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Minimum Operational Performance Standards for Airborne Thunderstorm Detection Equipment

RTCA DO-191
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F O R E W O R D

This document was prepared by Special Committee 154 of the Radio Technical Commission for Aeronautics. It was approved by RTCA on May 16, 1986.

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1.0 PURPOSE AND SCOPE

1.1 Introduction

This document contains minimum operational performance standards for non-radar airborne thunderstorm detection equipment. These standards specify system characteristics that should be useful to designers, manufacturers, installers and users of the equipment.

Compliance with these standards is recommended as one means of assuring that the equipment will perform its intended function(s) satisfactorily under all conditions normally encountered in routine aeronautical operations. Any regulatory application of this document is the sole responsibility of the appropriate governmental agencies.

Section 1.0 of this document provides information needed to understand the rationale for equipment characteristics and requirements stated in the remaining sections. It describes typical equipment applications and operational goals as envisioned by Special Committee 154. Definitions and assumptions essential to proper understanding of this document are also provided in this section.

Section 2.0 contains the minimum performance standards for the equipment. These standards specify the required performance under standard and environmental conditions. Also included are recommended bench test procedures necessary to demonstrate equipment compliance with the stated minimum requirements.

Section 3.0 describes the performance required of the installed equipment. Tests for the installed equipment are included when performance cannot be adequately determined through bench testing.

Section 4.0 describes the operational performance characteristics for equipment installations and defines conditions that will assure the equipment is used properly in the expected operational environment.

This document considers an equipment configuration consisting of, but not limited to: A receiver/processor, control panel, display, antenna(s) and interconnecting cables. Operational performance standards for functions or components that refer to equipment capabilities that exceed the stated minimum requirements are identified as optional features.

The word "equipment" as used in this document includes all components and units necessary for the system to properly perform its intended function(s). For example, the "equipment" may include an antenna, a receiver unit, a display, mounting trays, etc. In the case of this example, all of the foregoing components and units comprise the "equipment." It should not be inferred from this example that each equipment design will necessarily include all of the foregoing components or units. This will depend on the specific design chosen by the manufacturer.

If the equipment implementation includes a computer software package, the guidelines contained in RTCA/DO-178A, "Software Considerations in Airborne Systems and Equipment Certification," should be considered.

1.2 System Overview

Thunderstorms, by definition, contain electrical discharges and strong electrical fields. Statistically, these electrical discharges are usually present when the convective cell contains turbulence, visible precipitation and wind shear. Investigation has shown that electrical fields and discharges are detectable by airborne equipment for long periods of time during the life of the thunderstorm cell. The electrical gradient begins to build up early in the cell's life cycle and remains detectable through much of the cell's dissipation.

Airborne thunderstorm detection equipment provides the flight crew with range and bearing information to sferics or electrical discharge activity associated with thunderstorms, in order to identify areas likely to be associated with turbulence.

The equipment detects electromagnetic and/or electrostatic signals emanating from atmospheric electrical discharges; processes them in the receiver/processor; and displays them, by range and azimuth from the aircraft, on an indicator.

1.3 Operational Applications

It is envisioned that airborne thunderstorm detection equipment will be used in either a stand-alone installation, i.e. with no other weather avoidance equipment onboard the aircraft, or in conjunction with airborne weather radar or other devices. In either case, the equipment should assist the flight crew in assessing the location and severity of thunderstorm activity and selecting an avoidance flight path suitable to the flight characteristics of their aircraft.

1.4 Operational Goals

The severe weather associated with thunderstorm activity constitutes one of the most potentially dangerous environments to flight; therefore detection and knowledge of thunderstorm location would be of value to the pilot. Government-sponsored as well as industry research has revealed the extent and composition of the electrical fields in thunderstorms with sufficient accuracy to permit detecting statistically acceptable baseline data. Investigation has shown that where detectable electric fields and discharges exist, they exist in, or in close proximity to, potentially hazardous flight conditions in the convective cell. Therefore, equipment meeting the standards of this MOPS should be designed to meet the following operational goals:

a. The equipment should detect atmospheric electrical activity at a minimum distance of 5 nmi or less and a maximum range of at least 100 nmi from the aircraft to permit the pilot to make any course changes necessary to avoid the area of probable severe weather.

b. The sensing devices used should continuously scan the forward direction of flight with full 360 degree coverage desirable.

c. A suitable display system should provide the pilot with bearing and distance information with reference to the aircraft heading if the display is independent of other information or weather radar displays. Systems displaying individual fields or discharges should retain these targets on the display indicator for an adequate time to permit pilot evaluation of the probable area and intensity of electrical activity associated with the storm cell.

1.5 Assumptions

Adequate technology and scientific research exists to develop and provide pilots with acceptable equipment capable of meeting the goals and requirements of this MOPS. This assumption is based primarily upon, but not limited to, the following:

a. Flight and ground-based research conducted jointly by NASA and the Department of Defense.

b. Extensive experience by the Departments of Commerce and Interior utilizing ground-based detection systems.

c. Existence of U. S. patents for airborne detection systems utilizing electric and electromagnetic sensing technology.

d. Practical flight experience with over 8,000 airborne units utilizing this technology.

e. Approval by the Federal Aviation Administration of equipment using this technology to meet their regulatory requirement for thunderstorm avoidance equipment for some revenue passenger carriage.

f. Results of testing utilizing standard industry methods validated repeatable testing procedures.

g. Development of a statistically valid model of the electrical fields and discharges of a "typical" cell that can be used for detection criteria. It is recognized that any single discharge may vary from this proposed standard. However, research indicates that an acceptable degree of statistical distribution exists to assure that the equipment will perform its intended function.

1.6 Test Procedures

The test procedures specified in this document are intended to be used as one means of demonstrating compliance with the performance requirements. Although specific test procedures are cited, it is recognized that other methods may be preferred. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

The order of tests specified suggests that the equipment be subjected to a succession of tests as it moves from design, and design qualification, into operational use. For example, compliance with the requirements of Section 2.0 shall have been demonstrated as a precondition to satisfactory completion of the installed system tests of Section 3.0.

Four types of test procedures are specified. These include:

a. Environmental Tests

Environmental test requirements are specified in Subsection 2.3. The procedures and their associated limit requirements are intended to provide a laboratory means of determining the electrical and mechanical performance of the equipment under environmental conditions expected to be encountered in actual operations.

Unless otherwise specified, the environmental conditions and test procedures contained in RTCA/DO-160B, "Environmental Conditions and Test Procedures for Airborne Equipment," will be used to demonstrate equipment compliance.

b. Bench Tests

Bench test procedures are specified in Subsection 2.4. These tests provide a laboratory means of demonstrating compliance with the requirements of Subsection 2.2. Test results may be used by equipment manufacturers as design guidance, for monitoring manufacturing compliance and, in certain cases, for obtaining formal approval of equipment design.

c. Installed Equipment Tests

The installed equipment test procedures and their associated limits are specified in Section 3.0. Although bench and environmental test procedures are not included in the installed equipment tests, their successful completion is a precondition to completion of the installed tests. In certain instances, however, installed equipment tests may be used in lieu of bench test simulation of such factors as power supply characteristics, interference from or to other equipment installed on the aircraft, etc. Installed tests are normally performed under two conditions:

(1) With the aircraft on the ground and using simulated or operational system inputs.

(2) With the aircraft in flight using operational system inputs appropriate to the equipment under test.

Test results may be used to demonstrate functional performance in the intended operational environment.

d. Operational Tests

The operational tests are specified in Section 4.0. These test procedures and their associated limits are intended to be conducted by operating personnel as one means of ensuring that the equipment is functioning properly and can be reliably used for its intended function(s).

1.7 Definitions of Terms

Atmospherics - disturbances produced in radio receivers by atmospheric phenomena such as lightning.

Bearing - the angle between aircraft heading and the radio frequency signal as typically emitted from a lightning discharge.

Dart Leader - generally a downward smaller discharge of a charged cloud toward the ground before full contact is made.

Flash - the total discharge event consisting of Dart Leaders, Primary and Subsequent Return Strokes. Typically, the time duration may be one second.

Primary Return Stroke - the main discharge event from ground to cloud after contact is made with the Dart Leader.

Subsequent Return Stroke - one of multiple discharges that occur after the Primary Return Stroke. Typically, they are spaced from five to 60 milliseconds apart and follow the same discharge path.

Thunderstorm - a local storm produced by a cumulonimbus cloud. It is always accompanied by lightning and thunder, usually with strong gusts of wind, heavy rain, and sometimes hail.

1.8 References

RTCA/DO-160B, "Environmental Conditions and Test Procedures for Airborne Equipment," July 1984.

RTCA/DO-172, "Minimum Operational Performance Standards for Airborne Radar Approach and Beacon Systems for Helicopters," November 1980.

RTCA/DO-173, "Minimum Operational Performance Standards for Airborne Weather and Ground Mapping Pulsed Radars," November 1980.

RTCA/DO-174, "Minimum Operational Performance Standards for Optional Equipment Which Displays Non-Radar Derived Data on Weather and Ground Mapping Radar Indicators," March 1981.

RTCA/DO-178A, "Software Considerations in Airborne Systems and Equipment Certification," March 22, 1985.

Models for an Intracloud Lightning Flash, N. Cianos, E.T. Pierce, Stanford Research Institute.

"The Lightning Discharge," Bruce & Golde: The Journal of the Institution of Electrical Engineers, Vol. 88, Part II, No. 6, pp. 487-524, December 1941.

"Generation of Standard Fields in Shielded Enclosures," Fred Haber, IEEE Proceedings, pps. 1693-1698, November 1954.

Determining Distance to Lightning Strokes from a Single Station, Lothar H. Ruhnke, NOAA Technical Report ERL 195-APCL 16, January 1971.

"The Return Stroke of the Lightning Flash to Earth as a Source of ULF Atmospherics," A.S. Dennis and E.T. Pierce, Radio Science, Volume 68D, No. 7, July 1964.

"Lightning Return Stroke Models," Lin et. al., Journal of Geophysical Research, Vol. 85 C3, March 1980.

"The Modeling of Channel Current in the Lightning Return Stroke," G.H. Price, E.T. Pierce, Radio Science, Vol. 12, Pg. 381-388, 1977.

"A Review of Natural Lightning: Experimental Data and Modeling," M. Uman and E. Krider, IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-29, No. 2, May 1982.

"Electromagnetic Interference Characteristics," MIL-STD 461A, measurements of page 17, Table III. Notice for (EL) of 9 February 1971.

2.0 EQUIPMENT PERFORMANCE REQUIREMENTS AND TEST PROCEDURES

2.1 General Requirements

2.1.1 Airworthiness

In the design and manufacture of the equipment, the manufacturer shall provide for installation so as not to impair the airworthiness of the aircraft.

2.1.2 Intended Function

The equipment shall perform its intended function(s), as defined by the manufacturer, and its proper use shall not create a hazard to other users of the National Airspace System.

2.1.3 Federal Communications Commission Rules

All equipment shall comply with the applicable rules of the Federal Communications Commission.[1]

2.1.4 Fire Protection

All materials used shall be self-extinguishing except for small parts (such as knobs, fasteners, seals, grommets and small electrical parts) that would not contribute significantly to the propagation of a fire.

NOTE: One means of showing compliance is contained in Federal Aviation Regulations (FAR), Part 25, Appendix F.

2.1.5 Operation of Controls

The equipment shall be designed so that controls intended for use during flight cannot be operated in any position, combination or sequence which would result in a condition detrimental to the reliability of the equipment or operation of the aircraft.

2.1.6 Accessibility of Controls

Controls which do not require adjustment during flight shall not be readily accessible to flight personnel.

2.1.7 Effects of Test

The equipment shall be designed so that the application of specified test procedures shall not be detrimental to equipment performance following the application of these tests, except as

[1] It is not intended that this requirement relating to FCC rules be interpreted as a precondition for obtaining other applicable approvals, such as an FAA TSO authorization.

performance following the application of these tests, except as specifically allowed.

2.2 Equipment Performance - Standard Conditions

The manufacturer shall have a test signal to standardize and test system performance. Each manufacturer shall have supporting documented data relating to correlation of the standardized test signal and the actual storm data. See Appendix A.

2.2.1 System Performance

The system performance shall be measured using the standardized test signal of Subsection 2.2.

2.2.1.1 Azimuth Processing

The system shall be capable of receiving and processing signals from atmospheric discharges over at least the forward 180-degree sector.

When a heading reference option is used to rotate the displayed data as the aircraft heading changes, there shall be a means to disable this function in event of its failure.

2.2.1.2 Bearing Accuracy

The system bearing relative to the test signal shall be within ±5 degrees for the forward 60-degree sector and ±10 degrees for the remaining sectors for signals from 10 to 100 nmi.

2.2.1.3 Range Accuracy

The system range accuracy relative to the test signal shall be within 10 percent of full scale or 2.5 nmi, whichever is greater, for selected ranges between 10 and 100 nmi.

