



# National Institute of Justice

**Law Enforcement and Corrections Standards and Testing Program**

## **Fixed and Base Station Antennas**

**NIJ Standard-0204.02**

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The Law Enforcement and Corrections Standards and Testing Program is an applied research effort that determines the technological needs of justice system agencies, sets minimum performance standards for specific devices, tests commercially available equipment against those standards, and disseminates the standards and the test results to criminal justice agencies nationwide and internationally.

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## **Fixed and Base Station Antennas**

NIJ Standard-0204.02

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June 1998

## **National Institute of Justice**

Jeremy Travis  
Director

The technical effort to develop this standard was conducted under Interagency Agreement No. 94-IJ-R-004, Project No. 96-006.

This standard was formulated by the Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) under the direction of A. George Lieberman, Program Manager for Communications Systems, and Kathleen M. Higgins, Director of OLES. Revision of this standard was performed at the National Telecommunications and Information Administration, Institute for Telecommunications Sciences by John M. Vanderau and William A. Kissick. The preparation of this standard was sponsored by the National Institute of Justice, David G. Boyd, Director, Office of Science and Technology.

## FOREWORD

This document, NIJ Standard-0204.02, Fixed and Base Station Antennas, is an equipment standard developed by the Office of Law Enforcement Standards at the National Institute of Standards and Technology. It is produced as part of the Technology Assessment Program of the National Institute of Justice.

This standard is a technical document that specifies the performance parameters and other requirements that equipment should meet in order to satisfy the needs of the criminal justice agencies for high quality service. Purchasers can use the test methods described herein to determine whether a particular item of equipment meets the essential requirements, or they may have the tests conducted in their behalf by a qualified testing agency. Procurement officials may also refer to this standard in their purchasing documents and require that equipment offered for purchase meet these requirements. Compliance with the requirements of the standard may be attested to by the procuring agency, an independent laboratory, or guaranteed by the vendor.

Because this NIJ standard is designed as a procurement aid, it is necessarily technical in nature, however, every effort has been made to present the material herein as clearly and concisely as possible with a minimum of technical jargon. For those who seek general guidance concerning the selection and application of law enforcement equipment, user guides have also been developed and published. The guides explain in nontechnical language how to select equipment for a particular application.

NIJ standards are subjected to continuing review. Technical comments and recommended revisions are welcome. Please send suggestions to the Program Manager for Standards, National Institute of Justice, U.S. Department of Justice, Washington, DC 20531.

Before citing this or any other NIJ standard in a contractual document, users should verify that the most recent edition is being used. Write to: Director, Office of Law Enforcement Standards, National Institute of Standards and Technology, Gaithersburg, MD 20899-0001.

David G. Boyd, Director  
Office of Science and Technology  
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# NIJ STANDARD FOR FIXED AND BASE STATION ANTENNAS

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## COMMONLY USED SYMBOLS AND ABBREVIATIONS

A	ampere	H	henry	nm	nanometer
ac	alternating current	h	hour	No.	number
AM	amplitude modulation	hf	high frequency	o.d.	outside diameter
cd	candela	Hz	hertz (c/s)	$\Omega$	ohm
cm	centimeter	i.d.	inside diameter	p.	page
CP	chemically pure	in	inch	Pa	pascal
c/s	cycle per second	ir	infrared	pe	probable error
d	day	J	joule	pp.	pages
dB	decibel	L	lambert	ppm	part per million
dc	direct current	L	liter	qt	quart
$^{\circ}\text{C}$	degree Celsius	lb	pound	rad	radian
$^{\circ}\text{F}$	degree Fahrenheit	lbf	pound-force	rf	radio frequency
diam	diameter	lbf·in	pound-force inch	rh	relative humidity
emf	electromotive force	lm	lumen	s	second
eq	equation	ln	logarithm (natural)	SD	standard deviation
F	farad	log	logarithm (common)	sec.	section
fc	footcandle	<i>M</i>	molar	SWR	standing wave ratio
fig.	figure	m	meter	uhf	ultrahigh frequency
FM	frequency modulation	min	minute	uv	ultraviolet
ft	foot	mm	millimeter	V	volt
ft/s	foot per second	mph	mile per hour	vhf	very high frequency
<i>g</i>	acceleration	m/s	meter per second	W	watt
g	gram	N	newton	$\lambda$	wavelength
gr	grain	N·m	newton meter	wt	weight

area=unit<sup>2</sup> (e.g., ft<sup>2</sup>, in<sup>2</sup>, etc.); volume=unit<sup>3</sup> (e.g., ft<sup>3</sup>, m<sup>3</sup>, etc.)

### PREFIXES

d	deci (10 <sup>-1</sup> )	da	deka (10)
c	centi (10 <sup>-2</sup> )	h	hecto (10 <sup>2</sup> )
m	milli (10 <sup>-3</sup> )	k	kilo (10 <sup>3</sup> )
$\mu$	micro (10 <sup>-6</sup> )	M	mega (10 <sup>6</sup> )
n	nano (10 <sup>-9</sup> )	G	giga (10 <sup>9</sup> )
p	pico (10 <sup>-12</sup> )	T	tera (10 <sup>12</sup> )

### COMMON CONVERSIONS

(See ASTM E380)

ft/s × 0.3048000 = m/s	lb × 0.4535924 = kg
ft × 0.3048 = m	lbf × 4.448222 = N
ft·lbf × 1.355818 = J	lbf/ft × 14.59390 = N/m
gr × 0.06479891 = g	lbf·in × 0.1129848 = N·m
in × 2.54 = cm	lbf/in <sup>2</sup> × 6894.757 = Pa
kWh × 3 600 000 = J	mph × 1.609344 = km/h
	qt × 0.9463529 = L

$$\text{Temperature: } (T_{\text{F}} - 32) \times 5/9 = T_{\text{C}}$$

$$\text{Temperature: } (T_{\text{C}} \times 9/5) + 32 = T_{\text{F}}$$

# NIJ STANDARD FOR FIXED AND BASE STATION ANTENNAS

## 1. PURPOSE AND SCOPE

The purpose of this document is to establish minimum performance requirements and methods of test for antennas that are used at base stations or other fixed sites by law enforcement agencies. Whereas the antennas under test must meet all the electrical and radiation performance specifications cited in this document at ambient conditions, the environmental performance specifications stated herein should be selectively applied according to the anticipated operating environment of the antenna. That is, the antenna need only comply with those environmental specifications not waived by the procuring agency. This standard is a revision of NIJ Standard-0204.01, dated December 1981 [1]\*. This revision incorporates the latest recommended methods and procedures of industry standards related to communications antennas and environmental test procedures.

## 2. FREQUENCY BANDS

The “land mobile service” is the formal title of the type of radio service used by law enforcement agencies for their radio communications. The radio spectrum bands reserved for use by law enforcement agencies are labeled for “public safety” use. Land mobile service is defined as “a mobile radio service between base stations and land mobile stations, or between land mobile stations” by the NTIA Manual of Regulations and Procedures [2]. Another, commonly-used phrase for land mobile service is “land mobile radio.” The four land mobile radio frequency bands used in the United States are described below.

### 2.1 VHF Low-Band

This band is located at 25 to 50 MHz and generally uses channels 20 kHz wide.

### 2.2 VHF High-Band

This band is located at 150 to 174 MHz and uses channels 30 kHz wide. Adjacent channels may be separated by 15 kHz for geographically separated systems.

