.2 m	Figure 19-4 L=3.0 m

Paragraph	Test	Category ZN	Category AN	Category BN	Category CN
19.3.1	Magnetic Fields induced into the equipment	20 A rms at 350 Hz and 650 Hz	20 A rms at 350 Hz and 650 Hz	20 A rms at 350 Hz and 650 Hz	20 A rms at 350 Hz and 650 Hz
19.3.2	Magnetic fields induced into interconnecting cables	IxL=30 A-m from 350 to 650 Hz and reducing to 0.8 A-m at 26 kHz	IxL=18 A-m from 350 to 650 Hz	Not Applicable	IxL=120 A-m from 350 to 650 Hz reducing to 1.6 A-m at 26 kHz
19.3.3	Electric Fields induced into interconnecting cables	VxL=1800 V-m from 350 to 650 Hz	VxL=360 V-m from 350 to 650 Hz	Not Applicable	VxL=5400 V-m from 350 to 650 Hz reducing to 135 V-m at 26 kHz
19.3.4	Spikes induced into interconnecting cables	Figure 19-4 L=3.0 m	Figure 19-4 L=3.0 m	Figure 19-4 L=1.2 m	Figure 19-4 L=3.0 m

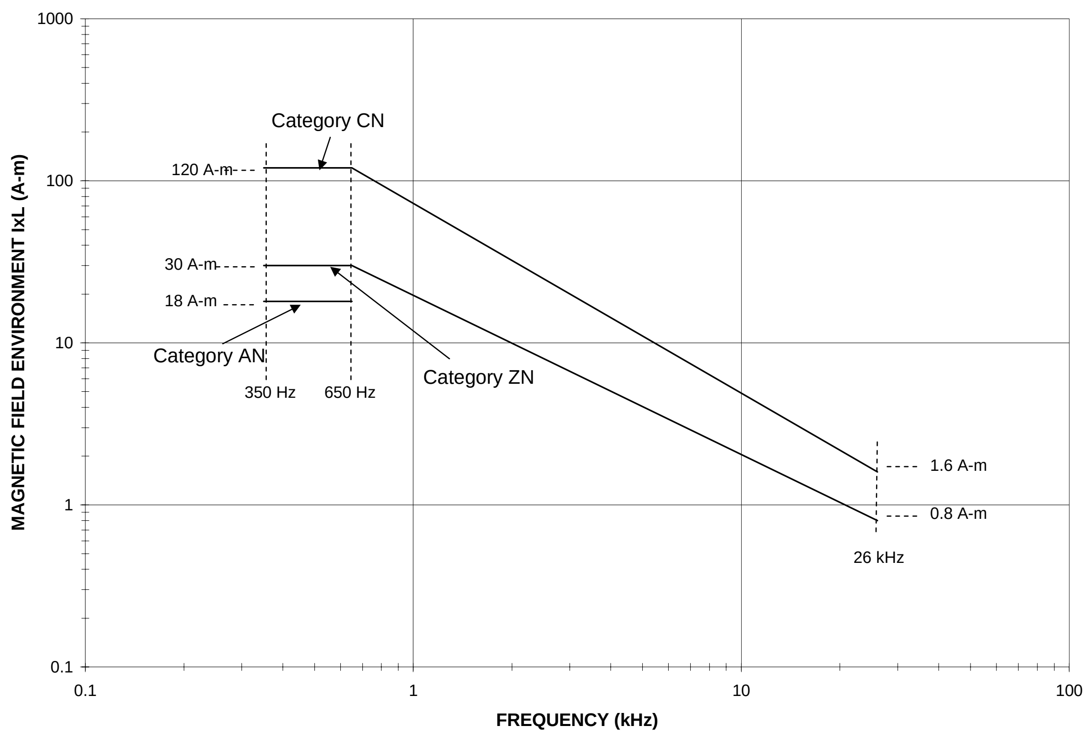
Table 19-1 **Applicability of Categories to Induced Signal Susceptibility (continued)**

Paragraph	**Test**	**Category ZW**	**Category AW**	**Category BW**	**Category CW**
19.3.1	Magnetic Fields induced into the equipment	20 A rms at 350 Hz and 800 Hz	20 A rms at 350 Hz and 800 Hz	20 A rms at 350 Hz and 800 Hz	20 A rms at 350 Hz and 800 Hz
19.3.2	Magnetic fields induced into interconnecting cables	IxL=30 A-m from 350 to 800 Hz and reducing to 0.8 A-m at 32 kHz	IxL=18 A-m from 350 to 800 Hz	Not Applicable	IxL=120 A-m from 350 to 800 Hz reducing to 1.6 A-m at 32 kHz
19.3.3	Electric Fields induced into interconnecting cables	VxL=1800 V-m from 350 to 800 Hz	VxL=360 V-m from 350 to 800 Hz	Not Applicable	VxL=5400 V-m from 350 to 800 Hz reducing to 135 V-m at 32 kHz
19.3.4	Spikes induced into interconnecting cables	Figure 19-4 L=3.0 m	Figure 19-4 L=3.0 m	Figure 19-4 L=1.2 m	Figure 19-4 L=3.0 m

Note: *When the manufacturer's installation and interface control drawings or diagrams specify a fixed length cable less than 3.3 m, the coupled length (L) of the field source wire shall be reduced to maintain the 0.15 m minimum separation distance at each end. The test level may be adjusted downward in proportion to the ratio of the reduced coupling length to the specified coupling length (L = 3.3 - (2 x 0.15) = 3 m). For example, if the manufacturer specifies a maximum cable length of 1.8 m, then L = 1.5 m. The adjusted level is then (1.5/3.0) = 0.5 times the voltage or current limits shown above. This test is not required when the manufacturer's installation and interface control drawings or diagrams specify a fixed length cable less than 1.5 m (L less than 1.2 m).*



<u>Figure 19-1(a)</u> Audio Frequency Magnetic Field Susceptibility Test Levels – Constant Frequency



<u>Figure 19-1(b)</u> Audio Frequency Magnetic Field Susceptibility Test Levels – Narrow Frequency

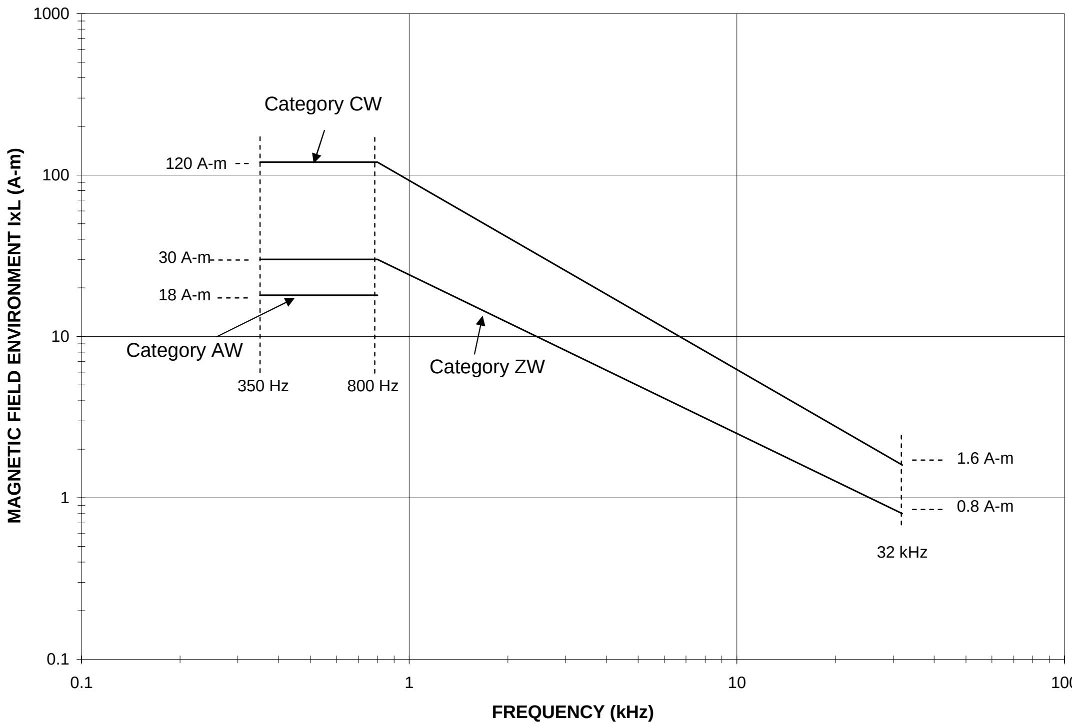
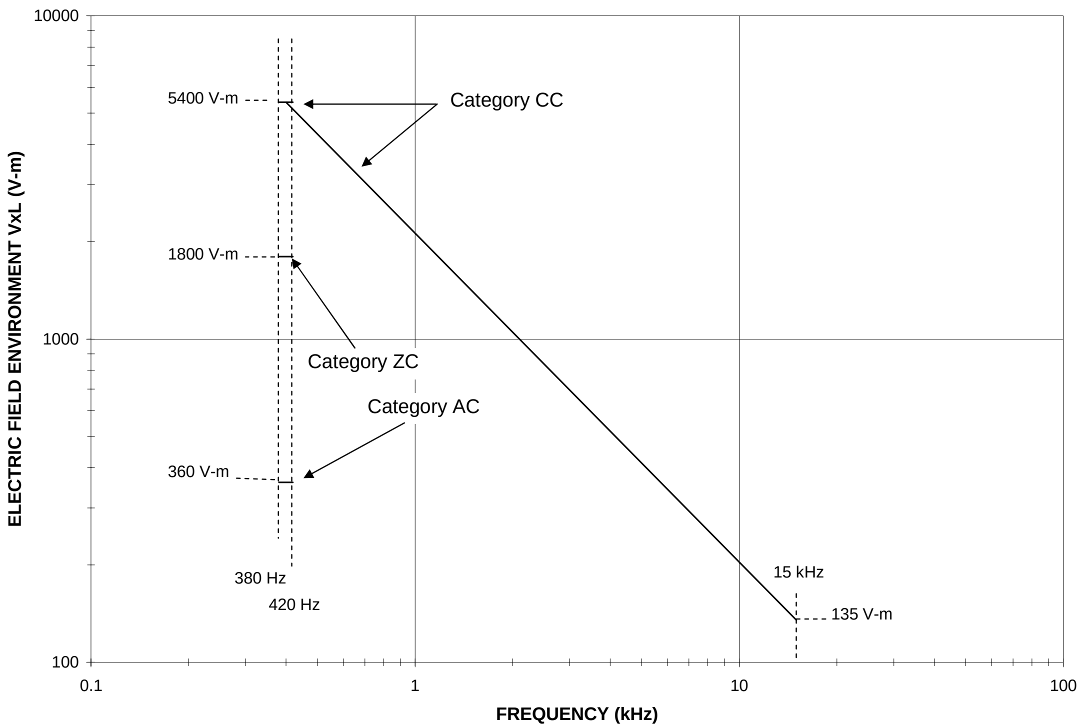
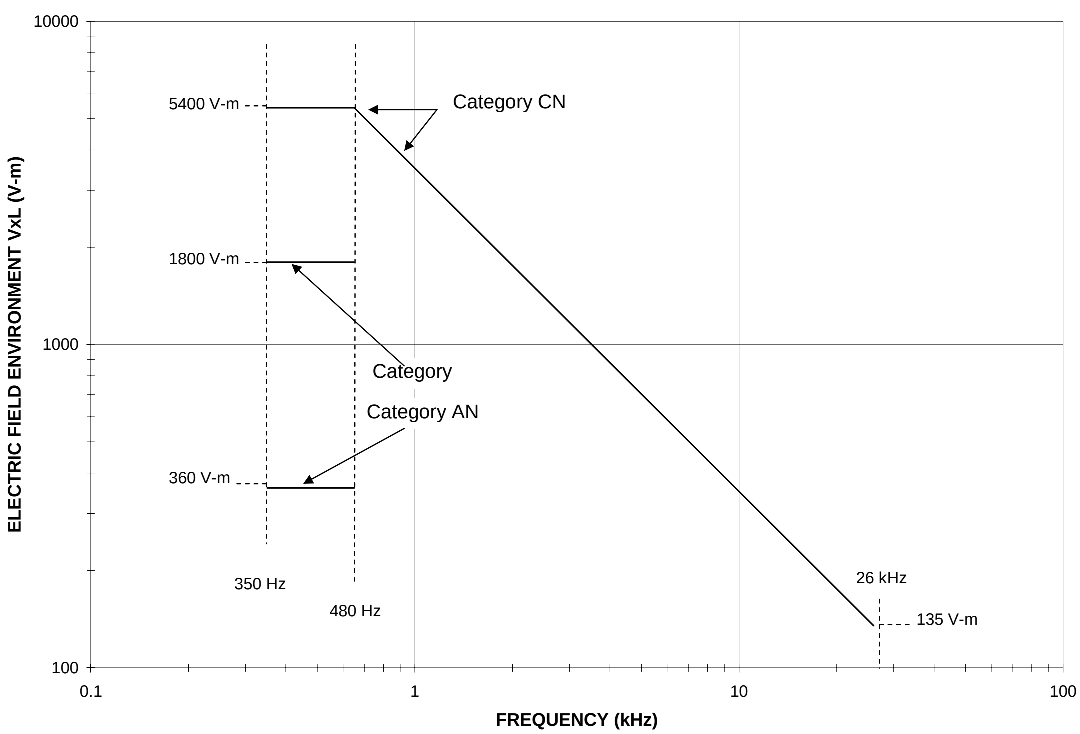


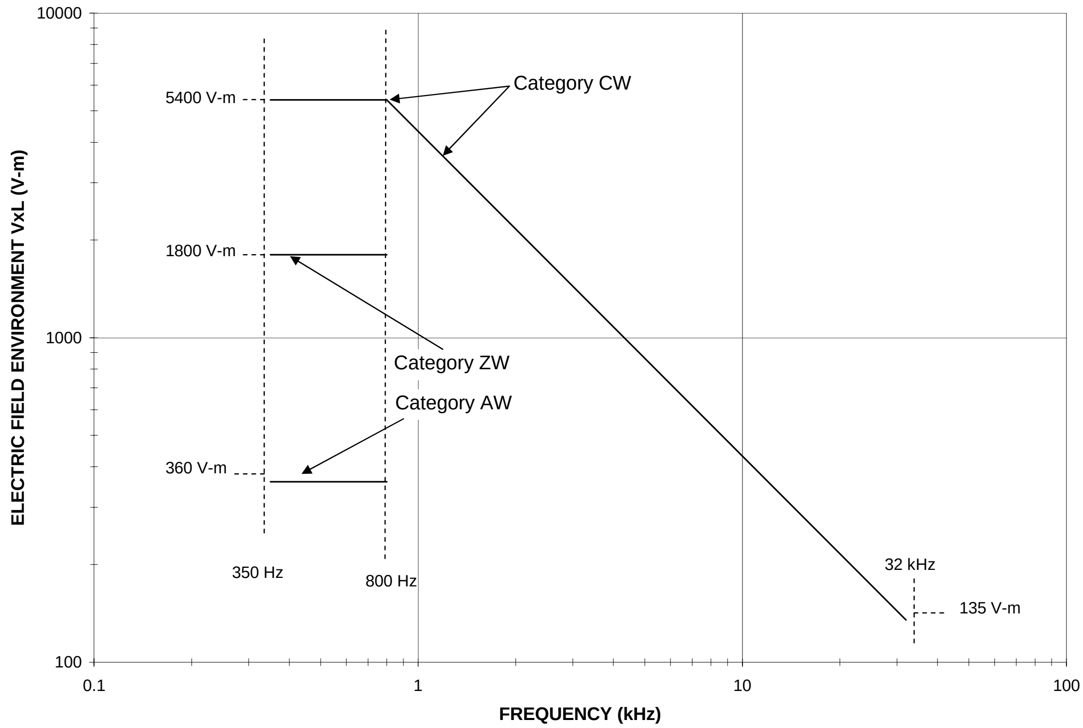
Figure 19-1(c) Audio Frequency Magnetic Field Susceptibility Test Levels – Wide Frequency



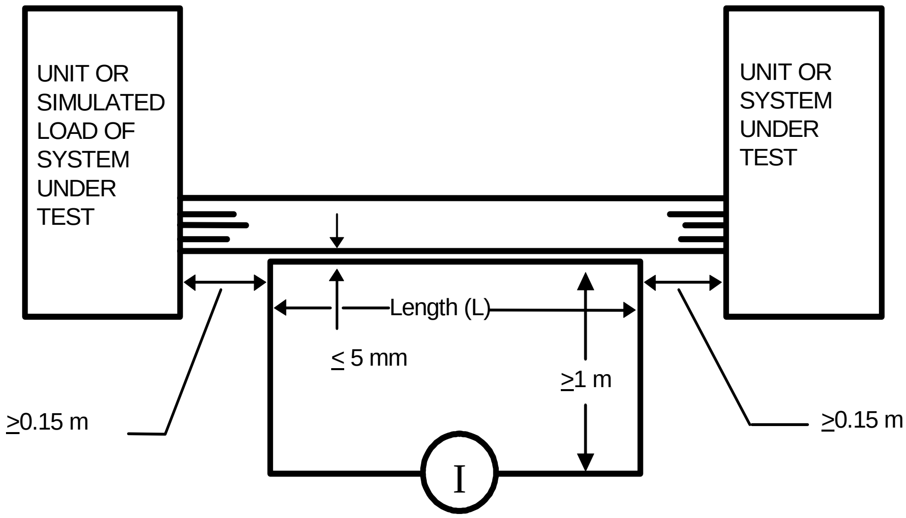
<u>Figure 19-1(d)</u> Audio Frequency Electric Field Susceptibility Test Levels – Constant Frequency



<u>Figure 19-1(e)</u> Audio Frequency Electric Field Susceptibility Test Levels – Narrow Frequency



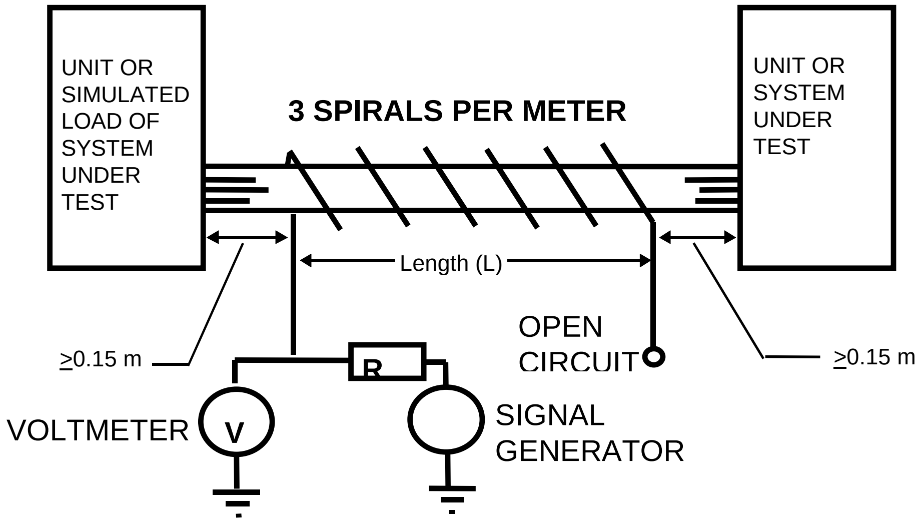
<u>Figure 19-1(f)</u> Audio Frequency Electric Field Susceptibility Test Levels – Wide Frequency



Note 1: The interconnecting wire bundle shall be spaced a minimum of 50 mm above the ground plane.

Note 2: Magnetic Field Environment = Current (I) x Length (L) (amperes rms x meters)

Figure 19-2 **Audio Frequency Magnetic Field Susceptibility Test Setup**

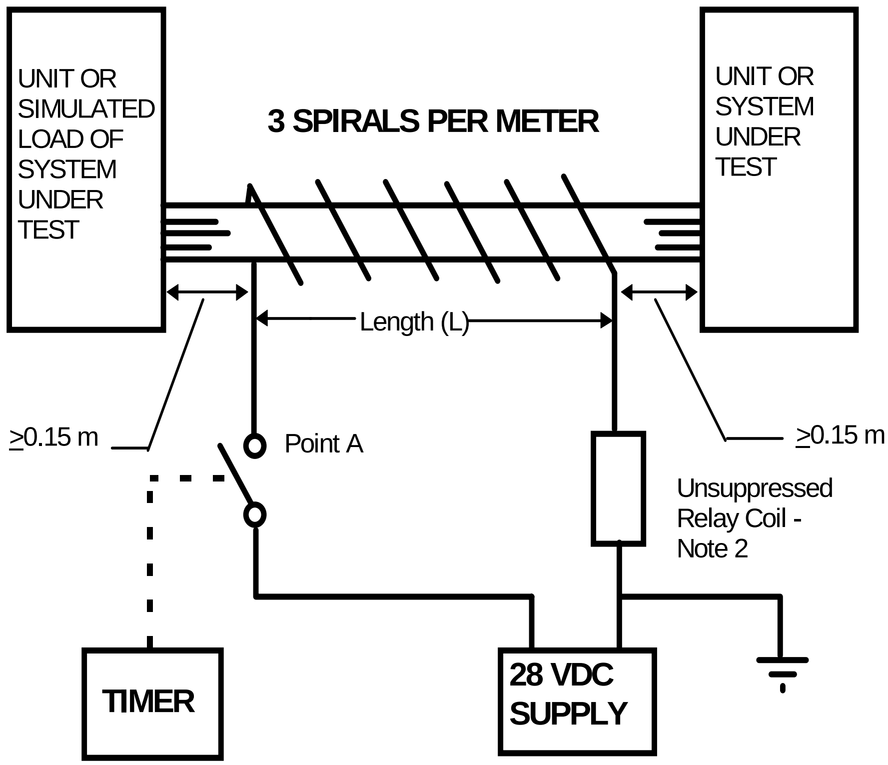


Note 1: The interconnecting wire bundle shall be spaced a minimum of 50 mm above the ground plane.

Note 2: Electric Field Environment = Voltage (V) x Length (L) (volts rms x meters)

Note 3: R sized for personnel high voltage protection

<u>Figure 19-3</u> Audio Frequency Electric Field Susceptibility Test Setup



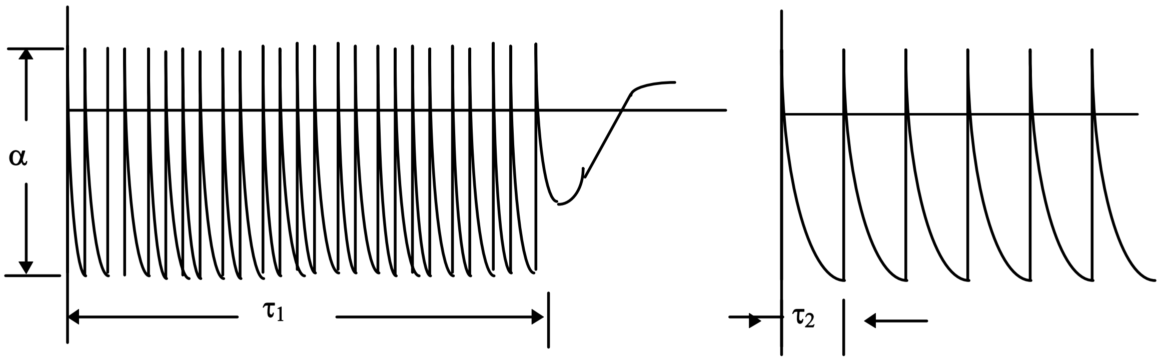
Note 1: The interconnecting wire bundle shall be spaced a minimum of 50 mm above the ground plane.

Note 2: The unsuppressed relay coil characteristics are as follows:

Voltage	=	28 volts dc
Current	=	160 mA
Resistance	=	175 ohms ± 10 %
Inductance	=	1.5 henries ± 10% in the energized position.

Note 3: 28 VDC supplied from ungrounded source with polarity reversing switch.

<u>Figure 19-4</u> Interconnecting Cable Spike Test Setup



α	Amplitude $\geq$ 600 v p-p
τ_1	Total Duration 50 to 1000 microseconds
τ_2	Repetition Period 0.2 to 10 microseconds

Note: Voltage waveforms measured between Point A of Figure 19-4 and the ground plane.

Figure 19-5 **Inductive Switching Transients**

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 20

Radio Frequency Susceptibility (Radiated and Conducted)

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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20.0 Radio Frequency Susceptibility (Radiated and Conducted)

20.1 Purpose of the Test

These tests determine whether equipment will operate within performance specifications when the equipment and its interconnecting wiring are exposed to a level of RF modulated power, either by a radiated RF field or by injection probe induction onto the power lines and interface circuit wiring.

Two test procedures are used: 1) From 10 kHz to 400 MHz, the equipment under test (EUT) is subjected to RF signals coupled by means of injection probes into its cable bundles, and 2) for frequencies between 100 MHz and the upper frequency limit, the EUT is subjected to radiated RF fields. There is an intentional overlap of the tests from 100 to 400 MHz.

Radiated susceptibility tests from 100 MHz to 18 GHz may be conducted using methods and materials as described within Section 20.5 or may be alternately conducted using methods and materials described within Section 20.6. The choice of methods is at the discretion of the applicant.

Equipment with special signal, frequency, modulation or bandpass characteristics may require test variations as specified by the applicable performance standards.

The result of these tests is to permit categories to be assigned defining the conducted and radiated RF test levels of the equipment. These tests are sufficient to obtain environmental qualification for radio frequency susceptibility of the equipment. Additional tests may be necessary to certify the installation of systems in an aircraft dependent on the functions performed.

20.2 Equipment Categories

Categories designate the RF test levels and establish the EUT minimum RF immunity level. The categories may be given in the applicable equipment performance standard.

The category to be applied to a system or equipment frequently must be chosen before the internal RF environment of the aircraft is known. Further, many systems or equipments are designed with the intent that they will be installed in several different types of aircraft. Therefore, if a category is not identified in the equipment specification, the equipment manufacturer should design, test and qualify the equipment to the category consistent with expected location, exposure and use.

Category designation for equipment consists of two characters. Conducted susceptibility test levels are designated with the first category character. Radiated susceptibility test levels are designated with the second category character.

To aid the equipment manufacturer in selecting appropriate test limits for the equipment and its interconnecting wiring, categories have been defined below. The descriptions are for guidance only. Equipment location, anticipated exposure/location of interconnecting wiring, and aircraft size and construction determine the test level.

Categories "A" through "L" are intended to provide test levels which directly relate to the high intensity radiated field (HIRF) external field environments as defined in the HIRF certification advisory documentation (AC/AMJ 20.1317). The category selection for the conducted susceptibility test is given in terms of expected aircraft type, dimensions, and the appropriate HIRF environments as shown in Table 20-1. The category selection for the radiated susceptibility test is given in terms of the expected level of aircraft attenuation at the equipment installation location and the appropriate HIRF environment as shown in Table 20-2.

Category “R” is intended to provide test levels for equipment when bench testing is allowed to meet the HIRF associated with the normal environment.

Category “S” is intended as a minimum test level where aircraft effects from the external electromagnetic environment are minor and where interference free operation on the aircraft is desirable but not required. This category may also be representative of the internal EMI environment from aircraft equipment.

Category “T” is intended to provide test levels for bench testing for compliance to lower RF susceptibility requirements. It is also specified in the HIRF rules. This category may also be representative of the internal EMI environment from aircraft equipment.

Categories “W” and “Y” are intended to provide test levels for bench testing to show compliance to interim HIRF rules.

Category "Q" is intended to indicate tests conducted at test limits or with modulations other than those specified in these procedures.

20.3 General Test Requirements

a. Equipment Under Test

The EUT shall be set up on a ground plane (test bench) and configured in accordance with the following criteria:

(1) Ground Plane – A copper, brass or aluminum ground plane, at least 0.25 mm thick for copper and aluminum, 0.5 mm thick for brass, 2.5 m^2 or more in area with a minimum depth (front to back) of 0.75 m shall be used. When a shielded enclosure is employed, the ground plane shall be bonded to the shielded enclosure at intervals no greater than one meter and at both ends of the ground plane. It is recommended that the DC bonding resistance should be 2.5 milliohms or less.

(2) Shock and Vibration Isolators – If specified by the equipment manufacturer, the EUT shall be secured to mounting bases incorporating shock or vibration

isolators. The bonding straps furnished with the mounting bases shall be connected to the ground plane. Bonding straps shall not be used in the test setup, when they are not incorporated in the mounting bases.

(3) Electrical Bonding – Only the provisions included in the EUT design or installation instructions, e.g., bonding of enclosure, mounting base and ground plane, shall be used for bonding.

The electrical bonding of equipment, connectors, and wire bundles shall be representative of aircraft installations as specified by the applicable installation and interface control drawings or diagrams. The test report shall describe the bonding methods employed.

(4) External Ground Terminal – When an external terminal is available for a ground connection on the EUT, the terminal shall be connected to the ground plane to ensure safe operating conditions during the test. The length of the connection defined in the installation instructions shall be used; if a length is not defined, use approximately 30 cm of a representative type of wire.

(5) Interconnecting Wiring/Cables – All EUT interconnecting wiring (e.g., shielded wires, twisted wires, etc.), cable bundles and RF transmission lines shall be in accordance with the applicable installation and interface control drawings or diagrams.

Cables shall be bundled in a manner similar to that of aircraft installations and the lowest point of the cable bundle supported at a minimum height of 50 mm above the ground plane unless greater heights have been specified as more representative of the aircraft installation (and recorded in the test report). The supporting material must be non-absorptive, non-conductive, and non-reflective. For complex cable bundle configurations, all cable bundles and interconnected loads should be kept separated from each other as much as practical to minimize coupling effects between cables.

Unless otherwise specified, cable lengths shall be at least 3.3 m. When the length of an interconnecting cable bundle is greater than the test bench, the cable bundle should be arranged with the excess length zigzagged at the back of the test bench approximately 50 mm above the ground plane. At least one meter of cable from the EUT must be 10 cm from the front of the test bench and parallel to the front of the test bench as shown in Figure 20-2 and Figure 20-9. For complex cable bundles, the edge of the first separated bundle shall be 10 cm from the edge. The cable bends at the EUT shall not extend past the edge of the ground plane. The EUT may be moved away from the edge to accommodate the minimum cable bend radius. Antenna spacing to EUT shall be maintained as shown in Figure 20-2.

Some special installations may require very long cable bundle lengths which cannot be accommodated on the test bench. Therefore, the recommended maximum length of the interconnecting cable bundles for these tests is 15 m. The exception to this limitation is where cable bundle lengths are matched or specified to a particular length for phase match or similar reasons.

Any inputs or outputs from, or to, other equipment or loads associated with the EUT shall be provided by an actual in-service type of device or shall be simulated taking into account the line-to-line and line-to-ground frequency dependent impedances.

(6) Power Leads – For cable bundle tests, power and return leads normally bundled with the control/signal leads shall remain in the cable bundle and only be separated from the bundle as close as possible to the cable bundle exiting the test area. These leads shall then be connected to Line Impedance Stabilization Networks (LISNs).

When the actual aircraft cable bundle configuration is unknown or when power and/or return leads are normally routed separately from the control/signal leads, the power and return leads should be broken out of the cable bundle near the connector of the EUT and run separately to the LISNs. Under these conditions, the length of the leads to the LISNs shall not exceed 1.0 m unless otherwise specified in the applicable equipment specification.

When the return lead is a local ground (less than 1 meter length), this lead may be grounded directly to the test bench, in accordance with the applicable installation and interface control drawings or diagrams.

(7) Dummy Antennas or Loads – For the purpose of this test, antenna cables may be terminated in a load equal to the cable characteristic impedance, or a dummy antenna. The dummy antenna, if used, shall be shielded and be designed to have electrical characteristics closely simulating the in-service antenna. It shall also contain electrical components normally used in the antenna, such as filters, crystal diodes, synchros and motors.

b. Shielded Enclosure and Test Equipment

Enclosures, test equipment and instruments shall be set up and operated in accordance with the following criteria:

(1) Bonding Test Equipment – Test equipment shall be bonded and grounded to minimize ground loops and ensure personnel safety.

(2) Line Impedance Stabilization Network (LISN) – An LISN shall be inserted in each EUT primary power line. Power return lines locally grounded in the aircraft installation do not require an LISN. The LISN case shall be bonded

to the ground plane. When LISNs with self resonances above 10 kHz are used (such as standard 5 µH LISNs), a 10 microfarad capacitor shall be inserted between each LISN power input terminal and the ground plane for the entire test. The RF measurement port of the LISN shall be terminated into 50 ohms for all tests. The input impedance characteristic is shown in Figure 20-1.

(3) Antenna Orientation and Positioning in Shielded Enclosures – Dipole, biconical or horn antennas shall be centered 0.3 m above the level of the ground plane and parallel to the ground plane as shown in Figure 20-2. If the transmitting antenna being used is a pyramidal horn, such as a standard gain horn or similar type radiator, as the dimensions of the antenna become small and the frequency of interest becomes higher, it is permissible to move the antenna closer to the EUT than the one meter shown in Figure 20-2. This can only be done when the far field boundary of the antenna is within this one meter distance. The position of the transmit antenna relative to the EUT must remain equal to or greater than the far field boundary of the transmitting horn antenna. If the far field boundary of the antenna extends beyond one meter then the standard one meter separation should be used.

If the transmit antenna far field boundary is less than or equal to one meter it is also allowable to move the antenna farther than one meter from the EUT. The appropriate field strength at the EUT must be maintained. Moving the transmit antenna farther away will increase the illuminated area, decreasing the number of antenna placements required for large EUT configurations.

Note: The far field boundary of the antenna is calculated by the following equation:

$$x = \frac{2 * D^2}{\lambda}$$

where x = *far field boundary distance in meters*
D = *largest dimension of the transmitting aperture in meters, and*
λ = *wavelength of the frequency of interest in meters.*

Note: For typical standard gain horns, far-field boundaries less than one meter from the antenna exist only for frequencies above approximately 8 GHz.

When the beam width of the antenna does not totally cover the system under test, multiple area scans shall be performed. However, it is required that each EUT within the system and at least one-half wavelength of wiring of that EUT shall be exposed in its entirety during the test. In shielded enclosure tests, the antenna shall be at least 0.3 m away from the shielded enclosure wall or absorber. Alternate antennas may be used provided the required field strengths are obtained.

Note: The above does not apply if the alternate radiated susceptibility test procedure of Section 20.6 is used.

(4) Injection Probes – Probes shall have the necessary power and range capabilities. Injection probe insertion loss limits are shown in Figure 20-3. A suggested test setup for measuring the injection probe insertion loss is shown in Figure 20-4. Support and center the probe in the fixture.

(5) Shielded Enclosure – Shield room effects on equipment and test setup shall be minimized to the greatest extent possible. RF absorber material shall be used during radiated testing inside a shielded enclosure to reduce reflections of electromagnetic energy and to improve accuracy and repeatability. As a minimum, the RF absorber shall be placed above, behind, and on both sides of the EUT, and behind the radiating antenna as shown in Figure 20-2. Minimum performance of the material shall be as specified in Table 20-3. The manufacturer's specification of their RF absorber material (basic material only, not installed) is acceptable.

Note: The above is not applicable if the alternate radiated susceptibility test procedure of Section 20.6 is used.

Fiber-optic interfaces may be provided for test equipment and sensors to help give susceptibility-free monitoring. The design and protection of test aids, monitors and load stimulation units should ensure appropriate simulation, isolation and immunity of test equipment interface circuits to RF currents.

(6) Amplifier System Harmonics - Distortion of sinusoidal susceptibility signals caused by non-linear effects in power amplifiers can lead to erroneous interpretation of results. When distortion is present, the EUT may actually respond to a harmonic of the intended susceptibility frequency, where the required limit may be lower. When frequency selective receivers are used to monitor the injected level, distortion itself does not prevent a valid susceptibility signal level from being verified at the intended frequency. However, harmonic levels should be checked when susceptibility is present to determine if they are influencing the results. When broadband sensors are being used, distortion can result in the sensor incorrectly displaying the required signal level at the intended frequency. In this case, distortion needs to be controlled such that correct levels are measured.

c. Amplitude Measurement

The amplitudes associated with the categories are based on the peak of the rms envelope over the complete modulation period as shown in Figure 20-5. Amplitude measurements shall be made in a manner which clearly establishes the peak amplitude of the modulated waveform. This instrument must have a fast enough time response to respond to signal amplitude variations, particularly for Section 20.6. A spectrum analyzer may be used. The detection, resolution, and video bandwidths of the measuring instrument must be greater than the modulating frequency. The measurement bandwidth shall be increased until the amplitude of the measured signal does not change by more than 1 dB for a factor of three change in bandwidth. This bandwidth setting shall then be used for the test. At the proper setting, the individual modulation sidebands will not be resolved. For the Conducted Susceptibility test of paragraph 20.4, an oscilloscope may be used as the amplitude measuring device. The oscilloscope must have an analog bandwidth compatible with the upper frequency limit of the test and must have the appropriate 50 ohm terminations

d. Test Frequency Exclusions

RF receiving equipment may show sensitivity to in-band receive frequencies during susceptibility testing. This sensitivity is normal for devices that are required to be sensitive according to the receiver MOPS. This sensitivity is therefore normal and such frequencies may need to be excluded or levels at these frequencies reduced during testing.

Unless otherwise specified by the applicable receiver minimum performance standard, the following exclusion band shall apply for radio receivers. The band of frequencies from ten percent below the lowest operating frequency in the band to ten percent above the highest operating frequency shall be tested to Category S levels. Required receiver performance shall be stated in the test procedure and report, or in the specific receiver performance standard. The frequencies from one percent below the radio receiver tuned frequency through one percent above the tuned frequency shall be tested to Category S for damage assessment only.

This test is not intended to evaluate the normal MOPS RF performance characteristics of the receivers, nor is the test intended to evaluate receiver performance in the presence of any interfering signal induced or coupled into the receiver's RF input port(s). Other responses due to power line and/or control/signal line coupling, or direct coupling through the receiver's enclosure shall be evaluated and pass/fail criteria determined based on the specific receiver specifications or performance requirements.

e. Frequency Scan Rates

Sweep or step rates shall be selected with consideration of equipment under test (EUT) response time, EUT susceptibility bandwidths, and monitoring test equipment response time. The scan rate selected shall be justified by this criteria, and documented in the test report.

For test equipment that generate discrete frequencies, the minimum number of test frequencies shall be 100 frequencies per decade above 100 kHz, and 10 frequencies per decade below 100 kHz. The test frequencies shall be logarithmically spaced. As an example (above 100 kHz), a formula which can be used to calculate these frequencies in ascending order is:

$$f_{n+1} = f_n * 10^{(1/99)}$$

where f_n is a test frequency and n = 1 to 100,
f_1 is the start frequency, and
f_{100} is the end frequency.

The dwell time at each test frequency shall be at least one second, exclusive of test equipment settling time. Additional dwell time at each test frequency may be necessary to allow the EUT to be exercised in appropriate operating modes and to allow for the “off time” during low frequency modulation. At least two full cycles of modulation must be applied. For example, if the applied modulation is a 1 Hz square wave modulation (SW), the dwell time shall not be less than two seconds. The dwell time selected shall be justified based on EUT and test equipment response time, as well as applied modulation, and documented in the test report.

For test equipment that generate a continuous frequency sweep, the minimum (fastest) sweep rate shall be equal to the number of discrete frequencies per decade multiplied by the dwell time, i.e., 100 discrete frequencies per decade times 1 second dwell time equals 100 seconds per decade sweep rate. The fastest sweep rate shall be used only when the EUT and associated test equipment are capable of fully responding to the test stimulus. Typically, slower rates are required, as described above.

Note: *Additional test frequencies should be included for known equipment response frequencies, such as image frequencies (nLO±IF; where n is an integer, LO is the local oscillator frequency, and IF is the intermediate frequency), IFs, clock frequencies, etc.*

20.4 Conducted Susceptibility (CS) Test

a. Applicability/Intent

Subject the EUT and interconnecting cables or circuits to the appropriate category of Table 20-1 and/or Figure 20-6, while monitoring the induced cable bundle current. All cable bundles and appropriate branches that connect the EUT to other equipment or interfacing units in the aircraft system are subject to this test.

Two different procedures are required for Categories A through L and Categories R, S, T, W, and Y. The latter categories are from the original version of DO-160D and are tested using the same procedure and limits. In this case the primary limit is in terms of the forward power to the injection probe to give a defined current in the calibration jig with a secondary limit in terms of induced current. The former categories are intended for testing to the new HIRF requirements for equipment performing certain critical display functions. In this case the primary limit is in terms of induced current on the wiring bundle under test with the secondary limit being in terms of the forward power to the injection probe. The reason for the change is that Categories A through L are based on aircraft induced cable bundle current measurements.

Interconnecting wiring can be tested as a whole or as individual wires. Simultaneous injection with separate probes on several bundles may be used, and may be required for equipment with built-in redundancy. Power return leads or ground leads that are grounded directly to the test bench, as required in Section 20.3.a.(6), shall not be included in the bundle under test and are not required to be tested.

b. Probe Calibration

Set up the signal generator, power amplifier, directional coupler, attenuator, amplitude measurement instruments, and install the injection probe in the calibration fixture per Figure 20-7. Support and center the probe in the fixture. Set the signal generator to 10 kHz, unmodulated. Increase the amplifier power fed through the directional coupler to the injection probe at 10 kHz until the current or power measured on amplitude measurement instrument #1 indicates the resulting current or power into the calibration fixture for the selected category of Table 20-1 and/or Figure 20-6.

CAUTION: RF fields due to re-radiation from the calibration jig may be hazardous. Observe appropriate RF exposure limits.

Record the signal generator/power amplifier forward power to the injection probe on amplitude measurement instrument #2.

Scan the frequency band (unmodulated) while recording forward power on amplitude measurement instrument #2 and maintaining power amplitudes on amplitude measurement instrument #1 per Table 20-4 and/or Figure 20-6 from 10 kHz to 400 MHz for the proper probe. The forward power plot will be used to either establish or limit the test level for the conducted susceptibility test, depending on the category tested.

The VSWR of the attenuators and loads shall be less than 1.2:1. The calibration jig VSWR without the probe installed shall not exceed the values of Figure 20-8.

c. CS Test Setup

Set up the EUT, wiring, associated interface circuitry, and test equipment per Figure 20-9. For test setups with shielded cables which include in-line connectors (e.g. aircraft installation stanchion or bulkhead disconnects), the in-line shield terminations must be lifted from ground to allow the CS current to flow on the shield for a minimum distance of 3m. Install the induced current monitor probe five centimeters from the EUT. If the EUT connector plus backshell length exceeds five centimeters, the probe shall be placed as close to the connector backshell as possible and the position noted. Support and center the probe. Install the injection probe five centimeters from the face of the monitor probe.

d. CS Test Procedure

Establish proper probe locations, software installation, modes of operation and stability of the EUT, test equipment and all monitoring circuits and loads.

CAUTION: RF fields due to re-radiation from the cable bundle under test can be hazardous. Observe appropriate RF exposure limits.

Set the signal generator to 10 kHz. Apply forward power to the injection probe to achieve the current or forward power for the selected category of Table 20-1, Table 20-4, and/or Figure 20-6. Monitor the induced cable bundle current with the amplitude measurement instrument and data recorder.

For Categories A-L:

Adjust and control the forward power to achieve the induced current on the cable bundle for the selected category level. When necessary, limit the forward power to not more than 6 dB above the calibration value determined during the probe calibration procedure in Section 20.4.b. Scan the frequency range at the proper current and forward power limit. Record the induced current in the test report.

For Categories R, S, T, W, and Y:

Establish the forward power to the injection probe at the power level determined during the probe calibration procedure in Section 20.4.b. When necessary, adjust and control the forward power to limit the induced current on the bundle to the following values:

CAT Y	1 A
CAT W	500 mA
CAT R	100 mA
CAT T	25 mA
CAT S	5 mA

Scan the frequency range at the proper forward power and bundle current limit. Record the induced current in the test report.

Dwell at internal modulation, data, clock frequencies, and other critical frequencies as required. When modulation is applied, ensure that the peak amplitude complies with the definitions of Section 20.3.c and Figure 20-5.

While scanning, evaluate EUT operation and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

e. CS Modulations

Apply both CW and square wave modulation. Modulate the RF carrier with a 1 kHz square wave at greater than 90 percent depth.

Also consider applying other modulations associated with the EUT, such as clock, data, IF, internal processing or modulation frequencies. Especially consider any possible low frequency response characteristic of the EUT, for example, a flight control equipment's response to 1 Hz modulation in the 2 to 30 MHz HF range. As an option, tests can be run using only the modulation to which the EUT is most susceptible.

20.5 Radiated Susceptibility (RS) Test

a. Applicability/Intent

Subject the EUT and interconnecting cables to the appropriate category of RF fields for Table 20-2 and Figure 20-10.

b. Radiated Field Calibration

Perform a field calibration in the test chamber prior to placement of the EUT within that test chamber, to establish the correct field strength for the category selected.

CAUTION: RF fields can be hazardous. Observe appropriate RF exposure limits.

Perform the reference CW field calibration using a three-axis omnidirectional electric field antenna (isotropic probe) or equivalent with appropriate frequency response. The isotropic probe should be centered at approximately the same location as the placement of the EUT on the groundplane, 30 cm above the groundplane. Alternatively, the probe may be placed in a different position within the shielded enclosure with the probe 30 cm above a similar ground plane, and with a similar absorber configuration. Radiate the isotropic probe, unmodulated, at the desired test frequency. Adjust the forward power to the transmit antenna to achieve the total field strength indication from the isotropic probe for the category selected. Total field strength is defined as the root sum squared (RSS) of the magnitude of the rectangular components. Record the forward power and use this power setting during the EUT radiated field test. Repeat this calibration over the required frequency range.

The forward power necessary to produce the desired category field strength at the isotropic probe with a CW signal becomes the reference forward power. Square wave (SW) and pulse modulated (PM) signals should be developed in a manner which produces the same forward power into the transmitting antenna as the calibration level. (Note that all levels are "peak rms" as defined in Section 20.3.c and Figure 20-5). Appropriate scale factors may be used if the reference CW calibration was performed at a different level than the desired square wave or pulse category field strength.

Forward power to the transmit antenna shall be monitored and recorded using an amplitude measurement instrument that meets the requirements in Section 20.3.c.

Both horizontal and vertical polarization field exposures are required. Circularly polarized transmit antennas are not permitted.

c. RS Test Set-up

Set up the EUT, wiring, associated interface circuitry and test equipment per Figure 20-2.

Signal generators, amplifiers, antennas and probes shall maintain required RF field levels to properly illuminate the EUT and interconnecting wiring. Position and aim antennas to establish the RF field strengths at the EUT and interconnecting wiring. Define the 3 dB points of the radiated field using antenna beamwidth specifications, or by mapping the area in which the EUT is to be placed. The beamwidths of the antennas used in the test should be stated in the test report. When the 3 dB beamwidth of the antenna does not totally cover the EUT and wiring, perform multiple area scans. Directly expose apertures in the EUT (e.g., displays, CRTs, connectors) to the transmitting antenna, which may require additional LRU orientations. Vertical and horizontal transmit antenna orientations are required.

d. RS Test Procedure

Establish appropriate antenna and isotropic probe locations, software installation, modes of operation and stability of the EUT, test equipment and all monitoring circuits and loads. The isotropic probe is used as verification that the transmit path is functioning correctly. The applied field strength is derived from the forward power calibration of Section 20.5.b.

CAUTION: RF fields can be hazardous. Observe appropriate RF exposure limits.

Use the forward power settings determined from the radiated field calibration. When modulation is applied, ensure that the peak amplitude complies with the definitions of Section 20.3.c and Figure 20-5.

Scan the frequency range to the upper frequency limit using appropriate modulations. Dwell at internal modulation, data and clock frequencies, as required.
While scanning, evaluate the EUT operation and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

e. RS Modulations

For category R use the following levels and modulations:

From 100 MHz to 400 MHz, use 20 V/m CW. Also use 20 V/m with 1 kHz square wave modulation with at least 90% depth.

From 400 MHz to 8 GHz, use 150 V/m pulse modulated (PM) at 0.1% duty cycle and 1 kHz pulse repetition frequency. Switch the signal on and off at a 1 Hz rate and 50% duty cycle to simulate the effect of rotational radars. In addition, to meet the average requirements, use 28 V/m with 1 kHz square wave modulation with at least 90% depth. This signal should also be switched on and off at a rate of 1 Hz and 50% duty cycle.

As an alternative to the two category R modulations (from 400 MHz to 8 GHz) described above, use 150 V/m pulse modulated at 4% duty cycle and 1 kHz pulse repetition frequency. Switch the signal on and off at a 1 Hz rate and 50% duty cycle to simulate the effect of rotational radars.

For categories S, T, W and Y, use the following modulations:

From 100 MHz to the upper frequency limit in Figure 20-10, use CW as well as 1 kHz square wave modulation with at least 90% depth. Also consider using additional modulations associated with the EUT such as clock, data, IF, internal processing, or modulation frequencies.

For categories A through G use the following modulations:

When testing to the appropriate SW/CW levels from Table 20-5, use CW and a 1 kHz square wave modulation with at least 90% depth from 100 MHz to 18 GHz. Also consider using additional modulations associated with the EUT such as clock, data, IF, internal processing or modulation frequencies.

From 400 MHz to 4 GHz, use the appropriate pulse modulated (PM) test level with a 4 μs pulse width (or greater) and 1 kHz pulse repetition frequency. From 4 GHz to 18 GHz, use the appropriate pulse modulated (PM) test level with a 1 μs pulse width (or greater) and 1 kHz pulse repetition frequency. Especially consider switching the signal on and off at a 1 Hz rate and 50% duty cycle for an EUT which may have a low frequency response (e.g. flight control equipment).

For categories H through L use the following modulations:

When testing to the appropriate SW/CW levels from Table 20-5, use CW and a 1 kHz square wave modulation with at least 90% depth from 100 MHz to 18 GHz. Also consider using additional modulations associated with the EUT such as clock, data, IF, internal processing or modulation frequencies.

From 400 MHz to 1 GHz, use the appropriate pulse modulated (PM) test level with a 4 μs pulse width (or greater) and 1 kHz pulse repetition frequency. From 1 GHz to 18 GHz, use the appropriate pulse modulated (PM) test level with a 1 μs pulse width (or greater) and 1 kHz pulse repetition frequency. Especially consider switching the signal on and off at a 1 Hz rate and 50% duty cycle for an EUT which may have a low frequency response (e.g. flight control equipment).

20.6 Radiated Susceptibility (RS) Test; Alternate Procedure – Reverberation Chamber

20.6.1 Applicability/Intent

Subject the EUT and interconnecting cables to the appropriate category of RF fields for Tables 20-2 and 20-5 and/or Figure 20-10.

20.6.2 Procedure Overview

This procedure defines an alternative radiated susceptibility test using a Reverberation Chamber. In a reverberation chamber test the field at the EUT is varied in polarization and illumination angle by the rotation of a metal tuner in fixed steps. For each step of the tuner, the tuner is paused for the required dwell time and the RF field applied. The number of steps of the tuner required for the test is a trade off:

- The more steps, the higher the achieved field strength for a given input power but the longer the test time.
- The less steps the shorter the test time.

However enough steps have to be made to meet the field uniformity requirements of Section 20.6.3.