2.2.1.4 Overload

The system shall recover without degradation after receiving a standard test signal of 500 volts/meter.

2.2.1.5 Interference Protection

The system shall be designed to prevent interference from standard broadcast and other man-made transmitters. The equipment shall meet the requirement of paragraphs 2.2.1.2 and 2.2.1.3 for a test signal equivalent to 50 nmi and from an interference source of 100 kW between 10 kHz to 550 kHz and between 550 kHz to 1600 kHz 5 nmi from the equipment. The equipment shall have a means to discriminate against false signals from sources less than 100 kW and more than 5 nmi from the transmitter and to reject other non-storm or other undesirable signals such that false data shall not be displayed. The provisions of Appendix D describe expected interference signal levels which are most likely to affect the equipment's operational performance.

NOTE: Particular objectionable frequencies may be identified to the ultimate user by the manufacturer.

2.2.1.6 Display

The information shall be provided on an independent display or integrated into other displays such as an EFIS (Electronic Flight Instrument System) or a weather radar display.

2.2.1.6.1 Display Data Obsolescence

A means shall be provided to distinguish or remove old data. Old data shall not be retained longer than four minutes.

2.2.1.6.2 Indicator Range Scale

The maximum displayed range shall be at least 100 nautical miles.

2.2.1.6.3 Range Markers

A linear range scale capable of displaying the maximum range for which the system is designed shall be provided with at least two range markers. All other range scales shall be provided with at least one range marker. The range shall increase from zero to full scale of the selected range.

2.2.1.6.4 Display Azimuth

The display shall have the capability of indicating electrical discharge patterns over the forward 120-degree sector relative to aircraft heading. The azimuth may be limited to the forward 90-degree sector when heading reference inputs are used to correct displayed data as the aircraft turns.

2.2.1.6.5 Azimuth Markers

There shall be the capability to display azimuth markers at 30 degrees either side relative to the aircraft heading.

2.2.1.7 Antenna

The antenna detects electromagnetic and electrostatic signals emanating from atmospheric electrical discharges. The antenna shall dissipate electrostatic charges that could degrade system operation.

2.2.2 Manually Controlled Modes

2.2.2.1 Clear Mode

A means shall be provided to manually clear the display of data.

2.2.2.2 Self-Test Mode

The equipment shall include a self-test feature to verify operation of the system.

2.3 Equipment Performance - Environmental Conditions

The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those which may be encountered in actual aeronautical operations.

Unless otherwise specified, the test procedures applicable to a determination of equipment performance under environmental test conditions are contained in RTCA Document DO-160B, "Environmental Conditions and Test Procedures for Airborne Equipment." General information on the use of DO-160B is contained in Sections 1.0 through 3.0 of that document. Also, a method of identifying which environmental tests were conducted and other amplifying information on the conduct of the tests is contained in Appendix A of DO-160B.

In addition to the exceptions above, certain environmental tests contained in this subsection are not required for minimum performance equipment unless the manufacturer wishes to qualify the equipment for additional environmental conditions. These tests are identified by the phrase "When Required." If the manufacturer wishes to qualify the equipment to these additional conditions, then these "When Required" tests shall be performed.

2.3.1 Temperature and Altitude Tests (DO-160B, Section 4.0)

RTCA/DO-160B contains several temperature and altitude test procedures which are specified according to equipment category. These categories are included in paragraph 4.3 of DO-160B. The following subparagraphs contain the applicable test conditions specified in Section 4.0 of DO-160B.

2.3.1.1 Low Operating Temperature Test

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 4.5.1, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.1.2 High Temperature Test

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 4.5.2, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.1.3 High Operating Temperature

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 4.5.3, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.1.4 In-Flight Loss of Cooling (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 4.5.4, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.1.5 Altitude Tests

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 4.6.1, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.1.6 Decompression Test (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 4.6.2, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.1.7 Overpressure Test

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 4.6.3, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.2 Temperature Variation Test (DO-160B, Section 5.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 5.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.3 Humidity Test (DO-160B, Section 6.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, Section 6.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.4 Shock Tests (DO-160B, Section 7.0)

2.3.4.1 Operation Shocks (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, Section 7.2, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.4.2 Crash Safety Shocks

The application of the Crash Safety Shock tests may result in damage to the equipment under test. Therefore this test may be conducted after the other tests have been completed. In this case, paragraph 2.1.7, "Effects of Test," does not apply.

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 7.3, and shall meet the requirements specified therein.

2.3.5 Vibration Tests (DO-160B, Section 8.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, Section 8.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.6 Explosion Test (DO-160B, Section 9.0) (When Required)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, Section 9.0. During these tests, the equipment shall not cause detonation of the explosive mixture within the test chamber.

2.3.7 Waterproofness Test (DO-160B, Section 10.0) (Antenna Only)

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2.3.7.1 Drip Proof Test

The antenna shall be subjected to the test conditions as specified in RTCA/DO-160B, Section 10.3.1, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.7.2 Spray Proof Test

The antenna shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 10.3.2, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

This test shall be conducted with the spray directed perpendicular to the equipment.

2.3.7.3 Continuous Stream Proof Test

The antenna shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 10.3.3, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

This test shall be conducted with the spray directed perpendicular to the equipment.

2.3.8 Fluids Susceptibility Tests (DO-160B, Section 11.0) (Antenna Only)

The following subparagraphs contain the applicable test conditions specified in Section 11.0 of DO-160B.

2.3.8.1 Spray Test

The antenna shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 11.4.1, and the following requirements of this standard shall apply:

a. At the end of the 24-hour exposure period, the antenna shall operate at a level of performance which indicates that significant failures of components or circuitry have not occurred.

b. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

(1) Paragraph 2.2.1.2 - Bearing Accuracy.
(2) Paragraph 2.2.1.3 - Range Accuracy.

2.3.8.2 Immersion Test

The antenna shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 11.4.2, and the following requirements of this standard shall apply:

a. At the end of the 24-hour immersion period, the antenna shall operate at a level of performance which indicates that significant failures of components or circuitry have not occurred.

b. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

(1) Paragraph 2.2.1.2 - Bearing Accuracy.
(2) Paragraph 2.2.1.3 - Range Accuracy.

2.3.9 Sand and Dust Test (DO-160B, Section 12.0) (Antenna Only When Required)

The antenna shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 12.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.10 Fungus Resistance Test (DO-160B, Section 13.0) (Antenna Only When Required)

The antenna shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 13.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.11 Salt Spray Test (DO-160B, Section 14.0) (Antenna Only When Required)

The antenna shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 14.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.12 Magnetic Effect Test (DO-160B, Section 15.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, Section 15.0, and shall meet the requirements of the appropriate instrument or equipment class specified therein.

2.3.13 Power Input Tests (DO-160B, Section 16.0)

2.3.13.1 Normal Operating Conditions

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraphs 16.5.1 and/or 16.5.2, as appropriate, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.13.2 Abnormal Operating Conditions

a. When the equipment is subjected to the test conditions of DO-160B, paragraph 16.5.3 or 16.5.4, it shall start and continue to operate electrically and mechanically. Degradation of performance is tolerable provided the equipment will resume normal operation when primary power is returned to normal operating conditions.

b. DC operated equipment shall operate satisfactorily within two minutes of returning primary power voltage(s) to normal after testing to low voltage conditions. The two-minute time period does not include the time required for operation of automatic protective circuits.

c. The gradual reduction to zero of the primary power voltage(s) for DC operated equipment shall produce no evidence of the presence of fire or smoke. The application of this test may result in damage to the equipment under test. Therefore, paragraph 2.1.7, "Effects of Test," does not apply.

2.3.14 Voltage Spike Conducted Test (DO-160B, Section 17.0)

The following subparagraphs contain the applicable test conditions specified in Section 17.0 of DO-160B.

2.3.14.1 Category A Requirements (If Applicable)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 17.3, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

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2.3.14.2 Category B Requirements (If Applicable)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraphs 17.4.1, "Intermittent Transients," and 17.4.2, "Repetitive Transients," and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.15 Audio Frequency Conducted Susceptibility Test (DO-160B, Section 18.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 18.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.16 Induced Signal Susceptibility Test (DO-160B, Section 19.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 19.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.17 Radio Frequency Susceptibility Test (Radiated & Conducted) (DO-160B, Section 20.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 20.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

2.3.18 Emission of Radio Frequency Energy Test (DO-160B, Section 21.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 21.0, and shall meet the requirements specified therein.

2.3.19 Lightning Induced Transient Susceptibility (DO-160B, Section 22.0)

The equipment shall be subjected to the test conditions as specified in RTCA/DO-160B, paragraph 22.0, and the following requirements of this standard shall be met:

a. Paragraph 2.2.1.2 - Bearing Accuracy.
b. Paragraph 2.2.1.3 - Range Accuracy.

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2.4 Equipment Test Procedures

2.4.1 Definitions of Terms and Conditions of Test

The following are definitions of terms and the conditions under which the following tests should be conducted.

a. Power Input Voltage - Unless otherwise specified, all tests shall be conducted with the power input voltage adjusted to design voltage plus or minus 2%. The input voltage shall be measured at the input terminals of the equipment under test.

b. Power Input Frequency

(1) In the case of equipment designed for operation from an AC source of essentially constant frequency (e.g., 400 Hz), the input frequency shall be adjusted to design frequency plus or minus 2%.

(2) In the case of equipment designed for operation from an AC source of variable frequency (e.g., 300 to 1,000 Hz), unless otherwise specified tests shall be conducted with the input frequency adjusted to within 5% of a selected frequency and within the range for which the equipment is designed.

c. Adjustment of Equipment - The circuits of the equipment under test shall be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests.

d. Test Equipment - All equipment used in the performance of the tests should be identified by make, model and serial number where appropriate, and its latest calibration date. When appropriate, all test equipment calibration standards should be traceable to national and/or international standards.

e. Test Instrument Precautions - Due precautions shall be taken during the tests to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes and other test instruments across the input and output impedances of the equipment under test.

f. Ambient Conditions - Unless otherwise specified, all tests shall be made within the following ambient conditions:

(1) Temperature: +15 to +35 degrees C (+59 to +95 degrees F).

(2) Relative Humidity: Not greater than 85%.

(3) Ambient Pressure: 84 to 107 kPa (equivalent to +5,000 to -1,500 ft) (+1,525 to -460 m).

When tests are conducted at ambient conditions which differ from the above values, allowances shall be made and the differences recorded.

g. Connected Loads - Unless otherwise specified, all tests shall be performed with the equipment connected to loads having the impedance values for which it is designed.

2.4.2 Required Test Equipment

The manufacturer shall have a test set capable of producing the standard test signal of Subsection 2.2 (see Appendix A). A transient generator, such as Solar Electronic's Model 6254-5 or equivalent, may be used to generate the signal. A standard test set may also be required (see Appendix B).

2.4.3 Detailed Test Procedures

The test procedures set forth below constitute a satisfactory method of determining required performance. The tests may be performed in the shielded room described in Appendix C. Although specific test procedures are cited, it is recognized that other methods may be preferred. Such alternate methods may be used if the manufacturer can show that they provide at least equivalent information. Therefore, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

2.4.3.1 Azimuth Processing (Paragraph 2.2.1.1)

a. The system's ability to receive and process signals over the forward 180-degree sector shall be tested in conjunction with bearing accuracy tests, paragraph 2.4.3.2.

b. The system shall be tested over the entire azimuth range as specified by the manufacturer. If heading reference is required, a test set shall be utilized to input heading information.

2.4.3.2 Bearing Accuracy (Paragraph 2.2.1.2)

a. Standard Conditions

Calibration of airborne thunderstorm detection equipment employing loop antennas shall be conducted in a shielded room equipped with a calibrated test transmission line terminated in a resistance equal to the line's characteristic impedance. This line shall be used in conjunction with a standard transient generator or standard test set (see Appendix B) to produce a signal of known, controllable strength accurately simulating the conditions under which the loop receiver would operate in a free-space, radiated signal field. See Figure 2-1 for an illustration of the test set-up and Appendix C for a detailed description.