### 2.3 UHF Bands

This band is divided into two parts. The first part is located at 450 to 470 MHz. The second part, from 470 to 512 MHz, shares spectrum with UHF television channels 14 through 20 in a few major urban areas. Channels are 25 kHz wide.

### 2.4 800/900-MHz Bands

The portion of the radio spectrum, from 806 to 940 MHz, is apportioned among many services, including cellular telephone, paging, nonpublic safety, and conventional and trunked public safety. Channels for public safety are reserved in blocks of channels, generally 25 kHz wide, in several locations within this portion of the radio spectrum.

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\*Numbers in brackets refer to references in Appendix A.



### 3. DEFINITIONS

The principal terms used in this document are defined in this section. These terms comply with accepted industry definitions specified in ANSI/IEEE STD 145-1993, IEEE Standard Definitions of Terms for Antennas [3]. Other terms are defined within this section and EIA/TIA-329B, Minimum Standards for Communications Antennas, Part I—Base Station Antennas [4].

#### 3.1 Ambient Conditions

Ambient conditions of temperature and humidity are defined as any combination of prevailing weather conditions of temperature between 13 to 35 °C (55 to 95 °F) and relative humidity between 25 to 85 percent.

#### 3.2 Dipole Antenna, Resonant Half-Wavelength

A straight metallic radiator, usually energized at its center, whose length is slightly less than one-half wavelength<sup>1</sup> of the energizing signal and whose diameter is small compared to its length. The current goes to zero at the ends of the antenna. The maximum radiation intensity lies in the plane passing through the center of the antenna and normal to its axis.

#### 3.3 Effective Antenna Volume

The effective antenna volume is the actual volume occupied by the radiating part of the antenna plus one-half wavelength all the way around.

#### 3.4 Gain

In a given direction, the ratio of the radiated power density to the power density that would be obtained if the power delivered to the antenna were radiated isotropically (see also Sec. 3.14 below).

#### 3.5 Isotropic Radiator

A hypothetical antenna that radiates or receives equally in all directions.

#### 3.6 Main Lobe (Major Lobe)

The radiation lobe that contains the direction of maximum gain.

#### 3.7 Pattern Recorder

A device that records the amplitude of the output signal from an antenna and receiver and displays the amplitude as a function of the direction relative to the antenna. This device may collect and store tabular data or graphics information originating from a network analyzer or similar radio frequency (rf) measurement device, and be capable of graphically plotting or displaying measured data or presenting the data in tabular format.

#### 3.8 Polarization

In a given direction from the antenna, the orientation of the electric field vector of the wave radiated from the antenna, or the orientation of the electric field vector of the wave incident upon the antenna which produces the maximum voltage at the antenna terminals.

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<sup>1</sup> Dipole antennas in free space which are exactly one-half wavelength long exhibit an impedance which has an inductive component and is represented by a complex number  $73.1 + j42.5 \Omega$ ; the imaginary part of the complex number indicates the inductive effects. The reactance of the antenna depends on the length and diameter (in wavelengths) of the antenna in a complicated fashion involving sine integral functions and cosine integral functions. By shortening the antenna slightly, the inductive component can be made equal to zero. When there is no inductive or capacitive component of impedance, then the antenna is said to be resonant. Shortening the antenna from one-half wavelength to bring it into resonance also lowers the radiation resistance from  $73 \Omega$  to a value of about  $58 \Omega$ ; this further improves the impedance match and VSWR between the antenna and the  $50 \Omega$  (nominal) coaxial cable transmission line.

### 3.9 Power Rating

The maximum continuous-wave power that can be endlessly applied to an antenna without degrading its performance.

### 3.10 Quiet Zone

That region of an antenna test range illuminated by an electromagnetic wave from the source antenna where the amplitude taper (ripple) is less than 0.25 dB and phase taper (ripple) is less than 22.5°. The quiet zone must totally enclose the effective antenna volume of the antenna under test.

### 3.11 Radiation Pattern (Antenna Pattern)

A complete radiation pattern (or antenna pattern) is a representation of the magnitude of the electric (or magnetic) field strength (or the power density) as a function of direction.<sup>2</sup> The pattern is generally displayed in a spherical coordinate system ( $r$ ,  $\theta$ ,  $\phi$ ), with the antenna located at the center (radial distance  $r = 0$ ). The shape of the pattern is independent of  $r$  for  $r$  sufficiently large (much greater than a wavelength and much greater than the largest dimension of the antenna). Often, only the relative field strength (or power density) is given and it is normalized to unity (0 dB) in the direction of the main lobe (maximum gain).

#### 3.11.1 Radiation Pattern Planes (Cuts)

The three-dimensional information of a radiation pattern cannot be easily displayed or used; therefore, only cross-sections (or pattern “cuts”) of the pattern in planes of interest are usually presented. The planes of greatest interest are the horizontal plane ( $\theta = 90^\circ$ ) and the vertical planes ( $\phi = \text{constant}$ ), with the antenna usually oriented so that the main lobe gain is at  $\theta = 90$  and  $\phi = 0^\circ$ . These are called the horizontal pattern and the vertical patterns, respectively.

### 3.12 Relative Antenna Gain

The ratio of the power received by the antenna under test to that of a reference antenna in the same direction, with the same incident power density, frequency, and polarization.

### 3.13 Scale Ratio ( $R$ )

The ratio of operating frequency of a scale model antenna to the operating frequency of the full size antenna.

### 3.14 Standard Gain Units

The reference units used to measure relative antenna gain. The reference units are usually either decibels relative to an isotropic antenna (dBi) or decibels relative to a lossless resonant half-wavelength dipole antenna (dBd). Gain expressed in dBi is related to gain expressed in dBd as follows:

$$G_{\text{dBi}} = G_{\text{dBd}} + 2.15 \quad (1)$$

### 3.15 Standing Wave Ratio (SWR) or Voltage Standing Wave Ratio (VSWR)

The ratio of maximum to minimum rf voltage (or current) appearing along a transmission line. This quantity indicates how well energy is coupled into an antenna. When the VSWR = 1, all of the energy is transferred to the antenna and none is reflected.

### 3.16 Wind Load Rating

The maximum wind load that an antenna system or assembly (including supporting structure) can withstand without physical damage or degradation to electrical or radiation performance.

<sup>2</sup> This statement implies that the antenna is used for transmitting. If the antenna does not contain active elements or nonlinear devices (e.g., ferrites) then it is reciprocal. In this case, its characteristics (e.g., antenna gain and pattern) are the same whether it is used for transmitting or receiving. An alternative statement for a receiving antenna is: The complete radiation pattern is a representation of the magnitude of the voltage induced at the antenna terminals as a function of direction of arrival of an incident plane electromagnetic wave of a give polarization.

## 4. REQUIREMENTS

### 4.1 Minimum Performance

The antenna shall meet or exceed all of the requirements of this standard as given below and summarized in Table 4.1-1. These performance requirements meet or exceed those specified in TIA/EIA STD 329-B [4].

