

American National Standard for Electromagnetic Compatibility— Radiated Emission Measurements in Electromagnetic Interference (EMI) Control—Calibration of Antennas (9 kHz to 40 GHz)

Accredited Standards Committee on Electromagnetic Compatibility, C63

accredited by the

American National Standards Institute

Secretariat

Institute of Electrical and Electronics Engineers, Inc.

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Abstract: Methods for determining antenna factors of antennas used for radiated emission measurements of electromagnetic interference (EMI) from 9 kHz to 40 GHz are provided. Antennas included are linearly polarized antennas such as loops, rods (monopoles), tuned dipoles, biconical dipoles, log-periodic dipole arrays, broadband horns, etc., which are used in measurements governed by ANSI C63.4-1992. The methods include standard site (i.e., 3-antenna), reference antenna, equivalent capacitance substitution, standard transmitting loop, standard antenna, and standard field methods.

Keywords: antenna factors, equivalent capacitance substitution, linearly polarized antennas, near free space, reference antenna, standard antenna, standard site, standard transmitting loop

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Introduction

[This introduction is not part of ANSI C63.5-1998, American National Standard for Electromagnetic Compatibility—Radiated Emission Measurements in Electromagnetic Interference (EMI) Control—Calibration of Antennas (9 kHz to 40 GHz)].

ANSI C63.4-1992, American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronics Equipment in the Range of 9 kHz to 40 GHz, has undergone several revisions since the original document covering methods of measurement was produced in 1940. Although many improvements were made in the standard from time to time, the reproducibility of measurements of radiated interference from one test site to another has not been completely satisfactory.

In 1982 a concerted effort was organized in Subcommittee One of the Accredited Standards Committee C63 to determine how the technique could be improved. Evidence showed that the variability was due, in part, to inadequate (a) control of site ground plane conductivity, flatness, site enclosures, effects of surrounding objects, and certain other site construction features, (b) accounting for antenna factors, associated cabling, and balun and device under test characteristics, and (c) consideration of mutual coupling effects between the device under test and the receiving antenna and their images in the ground plane. Accordingly, ANSI C63.4 has been revised, and ANSI standards C63.5, C63.6, and C63.7 were prepared to provide additional information. This standard provides methods of calibration of antennas for use on the test site.

In 1993 a concerted effort was begun to bring the Standard Site Method of ANSI C63.5 into CISPR as the method of antenna calibration to be used in CISPR Publication 16. During the ensuing discussions, it became apparent that several features of ANSI C63.5 were not acceptable to the international community. In particular, calibration measurements at 3 m were unacceptable. Furthermore, while ANSI C63.5 recommends that only horizontal polarization be used for antenna calibration, it included information on calibration using vertical polarization. This was considered ambiguous and unacceptable by CISPR Subcommittee A. During the use of ANSI C63.5 over the last several years a number of errors were discovered and these needed to be corrected. ANSI standards C63.2 and C63.4 specify antennas from 9 kHz to 30 MHz and from 1000 MHz to 40 GHz for which no calibration procedure was available in ANSI C63.5. Accordingly, ANSI C63.5 has been revised to eliminate those features that the international community found objectionable, and thus provides harmonization with international standards while allowing a US National deviation from those standards. This revision corrects errors which use of the standard has shown, and extends it to cover all of the antennas specified in ANSI standards C63.2 and C63.4 from 9 kHz to 40 GHz.

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1. Scope

This standard provides methods for determining antenna factors of antennas used for radiated emission measurements of electromagnetic interference (EMI) from 9 kHz to 40 GHz. Antennas included are linearly polarized antennas, such as loops, rods (monopoles), tuned dipoles, biconical dipoles, log-periodic dipole arrays, broadband horns, etc., that are used in measurements governed by ANSI C63.4-1992. The methods include standard site, reference antenna, equivalent capacitance substitution, standard transmitting loop, standard antenna, and standard field methods. The latter three methods are incorporated by reference in 4.4.

Harmonization of this standard with international standards is achieved by providing two sets of measurement geometries in the 30 MHz to 1000 MHz frequency range. One set of one measurement geometry is provided for calibrations to meet international requirements, and one set of four measurement geometries is provided for calibrations to meet US domestic requirements. The international measurement geometry and one of the four domestic measurement geometries are identical. The international geometry is the preferred calibration measurement geometry.

2. References

The following references shall form a part of this standard to the extent referenced. When the standards referred to in this standard are superseded by a revision, the revision shall apply.