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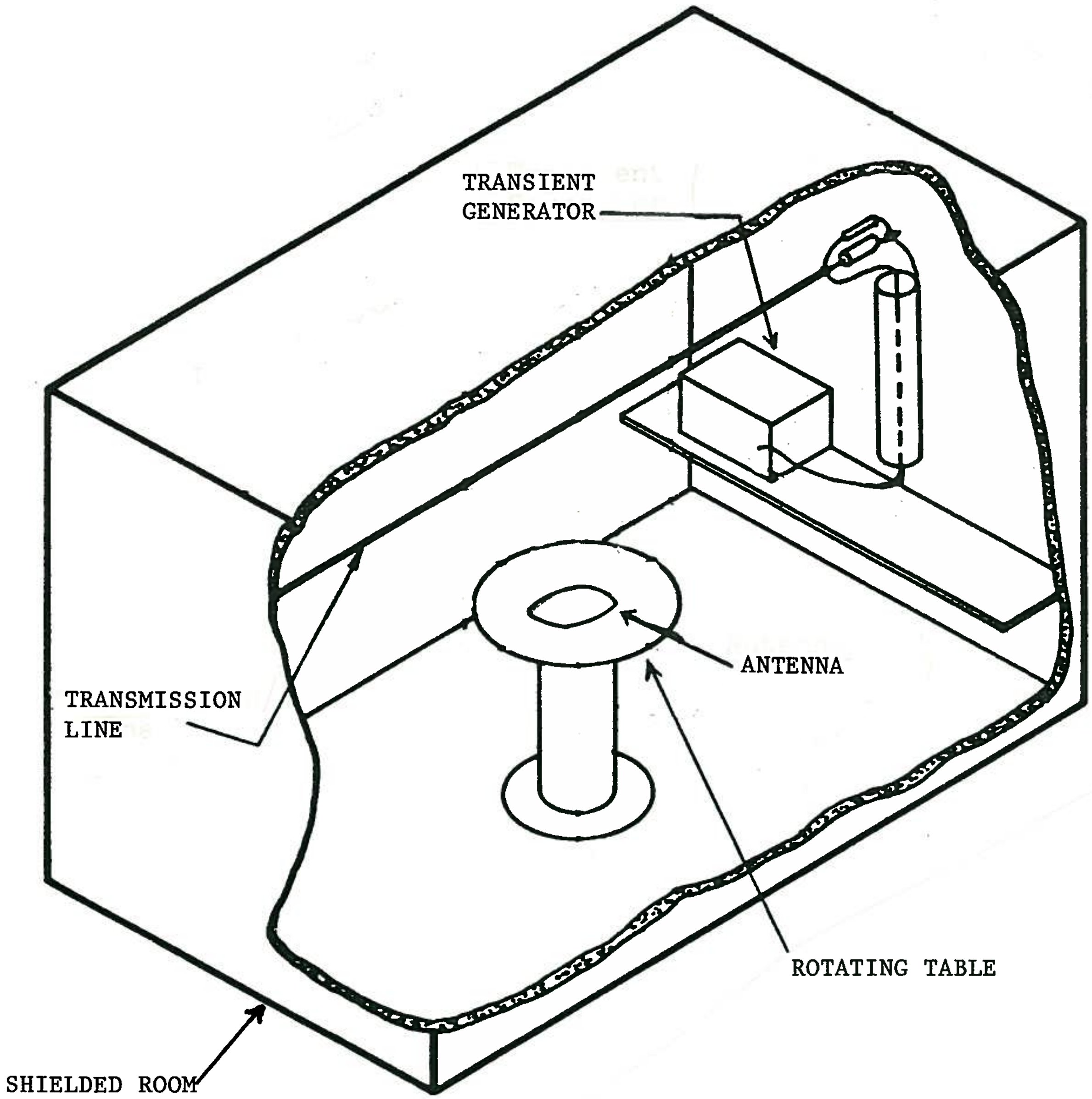

FIGURE 2-1 TEST SET-UP IN SHIELDED ROOM

Set up the generator to output to the transmission line a standard 100 nmi signal of 1-10 volts/meter peak (as specified by the manufacturer). Rotate the antenna in 30-degree increments and record bearing angle given on display for each position (0 degrees, 30 degrees, 60 degrees, etc.).

b. Environmental Conditions

For these conditions the test set described in Appendix B may be used and testing need only be done at the cardinal points (0, 90, 180, 270 degrees) and 100 nmi.

2.4.3.3 Range Accuracy (Paragraph 2.2.1.3)

a. Standard Conditions

Using the test set described in Appendix B (narrow band systems may use transient generator), apply the signal in accordance with manufacturer's recommendations, and record the information on the display. The range accuracy shall be tested at 10, 50 and 100 nmi. This test may be performed concurrently with the bearing accuracy test, paragraph 2.4.3.2, at the 0-degree azimuth.

b. Environmental Conditions

For these conditions the test set described in Appendix B may be used and testing need only be done at 0 degrees and 100 nmi. This test may be performed concurrently with the bearing accuracy test, paragraph 2.4.3.2, at the 0-degree azimuth.

2.4.3.4 Overload (Paragraph 2.2.1.4)

Adjust the transient generator to produce a signal equivalent to 500 V/m at the antenna under test. If necessary move the antenna closer to the transmission line. Turn the system on and apply a single signal to the system. Reduce the signal level to the equivalent of a 10 to 100 nmi signal and apply. The system shall resume normal operation.

2.4.3.5 Interference Protection (Paragraph 2.2.1.5)

Special Equipment Required

Signal generator with frequency output to 1600 kHz.

Measurement Procedure

a. Couple the outputs of the signal generator and transient generator to the antenna as shown in Figure 2-2.

b. Clear the display of data.

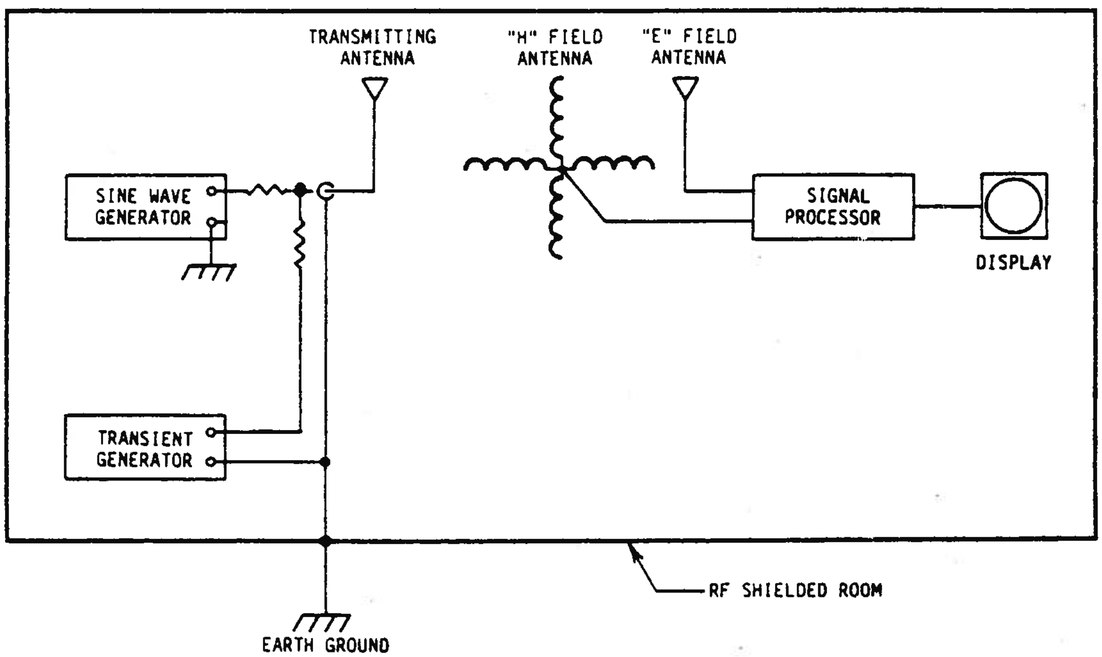

FIGURE 2-2 INTERFERENCE PROTECTION TEST SET-UP

c. With a standard 50 nmi signal specified by the manufacturer at the antenna supplied by the transient generator or test set and a .19 V rms/m field from the signal generator, scan the frequency range of the generator from 10 kHz-550 kHz and observe the range and bearing accuracy of paragraphs 2.2.1.2, 2.2.1.3 and 2.2.1.5.

d. With a standard 50 nmi signal specified by the manufacturer at the antenna supplied by the transient generator or test set and a .28 V rms/m field from the signal generator, scan the frequency range of the generator from 550 kHz-1600 kHz and observe the range and bearing accuracy of paragraphs 2.2.1.2, 2.2.1.3 and 2.2.1.5.

e. With the transient generator or test set and a .19 V rms/m field from the signal generator, scan the frequency range of the generator from 10 kHz-550 kHz and observe no false data in the range selected to 100 nmi.

f. With the transient generator or test set and a .19 V rms/m field from the signal generator, scan the frequency range of the generator from 10 kHz-550 kHz and observe no false data in the range selected to 100 nmi.

2.4.3.6 Display

A display shall be provided for the testing. If a system is to be integrated into an EFIS or weather radar an equivalent display or test set shall be adequate for bench tests.

2.4.3.6.1 Display Azimuth (Paragraph 2.2.1.6.4), Azimuth Markers (Paragraph 2.2.1.6.5)

Performance for display azimuth and azimuth markers is demonstrated by the test for bearing accuracy in paragraph 2.4.3.2.

2.4.3.6.2 Indicator Range Scale Range Markers (Paragraph 2.2.1.6.2)

Performance for range scale and range markers is demonstrated by the test for range accuracy in paragraph 2.4.3.3.

2.4.3.7 Display Data Obsolescence (Paragraph 2.2.1.6.1)

Equipment Required

Same as for bearing accuracy, paragraph 2.4.3.1, plus a stopwatch.

Measurement Procedure

Turn the system under test on and apply a signal from test set (see Appendix B) in accordance with the manufacturer's specifications. After a symbol has been displayed, turn the generator off and start the stopwatch. Stop the watch when the display extinguishes or removes the old data, and record the time.

2.4.3.8 Clear Mode (Paragraph 2.2.2.1)

Turn the system under test on and apply a signal from a test set (see Appendix B), in accordance with the manufacturer's specifications. After a symbol has been displayed, turn the generator off and clear the screen of data per the manufacturer's instructions.

2.4.3.9 Self-Test Mode (Paragraph 2.2.2.2)

Follow the manufacturer's procedure to activate the self-test feature. The display should give an indication to verify operation of the system.

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3.0 INSTALLED EQUIPMENT PERFORMANCE

3.1 Equipment Installation

3.1.1 Accessibility

Controls and monitors provided for in-flight operation shall be readily accessible from the pilot's normal seated position. The appropriate operator/crew member(s) shall have an unobstructed view of displayed data when in the normal seated position.

3.1.2 Aircraft Environment

Equipment shall be compatible with the environmental conditions present in the specific location in the aircraft where the equipment is installed.

3.1.3 Display Visibility

Display intensity shall be suitable for data interpretation under all cockpit ambient light conditions ranging from total darkness to reflected sunlight.

3.1.4 Dynamic Response

Operation of the equipment shall not be adversely affected by aircraft maneuvering or changes in attitude encountered in normal flight operations.

3.1.5 Failure Protection

Any probable failure of the equipment shall not degrade the normal operation of equipment or systems connected to it. Likewise, the failure of interfaced equipment or systems shall not degrade normal operation of this equipment.

3.1.6 Interference Effects

The equipment shall not be the source of harmful conducted or radiated interference nor be adversely affected by conducted or radiated interference from other equipment or systems installed in the aircraft.

NOTE: Electromagnetic compatibility problems noted after installation of this equipment may result from such factors as the design characteristics of previously installed systems or equipment and the physical installation itself. It is not intended that the equipment manufacturer design for all installation environments. The installing facility will be responsible for resolving any incompatibility between this equipment and previously installed equipment in the aircraft. The various factors contributing to the incompatibility shall be considered.

3.1.7 Inadvertent Turnoff

Appropriate controls shall be provided with adequate protection against inadvertent turnoff of the equipment.

3.1.8 Aircraft Power Source

The voltage and voltage tolerance characteristics of the equipment shall be compatible with the aircraft power source.

3.1.9 Special Installation Requirements

The equipment shall be installed in accordance with the manufacturer's installation instructions. The antenna shall not be painted by the installer.

3.2 Installed Equipment Performance

The installed equipment shall meet the requirements of Subsections 2.1 and 2.2 except as indicated in Subsection 3.4.

3.3 Conditions of Test

The following subparagraphs define conditions under which tests specified in Subsection 3.4 shall be conducted.

3.3.1 Power Input

Unless otherwise specified by the equipment manufacturer, tests shall be conducted with the equipment powered by the aircraft's electrical power generating system.

3.3.2 Associated Equipment or Systems

Unless otherwise specified by the equipment manufacturer, all aircraft electrical equipment and systems shall be operational.

3.3.3 Environment

During tests, the equipment shall not be subjected to environmental conditions that exceed those specified by the equipment manufacturer.

3.3.4 Adjustment of Equipment

Circuits of the equipment under test shall be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests.

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3.3.5 Warm-up Period

Unless otherwise specified by the equipment manufacturer, tests shall be conducted after a warm-up (stabilization) period of not more than fifteen minutes.

3.4 Test Procedures for Installed Equipment Performance

The following test procedures provide one means of determining installed equipment performance. Although specific test procedures are cited, it is recognized that other methods may be preferred. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

3.4.1 Conformity Inspection

Visually inspect the installed equipment to determine the use of acceptable workmanship and engineering practices. Verify that proper mechanical and electrical connections have been made and that the equipment has been located and installed in accordance with the manufacturer's recommendations.