TABLE 4.1-1. *Minimum performance standards for fixed and base station antennas.*

<i>Antenna Characteristic</i>	<i>Minimum Requirement</i>
Rated Power Output	No physical damage
Radiation Pattern	$\pm 1.5$ dB of the gain specified in the main lobe, $\pm 5$ dB of the gain in minor lobes
(Voltage) Standing Wave Ratio	1.5 or less for all frequencies of intended operation
Wind Load Rating	1.65 times the values specified in TIA/EIA-222F Chapter 16 [5], or comply with local building code regulations, whichever is more stringent

### 4.2 User Information

The following information shall be supplied to the purchaser by the antenna manufacturer, system integrator, or distributor, and shall include the following:

- (a) Operating frequency range
- (b) Power rating
- (c) Relative antenna gain in standard gain units over frequency range of intended use
- (d) Polarization
- (e) Vertical (elevation plane) radiation pattern
- (f) Horizontal (azimuthal plane) radiation pattern
- (g) Nominal impedance
- (h) Voltage standing wave ratio over frequency range of intended use
- (i) Connector type
- (j) Wind load rating (ice load rating if applicable)
- (k) Physical dimensions
- (l) Weight
- (m) Material composition
- (n) Operating, installation, and maintenance instructions
- (o) Rf radiation hazard zone at full rated power
- (p) Certification of compliance with this standard

### 4.3 User Information

Fixed and base station antennas shall be capable of withstanding the physical environment of the climatic regions in which they exist, as defined in MIL STD 210C [6]. Test methods described in MIL STD 810E [7] shall be employed by the manufacturer on representative sample lots to assure compliance with the following requirements. The applicable environmental tests performed and required performance parameters are influenced by the environment in which the candidate antenna system is to be deployed. Whereas the antennas under test must meet all the electrical and radiation performance specifications cited in this document at ambient conditions, the environmental performance specifications stated herein should be selectively applied according to the anticipated operating environment of the antenna. That is, the antenna need only comply with those environmental specifications not waived by the procuring agency.

#### 4.3.1 Wind Load Rating

Antennas shall be capable of withstanding repeated and sustained wind loads, at a factor of 1.65 times larger than those specified in Chapter 16 of TIA/EIA-222F [5], without degradation of electrical performance or structural integrity. Ice loading requirements of Section 4.3.8 may apply. Antenna structures and tower designs, including

payload, shall be certified by a professional civil engineer to withstand the stated wind loads and shall conform to all local building codes.

### 4.3.2 High Temperature/Solar Radiation

Antennas shall withstand sustained ambient temperatures as specified in table 4.3.2-1 as determined in accordance with Section 5.5.2.

TABLE 4.3.2-1. *High temperature/solar radiation performance requirements.*

<i>Region</i>	<i>Temperature</i>	<i>Solar Radiation</i>
CONUS, AK, HI, US territories except southwestern United States	43 °C (110 °F)	1120 W/m <sup>2</sup>
Southwestern United States	49 °C (120 °F)	1120 W/m <sup>2</sup>

### 4.3.3 Low Temperature

Antennas shall withstand sustained ambient temperatures as specified in table 4.3.3-1 as determined in accordance with Section 5.5.3.

TABLE 4.3.3-1. *Low temperature performance requirements.*

<i>Region</i>	<i>Temperature</i>
CONUS, HI, US territories and southern coastal regions of Alaska	-32 °C (-25 °F)
Southwestern inland regions of Alaska	-46 °C (-50 °F)
Northeastern and Central Alaska	-51 °C (-60 °F)

### 4.3.4 Blowing Rain

Electrical performance and structural integrity of antennas can be compromised by the penetration of rain into housings, connectors, radomes, matching networks, and other antenna system components, with consequent freezing, corrosion, and other adverse effects. Antennas, antenna systems, and related components shall be resistant to moisture penetration when subjected to the rainfall rates and wind velocity specified in table 4.3.4-1 as determined in accordance with Section 5.5.4.

TABLE 4.3.4-1. *Rainfall performance requirements.*

<i>Duration</i>	<i>Rainfall Rate</i>	<i>Ambient Temperature</i>	<i>Wind Velocity</i>
1 h	15 cm/h (5.9 in/h)	24 °C (75 °F)	64.8 km/h (35 knots)

### 4.3.5 Humidity

Detrimental effects induced by high humidity environments may manifest themselves in various ways, for example, the oxidation of metals, electrical shorts due to condensation, and degradation of electrical properties in insulating materials. Antennas, antenna systems, and related components shall be capable of withstanding repeated sustained relative humidities of 100 percent at the high and low temperature extremes cited in Sections 4.3.2 and 4.3.3 without degradation of electrical performance or structural integrity as determined in accordance with Section 5.5.5.

#### **4.3.6 Salt Fog**

Antenna systems located in coastal areas are subject to the corrosive effects of salt air, resulting in the oxidation of metals, electrical shorts due to condensation, and degradation of electrical properties in insulating materials. Antennas, antenna systems, and related components shall be capable of withstanding repeated sustained exposure to salt fog environments as determined in accordance with Section 5.5.6.

#### **4.3.7 Sand and Dust**

Penetration and accumulation of sand, dust, or blowing snow particles into connectors, seals, housings, etc., can result in abrasion of electrical connections, failure of insulators, intermittent short circuits, etc. These effects can be detrimental to the desired and necessary electrical and radiation performance of antenna systems. Antennas, antenna systems, and related components shall be capable of withstanding the effects of repeated exposure to sand, dust, and blowing snow as determined in accordance with Section 5.5.7.

#### **4.3.8 Icing/Freezing Rain**

Icing and freezing rain greatly increases the structural weight and wind loads while adding no structural integrity to the antenna or tower. Antenna systems and their supporting structures located in areas prone to ice build-up such as the New England states, mid-Atlantic states, northern mid-west and northwest states, shall be certified by a professional civil engineer as capable of withstanding 19 mm (3/4 in) thick ice glaze when subjected to the wind load specified in Section 4.3.1.

### **4.4 Antenna Power Rating**

The antenna shall meet the requirements of Sections 4.5 through 4.7 as determined by the tests described in Section 5.4.

### **4.5 Radiation Pattern**

#### **4.5.1 Vertical Plane (Elevation) Pattern**

The gain for all angles of the vertical radiation pattern, measured in accordance with Section 5.4.3, shall be within  $\pm 1.5$  dB for the main lobe and  $\pm 5$  dB for the minor lobes of the gain specified by the manufacturer in accordance with Section 4.2.e.

#### **4.5.2 Horizontal Plane (Azimuthal) Pattern**

The gain for all angles of the horizontal radiation pattern, measured in accordance with Section 5.4.3, shall be within  $\pm 1.5$  dB for the main lobe and  $\pm 5$  dB for the minor lobes of the gain specified by the manufacturer in accordance with Section 4.2.f. For omnidirectional antennas, the horizontal plane radiation pattern shall be within  $\pm 1.5$  dB throughout the full (360°) range in azimuth.

### **4.6 Voltage Standing Wave Ratio**

The VSWR of the antenna, measured in accordance with Section 5.7, shall be 1.5 or less, referenced to a 50  $\Omega$  system.

### **4.7 Radiation Hazard**

Radiation hazard zones shall be identified by measurements performed in conformance with the provisions of ANSI/IEEE C95.3-1991 [8]. Radiation hazard zones are those volumes of space surrounding the antenna where the electromagnetic power density and/or field strengths exceed the industry recognized limits of ANSI/IEEE C95.1-1991 [9]. The radiation hazard zone shall be determined when transmitting at the antenna's full power rating. For single radiating frequencies, permissible limits of exposure are 1 mW/cm<sup>2</sup> for VHF high-band antennas and ranging from about 1.4 mW/cm<sup>2</sup> to about 3.5 mW/cm<sup>2</sup> for UHF and 800/900 MHz antennas. For VHF low-band antennas,

permissible limits of exposure are expressed in field strength rather than power density, and range from about 61.4 V/m to about 80 V/m electric field strength. For multiple frequencies radiating simultaneously, the contribution from each must be derated appropriately in accordance with the provisions of ANSI/IEEE C95.1-1991 [9].