ANSI C63.2-1996, American National Standard for Electromagnetic Noise and Field-Strength Instrumentation, 10 kHz to 40 GHz—Specifications.¹

¹ANSI C63 publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331 USA.

ANSI C63.4-1992, American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.²

ANSI C63.6-1996, American National Standard Guide for the Computation of Errors in Open-Area Test Site Measurements.

ANSI C63.7-1992, American National Standard Guide for Construction of Open-Area Test Sites for Performing Radiated Emission Measurements.

ANSI C63.14-1998, American National Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD).

ANSI/NCSL Z540-1-1994, American National Standard for Calibration—Calibration Laboratories and Measuring and Test Equipment—General Requirements.³ (DoD has withdrawn MIL-STD-45662A and directed the use of ANSI/NCSL Z540-1-1994 instead.)

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms.⁴

IEEE Std 149-1979 (Reaff 1990), IEEE Standard Test Procedures for Antennas.

IEEE Std 291-1991, IEEE Standard Methods for Measuring Electromagnetic Field Strength of Sinusoidal Continuous Waves, 30 Hz to 30 GHz.

3. Definitions

The following definitions apply specifically to the subject treated in this standard. For additional definitions, see ANSI C63.14-1992 and IEEE Std 100-1996.

3.1 ambient level. The values of radiated and conducted signal and noise existing at a specific test location and time when the test sample is not activated.

3.2 antenna factor. Quantity relating the strength of the field in which the antenna is immersed to the output voltage across the load connected to the antenna. (Antenna factor is independent of measurement geometry. Antenna is aligned with field polarization.)

3.3 free-space antenna factor. Antenna factor when all influences from adjacent objects have been removed.⁵

3.4 ground plane. A conducting surface or plate used as a common reference point for circuit returns and electric or signal potentials.

3.5 ideal site. A test site on which the reflective surface is flat and has infinite conductivity and size.

3.6 normalized site attenuation (NSA). Site attenuation divided by the antenna factors of the radiating and receiving antennas (all in linear units).

²Compliant with Part 15 of the FCC Rules and Regulations.

³NCSL standards are available from National Conference of Standards Laboratories, 1800 30th Street, Suite 305B, Boulder, CO 80301 USA.

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331 USA.

⁵“The magnitude of the ratio of the field strength of an incident co-polarized plane wave to the voltage developed across a specified impedance terminating the antenna output port, when the antenna is located in free space.” (See Goedbloed [B7].)

3.7 radiated emissions test site. A site meeting specified requirements suitable for measuring radio interference fields radiated by a device, equipment, or system under test.

3.8 radio noise. An electromagnetic noise that may be superimposed upon a wanted signal and is within the radio-frequency range. For the purposes of this standard, an electromagnetic disturbance of a sinusoidal character is also considered radio noise.

3.9 random noise. Noise that comprises transient disturbances occurring at random.

NOTE—The part of the noise that is unpredictable except in a statistical sense. The term is most frequently applied to the limiting case where the number of transient disturbances per unit time is large, so that the spectral characteristics are the same as those of thermal noise (thermal noise and shot noise are special cases of random noise).

3.10 site attenuation. The ratio of the power input to a matched, balanced, lossless tuned dipole radiator to that at the output of a similarly matched, balanced, lossless tuned dipole receiving antenna for specified polarization, separation, and heights above a flat, reflecting surface.

3.11 standard antenna calibration site. A site comprised of a flat, open-area, devoid of nearby scatterers such as trees, power lines, and fences, that has a large metallic ground plane. The ground plane should be as large or larger than the first Fresnel ellipse and meet the Rayleigh criterion (see ANSI C63.7-1992). The clear area (sometimes referred to as the obstruction-free area) should be as large or larger than the third Fresnel ellipse (see ANSI C63.7-1992).

NOTE—A 10-meter test site that is weather-protected or installed in a suitable absorber-lined chamber may be used if it can be shown that the effects of the chamber or weather protection are insignificant.

4. General test conditions

This standard provides for “free-space” antenna factors that can be used for either vertically or horizontally polarized measurements at distances from the equipment under test (EUT) of 3 m or more. The general test conditions for antenna calibration are described in 4.1 through 4.4.

4.1 Measurement geometry

Accurate antenna calibration requires some restrictions on measurement geometry. The antenna separation distance R shall be great enough to ensure that near-field effects and antenna-to-antenna mutual coupling effects are minimized. Antenna heights (h_1 , h_2) shall be great enough to minimize antenna-to-ground plane mutual impedance and to ensure negligible contribution from the surface wave component of the ground-wave.

