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Editor's Note

The Role of Standards Development


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Even if you're just a casual reader of *Conformity* Magazine, you no doubt already understand and appreciate the important role that voluntary standards play in the development and marketing of electrical and electronic products.

Standards not only help to ensure the safety and reliability of the products we design, they serve as the foundation for regulations around the world affecting the sale and marketing of such products. And, internationally accepted standards minimize barriers to trade, thereby speeding the deployment of modern technologies to all corners of the earth.

But what you may not appreciate about voluntary standards is the scope and scale of the effort involved in creating and maintaining the tens of thousands of standards currently in place. The International Organization for Standardization (ISO), for example, has more than 17,000 standards within its portfolio, with at least 2000 separate standards undergoing revision during any given year.

And the International Electrotechnical Commission (IEC), the sister organization to the ISO, says that the development and continual revision of its standards involves approximately 10,000 individual experts in electrical and electronic devices, representing industry, testing laboratories, academia, government and other interested entities.

Concerns are sometimes raised that the process of developing and updating voluntary standards is controlled or influenced by parties who have a "special interest" in the outcome. But, when you consider the sheer number of standards involved, such charges are extremely rare. That's because standards development work is largely self-policed by the veritable army of technical professionals who unselfishly volunteer their time and energy to ensure that the products of their efforts are fair and unbiased.

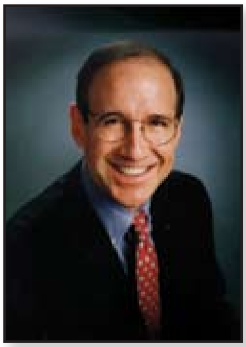
The cover story in this month's issue of *Conformity* showcases the depth and detail of the work being done by one such standards committee, Accredited Standards Committee (ASC) C63. The article, *The State of Antenna Calibration in the United States Using ANSI C63.5*, traces the efforts of ASC C63 over a nearly 30 year span to develop this important document, and to maintain its currency in light of technical developments.

Equally important, readers of this article will also learn how standards development efforts don't merely reflect the state of our technical understanding of issues but frequently contribute to the advancement of that understanding.

The State of Antenna Calibration in the U.S. is the work of three industry professionals, Mike Windler of Underwriters Laboratories, Zhong Chen of ETS-Lindgren, and Dennis Camell of the National Institute of Standards and Technology.

But an article of this significance is always a collaboration that extends beyond the authors. Bill DeLisi of Underwriters Laboratories contributed the excellent sidebar on measurement uncertainty. Bill Hurst of the Federal Communications Commission and Dan Hoolihan of Hoolihan EMC provided extensive suggestions and feedback during the article review process. And Don Heirman, chairman of ASC C63, offered generous and invaluable perspective and guidance throughout.

Finally, we'd like to acknowledge the special contribution of Janet O'Neil of the IEEE EMC Society for her help and assistance in working with the article's coauthors, and in coordinating the extensive review and approval process. We would not have been able to publish this important article without her tireless effort. Thank you, Janet!



Bill von Achen
Managing Editor

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The State of Antenna Calibration Standards in the United States Using ANSI C63.5

by Mike Windler, Underwriters Laboratories,
Zhong Chen, ETS-Lindgren,
and Dennis Camell, National Institute of Standards and Technology

Methods for calibrating antennas have been around since antennas were first used. Over the years our understanding of antennas and their performance in their intended applications has continued to evolve. In this article we seek to discuss the past, present, and future state of our antenna calibration work in the Accredited Standards Committee C63® (ASC C63®), which has resulted in the publication of the American National Standard, C63.5 "Radiated Emission Measurements in Electromagnetic Interference (EMI) Control–Calibration of Antennas (9 kHz to 40 GHz)." This work is performed by experts in ASC C63® which maintains the currency of ANSI C63.5.

Don Heirman, chairman of ASC C63®, believes that this article presents a major step forward in the understanding of what ASC C63® has and will be doing in bringing the latest theory and technology forward in the antenna calibration area. He also believes that ASC C63® is in a unique place to support this work, as its membership is from industry, regulatory bodies, military, universities, and consultants located in the U.S. It is this broad representation that lends itself to robust standards such as ANSI C63.5 as it is reviewed by the committee membership. This then lends itself to provide its expertise to the work being done internationally in the Special International Committee on Radio Interference (CISPR).

This article leads the reader through the history of the work on ANSI C63.5, from its beginning to the latest version that was published in 2006, and on to the future.