3.4.2 Displayed Data Readability

Determine that normal sunlight environment will not significantly affect the readability of displayed data.

3.4.3 Equipment Accessibility

Determine that all equipment controls and displayed data are readily accessible and easily interpreted.

3.4.4 Heading Correction (When Required)

For systems utilizing a gyro heading correction, generate a test signal and rotate the heading gyro display. Observe that the displayed signal tracks in azimuth in direct relation to the heading gyro.

3.4.5 Equipment Functions

Vary all controls of the equipment through their full range to determine that the equipment is operating according to the manufacturer's instructions and that each control performs its intended function.

3.4.6 Equipment Performance

Connect the test set as shown in Appendix B and apply signals to verify range and azimuth performance. With the range set on 100 nmi and at least 1 azimuth test point set between 30 and 60 degrees, the system shall meet the accuracy of ±10 degrees for the forward 120-degree sector. The range accuracy shall be within ten percent of full scale.

3.4.7 Interference Effects

With the equipment energized, individually operate each of the other electrically operated aircraft equipment and systems to determine that significant conducted or radiated interference does not exist. Evaluate all reasonable combinations of control settings and operating modes. Operate communication and navigation equipment on the low, high and at least one but preferably four mid-band frequencies. Make note of systems or modes of operation that should also be evaluated during flight. If appropriate, repeat tests using emergency power with the aircraft's batteries alone and the inverters operating.

3.4.8 Power Supply Fluctuations

Under normal aircraft conditions, cycle the aircraft engine(s) through all normal power settings and verify proper operation of the equipment as specified by the equipment manufacturer.

4.0 OPERATIONAL CHARACTERISTICS

4.1 Required Operational Characteristics

To ensure proper operation of the equipment in the expected operational environment, specific minimum acceptable performance parameters must be met. The following paragraphs identify those equipment operational characteristics which, if met, constitute an overall confidence check of equipment operation.

4.1.1 Power Input

Prior to flight, verify that the equipment is receiving primary input power necessary for proper equipment operation.

4.1.2 Equipment Operating Modes

The equipment must be capable of operating in each of its operating modes.

4.2 Test Procedures for Operational Characteristics

Operational equipment tests may be run as part of the normal pre-flight tests prior to the start of a flight in which the equipment is expected to be used. For those tests which can only be run in flight, procedures should be developed by the user to perform these tests as early during the flight as possible in order to establish confidence that the equipment is performing its intended function(s).

4.2.1 Power Input

With the aircraft's electrical power generating system operating, energize the equipment and verify that electrical power is available to the equipment.

4.2.2 Equipment Operating Modes

Verify that the equipment performs its intended function(s) as specified by the manufacturer for each of the following operating modes.

a. Self-Test.
b. Clear.
c. Range Selection.
d. Gyro (Optional as Required).

4.3 Operation and Interpretation During Flights

a. The equipment detects electrical activity associated with thunderstorms and provides a visual indication of the location and relative intensity of these thunderstorms. The equipment shall be used to locate areas of thunderstorm activity and not to locate individual electrical discharges.

b. Manufacturer's systems may detect and display thunderstorm activity in different ways. Sufficient instructions for the operation and interpretation of the information provided by the equipment is the responsibility of the manufacturer.

c. An interface with weather radar (where applicable) means that information is provided from two separate and distinct detection systems which may be placed on to one display. Care must be exercised as representation of areas of storm activity may not correlate. The location of electrical discharge activity is not always in the area of heaviest precipitation.

M E M B E R S H I P

Special Committee 154

MINIMUM OPERATIONAL PERFORMANCE STANDARDS FOR AIRBORNE THUNDERSTORM DETECTION EQUIPMENT

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A P P E N D I X   A

STANDARD TEST SIGNAL MODEL

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1.0 Introduction

This appendix describes the test signal model used to verify the performance of the equipment under test. General theory and reasons for selecting the test signal are specified. A standard reference signal model used to calibrate bearing is described in Section 4.1. Range calibration models for narrow band and wide band systems are described in Subsections 4.2 and 4.3 respectively. The assumption that an actual lightning signal may vary about the standard signal is discussed. The manufacturer may have an alternative test signal model to verify the equipment performance.

2.0 General Theory

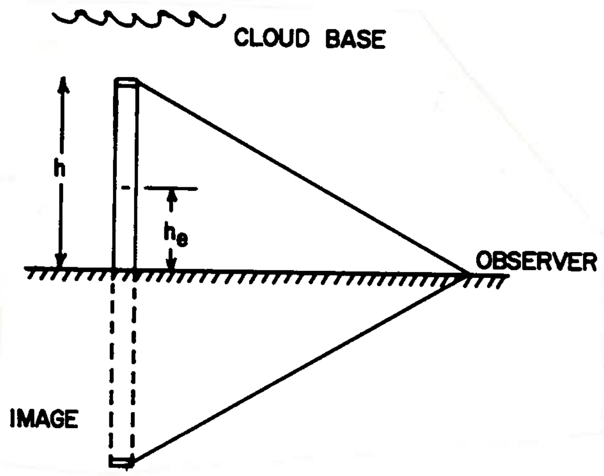
The electric and magnetic fields of a lightning discharge process have been measured and modeled for more than fifty years. In recent years, it has been possible to measure waveforms in the microsecond and submicrosecond range. The state of the art of the modeling of lightning currents and fields has been reported by Uman and Krider in "A review of Natural Lightning: Experimental Data and Modeling," May 1982, IEEE Transactions On Electromagnetic Compatibility.

The lightning discharge process produces transient field signals. Lightning discharges are classified as intracloud discharges, cloud-to-ground, cloud-to-cloud, or cloud-to-air. Each type of discharge produces many different signal characteristics that are difficult to simulate with a standard test signal generator. The cloud-to-ground discharge has been extensively analyzed and is the most understood lightning phenomenon. The other lightning discharges (such as intracloud) occur in a large percentage of all lightning discharges. For all of the discharges, the radiated pulses are generated over a large region of many miles in detectable range and in all directions. The test signal, however, represents the radiated pulse of a typical cloud-to-ground lightning return stroke with the aircraft on the ground. This signal is produced by the lightning current, originating on the ground. This ground return stroke can be more accurately located than the other signal processes because of the vertical channel characteristic. The test signal model simulates the radiation field of the return stroke process to determine the equipment performance. The return stroke process occurs when the downward-moving discharge or step leader has caused one or more upward-moving discharges to be initiated at the ground. The return stroke process occurs in the intracloud discharge in much the same manner, but produces a different signal waveform. The return stroke signal is the most extensively studied process, and its radiated field is used as a test signal model to verify the performance of the equipment under test.

It is recognized that the manufacturer may use different bandwidth characteristics to analyze the lightning discharge process. This would require variations in the models to accommodate these design approaches. These systems can be categorized as narrow band or wide band. Typically, wide band equipment is used for signature analysis, while narrow band equipment detects the primary discharge pulse.

3.0 Lightning Current and Electromagnetic Radiation Model Derivations

The current model assumes that all lightning currents are contained in straight vertical channels above a perfectly conducting ground plane. The radiated fields for this configuration are readily obtained as illustrated in the following analysis.



The dipole moment of straight vertical return stroke is given by:

$$M = 2\ Qh_e + Mc \qquad (1)$$

where Q is the total charge distributed along the channel at an equivalent height h_e and the factor of two accounts for ground image charge. Mc is the static dipole moment of the cloud. Since current is related to the rate of change in the charge as:

$$i(t) = dQ/dt \qquad (2)$$

then the rate of change in the dipole moment is given by:

$$dM/dt = i(t)h(t)dh \qquad (3)$$

The height of the charge flowing in the return stroke is assumed to travel at a velocity of:

$$V_t = V_o\varepsilon^{-\gamma t} \qquad (4)$$

where Bruce and Golde assumed the current propagation speed V_o equals 8×10^7 m/s and a time constant γ equals .03 /µs. (ε = 2.7128) By integrating Vt, the height of the return stroke is given as:

$$h(t) = \frac{V_o}{\gamma}(1-\varepsilon^{-\gamma t}) \tag{5}$$

The current flowing in the return stroke model at the ground is assumed, after Bruce and Golde, to have a time variation of:

$$i(t) = I_o\,(\varepsilon^{-\alpha t}-\varepsilon^{-\beta t}) \text{ where } I_o \text{ is 20 Kamps, } \alpha = .46\ /\mu s,\ \beta = .04\ /\mu s \tag{6}$$

We can now express the dipole moment as a function of time by substituting i in the above equation into equation 1:

$$M(t) = \int_o^\infty i\,dt \times \frac{V_o}{\gamma}(1-\varepsilon^{-\gamma t}) \tag{7}$$

Further simplification leads to

$$M = Mc + 2Qh_e = Mc + \frac{I_oV_o}{\gamma}(1-\varepsilon^{-\gamma t})\left(\frac{1}{\alpha}(1-\varepsilon^{-\alpha t})-\frac{1}{\beta}(-\varepsilon^{-\beta t})\right) \tag{8}$$

Substituting this into the dipole moment expression above, the rate of change of the dipole moment is:

$$\frac{dM}{dt} = I_oV_o\varepsilon^{-\gamma t}\left(\frac{1}{\alpha}(1-\varepsilon^{-\alpha t})-\frac{1}{\beta}(1-\varepsilon^{-\beta t})\right) \tag{9}$$

$$+ \frac{I_oV_o}{\gamma}(1-\varepsilon^{-\gamma t})(\varepsilon^{-\alpha t}-\varepsilon^{-\beta t})$$

The second derivative of the dipole moment is

$$\frac{d^2M}{dt^2} = 2I_oV_o\varepsilon^{-\gamma t}(\varepsilon^{-\alpha t}-\varepsilon^{-\beta t}) - \frac{I_oV_o}{\gamma}(1-\varepsilon^{-\gamma t})(\alpha\varepsilon^{-\alpha t}-\beta\varepsilon^{-\beta t}) \tag{10}$$

$$-I_oV_o\gamma\varepsilon^{-\gamma t}\left(\frac{1}{\alpha}(1-\varepsilon^{-\alpha t})-\frac{1}{\beta}(1-\varepsilon^{-\beta t})\right)$$

Dr. Ruhnke in "Determining Distance to Lightning Strokes from a Single Station," NOAA Technical report ERL 195-APCL 16, January 1971, presented the electric and magnetic fields at a given distance R from the return stroke expressed by the dipole moment M (a function of time) as:

$$E(t) = \frac{1}{4\pi\xi}\left(\frac{M}{R^3} + \frac{dM/dt}{cR^2} + \frac{d^2M/dt^2}{c^2R}\right) \text{ where } E(t) \text{ is volts/meter} \tag{11}$$

and

$$H(t) = \frac{1}{4\pi\xi Z}\left(\frac{dM/dt}{cR^2} + \frac{d^2M/dt^2}{c^2R}\right) \text{ where } H(t) \text{ is amps/meter} \qquad (12)$$

where c is the speed of light, 3×10^8 m/s and Z is impedance of free space 120π. ($\pi = 3.1416$, $\xi = 8.85 \times 10^{-12}$ Farads/m.)

Substituting equations (8), (9) and (10) into equation (11) with parameters published by the following researchers results in the plot of Figure A-1.