When tuned dipoles are calibrated using the methods in this standard, they shall be calibrated at separation distances R equal to or greater than 10 m and at heights equal to or greater than 2 m. The separation distance R between log-periodic array antennas is measured from the projection onto the ground plane of the mid-point of the longitudinal axis of each antenna.

4.2 Test instrumentation

Signal generators and power amplifiers shall have a 50 Ω output impedance. Radio noise meters, spectrum analyzers, other tuned voltmeters, and preamplifiers shall have a 50 Ω input impedance. Refer to ANSI C63.2-1996 for radio noise meter specifications.

An impedance mismatch at the output of signal sources or at the input of voltmeters may result in reflections that could cause antenna factor measurement errors. This should be avoided by the use of high-quality

padding attenuators of 10 dB—one at the output end of the transmitting cable and one at the voltmeter input. The signal sources should provide sufficient power to produce a signal at least 10 dB above the ambient and equivalent receiver noise at the receiver input. Preamplifiers may be used at the voltmeter input to meet this requirement. The source power and preamplifier gain requirements shall depend upon voltmeter/preamplifier sensitivity, antenna factors, cable losses, and measurement distance. It is preferable to use preamplifiers at the voltmeter input rather than power amplifiers at the source output. This will improve the signal-plus-voltmeter-noise-to-voltmeter-noise ratio, while minimizing the potential for interference with susceptible equipment or licensed radio services in the vicinity of the test area.

Signal generators, antennas, and receiving equipment (voltmeters and preamplifiers) shall be calibrated at regular intervals. Calibration shall include amplitude uncertainty,⁶ frequency uncertainty, drift, and sensitivity, where applicable. Effects of drift, especially during the measurement time, shall be compensated or corrected. These calibration standards shall be traceable to a national standard. An example of an acceptable program for calibration of instrumentation can be found in ANSI/NCSS Z540-1:1994.

4.3 Antenna factors

Individually measured antenna factors in the frequency range of 30 MHz to 1000 MHz, which are measured by these procedures, are capable of producing uncertainty values within ± 1 dB from 30 MHz to 800 MHz, and within ± 1.5 dB from 800 MHz to 1000 MHz. The user should verify that manufacturer-supplied antenna factors are based on individual calibrations of that specific antenna and that they are traceable to a national standard.

Antenna factors usually account for losses due to the balun. If a separate balun is used, its effects shall be measured or otherwise accounted for and included with the data to ensure that the user understands how any such separate balun is to be used and how its effects are to be accounted for. If the measured antenna factors are adjusted to correct for fixed-length cable losses, this shall be clearly stated in the antenna-factor data supplied to the user.

Experience has shown that variations of antenna factors with measurement geometry and polarization are negligible for electrically small antennas, provided that the antennas are well balanced. This includes the types of broadband antennas commonly used for EMI measurement from 30 MHz to 1000 MHz when used in the geometries recommended in ANSI C63.4-1992. Antenna factor variations may be caused by the use of unusual measurement geometries or mutual coupling, and measurement errors may be caused by poor balance and transmission line scattering for vertically polarized antennas. The antenna factors may be measured for a particular antenna as stated in 4.1. For this procedure, antenna height and pattern variation of less than ± 1 dB are considered acceptable, and the measured antenna factors are considered independent of those two parameters; hence, they are considered “near free space” antenna factors.

Although not part of the antenna calibration procedure, it is prudent to check the balun balance of the antenna. To do this

- a) Start by orienting the transmit and receive antennas horizontally with respect to the ground plane. Note the received signal in this position while keeping the transmit signal constant.
- b) Rotate the receive antenna (the antenna being checked for balance) 90° into a vertically polarized position with respect to the ground plane. Note the received signal with the transmit signal continuing to be held constant. There should be a signal null in this position of at least 20 dB.
- c) Next, rotate the receive antenna to 180° . Note the received signal. This signal level should be within 0.5 dB of that in the starting position, i.e., 0° .

⁶See [B8] and [B9] for definitions and discussions of uncertainty. Antenna factor measurement uncertainties are under consideration by IEC/CISPR.

- d) Next, rotate the receive antenna to 270° into the vertical position. There should be another signal null in this position of at least 20 dB.

If the nulls are not found in the 90° and 270° positions or the received signals in the 0° and 180° positions differ by more than 0.5 dB, then the balance of the antenna is inadequate for making emission measurements. The balun should be repaired before proceeding with calibration and use of the antenna.

NOTE—During the entire procedure, it is important that the receive antenna feed cable be carefully arranged to keep the cable orientation from causing an apparent unbalanced condition.