Historical Roots

The predominant method currently used to calibrate antennas in the frequency range of 30-1000 MHz is based on the work of Albert Smith [1] dating back to the early 1980s when he provided his expertise in ASC C63®. A companion article was published at the same time by Smith et al [2] on the calculation of normalized site attenuation using antenna factors. Together, these articles interlaced antenna calibrations and site attenuation for the foreseeable future.

Figure 1 shows a photo of the late Al Smith. There is an explicit recognition in [1] that the antenna factors measured using the standard site method depend on the site attenuation with the quote "The standard-site method of determining antenna factors is based on site attenuation measurements made on a near ideal, open-field site." However, how do we determine if a test site is a near ideal site? Answer: By measuring the site using antenna factors! This catch 22 scenario has always been a source of concern in some parts of the EMC community. Nonetheless, efforts have been made through the standards process to reconcile this concern.

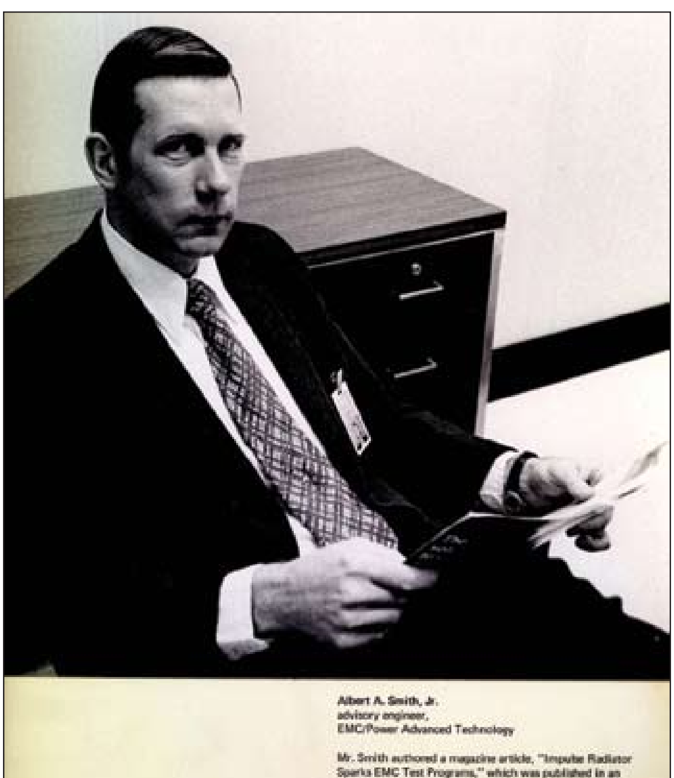

Figure 1: The late Al Smith is shown in his office at IBM. Mr. Smith's paper "Calculation of Site Attenuation from Antenna Factors," coauthored with R. F. German and J. B. Pate, was recognized as one of the top ten "Most Referenced" Transactions papers in the 50-year history of the IEEE EMC Society.

Several technical issues were recognized in these seminal articles. Those technical issues included restrictions on the measurement geometry discussed in [1]. Smith identified:

1. Measurement distance as a concern to minimize antenna-to-antenna coupling and near field effects;

2. The need to keep antenna heights (both transmitting and receiving) high enough to minimize antenna-to-ground plane mutual impedances and to ensure a negligible contribution from the surface-wave component of the ground wave;

3. The preference of horizontal over vertical polarity calibrations because "mutual coupling between the antenna and the orthogonal transmission line is negligible, calculations of the horizontal ground wave are simpler than calculations for the vertical ground wave, the surface-wave component for horizontal ground wave over earth is more tightly coupled to the surface, and the horizontal ground wave is less sensitive to differences in surface conductivity and permittivity than the vertical wave."

Due to the reciprocity of antenna calibrations and site attenuation, these concerns also represent sources of error in normalized site attenuation measurements. The standards consensus process, as always, is used to find acceptable compromises to such concerns, and in 1988 ASC C63® drafted the first antenna calibration standard, C63.5 [3]. Site attenuation was also added to ANSI C63.4 [4] soon thereafter.

This first draft of ANSI C63.5 recognized the need for an immediate alert, by recommending that antennas used to measure site attenuation not be calibrated on the same site to be evaluated. This first edition of C63.5 simply stated that the standard site method involved three site attenuation measurements. Later editions would refer to taking three "insertion loss measurements."

