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Foreword

(This Foreword is not a part of ANSI/IEEE Std 149-1979, IEEE Standard Test Procedures for Antennas.)

This document is a major revision of IEEE Std 149-1965 which it supersedes. It represents the second revision of the standard since the original issuance in 1948 of 48IRE2S2, Standards on Antennas—Methods of Testing. Practically every topic contained in the previous standard has been expanded to reflect the great changes that have taken place, since 1965, in metrology and instrumentation technology as applied to antenna measurements.

This document contains sections on the design, evaluation, and operation of antenna ranges, electromagnetic radiation hazards, and environmental factors which did not appear in the preceding standard. The section on the determination of scattering cross-section, which appeared previously, has been omitted since it will appear as a separate standard at a later date.

Suggestions for the improvement of this standard will be welcome. They should be sent to:

Secretary
IEEE Standards Board
The Institute of Electrical and Electronics Engineers, Inc
345 East 47th Street
New York, NY 10017

This standard was prepared by the Subcommittee 2.11 on Methods of Testing Antennas of the IEEE Antenna Standards Committee. The Subcommittee preparing this revision had the following membership:

W. H. Kummer, *Chair*

J. D. Dyson
E. S. Gillespie
T. Mukaihata
A. C. Newell
A. F. Seaton
G. P. Tricoles
A. T. Villeneuve

Members of the IEEE Antenna Standards Committee who contributed to this standard document were:

E. S. Gillespie, *Chair*

C. C. Allen
K. G. Balmain
P. L. Burgmyer
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J. D. Dyson
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A. T. Villeneuve
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IEEE Standard Test Procedures for Antennas

1. Scope

This document comprises test procedures for the measurement of antenna properties. It is a comprehensive revision and extension of the previous test procedure ANSI/IEEE Std 149-1965 (Reaff 1971).

Throughout this standard it is assumed that the antenna to be measured can be treated as a passive, linear, and reciprocal device. Therefore its radiation properties can be measured in either the transmitting or the receiving mode. Many of the test procedures decribed can, however, be adapted for use in the measurement of antenna systems containing circuit elements that may be active, nonlinear, or nonreciprocal. For these cases there is no simple relationship between the antenna system's transmitting and receiving properties. Therefore measurements shall be performed for the mode or modes in which the antenna system has been designed to be used.

A fundamental property of any antenna is its radiation pattern. The measurement of radiation patterns on an antenna range is discussed in Section 3., with the emphasis placed on amplitude patterns. The design of antenna ranges, or antenna test facilities, is described in Section 4.

The instrumentation required for the antenna range, directions for the evaluation of an (existing) range, and the operation of ranges are discussed in Sections 5., 6., and 8., respectively. A variety of special measurement techniques are included in Section 7.

The working environment in which an antenna is installed may substantially modify the intrinsic pattern of an antenna. Consequently measurements *in situ* are frequently required. These are discussed in Section 9.

For each direction of space, the radiation pattern is characterized by amplitude, phase, and polarization. The latter characteristics are taken up in Sections 10. and 11., respectively.

The relative amplitude-pattern information may be converted into absolute intensities through information derived from the measurement of antenna gain. The determination of gain and closely related directivity is described in Section 12.. Errors in conventional gain calibration measurements are discussed particularly in 12.5. Losses in the antenna itself can be of importance in some types of antennas. These losses can be accounted for by the radiation efficiency. Procedures for their determination are treated in Section 13.

Section 14. deals with boresight measurements, which are concerned with the precise determination of the direction of the beam or tracking axis of an antenna system. The sensitive components of the antenna frequently require protection from harsh influences of the environment. The electrically transmissive shield or radome which provides this protection shall frequently be evaluated so that its effect on the radiation pattern is understood. This topic is treated in Section 15.

Power transfer from generator to antenna is controlled by the input impedance to the antenna. This important parameter frequently limits the useful bandwidth of the antenna. Measurement procedures and network descriptions appropriate from low to microwave frequencies are presented in Section 16.

An important class of antennas relies on ground to enhance the received signal. In this case the ground shall be considered as an integral part of the antenna. The modification of antenna concepts and additional data on the ground-wave propagation are presented in Section 17.