4.4 Methods of antenna factor determination

Antenna factors can be accurately calibrated in several ways. The decision as to which approach is best in a particular case shall be based upon the time, instrumentation, and facilities available to the investigator.

Three methods are

- Standard Site Method (SSM)
- Reference Antenna Method (RAM)
- Equivalent Capacitance Substitution Method (ECSM)

These methods are described in Clauses 5, 6, and 7. The uncertainty of these methods depends on the quality of the measuring site for the SSM, the accuracy with which the reference antenna is constructed for the RAM, and the accuracy with which the monopole capacitance is simulated for the ECSM. The ECSM shall be used for calibration of rod (monopole) antennas from 9 kHz to 30 MHz for use in the measurements using monopole antennas in ANSI C63.4-1992.

Three additional methods are

- Standard Field Method (SFM) (IEEE Std 291-1991)
- Standard Antenna Method (SAM) (Fitzgerrel [B6],⁷ Taggart and Workman [B14], IEEE Std 149-1979)
- Standard Transmitting Loop Method (STLM)—a specialized version of the Standard Antenna Method (IEEE Std 291-1991)

These methods are incorporated in this standard by these references. If disagreements arise, the SSM, ECSM and RAM shall take precedence over the SFM and SAM. The STLM shall be used for calibration of loop antennas from 9 kHz to 30 MHz for use in the measurements using loop antennas required by ANSI C63.4-1992.

5. Standard Site Method (30 MHz to 40 GHz)

5.1 General

The SSM for determining antenna factors (Smith [B12]) requires a standard antenna calibration site. This procedure provides free-space antenna factors that are used without further correction for emission measurements at specified polarizations, distances from the EUT, or heights above the ground plane.

NOTE—Horizontally polarized antennas shall be at least 1 m above the ground plane and the lower tips of vertically polarized antennas shall be at least 25 cm above the ground plane.

⁷The numbers in brackets preceded by the letter B correspond to those of the bibliography in Annex F.

Antenna factor calibration errors caused by site anomalies can only be detected by measurements on two independent sites or on two independent paths on large sites. For example, two independent 10 m paths can be readily accommodated on a 30 m test site.

NOTE—Antennas used to measure attenuation of an open-area test site should not have been calibrated on that same site because site imperfections may have affected the measured antenna factors. An exception may be made in the case of large open-area test sites. On these large sites, antennas may be calibrated on a propagation path, which is independent of the path used for EMI measurements.

The SSM (based solely on horizontal polarized measurements) provides antenna factor measurements from 30 MHz to 1000 MHz for both US domestic use and international use. The measurement method is the same in both cases, but the geometries are different. For domestic use, measurement distances are 3 m and 10 m, transmit antenna heights are 1 m and 2 m, and receive antenna search heights are from 1 m to 4 m. For international use, the measurement distance is 10 m, the transmit antenna height is 2 m, and the receive antenna search heights are from 1 m to 4 m. These dimensions are annotated in Table 1, which provides values for $E_D^{\max}$ for all geometries. (Figure 2 provides all measurement geometries.) The international calibration measurement geometry is the *preferred* measurement geometry.

Antenna factors shall only be determined for horizontal polarization on a standard antenna calibration site, hereafter referred to as a standard site, using the SSM. This measurement is relatively insensitive to site variations for horizontal polarization, and it yields free-space antenna factors even though the reflecting plane will not create a free-space environment during calibration. Horizontal polarization is preferred for antenna calibration because

- a) Mutual coupling between the antenna and the orthogonal transmission line is negligible
- b) Scattering from the transmission line is negligible
- c) Calculations of the horizontal groundwave are simpler than calculations for the vertical groundwave
- d) The surface wave component of the horizontal groundwave over earth is more tightly coupled to the surface
- e) The horizontal groundwave is less sensitive to differences in surface conductivity and permittivity than the vertical wave
- f) Ground screen edge reflections are smaller for horizontal polarization

Certain antennas, for example, electrically small antennas, biconical dipoles, broadband dipoles, log-periodic arrays designed for use above approximately 100 MHz, and horn antennas designed for use above 1 GHz, have antenna factors that are independent of height and polarization if they are at least 1 m above the ground plane. It is unnecessary to calibrate standard gain horn antennas for use above 1 GHz; rather, they are used as gain standards to calibrate other antennas (see 12.3.1 of IEEE Std 149-1979).

NOTE—Certain studies (Stecher [B13], Austin and Fourie [B1]) have shown a small height dependence in some wire-cage biconical antennas above about 200 MHz.