The procedure consists of the following basic steps:

Prior to the fitting of the test bench and/or EUT:

a) A performance based field uniformity calibration technique shall be performed to demonstrate adequate reverberation chamber performance following initial construction or after major modification to the reverberation chamber. The chamber calibration technique is carried out to demonstrate the chamber meets the field uniformity requirements as defined in this procedure. In addition, it is important to determine the lowest useable frequency (LUF) of the reverberation chamber employed. The described chamber field uniformity calibration is to be carried out over a test/working volume, which includes the location of the conductive test bench within the reverberation chamber. The chamber calibration addresses only mode tuned (stepped tuner rotation) operation of the reverberation chamber: mode stirred (continuous tuner rotation) operation is not allowed. The field uniformity measurement should be carried out with the conductive test bench removed from the reverberation chamber. The test is to be carried out at 9 locations for 3 individual axes (x,y,z) at each test location, i.e. 27 measurement points in total (Section 20.6.3.1). The field within the chamber is considered uniform if the standard deviation is within 3dB above 400 MHz, and sloping linearly (on a semi-log plot) from 6 to 3 dB from 100 MHz to 400 MHz.

b) A calibration technique for linear/passive field monitoring antennas used during Equipment Under Test (EUT) testing. The linear/passive field monitoring antennas are to be calibrated against a three axis E-field sensor (calibrated in free space). The purpose of this aspect of the test is to allow continuous monitoring of the field during the test with an antenna and associated monitoring equipment with a fast response time. Again this test is performed with the test bench removed and conducted at the same time as the field uniformity test described above in section a) (Section 20.6.3.2).

c) A method of checking the impact of field uniformity and chamber loading following initial construction or after major modification to the reverberation chamber. This test is performed to determine the maximum acceptable loading of the chamber for future testing (Section 20.6.3.4).

Prior to the start of the test with the test bench and EUT installed in the chamber:

d) A "quick check" chamber performance measurement made when the equipment to be tested and test bench are installed in the chamber. The purpose of this test is to confirm the loading of the chamber is less than that simulated during the initial chamber calibration (c) (Section 20.6.4.2).

e) A method to measure the minimum pulse width that can be sustained in the room for pulse modulation testing (Section 20.6.4.3). If the chamber time constant is greater than 0.4 times the required pulse width for more than 10% of the test frequencies, absorber must be added or the pulse width increased (not to exceed 100 μs).

The EUT test:

f) The test procedure itself utilizes mode tuned procedures (Section 20.6.4.4). Mode stirred testing is not allowed.

g) There are two options to compute the input power required to derive E_{Test}.

   i) Input Power Computed Using E-field Probe Measurements (20.6.4.4.1)

   The maximum total vector field strength, E_{Total}, and the normalized E-field, $\left\langle \vec{E} \right\rangle_{27}$ (20.6.3.1.v), are required to compute input power using E-field probe measurements.

   ii) Input Power Computed Using Receive Antenna Calibration Measurements (20.6.4.4.2)

   Determination of normalized average squared magnitude of E-field, $|E_T|^2_{max}$ (20.6.3.3) is required to compute input power using receive antenna calibration measurements.

Some of the field probes available suffer pick up problems on the leads from the probe head to the processor unit at frequencies <400MHz. If this is the case for a particular test facility then method ii must be used. However correlation between the two methods is required at those frequencies where the probe is reliable; normally >400MHz. These checks should be carried out at every 10^{th} test frequency.

20.6.3 Calibration: Chamber Field Uniformity and Loading Validation

As an initial guide to chamber performance and input power requirements, perform a "one-time" empty chamber calibration (no EUT) using the procedures of 20.6.3.1. It is suggested the empty chamber calibration be carried out on an annual basis or after major modification to the reverberation chamber.

For normal operation the lowest test frequency (f_s) is 100 MHz, and field uniformity is demonstrated over the first decade of operation. If a start frequency other than 100 MHz is chosen, for example a small chamber used to generate high field strengths, the chamber field uniformity must still be verified over the first decade of operation. The frequency at which a chamber can be used to conduct measurements is the frequency at which the chamber meets the field uniformity requirements in Figure 20-11.

20.6.3.1 Field Uniformity Validation

i. Clear the working volume (i.e. remove test bench) and place the receive antenna at a location within the working volume of the chamber as outlined in the notes of Figure 20-12. Set the amplitude measurement instrument to monitor the receive antenna on the correct frequency.

ii. Place the E-field probe at a location on the perimeter of the chamber working volume as shown in Figure 20-12.

iii. Beginning at the lowest test frequency (f_s), adjust the RF source to inject an appropriate input power, P_{Input}, into the transmit antenna. The transmit antenna shall not directly illuminate the working volume or the receive antennas and probes. Directing the source antenna into one corner of the chamber is an optimum configuration. The frequency shall be in band for both the transmit and receive antennas which shall be linearly polarized antennas.

iv. Step the tuner through 360° in discrete steps (mode-tuned operation) and at each step care must be taken to ensure that the dwell time is sufficiently long enough that the amplitude measurement instrumentation and E-field probes have time to respond properly. It is recommended that for this part of the procedure a large number of steps of the tuner are used. This allows the field uniformity to be determined for fewer tuner positions from that one measurement. This enables the appropriate number of tuner positions to be chosen for the test depending on whether the highest field possible is required (more positions) or a faster test time is required (less positions). For example if one undertook the field uniformity measurement at 180 steps then the field uniformity could be determined for 180 steps, 90 steps, 60 steps, 45 steps, 30 steps, 15 steps etc. Each step must be an equal angular movement. The limitation on the minimum number of paddle positions is that the field uniformity requirements must still be met. The limit on the maximum number of positions is that each step should vary the field pattern in the chamber enough to be statistically significant eg an independent sample.

v. Record the maximum amplitude and average amplitude (linear average: i.e., watts, not dBm) of the receive signal (P_{MaxRec}, P_{AveRec}), the maximum field strength ($E_{Max\ x,y,z}$) for each axis of the E-field probe, the maximum total vectorial field strength (E_{Total}), and the average value of the input power (P_{Input}) over the tuner rotation.

Note: *The value for input power, P_{Input}, is the forward power averaged over the tuner rotation and the maximum total E-field is the root sum squared (RSS) of the magnitude of the rectangular components at one position of the tuner. The number of samples used to determine the average should be at least the same as the number of samples used for chamber calibration. All calibrations are antenna specific. Changing antennas may void calibrations. All power measurements are relative to the antenna terminals. This procedure provides generic values of antenna efficiency for log periodic and horn antennas. Other types of antennas may be used, provided their efficiency is known. Antenna efficiency is the ratio of the power accepted by an antenna to the total power at the measurement location. The measurement requires a spherical scan of the antenna. The typical gain and antenna factor provided by antenna manufacturers cannot be used to derive the antenna efficiency.*

vi. Repeat the above procedure in log spaced frequency steps as outlined in Table 20-6 until frequency is at least $10f_s$.

vii. Repeat for each of the nine probe locations shown in Figure 20-12 and for nine receive antenna locations (one of which must be at the center of the working volume) until $10f_s$.

viii. Above $10f_s$ only three probe and receive antenna locations need to be evaluated. The probe and antenna shall maintain the required clearance from each other and from chamber fixtures. One location for the probe and antenna shall be the center of the working volume. Repeat steps (iv.) and (v.) for the remainder of the calibration frequencies as outlined in Table 20-6.

Note: *The receive antenna should be moved to a new location within the working volume of the chamber for each change in probe location. The antenna should also be placed in a new orientation relative to the chamber axis at each location (at least 20° in each axis). For reference* *purposes x = chamber length (longest dimension), y = chamber width, and z = chamber height. The probe does not necessarily need to be oriented along the chamber axes during calibration.*

Care should be take to ensure that the proper separation distance between the antenna and probe are maintained. Each location should be at least 0.75 meter (or $\lambda/4$ at the lowest test frequency) from any previous location. If the receive antenna is to be mounted in a fixed position during routine testing, it is suggested that one of the locations should be the intended permanent location of the receive antenna.

ix. Using the data from step (v.), normalize each of the maximum E-field probe measurements to the square root of the average input power:

$$\overleftrightarrow{E}_{x,y,z} = \frac{E_{Max x,y,z}}{\sqrt{P_{Input}}}$$

where

$E_{Max x,y,z}$ = maximum measurement from each probe axis (i.e. 27 measurements below $10f_s$, and 9 above $10f_s$),

$\overleftrightarrow{E}_{x,y,z}$ = normalized maximum measurement from each probe axis, and

P_{Input} = average input power to the chamber during the tuner rotation at which $E_{Max x,y,z}$ was recorded.

AND

$$\overleftrightarrow{E}_{Total} = \frac{E_{MaxTotal}}{\sqrt{P_{Input}}}$$

where

$E_{MaxTotal}$ = maximum measurement of the total E-field from the probe at each location (i.e. 9 measurements below $10f_s$, and 3 above $10f_s$),

$\overleftrightarrow{E}_{Total}$ = normalized maximum total measurement from each probe location, and

P_{Input} = average input power to the chamber during the tuner rotation at which $E_{MaxTotal}$ was recorded.

x. For each calibration frequency, calculate the average of the normalized maximum for each axis of the E-field probe measurements, $\left\langle \vec{E}_{x,y,z} \right\rangle$:

(a) For each frequency below $10f_s$:

$$\left\langle \vec{E}_x \right\rangle_9 = \left(\sum \vec{E}_x\right)/9$$
$$\left\langle \vec{E}_y \right\rangle_9 = \left(\sum \vec{E}_y\right)/9$$
$$\left\langle \vec{E}_z \right\rangle_9 = \left(\sum \vec{E}_z\right)/9$$

Also calculate the average of the normalized maximum of all the E-field probe measurements giving equal weight to each axis (i.e. each rectangular component), $\left\langle \vec{E} \right\rangle_{27}$:

$$\left\langle \vec{E} \right\rangle_{27} = \left(\sum \vec{E}_{x,y,z}\right)/27$$

Note: $\langle \ \rangle$ denotes arithmetic mean, i.e.

$$\left\langle \vec{E} \right\rangle_{27} = \left(\sum \vec{E}_{x,y,z}\right)/27$$

represents the sum of the 27 rectangular E-field maximums (normalized) divided by the number of measurements.

(b) Repeat (a) for each frequency above $10f_s$, replacing 9 with 3, and 27 with 9.

xi. For each frequency below $10f_s$ determine if the chamber meets the field uniformity requirements as follows:

(a) The field uniformity is specified as a standard deviation from the mean value of the maximum values obtained at each of the nine locations during one rotation of the tuner. The standard deviation is calculated using data from each probe axis independently (e.g. σ_x) and the total data set (e.g. σ_{27}). **(<u>CAUTION</u>: DO NOT confuse "total data set" with the total E-field)**.

The standard deviation is given by:

$$\sigma = \alpha * \sqrt{\frac{\sum(\vec{E}_i - \langle \vec{E} \rangle)^2}{n-1}}$$

where

n	= number of measurements,
$\vec{E}_i$	= individual normalized E-field measurement,
$\langle \vec{E} \rangle$	= arithmetic mean of the normalized E-field measurements, and
α	= 1.06 for n ≤ 20 and 1 for n > 20.

For example, for the x vector:

$$\sigma_x = 1.06 * \sqrt{\frac{\sum(\vec{E}_{ix} - \langle \vec{E}_x \rangle_9)^2}{9-1}}$$

where

$\vec{E}_{ix}$	= individual measurement of x vector, and
$\langle \vec{E}_x \rangle$	= arithmetic mean of normalized $E_{Max\ x}$ vectors from all 9 measurement locations.

And for all vectors:

$$\sigma_{27} = \sqrt{\frac{\sum(\vec{E}_{ix,y,z} - \langle \vec{E} \rangle_{27})^2}{27-1}}$$

where

$\vec{E}_{ix,y,z}$	= individual measurements of all vectors (x, y and z),
$\langle \vec{E} \rangle_{27}$	= arithmetic mean of normalized $E_{Max\ x,y,z}$ vectors from all 27 measurements, and
σ_{27}	= standard deviation of all vectors (x, y, and z).

The standard deviation is expressed in terms of dB relative to the mean:

$$\sigma(dB) = 20 * \log\left(\frac{\sigma + \langle \vec{E} \rangle}{\langle \vec{E} \rangle}\right)$$

(b) The chamber passes the field uniformity requirements if the standard deviation of the individual field components (e.g. $\sigma_{x,y,z}$) does not exceed the standard deviation specified in Figure 20-11 for more than two frequencies per octave, and the standard deviation for all vectors (i.e. σ_{27}) does not exceed the specified standard deviation. If the chamber fails to meet the uniformity requirement it may not be possible for the chamber to operate at the desired lower frequency. If the margin by which the chamber fails to meet the uniformity requirement is small, it may be possible to obtain the desired uniformity by:

1) increasing the number of samples (i.e. tuner steps) by 10% to 50%,

2) normalizing the data to the net chamber input power ($P_{Net} = P_{Input} - P_{Reflected}$), or

3) reducing the size of the working volume.

If the chamber exceeds the required field uniformity, the number of samples required may be reduced, but not below a minimum of twelve tuner steps. This offers the ability to optimize each chamber for the minimum number of samples and therefore minimize test time.

Note: *If the tuner fails to provide the required uniformity then the uniformity may be improved by increasing the number of tuners, making the tuner(s) larger, or lowering the Q by adding absorber. The chamber characteristics (size, construction method, wall materials) should also be evaluated to determine if the chamber is likely to pass the requirement. Chambers with no more than 60 to 100 modes at the lowest test frequency or very high Qs (such as those encountered in all welded aluminum chambers) are likely to encounter difficulty in meeting the required uniformity.*

IMPORTANT: Once a chamber has been modified (e.g. absorber added, etc.) or the calibration procedure modified (e.g. changed number of tuner steps, etc.) to obtain a desired characteristic, that configuration and/or procedure must remain the same for the duration of the test for that calibration to remain valid.

20.6.3.2 Receive Antenna Calibration

The receive antenna calibration factor (ACF) for an empty chamber is determined to provide a baseline for comparison with a loaded chamber (20.6.4.2).

Calculate the receive Antenna Calibration Factor (ACF) for each frequency using the following equation:

$$ACF = \left\langle \frac{P_{AveRec}}{P_{Input}} \right\rangle_{9@\leq 10 f_s \quad or \quad 3@\geq 10 f_s}$$

where P_{Input} is the average input power from step (v.) above for the corresponding location at which the average received power (P_{AveRec}) from step (v.) above was measured. The calibration factor is necessary to correct the antenna measurements for several effects including antenna efficiency.

Note: *< > denotes arithmetic mean , i.e.* $< P_{AveRec} >_9 = (\Sigma P_{AveRec})/9$

20.6.3.3 Normalized Average Squared Magnitude of E-Field Calibration

Note: *Determination of* $|E_T|^2_{max}$ *is necessary if the tests are to be performed in accordance with section 20.6.4.4.2.*

The normalized average squared magnitude of the total electric field for a given number of tuner steps can be calculated from the average received power from an antenna using the following equation.

$$\left|E_T\right|^2_{\max} = \left\langle \frac{P_{averec}}{P_{input} * \eta_{rx}} \right\rangle * \frac{8\pi\eta}{\lambda^2} * R$$

where

R = *maximum to average ratio of the squared magnitude of E-field. Refer to Table 20-7. The value of R varies with the number of tuner steps. See Section 20.6.3.1.iv.*

P_{aveRec} = *the average received power over one tuner rotation at an antenna location from Section 20.6.3.1(v.) above. Nine antenna locations below 10*f_s *and 3 locations above 10*f_s*. (watts)*

P_{Input} = *the average chamber input power from Section 20.6.3.1(v.). (watts)*

η_{rx} = *the antenna efficiency factor for the receive antenna which can be assumed to be 0.75 for a log periodic antenna and 0.9 for a horn antenna.*

η = *wave impedance of free space (120* π *)*

λ = *wave length (m)*

20.6.3.4 Maximum Chamber Loading Verification

In order to determine if the chamber is adversely affected by an EUT which "loads" the chamber, perform a one-time check of the chamber field uniformity under simulated loading conditions. It is suggested the "loaded" chamber calibration be carried out only once in the life of the chamber or after major modification to the chamber. Prior to each test a calibration shall be conducted using the procedures of 20.6.4.2 and 20.6.4.3.

i. In the working volume of the chamber, install a sufficient amount of absorber to load the chamber to at least the level expected during normal testing (a factor of sixteen change in ACF (12 dB) should be considered as a nominal amount of loading).

ii. Repeat the calibration outlined in Section 20.6.3.1 using the eight outer locations of the E-field probe. Care should be taken to ensure that the E-field probe and receiving antenna maintain a distance of greater than λ/4 from any absorber.

iii. Determine the chamber loading by comparing the Antenna Calibration Factor (ACF) from the empty chamber to that obtained from the "loaded" chamber (See Section 20.6.3.2)

$$Loading = \frac{ACF_{Empty\ Chamber}}{ACF_{Loaded\ Chamber}}$$

iv. Repeat the calculation of the field uniformity using the data from only eight locations.

If the chamber loading results in the rectangular component of the fields exceeding the allowed standard deviation for more than two frequencies per octave, or if the standard deviation for all vectors (i.e. σ_{27}) exceeds the allowed standard deviation then the chamber has been loaded to the point where field uniformity is affected. In such case the chamber amount of loading must be reduced and the loading effects evaluation must be repeated.

No loading verification is required above $10f_s$.

20.6.4 Equipment Test

20.6.4.1 Test Setup

Except as specifically noted in this section, the requirements of Section 20.3 apply to the reverberation chamber tests.

The typical test setup should be as shown in Figure 20-13. The equipment layout should be representative of the actual installation as specified in Section 20.3.a.(5). The EUT shall be located inside the working volume as defined in Section 20.6.3.1. Moreover, the EUT volume shall not take up more than 8% of the chamber volume.

The transmit and receive antennas shall be the same antennas used in Section 20.6.3.1.

The transmit antenna should be in the same location as used for calibration. Establish software installation, modes of operation and stability of the EUT, test equipment, and all monitoring circuits and loads.

20.6.4.2 Chamber Loading Determination

Prior to each test, with the EUT and supporting equipment in the chamber, determine if the EUT has loaded the chamber according to the following procedure.

i. Place the receive antenna at a location within the working volume of the chamber and maintain 0.75 meter (or $\lambda/4$ at the lowest test frequency) separation from the EUT, supporting equipment, etc., as outlined in Figure 20-13. Set the amplitude measurement instrumentation to monitor the receive antenna on the correct frequency.

ii. Beginning at the lowest test frequency (f_s), adjust the RF source to inject an appropriate input power, (P_{Input}), into the transmit antenna.

iii. Operate the chamber and the tuner taking into account the possible additional features defined in Section 20.6.3.1.xi.(b) that have been required to meet the homogeneity criterion. The number of tuner steps must be the same as those to be used for the test.. Reduction in measurement uncertainty may be obtained by averaging over frequency (averaging over a maximum of 4 frequencies either side of the frequency being evaluated is allowed) Care must be taken to ensure that the dwell time is sufficiently long enough to ensure that the amplitude measurement has time to respond properly.

The number of tuner steps must be determined prior to testing (see Section 20.6.4.4) and should be selected from Table 20.6. The tuner should be rotated in evenly spaced steps so that one complete revolution is obtained per frequency.

iv. Record the average amplitude of the receive signal (P_{AveRec}), and the average value of the input power, P_{Input}. The measurement instruments should have a noise floor at least 20 dB below the maximum received power (P_{MaxRec}) in order to collect accurate average data.

v. Repeat the above procedure for each test frequency as defined in Section 20.3(e).

vi. Calculate the chamber calibration factor (*CCF)* for each frequency using the following equation:

$$CCF = \left\langle \frac{P_{AveRec}}{P_{Input}} \right\rangle_{n,f}$$

where

CCF = the normalized average received power over one tuner rotation with the EUT and supporting equipment present,

P_{AveRec} = the average received power over one tuner rotation from step (iv.),

P_{Input} = the forward power averaged over one tuner rotation from step (iv.), and

n = the number of antenna locations the CCF is evaluated for. Only one location is required; however, multiple locations may be evaluated and the data averaged over the number of locations, n.

f *= the number of frequencies over which the data was averaged. Averaging over a maximum of 4 frequencies either side of the frequency being evaluated is allowed*

vii. Calculate the chamber loading factor (CLF) for each frequency using the following equation:

$$CLF = \frac{CCF}{ACF}$$

where

CCF = the ratio of the average received power to input power obtained in step (vi.) above, and

ACF = the ratio of the average received power to input power obtained in the antenna calibration in Section 20.6.3.2.

If the magnitude of the chamber loading factor is in excess of that measured in Section 20.6.3.4.iii for more than 10% of the test frequencies, there is a possibility that the chamber may be loaded to the point where field uniformity is affected. In such case the chamber uniformity measurements outlined in Section 20.6.3.1 must be repeated with the EUT in place or with a simulated loading equivalent to the EUT.

Note: *If the value of P_{AveRec} measured in step 20.6.4.2.iv is within (i.e. not greater than or less than) the values recorded for all nine locations in Section 20.6.3.1.v, calculation of the CLF is not necessary and the value of the CLF can be assumed to be one (1). Averaging the data sets to be compared over 4 frequencies each side of the frequency being evaluated is allowed.*

20.6.4.3 Q and Time Constant Calibration

In order to assure that the time response of the chamber is fast enough to accommodate pulsed waveform testing, determination of the chamber time constant shall be accomplished using the following procedure:

i. Using the *CCF* from the chamber calibration (Section 20.6.4.2.vi), calculate the quality factor, Q, for every test frequency above 400 MHz using:

$$Q = \left(\frac{16\pi^2 V}{\eta_{Tx}\eta_{Rx}\lambda^3}\right)(CCF)$$

where

η_{Tx}, η_{Rx} = the antenna efficiency factors for the transmit and receive antenna respectively and can conservatively be assumed to be 0.75 for a log periodic antenna and 0.9 for a horn antenna,

V = the chamber volume (m^3),

λ = the free space wavelength (m) at the specific frequency, and

CCF = the chamber calibration factor.

ii. Calculate the chamber time constant, τ, for every test frequency above 400 MHz using:

$$\tau = \frac{Q}{2\pi f}$$

where

τ = time constant (sec)

Q = the value calculated in step (i.) above, and

f = the test frequency (Hz).

iii. If the chamber time constant is greater than 0.4 of any modulation test waveform pulse width for more than 10% of the test frequencies, absorber must be added to the chamber or the pulse width increased. If absorber is added, repeat the Q measurement and the calculation until the time constant requirement is satisfied with the least possible absorber. A new CLF must be defined if absorber material is required.

20.6.4.4 Mode Tuned RS Test Procedures

CAUTION: RF fields can be hazardous. Observe appropriate RF exposure limits.

Determine the chamber input power for each test frequency from the electric field intensity category level in Table 20-5 using the equation of section 20.6.4.4.1 or section 20.6.4.4.2. depending on whether the receive antenna or the field probe are to be the source of the calibration data.

Determine the number of tuner steps to be used for the test. The minimum number of steps that give acceptable field uniformity will result in the shortest test time and the most power required to obtain the desired test environment. If field uniformity requirements cannot be met or the needed RF power is not available then an increased number of tuner steps will be required. It is permitted to use a different number of tuner steps for different frequencies depending on test requirements.

The applied field strength is derived from P_{Input} computed below in this section. Set the input power to P_{Input} and record its value. The receive antenna is used as verification that the transmit path is functioning correctly.

Step through the frequency range to the upper frequency limit using the appropriate modulations. Modulate the carrier as specified in Section 20.5. When modulation is applied, ensure that the peak amplitude complies with the definitions of Figure 20-5. The dwell time for this procedure should be as specified in Section 20.3.e. Dwell at internal modulation, data and clock frequencies, as required.

While dwelling at each frequency, evaluate EUT operation and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

20.6.4.4.1 Input Power Computed Using E-field Probe Measurements

$$P_{Input} = \left[\frac{E_{Test}}{\left\langle \vec{E}_{Total} \right\rangle_n * \sqrt{CLF}} \right]^2$$

where

E_{Test} = the required field strength (V/m) from Figure 20-10 and/or Table 20-5,

CLF = the chamber loading factor from 20.6.4.2.vii., and

$\left\langle \vec{E}_{Total} \right\rangle_n$ = the mean of the normalized maximum total E-field as defined in Section 20.6.3.1.ix.

It will be necessary to interpolate between the calibration frequency points to obtain the normalized E-field calibration ($\vec{E}$) for the test frequencies.

20.6.4.4.2 Input Power Computed using Receive Antenna Calibration Measurements

Before this method can be used, as a one time check P_{input} calculated from this method must be compared with P_{input} using method 20.6.4.4.1 for frequencies above 4fs. This check must be done with the number of tuner steps being used for the test. Any discrepancies greater than +/- 3 dB between the probe and antenna based measurements must be resolved. These may be caused by:

- Problems and tolerances in the field probe
- Pick up on the receive antenna cables
- The receive antenna being too close to the test bench or walls
- The receive antenna being inadvertently pointed at the transmit antenna
- etc

If there are no discrepancies then the receive antenna equation can be used to determine the required input power during the test throughout the frequency range of the test instead of using the field probe information. This would be the case where the validity of the field probe results is in doubt at low frequencies through cable pick-up on the lead between the probe head and the fiber optic link transmitter.

$$P_{Input} = \frac{E_{Test}^2}{\left|E_T\right|^2{}_{\max} * CLF}$$

where

E_{Test} = the required field strength (V/m) from Figure 20-10 and/or Table 20-5,

CLF = the chamber loading factor from 20.6.4.2.vii., and

$\left|E_T\right|^2{}_{\max}$ = the maximum squared magnitude of the total E-field as defined in Section 20.6.3.3.

Note: The field uniformity obtained in Section 20.6.3.1.ix must be calculated for the number of tuner steps being used for the test as described in Section 20.6.3.1.iv.

It may be necessary to interpolate between the calibration frequency points to obtain $|E_T|^2{}_{\max}$ for the test frequencies.

TABLE 20-1 CATEGORY SELECTION FOR THE CONDUCTED SUSCEPTIBILITY TEST

Aircraft Type	Rotocraft Severe Environment	Certification Environment	Normal Environment
Helicopters	G	H	J
AC<25m	not applicable	A	B
25m ≤ AC < 50m	not applicable	C	D
AC ≥ 50m	not applicable	E	F
All Types	not applicable	K	L

TABLE 20-2 CATEGORY SELECTION FOR THE RADIATED SUSCEPTIBILITY TEST

Nominal Attenuation	Rotocraft Severe Environment	Certification Environment	Normal Environment
0 dB	L	G	G
6 dB	K	F	F
10 dB	_______	E	E
12 dB	J	D	D
14 dB	_______	C	C
18 dB	I	B	B
24 dB	H	A	A

TABLE 20-3 RF ABSORPTION AT NORMAL INCIDENCE

Frequency	Minimum Absorption
100 to 250 MHz	6 dB
Above 250 MHz	10 dB

TABLE 20-4 CONDUCTED SUSCEPTIBILITY TEST LEVELS VERSUS CATEGORY

Frequency	Category Levels (mA)														
(MHz)	A	B	C	D	E	F	G	H	J	K	L	R	S	T	W	Y
0.01	0.2	0.08	0.5	0.2	2.5	1	4.5	1.5	0.6	2.5	1	0.6	0.03	0.15	3	6
0.1	1.6	0.64	3.5	1.4	25	10	19.2	6.4	2.56	25	10	6	0.3	1.5	30	60
0.1	1.6	0.64	3.5	1.4	25	10	25.6	6.4	2.56	25	10	6	0.3	1.5	30	60
0.5	7	2.6	13.5	5.4	125	50	66	16.5	6.6	125	50	30	1.5	7.5	150	300
0.5	7	3.9	13.5	8.1	125	75	66	16.5	9.9	125	75	30	1.5	7.5	150	300
1.5	20	12	35	21	125	75	136	32	20	125	75	30	1.5	7.5	150	300
2	25	15	35	21	125	75	164	41	24.6	125	75	30	1.5	7.5	150	300
2	50	50	70	70	250	250	164	82	82	250	250	30	1.5	7.5	150	300
3	70	70	70	70	250	250	214	105	105	250	250	30	1.5	7.5	150	300
5	70	70	70	70	250	250	300	150	150	250	250	30	1.5	7.5	150	300
6	70	70	70	70	205	205	300	150	150	205	205	30	1.5	7.5	150	300
15	70	70	50	50	86	86	300	150	150	150	150	30	1.5	7.5	150	300
30	59	59	39	39	48	48	300	150	150	150	150	30	1.5	7.5	150	300
30	29.5	5.9	19.5	3.9	24	4.8	300	75	15	75	15	30	1.5	7.5	150	300
70	23.25	4.65	14	2.8	13	2.6	216	54	10.8	54	10.8	30	1.5	7.5	150	300
100	20.5	4.1	12	2.4	11.5	2.3	180	45	9	45	9	30	1.5	7.5	150	300
100	41	4.1	24	2.4	23	2.3	180	90	9	90	9	30	1.5	7.5	150	300
200	34	3.4	19.5	1.95	18.5	1.85	132	66	6.6	66	6.6	30	1.5	7.5	150	300
200	34	3.4	19.5	1.95	18.5	1.85	132	66	6.6	66	6.6	30	1.5	7.5	150	300
400	30	3	15	1.5	15	1.5	100	50	5	50	5	30	1.5	7.5	150	300

TABLE 20-5 RADIATED SUSCEPTIBILITY TEST LEVELS VERSUS CATEGORY

Certification and Normal Environment	Cat A (V/m) (24 dB)		Cat B (V/m) (18 dB)		Cat C (V/m) (14 dB)		Cat D (V/m) (12 dB)		Cat E (V/m) (10 dB)		Cat F (V/m) (6 dB)		Cat G (V/m) (0 dB)	
Frequency	SW/CW	PM	SW/CW	PM	SW/CW	PM	SW/CW	PM	SW/CW	PM	SW/CW	PM	SW/CW	PM
100-200 MHz	7	N/A	13	N/A	20	N/A	25	N/A	32	N/A	50	N/A	100	N/A
200-400 MHz	7	N/A	13	N/A	20	N/A	25	N/A	32	N/A	50	N/A	100	N/A
400-700 MHz	4	45	7	88	10	140	13	175	16	220	25	350	50	700
700 MHz-1 GHz	7	45	13	88	20	140	25	175	32	220	50	350	100	700
1-2 GHz	13	125	25	250	40	400	50	500	64	630	100	1000	200	2000
2-4 GHz	13	190	25	375	40	600	50	750	64	950	100	1500	200	3000
4-6 GHz	13	190	25	375	40	600	50	750	64	950	100	1500	200	3000
6-8 GHz	13	63	25	125	40	200	50	250	64	320	100	500	200	1000
8-12 GHz	19	190	38	375	60	600	75	750	95	950	150	1500	300	3000
12-18 GHz	13	125	25	250	40	400	50	500	64	630	100	1000	200	2000

Rotocraft Severe Environment	Cat H (V/m) (24 dB)		Cat I (V/m) (18 dB)		Cat J (V/m) (12 dB)		Cat K (V/m) (6 dB)		Cat L (V/m) (0 dB)		Notes
Frequency	SW/CW	PM	SW/CW	PM	SW/CW	PM	SW/CW	PM	SW/CW	PM	Note 1 – Test Levels for Category R, S, T, W, and Y are shown in Figures 20-10 (a & b)
100-200 MHz	13	N/A	25	N/A	50	N/A	100	N/A	200	N/A	
200-400 MHz	13	N/A	25	N/A	50	N/A	100	N/A	200	N/A	Note 2 – The value of (XX dB) in each column heading denotes the amount of airframe attenuation applied to the external HIRF environment.
400-700 MHz	13	45	25	90	50	180	100	365	200	730	
700 MHz-1 GHz	16	90	32	175	60	350	120	700	240	1400	
1-2 GHz	16	315	32	630	60	1250	125	2500	250	5000	
2-4 GHz	30	380	60	760	120	1500	245	3000	490	6000	
4-6 GHz	25	455	50	910	100	1800	200	3600	400	7200	
6-8 GHz	10	70	20	140	40	280	85	550	170	1100	
8-12 GHz	20	315	40	630	80	1260	165	2500	330	5000	
12-18 GHz	20	125	40	250	80	500	165	1000	330	2000	

TABLE 20-6 REVERBERATION CHAMBER TEST CRITERION

Frequency Range[1]	Number of frequencies[2] required for chamber loading factor (CLF) measurement.
f_s to $4f_s$	50/decade
$4f_s$ to $8f_s$	50/decade
Above $8f_s$	20/decade

1 f_s is the start frequency
2 log spaced

TABLE 20-7 MAXIMUM TO AVERAGE RATIO OF SQUARED MAGNITUDE OF E-FIELD

Tuner Steps	R
9	1.957
10	2
12	2.08
18	2.25
20	2.3
24	2.38
30	2.47
36	2.54
40	2.59
45	2.64
60	2.76
90	2.92
120	3.04
180	3.2

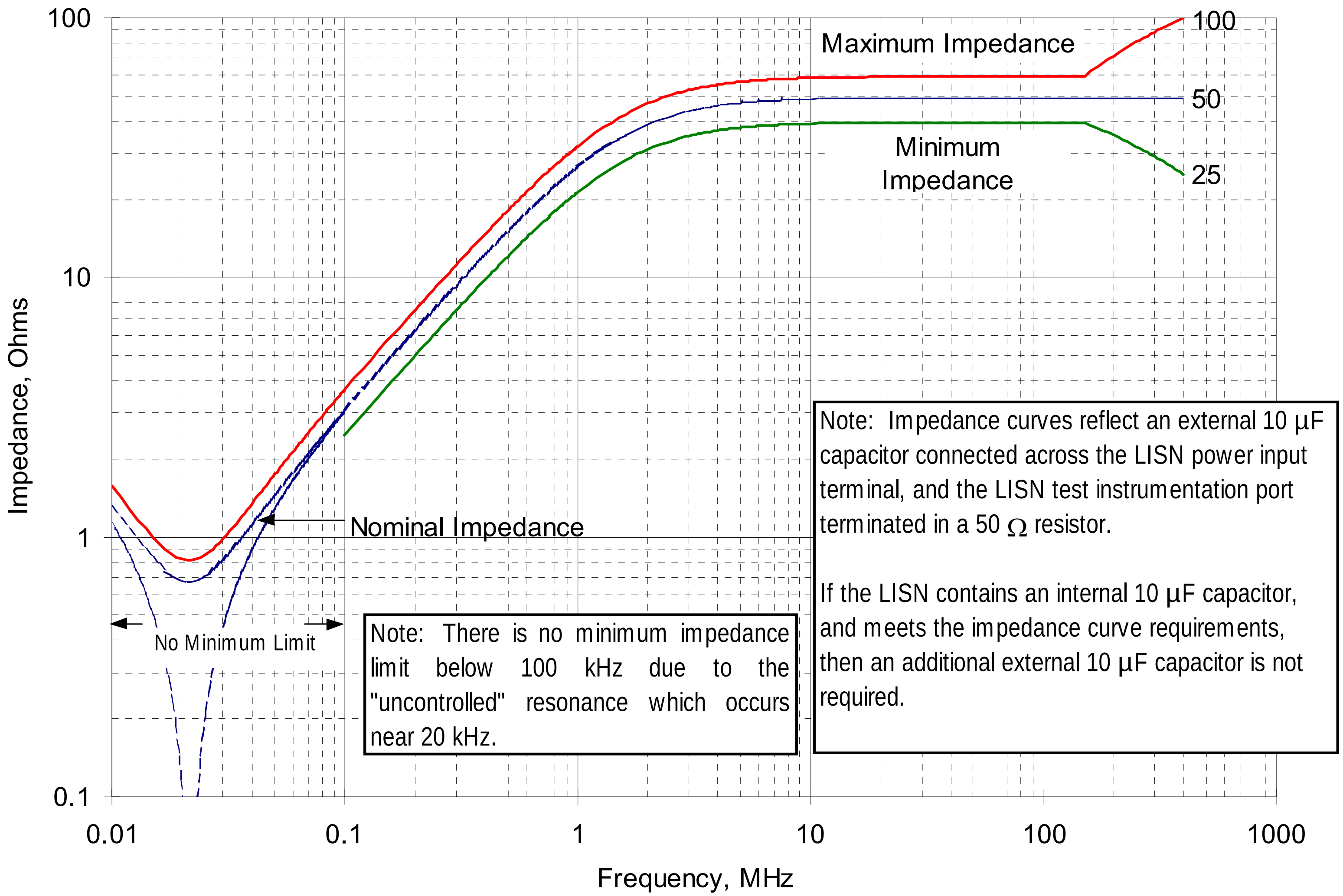
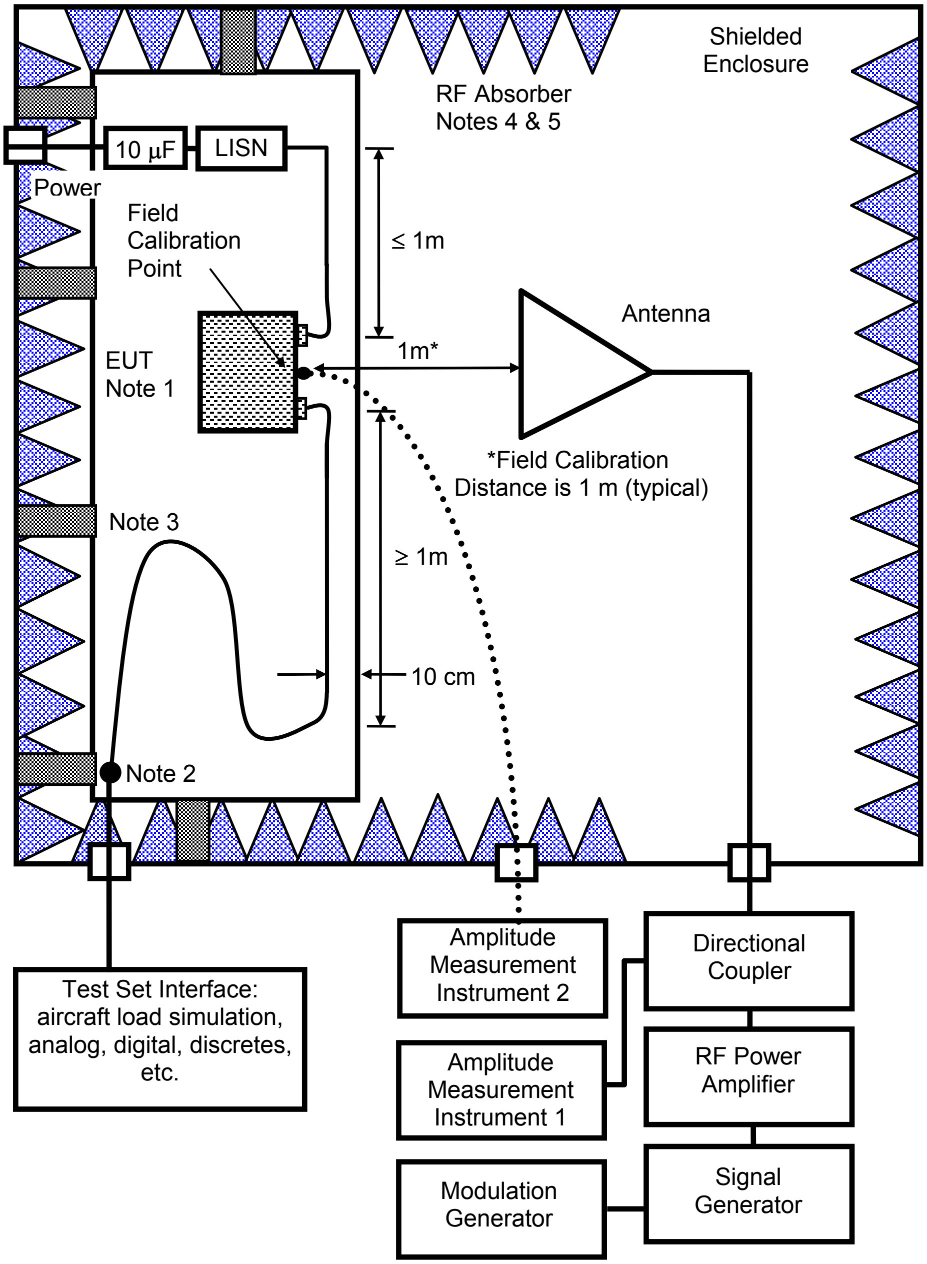


FIGURE 20-1 LISN IMPEDANCE STABILIZATION NETWORK INPUT IMPEDANCE



Note 1 See Section 20.3 for EUT general requirements.
Note 2 End of exposed cable. Unshielded cable may be shielded from here to the wall.
Note 3 Bonding strap.
Note 4 RF absorber shall be placed above, behind, and on both sides of test setup boundary, from ceiling to ground plane. The absorber shall extend ≥50 cm in front of the ground plane.
Note 5 RF absorber shall be placed behind the test antenna, from ceiling to floor. The distance between the absorber and the antenna shall be ≥30 cm.

<u>FIGURE 20-2</u> RADIATED SUSCEPTIBILITY TEST SETUP

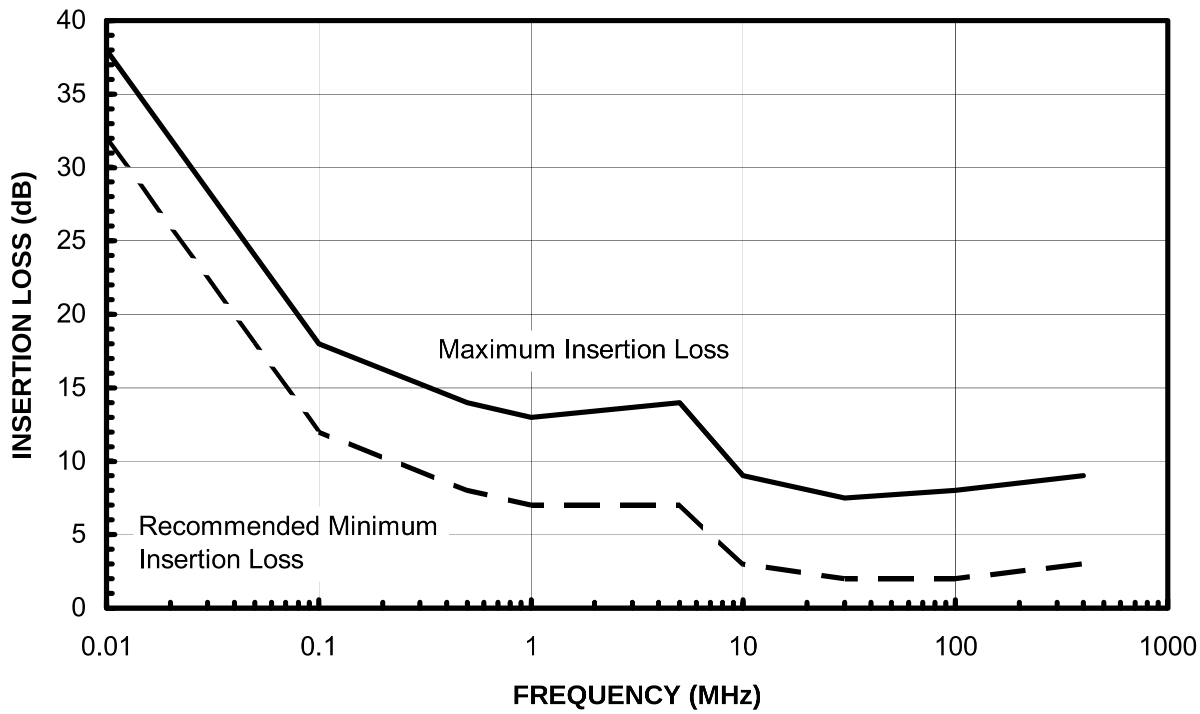


FIGURE 20-3 INJECTION PROBE INSERTION LOSS LIMITS

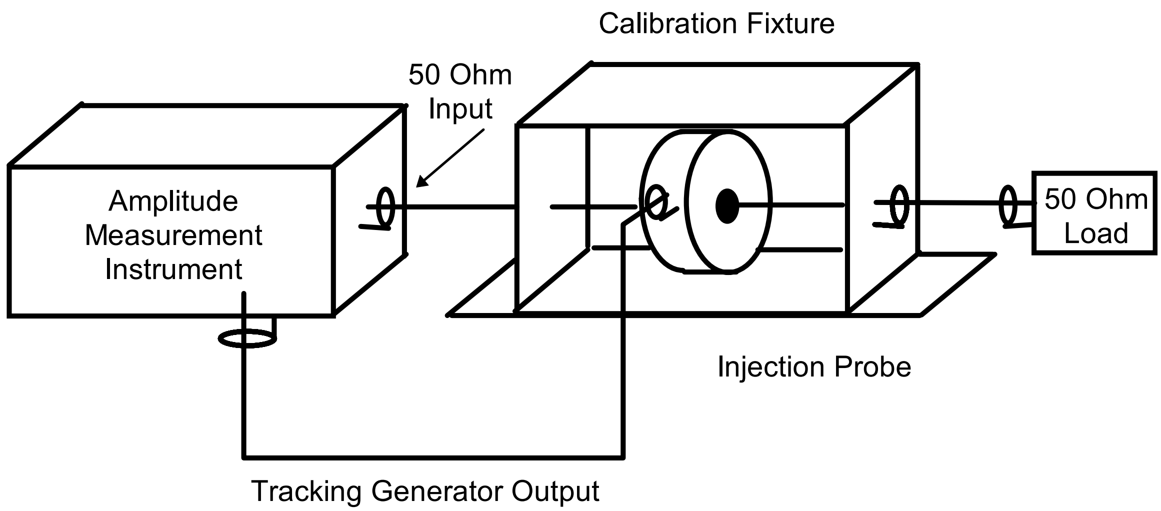
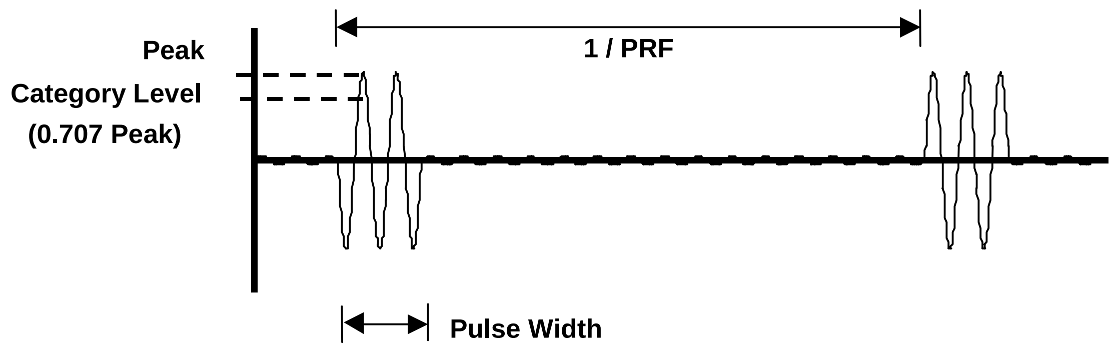
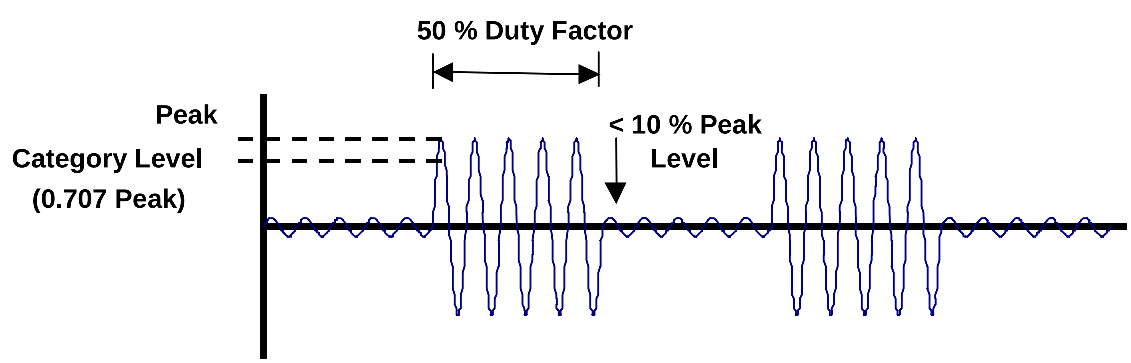


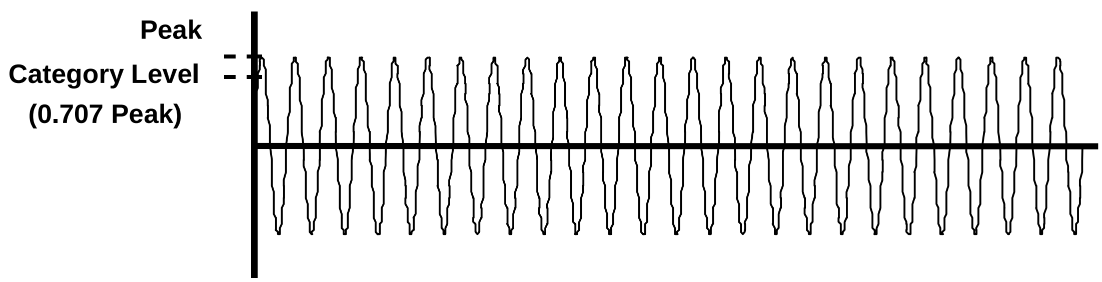
FIGURE 20-4 INJECTION PROBE INSERTION LOSS TEST SETUP