		α /μs	β /μs	I_o KA
Bruce-Golde	1941	.04	.46	19.75
Uman-McLain	1969	.02	.2	30.0
Berger	1975	.0079	1.3	30.8
Lin	1978	.016	.058	17.0
Levine	1978	.04	.80	30.0
Melander	1983	.014	2.50	20.6

$c = 3 \times 10^8$ m/s $\qquad R = 100$ nmi $= 1.852 \times 10^5$ m

$\xi = 8.85 \times 10^{-12}$ Farads/m $\qquad V_o = 8 \times 10^7$ m/s

$\gamma = .03$/μs

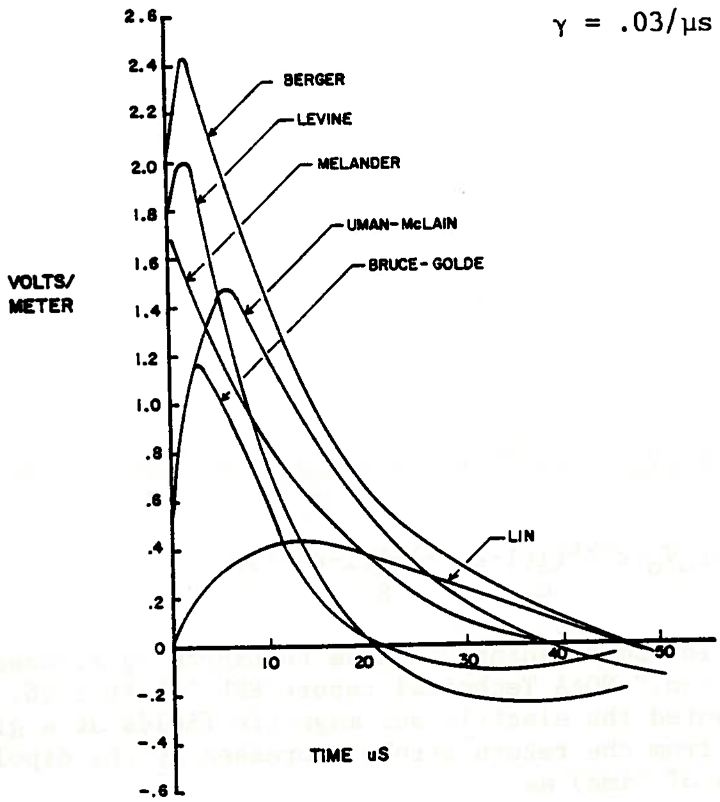


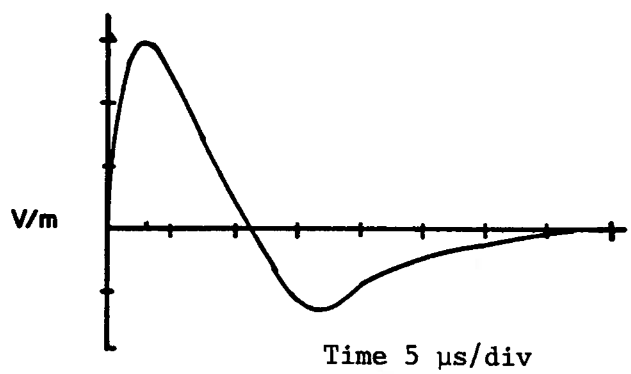
FIGURE A-1 RADIATED FIELD AT 100 NMI FROM PRIMARY RETURN STROKE

4.0 Standard Models

With the wide variation of lightning waveforms, as indicated in Section 3.0, it is necessary to devise standard waveform models for practical use by equipment designers and manufacturers. The most important aspect of the model is that it can be used to predict equipment performance for an idealistic lightning process under controlled conditions. The absolute accuracy of the model will vary greatly for each lightning signal received by the airborne equipment. One model can be used to test wide band and narrow band systems except for the range accuracy test for the wide band system.

4.1 Bearing Test Model

Figure A-2 is a standard waveform defined in MIL-STD-461 that has been used for years by the military and others for induced transient testing. It adequately resembles the lightning wave forms and is generated by the Model 6254-5 RFI transient generator produced by Solar Electronic Co. For the standard test waveform, the peak amplitude of the test signal as selected by the manufacturer ranges between 1 and 10 volts/meter for a 100 nmi signal.



WAVEFORM CHARACTERISTICS
Rise Time 1.05 μs
Pulse Width 10 μs
Peak 1-10 V/m (100 nmi)

FIGURE A-2 STANDARD WAVEFORM

4.2 Range Test Model for Narrow Band Systems

The narrow band systems provide range determination based upon the inverse amplitude versus range characteristic of the far field component. These systems may use the waveform model of Figure A-2 and vary the amplitude to determine range.

To find the radiation for a return stroke, it should be noted that there are three fundamental parts to equation 11 as shown below:

$$E(t) = \frac{1}{4\pi\xi}\left(\frac{M}{R^3} + \frac{dM/dt}{cR^2} + \frac{d^2M/dt^2}{c^2R}\right) \quad (13)$$

For simplification at 100 nmi the radiation part of the formula may be used for the far-field component of the radiated signal with minimal error.

$$E(t) = \frac{1}{4\pi\xi} \frac{(d^2M/dt^2)}{c^2R} \tag{14}$$

This equation shows the inverse relationship between the peak amplitude of the test waveform and distance. As an example of how this equation is used the following parameters may be substituted in equation (15) to calculate the amplitude characteristics.

Substituting equation (10) into equation 14 yields:

$$E(t) = \frac{I_oV_o}{4\pi R\gamma\xi c^2}\Big[2\gamma\varepsilon^{-\gamma t}(\varepsilon^{-\alpha t}-\varepsilon^{-\beta t})-(1-\varepsilon^{-\gamma t})(\alpha\varepsilon^{-\alpha t}-\beta\varepsilon^{-\beta t}) + \gamma^2\varepsilon^{-\gamma t}\ [1/\alpha(1-\varepsilon^{-\alpha t}) - 1/\beta(1-\varepsilon^{-\beta t})]\Big] \tag{15}$$

Shown below are the current parameters given by Bruce-Golde and a plot of the resulting radiated field.

$\varepsilon = 2.718$

$\gamma = .03/\mu s$

$R = 1.852 \times 10^5$ m (100 nmi)

$\alpha = .46/\mu s$

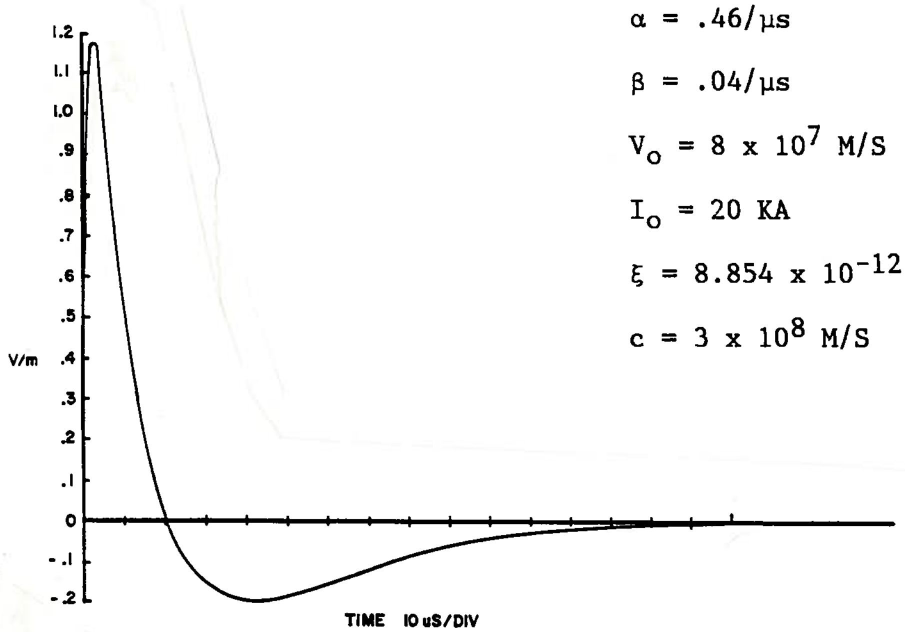
$\beta = .04/\mu s$

$V_o = 8 \times 10^7$ M/S

$I_o = 20$ KA

$\xi = 8.854 \times 10^{-12}$ F/M

$c = 3 \times 10^8$ M/S



The results of applying this equation are as follows:

R nmi	E(t) V/m
100	1.2
50	2.4
10	12.0

4.3 Range Test Model for Wide Band Systems

The wide band systems determine range to a lightning flash by assuming the physical phenomena that the magnitude of the electromagnetic fields for the induction field decreases with the square of the distance from the lightning, while the electrostatic field decreases with the cube of the distance. The variation of the magnetic field as a function of frequency and distance is demonstrated by transforming the Ruhnke equations 11 and 12 of Section 3.0 into the frequency domain as follows:

$$E(w) = \frac{1}{4\pi\xi}\left(\frac{M(w)}{R^3} + \frac{jwM(w)}{cR^2} + \frac{(jw)^2M(w)}{c^2R}\right) \tag{16}$$

$$H(w) = \frac{1}{4\pi\xi Z}\left(\frac{jwM(w)}{cR^2} + \frac{(jw)^2M(w)}{c^2R}\right) \tag{17}$$

where w is radians and M(w) is the dipole moment (charge x length) given by:

$$M(w) = \frac{-2I_oV_o}{\gamma}\left[\frac{k}{jw} + \frac{1}{\beta(\beta+jw)} - \frac{1}{\alpha(\alpha+jw)} - \frac{(1/\alpha-1/\beta)}{\gamma+jw} + \frac{1/\alpha}{\gamma+\alpha+jw} - \frac{1/\beta}{\gamma+\beta+jw}\right] \tag{18}$$

The magnetic field variation versus frequency and range is shown in Figure A-3. The Bruce-Golde constants were substituted in the above equation. The constant k is found empirically to be $0.29/I_o$.

The manufacturer selects a low and high frequency to measure the magnetic fields. For example, at 1 kHz and 70.7 kHz the absolute value of the ratio of H(1 kHz)/H(70.7 kHz) at 100 nmi is equal to 1.163, at 50 nmi is 1.079 and at 10 nmi is .434. The range test signal model is selected by the manufacturer so that the ratio of the test signal (as measured by the equipment) at the two frequencies is displayed at the desired range.

In addition to the ratio of the magnetic fields, wide band systems can measure the ratio of the electric fields to the magnetic fields. The ratio of the magnetic to the electric fields using the above equations (16 & 17) is shown in Figure A-4.

Both the magnetic and electric field signals' amplitude ratio is varied to display the desired range.

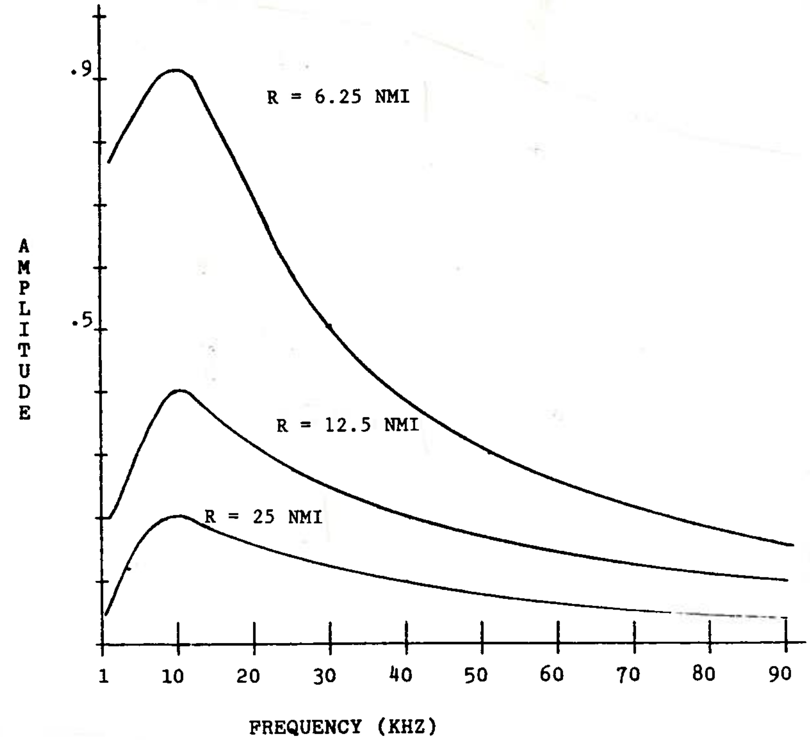


FIGURE A-3 H FIELD VARIATION VERSUS FREQUENCY

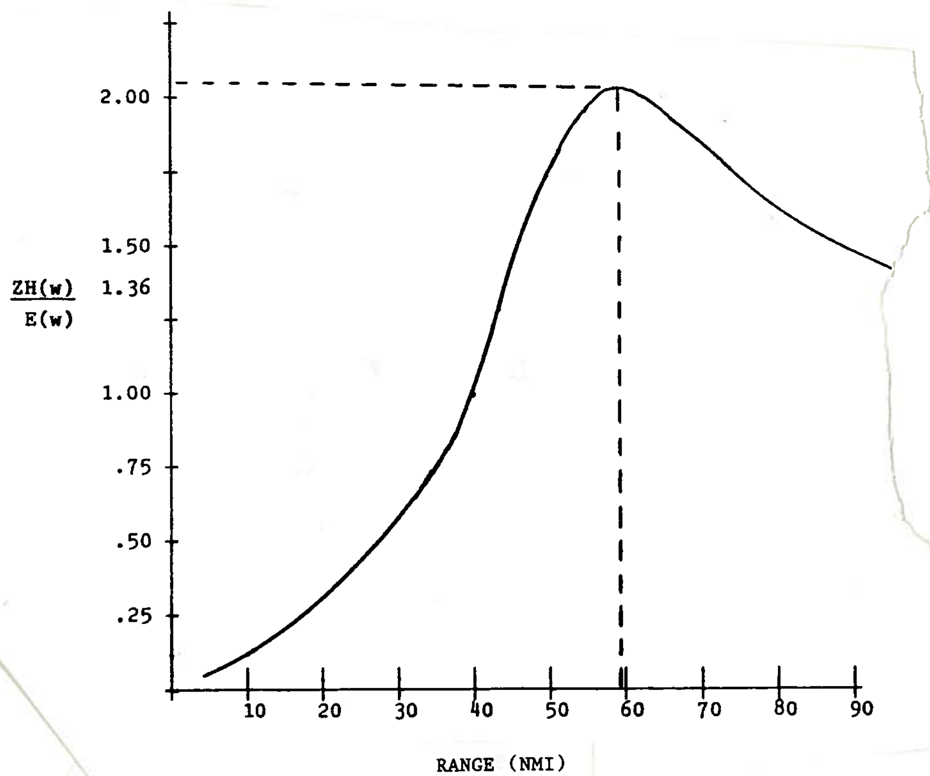


FIGURE A-4 ZH(w)/E(w) VERSUS DISTANCE AT 1 kHz

A P P E N D I X   B

BENCH AND INSTALLATION TESTING

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1.0 Introduction

This section describes typical test equipment used to test the airborne thunderstorm detection equipment.