Radiation hazard is not considered an “environmental” specification in the spirit of Section 4.3 and consequently cannot be selectively applied or waived as can individual environmental specifications in that section. Determination of radiation hazard zones is mandatory. Refer to ANSI/IEEE Standard C95.1-1991 [9] for recognized exposure levels and detailed test procedures.

## **5. TEST METHODS**

### **5.1 Standard Test Conditions**

Unless otherwise specified, perform all electrical and radiation performance measurements at the standard test frequencies under standard test conditions and ambient environmental conditions. Allow all measurement equipment to warm up to achieve sufficient measurement stability to perform accurate and repeatable measurements.

#### **5.1.1 Standard Test Frequencies**

The standard test frequencies shall be three frequencies, one in the 0 to 10<sup>th</sup> percentile, one in the 45<sup>th</sup> to 55<sup>th</sup> percentile, and one in the 90<sup>th</sup> to 100<sup>th</sup> percentile of the operating frequency range. Standard test frequencies for multi-band antennas (e.g., 150 MHz/450 MHz) shall consist of standard test frequencies for each frequency band.

#### **5.1.2 Standard Radiation Test Site**

A standard radiation test site shall be used to measure relative gain and radiation patterns. The standard radiation test site shall conform to the accepted industry standards and design principles stated in ANSI/IEEE STD 149-1979 (R1990) Section 4 [10] and FCC Report and Order 96-326 [11].

Outdoor ranges shall be free of large reflecting (especially metallic) objects, trees, electric/telephone poles and overhead wires, fences, buried wires or pipes, buildings, or other objects which could perturb the illuminating line-of-sight electromagnetic field for a minimum of 50 wavelengths or 100 m (328 ft), whichever is greater, from source and test antenna. Buried utility lines or control cables should be at least 0.3 m (1 ft) beneath the surface. In most cases, the ground should be level and exhibit uniform conductivity and permittivity characteristics. An exception to this policy is in the case of an elevated range over irregular terrain [10] where the source and test antennas are affixed to support structures located on adjacent mountain peaks or hilltops. For such ranges, however, additional design considerations are necessary to ensure that any points of specular reflection are sufficiently suppressed so as not to distort the illuminating line-of-sight electromagnetic field.

In any case, the amplitude and phase tapers of the wavefront illuminating the test antenna must be less than 0.25 dB and 22.5° throughout the effective antenna volume of the antenna under test. Measured field probe data of the test range shall be available to show compliance with these constraints. Site power delay profiles shall exhibit no multipath components. For all types of outdoor ranges, the ambient rf noise levels should be carefully monitored to ensure that they are at least 14 dB lower than the amplitude of the minimum measured signal strength.

Indoor ranges (anechoic chambers) are suitable for higher frequency measurements, typically to as low as 800 MHz, depending on the physical size of the chamber. Several different chamber designs are typical: rectangular, tapered, and compact range. Design characteristics of these indoor ranges are summarized in ANSI/IEEE 149-1979 (R1990), Section 4.5.4 [10].

#### **5.1.3 Standard Test Range**

Outdoor test ranges may be of the following types: elevated range over flat surface, elevated range over irregular terrain, elevated range with diffraction fences, ground reflection range, slant range, or compact range. Indoor test ranges may be of the following types: rectangular, tapered, pyramidal, and may incorporate compact range design features. Figures 5.1.3.1 through 5.1.3.9 depict these various types of ranges.

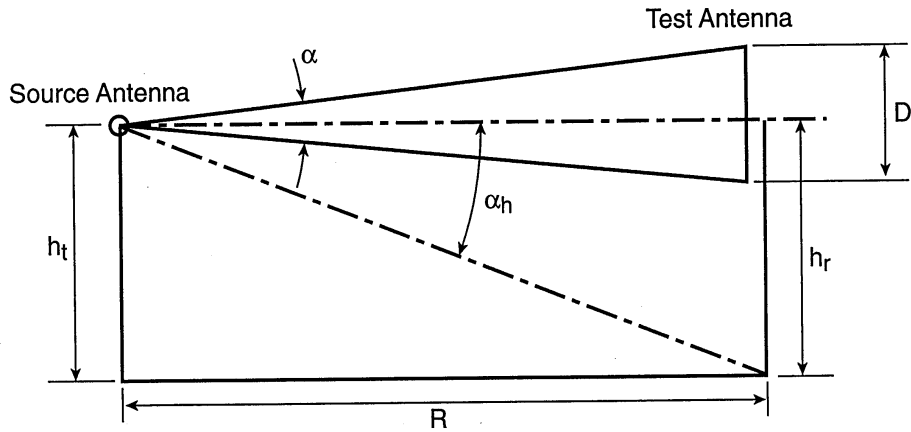


FIGURE 5.1.3.1. *Elevated range over flat surface, reprinted from IEEE Std 149-1979 (R1990) Copyright© 1979, IEEE<sup>3</sup>. All rights reserved. Used with permission.*

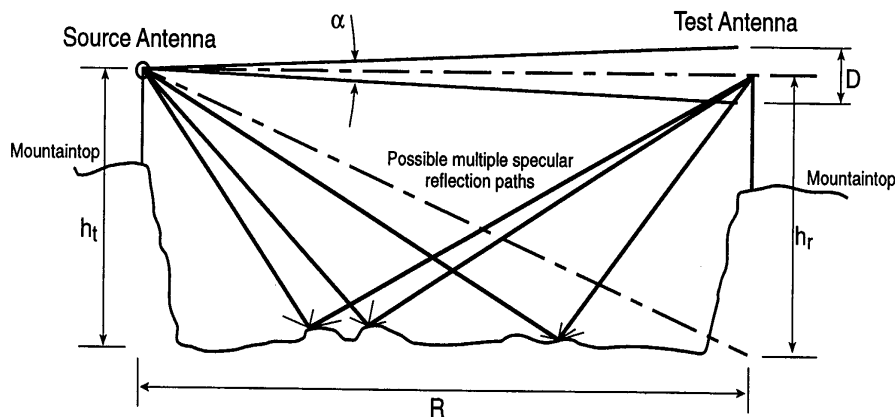


FIGURE 5.1.3.2. *Elevated range over irregular terrain. Minimize specular reflections by situating specular rays in nulls or highly suppressed sidelobes of the antenna patterns, or by other suitable technologies.*

## 5.2 Instrumentation

The instrumentation described in this section is limited to the equipment that is most critical in making the required measurements.

### 5.2.1 Signal Source

Frequency stability of at least  $10^{-5}$  is usually acceptable, but for more precise measurements, frequency stability of  $10^{-6}$  or better may be necessary. Phase noise shall not exceed  $-120$  dBc/Hz at 12.5 kHz or greater offset, where dBc means decibels relative to carrier power. Transmitter power shall be sufficient to ensure that the minimum measurable specified signal exceeds the ambient noise level by at least 14 dB.

### 5.2.2 Receiver

The receiver shall exhibit frequency stability equal to that of the transmitter, and shall be phase-locked to the transmitter. A vector network analyzer may serve as suitable alternative to a dedicated phase-locked measurement receiver and signal source. Input VSWR should not exceed 1.05 over the measurement frequency bands of interest and the receiver's frequency and power measurements capability shall be accurate to within 6 percent of true value. The receiver's frequency and power measurement accuracy shall be traceable to NIST calibration standards.