Pulse Modulated Waveform

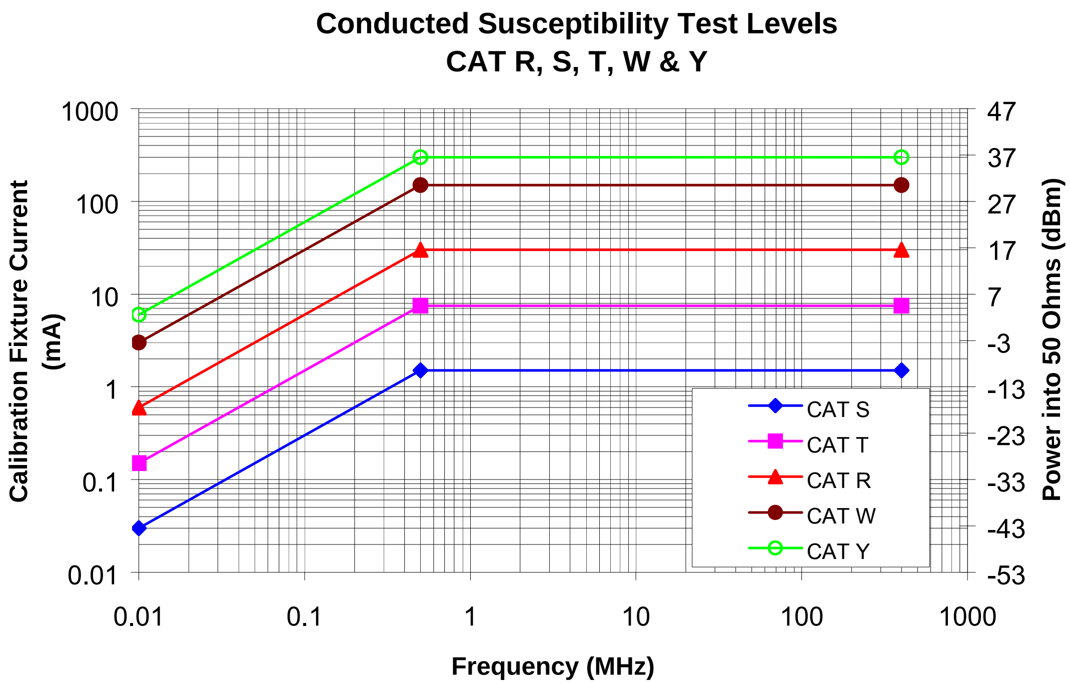


Square Wave (SW) Modulated Waveform



Unmodulated (CW) Waveform

FIGURE 20-5 AMPLITUDE MEASUREMENT



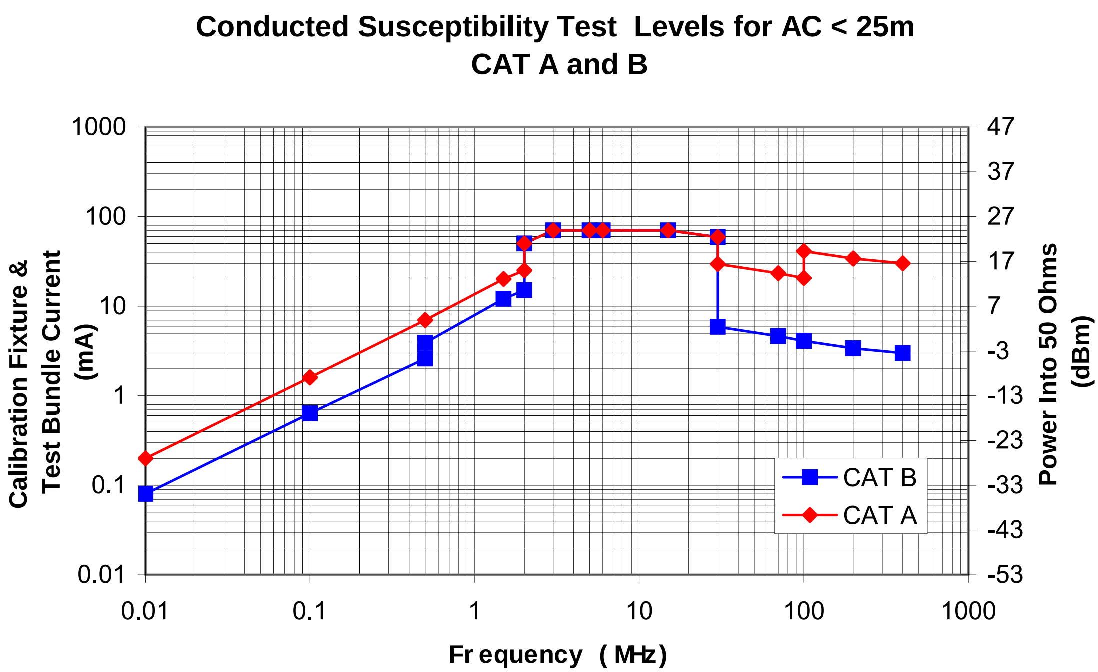
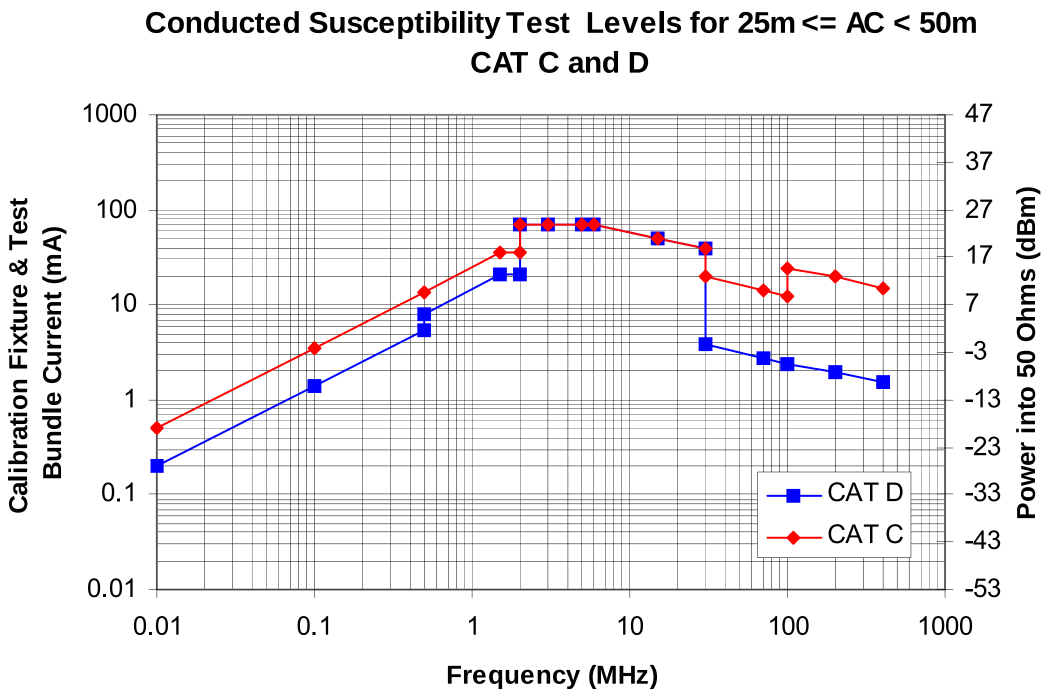
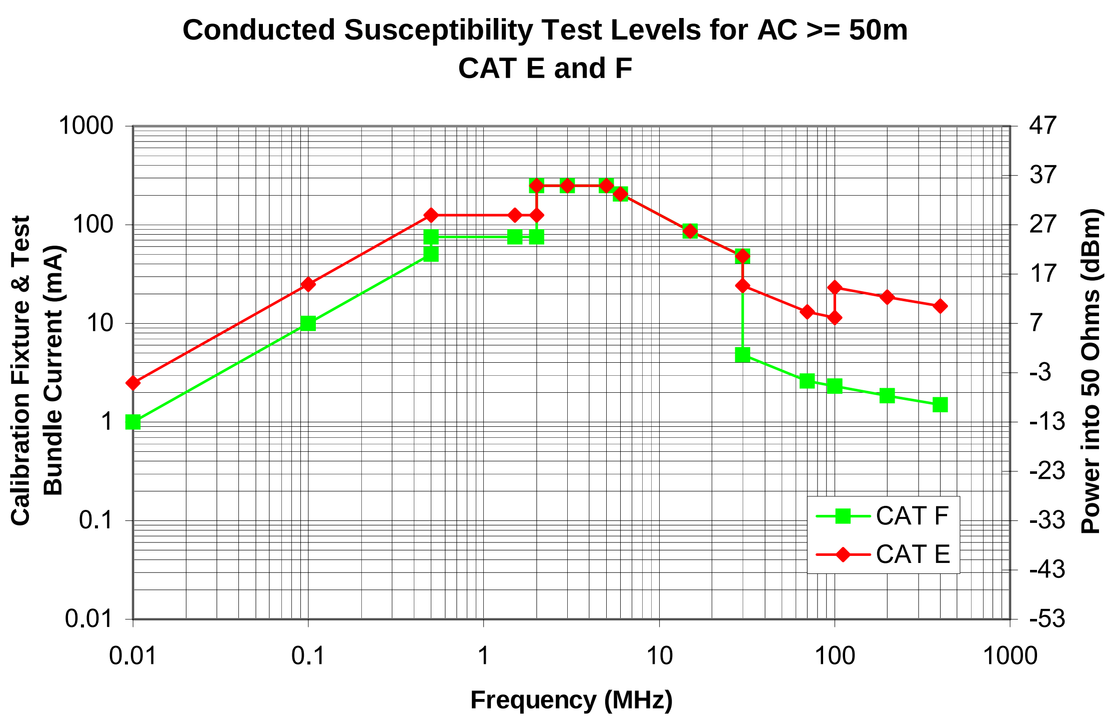
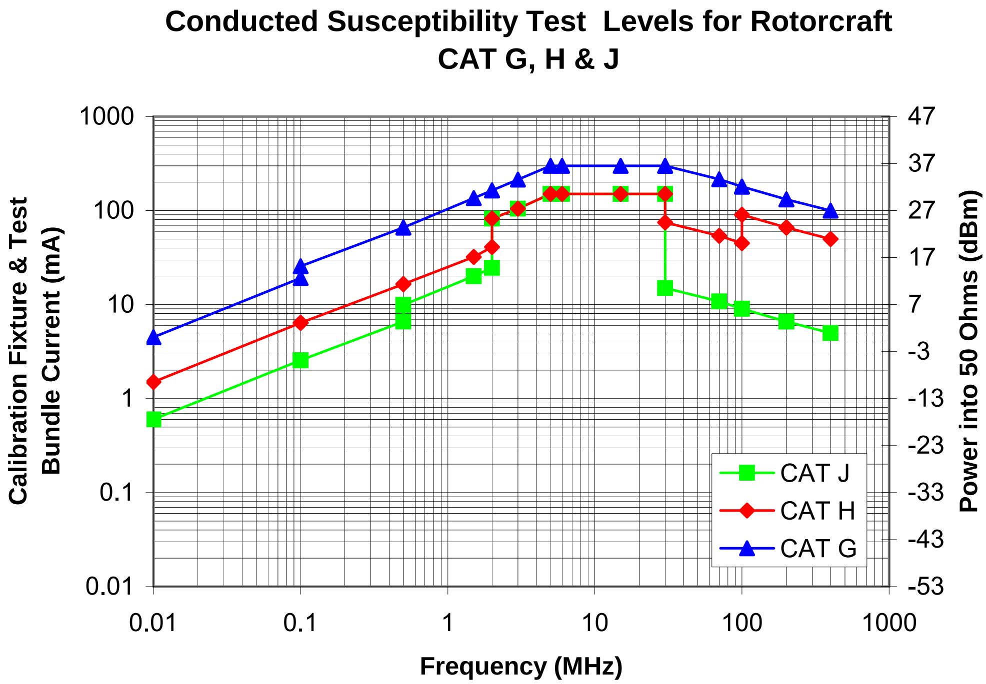


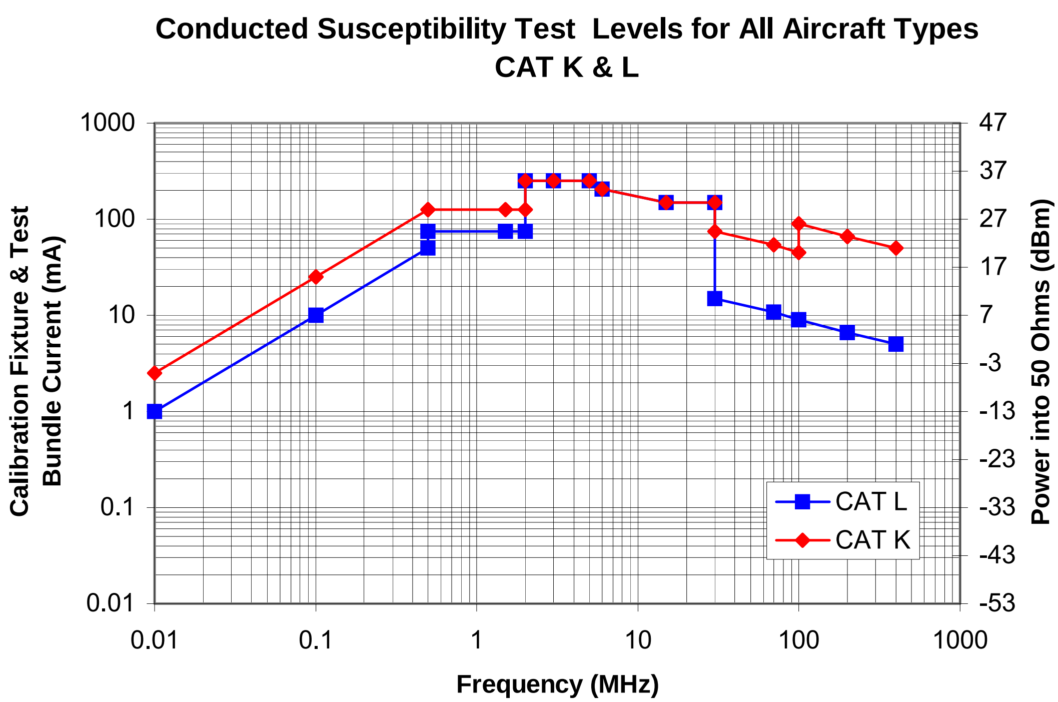
FIGURE 20-6 (A&B) CONDUCTED SUSCEPTIBILITY TEST LEVELS



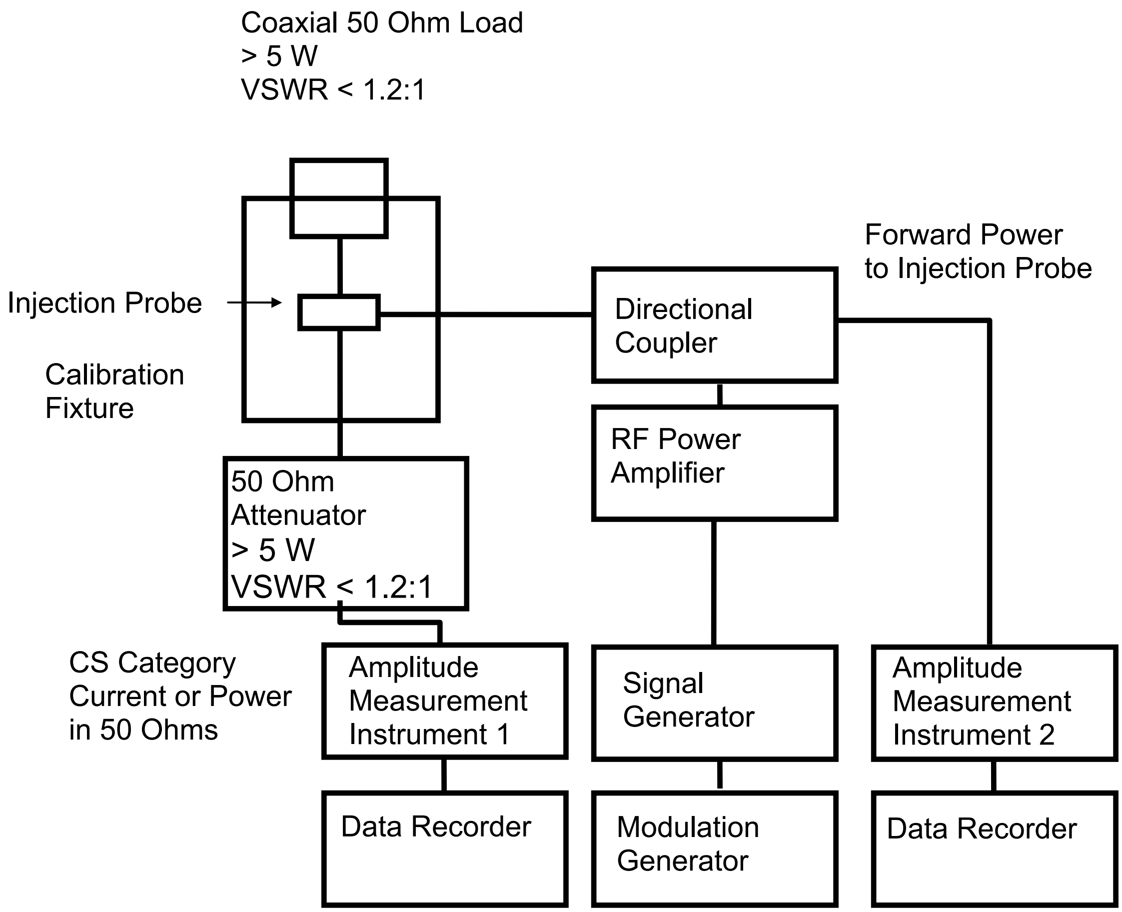


<u>FIGURE 20-6(C&D)</u> CONDUCTED SUSCEPTIBILITY TEST LEVELS





<u>FIGURE 20-6(E&F)</u> CONDUCTED SUSCEPTIBILITY TEST LEVELS



<u>FIGURE 20-7</u> CONDUCTED SUSCEPTIBILITY CALIBRATION SETUP

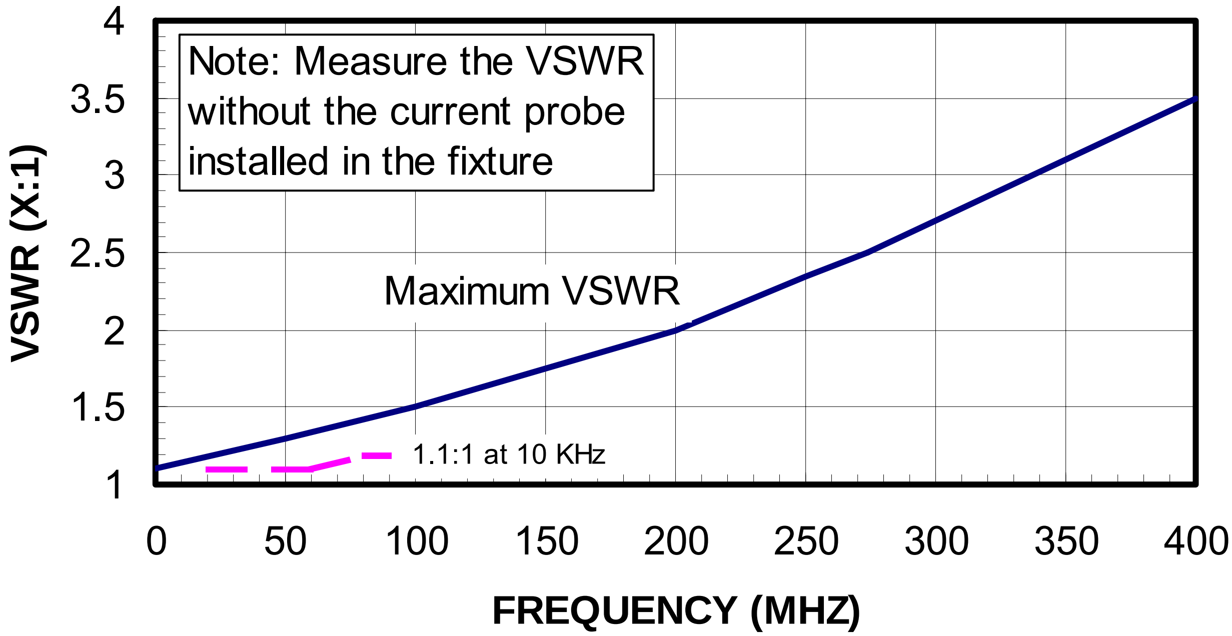
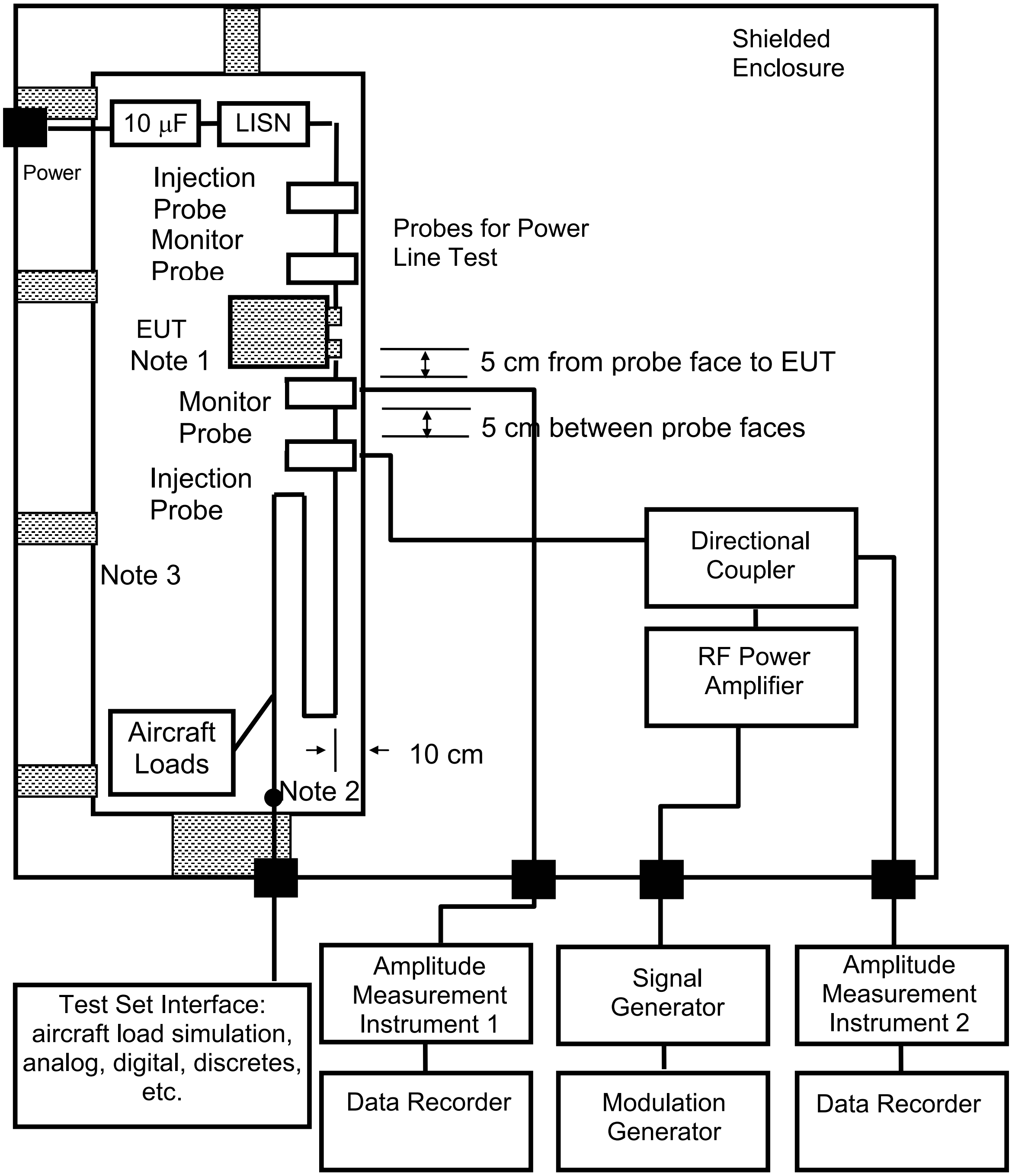
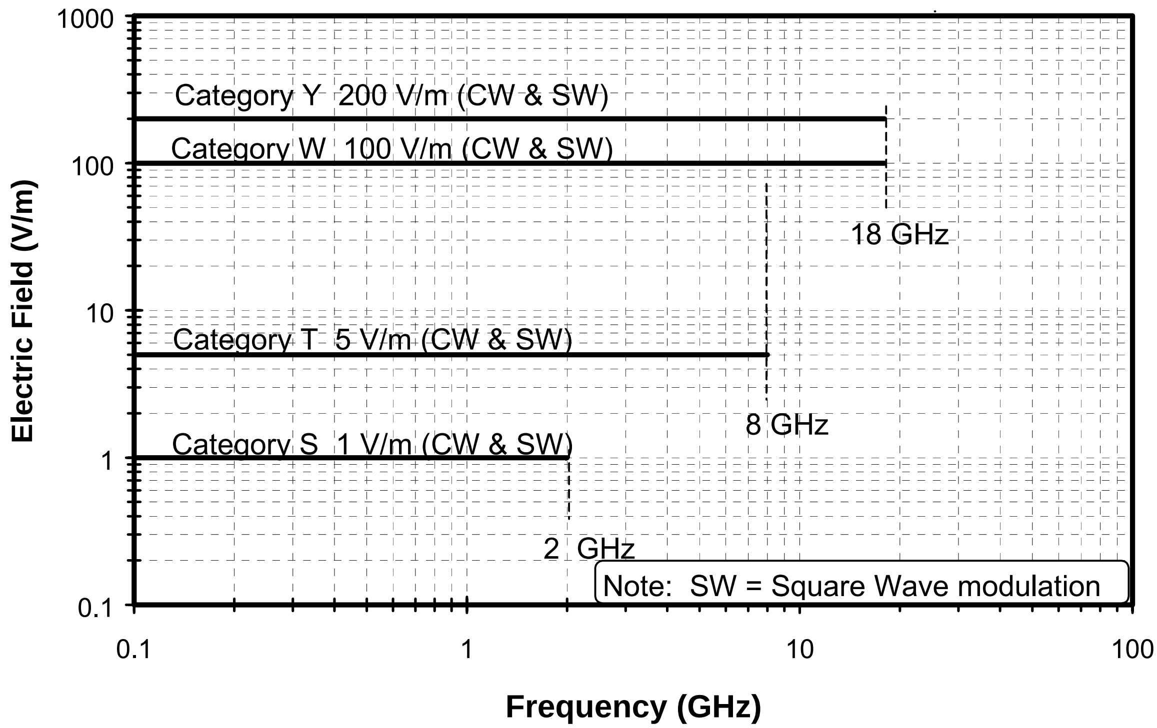


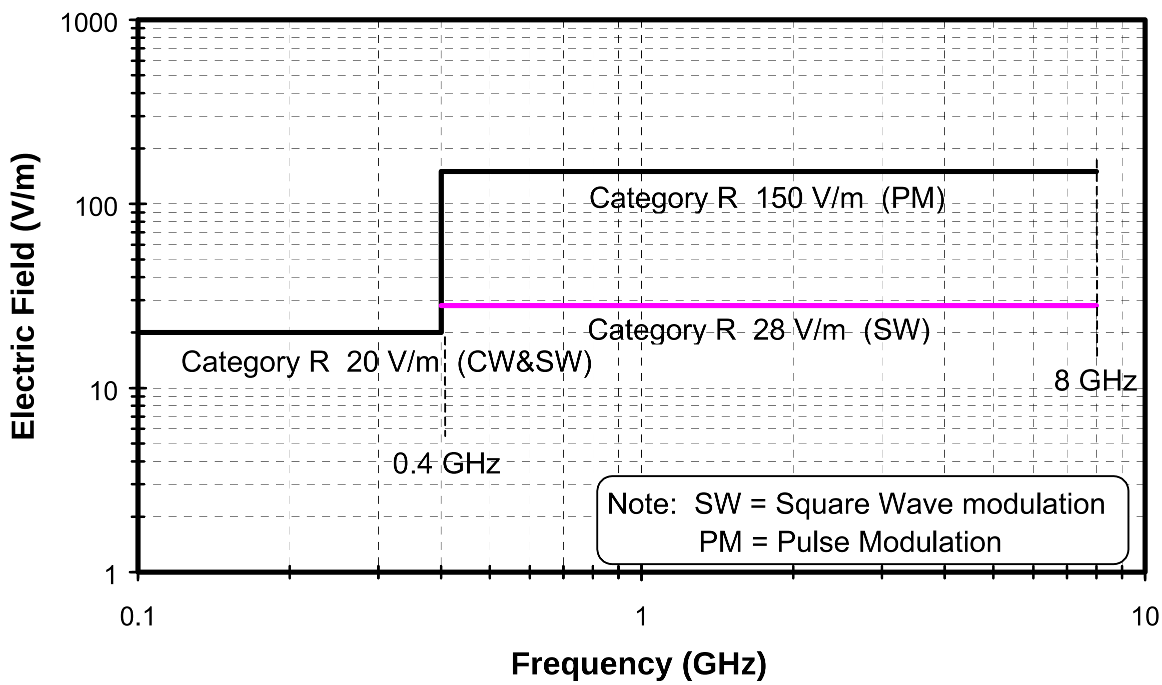
FIGURE 20-8 CALIBRATION FIXTURE MAXIMUM VSWR LIMITS



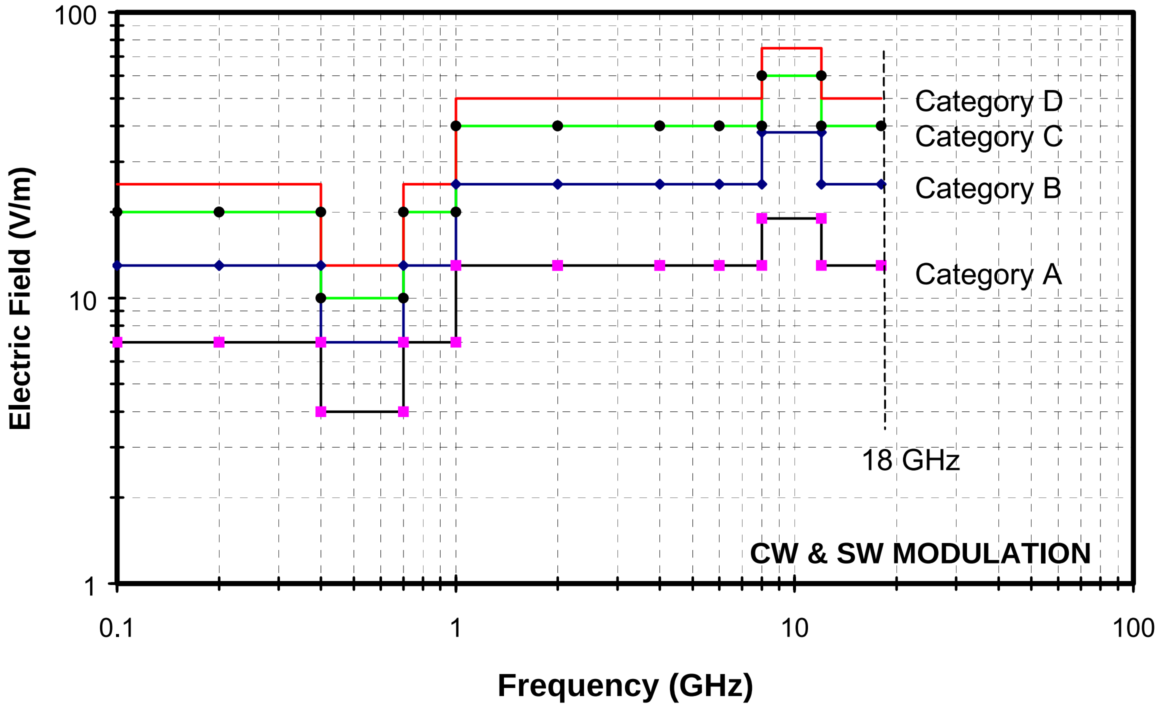
NOTE 1: See Section 20.3 for EUT general requirements.
NOTE 2: End of exposed cable. Unshielded cable may be shielded from here to the wall.
NOTE 3: Bonding strap.

FIGURE 20-9 CONDUCTED SUSCEPTIBILITY TEST SETUP





<u>FIGURE 20-10(A&B)</u> RADIATED SUSCEPTIBILITY TEST LEVELS



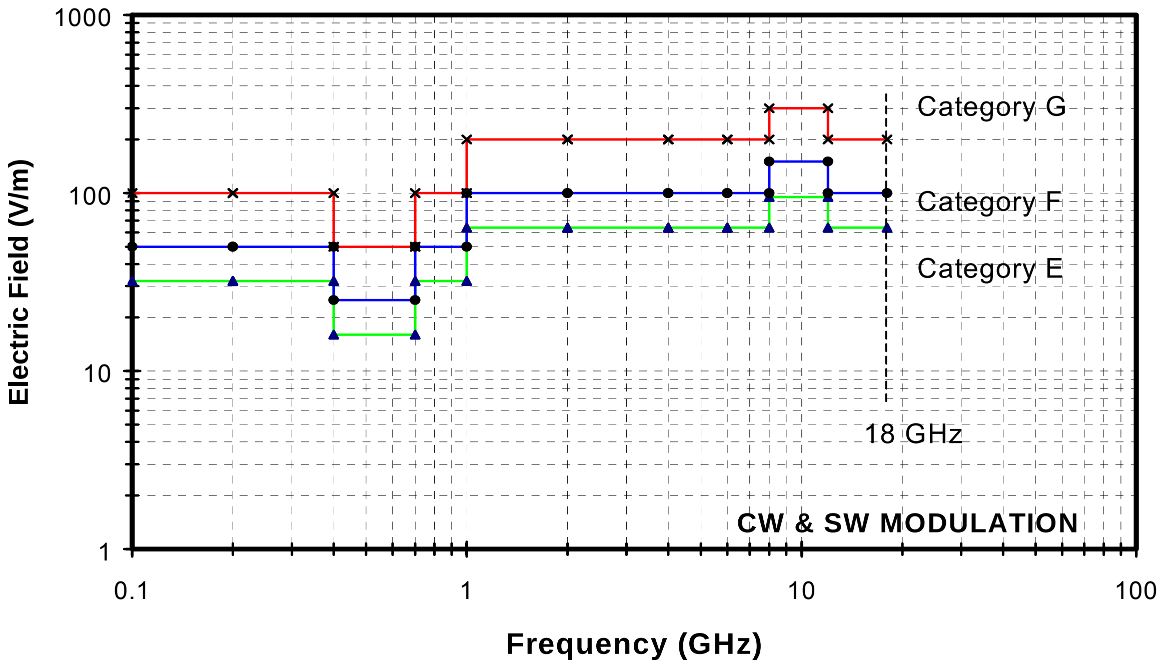
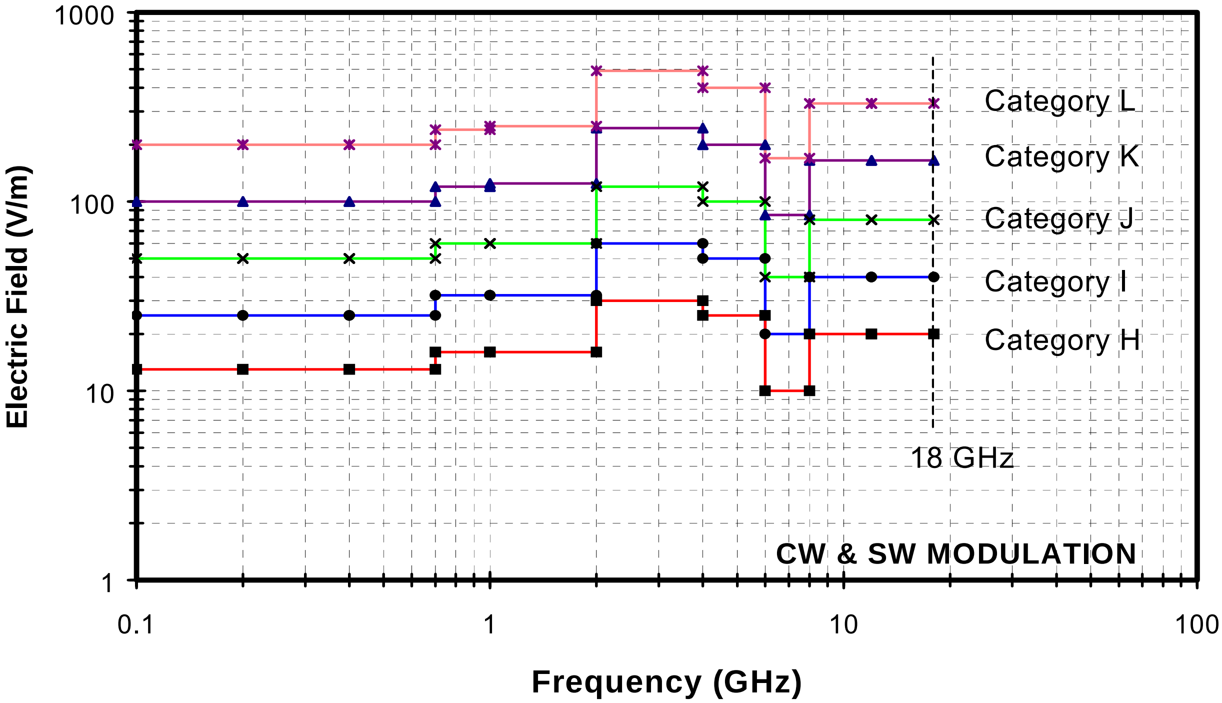


FIGURE 20-10(C&D) RADIATED SUSCEPTIBILITY TEST LEVELS



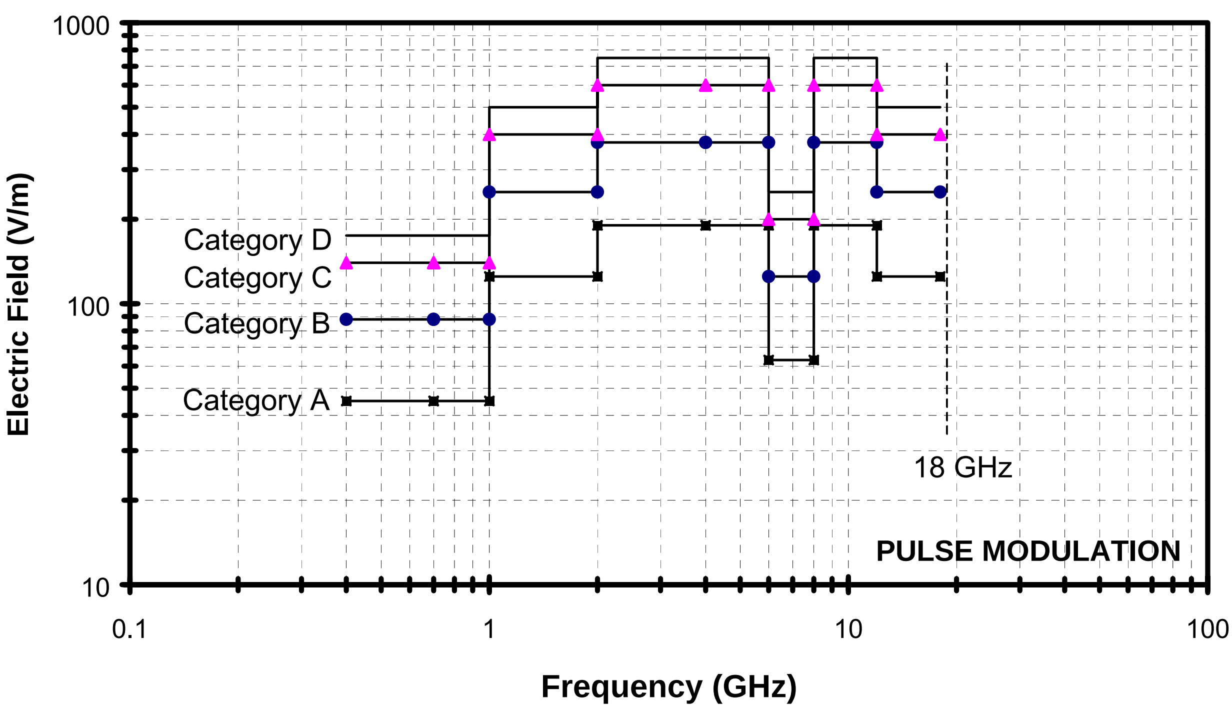
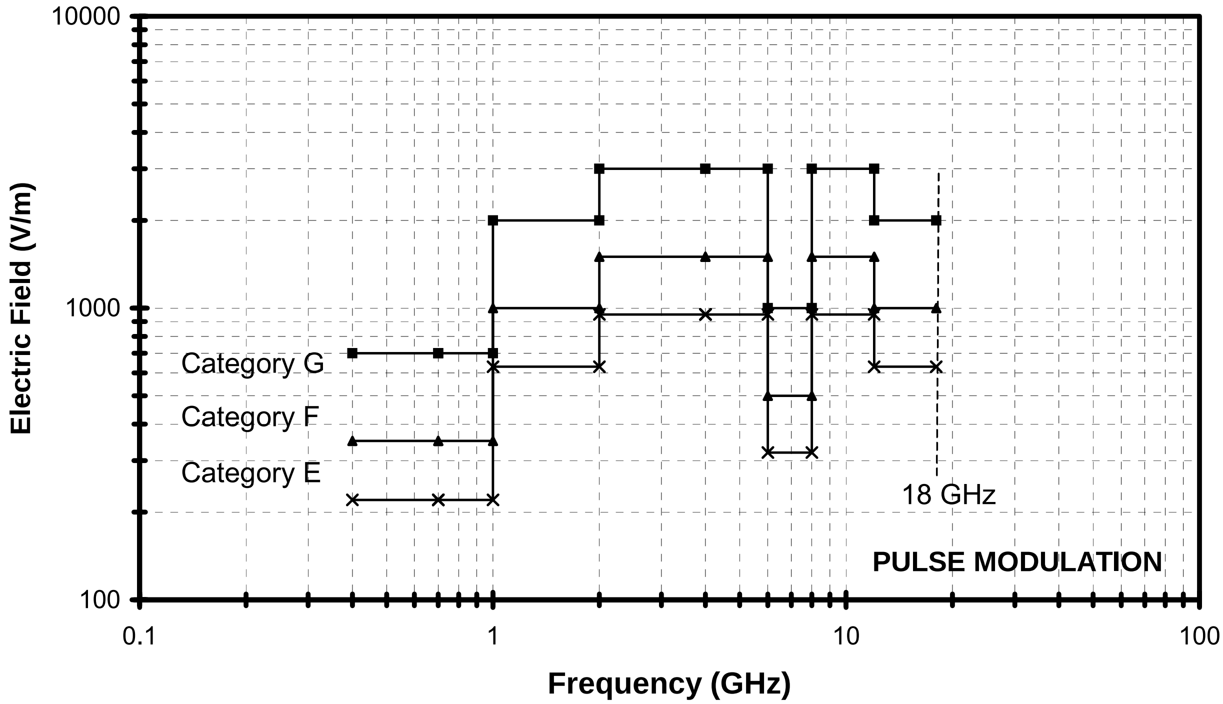
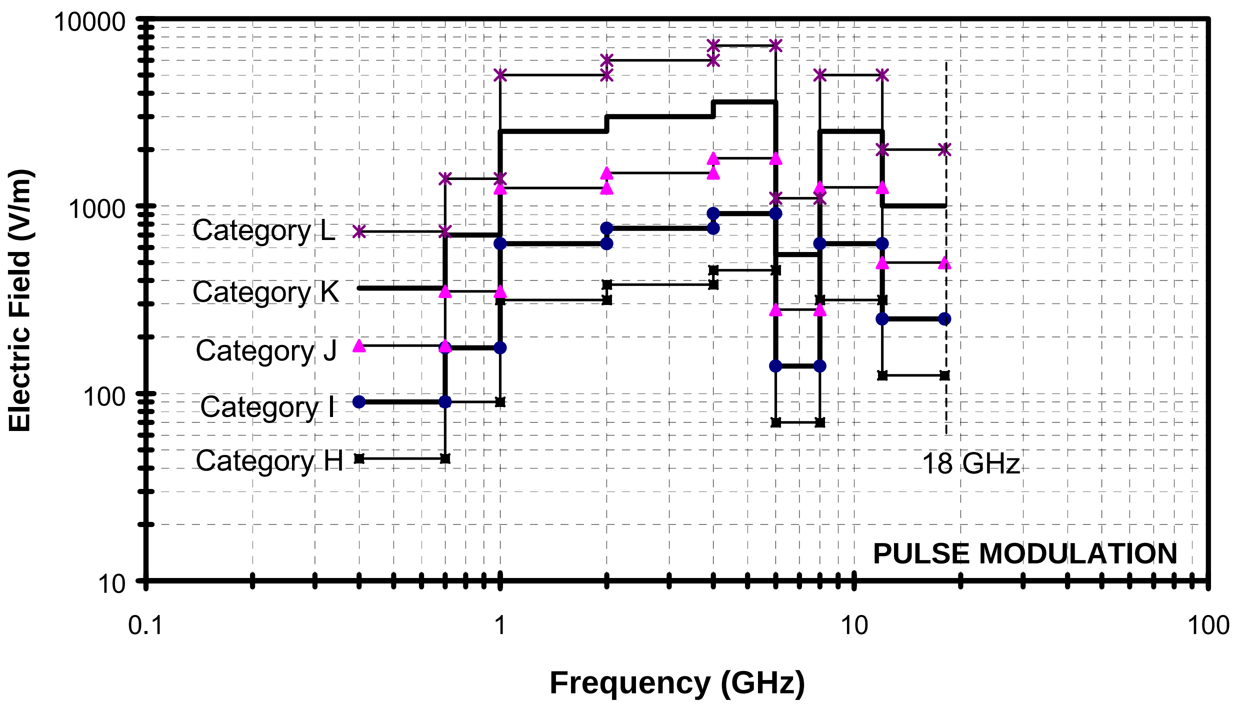


FIGURE 20-10(E&F) RADIATED SUSCEPTIBILITY TEST LEVELS





<u>FIGURE 20-10(G&H)</u> RADIATED SUSCEPTIBILITY TEST LEVELS

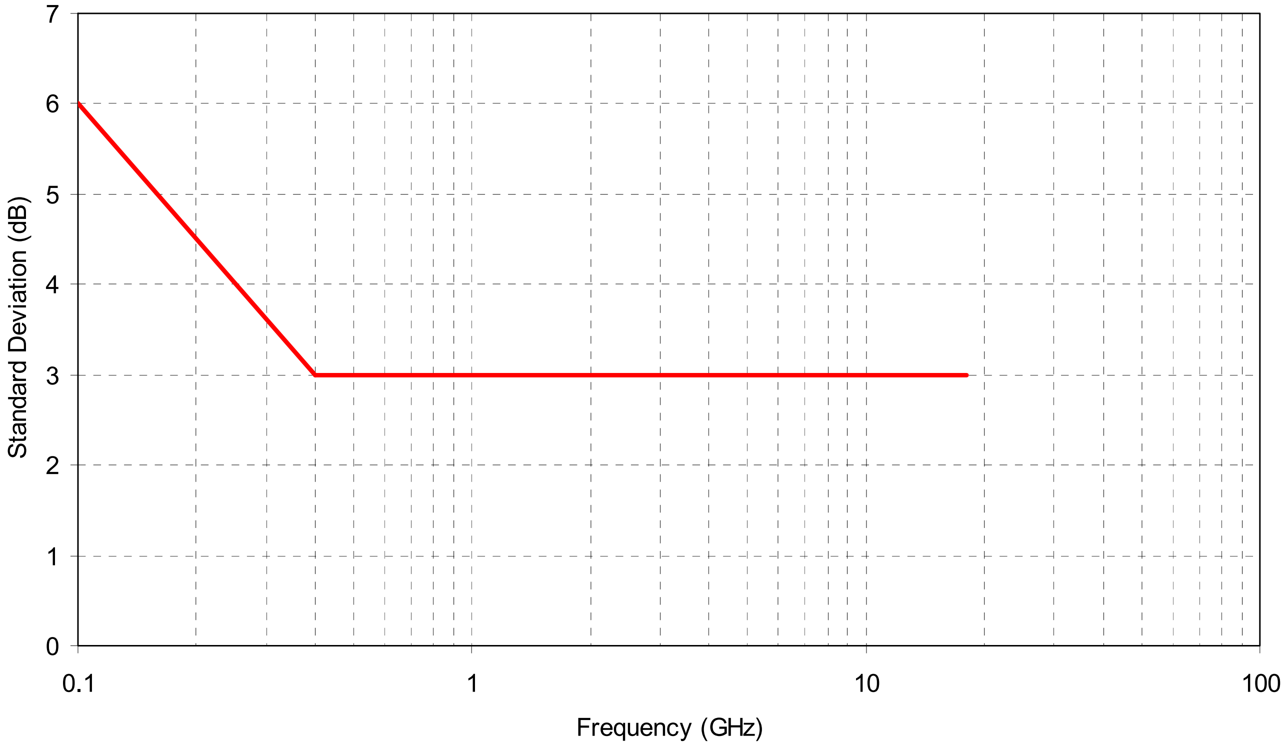
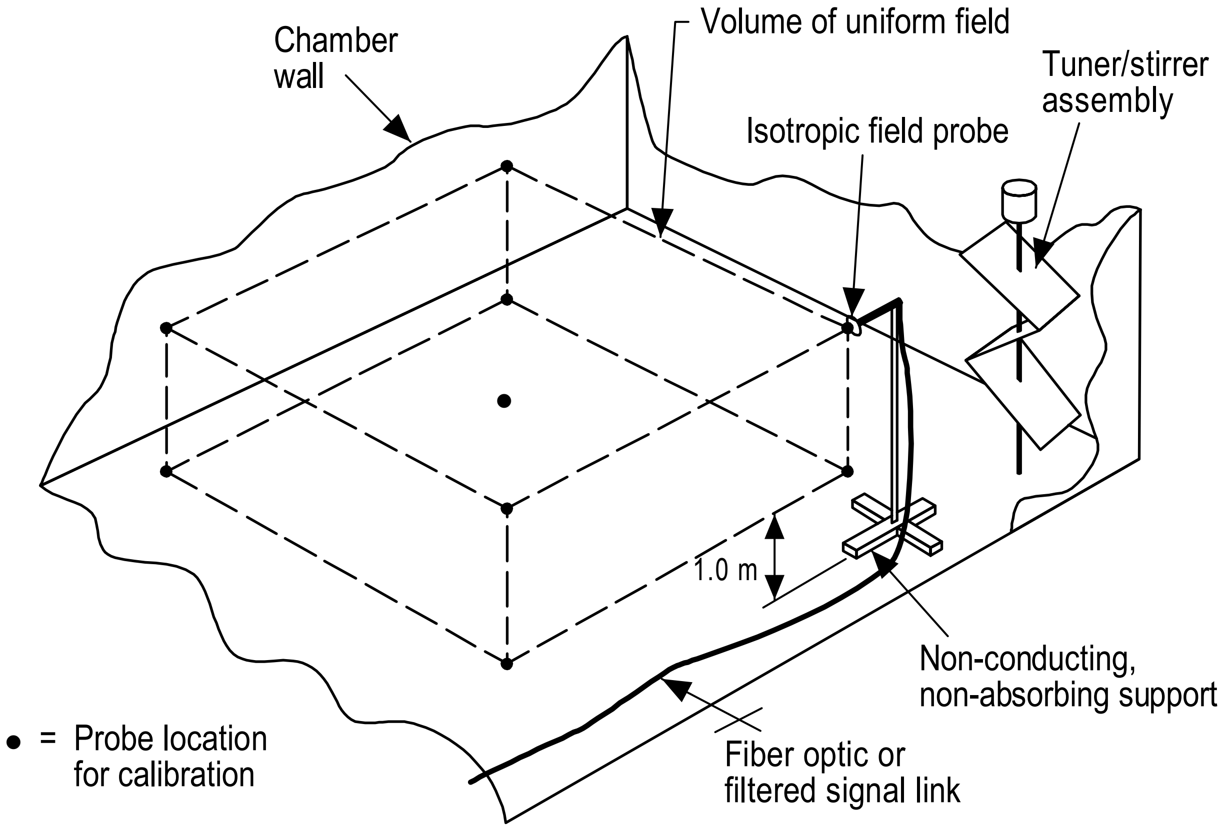


FIGURE 20-11 **ALLOWABLE STANDARD DEVIATION FOR FIELD UNIFORMITY TEST**



NOTE 1: Calibration of the fields inside the reverberation chamber shall consist of nine probe locations.