1.1 Class I Equipment - (Narrow Band)

a. General Description of Test Set

A portable tester is to be used to aid in the system checkout, as well as for periodic operation checks of the system. The tester generates controlled electrical discharges via a transmitting loop attached to the system antenna. By adjusting the range and azimuth switches, a pattern may be placed in any of the applicable positions on the display screen. The range is calibrated in nautical miles and the azimuth is calibrated in 30-degree increments. By rotating the azimuth switch through the full 360 degrees and then turning the tester off, a circular pattern (semi-circular where applicable) can be displayed on the screen. In this way an accurate evaluation of the functioning condition of the system may be made. See Figure B-1 for a block diagram of the unit.

b. Operation of the Test Set

With the test set connected as shown in Figure B-2 the tester should be placed to permit viewing of the display. The system should be turned on and allowed to warm up for 30 seconds and the tester turned on by moving the range selector switch from the off position to the desired range.

Select the 100 nmi range on the tester and the 100 nmi range on the display. Rotate the azimuth knob to each heading and verify the proper range and azimuth on the display at each heading.

1.2 Class II Equipment - Wide Band

a. General Description of the Test Set

The test set for wide band operation is similar to the Class I tester; however, Class II systems require a more accurate representation of lightning. A waveform generator has been incorporated to generate the signals required by a wide band system. An option has been included to drive the transmission line (see Appendix C), with the same test unit. See Figure B-3 for a block diagram of the unit. Functional controls concerning azimuth and range are identical to that of the Class I tester.

b. Operation of the Test Set

(1) With the tester connected as shown in Figure B-4 the system should be turned on and allowed to warm up. Turn the tester on and select the range to be tested, both on the tester and on the display. Rotate the azimuth switch to each heading and verify the proper range and azimuth on the display at each bearing.

(2) When using the shielded room of Appendix C, connect the system as shown in Figure B-5. The system should be turned on. Select the range to be tested both on the display and on the test set. Rotate the antenna in 30-degree increments and switch ranges to verify the range and azimuth information given on the display.