Notice of Upcoming Workshop

A workshop will be held on ANSI C63.5 - Antenna Calibration - on Saturday, August 15, 2009, just prior to the 2009 IEEE International Symposium on EMC in Austin, Texas. Held at ETS-Lindgren in nearby Cedar Park, the workshop will consist of lectures by Don Heirman of Don HEIRMAN Consultants, Chair of ANSI ASC C63, Mike Windler of UL, Chair of ANSI ASC C63 Subcommittee 1 on "Techniques and Development" and Dennis Camell of NIST, Chair of the Working Group for revisions to ANSI C63.5. Attendees will have the opportunity to apply what they learn via problem solving and performing an antenna calibration using ETS-Lindgren's expansive ISO 17205 certified open area test site and A2LA-accredited calibration lab. Registration information will be available on www.c63.org and www.emc2009.org after January 1, 2009.

During the ensuing years, efforts were made to get the international community to adopt ANSI C63.5 as an international standard for the calibration of antennas within CISPR 16. It turns out that this adoption almost happened well over a decade ago but, for several reasons, it did not "make the cut".

Several concerns were raised, including the fact that the standard allowed for vertical polarizations and did not explicitly restrict such measurements. In addition, the international community considered 3-meter calibration distances insufficient to reduce antenna-to-antenna coupling. This issue was implicitly addressed in ANSI C63.4 with the addition of mutual coupling correction factors for dipole antennas used in normalized site attenuation testing (Table 4 of [4]). The 1998 edition of C63.5 included 10-meter calibration distances and explicitly removed vertical antenna calibrations as CISPR was leaning to this approach.

This resulted in unintended consequences for site measurements. The use of horizontal antenna calibrations for vertical polarity site attenuation measurements assumes the issues 1-3 raised by Smith in 1982 were insignificant. This assumption was cast into doubt in light of the ±4 dB test site criteria in [5]. The errors, once thought to be negligible, needed to be redressed, as they represented between 1 and 2.8 dB of the ±4 dB test site criteria.

These errors were corrected in the 2004 edition of ANSI C63.5, which introduced numerical corrections for biconical dipole antennas and an alternative method for other hybrid antennas used to measure site attenuation. This alternative method included further restriction on reference sites used to calibrate antennas to be used in site validations.

Technical Drawbacks in Earlier Versions

To review, the Standard Site Method (SSM) and Normalized Site Attenuation (NSA) were first introduced by Smith et al. in 1982 [1, 2] in a pair of complementary papers noted above. The methods were adopted in ANSI C63.5-1988/C63.4-1992. It was a leap forward for EMC antenna calibration and site validation measurements, as they provided a standard way for calibrating EMC antennas. This had proved to be quite challenging until then because of the wide frequency ranges and relatively low gains (thus wide beamwidths) of these antennas. SSM was quickly adopted worldwide as the most popular EMC antenna calibration method.

The basic idea of SSM is quite simple. The method builds upon the far field Friis transmission equation, and adds a ray tracing component from the ground bounce of the wave over the conducting ground plane used for these calibrations. Even though a ground plane is used, the standard site method in recent times now aims to produce free-space antenna factors by removing the ground effect mathematically. The ground plane was introduced at the start to provide a repeatable, consistent, and predictable reference. To avoid signal nulls caused by the canceling of the ground-bounced and the direct rays, one of the antennas is scanned from 1 m to 4 m in height. Only the maximum response is kept as the base for calibration.

NSA measurements for site validation tests are a reverse of the SSM for antenna calibrations. In this case, the antenna factors are known, and site performance can be compared with a theoretical value to gauge its fitness (within ±4 dB as indicated in ANSI C63.6 [6]). NSA is defined to be the site attenuation (path loss between the antennas over the ground plane in decibels) subtracted from the antenna factors of the two antennas involved.

To make the Smith formulation work, several assumptions had to be made:

- Recalling the formulation is based on the free-space far-field Friis equation, the antennas are assumed to be in the far field of each other. Near field terms are not considered.