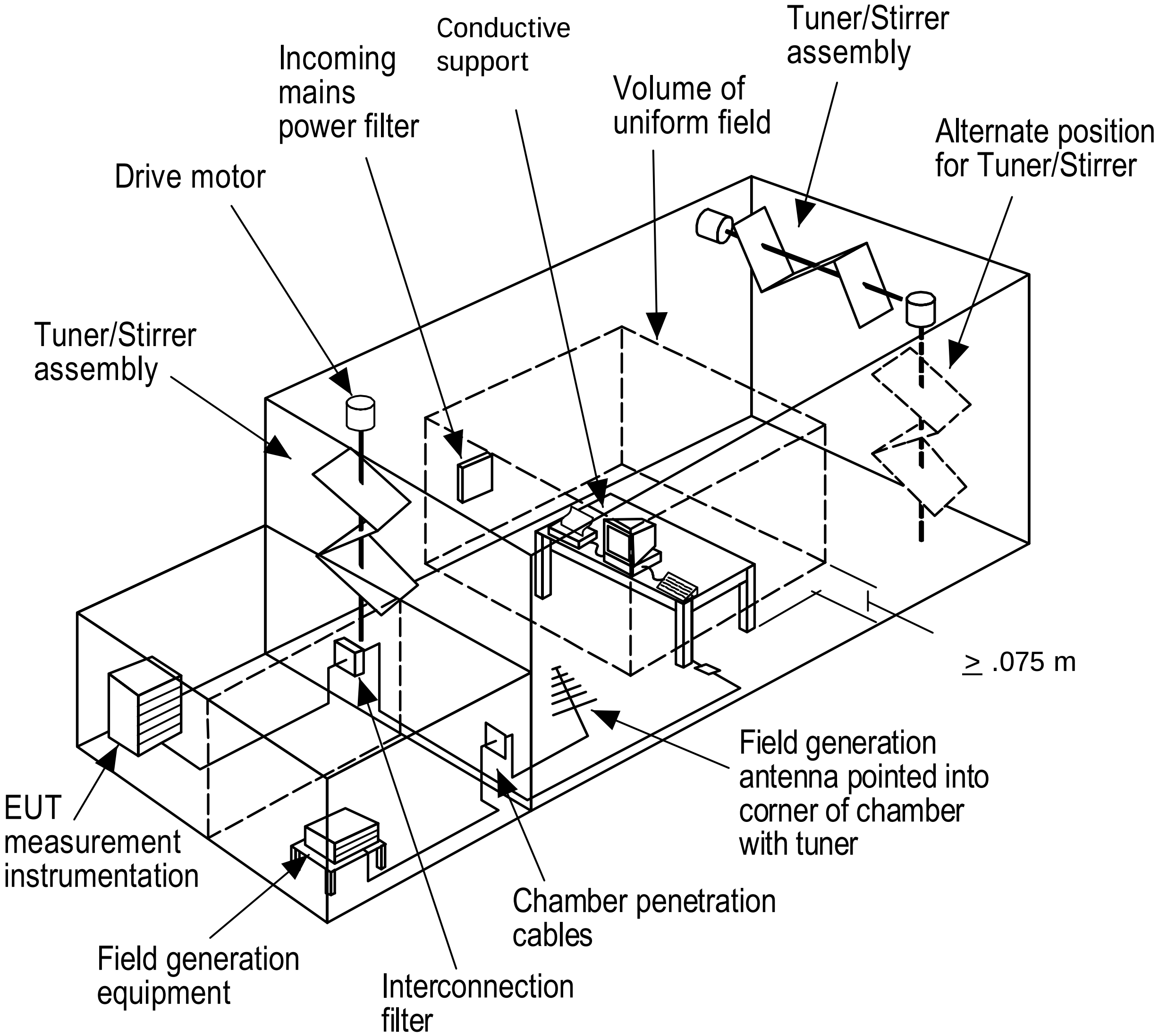
NOTE 2: The locations shall enclose a volume as shown above. This volume is the "working volume" of the chamber. The surfaces bounding the working volume should not be located closer than 0.75 meter (or $\lambda/4$ at the lowest test frequency) from any chamber surface, field generating antenna or tuner assembly. For calibration and monitoring purposes the receive antenna may be located at any location within the working volume. The transmit antenna should be directed into a corner of the chamber if possible. Directing the antenna into the tuner is also acceptable. The location of the transmit antenna shall remain fixed during calibration and testing. The location of the transmit antenna shall be the same for both calibration and testing.

NOTE 3: The working volume may be sized to suit the maximum working volume of the chamber or sized to suit the items to be tested. It is recommended that the working volume be sized to suit the maximum working volume since a second calibration will be required if larger items are to be tested.

NOTE 4: An isotropic probe which provides access to each of the three axes shall be used to conduct calibrations. A calibrated electrically short dipole antenna (i.e. less than 0.1 m) may be substituted provided that the dipole antenna is positioned at three mutually perpendicular orientations for each measurement location. Care should be taken to ensure that the dipole is not influenced by its connecting cable. An optically isolated measurement system (isotropic probe or dipole) is recommended.

NOTE 5: The minimum separation distance may be reduced to less than 0.75 meter provided that the separation is greater than $\lambda/4$ for the lowest test frequency. Separation distances of less than 1/4 meter are not recommended in any case.

<u>FIGURE 20-12</u> PROBE LOCATIONS FOR REVERBERATION CHAMBER CALIBRATION



NOTES:

(1): Working volume must be at least .75 meter (or λ/4) from any chamber surface, field generating antenna or tuner assembly.

(2): The chamber should remain free of any unnecessary absorbing materials. Items such as wooden tables, carpeting, floor covering, wall covering or ceiling tiles should not be used. Exposed light fixtures are also a source of potential loading. For new chambers, it is recommend that an evaluation of the chamber be conducted prior to installation of any support equipment other than doors, vents and access panels.

FIGURE 20-13 EXAMPLE OF SUITABLE REVERBERATION CHAMBER TEST FACILITY

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 21

Emission of Radio Frequency Energy

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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Prepared by: SC-135

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21.0 Emission of Radio Frequency Energy

21.1 Purpose of the Test

These tests determine that the equipment does not emit undesired RF noise in excess of the levels specified below. The notches specified in the radiated emissions limits are included to protect aircraft RF sensors operating frequencies.

21.2 Equipment Categories

Categories are defined in terms of location and separation between the equipment and aircraft radio antennas. As these parameters are widely linked to aircraft type and size, some examples are given with each category definition.

<u>Category B</u>

This category is intended primarily for equipment where interference should be controlled to tolerable levels.

<u>Category L</u>

This category is defined for equipment and interconnected wiring located in areas far from apertures of the aircraft (such as windows) and far from radio receiver’s antenna. This category may be suitable for equipment and associated interconnecting wiring located in the electronic bay of an aircraft.

<u>Category M</u>

This category is defined for equipment and interconnected wiring located in areas where apertures are EM (electro-magnetically) significant and not directly in view of radio receiver’s antenna. This category may be suitable for equipment and associated interconnecting wiring located in the passenger cabin or in the cockpit of a transport aircraft.

<u>Category H</u>

This category is defined for equipment located in areas which are in direct view of radio receiver’s antenna. This category is typically applicable for equipment located outside of the aircraft.

21.3 Conducted RF Emission

a. Interference currents generated by the equipment and measured by using a clamp-on interference measuring device within the frequency ranges and in excess of the values given in <u>Figure 21-1 (a)</u> shall not appear on any power line normally connected to an aircraft bus. Measure conducted emissions from 150 kHz to 30 MHz.

Line Impedance Stabilization Networks (LISNs) shall be used as shown in Figure 21-3. Figure 20-1 provides technical data for a LISN. Power return wires tied locally to the ground plane as noted in Section 20.3.a (6) are not tested.

b. Interference currents on interconnecting cable bundles other than antenna feed cables and primary power lines shall be measured by using a clamp-on interference measuring device. Measure conducted emissions from 150 kHz to 30 MHz. The emission limits are shown in Figure 21-2.

Figure 21-3 shows a simplified test arrangement for the use of the current probe.

Install the current probe five centimeters from the EUT. If the EUT connector plus backshell length exceeds five centimeters the probe shall be placed as close to the connector backshell as possible and the position noted.

21.4 Radiated RF Emission

Radiated interference fields generated by the equipment within the frequency ranges, and in excess of the values shown in Figures 21-4, 21-5 and 21-6 for the appropriate categories, shall not be radiated from any unit, cable or interconnecting wiring. This does not include radiation emanating from antennas or, in the case of transmitters, any radiation on the selected frequency ±50% of the band of frequencies between adjacent channels; when the transmitter is keyed and supplying RF to the load. Radio transmitters or receiver/transmitters must meet specified emissions requirements (including the selected frequency ±50% of the band of frequencies between adjacent channels) while in an unkeyed or receive mode. A typical arrangement of equipment for conducting the radiated RF emission test is shown in Figure 21-7.

Note: Subsection 21.4 does not measure or control spurious signals conducted out of the antenna terminals of receivers and transmitters. That control should be specified in the equipment performance standard for that receiver or transmitter.

21.5 General Requirements

The equipment under test shall be set up on a ground plane and operated in accordance with the criteria in Subsection 20.3 subparagraph a and parts 1, 2 and 5 of subparagraph b, with the following additions:

a. Interference shall be measured using the peak detector function of the interference measuring equipment. Interference measuring instruments with selectable IF bandwidths (BWI) may be used, and the selected BWI must be the values given in the following table.

The time constant of the peak detector must be lower or equal to 1/BWI. Where applicable, video bandwidths shall be selected to be greater than or equal to the resolution bandwidth.

Frequency Bands	BWI
0.15-30 MHz	1 kHz
30-400 MHz	10 kHz
400-1000 MHz	100 kHz
1000-6000 MHz	1 MHz

Note: During radiated tests the above bandwidths may not provide a low enough noise floor to make proper measurements in the notches defined for categories M & H. In that case, a 10 kHz BWI shall be used for measurements in the notches with no correction factor being applied.

b. Field strength units are obtained by using any appropriate antenna and adding the appropriate antenna factor to the measured voltage in dB microvolts. Appropriate correction factor for cable losses and matching networks must also be applied.

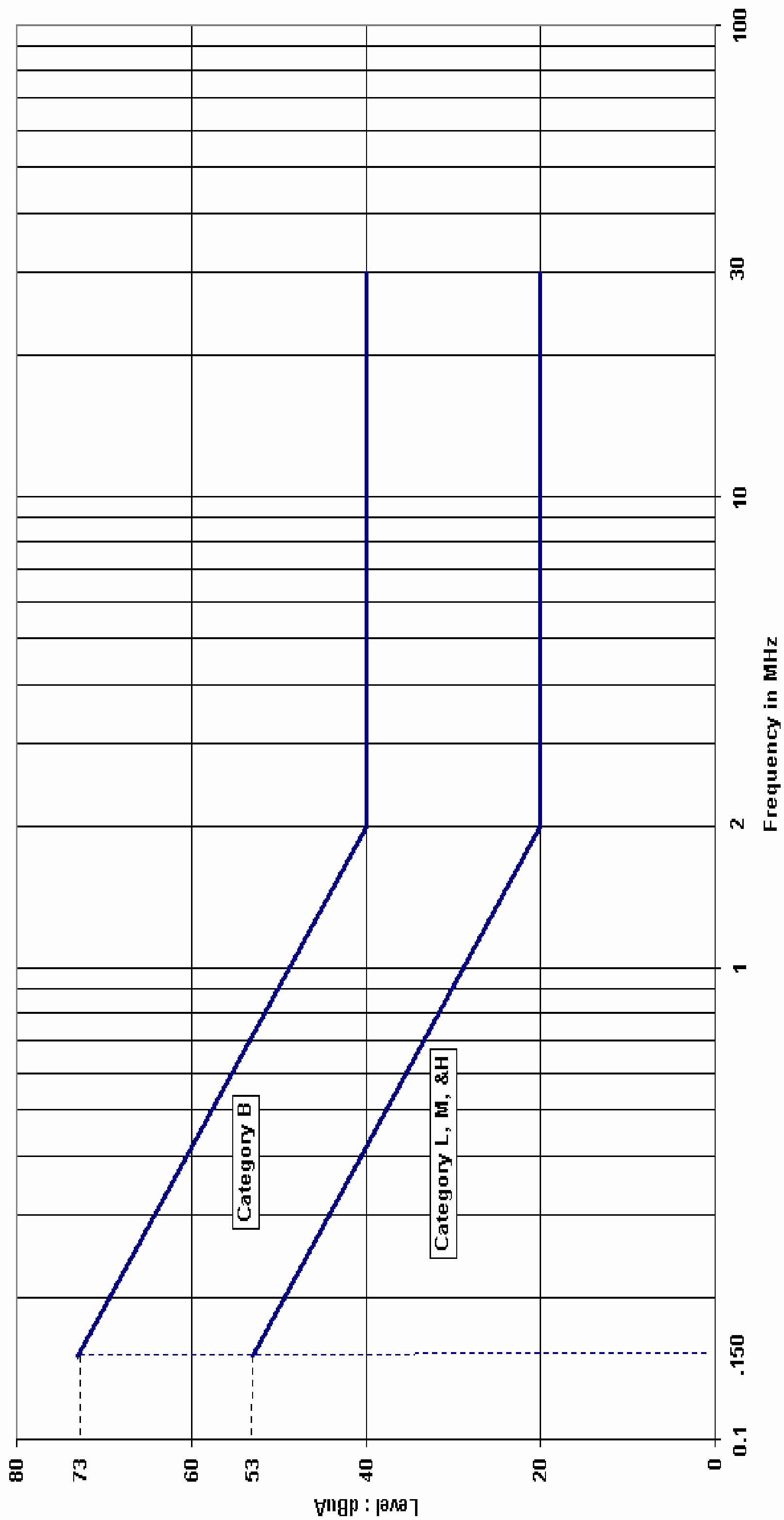
c. Linearly polarized antennas are required for radiated tests. Above 25 MHz, measure radiated emissions using both vertically and horizontally polarized orientations.

d. For EUT with multiple apertures and sensors such as displays, several different orientations may be required, for example connector side and aperture side(s) facing the antenna.

e. Consider EUT realistic operating modes which produce maximum emission.

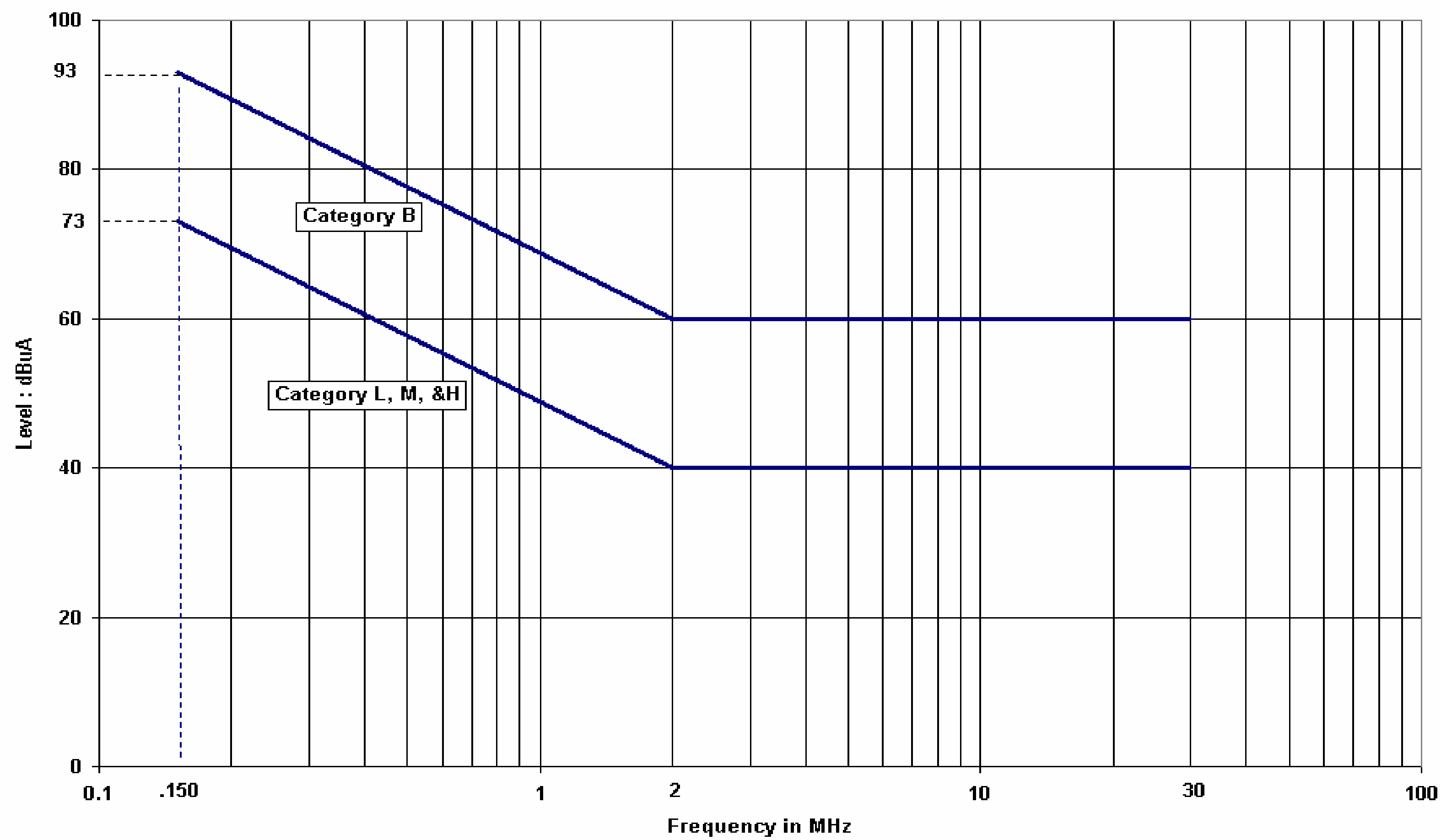
f. Radiated ambient data (EUT “off” and test support equipment “on”) is required only if EUT emissions are greater than 3 dB below the selected category limit. It is good engineering practice to check ambient radiated emissions prior to a radiated emissions test, and it is desirable that the ambient emissions be at least 6 dB below the selected limit line.

g. Measure and record the EUT emissions conditions and apply the appropriate limit from Figures 21-4, 21-5 or 21-6 for the selected category.



Curve definition : Limit Level = slope * log(freq in MHz) + intercept
Category B: F<2 MHz slope = -29.335, intercept = 48.83
Category L,M,&H: F<2 MHz slope = -29.335, intercept = 28.83

Figure 21-1 : Maximum Level of Conducted RF Interference – Power Lines



Curve definition : Limit Level = slope * log(freq in MHz) + intercept
Category B: F<2 MHz slope = -29.335, intercept = 68.83
Category L,M&H: F<2 MHz slope = -29.335, intercept = 48.83

Figure 21-2 : Maximum Level of Conducted RF Interference – Interconnecting Bundles

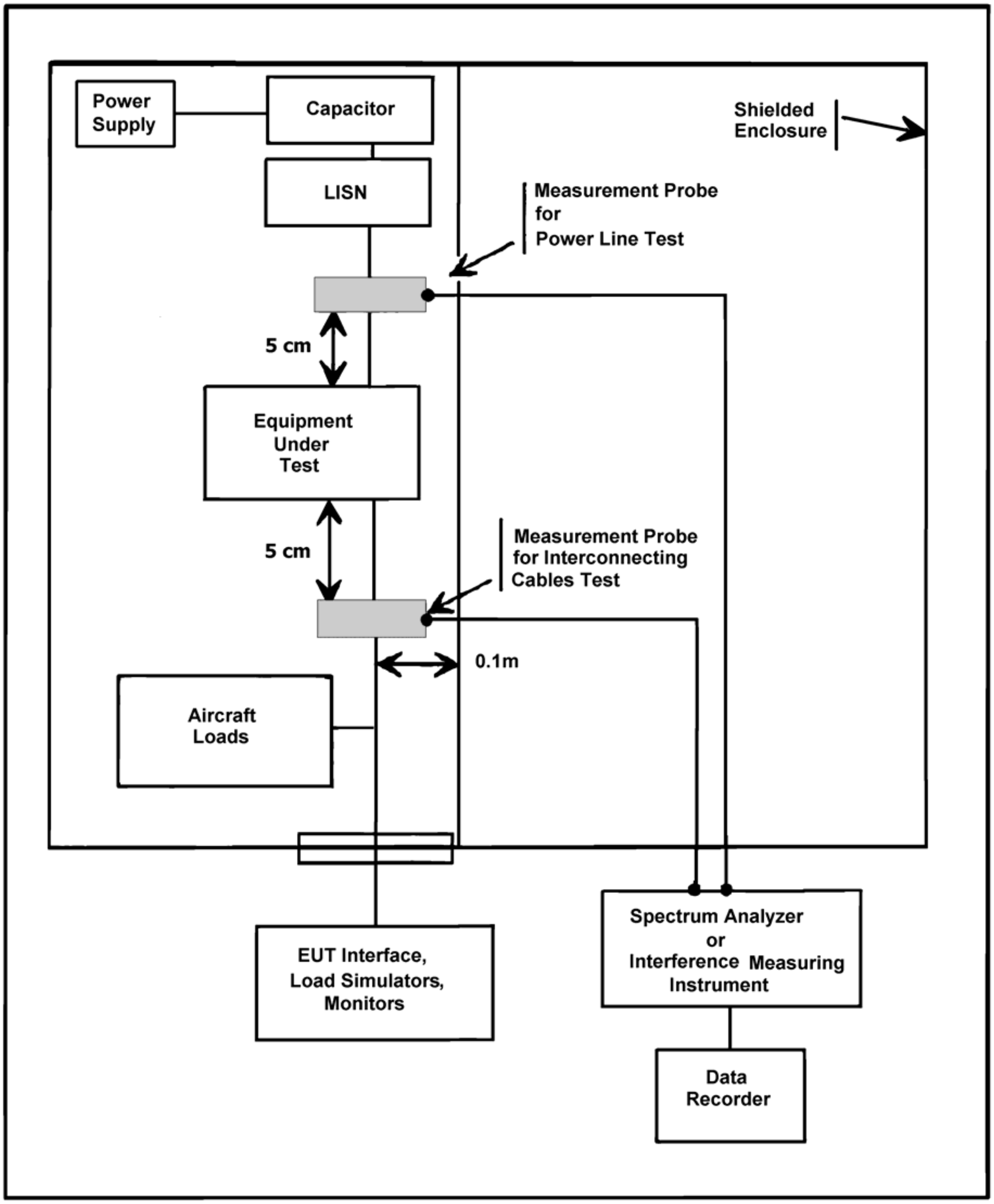
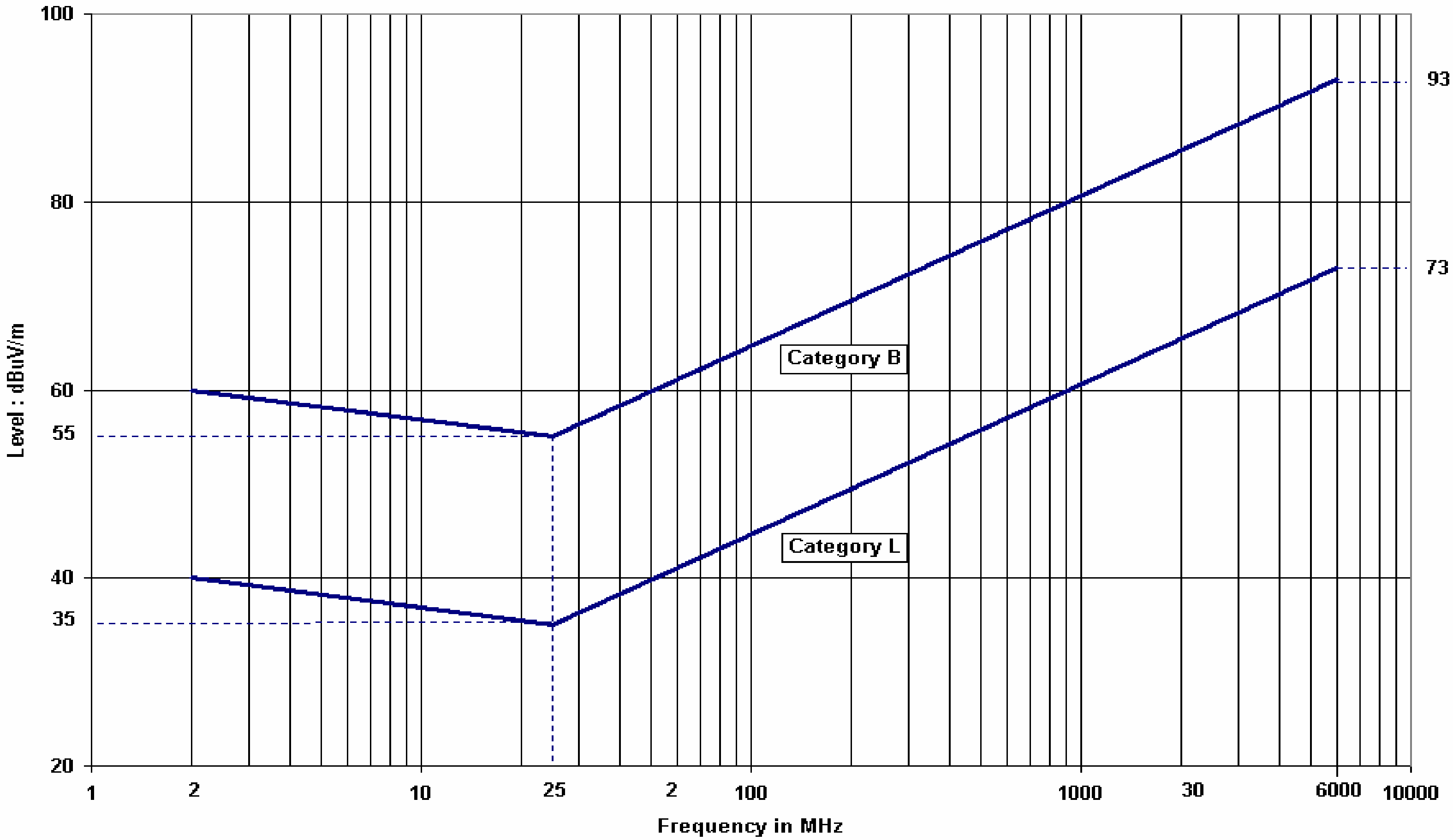
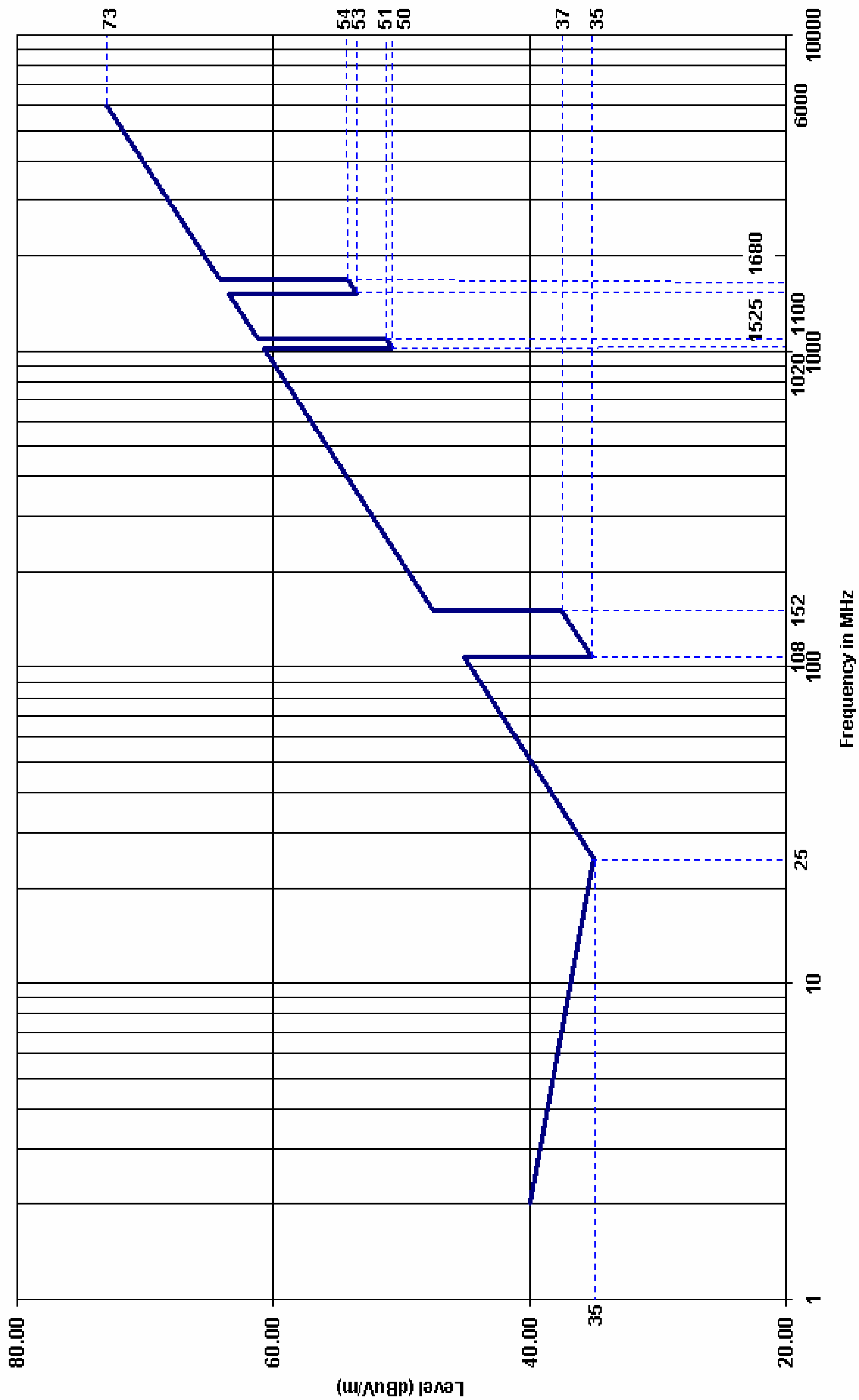


Figure 21-3 **Typical Setup for Conducted RF Interference Test**



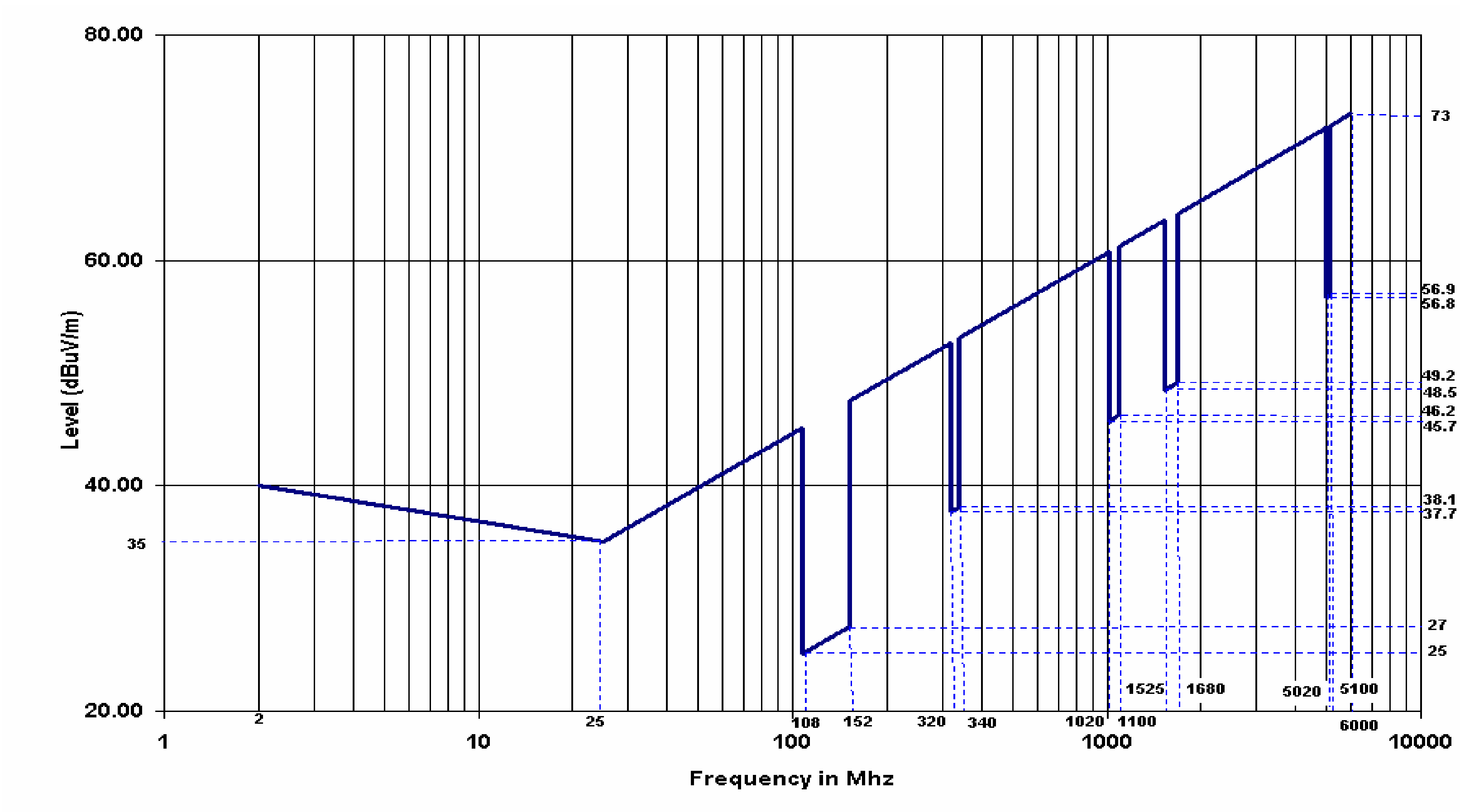
Curve definition : Limit Level = slope * log(Freq in MHz) + intercept
Category B: F<25 MHz slope = -4.558, intercept = 61.372 **F>25 MHz slope = 15.965, intercept = 32.682**
Category L: F<25 MHz slope = -4.558, intercept = 41.372 **F>25 MHz slope = 15.965, intercept = 12.682**

Figure 21-4 : Maximum Level of Radiated RF Interference – Category B & L



Curve definition outside of notches: Limit Level = slope * log(freq in MHz) + intercept
Category M: F<25 MHz slope = -4.558, intercept = 41.372   F>25 MHz slope = 15.965, intercept = 12.682

Figure 21-5 : Maximum Level of Radiated RF Interference – Category M



Curve definition outside of notches: Limit Level = slope * log(freq in MHz) + intercept
Category M: F<25 MHz slope = -4.558, intercept = 41.372 F>25 MHz slope = 15.965, intercept = 12.682

Figure 21-6 : Maximum Level of Radiated RF Interference – Category H

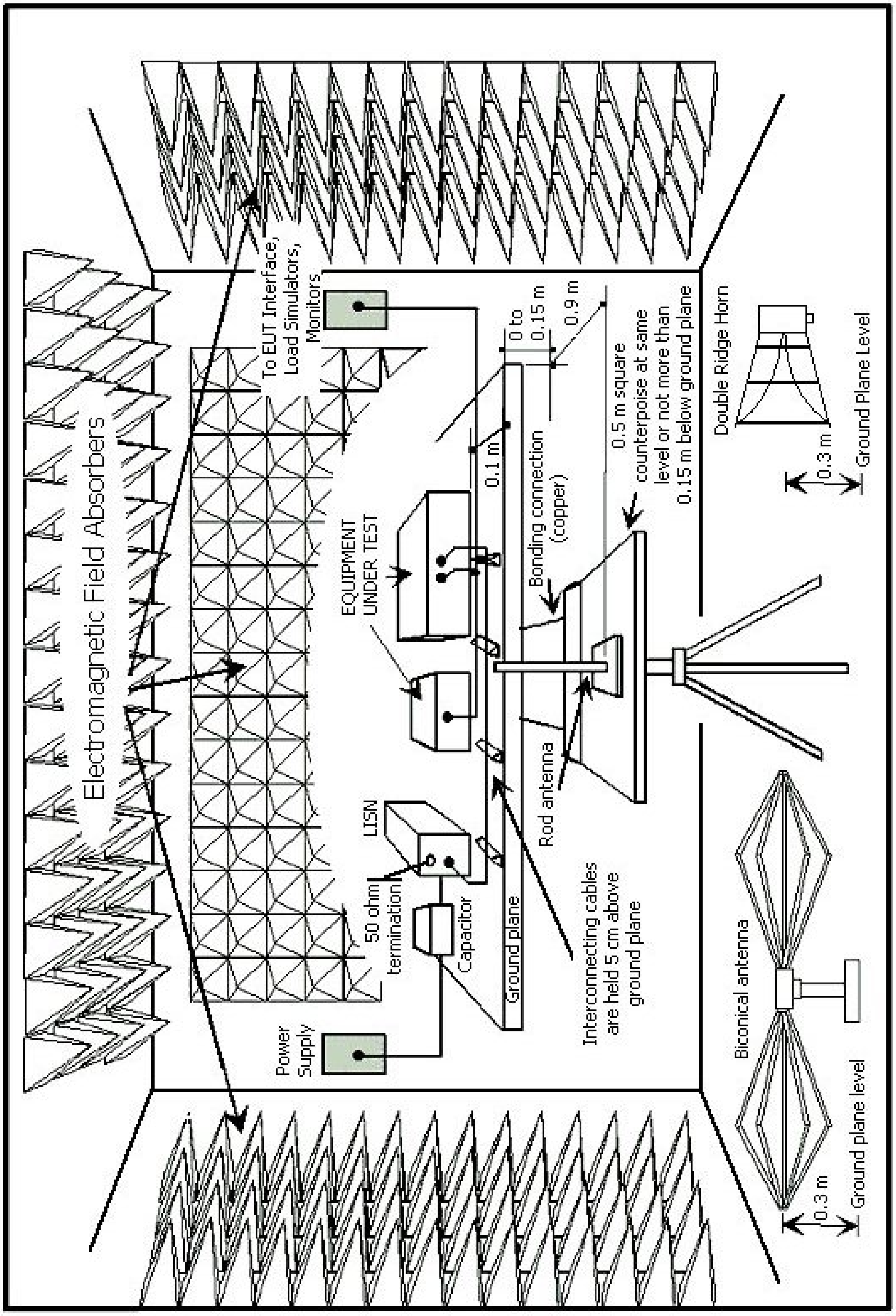


FIGURE 21-7 : TYPICAL SETUP for RADIATED RF INTERFERENCE TEST

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 22

Lightning Induced Transient Susceptibility

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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22.0 Lightning Induced Transient Susceptibility

22.1 Purpose of Tests

These test methods and procedures apply idealized waveforms to verify the capability of equipment to withstand effects of lightning induced electrical transients. The criteria for equipment performance in the presence of lightning transients shall be defined in the applicable equipment specification.

Two groups of tests may be used for equipment qualification. The first is a damage tolerance test performed using pin injection as described in paragraph 22.5.1. The second group, as described in paragraph 22.5.2, evaluates the functional upset tolerance of equipment when transients are applied to interconnecting cable bundles. Cable bundle tests include single stroke, multiple stroke, and multiple burst, response tests (hereafter referred to as single stroke, multiple stroke and multiple burst). Cable bundle tests can also provide an indication of damage tolerance. The appropriate test group or groups will be defined in the applicable equipment specifications.

Note: These tests may not cover all aspects of lightning induced interaction and effects on equipment, particularly when incorporated into a system. Additional tests such as application of different waveforms, simultaneous cable bundle injection and multiple frequency, may be required to achieve certification of the equipment/system installation, depending upon the functions performed. Tests for the direct effects of lightning on equipment are covered in Section 23.0 of this document.

22.2 Definitions

Cable Bundle
A group of wires and/or cables bound or routed together that connect a piece of equipment to one or more pieces of equipment comprising the system under test.

Calibration Loop
A heavy duty, low self-inductance, low resistance, single turn wire loop passed through the injection transformer to form an insulated secondary winding. It should be low enough in impedance to achieve the test level and waveform.

Core Wire
An individual wire inside a shield. The individual wire induced voltages/currents are reduced from the driven loop voltages/currents by the presence of the shield (i.e. by the shield transfer impedance).

Generator
A set of equipment (waveform synthesizer, amplifiers, couplers, etc.) that delivers a voltage or current waveform, via direct or indirect coupling to the equipment under test (EUT).

Local Ground
Any ground strap or conductor that is connected to the equipment and the same part of airframe structure to which that equipment is installed. The ground strap or conductor would therefore be bonded to the same ground plane that the equipment is mounted to and, during a lightning strike, would be at the same potential as the equipment.

Monitor Loop

A close fitting, single turn, wire loop wound through the injection transformer to form an insulated secondary winding. It is used to monitor the induced cable bundle or calibration loop voltage.

Multiple Burst Application
A set of transient waveforms intended to represent the induced effects of the external lightning Multiple Burst Waveform Set in aircraft wiring. The Multiple Burst Application includes an induced transient corresponding to each current pulse in the external environment. Each of the induced transients is the response to the external environment. There are three groups of twenty transients in the Multiple Burst Application.

Multiple Stroke Application
A set of transient waveforms intended to represent the induced effects of the external lightning Multiple Stroke Waveform Set in aircraft wiring. The Multiple Stroke Application includes an induced transient waveform corresponding to each stroke in the external multiple stroke environment. There are fourteen transients in the Multiple Stroke Application. The first induced transient is the response to first return stroke of the external environment and the following thirteen transients are the response to follow on or multiple return strokes of the external lightning environment.

Shield
For the purposes of this section, a shield is a conductor which is grounded to an equipment case or aircraft structure at both ends and is routed in parallel with and bound within a cable bundle. It usually is a wire braid around some of the wires or cables in the cable bundle or may be a metallic conduit, channel or wire grounded at both ends within the cable bundle. The effect of the shield is to provide a low resistance path between equipment so connected.

Shielded Cable Bundle
A cable bundle that contains one or more shields. Such cable bundles may include some unshielded wires.

Single Stroke Response
Representative wiring response to the most severe external component of a lightning strike to an aircraft.

Unshielded Cable Bundle
A cable bundle that contains no shields.

22.3 Categories

The equipment manufacturer must test the equipment to the test levels and waveforms consistent with its expected use and aircraft installation.

Category designation for equipment shall consist of five characters:

a. Pin test waveform set letter (A or B) as designated in Table 22-1 or Z or X.

b. Pin test level (1 to 5) as designated in Table 22-2 or Z or X.

c. Cable bundle test waveform set letter (C through K) as designated in Table 22-1 or Z or X.

d. Cable bundle single and multiple stroke test level (1 to 5) as designated in Table 22-3 and Table 22-4 or Z or X.

e. Cable bundle multiple burst test level (1 to 5) as designated in Table 22-5 or Z or X.

Category designation should, therefore, appear as follows:

B	**3**	**G**	**4**	**3**
Pin Test Waveform Set	Pin Test Level	Cable Bundle Test Waveform Set	Cable Bundle Single and Multiple Stroke Test Level	Cable Bundle Multiple Burst Test Level

In the above example, Category B3G43 identifies an equipment with Pin Injection test using waveform set B (Table 22-1), level 3 (Table 22-2) and cable bundle test with waveform set G including single stroke tests at level 4 as indicated in Table 22-3, multiple stroke tests at level 4 as indicated in Table 22-4, and multiple burst tests at level 3 as indicated in Table 22-5. In another example B3XXX would identify an equipment pin test with waveform set B at level 3 as indicated in Table 22-2. When no tests are performed, the category designation is XXXXX.

A general installation case for cable bundles is illustrated in Figure 22-1. Figure 22-2 through Figure 22-8 define the individual waveforms associated with waveform sets A through K.

The use of Z in the waveform set designator positions indicates that either the waveform set or the test configuration (i.e. shielding, grounding) was different from that designated in Table 22-1. Similarly, a Z in the test level position indicates that the test levels applied were different from those designated in Table 22-2 through Table 22-5. For example, AZZ33 indicates that pin tests were conducted at level(s) other than those designated, and the single stroke, multiple stroke and multiple burst tests were performed using an alternate waveform set or an alternate configuration at level 3. The specific test conditions and test levels shall be described in the test report.

22.3.1 Waveform Set Designators (First and Third Characters)

Waveform sets A, C, E, G and J are applicable to equipment interconnected with wiring installed within airframes or airframe sections where apertures, not structural resistance, are the main source of induced transients as would be the case in an all-metal airframe. For the same reasons, these waveform sets can also apply to equipment in airframes composed of metal framework and composite skin panels, and to equipment in carbon fiber composite (CFC) airframes whose major surface areas have been protected with metal meshes or foils.

Waveform sets B, D, F, H and K are applicable for equipment interconnected with wiring installed within any airframe or airframe section when structural resistance is also a significant source of induced transients, (i.e., carbon fiber composite structures). In these cases the wiring is exposed to high structural voltages and redistributed lightning currents, which are represented by Waveform 5A.

A and B are for pin injection tests.

C through F are for cable bundle single stroke tests.

G through K are for cable bundle single stroke, multiple stroke, and multiple burst tests.

Z indicates tests other than those specified in Table 22-1 were conducted, such as the use of waveform set C, D, G, or H with shielded cables.

22.3.2 Test Level Designators (Second, Fourth and Fifth Characters)

Test level descriptions for internal aircraft environments are provided below with specific levels for each test waveform listed in Table 22-2 through Table 22-5. Levels 1 through 5 allow flexibility in the protection of equipment. The descriptions are for guidance only. Anticipated exposure of interconnecting wiring and equipment location determines the test level.

Level 1 is intended for equipment and interconnecting wiring installed in a well-protected environment.

Level 2 is intended for equipment and interconnecting wiring installed in a partially protected environment.

Level 3 is intended for equipment and interconnecting wiring installed in a moderately exposed environment.

Levels 4 and 5 are intended for equipment and interconnecting wiring installed in severe electromagnetic environments.

Z indicates tests conducted at voltage and/or current levels other than those specified in Table 22-2 through Table 22-5.

22.4 General Test Requirements

a. Equipment Under Test - The EUT shall be set up on a ground plane and configured in accordance with the following criteria unless otherwise specified by the individual equipment specification:

(1) Ground Plane - A copper, brass or aluminum ground plane, at least 0.25 mm thick for copper and aluminum, 0.5 mm thick for brass, 2.5 m^2 or more in area with a minimum depth (front to back) of 0.75 m shall be used. When a shielded enclosure is employed, the ground plane shall be bonded to the shielded enclosure at intervals no greater than one meter and at both ends of the ground plane. It is recommended that the dc bonding resistance should be 2.5 milliohms or less.

(2) Shock and Vibration Isolators - If specified by the equipment manufacturer, the EUT shall be secured to mounting bases incorporating shock or vibration isolators. The bonding straps furnished with the mounting bases shall be connected to the ground plane. When mounting bases do not incorporate bonding straps, they shall not be used in the test setup.

(3) Electrical Bonding - Only the provisions included in the EUT design or installation instructions (e.g., bonding of enclosure, mounting base and ground plane) shall be used for bonding. The electrical bonding of equipment, connectors and wire bundles shall be representative of aircraft installations and in accordance with the equipment manufacturers' requirements for minimum performance.

Equipment intended to be grounded by means other than the bonding supplied by the installation method should be placed on an insulating mat. The test report shall describe the bonding methods employed.

(4) External Ground Terminal - When an external terminal is available for a ground connection on the EUT, the terminal shall be connected to the ground plane to ensure safe operating conditions during the test, unless otherwise specified for these tests. The length of the connection defined in the installation instructions shall be used; if a length is not defined, use approximately 30 cm of a representative wire or strap.

These grounds should not be included as a parallel current path with the cable bundle under test unless these grounds are routed with the cable bundle for its entire length. If present at the unit under test during ground injection tests, these grounds should be tied to the EUT chassis.

(5) Interconnecting Wiring/Cable Bundles - For cable bundle tests, all EUT interconnecting wiring (e.g., shielded wires, twisted wires, etc.), cable bundles and RF transmission lines shall be in accordance with the applicable installation and interface control drawings or diagrams.

Cables shall be bundled in a manner similar to that of aircraft installations and the lowest point of the cable bundle supported at a height of 50 mm above the ground plane unless greater heights have been specified as more representative of the aircraft installation (and recorded in the test report). The supporting material must be non-absorptive, non-conductive, and non-reflective. For complex cable bundle configurations, all cable bundles and interconnected loads should be kept separated from each other as much as practical to minimize coupling effects between cables.

Unless otherwise specified, the cable bundle shall be at least 3.3 m. When the length of an interconnecting cable bundle is greater than the test bench, the cable bundle should be arranged with the excess length zig-zagged at the back of the test bench approximately 50 mm above the ground plane.

Some special installations may require very long cable bundle lengths which cannot be accommodated on the test bench; therefore, the recommended maximum length of the interconnecting cable bundles for these tests should not exceed 15 m. The exception to this limitation is where cable bundle lengths are matched or specified to a particular length for phase match or similar reasons.

(6) Power Leads - For cable bundle tests, power and return leads normally bundled with the control/signal leads shall remain in the cable bundle and only be separated from the bundle just prior to the cable bundle exiting the test area. These leads shall then be connected to Line Impedance Stabilization Networks (LISNs). See paragraph 22.4b (2).

When the actual aircraft cable bundle configuration is unknown or when power and/or return leads are normally routed separately from the control/signal leads, the power and return leads should be broken out of the cable bundle near the connector of the EUT and run separately to the LISNs. Under these conditions, the length of the leads to the LISNs shall not exceed 1.0 m unless otherwise specified in the applicable equipment specification.

When the return lead is a local ground (less than 1 meters length), this lead may be grounded directly to the test bench, in accordance with the applicable installation and interface control drawings or diagrams.

(7) Interface Loads and Support Equipment - Cable bundle tests ideally should be performed on fully functioning equipment. EUTs should be suitably loaded with actual interface equipment.

Where the interface equipment must be simulated, the simulated electrical, electronic and/or electromechanical characteristics of the loads should be representative of the aircraft installation. To avoid altering the voltage and current distributions in the cable bundles, the electrical/electronic loads should simulate the actual load line-to-line and line-to-ground impedances (including stray capacitance) as far as is practical. This load simulation shall take into account the actual impedance existing in the system under lightning conditions, when surge suppressors, if any, are activated.

Care should be taken that any test configuration, simulated load or monitoring equipment does not alter the susceptibility or immunity of the EUT. The support equipment may require protection from the effects of the applied transients in order to avoid upset or damage.

(8) Dummy Antennas or Loads - For the purpose of this test, antenna cables may be terminated in a load equal to the cable characteristic impedance, or a dummy antenna. The dummy antenna, if used, shall be shielded and be designed to have electrical characteristics closely simulating the in-service antenna. It shall also contain electrical components normally used in the antenna, such as filters, crystal diodes, synchros and motors.

b. Test equipment - These shall be set up and configured in accordance with the following criteria:

(1) Bonding - Test equipment shall be bonded and grounded to minimize ground loops and ensure personnel safety. When high current levels are to be applied to cable bundles, care shall be exercised to ensure that these currents are safely transferred from the shields to the wall of the shielded enclosure or that adequate bonding and shielding is provided outside the shielded enclosure to minimize risk to personnel.

(2) Line Impedance Stabilization Network - A LISN shall be inserted in each primary power input and return line. Power return lines locally grounded in the aircraft installation do not require a LISN. The LISN case shall be bonded to the ground plane. When LISNs with self resonances above 10 kHz are used (such as standard 5uH LISN), capacitors shall be inserted at each LISN power input terminal as shown in Figure 22-17 or Figure 22-19 for the entire test. The RF measurement port of the LISN shall be terminated into 50 ohms for all tests. The input impedance characteristic of the LISN is shown in Figure 22-9.

(3) Measurement and Injection Probes - Probes shall have the necessary power, bandwidth and dynamic range capabilities to reproduce the test waveform(s). Waveform 3 tests shall use probes with electrostatic shielding.

c. Data Required In Test Report - The test report shall include the following test setup and data items.

(1) Cable Configuration(s) - The length of each cable bundle, types of wiring, shielding and shield terminations (including individual as well as overall shields), and the wiring diagram of the test harness.

(2) Test Setups - Schematic or block diagrams or photographs of each test setup including layout of cable bundles, placement of transient injection and measurement probes and EUT bonding methods.

(3) EUT Operating Mode(s) - The mode(s) of operation used during cable bundle tests.

(4) Load(s) - A description of all loads, either actual or simulated. Simulated loads shall identify the extent of impedance simulation both line-to-line and line-to-case (ground).

(5) Test Waveforms and Levels - Calibration/verification oscillograms of each test waveform and level.

(6) Applied Transients – Waveforms of representative test currents and voltages measured on interconnecting cable bundle(s) or pin(s) as applicable to each test setup.

(7) Pass/Fail Criteria - A description of the pass/fail criteria.

(8) Test Results - The results of the test and any responses that do not meet the pass/fail criteria.

22.5 Test Procedures

Pin injection tests are primarily for damage assessment and involve the injection of transients directly into EUT interface circuits.

Cable bundle tests determine whether functioning equipment will experience upset or component damage when the equipment and its interconnecting wiring are exposed to the applied transients. The test methods and procedures are applicable to configurations composed of the EUT, interconnecting cable bundle(s) and load(s). (See Figure 22-1).

EUTs included in complex systems where various cable bundles are exposed to widely different environments may require different test levels on different cable bundles, requiring a Z category designator (see paragraph 22.3).