The antenna and its associated circuits rather than the capacity of the transmitter generator may limit the amount of power, either average power or peak power, that can be effectively radiated. It is desirable therefore to determine these limitations as well as the environmental factors that may modify them independently of the system context. Procedures for testing power-handling capacity are outlined in Section 18.

Another concern to the antenna engineer is that of radiation hazards. It is well known that radio-frequency (rf) fields of sufficient intensity can cause damage to biological tissue. Therefore it is usually necessary to determine the level of the radiation intensity in the vicinity of antennas radiating high radio-frequency power so that appropriate safety precautions can be taken before personnel enter the area. This important aspect of antenna measurements is discussed in Section 19.

Mechanical or structural properties along with environmental factors are described in Section 20. Because these properties are so varied and specialized in nature, no attempt has been made to include descriptions of actual measurements in this test procedure. The environmental impact of an antenna is also an important consideration for the antenna engineer. One aspect of environmental impact is that of aesthetics. Large antenna structures are necessarily conspicuous, and their appearance is of concern to those who live in their vicinity. This is particularly true in an urban setting. Since the aesthetic quality of the antenna structure is highly subjective, it is beyond the scope of this document to suggest any evaluation procedure.

Throughout this test procedure an attempt has been made to discuss measurement techniques as thoroughly as is practicable. However, in general step-by-step procedural descriptions have been avoided. References are provided which are illustrative of measurement techniques and in which details may be found. Because measurement techniques undergo continuing refinement, the reader should be alert to references on the subject of antenna measurement that will have appeared after this test procedure was prepared.

Many commonly used terms used in this test procedure are defined in ANSI/IEEE Std 145-1973, Definitions of Terms for Antennas. Commonly used terms that do not appear in that standard are italicized in this test procedure.

2. Standards References

When the following standard documents referenced in the text are superseded by an approved revision, the revision shall apply.

ANSI C95.1-1974, Safety Level of Electromagnetic Radiation with Respect to Personnel.

ANSI C95.3-1973, Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies.

ANSI/IEEE Std 100-1977, Dictionary of Electrical and Electronics Terms.

ANSI/IEEE Std 145-1973, Definitions of Terms for Antennas.

ANSI/IEEE Std 148-1959 (Reaff 1971), Measurement of Waveguides and Components.

IEEE Std 211-1977, Standard Definitions of Terms for Radio Wave Propagation.

IEEE Std 291-1969, Standards Report on Measuring Field Strength in Radio Wave Propagation.

3. Antenna-Range Measurements of Radiation Patterns

3.1 General

Associated with the antenna under test is an operational coordinate system [1, pp 5.4–5.7],[1] usually a spherical one. Generally this coordinate system is defined by the system in which the antenna is used, although at times, for testing a specific antenna, it may be necessary to define a different coordinate system. The Inter-Range Instrumentation Group of the Range Commanders Council [2, p 120], for example, has defined a coordinate system specifically for use with rockets, missiles, and space vehicles (Fig 1).