<sup>3</sup> Figure 5.1.3.1 reprinted from IEEE Std 149-1979 (R1990), "IEEE Standard Test Procedures for Antennas," Copyright© 1979 by the Institute of Electrical and Electronics Engineers, Inc. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner. Information is reprinted with the permission of the IEEE.

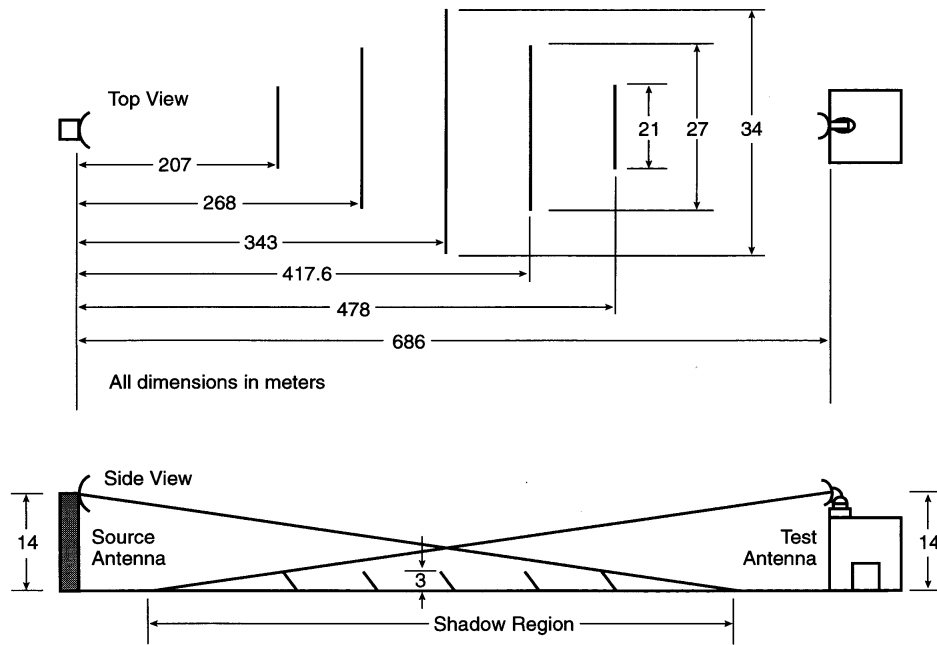


FIGURE 5.1.3.3. Example of 686-meter elevated range with diffraction fences, reprinted from IEEE Std 149-1979 (R1990) Copyright© 1979, IEEE.<sup>4</sup> All rights reserved. Used with permission. Diffraction fences are typically metallic screens with serrated top edges. Their purpose is to scatter electromagnetic energy that would otherwise be reflected from the range surface toward the antenna under test.

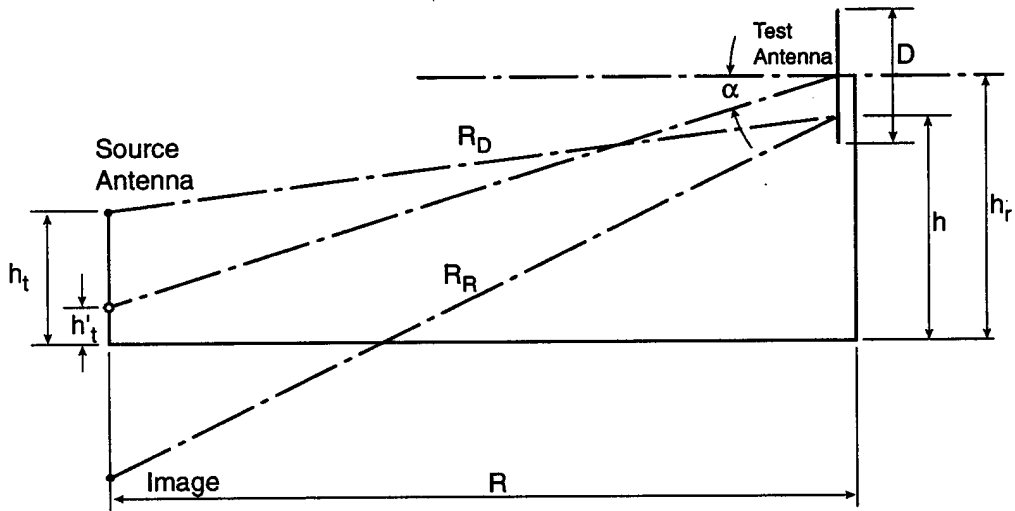


FIGURE 5.1.3.4. Ground reflection range, reprinted from IEEE Std 149-1979 (R1990) Copyright© 1979, IEEE.<sup>5</sup> All rights reserved. Used with permission.

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<sup>5</sup> Figure 5.1.3.4 reprinted from IEEE Std 149-1979 (R1990), “IEEE Standard Test Procedures for Antennas,” Copyright© 1979 by the Institute of Electrical and Electronics Engineers, Inc. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner. Information is reprinted with the permission of the IEEE.



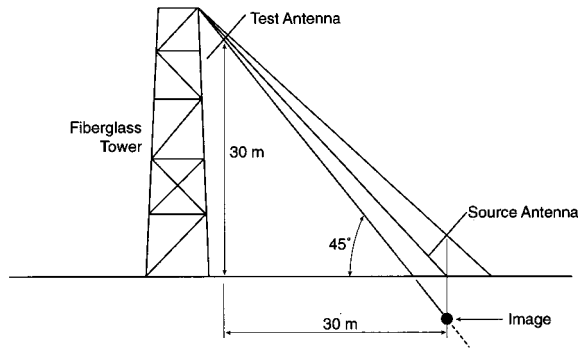


FIGURE 5.1.3.5. Slant range, reprinted from IEEE Std 149-1979 (R1990) Copyright© 1979, IEEE.<sup>6</sup> All rights reserved. Used with permission.

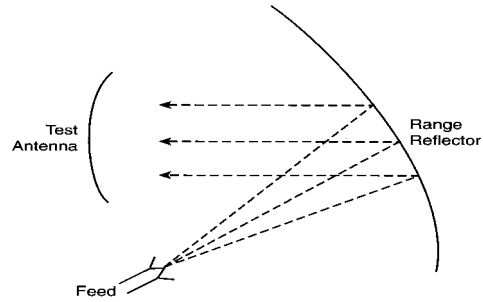


FIGURE 5.1.3.6. Compact range, reprinted from IEEE Std 149-1979 (R1990) Copyright© 1979, IEEE.<sup>7</sup> All rights reserved. Used with permission. Range reflector collimates beam to minimize phase taper. Allows smaller range distance to antenna under test than standard ranges.

Amplitude Taper of Wavefront

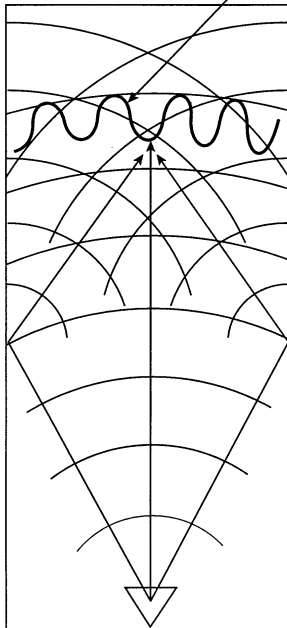


FIGURE 5.1.3.7. Rectangular anechoic chamber, reprinted from IEEE Std 149-1979 (R1990) Copyright© 1979, IEEE.<sup>8</sup> All rights reserved. Used with permission.