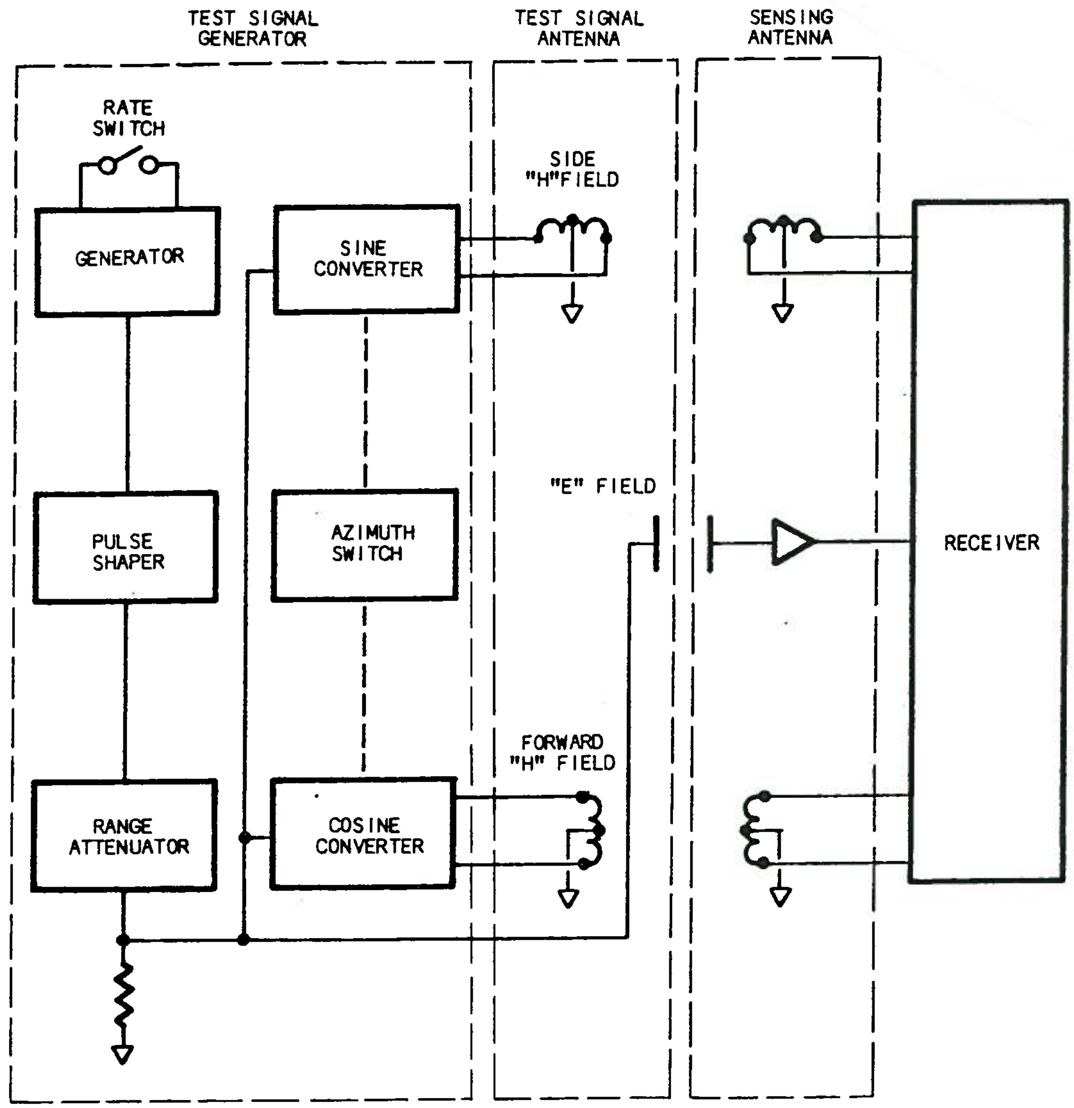

FIGURE B-1 BLOCK DIAGRAM OF NARROW BAND TEST SET

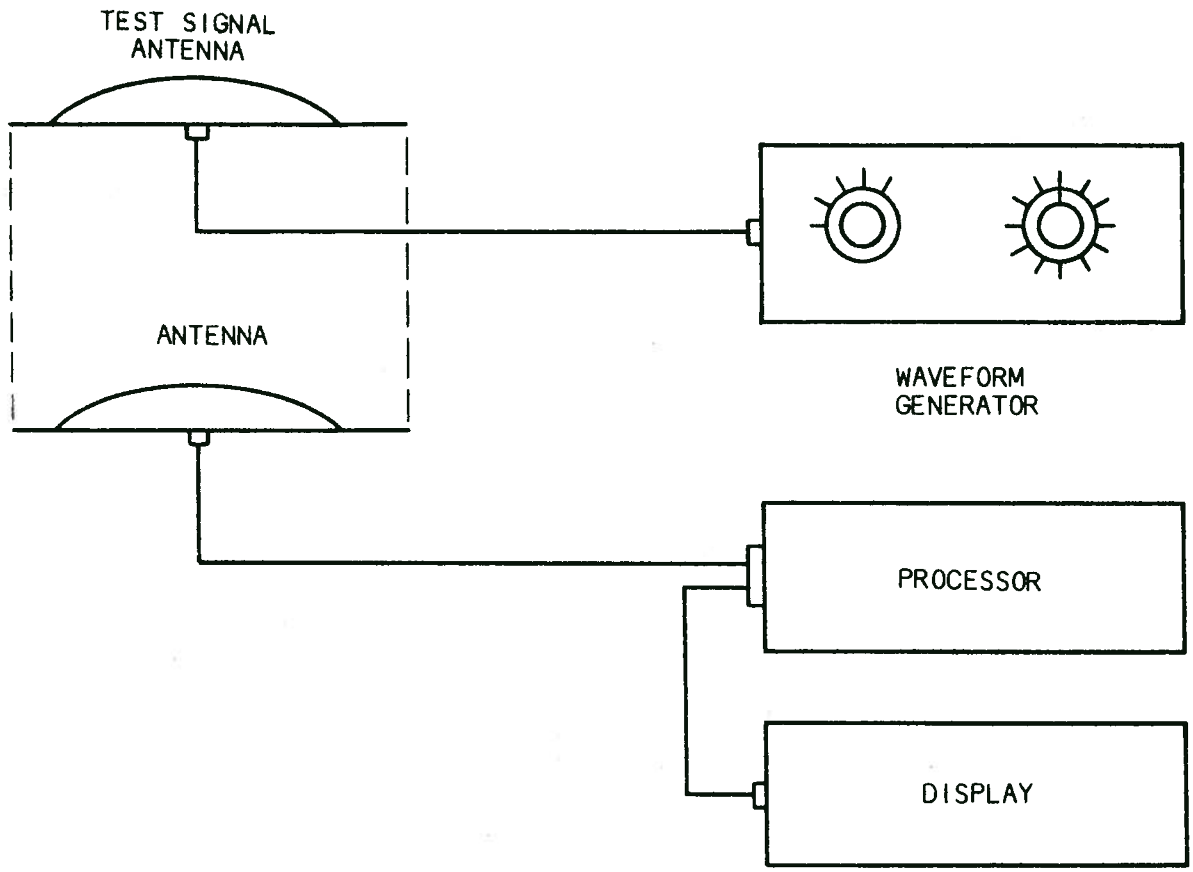

FIGURE B-2 TEST SET HOOK UP

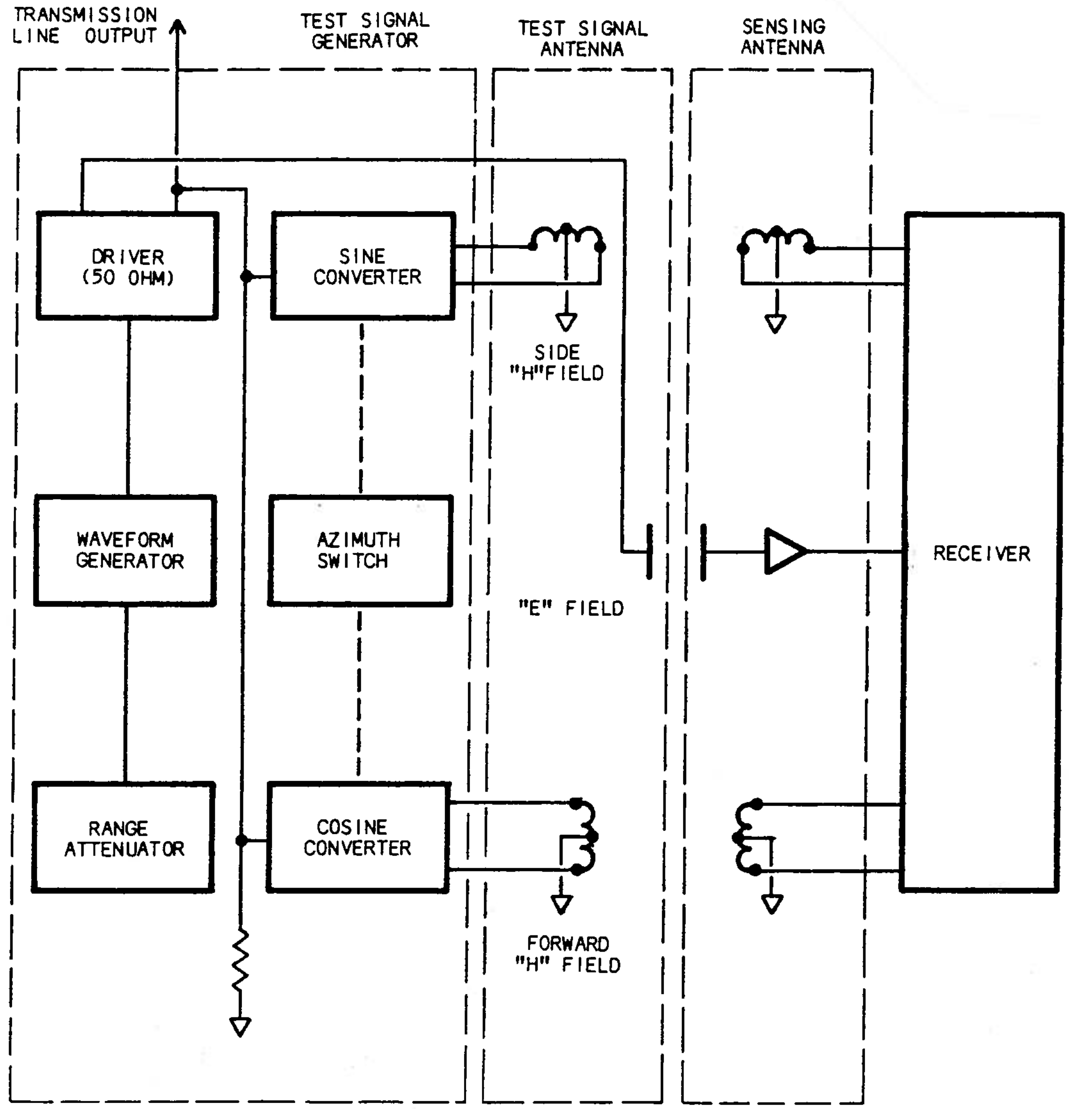

FIGURE B-3 BLOCK DIAGRAM OF WIDE BAND TEST SET

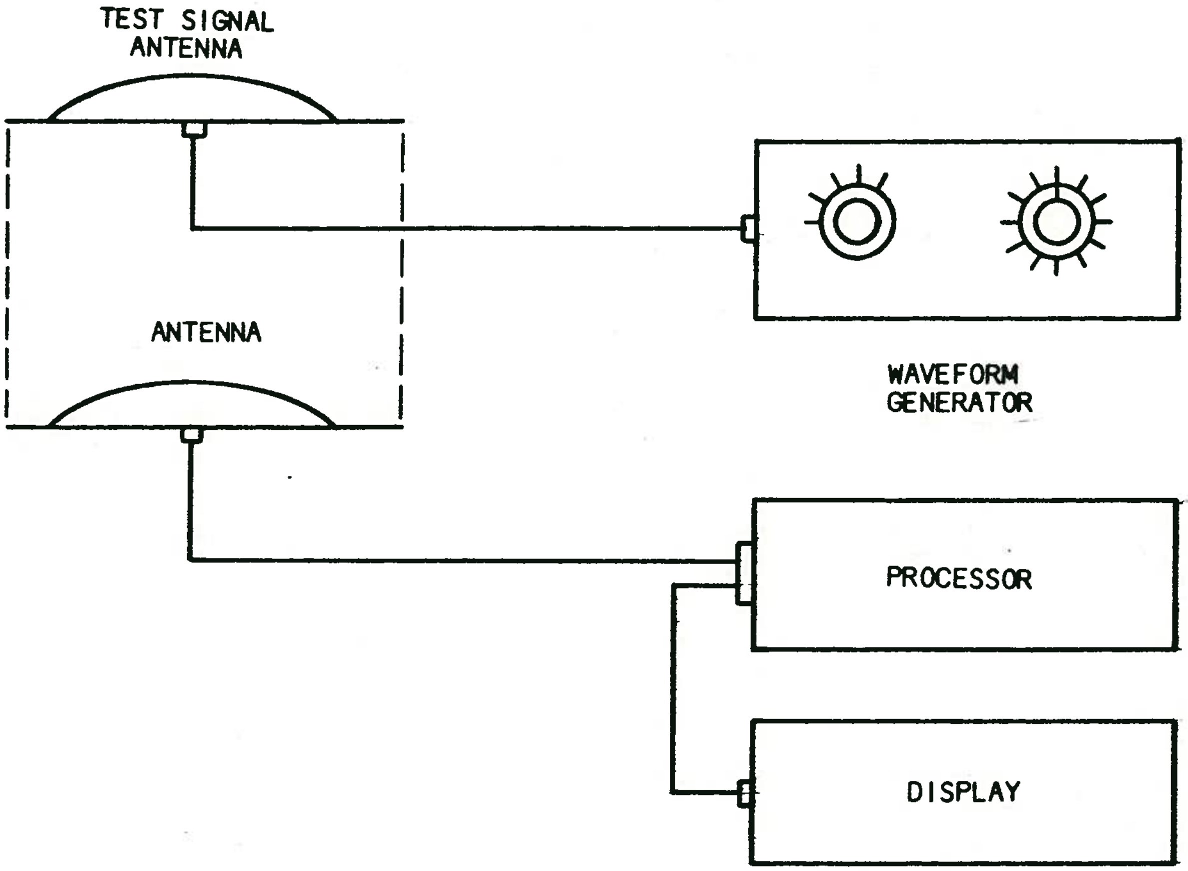

FIGURE B-4 TEST SET HOOK UP

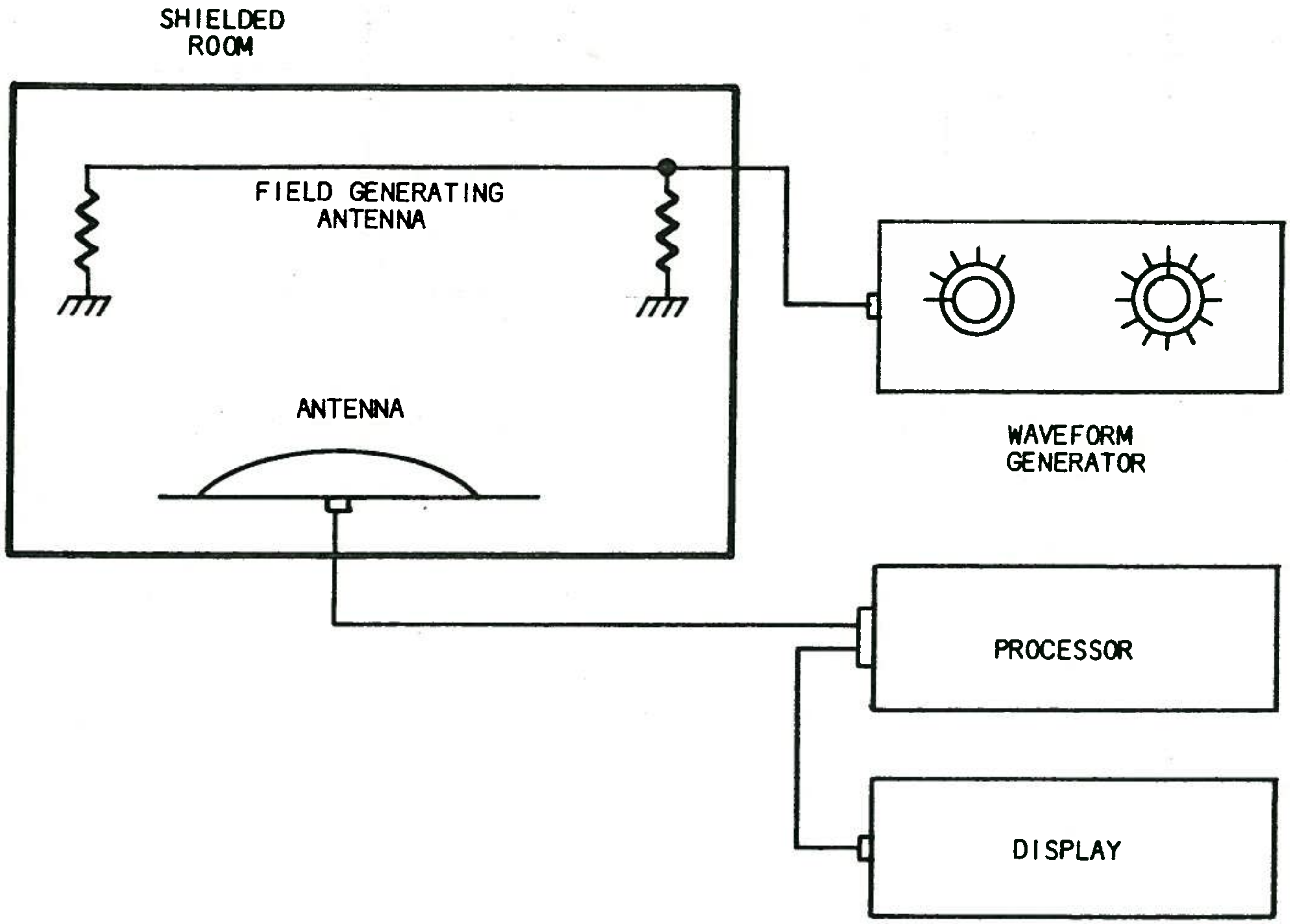

FIGURE B-5 TEST SET HOOK UP

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APPENDIX C

PRIMARY STANDARD CALIBRATION

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1.0 Introduction

This section describes a primary standard reference calibration procedure.

1.1 Primary Standard Calibration

a. Shielded Room

Prefabricated rooms can be purchased or the room can be constructed as shown in Figure C-1. Completely shield the room with sheet copper or copper screen and install a second shield, spaced approximately four inches from the first, if interference is severe. The shield(s) should be properly grounded and interconnected. Provision should be made to connect the door shielding to the room by providing shielding around the entire periphery of the door when it is closed. The power circuits should be brought into the room at the point of the ground connection and should be filtered to remove interference. All conduit within the room should be bonded to the shielding.

b. Test Transmission Line Construction

The test transmission line shall be parallel to and midway between the side walls of the room. The line shall be horizontal and shall extend to within four inches from the end walls of the room. The line shall be stretched tightly with strain insulators at each end.

Refer to Figure C-2. The loop shall be located directly below the center of the test transmission line. The distance d from the line to the ceiling and the distance x from the ceiling to the center of the loop may vary somewhat, depending on the height of the room. However, it is preferable that dimension d be not less than 12 inches and that dimension x be not more than 50 inches nor less than 24 inches for loops of average size.

Connect the test transmission line to the signal generator with a length of concentric line mounted in a vertical position.

c. Loop Stand

The loop must be mounted on a rotatable table so that its angular position can be accurately determined. Flush or low-silhouette loops should be mounted on a ground plane simulating the aircraft surface. A circular or square plate 18 to 30 inches across is satisfactory.