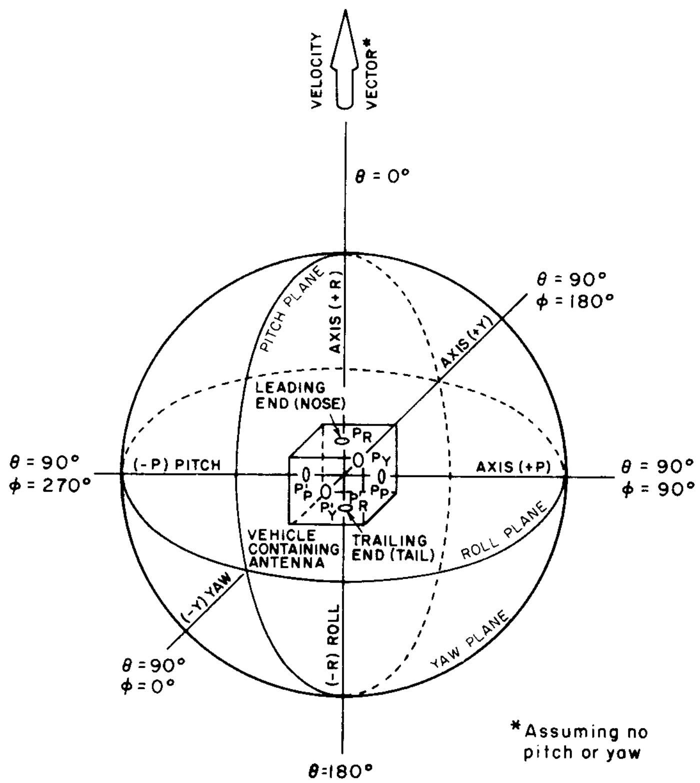

Figure 1—Coordinate System of Inter-Range Instrumentation Group

The antenna's coordinate system is typically defined with respect to a mechanical reference on the antenna. A means of establishing the mechanical reference should be provided. The standard spherical coordinate system used in antenna measurements is shown in Fig 2.

To completely characterize the radiation field of an antenna, one shall measure its relative amplitude, relative phase, polarization, and the power gain on the surface of a sphere the center of which is located at the antenna under test. A representation of any of these radiation properties as a function of space coordinates is defined as a radiation pattern, or antenna pattern, of the test antenna. Since the distance R from the antenna under test to the measuring point is fixed, only the two angular coordinates are variables in a given radiation pattern. Usually the radio frequency of operation is treated as a parameter, with the radiation pattern being measured at specified frequencies. For some antenna applications it is necessary to make frequency a variable. If frequency is varied continuously, such a procedure is called a swept-frequency technique; it is discussed in 7.4. It is impractical to measure the radiation pattern of an antenna completely, and therefore it is necessary to resort to sampling techniques. For example, with the frequency of

[1]Numbers in brackets correspond to those of the Bibliography, Section 21. of this standard.

operation and polarization fixed, the θ coordinate can be varied incrementally, and for each increment the desired antenna property can be measured continuously over the range of ϕ. If the increments are small enough, then for all practical purposes the complete antenna pattern is obtained. The resulting patterns taken for all increments of θ are usually referred to as a set of radiation patterns.

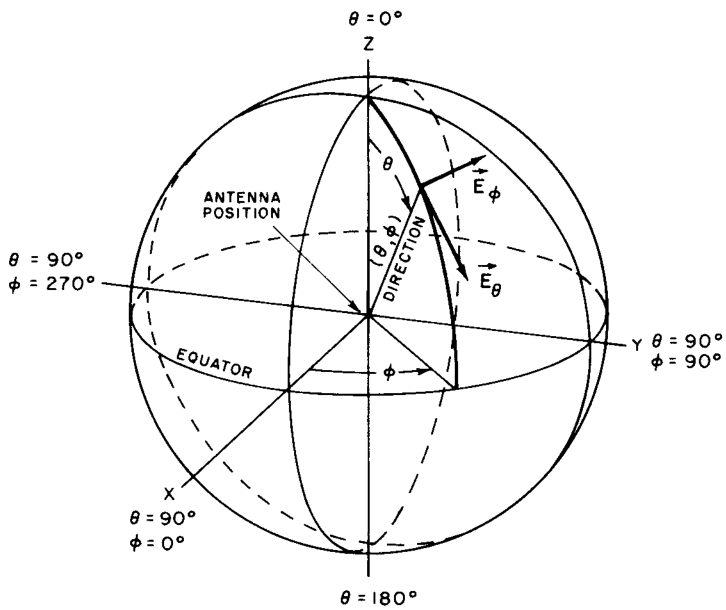

Figure 2—Standard Spherical Coordinate System Used in Antenna Measurements

There are situations in which the operational antenna illuminates structures in its immediate vicinity which alter the radiation field of the isolated antenna. In these cases it may be necessary for measurements of the radiation field to include with the antenna those relevant parts of the nearby structures. The use of scale models is quite common for such cases (see 7.1). Throughout this standard the expression "test antenna" or, alternately, "antenna under test" shall mean the antenna itself plus any structure included with it. This means that the test antenna can be physically larger than the antenna alone.