WARNING

The transient generators used in these tests produce lethal voltage and current levels. Exercise all operational safety precautions to prevent injury or death of test and support personnel.

22.5.1 Pin Injection Tests

Pin injection testing is a technique whereby the chosen transient waveform(s) is applied directly to the designated pins of the EUT connector, usually between each pin and case ground. This method is used for assessing the dielectric withstand voltage or damage tolerance of equipment interface circuits.

A dielectric withstand voltage or high potential (hi-pot) test may be used in lieu of the pin injection test to verify the ability of electrically simple devices such as actuators, linear variable differential transformers (LVDTs), and speed sensors to demonstrate compliance to the pin test requirements. These simple electrical devices must be passive with no EMI filters or transient voltage suppressors (or other similar electrical circuit elements that are connected through case ground to aircraft structure). In addition, the hi-pot test is applicable for electrical devices that are electrically isolated from case and local airframe grounds. In these cases, the interface signal and return wiring must be routed together (e.g. twisted pair) in the intended installation such that an insignificant line-to-line induced voltage results. The hi-pot test voltage level is to be at least the peak amplitude of a level in Table 22-2 (Note: when testing pins which normally have a bias voltage, i.e. power line inputs or other sources, this voltage must be added to the peak test voltage of Table 22-2). This test voltage may be applied from each pin to case or from all pins, simultaneously, to case.

Power shall be applied to the EUT except when the EUT has only passive components (e.g. electromechanical devices, temperature probes, hydraulic valves, etc.) and the presence of operating voltages and associated currents is not a factor in component failure.

When testing a unit with power applied, a suitable means must be used to ensure that the transient generator does not produce excessive loading of power supply or signal lines. In addition, when testing input power lines with power applied to the unit, some form of blocking device may be necessary to ensure that the applied transients will be directed to the interface of the equipment and not into the power supply or any other load.

In order to ease possible testing difficulties, pin tests under excitation of input power may also be accomplished by cable induction testing using the appropriate pin test waveforms and levels (Calibrated per Figure 22-11 and tested per Figure 22-14). Any shields on primary power lines being tested using this method shall be removed.
Groups (Four or more) of EUT circuits (pins) with the same circuit design for both protection and operation may be qualified by testing three representative pins of each group. The remaining pins in the group are qualified by similarity.

Multiple pins may be tested simultaneously if the applied test voltage amplitude and waveshape remains within the tolerances of the calibration open circuit voltage amplitude and waveshape. This is applicable only for input / output that are high impedance even under lightning conditions (and during tests).

When the remote load impedance characteristics (including dielectric strength characteristics) are specified in the equipment installation requirements, that impedance may be inserted in series with the generator and EUT provided that the load does not employ a protective device that would short out the load impedance. To account for cable characteristic impedance effects the maximum inserted series impedance shall be limited to 75 ohms during Waveform 3 tests, thereby resulting in a maximum source impedance of 100 ohms. When the remote load impedance is inserted in the test circuit, the category designator shall be Z. The test method, remote load impedance and dielectric strength shall be noted in the qualification test form and test report.

When the signal ground is connected to the structure outside the equipment in the real installation, it shall be also connected to the ground during laboratory tests. See Figure 22-13, Note 4. Warning: In some designs a single protection device may be used to protect multiple interfaces. In such designs the single pin to case test might not account for transients appearing on multiple interfaces at the same time. An assessment of the protection device rating and/or test method may be required.

22.5.1.1 Procedures - Generator Calibration

Calibration set-up to be as shown in Figure 22-10. For the pin injection tests with power on, in order to avoid shorting EUT currents through the generator low source impedances, a current blocking component should be included at the output of the pin test generator. This current blocking component is to be included as part of the calibration setup as shown in Figure 22-10.

When testing power pins with external power applied, the calibration setup of Figure 22-11 or Figure 22-12 would be applicable. In these setups, a means must be provided to bypass the power supply impedances to ensure that the transient waveform can be achieved at the calibration point. This bypass circuit also serves to protect the power supply. Note that power should not be applied while performing the following calibration procedure.

a. Adjust the transient generator such that the applicable open circuit voltage (Voc) waveform parameters identified in Figure 22-4 to Figure 22-6 and level of Table 22-2 are attained at the calibration point shown in Figure 22-10, Figure 22-11 or Figure 22-12 as applicable.

b. Record the Voc, and verify that the applicable waveform parameters have been satisfied. Note the waveform polarity.

c. Record the generator setting so that the test level can be repeated during testing.

d. As illustrated in Figure 22-10, Figure 22-11 or Figure 22-12, connect a non-inductive resistor equal in value to the test waveform source impedance (see Table 22-2, Note 4).

e. With the generator set as previously determined, record the voltage across the non-inductive resistor and verify that the voltage amplitude reduces to one half of Voc (±10%). The waveform shall retain its general shape. This verifies that the generator source impedance is correct.

f. Remove the non-inductive resistor added in step d.

Note: *The generator source impedance can also be verified by recording the short circuit current (Isc) for the previously determined generator setting.*

22.5.1.2 Procedures - Test Sequence

a. As illustrated in Figure 22-13 or for power pins, Figure 22-14 or Figure 22-15, connect the calibration point to a designated pin of the EUT by means of a short, low inductance lead.

b. If applicable, apply power to the EUT.

c. At the generator setting previously established in paragraph 22.5.1.1 apply ten individual transients to the selected pin. Monitor the waveform of each applied transient for signs of unexpected changes in the waveshape.

d. Repeat step c for each designated pin in each connector of the EUT.

e. Reverse the transient generator polarity; repeat the generator calibration, and repeat steps a through d.

f. Repeat the generator calibration and test sequence for each test waveform.

g. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

22.5.2 Cable Bundle Tests

Cable bundle testing is a technique where transients are applied by cable induction or ground injection. These methods are used to verify that aircraft equipment can withstand the internal electromagnetic effects produced by the external lightning environment without experiencing functional upset or component damage. In either method, the test must be performed on fully configured and functioning equipment complete with interconnecting cable bundles and interface loads. This test requirement is satisfied by applying the specified waveforms and limits to interconnecting cable bundle(s) individually or simultaneously.

Power leads individual conductor current is not to exceed the corresponding pin test short circuit current level as presented in Table 22-2.

For the purposes of multiple stroke and multiple burst testing, the effect of random spacing is achieved through the timing of the application of the individual pulses and bursts in the sets of transients. See Figure 22-7 and Figure 22-8.

Normally cable bundle tests are done with all shields that are present in the cable bundle connected at both ends. If the required test level (I_T) is greater than level 5, the tested cable is too long for the required I_T to be reached in this cable, or if requested by the system installer, then it is allowable to test with shields disconnected and pulse the core wires directly. For this test option, shields that are not needed for functionality during the test shall be disconnected at all terminations (EUT, Support Equipment, and any in line connectors simulating aircraft installation stanchion or bulkhead disconnects). Cables with shields needed for functionality during the test (e.g., data busses, coaxes), shall be maintained and core wires pulsed through a breakout box or tested separately as specified by the system installer. In either case, the relationship between shield current and core wire transient level must be determined by transfer impedance assessment. The test level shall be selected from Table 22-3 through Table 22-5 and the waveform selected from Figure 22-2 through Figure 22-8 to most closely represent the actual core wire transients and calibrated per Figures 22-16 and Figure 22-18. If this test method option is used, the category designator shall be Z for the cable bundle test waveform set. The test level designator should reflect the actual level used, not the resulting level from the application of the transfer impedance. The test method, along with the transfer impedance shall be noted in the qualification test form.

The cable bundle single stroke test may be combined with the multiple stroke test. In this case the test level of the first transient of the multiple stroke test application is replaced with the single stroke test level provided in Table 22-3.

The qualification results are valid for the configuration tested (Reference 22.4.c). All other configurations must be assessed for applicability.

22.5.2.1 Cable Induction Tests

The procedures outlined in the following paragraphs are applicable for Single Stroke, Multiple Stroke and Multiple Burst tests. Cable induction is the recommended procedure for the pulse waveforms 1, 2, and 3. Use of this application technique with other waveforms is acceptable provided that the waveform calibration procedure per paragraph 22.5.2.1.1(b) can be achieved in the calibration loop of the injection transformer.

Local ground leads (less than 1 meter length) grounded directly to the test bench shall not be included in the bundle under test and are not required to be tested

22.5.2.1.1 Procedures - Generator Performance

a. Connect the transient generator to the primary inputs of the injection transformer (see Figure 22-16).

b. For each generator, record the voltage waveform with the calibration loop open and the current waveform with the calibration loop shorted. For the Single Stroke tests verify the relevant waveshape parameters identified in Figure 22-2, Figure 22-3 or Figure 22-4 and verify that the maximum designated test level (V_T or I_T) of Table 22-3 can be achieved. (Note: It is not necessary for the test generator to produce the calibrated voltage or current test limit as long as the generator can produce the voltage or current test level). For the multiple stroke and multiple burst tests, verify the relevant waveshape parameters and applicable pulse patterns and timing identified in Figure 22-2 through Figure 22-8, and verify that the maximum designated test level (V_T or I_T) of Table 22-4 or Table 22-5 can be achieved.

22.5.2.1.2 Procedures - Test Sequence

a. Configure the EUT, support equipment and interconnecting cable bundles as shown in Figure 22-17 with the injection transformer around the cable bundle under test. If the shield disconnect test method option described in paragraph 22.5.2 is being utilized, disconnect the shields.

b. Connect the current and voltage monitoring probes to an oscilloscope. For uniformity of test results, the probe positions should be as close as possible to those shown.

c. Apply power to the EUT and configure it in the selected operating mode(s). Verify proper system operation as described in the applicable equipment specification.

d. While applying transients, increase the generator setting until the designated test level (V_T or I_T) or the limit level (V_L or I_L) is reached. Record the waveforms. If V_L or I_L is reached before V_T or I_T, the test shall be reevaluated to determine if another generator and/or waveform set is required.

e. For the Single Stroke test, at the generator setting established in step d, apply a minimum of ten transients while monitoring the operation of the EUT.

f. For the Multiple Stroke test, at the generator setting established in step d, apply a minimum of ten multiple stroke applications while monitoring the operation of the EUT.

g. For the Multiple Burst test, at the generator setting established in step d, apply a multiple burst application every 3 seconds (3 seconds between the start of each set of three bursts) continuously for at least five minutes. Longer durations may be specified in the applicable equipment specification.

h. Repeat steps d through g for each mode of EUT operation to be tested.

i. Reverse the transient generator polarity; repeat the generator performance verification, and repeat steps b through h.

j. Repeat steps b through i for each injection transformer position.

k. Repeat the generator performance verification and steps b through j for each waveform applied.

l. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

22.5.2.2 Ground Injection

The procedures outlined in the following paragraphs are applicable for Single Stroke and Multiple Stroke tests. Ground injection is the recommended procedure for the pulse waveforms 4 and 5A. Use of this application technique with waveforms 1 and 2 is acceptable provided that the waveform calibration procedure per paragraph 22.5.2.2.1 can be achieved at the injection point.

Equipment external ground terminals, chassis ground wires and power return leads, which are connected to the ground plane locally in accordance with the applicable installation/interface control drawings, must be isolated from the ground plane during this test. In addition, if the power leads are routed separately from the main signal bundle, it may be necessary to insert AC series impedance (in addition to the LISN) in the power bundle to ensure that the proper signal bundle test levels are achieved.

The intent of this test is to achieve the applicable test level in each cable bundle, therefore tests may need to be conducted at more than one injection point. For an EUT with multiple cable bundles the current must be measured in each cable bundle to ensure that the applicable test level is achieved and the current limit is not exceeded in any one cable bundle.

22.5.2.2.1 Procedures - Generator Performance Verification

For each generator, record the voltage waveform across an open circuit and the current waveform through a shorted calibration loop as shown in Figure 22-18. For the Single Stroke test verify the relevant waveshape parameters identified in Figure 22-5 or Figure 22-6, and verify that the maximum designated test level (V_T or I_T) of Table 22-3 can be achieved. (Note: It is not necessary for the test generator to produce the calibrated voltage or current test limit as long as the generator can produce the voltage or current test level). For multiple stroke tests verify the relevant waveshape parameters and applicable pulse patterns and timing identified in Figure 22-5, Figure 22-6 or Figure 22-7 and verify that the maximum designated test level (V_T or I_T) of Table 22-4 can be achieved.

22.5.2.2.2 Procedures - Test Sequence

a. The general requirements of paragraph 22.4 shall apply to this test setup except that the case and all local grounds or returns at the transient injection point (EUT or a load) shall be insulated from the ground plane and connected to the equipment case. The insulator used between the case and ground plane must be capable of withstanding the maximum applied test voltage.

b. Configure the EUT, support equipment and interconnecting cable bundles as shown in Figure 22-19 with the transient generator connected between the EUT case and ground plane. If the shield disconnect test method option described in paragraph 22.5.2 is being utilized, disconnect the shields.

c. Connect the applicable current and voltage monitoring probes to an oscilloscope.

d. Apply power to the EUT and configure it in the proper operating mode(s). Verify proper system operation as described in the applicable equipment specification.

e. While applying transients, increase the generator setting until the designated test level (V_T or I_T) or the limit level (V_L or I_L) is reached. Record the waveforms. If V_L or I_L is reached before V_T or I_T, the test shall be reevaluated to determine if another generator and/or waveform set is required.

f. For the Single Stroke test, at the generator setting established in step e, apply a minimum of ten transients while monitoring the operation of the EUT.

g. For the Multiple Stroke test, at the generator setting established in step e, apply a minimum of ten events while monitoring the operation of the EUT.

h. Repeat steps e through g for each mode of EUT operation to be tested.

i. Reverse the transient generator polarity; repeat the generator performance verification, and repeat steps b through h.

j. Repeat steps b through i for each designated injection location.

k. Repeat the generator performance verification and steps b through j for each designated waveform.

l. <u>DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS</u>.

Table 22-1 Test Requirements

Waveform Set	Test Type	Test Levels	Waveform Nos.	Recommended Test Method	Notes
A (aperture coupling)	Pin	Table 22-2	3, 4	22.5.1	1
B (aperture and resistance coupling)	Pin	Table 22-2	3, 5A	22.5.1	1
C Cable Bundle (unshielded, aperture coupling)	Single Stroke	Table 22-3	2, 3	22.5.2.1	2, 5
			4	22.5.2.2	
D Cable Bundle (unshielded, aperture and resistance coupling)	Single Stroke	Table 22-3	2, 3	22.5.2.1	2, 3, 5
			5A	22.5.2.2	
E Cable Bundle (shielded aperture coupling)	Single Stroke	Table 22-3	1, 3	22.5.2.1	2, 4, 5
F Cable Bundle, (shielded, aperture and resistance coupling)	Single Stroke	Table 22-3	3	22.5.2.1	2, 5
			5A	22.5.2.2	
G Cable Bundle (unshielded, aperture coupling)	Single Stroke	Table 22-3	2, 3	22.5.2.1	2, 5
			4	22.5.2.2	
	Multiple Stroke	Table 22-4	2, 3	22.5.2.1	
			4	22.5.2.2	
	Multiple Burst	Table 22-5	3	22.5.2.1	2
H Cable Bundle (unshielded, aperture and resistance coupling)	Single Stroke	Table 22-3	2, 3	22.5.2.1	2, 3, 5
			5A	22.5.2.2	
	Multiple Stroke	Table 22-4	2, 3	22.5.2.1	
			5A	22.5.2.2	
	Multiple Burst	Table 22-5	3	22.5.2.1	2
J Cable Bundle (shielded, aperture coupling)	Single Stroke	Table 22-3	1, 3	22.5.2.1	2, 4, 5
	Multiple Stroke	Table 22-4	1, 3	22.5.2.1	
	Multiple Burst	Table 22-5	3	22.5.2.1	2
K Cable Bundle (shielded, aperture and resistance coupling)	Single Stroke	Table 22-3	3	22.5.2.1	2, 5
			5A	22.5.2.2	
	Multiple Stroke	Table 22-4	3	22.5.2.1	
			5A	22.5.2.2	
	Multiple Burst	Table 22-5	3	22.5.2.1	2

Notes:

1. *For pin injection tests, waveform 3 is applied at 1.0 MHz (±20%).*

2. *For cable bundle tests, waveform 3 is applied at 1.0 MHz (±20%) and 10 MHz (±20%).*

3. *Waveform 5A occurs as a voltage waveform if unshielded harnesses are routed in metallic trays, conduits or have overbraids when installed in the aircraft. For Cable Bundle tests, the appropriate test level (V_T) is the waveform 5A voltage limit (V_L) of Table 22-3 and Table 22-4.*

4. *Waveform 1 may be applied by using either test method in paragraph 22.5.2.1 or 22.5.2.2.*

5. *The criterion for deciding whether or not another generator or waveform set has to be used is whether or not the measured shapes of the current and voltage waveforms are appropriate for the waveform set under consideration. For example, waveform set E is applicable to shielded cables, which would usually result in a loop under test behaving as an inductive load. In this case, a generator capable of delivering current waveforms is required. If the inductance is high, then the voltage limit could be reached first; but the waveform shapes will be correct, and the test need not be redone.*

   If the load is predominantly resistive, the voltage limit will be reached first, but the monitored voltage waveform shape will be incorrect; another test with another generator/waveform set should be selected and the test redone.

   Waveform set C is applicable to unshielded cables, which would usually result in a loop under test behaving as a resistive load. In this case, a generator capable of delivering voltage waveforms is required. If the resistance and inductance are low, the current limit would be reached first, and depending on the impedance of the generator, the waveform shapes could be incorrect. In this case, reevaluation would indicate waveform set E should be used.

   It should be noted that if a low impedance source generator is available, the appropriate response will be achieved, and in this case, the test will be completed when either a test level or limit is reached.

   The category put on the label applies to the class of tests that were passed.

Table 22-2 Test Levels for Pin Injection

Level	Waveforms		
	3	4	5A
	Voc/Isc	Voc/Isc	Voc/Isc
1	100/4	50/10	50/50
2	250/10	125/25	125/125
3	600/24	300/60	300/300
4	1500/60	750/150	750/750
5	3200/128	1600/320	1600/1600

Notes:

1. *Voc = Peak Open Circuit Voltage (Volts) available at the calibration point shown in Figure 22-10, Figure 22-11, or Figure 22-12.*

2. *Isc = Peak Short Circuit Current (Amps) available at the calibration point shown in Figure 22-10, Figure 22-11, or Figure 22-12.*

3. *Amplitude Tolerances +10%, -0%.*

4. *The ratio of Voc to Isc is the generator source impedance to be used for generator calibration purposes.*

5. *Waveforms 3, 4 and 5A are identified in Figure 22-4, Figure 22-5 and Figure 22-6.*

6. *In certain situations related to airframe design and wiring layout, equipment may be exposed to higher levels of Waveform 5A or to longer duration waveforms designated as Waveform 5B (see Figure 22-6). Tests conducted under these conditions should be given designator Z.*

<u>Table 22-3</u> Test Levels for Cable Bundles Single Stroke Tests

Level	Waveforms				
	1	2	3	4	5A
	V_L/I_T	V_T/I_L	V_T/I_L	V_T/I_L	V_L/I_T
1	50/100	50/100	100/20	50/100	50/150
2	125/250	125/250	250/50	125/250	125/400
3	300/600	300/600	600/120	300/600	300/1000
4	750/1500	750/1500	1500/300	750/1500	750/2000
5	1600/3200	1600/3200	3200/640	1600/3200	1600/5000

Notes:

1. *Amplitude tolerances are +20%, -0%.*

2. *Waveforms 1, 2, 3, 4 and 5A are identified in <u>Figure 22-2</u>, <u>Figure 22-3</u>, <u>Figure 22-4</u>, <u>Figure 22-5</u> and <u>Figure 22-6</u>, respectively.*

3. *Under each waveform, V_T represents the test voltage level in Volts, and I_T represents the test current level in Amperes. V_L (Volts) and I_L (Amperes) represent limits intended to prevent over-stressing the EUT beyond requirements.*

4 *Test generators can produce switching transients during the early part of the waveforms. These switching transients should not be used to determine the amplitude of the test waveform..*

5. *In certain situations related to airframe design and wiring layout, equipment may be exposed to higher levels of Waveform 5A (i.e., up to 10kA) or to longer duration waveforms designated as Waveform 5B (see <u>Figure 22-6</u>) up to 5kA. Tests conducted under these conditions should be given designator Z.*

Table 22-4 Test Levels for Cable Bundle Multiple Stroke Tests

Level		Waveforms				
		1	2	3	4	5A
		V_L/I_T	V_T/I_L	V_T/I_L	V_T/I_L	V_L/I_T
1	First Stroke	50/50	50/50	100/20	25/50	20/60
	Subsequent Stroke	25/25	25/25	50/10	12.5/25	10/30
2	First Stroke	125/125	125/125	250/50	62.5/125	50/160
	Subsequent Stroke	62.5/62.5	62.5/62.5	125/25	31.25/62.5	25/80
3	First Stroke	300/300	300/300	600/120	150/300	120/400
	Subsequent Stroke	150/150	150/150	300/60	75/150	60/200
4	First Stroke	750/750	750/750	1500/300	375/750	300/800
	Subsequent Stroke	375/375	375/375	750/150	187.5/375	150/400
5	First Stroke	1600/1600	1600/1600	3200/640	800/1600	640/2000
	Subsequent Stroke	800/800	800/800	1600/320	400/800	320/1000

Notes:

1. *Amplitude tolerance for the first stroke is +20%, -0%. Amplitude tolerance for the subsequent stroke is +50%, -0%.*

2. *Waveforms 1, 2, 3, 4 and 5A are identified in Figure 22-2, Figure 22-3, Figure 22-4, Figure 22-5 and Figure 22-6, respectively.*

3. *Multiple Stroke is identified in Figure 22-7.*

4. *Under each waveform, V_T represents the test voltage level in volts, and I_T represents the test current level in amperes. V_L (Volts) and I_L (Amperes) represent limits intended to prevent over-stressing the EUT beyond requirements.*

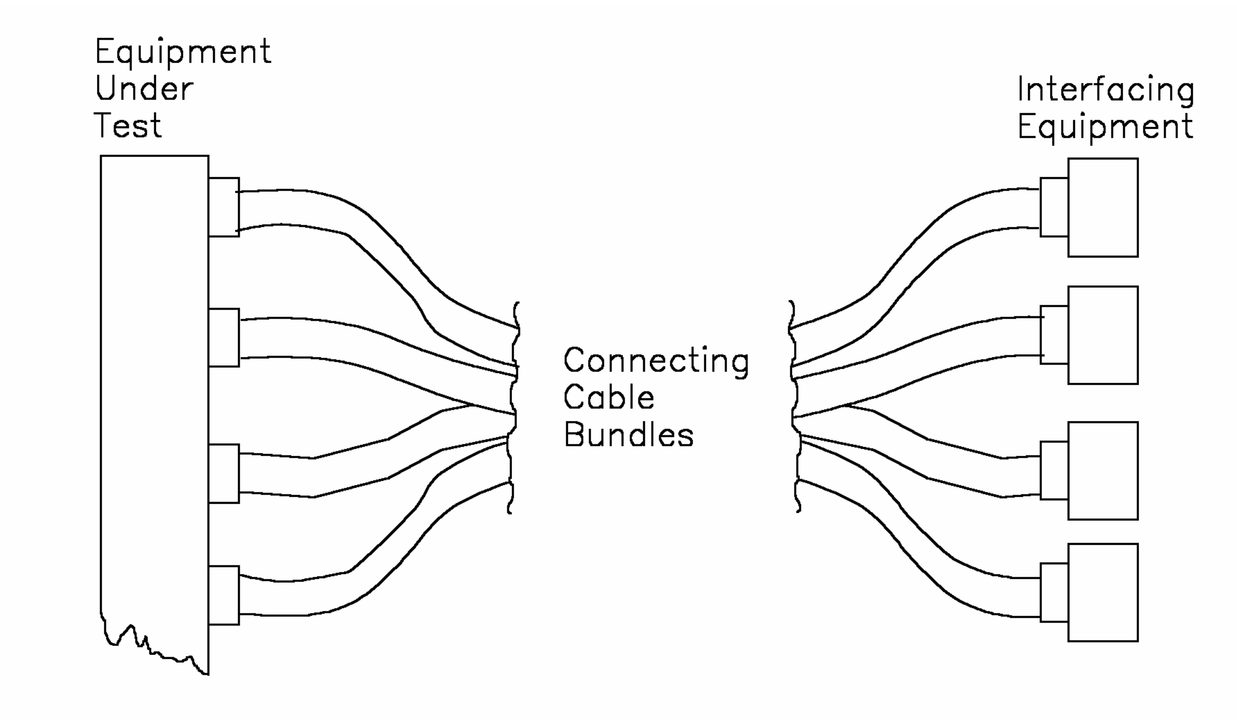
5. *Test generators can produce switching transients during the early part of the waveforms. These switching transients should not be used to determine the amplitude of the test waveform.*

<u>Table 22-5</u> Test Levels for Cable Bundle Multiple Burst Tests

Level	Waveform 3 V_T/I_L
1	60/1
2	150/2.5
3	360/6
4	900/15
5	1920/32

Notes:

1. *Amplitude tolerances are +20%, -0%.*
2. *Waveform 3 is identified in Figure 22-4.*
3. *Multiple Burst is identified in Figure 22-8.*
4. *Under each waveform, V_T represents the test voltage level in Volts, and I_T represents the test current level in Amperes. V_L (Volts) and I_L (Amperes) represent limits intended to prevent over-stressing the EUT beyond requirements.*



Notes:

1. *When each cable bundle is tested to the same level, that level is marked in the cable bundle test designator.*

2. *When interfacing equipment is co-located and their associated cable bundles are routed together, the cables can be tested as one bundle. Each individual bundle must meet its expected test level.*

3. *When cable bundles are tested to different levels, the cable bundle test designator is marked with a Z.*

Figure 22-1 Installation Configuration - General Case

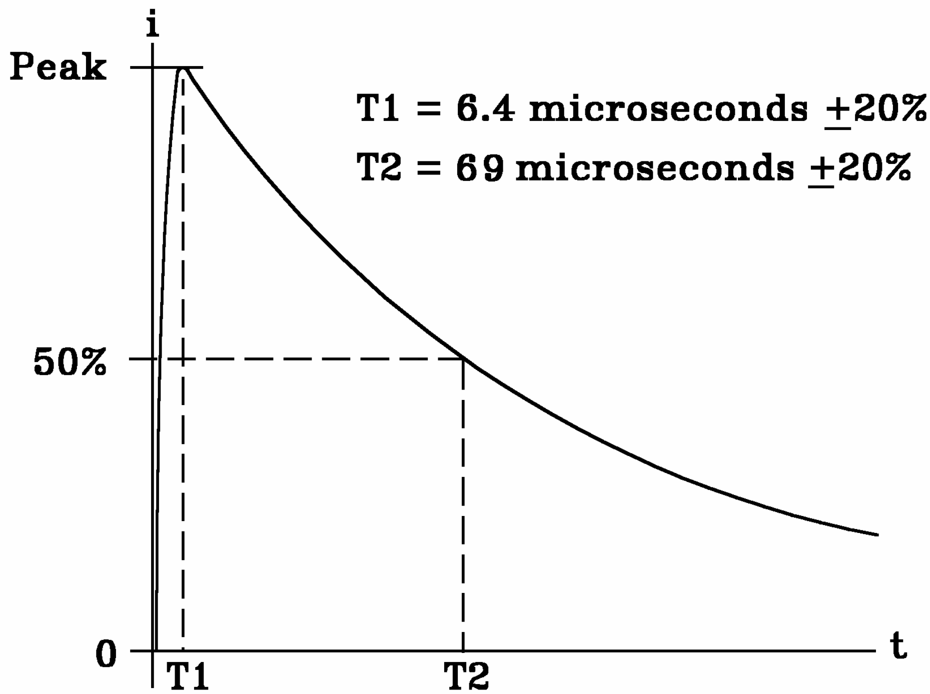


Figure 22-2 Current Waveform 1

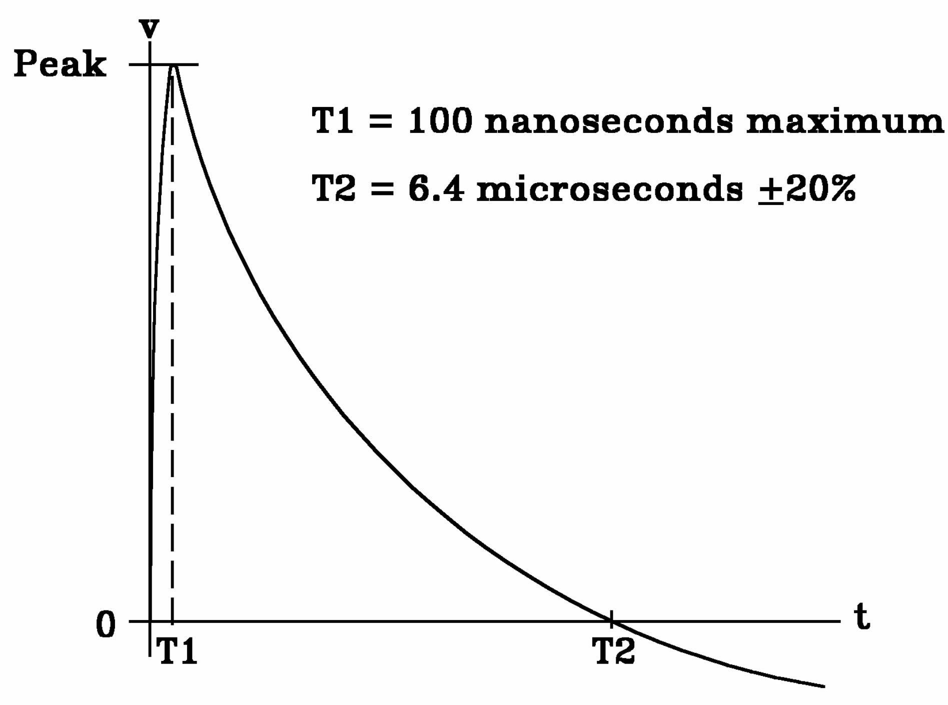
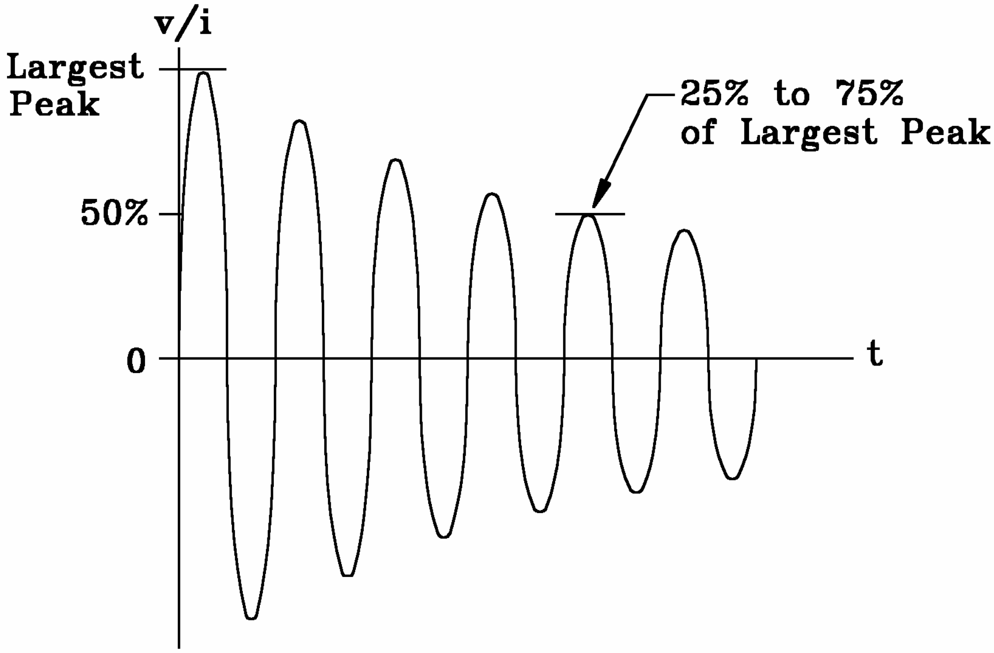


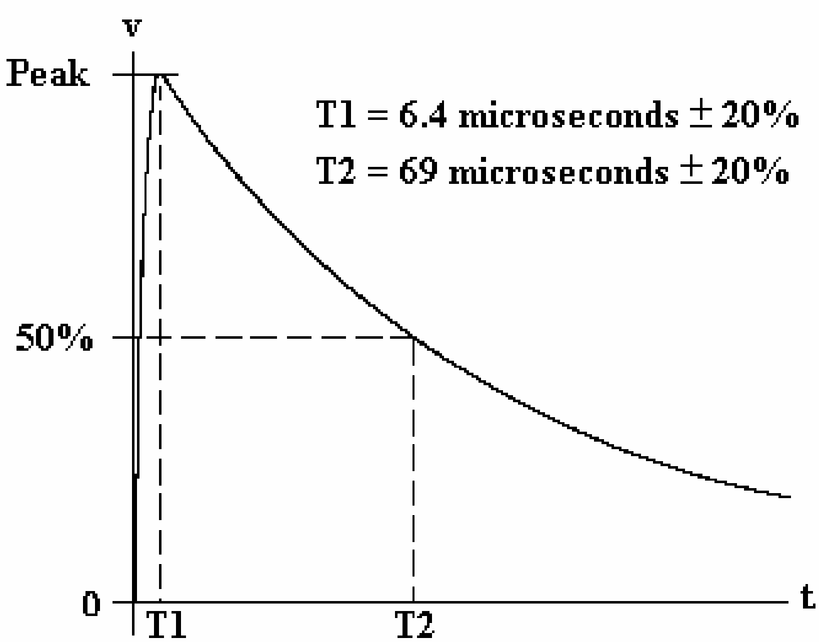
Figure 22-3 Voltage Waveform 2



Notes:
1. *Voltage and current are not required to be in phase.*

2. *The waveshape may have either a damped sine or cosine waveshape.*

<u>Figure 22-4</u> Voltage/Current Waveform 3



<u>Figure 22-5 Voltage Waveform 4</u>

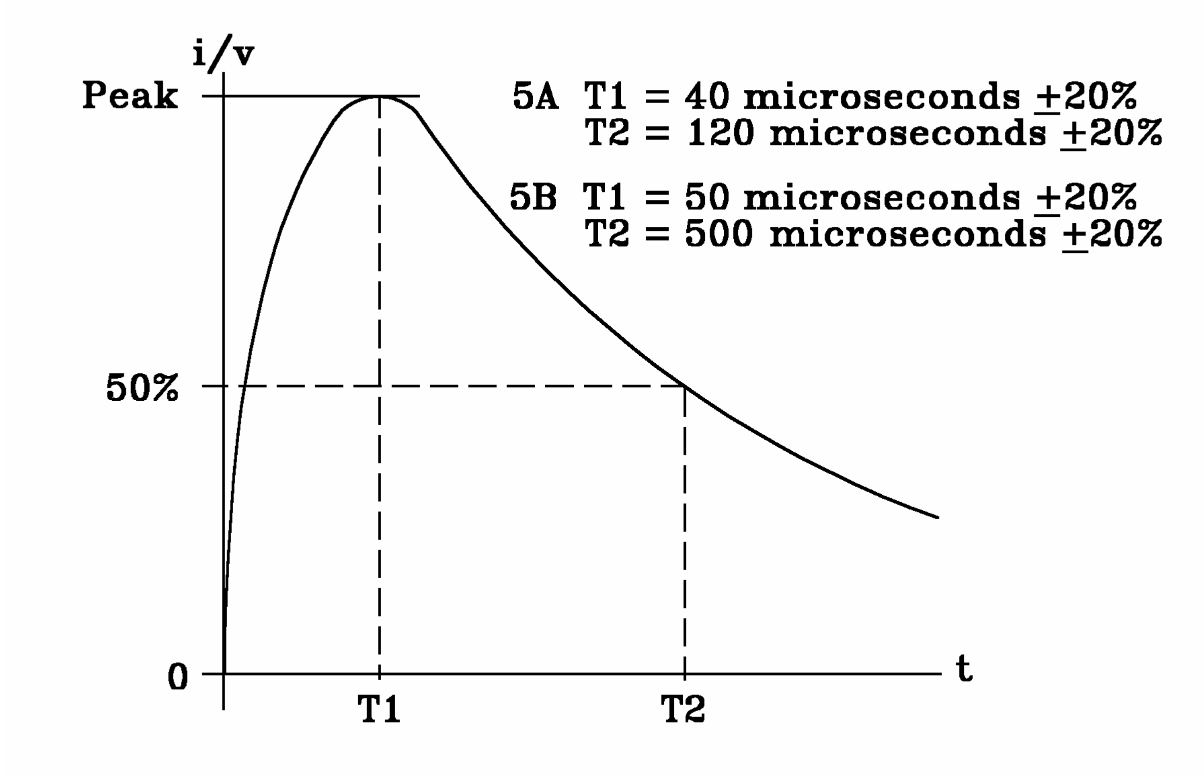


Figure 22-6 **Current/Voltage Waveform 5**

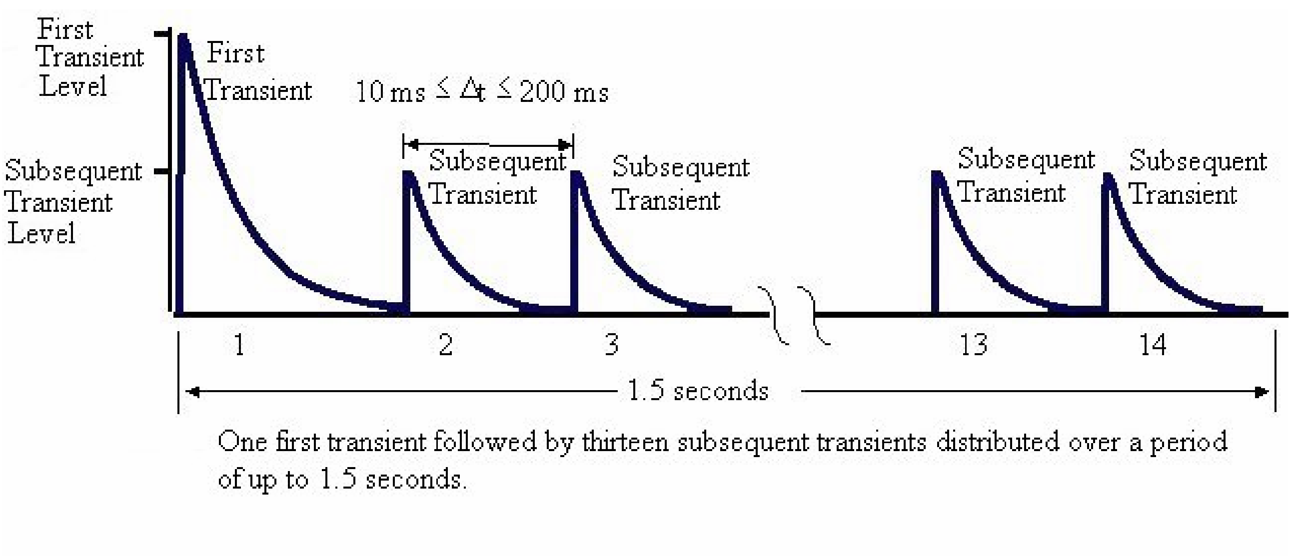
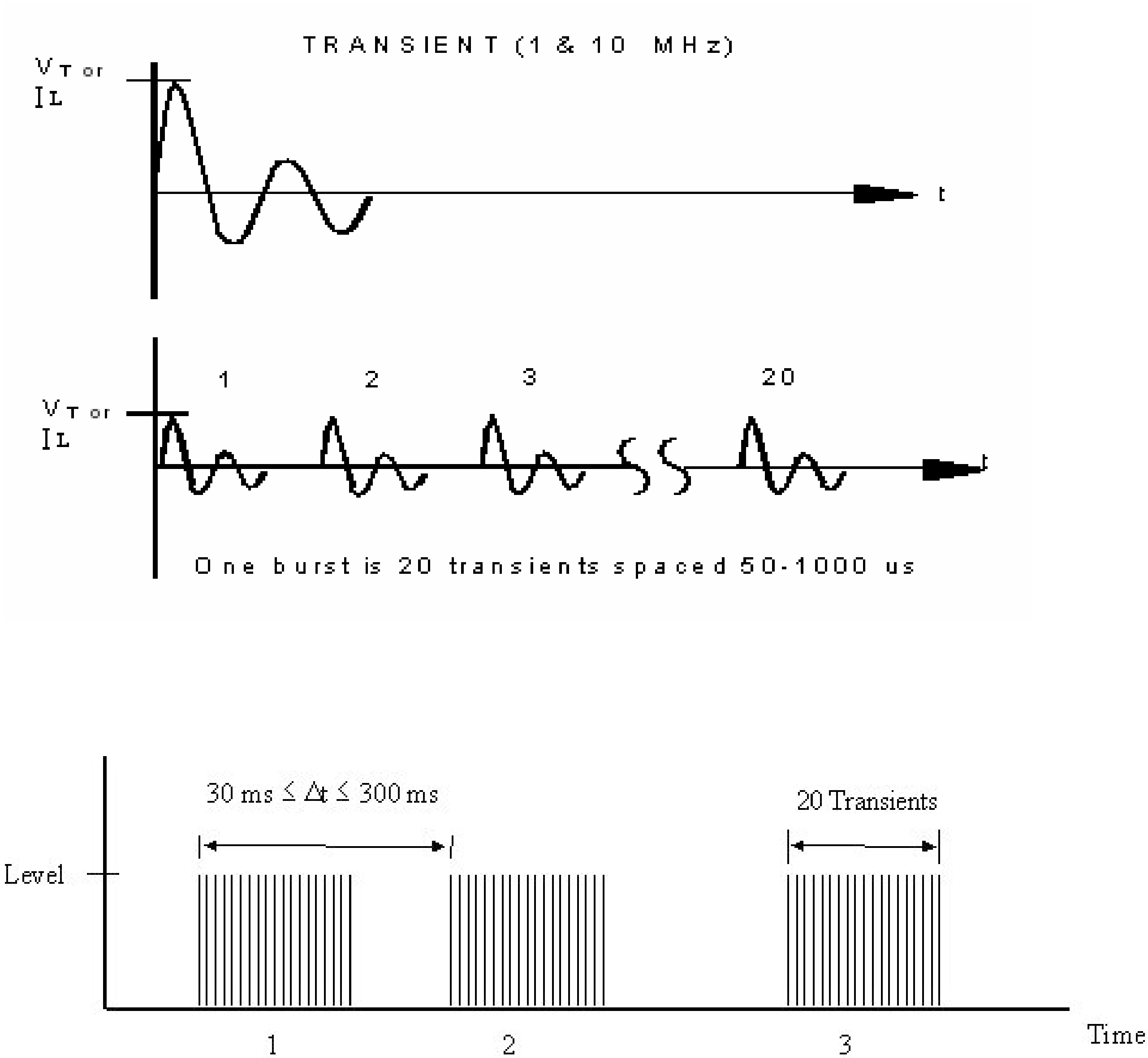


Figure 22-7 **Multiple Stroke Application**



<u>Figure 22-8</u> Multiple Burst Application

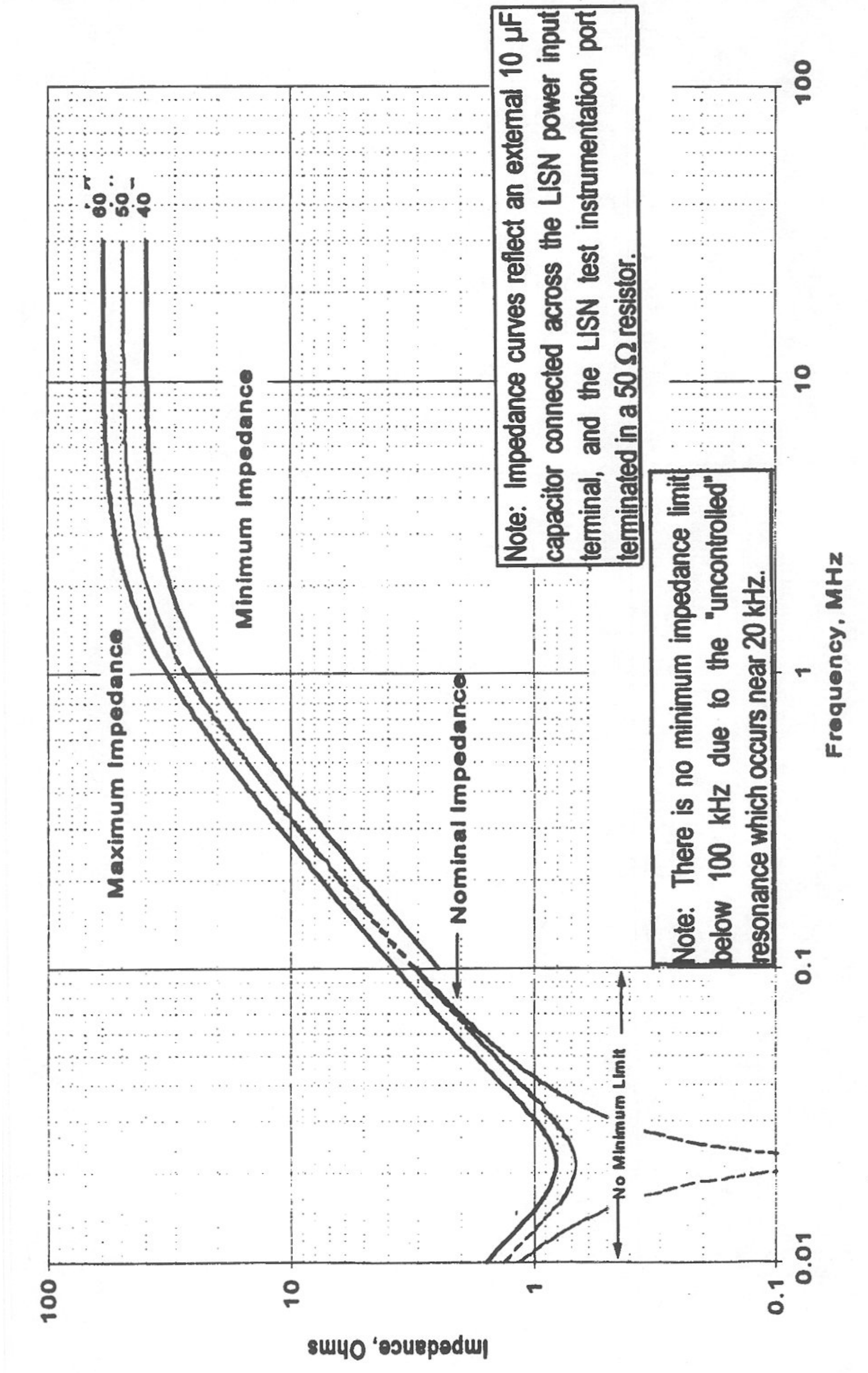
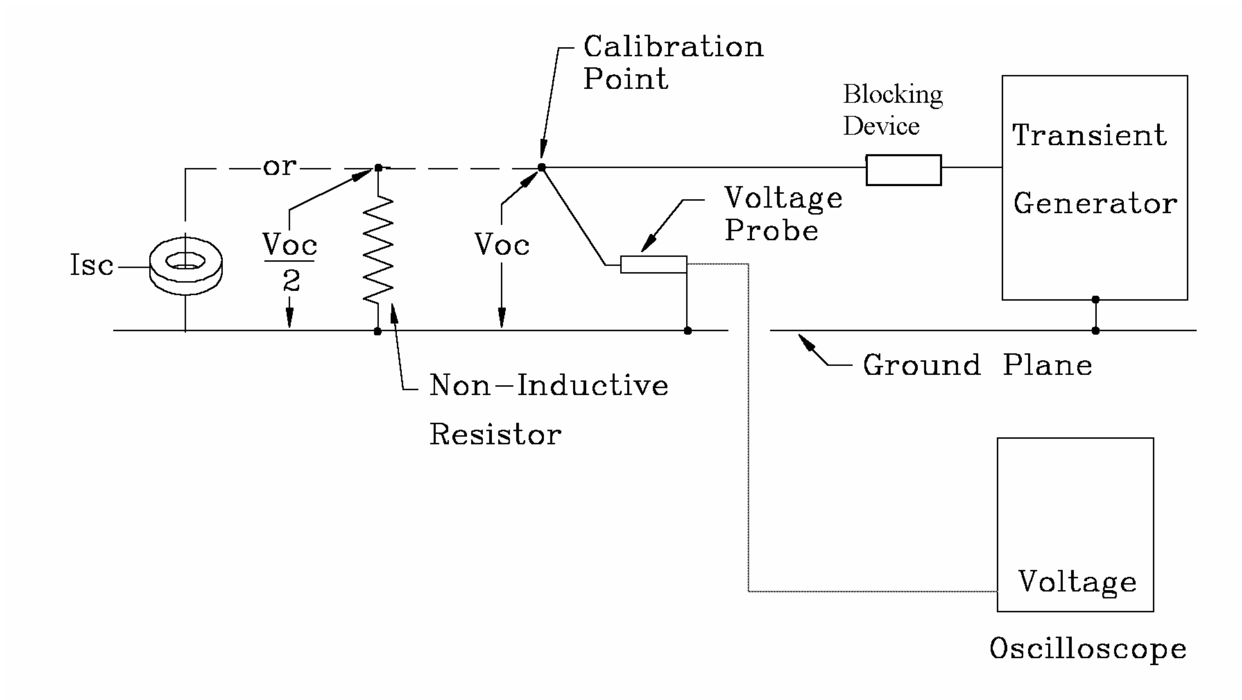


Figure 22-9 **LISN Input Impedance Characteristic**



Notes:

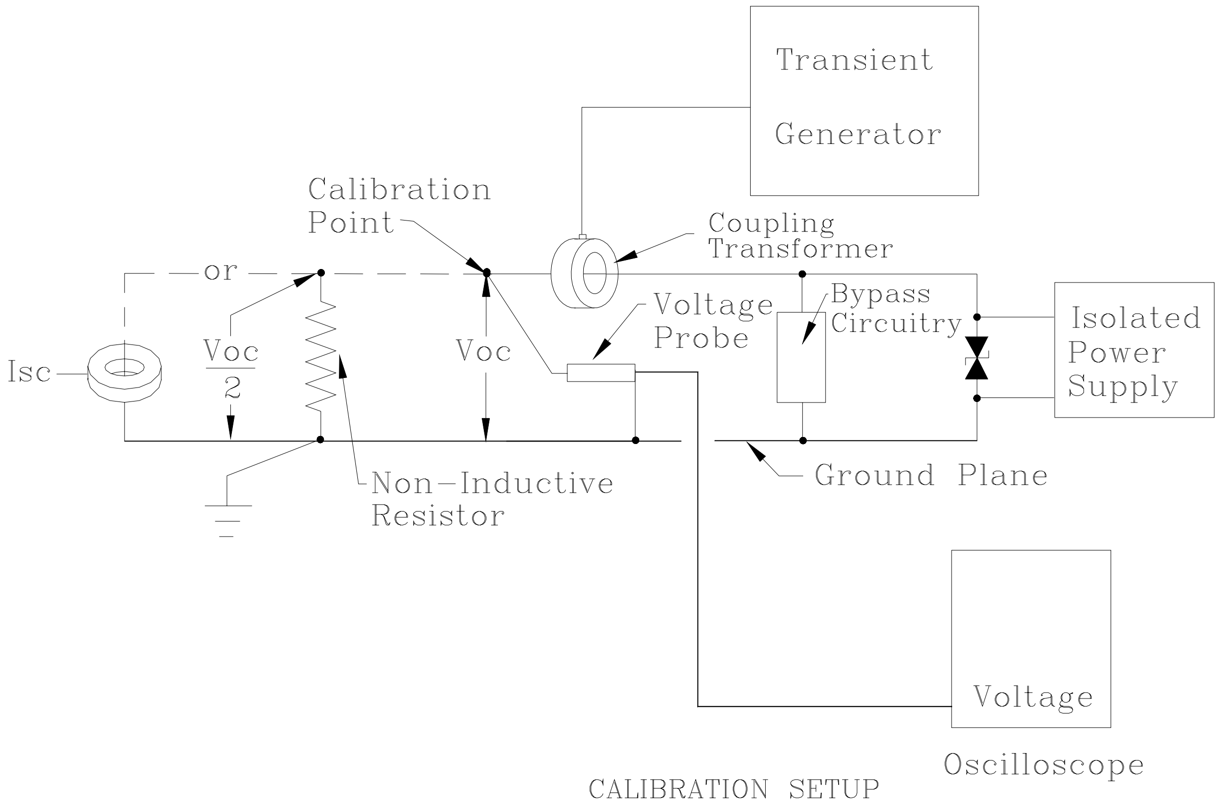
1. *A non-inductive or low-inductance resistor equal to the generator source impedance should be used for verifying the generator impedance. A carbon composition resistor(s) of appropriate wattage and short lead length is sufficient for the pin test waveforms. Measuring the short circuit current is also an acceptable means of verifying the generator source impedance.*