Amplitude Taper of Wavefront

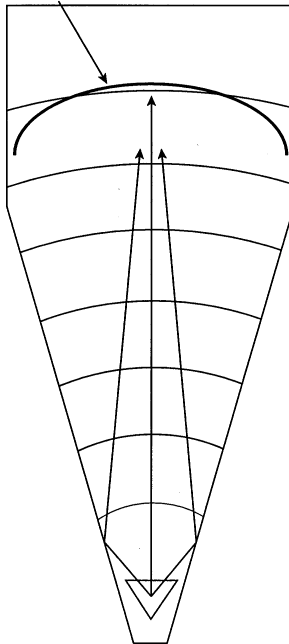


FIGURE 5.1.3.8. Tapered anechoic chamber, reprinted from IEEE Std 149-1979 (R1990) Copyright© 1979, IEEE.<sup>9</sup> All rights reserved. Used with permission.

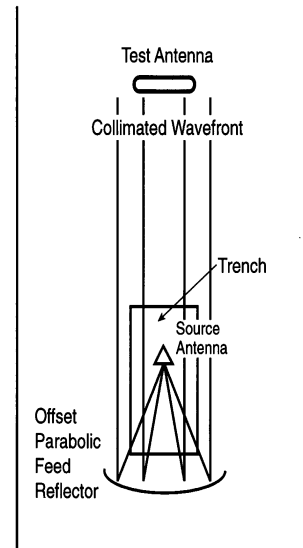


FIGURE 5.1.3.9. Compact range anechoic chamber. See Fig. 5.1.2.6 for plan review.

<sup>6</sup> Figure 5.1.3.5 reprinted from IEEE Std 149-1979 (R1990), "IEEE Standard Test Procedures for Antennas," Copyright© 1979 by the Institute of Electrical and Electronics Engineers, Inc. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner. Information is reprinted with the permission of the IEEE.

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<sup>8</sup> Figure 5.1.3.7 reprinted from IEEE Std 149-1979 (R1990), "IEEE Standard Test Procedures for Antennas," Copyright© 1979 by the Institute of Electrical and Electronics Engineers, Inc. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner. Information is reprinted with the permission of the IEEE.

<sup>9</sup> Figure 5.1.3.8 reprinted from IEEE Std 149-1979 (R1990), "IEEE Standard Test Procedures for Antennas," Copyright© 1979 by the Institute of Electrical and Electronics Engineers, Inc. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner. Information is reprinted with the permission of the IEEE.

### 5.2.3 Antenna Pattern Recorder

The antenna pattern recorder shall be such that it can reproduce patterns to within  $\pm 0.2$  dB accuracy. The recorder should be of automated data acquisition design, however, so long as results can be displayed in tabular and graphical form to within the required accuracy, manual collection systems are acceptable.

### 5.2.4 Power Meter

The power meter shall measure forward and reflected power in a  $50 \Omega$  system with full-scale uncertainty of 5 percent or less. It may be a through-line directional power meter, or two power meters attached to a directional coupler, or as part of a vector network analyzer.

### 5.2.5 Reference Antennas

Either an adjustable half-wavelength standard dipole antenna or an EIA standard gain antenna [4] shall be used for reference gain measurements. The standard dipole is described in Figure 5.2.5.1 whereas the EIA standard gain antenna is described in Figure 5.2.5.2.

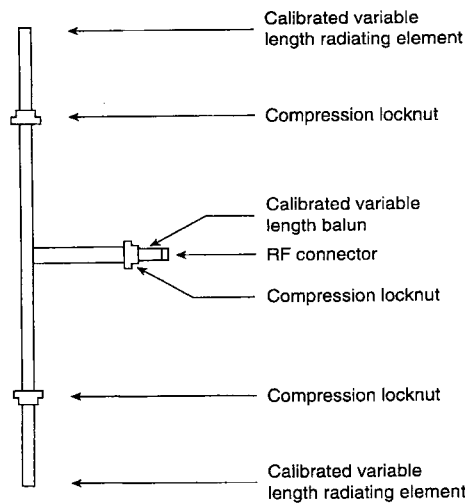


FIGURE 5.2.5.1. Adjustable half-wavelength calibrated dipole.

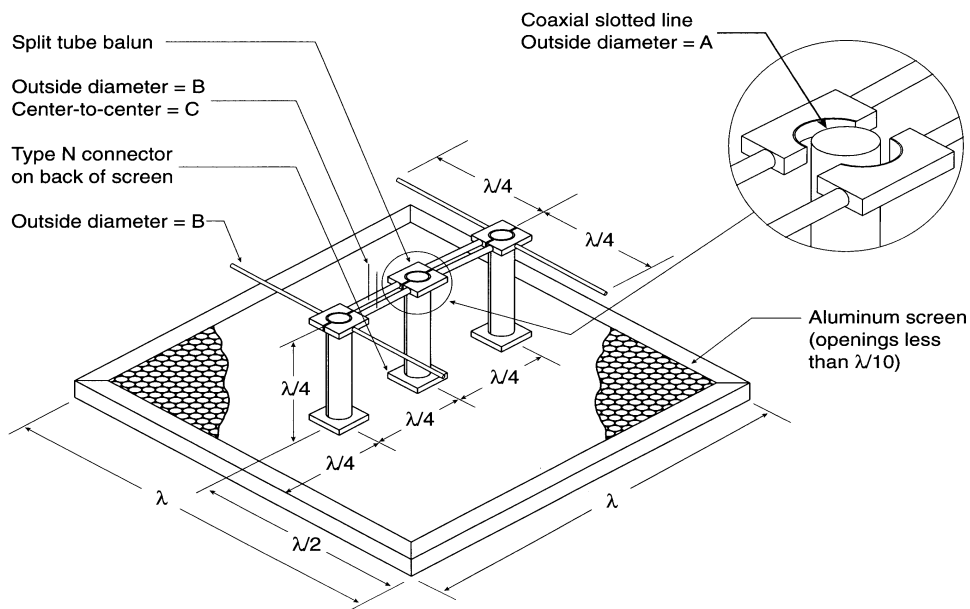


FIGURE 5.2.5.2. EIA reference gain antenna. See Table 5.2.5-1 for dimensions. See Jasik [12] for further information on the split tube balun.

The standard dipole is omnidirectional (in azimuth) and has a gain of 0 dBd. The main lobe gain of the EIA standard gain antenna is given in Tables 5.2.5-1 and 5.2.5-2.

Table 5.2.5-1. *Dimensions for EIA reference gain antennas.*

<i>Band (MHz)</i>	<i>Wavelength, <math>\lambda</math> (mm)</i>	<i>A (mm)</i>	<i>B (mm)</i>	<i>C (mm)</i>
148–174	1875.0	41.1	17.45	38.38
406–450	701.0	22.1	7.92	17.45
450–512	622.0	22.1	7.92	17.45
800–960	343.0	7.9	4.75	10.44

Table 5.2.5-2. *Gain of EIA reference gain antenna.*

<i>Band (MHz)</i>	<i>Frequency (MHz)</i>	<i>Gain (dBd)</i>
148–174	148	7.5
	160	7.7
	174	8.0
406–450	406	7.6
	428	7.7
	450	7.9
450–512	450	7.5
	481	7.7
	512	7.9
800–960	800	7.5
	882	7.7
	960	8.0

### 5.3 Scale Model Measurements

Accurate radiation pattern and relative gain measurements are difficult to obtain for VHF low-band antennas because of their physical size. Consequently, for these antennas, scale model techniques may be used. The parameters that must be scaled include:

$$\begin{aligned}
 L_s &= (L \pm 1\%)/R \\
 \epsilon_s &= \epsilon \\
 \sigma_s &= R\sigma \\
 f_s &= Rf
 \end{aligned}
 \tag{2}$$

where  $1 \leq R \leq 6$

$R$  is the scale factor,  $L$  is the full-scale dimension, and  $L_s$  is the scaled dimension. Parameters  $\epsilon$  and  $\sigma$  are the permittivity and conductivity of any materials comprising the antenna, and their “s” subscript counterparts correspond to the scaled model’s permittivity and conductivity. Also,  $f$  is the operating frequency and  $f_s$  is the operating frequency for the scaled model measurement.