3.2 Pattern Cuts

A direct method of measuring the radiation pattern of a test antenna is to employ a suitable source antenna, which can be positioned in such a manner that it moves relative to the test antenna along lines of constant θ and constant ϕ (see Fig 2). The loci of constant θ directions describe cones; hence measurements made with ϕ as the variable and θ as a parameter are called *conical cuts* or *ϕ cuts*. Those made with θ as the variable and ϕ as a parameter are called *great-circle cuts* or *θ cuts*. Note, however, that the conical cut for $\theta = 90°$ is also a great-circle cut.

Though rarely done, it is possible to position the antenna in such a manner that the loci of directions describe a spiral. For this case both θ and ϕ are variables, and the resultant motion is called a *spiral cut*. When spiral cuts are being made, it is usual for the motion in θ to be slowly varying with respect to that in ϕ; hence for each 360° rotation in ϕ the resulting pattern is approximately a conical cut.

Principal-plane cuts refer to orthogonal great-circle cuts which are through the axis of the test antenna's major lobe. For this definition to hold, the beam axis shall lie either in the equator of the spherical coordinate system ($\theta = 90°$) or at one of the poles ($\theta = 0°$ or $\theta = 180°$).

If the positioner system is designed to provide θ and ϕ cuts, then the alignment of the axis of a pencil-beam antenna along the poles is usually avoided. This is because the ϕ cut for the $\theta = 0°$ orientation yields only a polarization pattern (see 11.2.2). When near the poles θ cuts involve radical changes in the direction of polarization of the incident field relative to the test antenna's polarization, except when the incident field is identically circularly polarized. For these reasons if the test antenna is of a pencil-beam type, it is usually oriented with its beam axis in any desired direction in the equator (most often in the $\phi = 0°$ or $\phi = 180°$ direction).

3.3 Basic Antenna-Range Configurations

There are two basic range configurations that accomplish the position requirement for θ and ϕ cuts [1, pp 5.12-5.24]. One is the *fixed-line-of-sight* configuration. Here the test antenna and its associated coordinate system are rotated about a suitable axis (usually one passing through the phase center (see 10.3) of the test antenna). If the test antenna is operating in the receive mode, then the signal that it receives from an appropriately located fixed source antenna is recorded. The other one is called the *movable-line-of-sight* configuration. For this case the source antenna is moved incrementally or continuously along the circumference of a circle centered approximately at the phase center of the antenna under test. If it is moved incrementally, then for each position of the source antenna the test antenna is rotated and the received signal is recorded. Alternately the test antenna can be rotated incrementally, and for each of its positions the source antenna is moved continuously along its circumferential path.

If the test antenna and the source antenna are both reciprocal devices, the functions of receive and transmit may be interchanged. The measured patterns should be identical. This means that the test antenna may be used in either the receive or the transmit mode; most often it is used in the receive mode. In the following, unless otherwise stated, the test antenna shall be considered as the receiving antenna, and it will be illuminated by the field of the transmitting source antenna.

4. Antenna-Range Design

4.1 General

Antenna ranges have been developed for the purpose of measuring the radiation patterns of antennas independent of their operational environment. The antenna range consists of the appropriate instrumentation and the physical space required for the measurements. In this section the design is discussed. Evaluation and use of antenna ranges are described in Sections 6. and 8.. Emphasis is placed on the measurement of the relative amplitude patterns. The measurement of relative phase, polarization, and power gain is discussed in Sections 10., 11., and 12., respectively. It should be pointed out that the various criteria for antenna-range design presented here, as well as the methods of evaluation, apply equally well to other types of ranges usually found at antenna testing facilities, such as *radome ranges* and *scattering ranges*. Radome measurements are discussed in Section 15., and scattering ranges are beyond the scope of this standard.

The ideal incident field for measuring the radiation characteristics of the test antenna is that of a uniform plane wave. In practice it is only possible to approximate such a field. Attempts to do this have led to the development of two basic types of ranges:

1) *Free-space ranges*. This type of range is designed in such a manner that all the effects of the surroundings are suppressed to acceptable levels.
2) *Reflection ranges*. This type of range is designed to judiciously use reflections in order to produce an approximated plane wave.

Typical ranges that come under the free-space-range classification are: the elevated range, the slant range, the compact range, and most anechoic chambers.