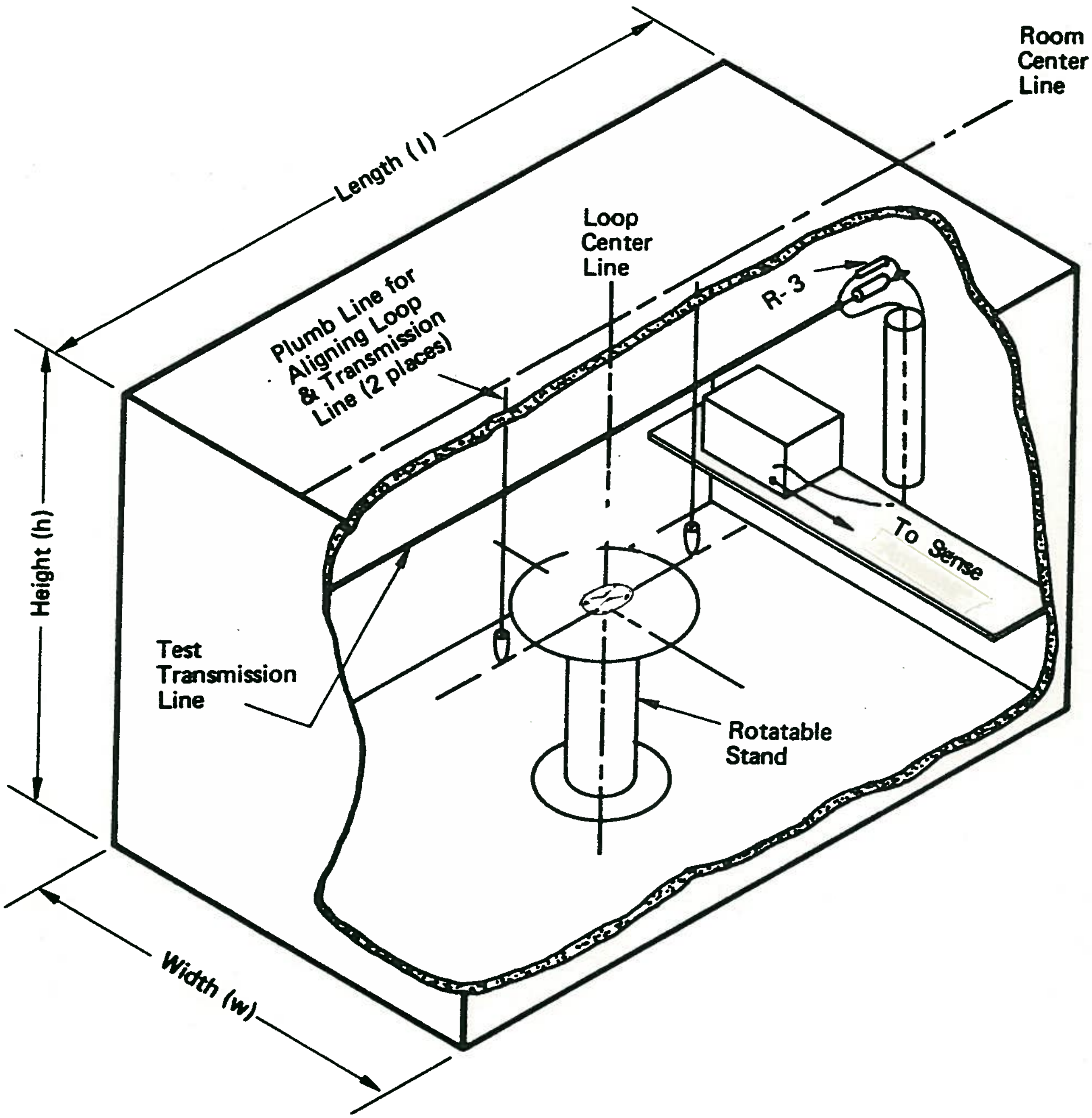

FIGURE C-1 SHIELDED ROOM

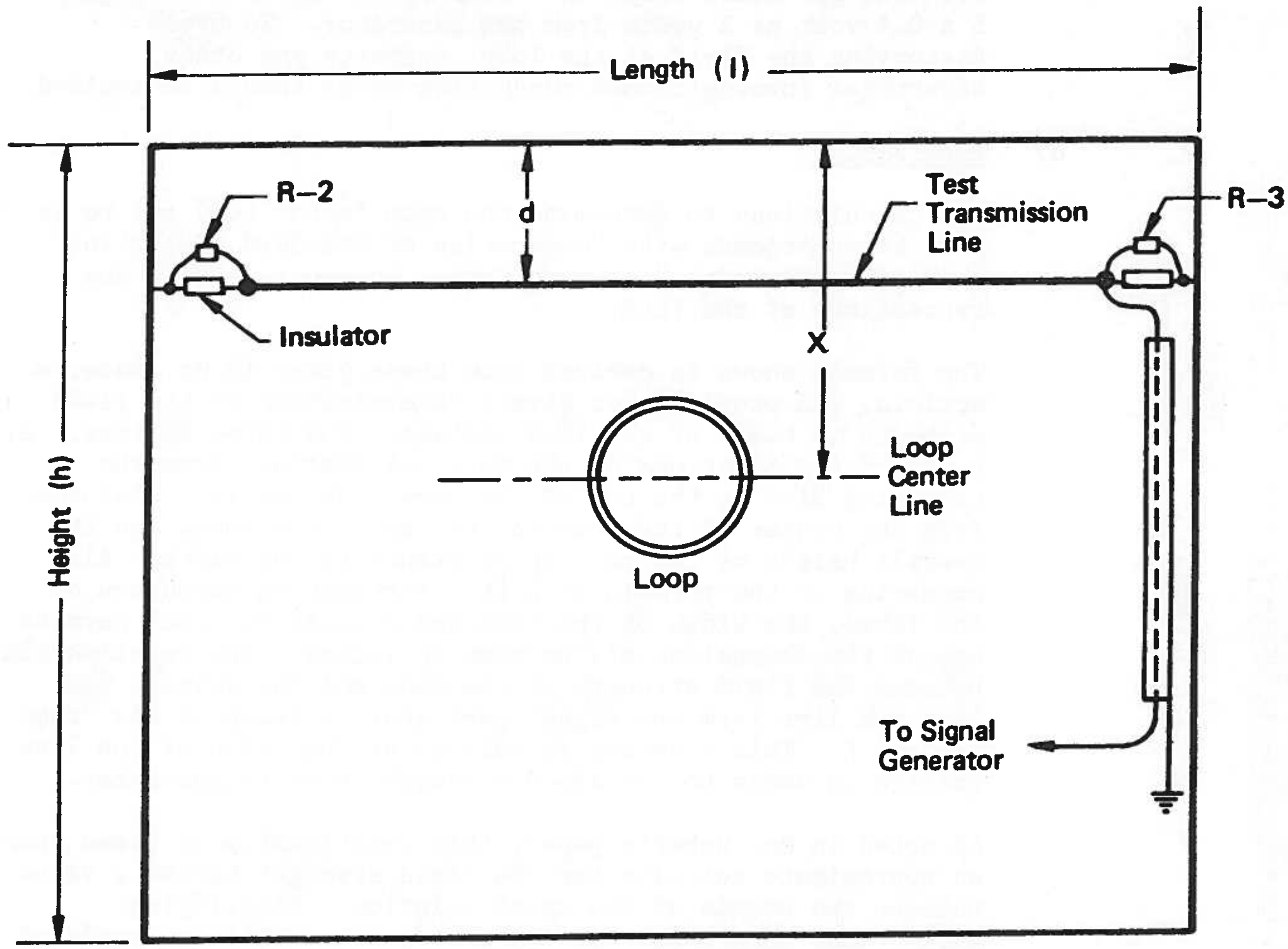

FIGURE C-2 SHIELDED ROOM (SIDE VIEW)

The spacing between the loop and the line is a compromise. The variation in the field strength over the loop becomes less as the distance between the loop and the line increases. However, the field strength decreases with distance from the line requiring more power from the signal generator. A 0.4 volt per meter field in a room whose factor is 5 requires 5 x 0.4 volt or 2 volts from the generator. To avoid distorting the field at the loop, supports and other structures forming closed conducting loops should be avoided.

d. Room Factor

The calculations to determine the room factor (Kd) are to be made in accordance with "Generation of Standard Fields in Shielded Enclosures," by Fred Haber, November 1954 of the Proceedings of the IEEE.

The formula shown is derived from those given in Mr. Haber's article, and provides for direct determination of the field strength in terms of the line voltage. The three factors, "a, b and c" are functions of the vertical distance from the radiating line to the top of the room, the vertical distance from the center of the loop to the top of the room, and the overall height of the room in reference to the width. Also appearing in the formula is Z (the terminating impedance on the line), the width of the room and a constant which permits use of the dimensions of the room in inches. The relationship between the field strength at the loop and the voltage fed into the line from the signal generator is known as the "room factor" K. This constant is defined as the ratio of the line voltage in volts to the field strength in volts per meter.

As noted in Mr. Haber's paper, this relationship is based upon an approximate solution for the field strength having a value between the bounds of the exact solution. Simplifying assumptions were made, but these will not result in errors of greater than 1% as long as the ratio of height to width of the room is one or greater. If the ratio of height to width is as small as 1/2, an error of up to 4% might be expected.

This relationship gives the field strength at a point directly below the radiating line, and spaced by the dimension X from the top of the room. If the loop is large compared to the distance from the center of the loop to the radiating line, a more accurate determination of the average field strength at the loop may be required.

Theoretically, the terminating resistance Z_L should be equal to the characteristics impedance of the line to prevent the formation of standing waves. However, as the dimensions of the average room are usually small compared to the wavelength,

APPENDIX D

INTERFERENCE SIGNAL IDENTIFICATION

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1.0 Introduction

This section indicates possible sources of interference signals and establishes criteria for interference testing.

The lightning discharges frequency spectrum is shown in Figure D-1 for a return stroke signal. Most of the lightning signal's energy is between 5 kHz and 800 kHz with the signal level decreasing at higher frequencies. Lightning detection systems which operate below 800 kHz will experience interfering signals from a few very high-powered stations such as that of Cutler, Maine in the U. S. with a radiated power of 1,000 kilowatts on frequency of 17.8 kHz. Other signals in this low frequency end of the spectrum are of lesser power. The greatest number of potentially interfering signals exists in the frequency range of 550 kHz to 1600 kHz (AM broadcast band), which can generate radiated peak power levels of 50 kW. There are also transmitters known to produce high peak transmit power via directional antennas operating well above the 2 MHz frequency range, but these signals are expected to cause insignificant interference. To establish interference test criteria, two potential interference bands are selected to be 10 kHz-550 kHz band and 550 kHz-1600 kHz (AM broadcast band). Interference in other bands is not expected to be objectionable. The 10 kHz-550 kHz band sources range in power up to 1,000 kilowatts. Although the number of stations with power over 80 kilowatts is limited (FCC Rules and Regulations, Part 81, 134), a test criteria of 100 kilowatts is selected for the 10 kHz-550 kHz band.

The designer may use the following equation to estimate the field strength of a station:

$$E = \frac{(K\ Pt)\ 1/2}{R} \qquad (1)$$

where:
- E is volts/meter (V/m)
- Pt is peak interfering transmitter radiated power in watts
- R is distance in meters from interfering transmitter (1,852 m/nmi)
- K is 30 for 10 kHz-550 kHz (ITT Reference Data for Radio Engineers Fifth Edition Pg. 25-7)

Using this equation, the interfering 100 kW station at a range of 5 nmi will produce a signal of 0.187 V/m which is a signal-to-noise ratio of 28.5 dB compared with a 5 V/m referenced test signal at a range of 100 nmi. Therefore, the test criteria for interference testing in the 10 kHz-550 kHz band is selected to be 0.187 V/m.

FCC Rules and Regulations, Part 73.182 Radio Broadcast Services, October, 1982 requires a Class I station to provide a signal strength of 225 mV/meter for 1 kW input at one statute mile (1610 m). A Class I station transmits 50 kW.

Solving for K of equation (1).

$$K = \frac{(RE)^2}{Pt} = \frac{(1610m \times .225 \text{ V/m})^2}{1000 \text{ watt}} = 131.3 \tag{2}$$

To find the field strength E for 50 kW at 5 nm use equation (1) with a K = 131.3.

$$E = \frac{(131.3 \times 50000 \text{ W})^{1/2}}{5 \text{ nm} \times 1852 \text{ m/nm}} = .277 \text{ V/m} \tag{3}$$

The test criteria for interference testing in the 550 kHz - 1600 kHz (AM broadcast band) is .277 V/m.

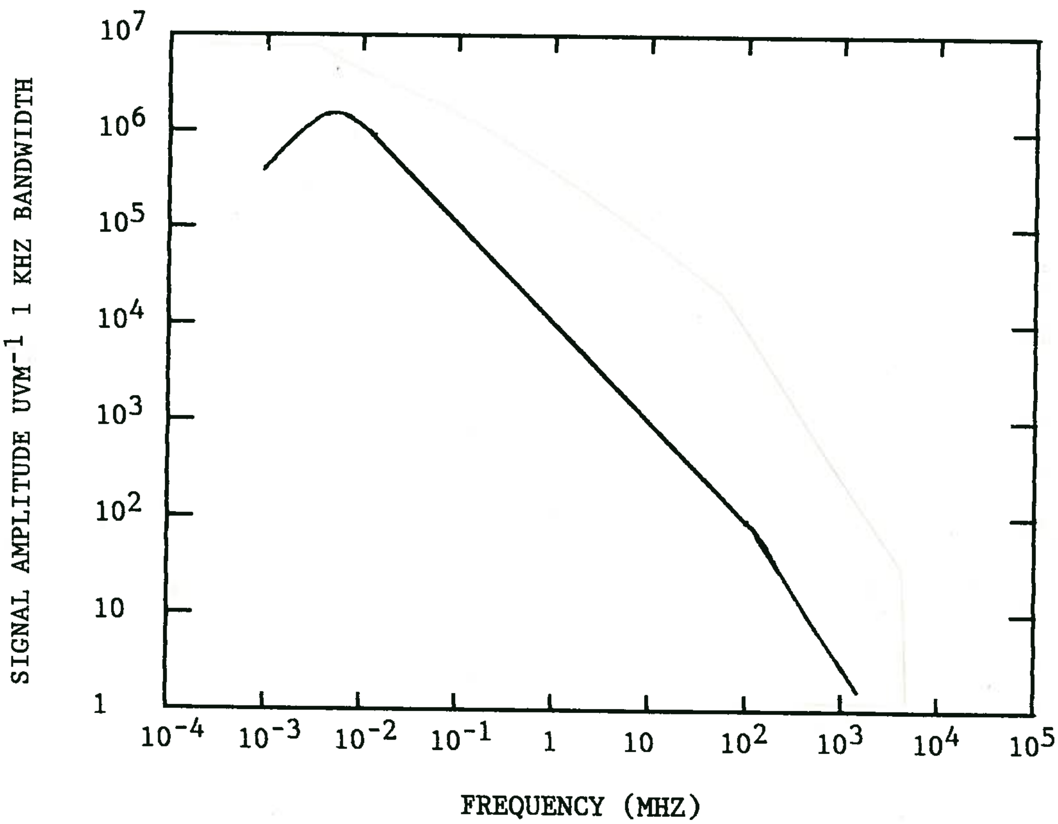

FIGURE D-1 SPECTRUM OF TOTAL LIGHTNING FLASH NORMALIZED TO A BANDWIDTH OF 1 KHZ AND DISTANCE OF 10 KM