It may be impractical to select a material for the scale model having an accurately scaled conductivity. In that case, relative gain measurements cannot be performed on the scale model. However, radiation pattern and directivity measurements can be measured. If the efficiency of the antenna can be established by other means, then the relative power gain can be determined from the scale model antenna’s directivity measurement.

## 5.4 Electrical and Radiation Performance Tests

### 5.4.1 Standing Wave Ratio (Voltage Standing Wave Ratio)

Voltage standing wave ratio may be determined by measuring the forward and reflected power and solving the following equation:

$$VSWR = (\sqrt{P_f} + \sqrt{P_r}) / (\sqrt{P_f} - \sqrt{P_r}) \quad (3)$$

where  $P_f$  is the forward measured power and  $P_r$  is the reverse, or reflected measured power. Many network analyzers have provision for measuring and directly displaying VSWR in Cartesian or polar (Smith chart) form. If the line loss between the antenna under test and the measurement device exceeds 0.5 dB, the measured VSWR must be corrected to compensate for the line loss, which will otherwise make the antenna appear to have lower VSWR than it really has. Ideally, the measurement device should be located at the antenna feed point.

### 5.4.2 Relative Antenna Gain Test

Relative antenna gain of the antenna under test is determined by illuminating a standard gain reference antenna with an electromagnetic wave of a particular frequency, power, and polarization and measuring its voltage or power delivered to a measurement device. This value is compared to that measured after replacing the standard gain reference antenna with the antenna under test and illuminating it under the same conditions of frequency, power, and polarization as before.

### 5.4.3 Radiation Pattern Test

The basic procedure for performing radiation pattern measurements is fully described in ANSI/IEEE STD 149-179 (R1990) [10] in various sections. The technique is illustrated in Figures 5.4.3.1 and 5.4.3.2. Essentially, the source and test antennas are securely affixed to their respective supporting structures in such a way that their mutual polarization is as desired, usually co-polarized. As the antenna under test is rotated in the plane of rotation (see Fig. 5.4.3.1) or about its axis (see Fig. 5.4.3.2), a line-of-sight ray originating from the source antenna traces out a path along an imaginary sphere which surrounds the test antenna and rotates with it. This defines the plane of the radiation pattern cut. The voltage or power response of the antenna under test at each angular orientation is mapped to a radial distance as a function of the angle in this plane. This gives an indication of the antenna pattern, or radiation pattern, which shows the response of the antenna to an electromagnetic wave incident from some prescribed direction.

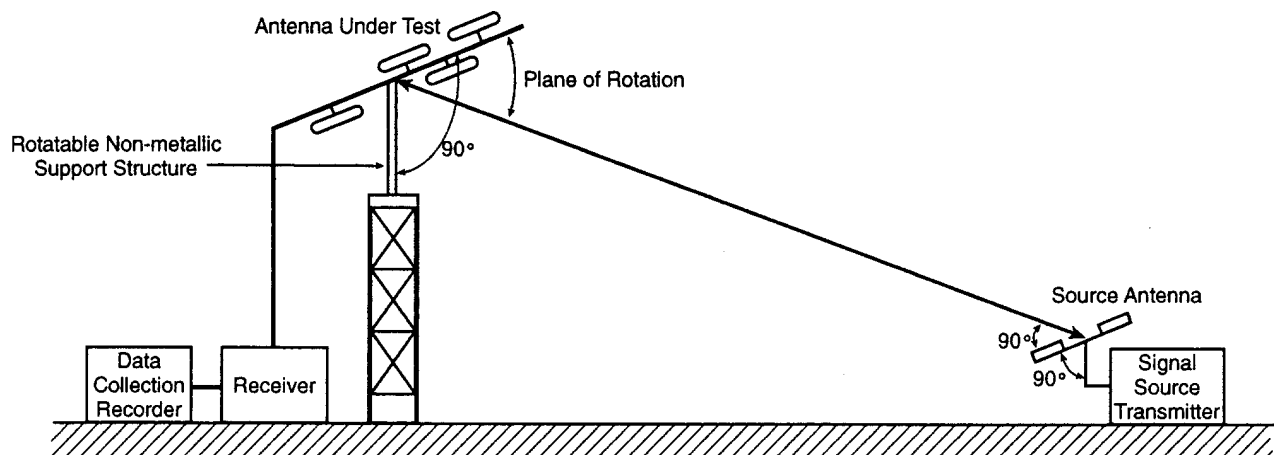


FIGURE 5.4.3.1. Example of an elevation plane radiation pattern measurement at a slant range.

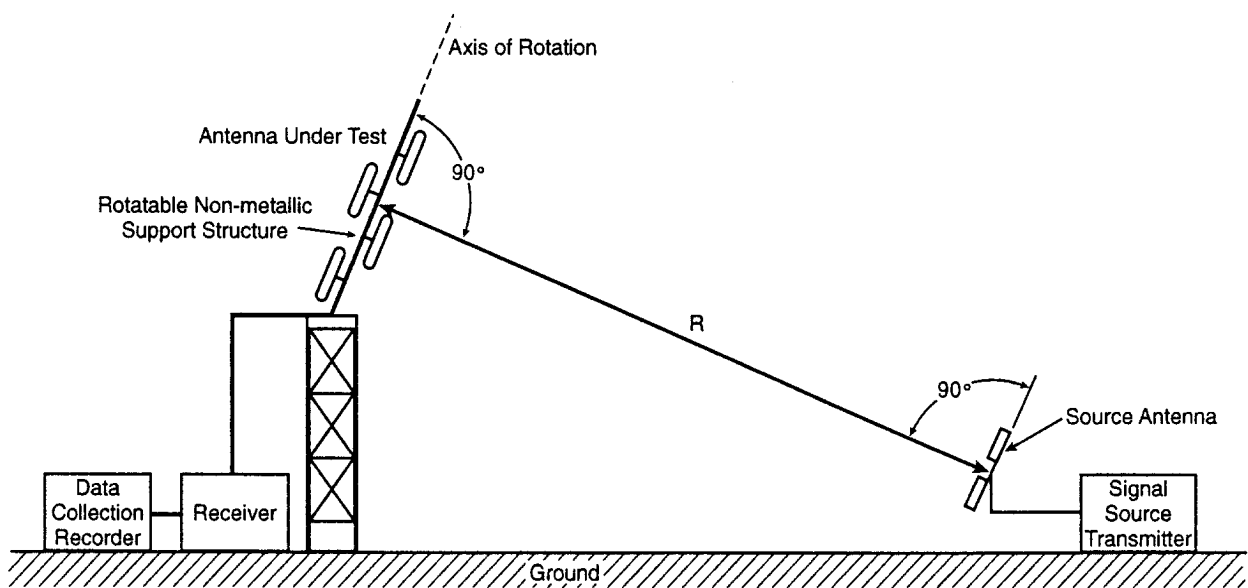


FIGURE 5.4.3.2. Example of an azimuth plane radiation pattern measurement at a slant range.