2. *Tests of active ac power circuits may require transformer coupling of the applied transients to the power lines, and transients should be synchronized to the peak of the ac waveform.*

3. *A blocking device may be used to isolate voltages at the pins of the EUT from the low generator impedance and must be present during calibration since they may adversely affect the waveform calibration. Typical blocking devices are bipolar suppression devices for Waveforms 4 and 5 or a series capacitor for Waveform 3. The bipolar suppression device is selected with a voltage rating close to the expected EUT operating voltage but may have a nominal value to allow testing with one calibrated setup. A voltage rating that represents a significant percentage of the applied transient will affect waveform calibration. The capacitor is selected to achieve the calibration current; too large a value may produce unwanted resonance during test.*

4. *The Blocking Device is not necessary for tests on un-powered equipment.*

Figure 22-10 Pin Injection Calibration Setup for Signal Pins



Notes:

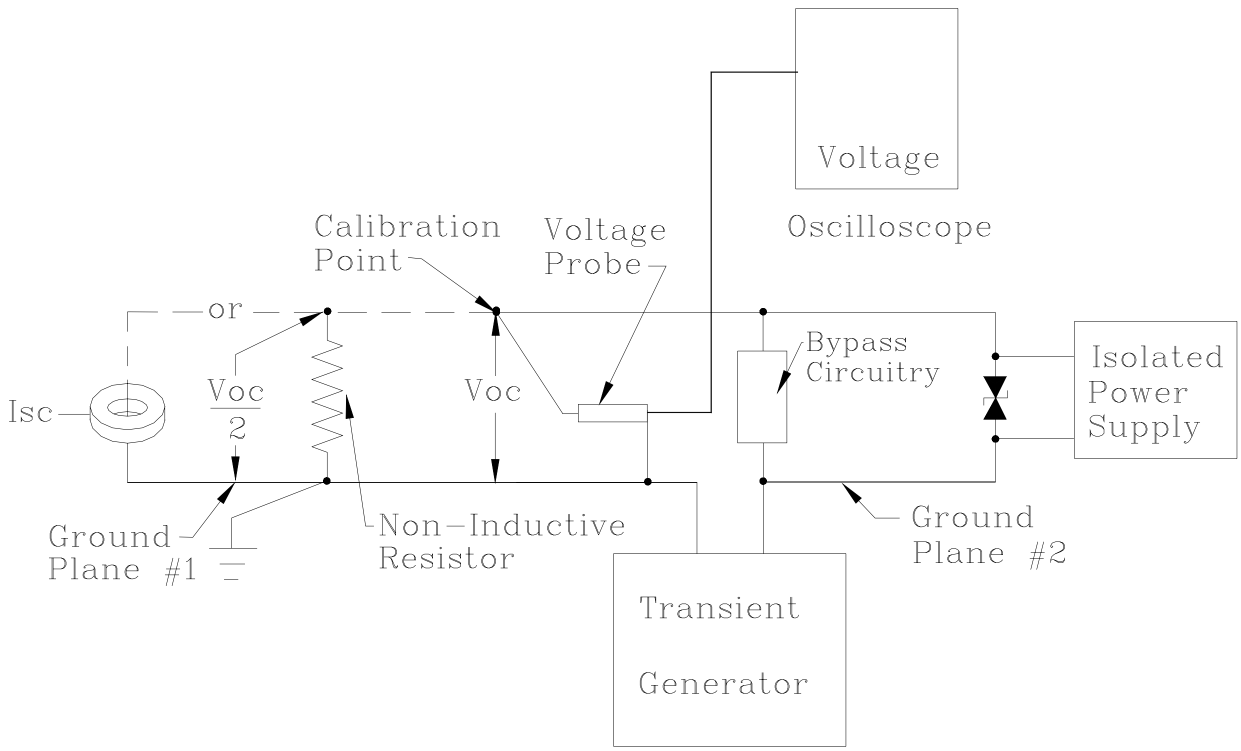
1. *This setup is intended for use with Waveform 3 but can be performed with Waveforms 4 and 5 provided the coupling transformer can adequately support the open circuit voltage waveform and related short circuit current. All indicated support equipment must be present for calibration. Specified waveforms must be achieved at the calibration point.*

2. *A non-inductive or low-inductance resistor equal to the generator source impedance should be used for verifying the generator impedance. A carbon composition resistor(s) of appropriate wattage and short lead length is sufficient for the pin test waveforms. Measuring the short circuit current is also an acceptable means of verifying the generator source impedance. The power supply should be OFF during calibration.*

3. *The current bypass circuit is used to limit the size of the calibration loop and assure delivery of the short circuit current. For DC Power pins, this may consist only of a capacitor of appropriate size and power rating. For AC power pins, the bypass circuit may consist of a capacitor and/or low impedance isolation transformer. The goal of the calibration setup should be to achieve the desired open circuit voltage and short circuit current amplitudes at the calibration point with the proper waveforms and source impedances.*

4. *In equipment powered from multiple phases, the bypass circuit must be duplicated for each phase. Transients generally would be applied simultaneously to all the phases to evaluate the common-mode condition; however, the short circuit currents must be adjusted to account for the multiple lines under test.*

Figure 22-11 Pin Injection Calibration Setup, Power Pins – Cable Induction Method



CALIBRATION SETUP

Notes:

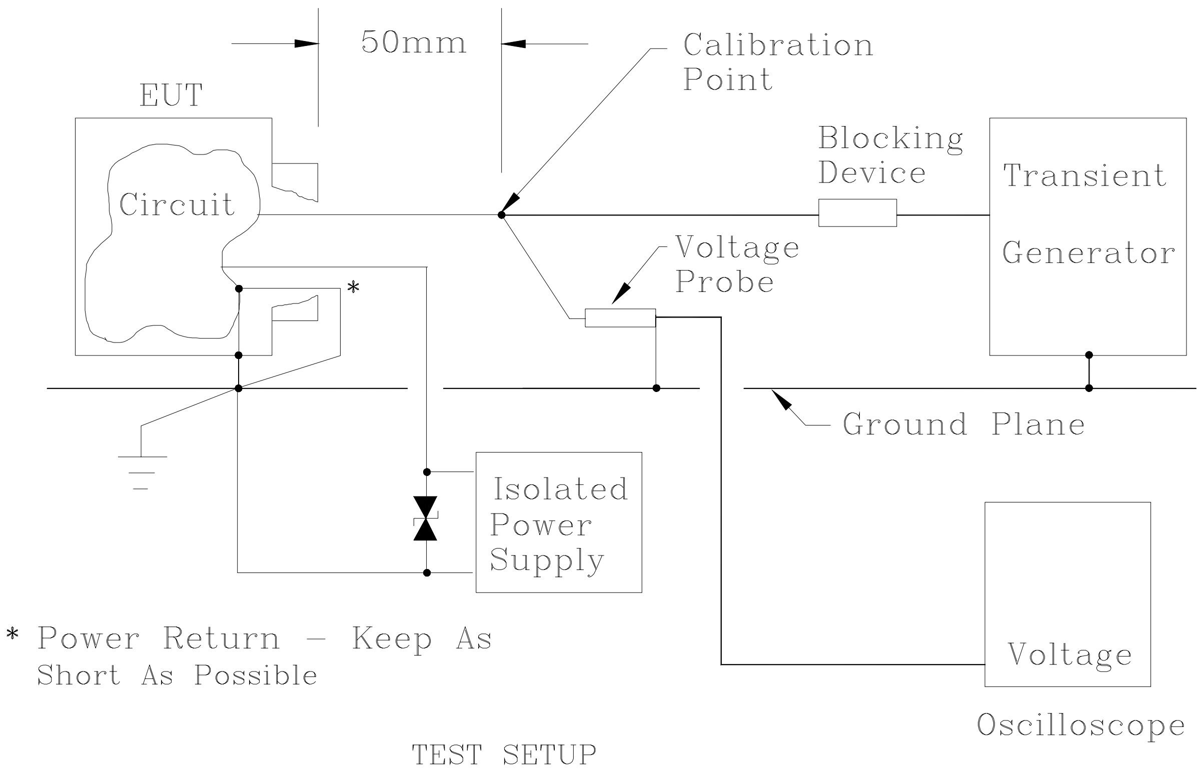
1. *This setup is intended for use with Waveforms 4 and 5. Generator output impedance should be low to avoid excessive voltage drop on the power line. All indicated support equipment must be present for calibration. Specified waveforms must be achieved at the calibration point.*

2. *A non-inductive or low-inductance resistor equal to the generator source impedance should be used for verifying the generator impedance. A carbon composition resistor(s) of appropriate wattage and short lead length is sufficient for the pin test waveforms. Measuring the short circuit current is also an acceptable means of verifying the generator source impedance. The power supply should be OFF during calibration.*

3. *The current bypass circuit is used to limit the size of the calibration loop and assure delivery of the short circuit current. For DC Power pins, this may consist only of a capacitor of appropriate size and power rating. For AC power pins, the bypass circuit may consist of a capacitor and/or low impedance isolation transformer. The goal of the calibration setup should be to achieve the desired open circuit voltage and short circuit current amplitudes at the calibration point with the proper waveforms and source impedances.*

4. *In equipment powered from multiple phases, the bypass circuit must be duplicated for each phase. Since transients are applied simultaneously to the phases through the neutral, short circuit currents must be adjusted to account for the multiple lines under test.*

<u>Figure 22-12</u> Pin Injection Calibration Setup, Power Pins – Ground Injection Method



Notes:

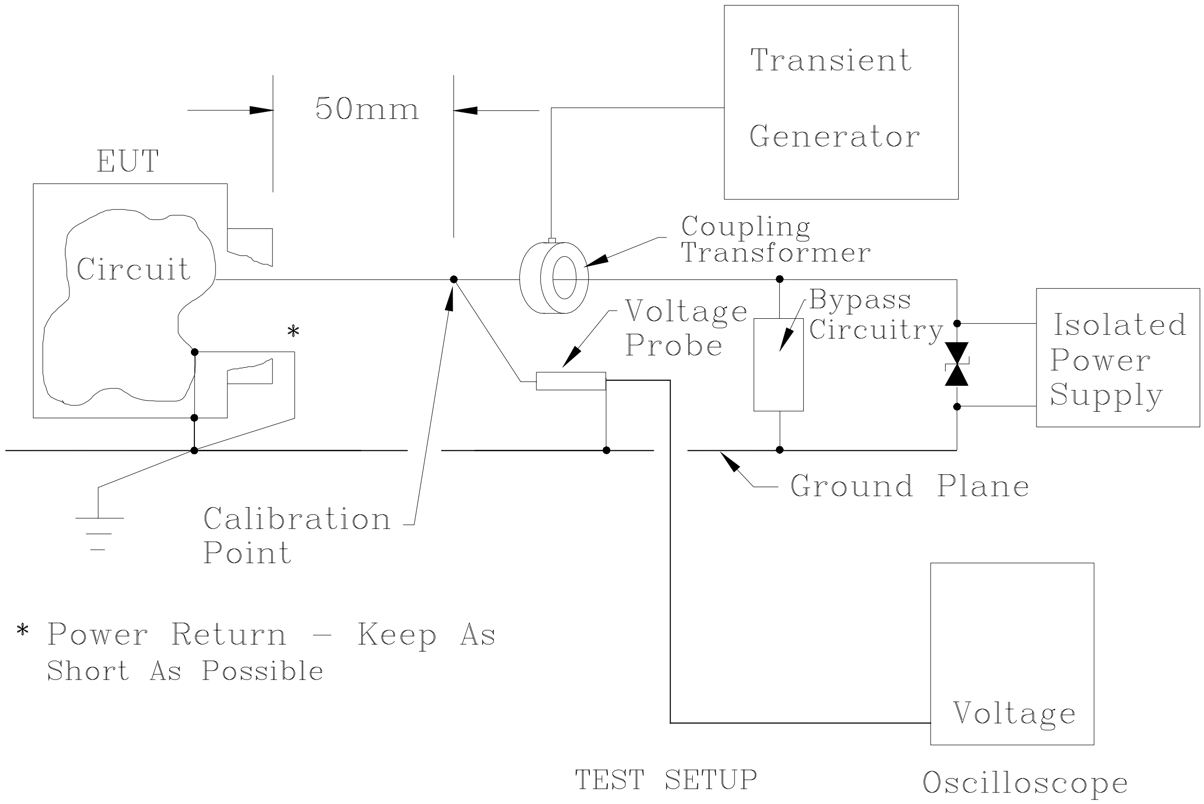
1. *The notes from the calibration setup of* <u>*Figure 22-10*</u> *apply.*

2. *Test setup and procedures assume lightning transients appear common-mode between all signal pins and case and differentially with respect to the power and return lines. If power and return are supplied from a remote LRU, in the same cable bundle with the signals, then the test setup should use an isolated power return to ensure the proper common-mode evaluation.*

3. *The power supply is not necessary for tests on un-powered equipment.*

4. *Test procedures assume lightning transients appear common-mode between all pins and case. If the expected installation utilizes local power and/or signal returns tied either internally or externally to case or aircraft structure, tests shall be performed with the return(s) tied to the case.*

<u>Figure 22-13</u> Pin Injection Test Setup, Signal Pins



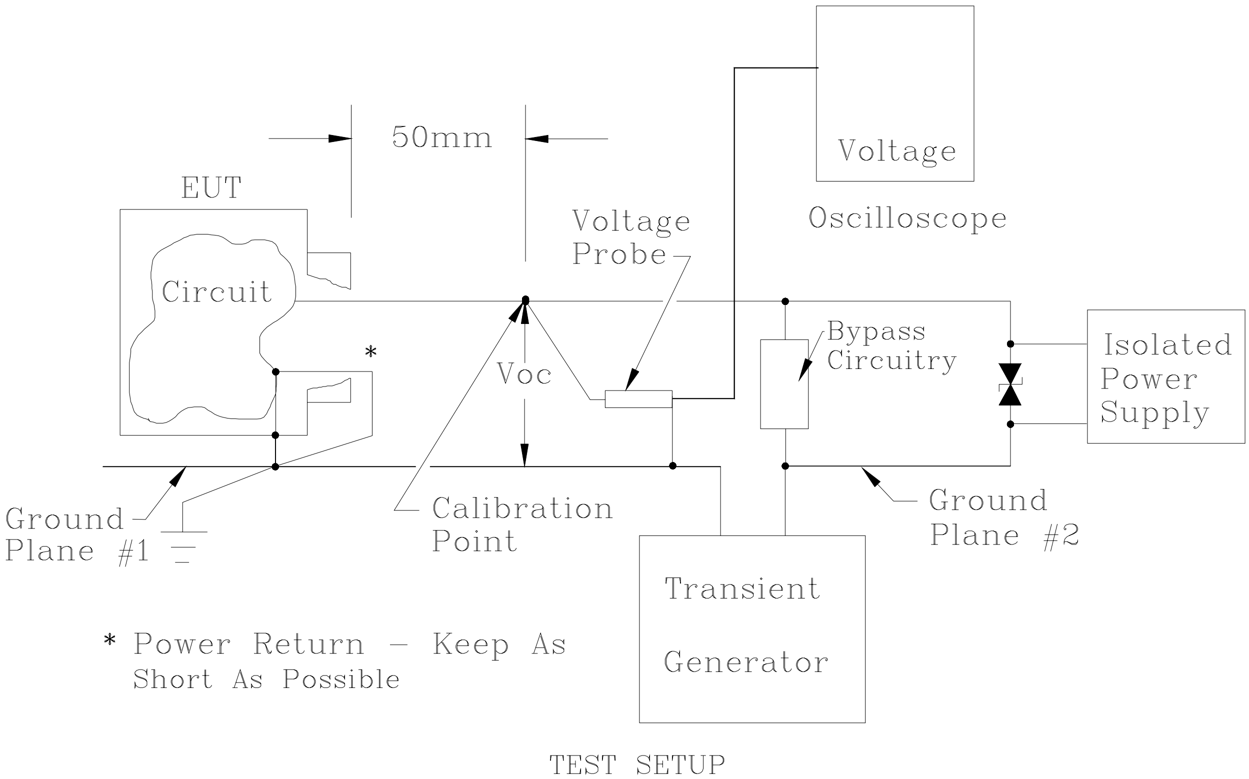
Notes:

1. *The notes from the calibration setup of Figure 22-11 apply.*

2. *Test setup and procedures assume lightning transients appear differentially with respect to the power and return/neutral lines. If power and return/neutral are supplied from a remote LRU, in the same cable bundle with the signals, then the test setup should use an isolated power return to ensure the proper common-mode evaluation.*

3. *Injection should also be performed on the power return/neutral unless it is tied directly to case at the connector.*

Figure 22-14 Pin Injection Test Setup, Power Pins - Cable Induction Method



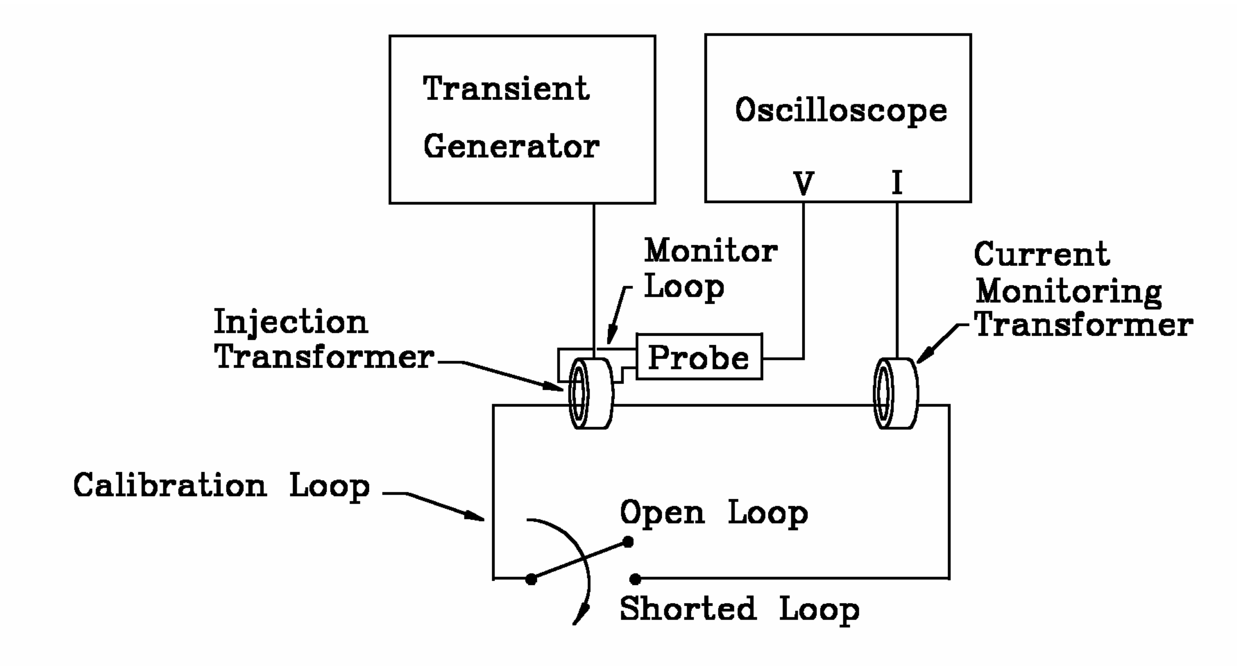
Notes:

1. *The notes from the calibration setup of Figure 22-12 apply.*

2. *Test setup and procedures assume lightning transients appear differentially with respect to the power and return/neutral lines. If power and return/neutral are supplied from a remote LRU, in the same cable bundle with the signals, then the test setup should use an isolated power return to ensure the proper common-mode evaluation.*

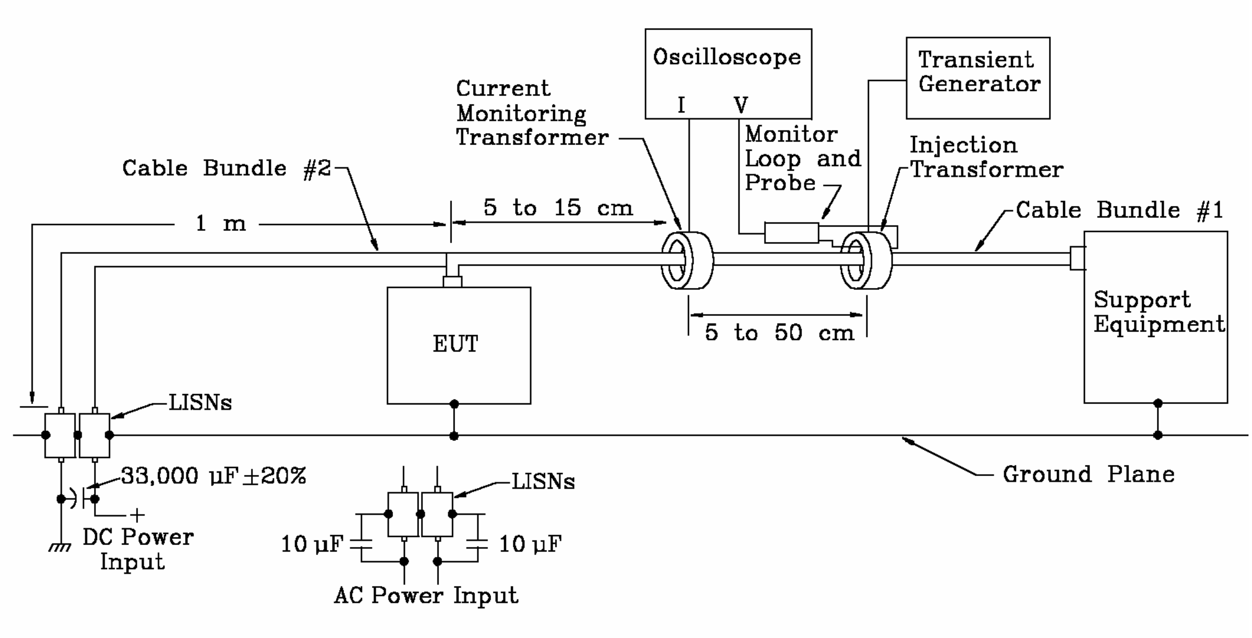
3. *Injection should also be performed on the power return/neutral unless it is tied directly to case at the connector.*

Figure 22-15 Pin Injection Test Setup, Power Pins - Ground Injection Method



Note: A series current-monitoring resistor may be used instead of the current-monitoring transformer.

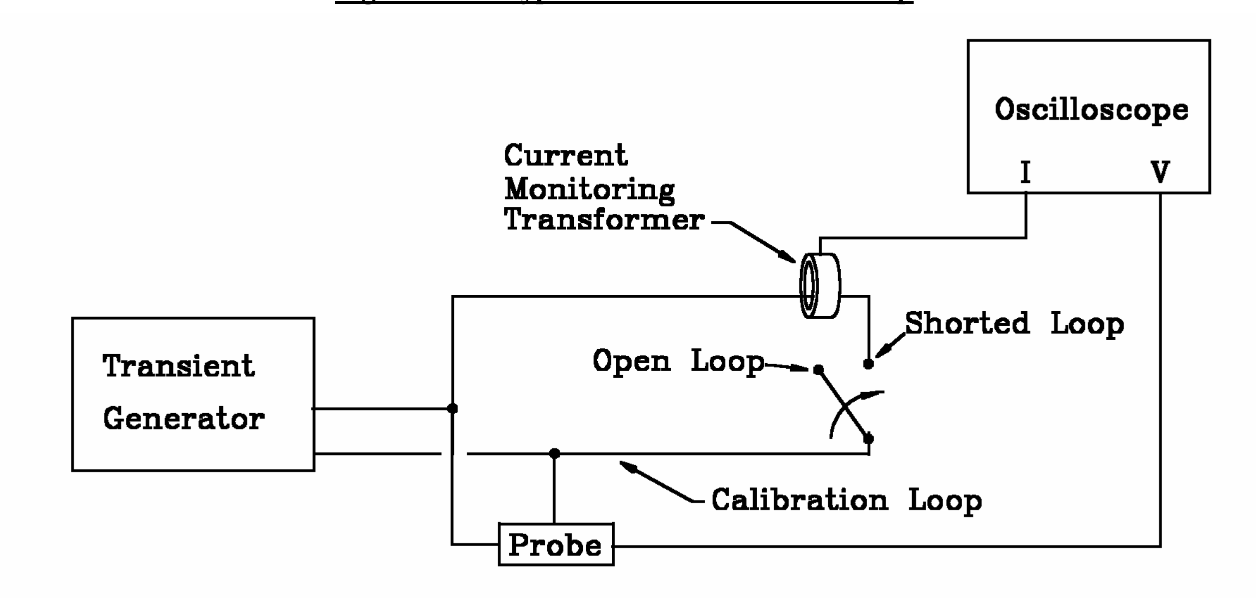
<u>Figure 22-16</u> Typical Generator Performance Verification Setup for Cable Induction Tests



Notes:
1. *Capacitor(s) shall be applied on power inputs to provide a low impedance to ground, as shown.*

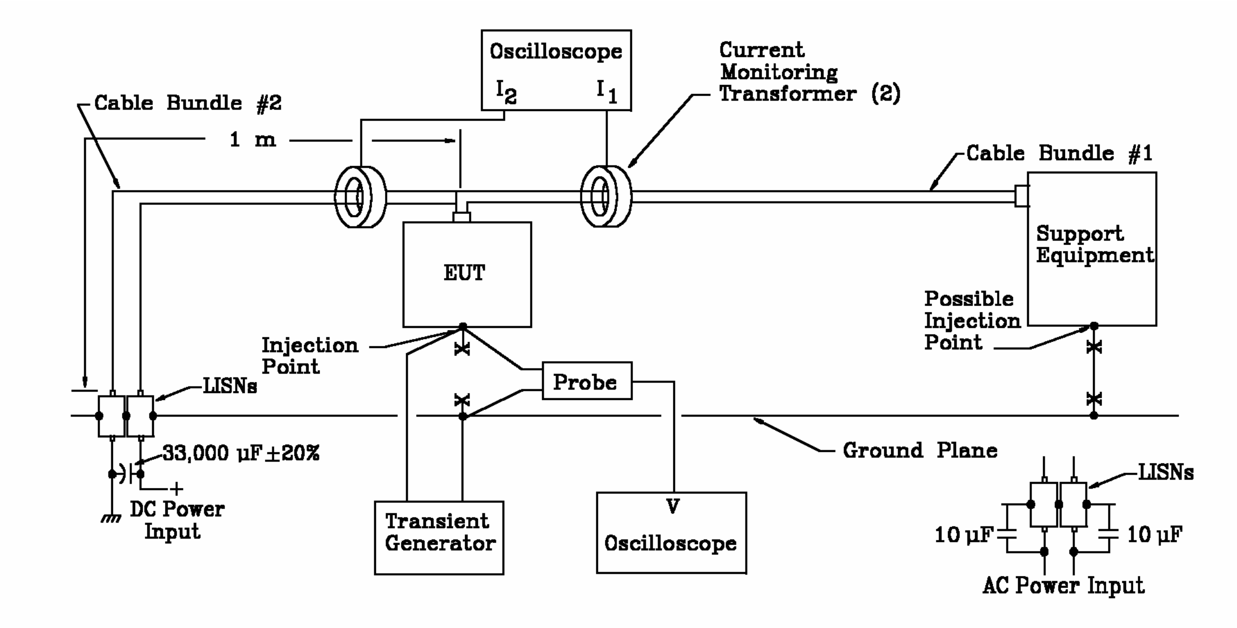
2. *A series current-monitoring resistor may be used instead of the current-monitoring transformer.*

<u>Figure 22-17 Typical Cable Bundle Test Setup</u>



Note: A series current-monitoring resistor may be used instead of the current-measuring transformer.

<u>Figure 22-18</u> Typical Generator Performance Verification Setup for Ground Injection Tests



Notes:

1. *Capacitor(s) shall be applied on power inputs to provide a low impedance to ground, as shown.*

2. *A series current-monitoring resistor may be used instead of the current-monitoring transformer.*

Figure 22-19 Typical Ground Injection Test Set-up

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RTCA/DO-160E

Environmental Conditions and Test Procedures for Airborne Equipment

Section 23

Lightning Direct Effects

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2, and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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December 9, 2004

Supersedes: RTCA/DO-160D
Prepared by: SC-135

Page

23.0 Lightning Direct Effects

23.1 Purpose of Tests

The tests described in this section are intended to determine the ability of externally mounted electrical and electronic equipment to withstand the direct effects of a severe lightning strike. The term “externally mounted equipment” refers to all electrical and electronic equipment mounted externally to the main skin of the aircraft and includes all such equipment that is covered only by a dielectric skin or fairing that is an integral part of the equipment. It also includes connecting cables and associated terminal equipment furnished by the equipment manufacturer as a part of the equipment. The tests described herein specifically exclude the effects of voltages and currents induced into the externally mounted equipment and its associated circuitry by means of magnetic or electric field coupling. These indirect effects are covered in Section 22.0.

Examples of equipment covered by this section are antennae, exterior lights, air data probes, external sensors, and anti-ice and de-ice equipment which is mounted external to the structure, i.e. electrically heated anti-ice boots. Electrical and electronic equipment such as lights and fuel quantity probes mounted on fuel tanks and exposed to direct or swept lightning strikes is also covered by this section.

Examples of equipment not covered by this section are mechanical devices such as fuel filler caps, equipment that is an integral part of the aircraft structure (i.e., heated or unheated windshields, electrically de-iced leading edges where the de-ice system is an integral part of the leading edge structure or is enclosed by the leading edge structure), and externally mounted equipment that is protected by aircraft nose radomes or dielectric coverings which are specific to the aircraft structure and are not integral with the equipment itself. Components such as these are to be addressed and/or tested as a part of the airframe lighting certification program specified by the aircraft manufacturer, or by other test method(s) appropriate to the component being qualified.

Normally the equipment will not be powered up or operating during the tests described herein. In situations where a power-on condition could change the susceptibility or vulnerability of the equipment to the direct effects of lightning, the equipment will have to be powered up or, alternatively, means employed to simulate the powered up condition. The need to do this should be defined in the test plan.

23.2 Definitions

23.2.1 Lightning Definitions

Arc Root

The location on the surface of a conducting body at which the lightning channel is attached while high current flows.

Continuing Current

A low level long duration current pulse that might occur between or after the high current strokes.

Direct Effects

Any physical damage to the aircraft and/or equipment due to direct attachment of the lightning channel and/or conduction of lightning current. This includes dielectric puncture, blasting, bending, melting, burning and vaporization of aircraft or equipment surfaces and structures. It also includes directly injected voltages and currents in associated wiring and plumbing.

First Return Stroke

The high current surge that occurs when the leader completes the circuit between the two charge centers. The current surge has a high peak current, high rate of change of current with respect to time (di/dt) and a high action integral.

Flash Hang-on

During the period of the lightning flash, the lightning channel may be swept backwards from one part of the aircraft to another as a result of the forward movement of the aircraft, attaching at various points along the surface of the aircraft. When the attachment point reaches the last point where attachment to the aircraft is possible, it stays with that point for the remaining duration of the flash.

Intermediate Current

After the initial decay following the peak current of some strokes, there is often a low level current of a few kiloamperes that persists for several milliseconds. This current is termed the intermediate current.

Leader

The low luminosity, low current precursor of a lightning return stroke, accompanied by an intense electric field.

Lightning Flash

The total lightning event in which charge is transferred from one charge center to another. It may occur within a cloud, between two clouds, or between cloud and ground. It consists of a leader and a first return stroke. It may also include an intermediate current, a continuing current and one or more restrikes.

<u>Restrike</u>

A subsequent high current surge during the lightning flash, which has a lower peak current, a lower action integral, but a higher di/dt than the first return stroke. This normally follows the same path as the first return stroke, but may reattach to a new location further aft on the aircraft.

<u>Slow Components</u>

This term is used to refer to the intermediate current and the continuing current collectively.

<u>Swept Leader</u>

A lightning leader that has moved its position relative to an aircraft, subsequent to initial leader attachment, and prior to first return stroke arrival, by virtue of aircraft movement during continued leader propagation.

23.2.2 General Definitions

<u>Action Integral</u>

The action integral of a current waveform is the integral of the square of the time varying current over its time of duration. It is usually expressed in units of ampere-squared seconds (A^2s).

<u>Discharge</u>

When used to refer to discharge of High Voltage (HV) or High Current (HC) impulse generators, the term "discharge" shall mean the discharge of the storage capacitors. This may or may not cause an electrical breakdown of the gap between the electrodes connected to the output terminals of the generator.

<u>Flashover</u>

This term is used when the arc produced by a gap breakdown passes over or close to a dielectric surface without puncture.

<u>Fuel Vapor Regions</u>

A fuel vapor region is a region in the aircraft that may have fuel or fuel vapor present.

<u>Gap Breakdown</u>

This term is used when the discharge of the capacitors of an HV or HC impulse generator results in the electrical breakdown of the gap between the electrodes connected to the generator output terminals.

<u>V_{90}</u>

This is nominally the voltage to which an HV impulse generator must be erected in order that 90 percent of all discharges will result in gap breakdown. For test purposes, a notional V_{90} is used as described in paragraph 23.5.1.

23.2.3 Zoning Definitions

The following text defines the various lightning zones. The areas appropriate to these zones on any particular aircraft shall be agreed between the airframe manufacturer and the appropriate certifying authority.

Zone 1A

All areas of the aircraft surfaces where there is a high possibility of an initial lightning attachment with a low possibility of flash hang-on are designated Zone 1A. For the purposes of this document, swept leader attachment areas are also included in Zone 1A. (In the future, those surfaces where first return strokes may only arrive by sweeping of the leader may be separately designated.)

Zone 1B

All areas of the aircraft surface where there is a high possibility of an initial lightning attachment and a high possibility of flash hang-on are designated Zone 1B.

Zone 2A

All areas of the aircraft surface where there is a high possibility of a lightning attachment being swept onto it from a Zone 1A, but having a low possibility of flash hang-on, are designated Zone 2A.

Zone 2B

All areas of the aircraft surface where there is a high possibility of a lightning attachment being swept onto it from a Zone 1A or 2A, but having a high possibility of flash hang-on, are designated Zone 2B.

Zone 3

All areas of the aircraft surface not covered by all Zones 1 and 2 are designated Zone 3. In Zone 3, there is a low possibility of a direct lightning attachment.

Note: All zones of the aircraft (including Zone 3) may be required to carry part or the whole of the total lightning flash currents flowing between two attachment points.

23.3 Equipment Categories

The nature and severity level of the tests to be applied to externally mounted equipment will depend upon the designated category of that equipment.

<u>Category 1A</u>

Equipment externally mounted in those areas of the aircraft identified as Zone 1A is designated Category 1A, unless otherwise designated as Category X.

Note: Equipment intended for use in areas where the first return stroke attachment can only arrive by sweeping of a leader must qualify as Category 1A unless otherwise designated as Category X.

<u>Category 1B</u>

Equipment externally mounted in those areas of the aircraft identified as Zone 1B is designated Category 1B, unless otherwise designated as Category X.

<u>Category 2A</u>

Equipment externally mounted in those areas of the aircraft identified as Zone 2A is designated Category 2A, unless otherwise designated as Category X.

<u>Category 2B</u>

Equipment externally mounted in those areas of the aircraft identified as Zone 2B is designated Category 2B, unless otherwise designated as Category X.

<u>Category 3</u>

Equipment externally mounted in those areas of the aircraft identified as Zone 3 is designated Category 3, unless otherwise designated as Category X.

<u>Equipment classified as suitable for use in fuel vapor regions</u>

Equipment intended for use in fuel vapor regions must have additional test requirements over and above those applicable to the appropriate zone for non-fuel vapor region equipment. Equipment so tested will have the additional classification “F” after the zone classification, which will indicate that the equipment may be used in a fuel vapor region, e.g., classification 2AF will clear the equipment for use in fuel vapor regions in zone 2A. When qualified to obtain the “F” classification for a particular zone/category, the configuration tested should be clearly defined. Comparison between this and the final aircraft installation may indicate that further tests are not required. Equipment not having the additional “F” classification may not be used in fuel vapor regions without further testing.

23.4 Lightning Direct Effects and Associated Parameters

This Subsection lists and describes the various direct effects failure mechanisms that can affect externally mounted equipment during a lightning strike to an aircraft. It also identifies the lightning current parameters and thereby the phase of the lightning flash associated with specific failure mechanisms.

23.4.1 Ohmic Heating

The instantaneous power dissipated as heat in a conductor due to an electrical current is i^2R watts. The ohmic heating generated by the complete lightning pulse is therefore the ohmic resistance of the lightning path through the aircraft multiplied by the action integral of the pulse and is expressed in Joules or watt seconds. In a lightning discharge, the high action integral phases of the lightning flash are of too short a duration for any heat generated in an aircraft structure by ohmic heating to disperse significantly. The phases of the lightning flash relevant to this failure mechanism are the first return stroke and any restrike.

23.4.2 Exploding Conductors (Disruptive Forces)

Where conductors having a very small cross sectional area are required to carry a substantial part of the lightning current, they may vaporize explosively. The associated shock wave can give rise to severe damage particularly in confined spaces. This failure mechanism is particularly significant in electric wiring connected to external equipment, e.g., navigation lights, antennae, pitot heaters, etc. If these are not adequately protected and are confined in or pass through closed compartments in the aircraft, they can present a significant hazard. In addition, small cross section metal foils etc. encapsulated in a dielectric, such as in an externally mounted blade antenna, or high energy internal arcs such as may result from the penetration of a non-conductive cover, can present a hazard from disruptive forces. The relevant current parameter is action integral, and the relevant phases of the lightning flash are the initial return stroke and restrikes.

23.4.3 Arc Root Thermal Damage

Burn through and material erosion can occur at the arc root. In metal, this is mainly a complex function of current and time. In the arc root area, there is a large thermal input from the arc root itself, as well as a concentration of ohmic heating due to the high current densities. Most of the energy is generated at or very close to the surface of the metal, and must therefore be dissipated by conduction. The heat generated in the immediate arc root area is in excess of that which can be absorbed into the metal by conduction, and the excess is either lost in melting and vaporizing the metal, or reradiated. There is minimum current and a minimum time for any given thickness of any given material below which burn through cannot occur. It is only the slow components phase of the lightning flash that can exceed the minimum requirements of both current and duration for metal burn through or severe erosion of any practical thickness of metal.

In carbon fiber composites the thermal effects are more pronounced, but the lower thermal conductance and higher electrical resistance affects the proportions of vaporizing and propagation processes. This leads to an increase in area in relation to the depth of damage.

The arc root burning voltage of carbon is higher than that of metals. This effect, plus the high bulk resistivity, generates more heat in the immediate arc root area and the hot spot remains for a longer period than for most metals. Thus, short duration high action integral pulses as well as low current long duration pulses produce high thermal inputs, and so all phases of the lightning flash are significant in producing arc root damage in carbon fiber composites.

23.4.4 Hot Spot Formation

Hot spot formation may occur on the inner surface of the aircraft skin as a result of one of two processes: first on an inner surface under an arc root, and second from local high current densities. The effects of hot spots are usually only significant with regard to ignition in fuel and other highly flammable substances. All phases of the lightning flash are significant to the first process, while the high peak current phases are significant to the second process.

23.4.5 Acoustic Shock Wave Damage

At the commencement of the first return stroke, there is a rapid pinching of the arc channel due to the increase in the magnetic field surrounding the channel. This produces a radial acoustic shock wave. At the same time, the rapid heating of the arc channel itself produces an axial shock wave. The latter is probably the most significant in its reaction with the aircraft. The severity of the shock is dependant upon both the peak current value and rate of rise of the current. It is therefore related to the first return stroke and in some instances to restrikes.

In general, the damage due to acoustic shock wave is insignificant on metal skins, but less malleable composite skins can rupture.

23.4.6 Magnetic Pressure

This pressure is only significant when the surface current density is greater than several kiloamperes per millimeter. For example, a conductor of five millimeters diameter carrying a pulse of 200 kA peak current would experience a surface pressure of 1000 atmospheres. The pressure is proportional to the square of the current (i^2) and the inverse square of the diameter. Thus, doubling the diameter or halving the current would reduce the pressure to 250 atmospheres.

In some cases, however, even relatively small pressures can be significant, such as the case of metal braid bonding strips. These can be compressed to near solid conductors leading to metal embrittlement and subsequent mechanical failure.

The relevant current phase is the first return stroke.

23.4.7 Magnetic Interaction

Considerable magnetic forces can exist from the interaction of the magnetic fields of two current carrying conductors or from two separate sections of the same conductor where the lightning current is forced to change direction. This force can also exist between current in the aircraft and the arc channel. This force is usually only of significance where the lightning current is confined to small cross-section conductors as might occur in some externally mounted equipment. The peak value of the force is proportional to the square of the peak current (I^2). The ultimate effect on the test object concerned can be a complex function of I^2, rise time, decay time, action integral and the mechanical response of the test object. The failure mechanism is therefore related to the first return stroke and in some cases to the restrikes.

23.4.8 Direct Effects Sparking

Direct effects sparking occurs when very high currents are forced to cross a joint between two conducting materials, or forced to take very convoluted paths. Two different types of sparking can occur: thermal sparking and voltage sparking.

Most thermal sparking occurs near the edges of high spots on the mating surfaces where the interface pressure is at or close to zero. The primary causes are high current density and inadequate interface pressure. Thermal sparks are burning particles of material ejected from the contact area by vaporization pressures occurring after the contact point melts. The ejected particle sizes cover the range from non-incendiary (<20 µm dia. Al.) to incendiary and move at various velocities. Ignition of a flammable mixture is the best detection method to evaluate ignition hazards. The relevant current parameter is peak current and the appropriate lightning current phase is the first return stroke and restrikes.

Voltage sparking occurs where the current is forced to take a convoluted path through the joint. The gap geometry and spacing has a significant effect on the energy necessary for ignition. Close spacings act more like thermal sparks. Ignition of a flammable mixture is the best detection method to evaluate ignition hazards. The significant current parameter is di/dt and the appropriate phase is the first return stroke and restrikes.

23.4.9 Dielectric Puncture

The puncture of any dielectric skin covering any externally mounted equipment could permit the direct attachment of lightning to that equipment. The probability of puncture of a dielectric will be a function of the presence of any conductor underneath the dielectric that raises the electric field stress, the thickness and strength of the dielectric, the condition of the dielectric surface, and the proximity of other conducting surfaces. As a general guide, puncture of the dielectric must be considered possible unless the voltage required to puncture the dielectric at any point is significantly greater than the voltage required to cause flashover to the nearest conducting point of the airframe. The conditions for dielectric puncture are generated in the pre-discharge phase and at the onset of the first return stroke phase of the lightning flash. Puncture might also occur as a result of a restrike, or a swept stroke reattachment.

23.5 Test Parameters

23.5.1 Voltage Waveforms and Levels

High Voltage tests shall be conducted using a high voltage pulse generator capable of delivering a 1.2/50 µs open circuit output voltage waveform (risetime from zero to peak voltage in 1.2 µs ±20 percent and decaying from peak voltage to half peak voltage in 50 µs ±20 percent; see Figure 23-l.). This waveform shall be used in conjunction with the "Up-down Voltage Transfer Method" (UDVTM) for testing. This method defines a notional V_{90} level.

The UDVTM is a technique first proposed by Bakken for testing with breakdowns at or about the V_{90} level in which the level is formed during testing. To find the V_{90} level would otherwise require a very large number of tests to raise confidence through a statistically significant sample. UDVTM involves varying the generator voltage by increments in accordance with a set procedure as the gap breakdown occurs or fails to occur. The formula for incremental changes is as follows:

a. Start at a voltage slightly below gap breakdown voltage.

b. Whenever gap breakdown fails to occur, raise the voltage by five percent.

c. After three consecutive gap breakdowns at the same voltage, lower the voltage by five percent.

d. If breakdown still occurs after lowering the voltage then lower the voltage by an additional five percent.

Each gap breakdown that occurs should be counted towards the number required to complete the test. Each failure to break down should be discounted.

Alternative waveforms and tests may be used as follows:

a. A voltage rising at the rate of 1000 kV/µs ±50 percent may be applied. See Figure 23-2. This voltage is applied across the gap and allowed to rise until gap breakdown occurs.

b. A voltage rising to peak in between 50 µs and 250 µs. See Figure 23-3. This voltage is applied across the gap and the peak voltage adjusted to a value where gap breakdown occurs at or just after peak voltage.

23.5.2 Current Waveforms and Levels

For verification purposes, the natural lightning environment is represented by current test components A, B, C and D in Figure 23-4. Each component simulates a different characteristic of the current in a lightning flash. When testing is carried out, the application of these waveforms to the appropriate category is obtained from the table associated with Figure 23-4. They shall be applied individually or as a composite of two or more components together in one test.

a. Component A - First Return Stroke Current

Component A has a peak amplitude of 200 kA ±10 percent and an action integral of $2 \times 10^6 A^2s$ ± 20 percent with a total time duration not exceeding 500 µs. This component may be unidirectional or oscillatory. The rise time (make consistent with component D) from 10 to 90 percent peak current shall be less than 50 µs.

Note: For magnetic forces tests, a unidirectional pulse is preferred. When an oscillatory pulse is used, account must be taken of the mechanical response of the system under test.

b. Component B - Intermediate Current

Component B has an average amplitude of two kA ±20 percent and charge transfer of 10 coulombs ±10 percent in five milliseconds ±10 percent. The waveform shall be unidirectional and may be rectangular, exponential or linearly decaying.

c. Component C - Continuing Current

Component C transfers a charge of 200 coulombs ±20 percent in a time of between 0.25 s and 1.0 s. The waveform shall be unidirectional, may be rectangular, exponent or linearly decaying, and its amplitude shall be between 200 and 800A.

d. Component D - Re-strike Current

Component D has a peak amplitude of 100 kA ±10 percent and an action integral of $0.25 \times 10^6 A^2s$ ±20 percent. This component may be either unidirectional or oscillatory with a total time duration not exceeding 500 µs. The time from 10 percent peak current to 90 percent peak current shall be less than 25 µs.

Note: For magnetic forces tests, a unidirectional pulse is preferred. Where an oscillatory pulse is used, account must be taken of the mechanical response of the system under test.

The current components applicable to each category shall be as shown in Figure 23-4.

23.6 Test Procedures and Levels

WARNING

Lightning simulation tests require high energy electrical equipment which may be charged to very high voltages during their operation. Therefore, all safety precautions relevant to this type of test apparatus should be complied with. All tests should be conducted in a controlled access area by personnel experienced in high voltage/high current testing.

23.6.1 General

This paragraph contains scope and descriptions of high voltage and high current tests for externally mounted equipment. Equipment that has an integral dielectric covering should first be tested with high voltage as defined in paragraph 23.6.2 to establish surface flashover or puncture paths. If the protecting insulation of an equipment, such as a blade antenna, does not puncture during high voltage tests, then normally a high current test will be required to demonstrate survival of the equipment from thermal and acoustic effects arising from proximity to the high current arc following the flashover paths indicated during the high voltage tests.

If puncture of the protecting dielectric does occur, and this does not in itself constitute failure of the equipment, high current tests shall be carried out at the level of the category chosen with the arc directed along the path(s) of the puncture(s) caused during the high voltage tests.

All equipment that has no dielectric covering must be subjected to high current tests using the current waveforms appropriate to the category chosen, as defined in Subsection 23.3 and Figure 23-4 to determine the ability to transfer these currents to the airframe safely, and to assure that excessive currents or voltages are not conducted into the aircraft on associated interconnections and interconnected equipment.

Equipment that is partially covered by a dielectric shall be subjected first to high voltage tests for those parts covered by the dielectric as defined in paragraph 23.6.2, and also subjected to high current tests to all exposed conducting parts including fasteners, using the current waveforms appropriate to the category chosen as defined in Subsection 23.3 and Figure 23-4.

A flow chart giving the sequence of testing is shown in Figure 23-5.

23.6.2 High Voltage Tests

23.6.2.1 Applicability and General Requirements

The HV tests are applicable to all categories where the equipment is covered by a dielectric that is integral to the equipment, except for category 3. In all cases where HV tests are applied, they will be flashover versus puncture tests.

The specimen shall be fully representative of the production standard, and all installation requirements that could affect the test results, such as electrical bonding, shall be addressed.

The equipment under test should be mounted in accordance with the installation requirement onto a conducting ground plane as indicated in Figure 23-6. All conducting parts of the equipment normally bonded to the airframe shall be bonded to the ground plane and to one terminal of the pulse generator. The other terminal of the generator shall be connected to a large plate electrode as shown in Figure 23-6. The ground plane and the electrode shall be stress relieved on all edges and corners. They may be either square or circular in plan view.

All dimensions of the ground, the electrode, and the test gap shall be related to the dimensions of the test object as defined in Figure 23-6 and quantified in the associated table.

The Environmental Qualification Form (Appendix A), or DDP Form, if appropriate, should identify equipment that has been subjected to the high voltage tests.

23.6.2.2 Test Set-up and Procedures

The tests shall be conducted by using either the notional V_{90} method as defined by paragraph 23.5.1 and Figure 23-l, or one of the two alternative methods as defined in paragraph 23.5.1 and Figures 23-2 and 23-3. The tests shall continue until the gap breakdown requirements have been met.

Whichever method is chosen, a total of five discharges resulting in gap breakdown shall be applied at each polarity on each specimen tested. Discharges that do not result in gap breakdown shall be discounted.

During each discharge the voltage waveform shall be recorded, and a photograph of the test article shall be taken to record all gap breakdowns. After any suspected puncture, and at the completion of the test series, inspection of the recorded data, with any other diagnostics used, and a visual inspection of the equipment under test shall be done to establish if surface flashover or puncture has occurred.

If dielectric puncture occurs and the damage associated with the puncture does not exceed the damage criteria, then the appropriate high current tests should follow using the puncture already created or a deliberately drilled hole at the same location as the puncture.

If puncture does not occur, then high current tests will normally be conducted to demonstrate the ability of the test object to survive the normal thermal effects and acoustic shock wave effects of a surface flashover. These tests will be conducted as described in paragraph 23.6.3.

In the event that high voltage tests performed in accordance with Sections 23.6.2.1 and 23.6.2.2 using the high voltage electrode configuration described in Figure 23-6 do not result in flashovers to the test object, the high voltage test should be repeated with a spherical electrode with a minimum diameter of 10 ±1 cm and be positioned at distance l_2 from the surface of the test object as illustrated in Figure 23-6.

Other aspects of this high voltage test should be the same as those described in paragraphs 23.6.2.1 and 23.6.2.2.

In cases where the large flat electrode is not likely to produce flashovers to the test object, tests with this electrode may be omitted and the high voltage tests begun with the spherical electrode.

In all cases, the procedures as shown in the flow chart of Figure 23-5 shall be followed.

23.6.3 High Current Tests

23.6.3.1 General Requirements

The current components (A,B,C and D) applicable to each category depend upon the zone appropriate to the category, as defined in Subsection 23.3. The current components applicable to each zone are specified in paragraph 23.5.2. If a specific category is not identified in the individual specification, the equipment manufacturer should design and qualify the equipment to the category consistent with the expected lightning zone in which it will be installed and state the category.

a. Test Specimen

The test specimen shall be fully representative of the production standard and all installation requirements which could affect the test results, such as electrical bonding, shall be addressed.

b. Test Electrode and Arc Root Wander Limitation

For arc entry tests (Categories 1A, 1B, 2A and 2B), the electrode material shall be a good electrical conductor. It may be a plain rod or, preferably, a "jet diverting electrode." The jet diverting electrode has an insulating material covering all surfaces that face the test object, thus forcing the arc to originate from a surface which faces away from the test object. The area close to the point of entry on the test object shall be protected by a thin dielectric shield to prevent excessive wander of the arc root. The arc shall be directed to the surface of the test object through a circular hole in the protecting dielectric of between 10 mm and 12 mm radius.

c. Electrode Gap

The electrode gap is the distance between the electrode and the attachment point to a conductor on or in the test specimen. To prevent arc jet and blast pressure effects from influencing the test results, it is recommended that a spacing of not less than 50 mm, measured from the conducting surface of the electrode to the surface of the test object, be employed if a jet diverting electrode is used and not less than 150 mm with a plain electrode. Spacings less than the above would constitute a more severe test due to blast pressure, but would not disqualify the test if the specimen passed.

d. Arc Initiation

A fine wire not exceeding 0.1 mm diameter may be used to initiate the current discharge of low voltage driven generators without adversely affecting the results. The conducting wire can be metallic (e.g., copper) or carbon fiber. The wire will also enable the arc to be directed to the exact point of interest on the test specimen.

For surface flashover testing, the arc will be directed along the line(s) of the surface flashover(s) determined by the HV tests by supporting the wire throughout its length at a distance between 5 mm and 15 mm from the surface of the test object. The gap between the initiating wire and the surface of the test object shall be unobstructed for not less than 90 percent of the total distance.

An alternative method of initiating the arc may be to use a high voltage discharge generated by a Tesla coil or similar device.

Note: Both the fine wire or the high voltage discharge methods of initiating the arc will introduce very high dE/dt transients (10^{10} v/m/s) into the region above the object under test. Antennas, which are nominally dE/dt detectors, will respond to such transients.

e. Electrode Polarity

In most cases, electrode polarity is not important when the electrode spacing complies with subparagraph 23.6.3.1.c. However, if in doubt, the electrode polarity should be negative.

f. Conducted Entry Tests

For conducted entry tests (Category 3), the test current shall be conducted through the ground plane on which the test object is mounted in a manner representative of the lightning current distribution in an aircraft during a lightning strike. As a minimum, a surface current density of 50 kA/m should be applied. This represents the surface current density approximately 650 mm from the arc root.

23.6.3.2 Test Set-up - Non Fuel Vapor Region Equipment

a. Current Flow Through the Test Specimen

The test set-up should ensure that the simulated lightning current distribution through the test specimen is representative of an aircraft being struck by lightning.

b. Electrode Location

The test electrode should be positioned so as to direct the arc to the equipment surface selected for the test.

c. Test Apparatus

The test apparatus shall include:

(1) A high current generator(s) capable of producing the waveforms specified in paragraph 23.5.2.

(2) All necessary high current, high voltage, thermal and other measuring devices or recording instruments.

(3) Photographic equipment for recording strike points/damage areas.

d. Installation of Recording Instrumentation

The recording instrumentation shall be adequately shielded or decoupled from electromagnetic fields associated with the simulated lightning test currents or other sources. A calibration check shall be carried out to verify the accuracy of all recorded data.

e. Test Arrangement

A schematic diagram of the high current test setup is illustrated in Figures 23-7 and 23-8. Measurements shall be made of voltages and currents originating within the equipment as a consequence of this test in accordance with applicable equipment performance standards. This may require that a short length of cable be utilized to facilitate measurement of voltages and currents, as illustrated in Figures 23-7 and 23-8. All measurements must be recorded in the test report.

It should be noted that voltages and currents measured in cable shields or conductors are not necessarily representative of those that would occur in specific aircraft installations and may only be significant in establishing whether or not there are any voltages or currents.

23.6.3.3 Test Set-up - Fuel Vapor Region Equipment

The test set-up requirements detailed for non-fuel vapor regions in subparagraph 23.6.3.2 also apply to fuel vapor regions in addition to the points listed below. A typical setup is shown in Figure 23-9.

a. Test Specimen

The external equipment (test object) shall be mounted on an appropriate section of the simulated airframe skin, and a light or gas tight chamber shall be constructed on the inside (vapor side) of the skin. The applied test currents shall be in accordance with paragraph 23.5.2.

b. Detection of Sparking and Arcing

Where photography is employed, the film speed, aperture number and the distance from lens to object shall be such that the apparatus can detect and record voltage sparks of 200 μJ or less. An acceptable technique is one using a 3000 ISO/ASA panchromatic film together with a lens aperture no smaller than f/4.7 with a field of view not exceeding one meter wide. The sensitivity of the ignition detection technique employed to 200 μJ sparks must be demonstrated and that data included in the test report. It shall be verified that the chamber is light-tight and shall, if necessary, be fitted with an array of mirrors to make any sparks visible to the camera. Some means shall be employed to demonstrate that the camera shutter was open during the current discharge.

Alternative methods of achieving the same sensitivity of detection and recording may be used instead of, or in addition to, photographic methods.

c. Detection of Hot Spots

A number of techniques are available for detection of ignition sources due to hot spots. They include infra-red detection systems, optical pyrometry, fast response thermocouples and temperature sensitive paints.

d. Ignition Detection Using Ignitable Mixtures

If there are regions where a hot spot or sparking activity is not accessible to detection by any of the above means, then ignition tests may be carried out by placing an ignitable gas-air mixture inside the chamber. This may be any gas mixture that has a high ignition probability from a 1.5 to 2 mm long, 200 μJ spark, such as ethylene/air in a 1.3 to 1.4 stoichiometric mixture. A propane/air mixture requires oxygen enrichment to obtain adequate sensitivity.

WARNING

When making tests with combustible gas mixtures, suitable precautions shall be taken such as blow out panels to preclude explosions of the structure, the location of fire extinguishing equipment nearby and protection of test personnel from possible flame or blast effects and possible flying parts. The possibility of seepage of the gas mixture into unvented parts of the structure resulting in serious explosion damage, should be considered.

23.6.3.4 General Operating Requirements

a. Arcing

The discharge circuit of the current generator(s) should be designed and maintained to avoid inadvertent arcing and other phenomena that may affect personnel and equipment safety, and test accuracy.

b. Personnel Protection

All personnel should be provided with appropriate eye and ear protection.

23.6.3.5 Test Procedures

This method is used to determine the direct effects that result from the interaction of lightning currents with externally mounted electrical and electronic equipment.

a. Set up the high current generator(s), discharge circuit and sensing and recording equipment.

b. Insert a dummy test object beneath the electrode or place a conductive bar over the actual test object such that waveform checkout discharges cannot damage the test object. Preferably, these should have the same inductance and resistance as the test object.

c. Inspect the test set-up, test and calibration equipment and areas for safe operation.

d. Initiate a discharge to the dummy test object or conductive bar to check the current waveforms, to verify that the specified levels are being met and to check the correct functioning and calibration of the diagnostic equipment.

e. Remove the dummy test object and place the actual test object in the discharge circuit and record its physical and functional condition.

f. Initiate a discharge and inspect the specimen after the test and record the result.

g. Correlate photographs with the arc entry points/damage areas observed on the test object.

h. Any requirements for functional tests before or after the application of the test current waveforms shall be in accordance with the applicable equipment performance standard.

Note: When these procedures are used for tests on equipment to be used in fuel vapor regions, or to determine the possibility of combustible vapor ignition as a result of equipment skin puncture, internal hot spot temperatures and/or sparking and arcing, the following additional procedures must be observed.

i. Determine the presence of an ignition source by photography, ignition of an ignitable mixture or temperature measurement, as appropriate. If photography is employed, any light indication due to internal sparking during the test shall be taken as sparking sufficient to ignite fuel. If an ignitable mixture is used and no ignition occurs during the test, verification of the mixture combustibility shall be obtained by ignition with a spark of the defined energy and length introduced into the test chamber or exhaust (see Figure 23-9) immediately after the lightning test. If the combustible mixture is not ignited by the artificial source, the lightning tests shall be considered invalid and the tests repeated with a new mixture until either the lightning tests or the artificial source ignites the mixture.

j. If photography is employed, verify that the camera shutter is open for the entire duration of the discharge. This is normally done by use of a "tell-tale" light. Inspect and record its physical and functional condition.

Note: Sparking may take place well away from the attachment point.

23.6.4 Data Required to Assist in Interpretation of Test Results

a. Environmental data such as temperature, pressure and humidity.

b. Description and photographs of the test set-up and specimen, including specimen description (model/part no., materials, thicknesses, surface treatments, corrosion protection, sealants, etc.).

c. Date and names of personnel performing and witnessing the tests, and name of the test facility.

d. Photographs and description of the test specimen both before and after the test. Photographs shall clearly show sample identification marks and change(s) in physical condition and a dimensional scale. The sample may be damaged at points remote from the arc attachment.

e. Test voltage and current waveforms and magnitudes.

f. Currents and voltages, as applicable, on the equipment cables and/or terminations.

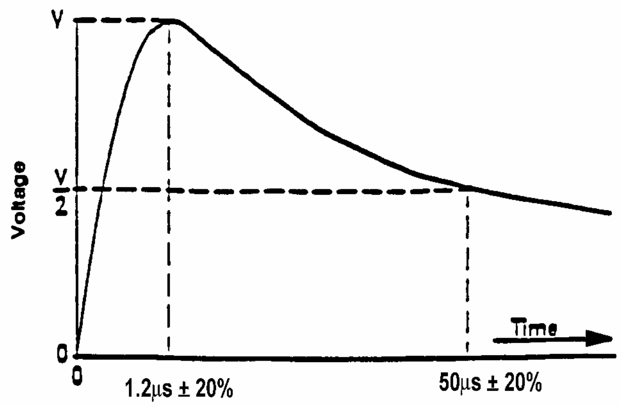
g. Photograph and descriptions of discharges and arc attachment points and all damage on the test object.

Note: The following items apply only to fuel vapor region tests.

h. Where applicable, photographs of the interior of the fuel chamber under study during the test, or other evidence of the presence or absence of sparking during the tests.

i. Where photography is used for the detection of sparking, the film speed, aperture number, focal length and lens-to-object distance shall be recorded.

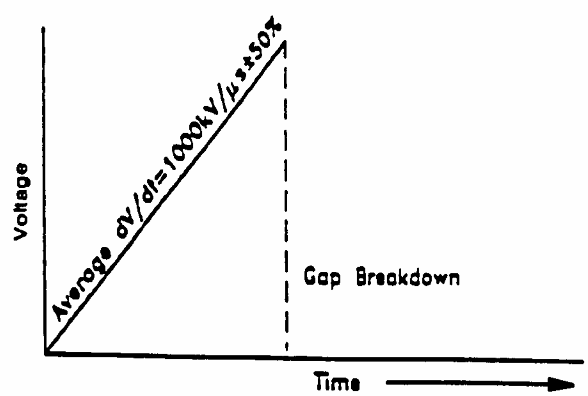
j. If an ignitable gas-air mixture is employed all relevant details shall be recorded, including the method used to verify its ignitability.



Total Gap Length	Electrode Positive	Electrode Negative
0.5m	250kV	600kV
0.8m	400kv	900kV
1.0m	500kV	1100kV
1.5m	800kV	1500kv

Approximate Voltage Requirements

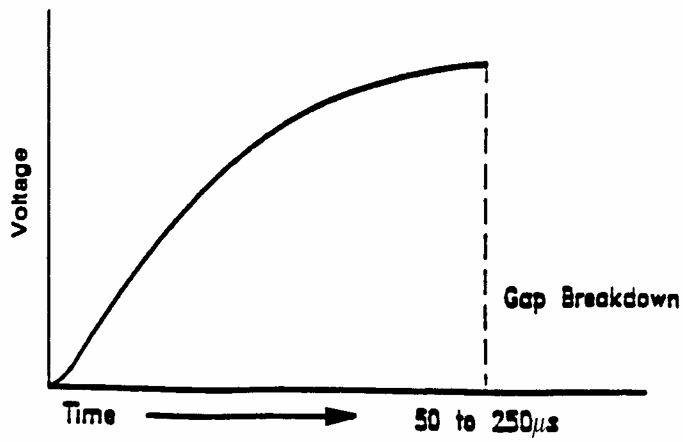
FIGURE 23-1 HIGH VOLTAGE WAVEFORM FOR V_{90} METHOD



Total Gap Length	Electrode Positive	Electrode Negative
0.5m	750kV	790kV
1.0m	1300kv	1400kV
1.5m	2250kV	2400kV

Approximate Voltage Requirements

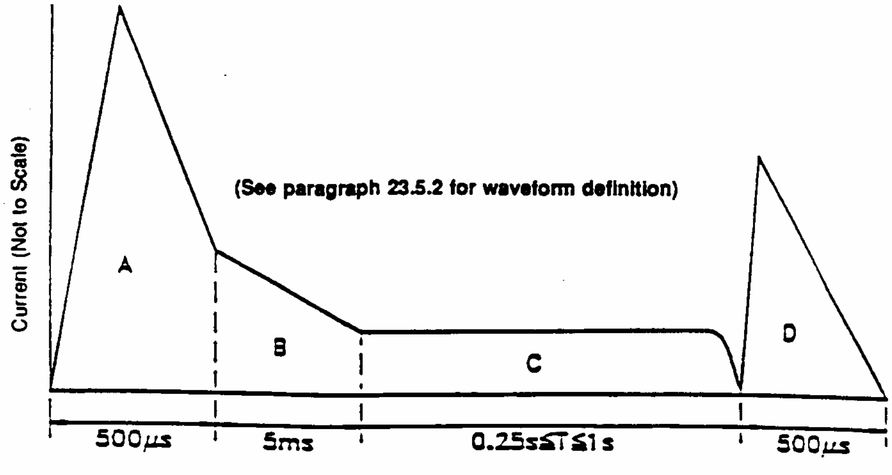
FIGURE 23-2 HIGH VOLTAGE WAVEFORM FOR ALTERNATE METHOD



Total Gap Length	Electrode Positive	Electrode Negative
0.5m	350kV	400kV
1.0m	500kv	600kV
1.5m	600kV	700kV

Approximate Voltage Requirements

Figure 23-3 High Voltage Waveform for Alternate Method
(Voltage Rising to Peak in Between 50 μs and 250 μs)



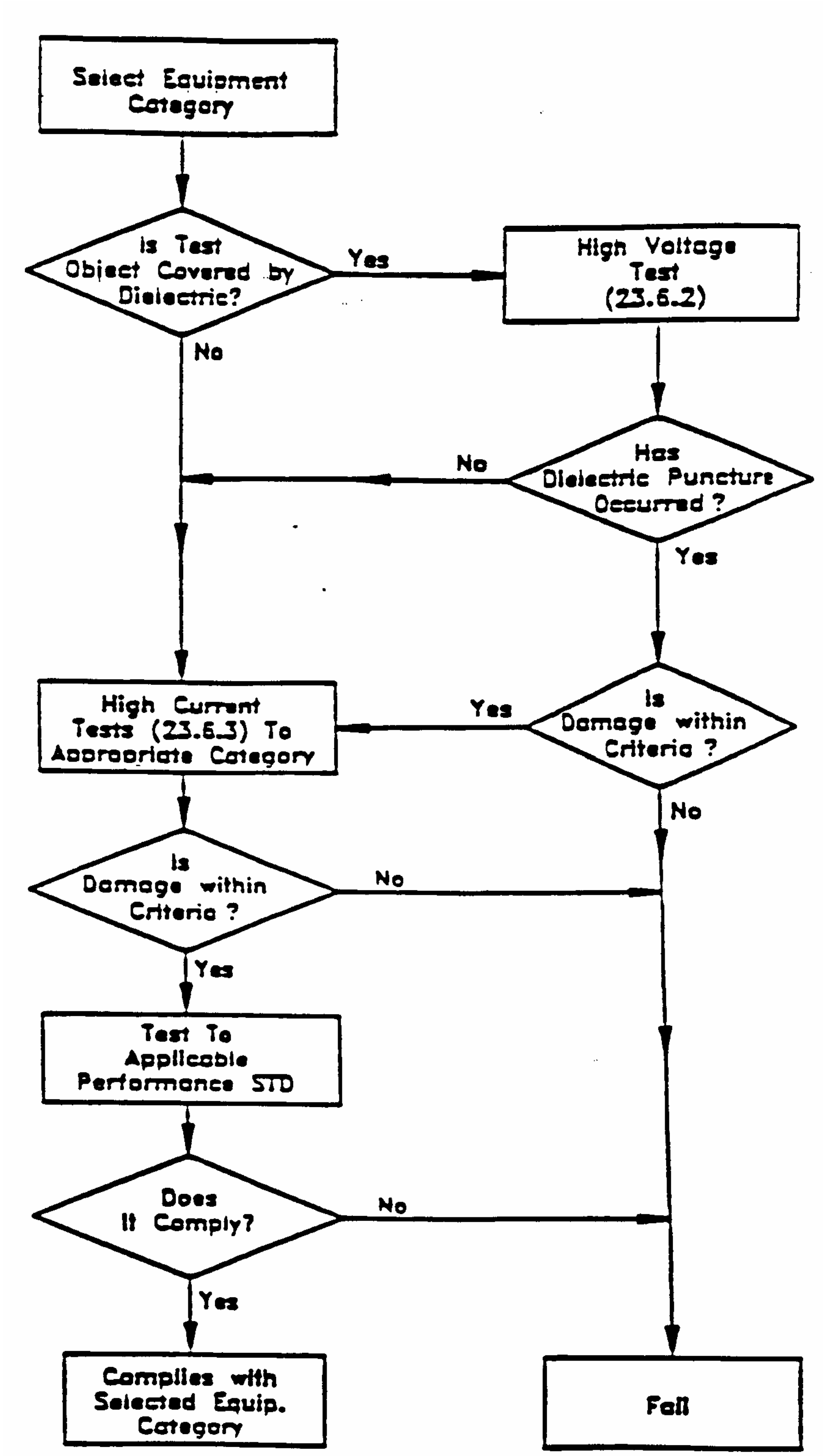
Test	Category	Current Components			
		A	B	C	D
Direct Effects on Externally Mounted Equipment	1A	X	X	X[1]	
	1B	X	X	X	X
	2A		X	X[1]	X[3]
	2B		X	X	X[3]
	3	X[2]		X[2]	

Note 1: The full duration of component C is not applied for categories 1A and 2A. Apply the average current of 400 A for 45 ms ±10 percent to deliver 18 coulombs ±20 percent.

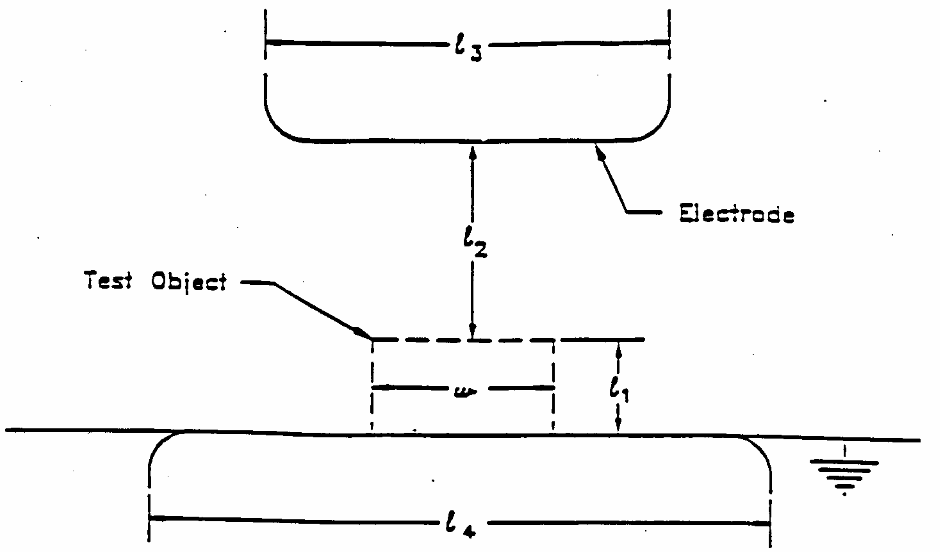
Note 2: These current components are applied by direct connection i.e., not by arc, and in some cases will only be applied to flow in the skin alongside the equipment under test. As a minimum, a surface current density of 50 KA per meter should be applied.

Note 3: Component D to be applied first.

Figure 23-4 Current Waveforms



<u>Figure 23-5</u> Flow Chart for High Voltage and High Current Tests



Notes: 1) For a symmetrical shape, ω is the smaller of the length or width, or for a non-symmetrical shape, twice the distance from the centroid of the object's surface foot print to its surface edge.

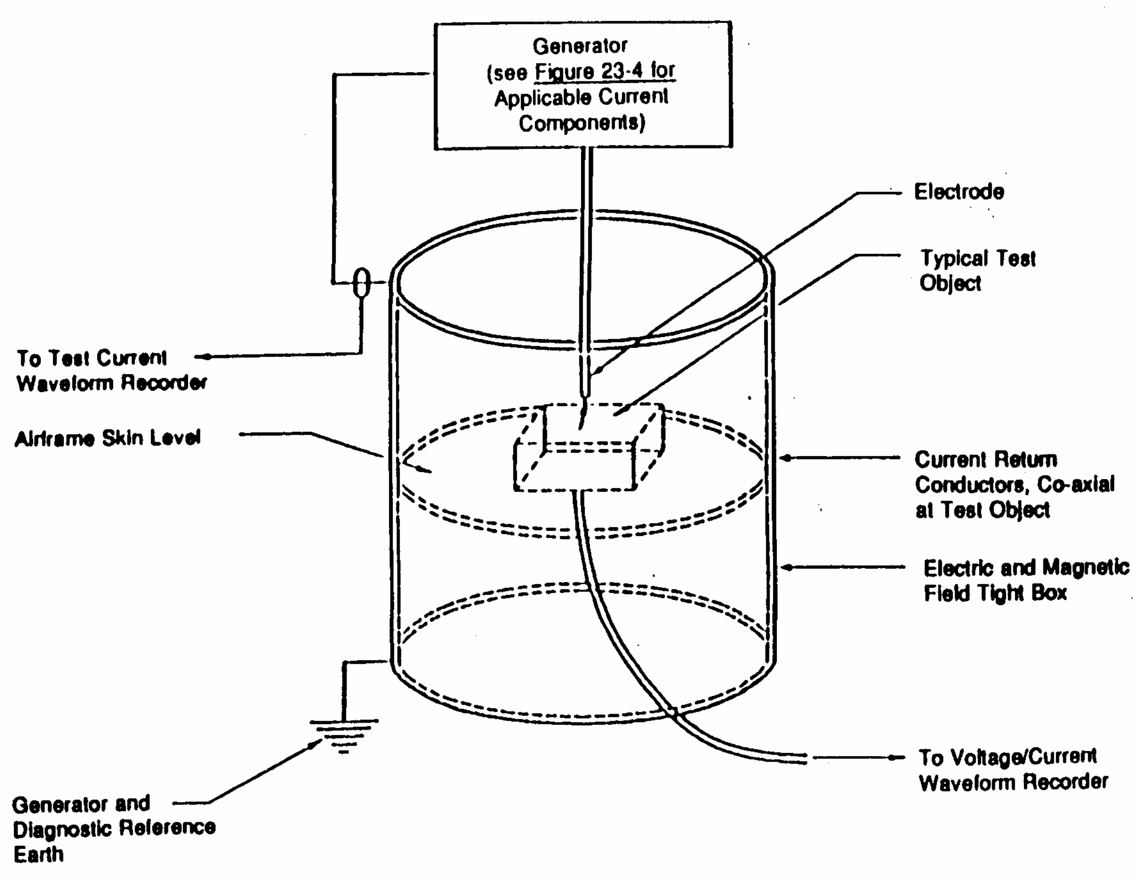
2) The ground plane may be either a very broad, flat one, or one with a profiled edge of width l_4.

Test Set up Dimensions	For ω and l<100mm	For $l_1>\omega$ and $l_1>100$mm	For $\omega>l_1$ and $\omega>100$mm
l_2	150mm	$\geq 1.5 l_1$	$\geq 1.5\omega$
l_3	$>2l_2$	$>2l_2$	$>2l_2$
l_4	$\geq l_3$	$\geq l_3$	$\geq l_3$

Gap and Electrode Dimensions for High Voltage Tests

Notes: The tolerance for l_2 is 20 percent.
The values for l_2 and l_4 are minimum values.

Figure 23-6 Test Arrangement and Dimensions for High Voltage Tests



<u>Figure 23-7</u> Typical High Current Set-Up for Non-Fuel Areas Arc-Entry Tests

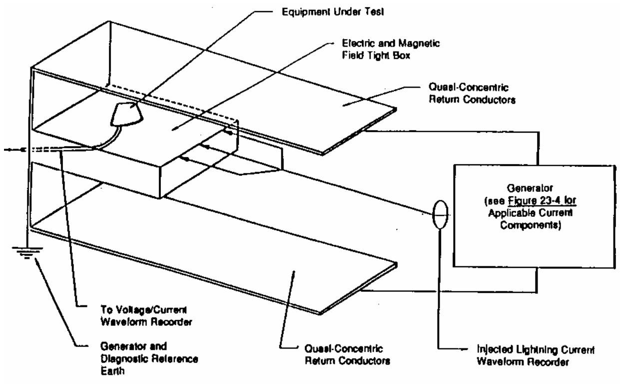


Figure 23-8 Typical High Current Set-Up for Non-Fuel Areas Conducted Entry Tests

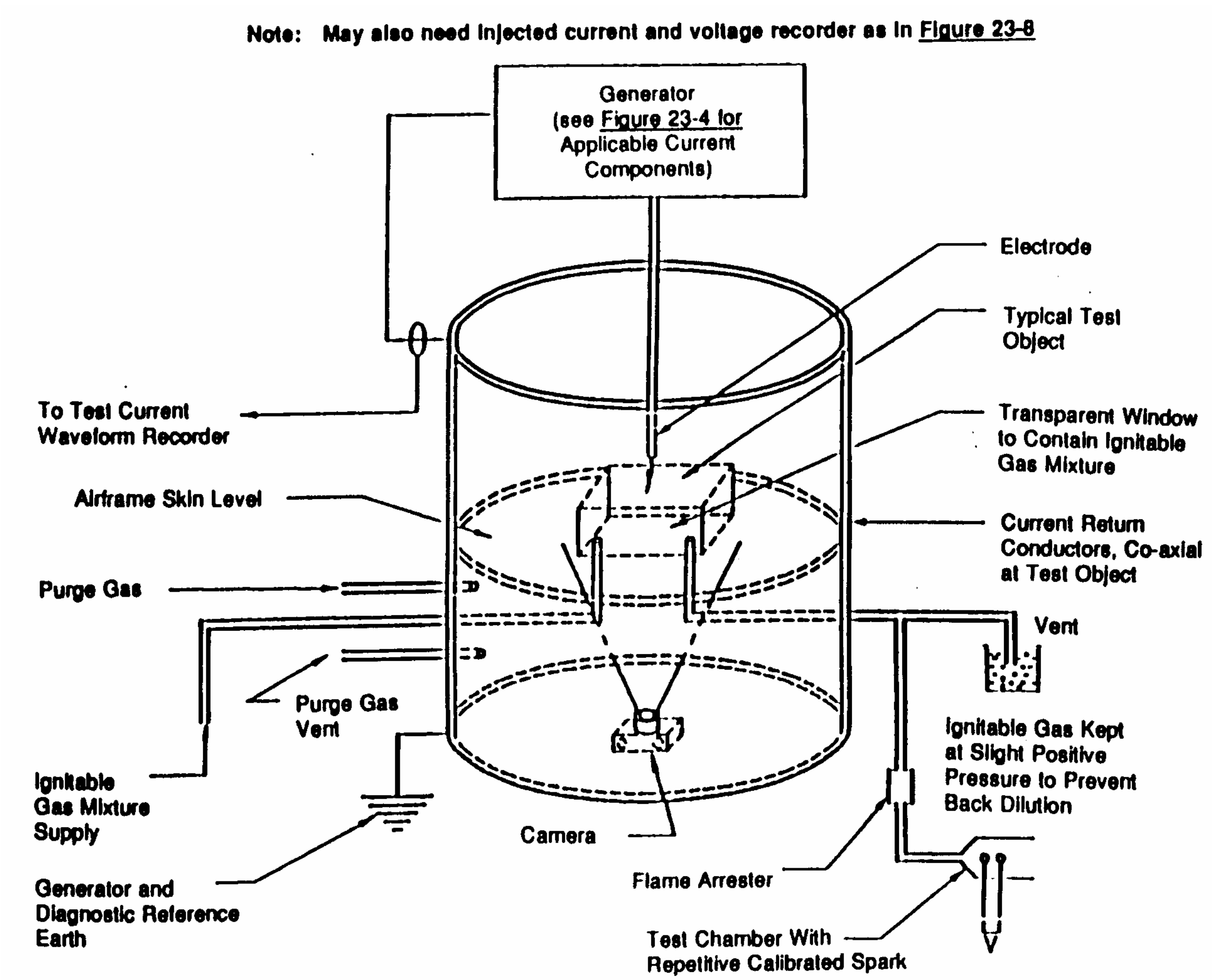


Figure 23-9 Typical High Current Set-Up for Fuel Vapor Region Requirements

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 24

Icing

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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24.0 Icing

24.1 Purpose of the Test

These tests determine performance characteristics for equipment that must operate when exposed to icing conditions that would be encountered under conditions of rapid changes in temperature, altitude and humidity.

24.2 General

Three icing test procedures are specified according to the category for which the equipment is designed to be used and installed in the aircraft (see Subsection 24.3).

Note: The selection of icing category depends on equipment location in (or on) the aircraft and the type of icing conditions expected. These conditions must be considered by the equipment designer in evaluating these requirements, which are determined by the end application and use of the equipment. These tests generally apply to equipment mounted on external surfaces or in non-temperature controlled areas of the aircraft where rapid changes in temperature, altitude and humidity are generally encountered.

These procedures specify test methods for evaluating the effects of various icing conditions on the performance or aircraft equipment, namely:

a. The effects of external ice or frost adhering to it.

b. The effects of ice caused by freezing of water condensation or by re-freezing of melted ice.

c. The effects of ice build-up caused by direct water exposure.

24.3 Equipment Categories

The following categories cover the anticipated ice formation conditions generally encountered in aircraft.

<u>Category A</u>

This test is applicable to equipment mounted externally or in non-temperature-controlled areas of the aircraft, where ice or frost may form due to condensation when the equipment is cold soaked to extremely low temperatures and subsequently encounters humid air at above freezing temperatures.

Category B

This test is applicable to equipment with moving parts where such movement could be prevented or impeded by ice formation, or where forces resulting from the expansion of ice could damage structural or functional components. The ice formed in or on the equipment results from condensation, freezing, melting and/or re-freezing and may progressively accumulate water or ice inside non-sealed enclosures.

Category C

This test is applicable to items mounted externally or in non-temperature-controlled areas where there is risk of accumulating free water, which could subsequently freeze on the cold surfaces of the equipment. The test is intended to examine the effects of a representative thickness of ice on the performance of the equipment or to determine the maximum thickness that can be permitted before de-icing action is necessary. The required thickness and distribution of ice and any requirement for progressive build-up of ice shall be defined by the APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

24.4 Test Procedure

24.4.1 General

Mount the equipment under test in a manner representative of the normal installation in the aircraft. Remove all non-representative contaminants, such as oil, grease and dirt, which would effect adhesion between ice and the surfaces of the equipment under test, before beginning the appropriate tests. Operation of equipment that generates heat shall be limited to only that period of time necessary to determine compliance. The steps described in the Category A and Category B procedures are illustrated in Figure 24-1 and Figure 24-2.

24.4.2 Category A

a. With the equipment not operating, stabilize the equipment temperature at the low ground survival temperature specified in Table 4-1 at ambient room pressure and humidity.

b. As quickly as practical, expose the equipment to an environment of 30 degrees C with a relative humidity of at least 95 percent. Monitor the surface temperature of the equipment.

c. Maintain the environment at 30 degrees C and a relative humidity of at least 95 percent until the surface temperature of the equipment reaches five degrees C. As quickly as practical, change the environment to the appropriate ground survival low temperature at ambient pressure and humidity.

d. Repeat steps a. through c. for two additional cycles (total of three cycles).

e. At the end of the third cycle, stabilize the equipment at the ground survival low temperature. Increase and maintain the chamber temperature to -10 degrees C and permit the surface temperature of the equipment to rise. When the surface temperature reaches -10 $\pm$5 degrees C, place the equipment into the operating state and DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: This test is designed to expose the equipment alternately to cold dry and warm moist environments. The use of separate chambers representing these two distinct environments is recommended.

24.4.3 Category B

a. With the equipment not operating, stabilize the equipment temperature at -20 degrees C at ambient room pressure. Maintain this temperature and decrease the chamber pressure to the appropriate maximum operating altitude specified in Table 4-1. Maintain this condition for a period of at least 10 minutes.

b. Raise the chamber temperature at a rate not exceeding three degrees C/minute while simultaneously increasing and maintaining the relative humidity in the test chamber to not less than 95 percent. Maintain this condition for a sufficient period of time to melt all frost and ice or until the surface temperature of the equipment reaches between zero to five degrees C. The chamber temperature should not be allowed to exceed 30 degrees C at any time during this step.

c. Increase the chamber pressure to room ambient at a uniform rate in a period of 15 to 30 minutes. At the completion of the re-pressurization, reduce the relative humidity in the chamber to normal room ambient.

d. Repeat steps a. through c. for a total of 25 cycles or as defined in the applicable equipment specification, whichever is less.

Note: If it becomes necessary to interrupt the test sequence, the interruption shall take place while the equipment is held at the low temperature condition.

e. During the last test cycle, after the equipment temperature has stabilized at -20 degrees C, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

24.4.4 Category C

a. With the equipment not operating, stabilize the equipment at a temperature that will permit clear, hard ice to form on the equipment when sprayed with water.

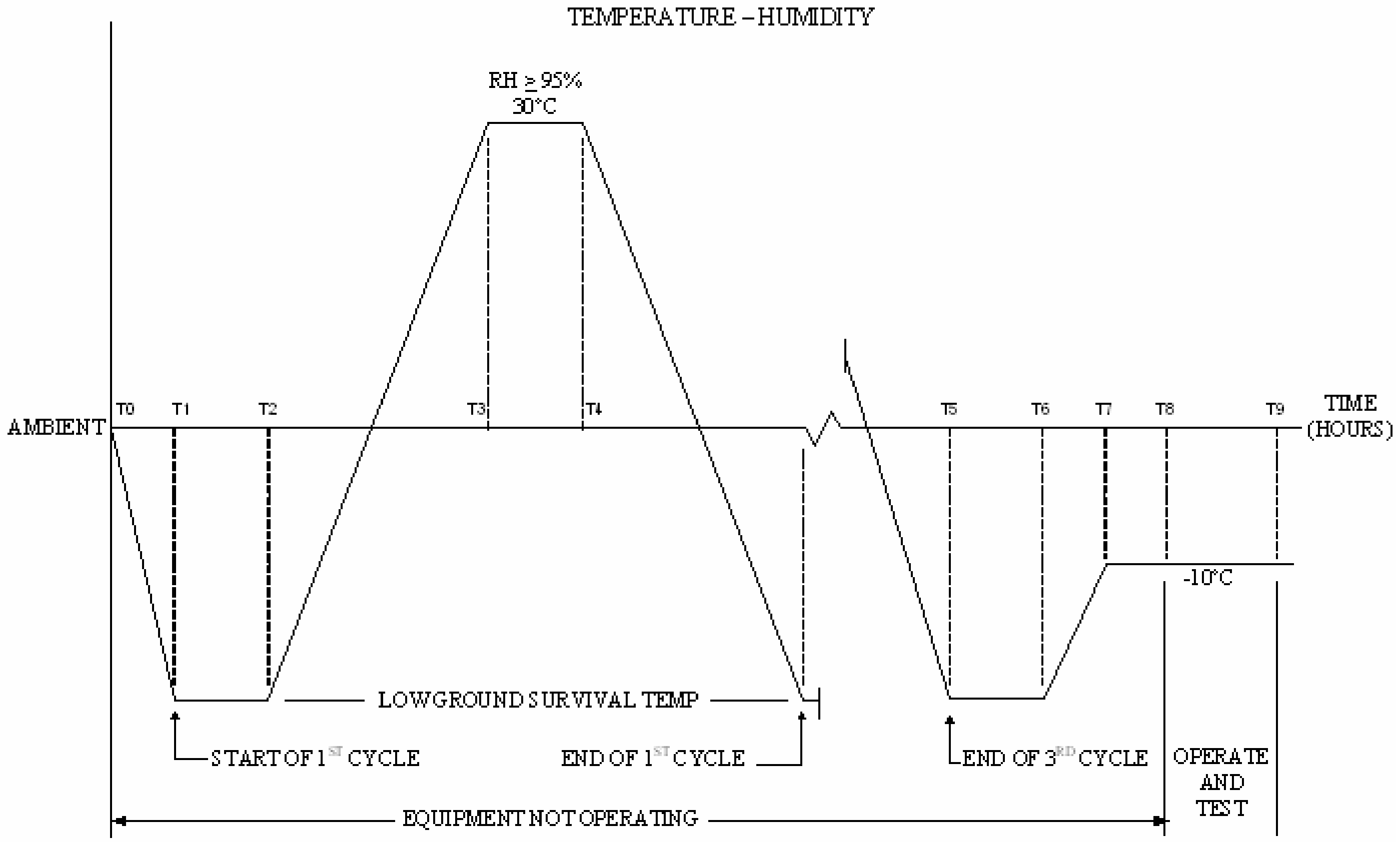
Note 1: For this test, the ice formed shall be clear and hard. “White” or air-pocketed ice is not acceptable.

Note 2: The optimum temperature is likely to be between -1 and -10 degrees C depending on the thermal mass of the equipment and is best determined by *experiment.*

b. Build up a homogeneous layer of clear hard ice to a thickness defined by the APPLICABLE EQUIPMENT PERFORMANCE STANDARD by hand spraying a fine mist of water at a temperature that is close to freezing.

c. When the required thickness of ice has been achieved, discontinue the spraying. Place the equipment into the operating state and stabilize the equipment at a temperature of -20 degrees C. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

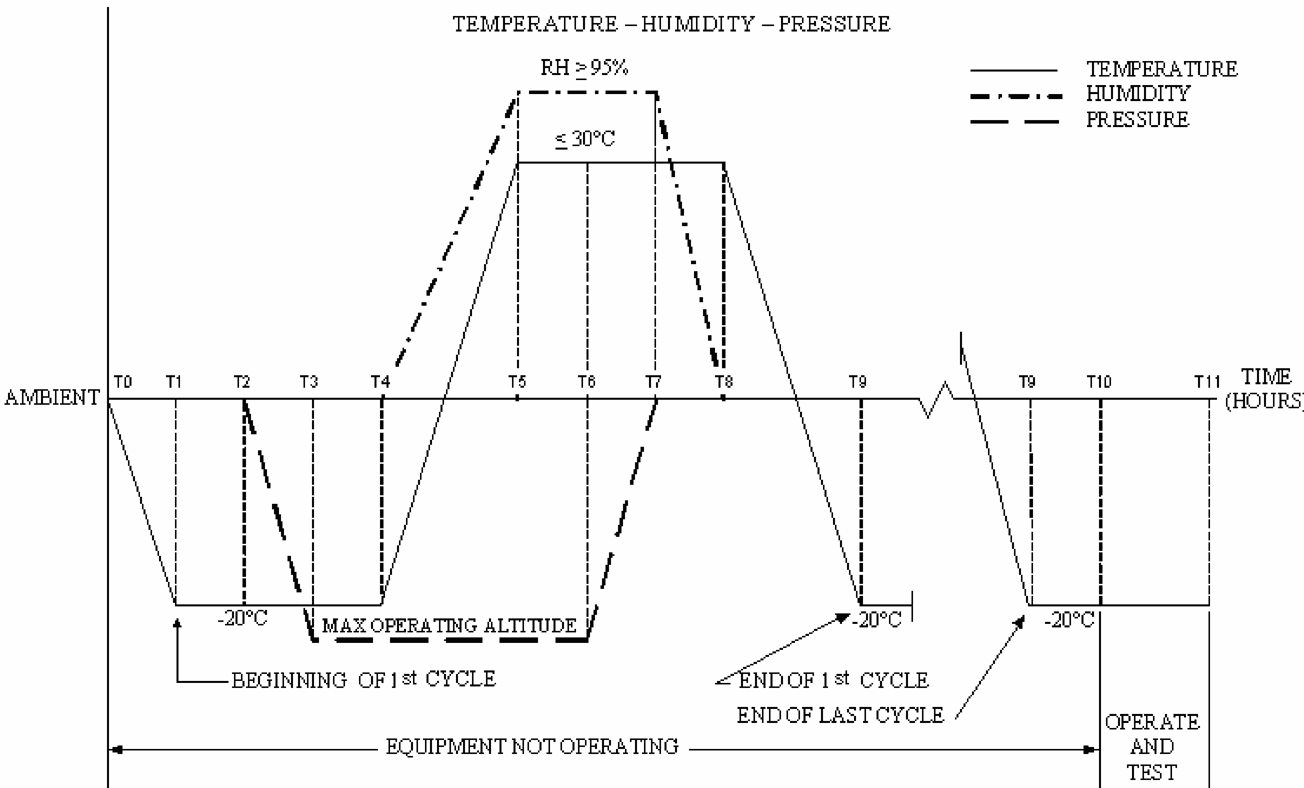
Note: I*f multiple tests with increasing thickness of ice formation are required, a series of separate tests shall be performed with each thickness level formed in a continuous operation.*



NOTES:

1. Unless otherwise specified, temperature and humidity change rates are optional.
2. T1 to T2 and T5 to T6 are times for equipment temperature to stabilize.
3. T2 to T3 and T4 to T5 are to be accomplished as quickly as practical.
4. T3 to T4 is time for surface temperature of equipment to reach 5°C.
5. T7 to T8 is time for surface temperature of equipment to reach -10°C.

FIGURE 24-1 CATEGORY A ICING TEST



NOTES:

1. Unless otherwise specified, temperature, humidity and pressure change rates are optional.
2. T1 to T2 and T9 to T10 are times for equipment temperature to stabilize.
3. T3 to T4 is 10 minutes, minimum.
4. From T4 to T5 temperature rate of change is 3°C per minute maximum.
5. T5 to T6 is minimum time to melt all ice and frost.
6. From T5 to T8 chamber temperature should not exceed 30°C.
7. T6 to T7 is 15 to 30 minutes.

FIGURE 24-2 CATEGORY B ICING TEST

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 25

Electrostatic Discharge (ESD)

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2, 3 and 20. Further, Appendix A is applicable for identifying the environmental tests performed.

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25.0 Electrostatic Discharge (ESD)

25.1 Scope

The Electrostatic Discharge test relates to airborne equipment which may be involved in static electricity discharges from human contact. Some factors contributing to an ESD event may be: low relative humidity, temperature, use of low conductivity (artificial fiber) carpets, vinyl seats and plastic structures which may exist in all locations within an aircraft. This test is applicable for all equipment and surfaces which are accessible during normal operation and/or maintenance of the aircraft.

25.2 Purpose of the Test

The electrostatic discharge test is designed to determine the immunity or the ability of equipment to perform its intended function without permanent degradation of performance as a result of an air discharged electrostatic pulse.

25.3 Test Description

The immunity to electrostatic discharge shall be determined by the ability of the equipment under test (EUT) to withstand a series of electrostatic pulses at a selected severity level of 15,000 volts, directed at specific human contact locations on the EUT. The quantity of pulses shall be ten (10) in each of the selected locations in both positive and negative voltage polarities. The test configuration is depicted in Figure 25-1.

25.4 Equipment Categories

Category A - Electronic equipment that is installed, repaired or operated in an aerospace environment.

25.5 Test Procedure

With the equipment powered and operated in the required mode the electrostatic discharge test will be performed under the following conditions:

25.5.1 **Test Configuration -** The EUT shall be set up as shown in Section 20.3a (General Test Requirements). Connect and orient the equipment as specified by the applicable installation and interface control drawings or diagrams. Care must be taken in routing and grounding of the cabling associated with the ESD generator to minimize the potential for secondary effect of the radiated field from the cabling. This test is intended to test the primary effect which is the discharge from the ESD generator to the enclosure of the equipment under test. This includes the normal method of mounting, bonding, and grounding of the equipment.

25.5.2 **ESD Generator -** The ESD generator shall have a general schematic as shown in Figure 25-2, with a discharge resistor of 330 ohms (±20%) and an energy storage capacitor of 150 pf

(±20%), and shall be capable of generating a pulse of 15,000 volts. The ESD generator shall also have an air discharge tip as shown in Figure 25-3. Prior to performing the test, the output of the ESD generator should be calibrated to produce a 15,000 volt minimum peak output pulse. This can be done by verifying the output waveform of the ESD generator or by setting the high voltage power supply to 15,000 volts minimum. The generator setting required to produce this output should be recorded.

25.5.3 **EUT Test Modes -** EUT test modes should include the software chosen to exercise all normal modes of operation of the EUT.

Note: If monitoring equipment is required, it should be decoupled in order to reduce the possibility of erroneous failure indications.

25.5.4 **Pulse Application -** The ESD discharges shall be applied only to those points and surfaces of the EUT which are accessible to personnel during normal operation (including as installed on aircraft maintenance).

With the ESD generator set at the value recorded during calibration the ESD generator shall be held perpendicular to the surface to which the discharge is applied. The discharge return cable of the generator shall be grounded to the ground plane and kept at a distance of at least 0.2 meters from the EUT and its cabling.

25.5.5 **Test Technique -** Move the tip of the ESD generator toward the EUT at the same speed a human hand would reach to touch an object (approximately 0.3 meters/second) until the generator discharges or until contact is made with the EUT. After each discharge, the ESD generator (discharge electrode) shall be removed from the EUT. The generator is then retriggered for a single discharge. This procedure shall be repeated until the 10 discharges in each polarity and each location are completed.

25.6 Evaluation of the Test Results

Following application of the pulses, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS, unless specified otherwise.

25.7 Selection of Test Points

The test points to be considered shall include the following locations as applicable: any point in the control or keyboard area and any other point of human contact, such as switches, knobs, buttons, indicators, LEDs, slots, grilles, connector shells and other operator accessible areas.

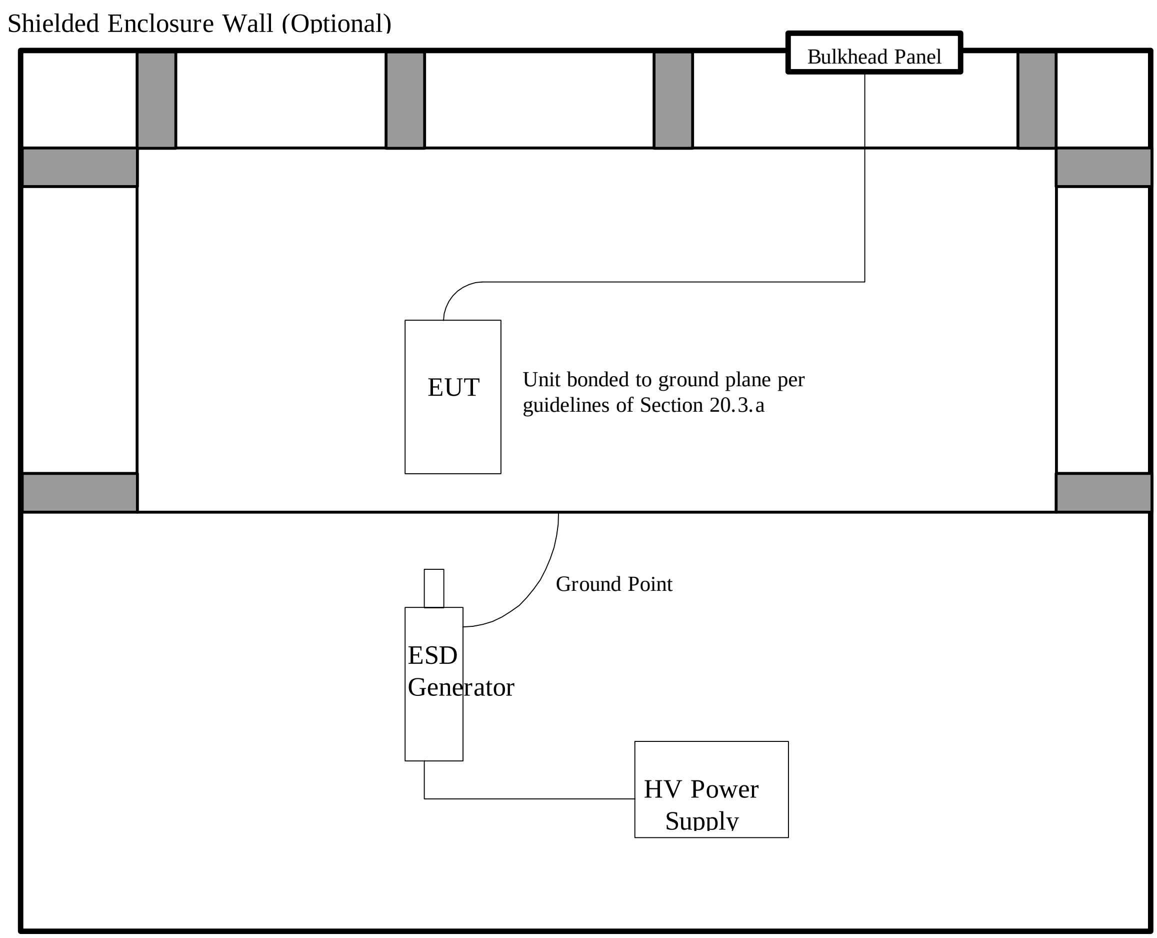
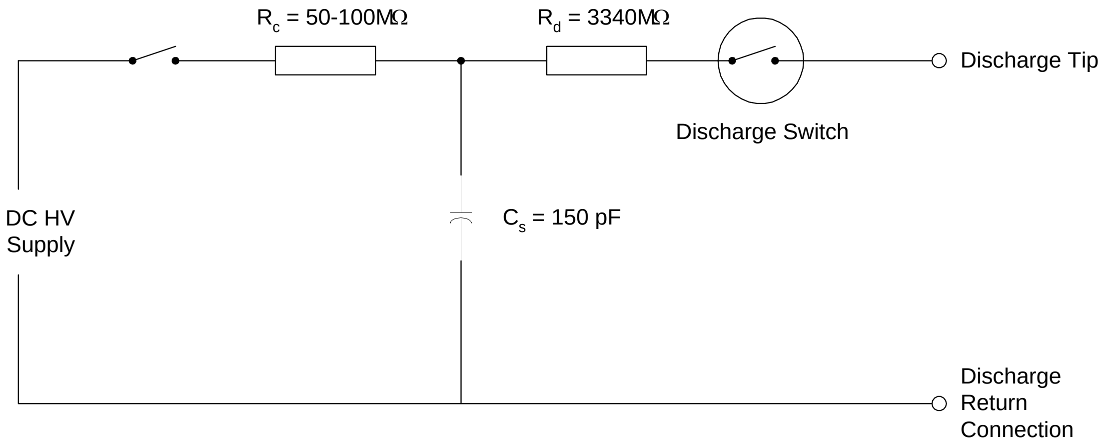
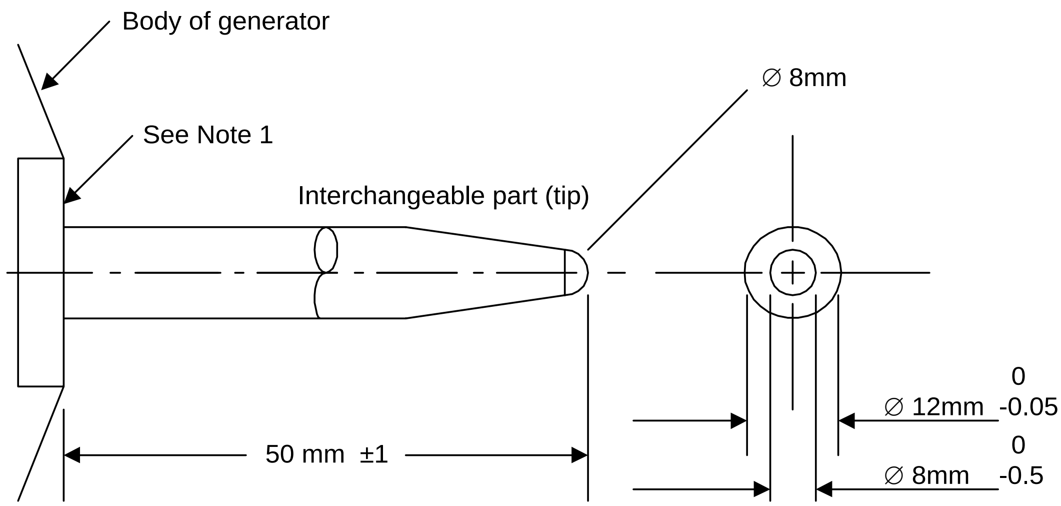


Figure 25-1 **Electrostatic Discharge Typical Test Setup**



Note - C_d, omitted in the figure, is a distributed capacitance which exists between the generator and the ET, GRP, and coupling planes. Because the capacitance is distributed over the whole of the generator, it is not possible to show this in the circuit.