#### 5.4.4 Rated Power Test

Affix the antenna to its host platform or mock-up thereof at a suitable standard radiation test site. Measure antenna VSWR at each standard test frequency to establish a performance baseline. Apply rated full continuous wave power at each of the standard test frequencies for a minimum of 4 h per frequency. At the conclusion of each application of full rated power, measure VSWR to determine performance degradation, if any. VSWR should read within  $\pm 5$  percent of performance baseline. Visually inspect the antenna for physical damage.

### 5.5 Environmental Test Methods

Procedures for conducting the environmental tests described below are detailed in MIL STD 810E [7] under the applicable methods identified herein. Where *in situ* “operational” environmental testing of an item is impractical because of the size and/or cost of its host platform, the test items may be installed on mock-ups of its host platform. For example, vehicular antennas may be mounted on ground planes approximating the size of a vehicle roof, or base station antennas may be mounted on single tower sections.

In order to establish baseline performance characteristics, and also to reject defective items before committing the effort to perform environmental performance tests, electrical and radiation performance tests shall be conducted at ambient test conditions (Sec. 3.1) prior to exposing the test items to the environmental tests specified herein. At the conclusion of each environmental test, electrical and radiation performance tests shall be conducted at ambient conditions to ensure that the test item has not degraded.

Whereas the antennas under test must meet all the electrical and radiation performance specifications cited in this document at ambient conditions, the environmental performance specifications stated herein should be selectively applied according to the anticipated operating environment of the antenna. That is, the antenna need only comply with those environmental specifications not waived by the procuring agency. The test methods described below provide an industry-recognized, standardized, and measurable techniques to quantify antenna performance against various environmental stress factors.

#### 5.5.1 Wind Load Rating

Antenna systems, in particular antenna towers, shall be capable of withstanding repeated sustained wind loads 1.65 times that specified in Chapter 16 of TIA/EIA-222F [5], without degradation of electrical performance or structural integrity. Ice loading requirements of Section 4.3.8 may apply. Antenna structures and tower designs, including payload, shall be certified by a professional civil engineer to withstand the subject wind loads and shall conform with all local building codes.

### **5.5.2 High Temperature/Solar Radiation**

Use MIL STD 810E, Method 505.3, Procedure II [7]. Test item shall be subjected to a minimum of three test cycles. Applied temperature and radiance variation within an individual cycle shall conform to those listed in Table 505.3-I (Basic Hot) and Figure 505.3-2 of MIL STD 810E [7]. If the antenna system will be deployed in the southwestern United States, the temperature/radiance conditions specified in Table 505.3-I (Hot-Dry) and Figure 505.3-2 of MIL STD 810E [7] shall apply instead. All performance tests are waived during high temperature/ solar radiation cycling except VSWR, which shall be conducted at each temperature step of each cycle. At the conclusion of the temperature cycling, visually inspect the test items for physical damage or degradation.

### **5.5.3 Low Temperature**

Use MIL STD 810E [7], Method 502.3, Procedure II. Test item shall be subjected to a minimum of three test cycles. Applied temperature and humidity variation within an individual cycle shall conform to those listed in Tables X (Ambient) (CONUS and Alaska coastal regions) or XII (Ambient) (southwestern Alaska) of MIL STD 210C [6]. For deployment in northeastern regions of Alaska, the test item shall be subjected to the constant temperature specified in Section 4.3.3 for a like period of time. All performance tests are waived during low temperature exposure except VSWR, which shall be conducted at each temperature step of each cycle. At the conclusion of the low temperature testing, visually inspect the test items for physical damage or degradation.

### **5.5.4 Blowing Rain**

Use MIL STD 810E, Method 506.3, Procedure I [7]. Test item shall be subjected to conditions specified in Section 4.3.4, Table 4.3.4-1 above. All performance tests are waived during blowing rain exposure except VSWR, which shall be conducted just prior to cessation of this test. At the conclusion of blowing rain testing, visually inspect the test items for physical damage, leakage, or degradation.

### **5.5.5 Humidity**

Use MIL STD 810E, Method 507.3, Procedure III [7]. All performance tests are waived during aggravated humidity exposure except VSWR, which shall be conducted during the fifth and tenth humidity cycles of this test. At the conclusion of humidity testing, visually inspect the test items for physical damage, leakage, or degradation.

### **5.5.6 Salt Fog**

Use MIL STD 810E, Method 509.3, Procedure I [7]. Cycle the test article to alternating 24 h periods of salt fog exposure and standard ambient drying for a minimum of four 24 h periods. All performance tests are waived during salt fog exposure. At the conclusion of salt fog testing, visually inspect the test items for physical damage, corrosion, or degradation.

### **5.5.7 Sand and Dust**

Use MIL STD 810E, Method 510.3, Procedures I and II [7]. All performance tests are waived during sand and dust exposure. At the conclusion of salt fog testing, visually inspect the test items for physical damage, erosion of surfaces, or degradation.

### **5.5.8 Icing/Freezing Rain**

Use MIL STD 810E, Method 521.1, Procedure I [7]. All performance tests are waived during icing exposure. At the conclusion of icing testing, visually inspect the test items for physical damage.

## **5.6 Radiation Hazard**

Radiation hazard is not considered an “environmental” test in the spirit of Section 5.5 and consequently cannot be selectively applied or waived as can individual environmental tests in that section. Determination of the spatial boundaries of the radiation hazard zone when the antenna is operated at its fully rated output power is a mandatory requirement. Refer to ANSI/IEEE Standards C95.1-1991 and C95.3-1991 [8,9] for permissible exposure levels and detailed test procedures.

## APPENDIX A— REFERENCES

- [1] NIJ Standard-0204.01, Standard for Fixed and Base Station Antennas, December 1981, National Institute of Justice.
- [2] NTIA Manual of Regulations and Procedures for Federal Frequency Management, Stock No. 903-008-00000-8, U.S. Government Printing Office, Superintendent of Documents, Washington, DC.
- [3] ANSI/IEEE 145-1993, IEEE Standard Definitions of Terms for Antennas.
- [4] TIA/EIA 329-B<sup>10</sup>, Minimum Standards for Communications Antennas, Part I—Base Station Antennas.
- [5] TIA/EIA 222-F<sup>10</sup>, Structural Standards for Steel Antenna Towers and Antenna Supporting Structures.
- [6] MIL STD 210C, Climatic Information to Determine Design and Test Requirements for Military Systems and Equipment.
- [7] MIL STD 810E, Environmental Test Methods and Engineering Guidelines.
- [8] ANSI/IEEE C95.3-1991, IEEE Standard Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields—RF and Microwave.
- [9] ANSI/IEEE C95.1-1991, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.
- [10] ANSI/IEEE 149-1979 (R1990), IEEE Standard Test Procedures for Antennas.
- [11] Federal Communications Commission Report and Order 96-326 (1996 Aug. 1) “Guidelines for Evaluating the Environmental Effects of Radio Frequency Radiation.”
- [12] Jasik, H., Antenna Engineering Handbook, Sec. 31.6, McGraw-Hill, 1961.

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<sup>10</sup> To purchase the complete text of any TIA document, call Global Engineering Documents at 1-800-854-7179 or send a facsimile to 1-303-397-2740.