Figure 25-2 Simplified Diagram of the ESD Generator



Note - The discharge switch (e.g., vacuum relay) shall be mounted as close as possible to the tip of the discharge electrode.

Figure 25-3 Discharge Electrode of the ESD Generator

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 26

Fire, Flammability

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2, and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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26 Fire, Flammability

26.1 Purpose

This section defines test conditions and procedure for Flammability and Fire resistance.

26.2 Applicability

Flammability and fire tests apply to equipment installed on fixed wing propeller driven aircraft, fixed-wing turbojet aircraft, turbofan aircraft, prop-fan aircraft, and helicopters.

These tests are applicable for equipment:

- Mounted in pressurized zones
- Mounted in fire zones
- Mounted in non-pressurized, non fire zones

26.3 Equipment Categories

26.3.1 Category A: Fire-Proof

Equipment installed in fire zone which must function during the first five minutes of fire and which must keep its safety functions for at least fifteen minutes. For fluid handling components, there shall be no leakage to support a flame after the burner has been removed (wetting or droplet that self extinguishes may be acceptable). For air handling components there shall be no leakage that may additionally feed the fire. Equipment shall remain firmly attached to the mounting.

The *fire-proof* procedure shall be applied.

Test will be performed on equipment in the operating mode

26.3.2 Category B: Fire Resistance

Equipment installed in fire zone, which must function or not cause a hazardous condition during the five first minutes of fire without structural degradation. For fluid handling components there shall be no leakage to support a flame after the burner has been removed (wetting or droplet that self extinguishes may be acceptable). For air handling components there shall be no leakage that may additionally feed the fire. In general any leakage or continued burning of the test article at the end of the five minutes would be considered a test failure unless it can be shown that there is not a significant increase in the overall fire hazard. An example of this would be if the fire extinguishing equipment is capable of extinguishing the residual flame.

The *fire resistance* procedure shall be applied.

Test will be performed on equipment in the operating mode.

26.3.3 Category C: Flammability

Non-metallic equipment, component parts, sub-assemblies installed in pressurized or non-pressurized zones and non-fire zones with largest dimension greater than 50 mm.

The *flammability* procedure shall be applied.

Note: If all materials used in the construction of the equipment can be shown to meet the equivalent vertical and horizontal flammability tests herein, either through composition or previous testing, this test is not required.

Test to be performed on equipment in a non-operating mode. The purpose of this test is to check the non-propagation of the flame in the case where ignition would appear inside or outside of the equipment. Tests will be performed on specimens of material.

26.4 Chambers

Test chamber, enclosure, or laboratory hood shall be free of induced or forced coolant air during tests. For fire-proof and fire resistance tests, sufficient airflow to exhaust combustion gases and smoke is acceptable.

26.5 Apparatus

Fire-proof/resistancet test: Burner with a flame standardized of 1100°C $\pm$80°C. A modified gun type burner with extension tube shall be used with kerosene. Adjustment of fuel flow and air is allowed during the pre-test calibration only to achieve the required characteristics of the flame.

Flammability test: Laboratory burner: A Bunsen burner having a tube length of 80 to 100 mm and an inside diameter of 9.4 +1.6 mm and -0 mm.

Gas supply: a supply of technical grade methane gas with regulator and meter for uniform gas flow. Natural gas like methane having a heat content of approximately 37 MJ/m^3 or any other fuel gas such as butane with a higher heat content value may be used.

26.6 Steady State Operating Conditions

Steady state operating conditions should be chosen to represent the worse case scenario for the unit under test. Considerations shall include the minimal cooling, highest pressures, and maximum working fluid temperatures the product may experience. It is not required for the chamber to simulate the maximum ambient temperature of the equipment, room temperature ambient is sufficient. Ground idle conditions are often chosen to represent a worse case scenario. Ground idle conditions are often chosen to represent a worse case scenario.

26.7 Fire-Proof/Resistance Test Procedure

Burner Calibration:

The following burner calibration steps shall be taken after a five minute warm-up period. Do not expose the heat transfer copper tube to the flame during this warm-up period to avoid carbon build-up on the tube.

26.7.1 Flame Temperature

The flame temperature shall be adjusted to provide 1100°C $\pm$ 80°C as measured by a thermocouple rake placed 100 mm (nominal) from the burner. The equipment under test must be placed 100 mm (nominal) from the burner during the test. The rake consists of seven thermocouples centered across the torch at a distance of 100 mm (nominal) in front of the nozzle (see figure 26-2). Temperature data shall be taken at least every 30 seconds for a three minute period during the pre and post test flame temperature calibration to ensure steady-state conditions.

26.7.2 Flame Intensity

The flame heat content is required to provide 4,500 Btu/hr minimum input to a 380 mm exposed length of 127 mm by 0.81 mm (0.5" by 0.032") refrigeration type copper tubing with a water flow rate of one gallon/minute (500 lb/hr). This measurement is taken at the same location in the flame where the requirements of Flame Temperature are satisfied. The temperature delta multiplied by the water flow rate through the tube (500 lb/hr) = the Btu/hr input into the tube.

1- Clean the copper tubing with fine steel wool before the pre test calibration.

2- The supplied water temperature shall be between 10°C and 21°C.

3- Water flow rate through tube shall be adjusted to 500 lb/hr minimum.

4- Transfer the burner to the heat transfer tube and begin a three-minute warm-up period to ensure stable conditions.

5- Record inlet and outlet water temperature at least every thirty seconds for a three minute period.

6- Perform calculations to ensure minimum requirements are met. Refer to figures 26-4 and 26-5 for additional details on the heat flux measurement apparatus.

26.7.3 Preliminary

Whatever the required test procedure, the equipment, component parts, sub-assemblies or material specimens shall be in conformity with the final product (chemical processing...) and a flammability test item should have been conditioned for at least twenty-four hours at 23 $\pm$ 2 °C and relative humidity of 50 $\pm$ 5 percent prior to testing.

26.7.4 Fire-Proof Test

Perform the following tests using the appropriate test flame of paragraph 26.5.

Connect the equipment so that it is both powered on and functional. All connections (electrical, fluid, pneumatic, etc.) to the test article must be of the type design configuration. The use of non-type design cables, bundles, and connectors is permitted at locations not directly interfacing with the test article. All non-type design hardware may be protected during the test as long as the protection provided does not interfere with the test article flame exposure. High temperature ceramic insulation is recommended to protect non-type design cables and tubing.

With the equipment operating, apply the normal flame for fifteen minutes.

ONLY DURING THE FIRST FIVE MINUTES OF THE TEST DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

At the completion of the test, (after the last ten minutes) the equipment shall be inspected and shall show no evidence of continued combustion or flame propagation and shall be self extinguishing.

CAUTION: In particular cases (e.g. systems of fluids), a specific procedure could be specified by the aircraft or engine manufacturer.

26.7.5 Flame Direction and Location(s) Determination

The test flame impingement location(s) on the test article is established via analysis based on most critical location(s) with respect to the fire source and the most susceptible location(s) on the test article considering critical circuitry, fluid flow, wall thickness, seals, etc. The most likely flame direction (i.e. bottom of unit) may also be considered in the impingement location analysis but this may result in limiting future changes/use of unit. The flame must impinge the critical location(s) on the test article determined from the impingement analysis. For equipment determined to have more than one critical location, additional tests may be required if a single, representative impingement location can not be identified to adequately address all locations. If multiple locations are required, multiple test articles may be used but are not required.

26.7.6 Data Recording

a) Data recording of key parameters (T/C's, flows, pressures, etc) throughout the test is required, including key parameters for calibration determination.

b) The entire test is to be video recorded. Multiple views are recommended. Post test photos are required also.

26.8 Fire Resistance Test

Perform the following tests using the appropriate test flame of paragraph 26.5.

Connect the equipment so that it is both powered on and functional. The use of non-type design cables, bundles, and connectors is permitted. All non-type design hardware may be protected during the test as long as the protection provided does not interfere with the test article flame exposure. High temperature ceramic insulation is recommended to protect non-type design cables and tubing.

After the pre-test flame calibration and with the equipment operating, apply the flame for five minutes.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING THE TEST OR DEMONSTRATE THAT A NON-HAZARDOUS CONDITION IS MAINTAINED DURING THE FIVE MINUTE PERIOD.

At the completion of the test, without extinguishing the flame, a post test calibration of the flame temperature shall be performed. In addition, the equipment shall be inspected and shall show no structural default or evidence of continued combustion or flame propagation and shall be self-extinguishing. In general any leakage or continued burning of the test article at the end of the five minutes would be considered a test failure unless it can be shown that there is not a significant increase in the overall fire hazard. An example of this would be if the fire extinguishing equipment is capable of extinguishing the residual flame.

<u>CAUTION</u>: In particular cases (e.g. systems of fluids), a specific procedure could be specified by the aircraft or engine manufacturer.

26.9 Flammability Test

26.9.1 Determination of the Type of Test

The following table defines dimensions of specimen and which test shall be applied to demonstrate that the equipment complies with flammability requirements.

Greatest dimension of equipment (L)	**Specimen dimensions**	**Orientation of longitudinal axis (note 1)**	**Flammability test**
L < 50 mm	Not applicable	Not applicable	Not applicable
50 mm < L < 127 mm	Length: actual length Width: actual width Thickness: (note 2)	Either axis	Vertical test
L > 127 mm	Length: 127 mm Width: 12.7 mm Thickness: (note 2)	Horizontal	Horizontal or vertical (note 3)
		Vertical or Arbitrary or Variable or Unknown	Vertical

Note 1: supplier shall establish orientation of longitudinal axis of equipment on board the aircraft. It will be considered normal horizontal flight conditions.

Note 2: Thickness: test specimens shall be provided in the minimum thickness of the equipment, limited to a maximum value of 12.7 mm.

Note 3: For equipment, component parts or sub-assemblies which have thickness greater than 50 mm, vertical test shall be applied.

26.9.2 Vertical Test

Five specimens shall be used for vertical test.

Perform the following test using the appropriate test flame of paragraph 26.5 on the five specimens.

Each specimen is to be supported from the upper 6.4mm of the specimen with the longitudinal axis vertical so that the lower end of specimen is 9.5mm above the burner tube and 305 mm above the dry absorbent surgical cotton.

The horizontal cotton layer shall approximately 12.7 mm x 25.4 mm, obtained after spreading 5 mm thick square pieces of surgical cotton.

Perform the following procedural steps:

1. Place the flame centrally under the lower end of the test specimen for ten seconds.

2. Remove the burner from the specimen.

3. If specimen hasn't ignited, test is completed. Skip to next specimen and go to step 1.

4. If specimen has ignited, observe and record the following:

   - Duration of flaming after flame removal.
   - Whether or not specimen burned up to holding clamp.
   - Whether or not specimen drips flaming particles that ignite cotton swatch.

5. When flaming of specimen ceases, and if specimen hasn't burned up to holding clamp, the flame has to be immediately placed again under the specimen during ten seconds. The following are to be observed and recorded:

   - Duration of flaming after flame application.
   - Whether or not specimen burns up to holding clamp.
   - Whether or not specimen drips flaming particles that ignite cotton swatch.

6. If specimen has burned up to holding clamp, skip to next specimen and go to step 1.

Test criteria are defined in Table 26-1.

26.9.3 Horizontal Test

Three specimens shall be used for horizontal test. Perform the following test using the appropriate test flame of paragraph 26.5 on the three specimens.

Each specimen is held on one end with the longitudinal axis horizontal and is marked at 25.4mm and 101.6mm from the free end.

A metal support may be used for testing specimens that sag or bend at their free end.

The flame shall be applied at an angle of approximately 45°, so that the front edge of the specimen to a depth of approximately 6.4mm is subjected to the test flame for thirty seconds; the flame application has to be discontinued if the flame reaches 25.4 mm.

The following are to be observed and recorded:

- If the specimen continues to burn after removal of the test flame, the time for the flame front to travel from 25.4mm from to 101.6 mm shall be determined and the rate of burning calculated.

Tests criteria are defined in Table 26-2.

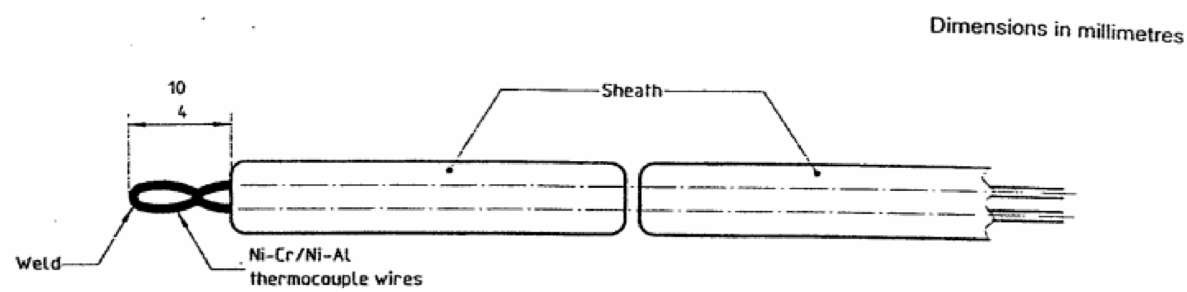
Location	Distance before stop of the flame or glowing combustion.	Maximum duration of flaming combustion after each application of the test flame.	Cumulated duration of total flaming combustion after 10 flame application for the five specimens.	Maximum duration of glowing combustion after second removal of the test flame.	Not to have any specimen that drips flaming particles which ignite surgical cotton.
Equipment, component parts or sub-assemblies intended for installation inside metallic box	120 mm (note 1)	30 seconds after first application	250 seconds after 10 applications with five specimens	60 seconds	Not Applicable
Equipment, component parts or sub-assemblies intended for installation in other location	120 mm (note 1)	10 seconds after first application	50 seconds after 10 applications with five specimens	30 seconds	Applicable

Note 1: If the specimen length is less than 127 mm, it can burn with flaming or glowing combustion up to the holding clamp

TABLE 26-1 Acceptance criteria for vertical flammability test

Specimen thickness	Burning rate over 76.2 mm span	Distance before stop of the flame combustion.
3mm < thickness < 12.7 mm	38.1 mm / minute	101.6 mm
Thickness < 3 mm	76.2 mm / minute	101.6 mm

TABLE 26-2 Acceptance criteria for horizontal flammability test



NOTES

1 The diameter of the thermocouple wire shall be between 0,6 mm and 1 mm.

2 If a metal sheath is used, the maximum diameter shall not exceed 3 mm. .118 max

3 The thermocouple shall be unshielded and non-aspirated.

<u>FIGURE 26-1</u> **Details of Thermocouple**

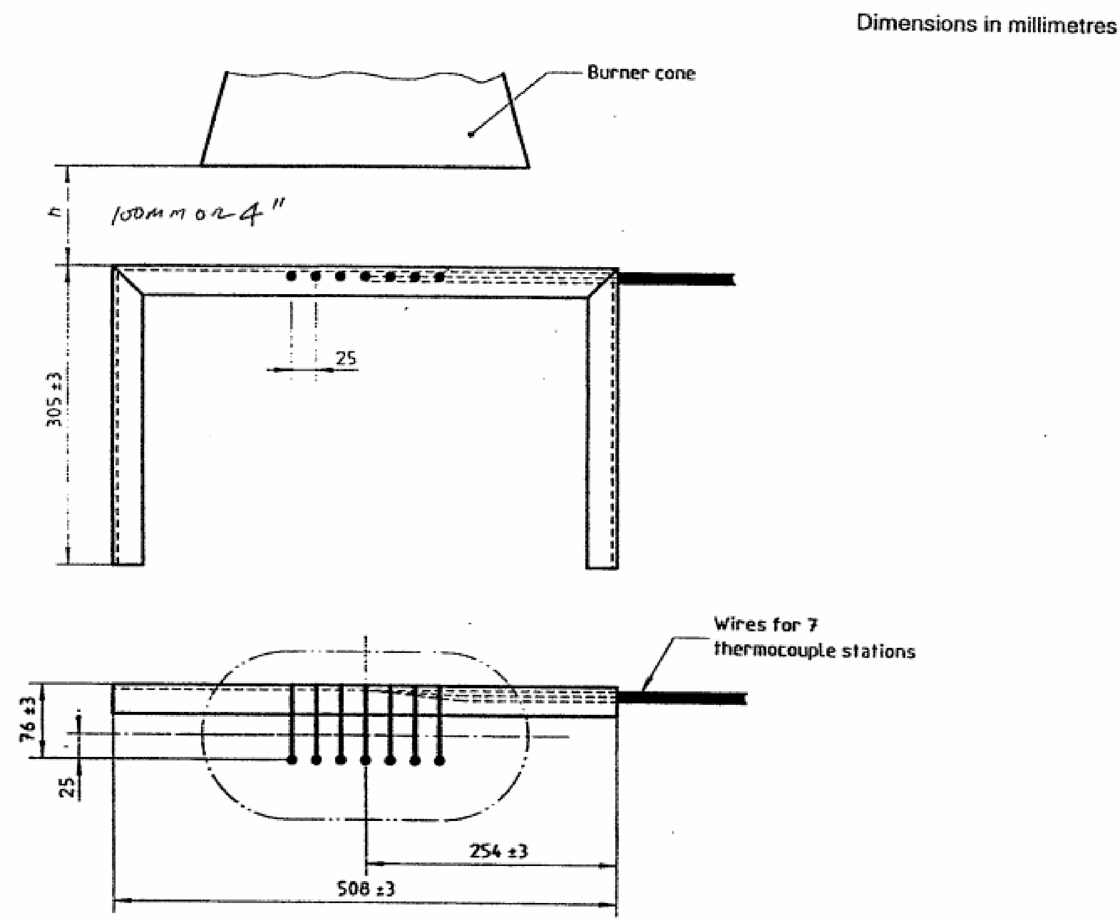


FIGURE 26-2 **Liquid Fuel Burner – Thermocouple Positions**

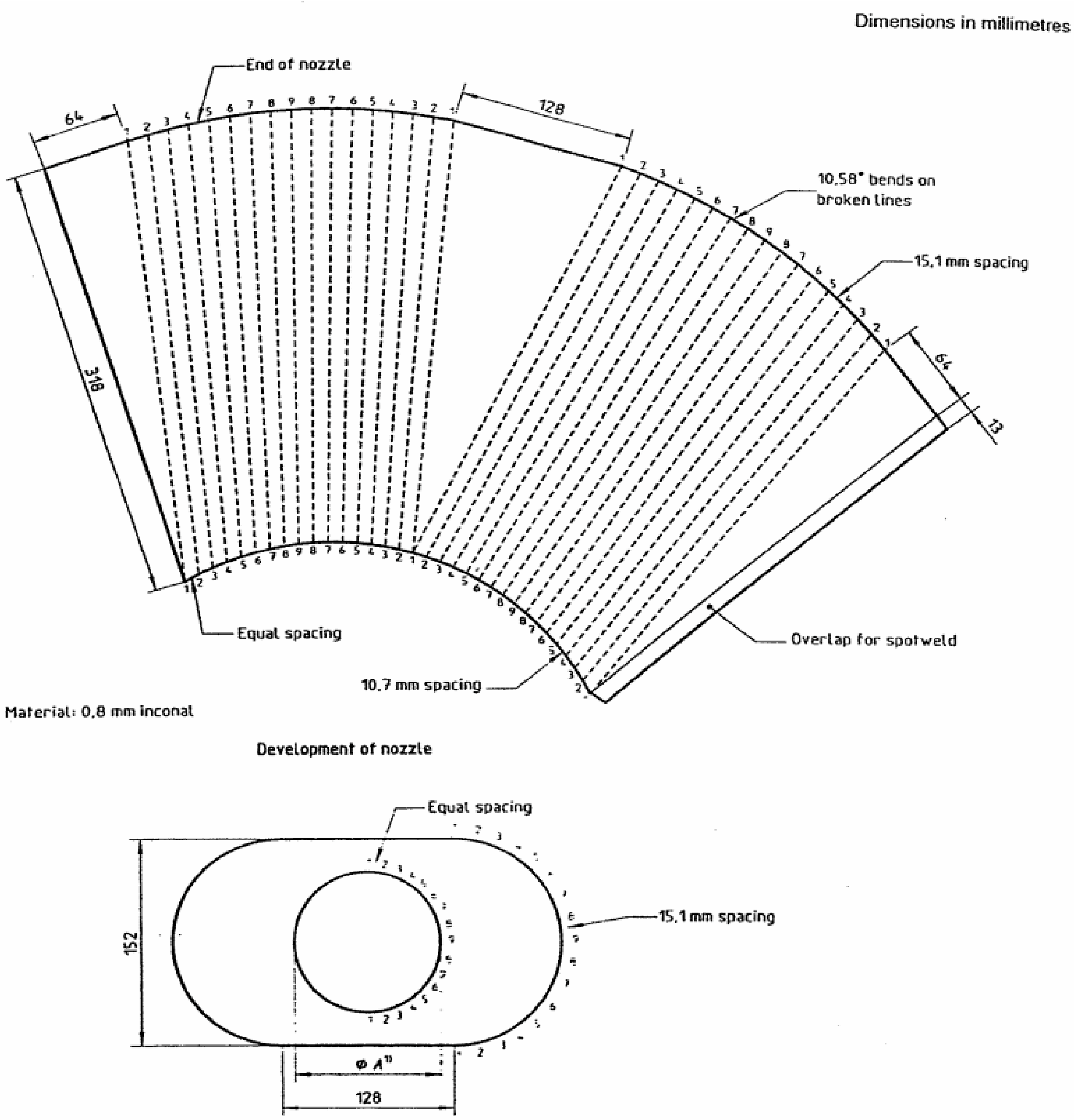
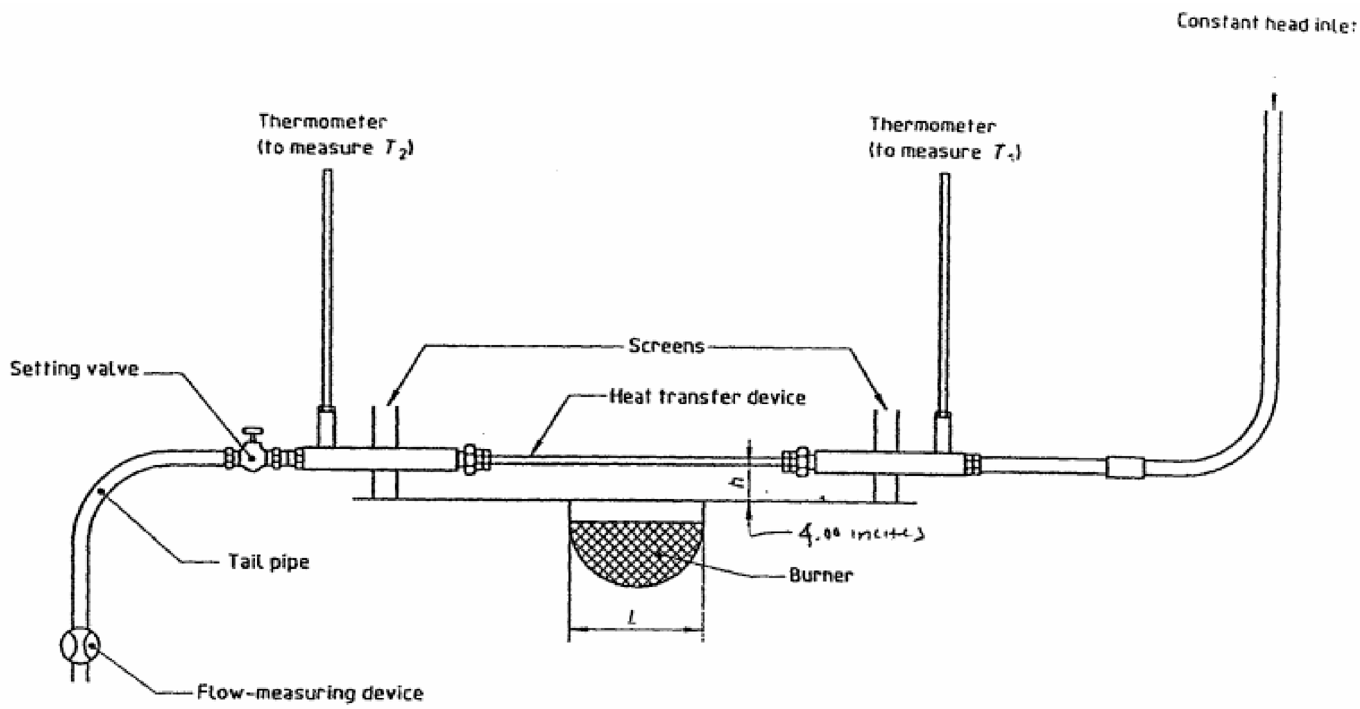


FIGURE 26-3 **Liquid Fuel Burner Nozzle**



<u>FIGURE 26-4</u> **Set-Up of Standard Heat Flux Density Measuring Apparatus**

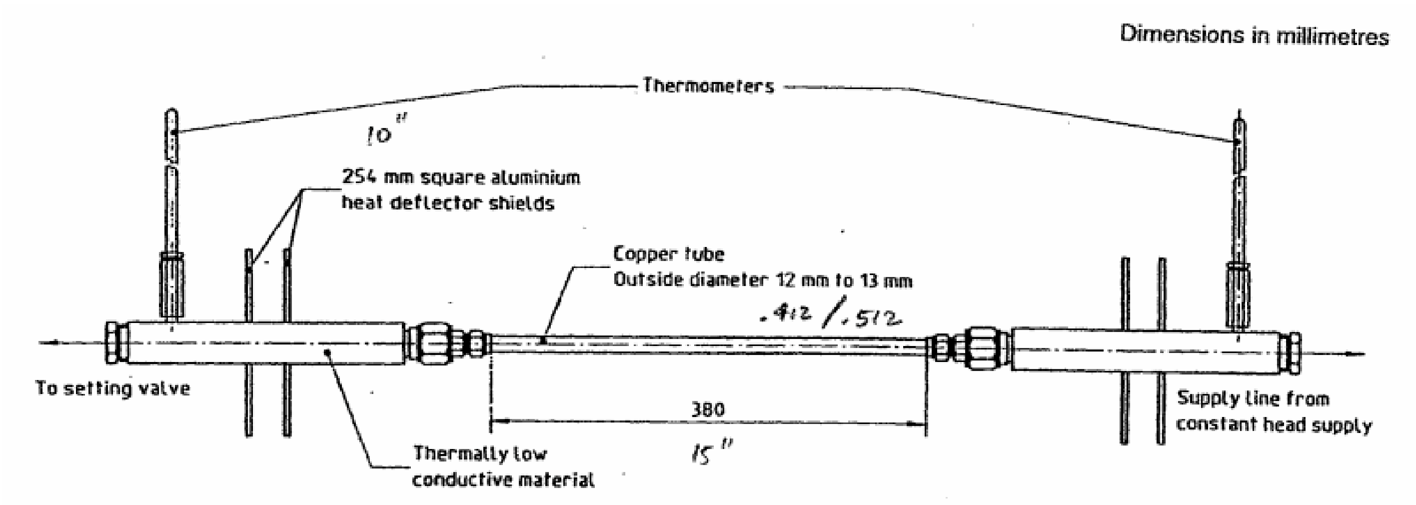


FIGURE 26-5 **View of Mounting Heat Flux Density Measuring Tube**

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RTCA/DO-160E

Environmental Conditions and Test Procedures for Airborne Equipment

<u>Appendix A</u>

Environmental Test Identification

Important Notice

Information pertinent to section is contained in Sections 1, 2 and 3. This appendix is applicable for identifying the environmental tests performed.

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A.1 Introduction and Scope

A need exists to provide a permanent record of the particular environmental test categories that equipment has passed. This need includes post-incident or accident investigation, installation certification, repair, etc. This procedure provides for a paper record (hereafter referred to as the Environmental Qualification Form) to be included in the equipment data package submitted for Technical Standard Order (TSO) authorization and in the installation and maintenance instructions. In addition to the Environmental Qualification Form, the traditional nameplate marking system may be used. This nameplate marking system is a supplemental and optional method of identifying the environmental test results. Due to the declining use of nameplate marking, it is envisioned that future versions of DO-160 may not support this method of test declaration.

Since it is not envisioned that the Environmental Qualification Form will be related to a particular equipment by serial number or date of manufacture, association must be achieved through the equipment type, model or part number. Manufactures should identify the method used to establish traceability to the environmental test categories to which the equipment was tested, including the applicable revision number of the test procedure (Section of RTCA/DO-160) used.

A.2 Environmental Qualification Form (see Figure A-1)

This form provides the necessary information regarding which environmental tests were conducted and, where applicable, the appropriate environmental category of the equipment being tested.

Additional information is included to identify the specific equipment type or model to which the environmental test results apply. A suggested format is depicted in Figure A-1. An example Environmental Qualification Form is shown is Figure A-2 and has been annotated to illustrate a completed form. Equipment manufacturers should expand on the data included on this form to provide added clarity.

In some cases, the manufacturer may wish to qualify the equipment to more than one category for a particular environmental test. If one category is more stringent, only the more stringent category need be identified. In other cases, such as Temperature/Altitude or Vibration, where the test requirements for various categories are different but not necessarily more severe, more than one category should be indicated on the form.

Also, information such as vibration tests conducted with or without shock mounts, fluid tests conducted with Jet A fuel, type of de-icing fluid, and other parameters pertinent to the tests shall be included on the form.

A.3 Supplemental Method of Equipment Nameplate Marking

a. The following is a supplemental method of marking equipment nameplates to indicate the particular environmental test categories to which the equipment has been tested. If this method of marking equipment nameplates is used, an Environmental Qualification Form is still required to completely document the environmental test results. This optional method of marking equipment nameplates provides a supplemental method of communicating the test results to the end customers.

b. There are 24 environmental test procedures in this document for which categories have been established. These should be identified on the equipment nameplate by the words “DO-160E Environmental Categories” or, as abbreviated, “DO-160E Env. Cat.,” followed by the letters and numbers (or sets of letters and numbers) which identify the categories designated in this document. Reading from left to right the category designations should appear on the equipment nameplate in the following order, so that they may be readily identified:

	SECTION	TEST
1.	4.0	Temperature and Altitude Test (2 spaces minimum)
2.	4.5.5	In-Flight Loss of Cooling Test
3.	5.0	Temperature Variation Test
4.	6.0	Humidity Test
5.	7.0	Operational Shock and Crash Safety Test
6.	8.0	Vibration Test (2 spaces minimum)
7.	9.0	Explosive Atmosphere Test
8.	10.0	Waterproofness Test
9.	11.0	Fluids Susceptibility Test
10.	12.0	Sand and Dust Test
11.	13.0	Fungus Resistance Test
12.	14.0	Salt Fog Test
13.	15.0	Magnetic Effect Test
14.	16.0	Power Input Test (1 space min for DC, 6 spaces min for AC)
15.	17.0	Voltage Spike Test
16.	18.0	Audio Frequency Conducted Susceptibility Test (1 space min for DC, 5 spaces min for AC)
17.	19.0	Induced Signal Susceptibility Test (2 spaces)
18.	20.0	Radio Frequency Susceptibility Test (2 spaces)
19.	21.0	Emission of Radio Frequency Energy Test
20.	22.0	Lightning Induced Transient Susceptibility Test (5 spaces)
21.	23.0	Lightning Direct Effects Test (1, 2 or 3 spaces)
22.	24.0	Icing Test
23.	25.0	Electrostatic Discharge Test
24	26.0	Fire, Flammability Test

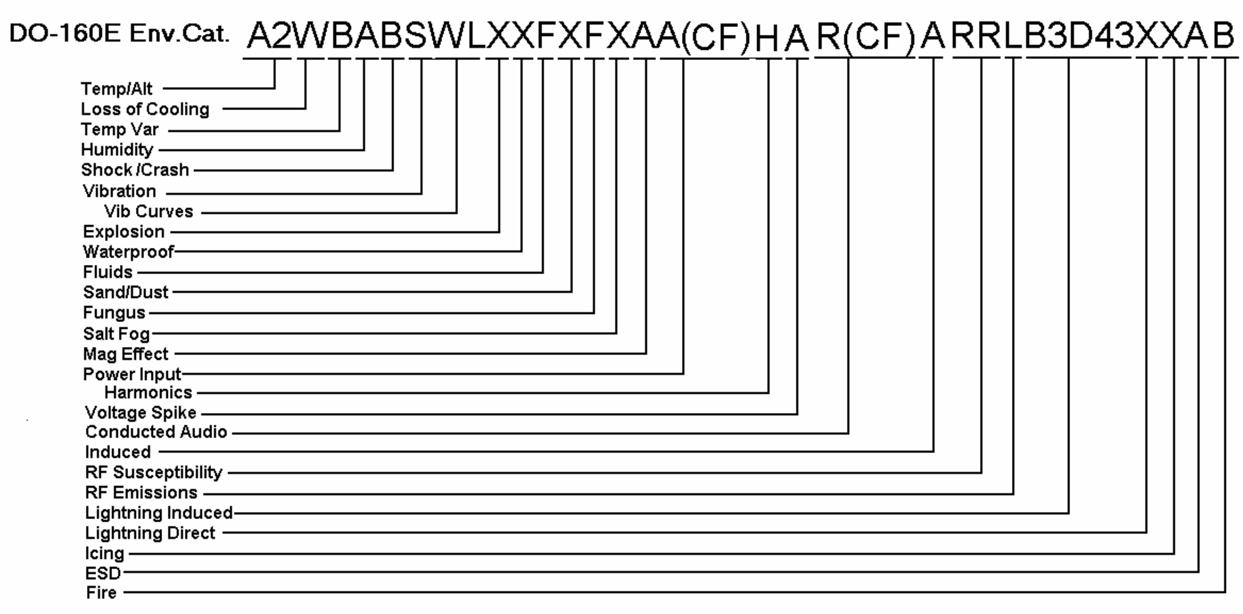

Figure 1-A Declaration Character Positions

c. For Vibration, identify the aircraft type and aircraft zone, as well as the applicable test category, by designating the corresponding letters for the test category and for the primary vibration curve(s) (refer to Table 8-1). If the size of the equipment nameplate allows, the following guidelines should be applied for improved readability. Use square brackets [ ] to enclose the category letters for a single section where more than one character is required, such as Vibration. Use parenthesis ( ) within the brackets to enclose category letters where more than one test is performed and more than one letter is required per category, such as Temperature/Altitude (see paragraph d. below). Typical equipment nameplate identifications are as follows:

DO-160E Env. Cat. A2WBABSWLXXFXFXAAARACRRLB3D43XXAB

or

DO-160E Env. Cat. [A2W]BAB[SWL]XXFXFXAAAR[AC][RR]L[B3D43]XXAB

d. In some cases, the manufacturer may wish to qualify the equipment to more than one category for a particular environmental test. If one category is definitely more stringent, only the more stringent category need be identified. In other cases such as Temperature/Altitude or Vibration, where the test requirements for various categories are different but not necessarily more severe, more than one category should be marked on the equipment nameplate.

For example, the following nameplate identification is the nameplate marking for the example test results shown in the Environmental Qualification Form in Figure A-2:

DO-160E Env. Cat. [(A2)(F2)W]BAB[SWL]XXFXFXAAAR[AC][RR]H[B3D43]XXAB

e. In the case of the Vibration Test, the equipment may be qualified for one category without shock mounts and to another with shock mounts. This differentiation should be shown by listing those categories without shock mounts above the line and those with shock mounts below the line. For example, the following nameplate identification is identical to the above example, except that the equipment has been qualified to Vibration Category S, aircraft zone 4, for fixed wing turbojet, unducted turbofan, and reciprocating engine aircraft less than 5,700 kg. without shock mounts (primary vibration curves W & L) and for reciprocating engine aircraft over 5,700 kg. with shock mounts (vibration curve U):

SWL
DO-160E Env. Cat. [(A2)(F2)W]BAB[SU]XXFXFXAAAR[AC][RR]H[B3D43]XXAB

f. In the case of the fluid test, the detailed category information shall be included in the Environmental Qualification Form. The nameplate shall be marked F if any of the fluid tests have been satisfactorily completed or X if fluid testing was not performed

g. In the case of section 16 category A dc input power, the marking is"A". For Section 16 Category A ac input power, 6 characters minimum must be marked, "A(CF)", "A(NF)" or "A(WF)" followed by either an "H" or an "X" to indicate if the harmonic currents were controlled or not.

h. In the case of section 18 category K dc input power, the marking is "K". For Section 18 Category A ac input power, 5 characters minimum must be marked, "R" or "K" followed by "(CF)", "(NF)" or "(WF)".

The following is an example of a category A dc input with category R section 18 conducted susceptibility:

DO-160E Env. Cat. [(A2)(F2)W]BAB[SWL]XXFXFXZAARZ[RR]H[B3D43]XXAB

The following is an example of category A wide variable frequency ac input power with harmonic current control and category K section 18 input conducted susceptibility:

DO-160E Env. Cat. [(A2)(F2)W]BAB[SWL]XXFXFXZ[A(WF)H]A[K(WF)]W[RR]H[B3D43]XXAB

The following is an example of an LRU that accepts either category A wide variable frequency ac input power with harmonic current control or category BZ dc input power and category K section 18 for ac input conducted susceptibility and category Z for dc input.

DO-160E Env. Cat. [(A2)(F2)W]BAB[SWL]XXFXFXZ[A(WF)HBZ]A[K(WF)Z]W[RR]H[B3D43]XXAB

Figure A-1 Environmental Qualification Form

NOMENCLATURE: ______________________________
TYPE/MODEL/PART NO: ______________________ TSO NUMBER______________________
MANUFACTURER'S SPECIFICATION AND/OR OTHER APPLICABLE SPECIFICATION: ______________________
____
MANUFACTURER: ______________________________
ADDRESS: ______________________________
____
REVISION & CHANGE NUMBER OF DO-160: _______________ DATE TESTED: ______________________

CONDITIONS	SECTION	DESCRIPTION OF TESTS CONDUCTED
Temperature and Altitude Low Temperature High Temperature In-Flight Loss of Cooling Altitude Decompression Overpressure	4.0 4.5.1 4.5.2 & 4.5.3 4.5.4 4.6.1 4.6.2 4.6.3	
Temperature Variation	5.0	
Humidity	6.0	
Operational Shock and Crash Safety	7.0	
Vibration	8.0	
Explosive Atmosphere	9.0	
Waterproofness	10.0	
Fluids Susceptibility	11.0	
Sand and Dust	12.0	
Fungus	13.0	
Salt Fog Test	14.0	
Magnetic Effect	15.0	
Power Input	16.0	
Voltage Spike	17.0	
Audio Frequency Susceptibility	18.0	
Induced Signal Susceptibility	19.0	
Radio Frequency Susceptibility	20.0	

Figure A-1 Concluded

CONDITIONS	SECTION	DESCRIPTION OF TESTS CONDUCTED
Radio Frequency Emission	21.0	
Lightning Induced Transient Susceptibility	22.0	
Lightning Direct Effects	23.0	
Icing	24.0	
Electrostatic Discharge	25.0	
Fire, Flammability	26.0	
Other Tests		

REMARKS - - - - Special Conditions: Include power, special cooling, installation instructions, etc.

Figure A-2 Environmental Qualification Form

EXAMPLE

NOMENCLATURE: ______________________________
TYPE/MODEL/PART NO: ______________________ TSO NUMBER ______________________
MANUFACTURER=S SPECIFICATION AND/OR OTHER APPLICABLE SPECIFICATION: ______________________
____
MANUFACTURER: ______________________________
ADDRESS: ______________________________
____

REVISION & CHANGE NUMBER OF DO-160: ________________ **DATE TESTED:** ______________________

CONDITIONS	SECTION	DESCRIPTION OF TESTS CONDUCTED
Temperature and Altitude Low Temperature High Temperature In-Flight Loss of Cooling Altitude Decompression Overpressure	4.0 4.5.1 4.5.2 & 4.5.3 4.5.4 4.6.1 4.6.2 4.6.3	Equipment tested to Categories A2, F2 With auxiliary air cooling, tested to Category W
Temperature Variation	5.0	Equipment tested to Category B.
Humidity	6.0	Equipment tested to Category A.
Operational Shock and Crash Safety	7.0	Equipment tested to Category B.
Vibration	8.0	Equipment tested to Category S, aircraft zone 4 for fixed wing turbojet engine aircraft, fixed wing unducted turbofan engine aircraft and fixed wing reciprocating/turbojet engine aircraft less than 5,700 kg using vibration test curves W and L.
Explosive Atmosphere	9.0	Equipment identified as Category X, no test performed.
Waterproofness	10.0	Equipment identified as Category X, no test performed.
Fluids Susceptibility	11.0	Equipment identified as Category F Equipment spray tested with phosphate ester-based hydraulic fluid and immersion tested with AEA Type 1 De-icing fluid.
Sand and Dust	12.0	Equipment identified as Category X, no test performed.
Fungus	13.0	Equipment tested to Category F.
Salt Fog Test	14.0	Equipment identified as Category X, no test performed.
Magnetic Effect	15.0	Equipment is Category A.

Figure A-2 Concluded

CONDITIONS	SECTION	DESCRIPTION OF TESTS CONDUCTED
Power Input	16.0	Equipment tested to Category A.
Voltage Spike	17.0	Equipment tested to Category A.
Audio Frequency Susceptibility	18.0	Equipment tested to Category R.
Induced Signal Susceptibility	19.0	Equipment tested to Category AC.
Radio Frequency Susceptibility	20.0	Equipment tested for conducted susceptibility to Category R and for radiated susceptibility to Category R.
Radio Frequency Emission	21.0	Equipment tested to Category H .
Lightning Induced Transient Susceptibility	22.0	Equipment tested to pin test waveform set B, level 3, and cable bundle test waveform set D, Single/Multiple Stroke Level 4, Multiple Burst Level 3.
Lightning Direct Effects	23.0	Equipment identified as Category X, no test performed.
Icing	24.0	Equipment identified as Category X, no test performed.
Electrostatic Discharge	25.0	Equipment tested to Category A.
Fire, Flammability	26.0	Equipment tested to Category B.
Other Tests		Fire resistance tests were conducted in accordance with Federal Aviation Regulations Part 25, Appendix F.

REMARKS

- Tests were conducted at Environmental Laboratories, Inc.
- In the fluids susceptibility tests, material specimens were used
- In the power input test, equipment was tested to subparagraph 16.5.1.4 b, requirement for equipment with digital circuits.

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Environmental Conditions and Test Procedures for Airborne Equipment

<u>Appendix B</u>

Membership

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Membership

Special Committee 135

**Environmental Conditions and Test Procedures
For Airborne Equipment**

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Werner Kleine-Beek	Bundesministerium fur Verkehr Bau-und Wohnugswesen
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Rick Robles	Gables Engineering, Inc.
Pierre-Charles Rolland	Airbus France
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Paul Schwerman	Honeywell International, Inc.
Rolland Sicard	Universal Avionics Systems Corporation
Michael Smith	Ametek Aerospace
Alan Thompson	Environ Laboratories, LLC
Ralph Thompson	IATA
Steve Uhrich	The Boeing Company
Walter Viebrock	The Boeing Company
Gary Vieth	The Boeing Company
Matthew Wade	Federal Aviation Administration
David Walen	Federal Aviation Administration
Kenneth Webb	Rockwell Collins, Inc.
Frank White	Garmin International, Inc.
Reuben Williams	National Aeronautics & Space Administration

Matthew Wills	Cessna Aircraft Company
Karl Yaeger	Pratt & Whitney Aircraft

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DO-160E

Environmental Conditions and Test Procedures for Airborne Equipment

Appendix C
Change Coordinators

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SC-135 / WG-14 Change Coordinators and Assignments

Section	Section Title/Assignment	US Change Coordinator Address, Phone/Fax	EU Change Coordinator Address, Phone/Fax
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2.0	Definitions of Terms	Jim Lyall	Marc Ponçon
3.0	Conditions of Test	Jim Lyall	Marc Ponçon
4.0	Temperature and Altitude	Jeff Dinsmore Honeywell, Inc. Commercial Flight Systems Group 8840 Evergreen Blvd., M/S MN 51-1305 Minneapolis, MN 55433-0640 (P) 763-957-4582 (F) 763-957-4731 (E) jeff.dinsmore@honeywell.com	Arnaud Ledreux Seditec for Airbus Immeuble Arc en ciel 1, chemin de la crabe 31300 Toulouse (P) 33 5 34 50 12 41 (F) 33 5 34 50 12 12 (E) arnaud.ledreux@aeroconseil.com
5.0	Temperature Variation	Jeff Dinsmore	Arnaud Ledreux
6.0	Humidity	Richard Errhalt Commander Electronic Proving Ground Range Support and Operations Division- ETF Bldg. 82812, Arizona St. Fort Huachuca, Arizona 85613-7063 (P) 520-538-3928 (F) (E) Richard.Errhalt@epg.army.mil	
7.0	Shock	Gary Vieth Boeing Commercial Airplane Company P.O. Box 3707, MS 67-HL Seattle, WA 98124 (P) 425-294-4833 (F) 425-294-7864 (E) gary.l.vieth@boeing.com	Marc Ponçon
8.0	Vibration	Gary Vieth	Marc Ponçon
9.0	Explosive Atmosphere	Brad Green Honeywell International, Inc. 23500 W. 105th Street, MS-56 Olathe, KS 66062-1212 (P) 913-712-2674 (F) 913-712-1399 (E) bradf.green@honeywell.com	
10.0	Waterproofness	Brad Green	
11.0	Fluids Susceptibility	Brad Green	
12.0	Sand and Dust	Richard Errhalt	
13.0	Fungus Resistance	Richard Errhalt	

14.0	Salt Spray	Richard Errhalt	
15.0	Magnetic Effect	Paul Schwerman Honeywell, Inc. BRGA 5353 West Bell Road, M/S AV2-DD80 Glendale, AZ 85308 (P) 602-436-4142 (F) 602-436-4678 (E) paul.schwerman@honeywell.com	Gilles Crouzier Turbomeca Usine de bordes 64511 Bordes Cedex France (P) 33 5 59 12 58 26 (F) 33 5 59 12 51 48 (E) gilles.crouzier@turbomeca.fr
16.0	Power Input	Paul Schwerman	C.Bertran Airbus France S.A.S 31060 Toulouse cedex France Ph: (0)5 62 11 07 88 fax: (0)5 61 93 46 40 christian.bertran@airbus.com
17.0	Voltage Spike Conducted	John Covell Goodrich Corporation Fuel and Utility Systems Vergennes, Vermont (P) 802-877-4594 (F) 802-877-4444 (E) john.covell@goodrich.com	Philippe Leroux Sagem (E)philippe.leroux@sagem.com
18.0	Audio Frequency Conducted Susceptibility	John Birkland Rockwell Collins 400 Collins Road, NE, M/S 106-183 Cedar Rapids, IA 52498 (P) 319-295-3091 (F) 319-295-0654 (E) jabirkla@collins.rockwell.com	Nigel Carter Qinetiq (E) NJCARTER@qinetiq.com
19.0	Induced Signal Susceptibility	Jim Hatlestad The Boeing Company P.O. Box 3707, MC 03-HT Seattle, WA 98124-2207 (P) 425-266-6506 (F) 425-266-8208 (E) james.r.hatlestad@boeing.com	Nigel Carter
20.0	RF Susceptibility (Radiated and Conducted)	Jim Hatlestad	Nigel Carter
21.0	Emission of Radio Frequency Energy	Matthew Wills Cessna Aircraft Company P.O. Box 7704, M/S W7-6 Wichita, KS 67277-7704 (P) 316-858-1114 (F) 316-206-6857 (E) mwills@cessna.textron.com	Franck Flourens Airbus France S.A.S 31060 Toulouse cedex France (P) 33 5 61 93 95 96 (F) 33 5 61 93 87 47 (E) franck.flourens@airbus.com
22.0	Lightning Induced Transient Susceptibility	Richard Hess Senior Fellow Honeywell International, Inc. P.O. Box 21111, M/S L29D1 Phoenix, AZ 85036 (P) 602-436-1285 (F) 602-436-3650 (E) richard.hess@honeywell.com	Jean.Patrick Moreau Dassault Aviation (E) jean-patrick.moreau@dassault-aviation.fr
23.0	Lightning Direct Effects	Richard Hess	Jean.Patrick Moreau

24.0	Icing	Alan G. Thompson Environ Laboratories LLC 9725 Girard Avenue South Bloomington, MN 55431 (P) (952) 888-7795 (F) Fax (952) 888-6345 (E) agt@environlab.com	
25.0	Electro-Static Discharge	Rick Gaynor National Technical Systems 36 Gilbert Street South Tinton Falls, NJ 07701 (P) 732-936-0800 (F) 732-936-0700 (E) richardg@ntscorp.com	
26.0	Fire Resistance	Rick Gaynor	SANT-ANNA Philippe Airbus France S.A.S 31060 Toulouse cedex France (P) 33 5 61 18 64 29 (F) 33 5 61 18 78 96 (E) philippe.sant-anna@airbus.com
Appendix A	Environmental Test Identification	Jim Lyall	Marc Ponçon
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SC-135	Secretary	Rick Gaynor	
SC-135	Designated Federal Representative	John Dimtroff FAA - Transport Standards Federal Aviation Administration/ANM-118D 1601 Lind Avenue, SW Renton, WA 98055 (P) 425-227-1371 (F) 425-227-1181 (E) john.dimtroff@faa.gov	
RTCA	Program Director	Harold Moses 1828 L Street, NW, Suite 805 Washington, DC 20036 (P) 202-833-9339 (F) 202-833-9434 (E) hmoses@rtca.org	

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