Figure 2: An example of an Open Area Test Site (OATS) used for calibrating antennas (photo courtesy of ETS-Lindgren)

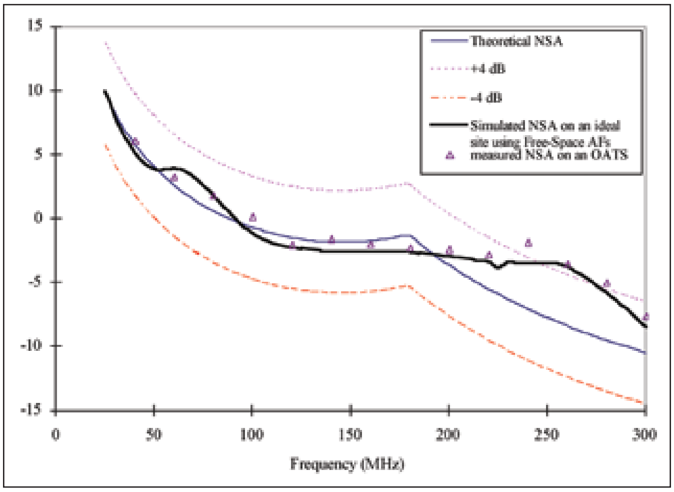

Figure 3: Measured NSA on an open area test site and numerically simulated NSA on a theoretical perfect site (vertical polarization, R=3 m, h1=1 m, and h2= 1~4 m), both by using free-space AFs

- To mathematically remove the ground bounce, the antenna pattern had to be known a priori. Since they are not known, all antennas are assumed to have the same pattern as a point dipole; i.e., with the well-known donut shape.
- Mutual couplings among antennas and their ground images are not considered in the formula, and thus assumed to be negligible.
- Antennas are considered to be physically small, so that the whole of the receiving antenna is considered immersed in a uniform field.
- The separation distance is assumed to be known, which is the same as that of the two theoretical point dipoles.

These assumptions work well for some geometries, such as in the case of biconical antennas at 10 m separation distance, horizontal polarization, and the transmit antenna at 2 m height. However, for site validation measurements over a volume occupied by the equipment under test, NSA as defined in ANSI C63.4 involves four geometries per separation distance (two antenna heights in horizontal and two heights in vertical polarization).

It was quickly realized by many involved in site validation tests that errors due to these assumptions may be so large (they can be on the order of 3 or 4 dB in some instances) that they overwhelm and obfuscate the true site performance. An example of an OATS is shown in Figure 2. As shown in Figure 3, for example, a perfect site would fail the NSA measurement if only free-space AFs are allowed when measured with a pair of common biconical antennas. Test labs and anechoic chamber manufactures got around the limitations caused by these imperfect assumptions in the theoretical model by using the so called "geometry-specific antenna factors."

In practice, people first calibrated their antennas at all geometries required by NSA measurements, and generated antenna factors (using the SSM) for these specific setups. Of course, these antenna factors have the errors (caused by the above assumptions) built in. When the NSA measurements were performed, these same antenna factors were plugged back into the NSA formula. Realizing that NSA procedures are just the reverse of the antenna calibration process, the same errors cancel out.

In reality, this is exactly the same as a site-to-site comparison method. Users end up comparing the site attenuation of the site-under-test to the site where the antenna calibrations were performed. Any of the mathematical calculations involving theoretical NSA and antenna factors are unnecessary (as they cancel out) when using the "geometry-specific antenna factors."

In the late 1990s, a drive to use free-space antenna factors for product testing was gaining momentum, both domestically and internationally. This is because free-space AFs provide a good average value when these antennas are scanned over 1-4 m above a conducting ground plane. ANSI C63.5-1998 was published to harmonize with the CISPR standards. In the 1998 release, antennas can only be calibrated in the near-free-space setup (10 m separation/horizontal polarization/transmit antenna at 2 m height). It is called near-free-space because the SSM assumptions give rise to very small errors (less than 0.5 dB).

This, however, becomes a big problem for users who adopted "geometry-specific antenna factors," as no other geometries are allowed for calibration. An ad hoc group was quickly formed in 1998 to address the situation. The group later became a working group (WG 1-15.6) in Subcommittee 1 which reports to ASC C63®. It was noted that the "geometry-specific AF" is nothing more than a site-to-site comparison and, to make the method consistent, a "golden site" would be needed to complete the theory. There was a great deal of reluctance to the "golden site" concept because of practical concerns. Incidentally, SSM/NSA was embraced originally to avoid a site-to-site comparison method. A different approach was now preferred.

As it turns out, Albert Smith had realized some limitations in his method. He addressed them by providing mutual coupling correction factors for dipole antennas in his seminal SSM/NSA papers. In ANSI C63.5-1988, correction factors for Roberts' dipole were already included. Due to the precedent, and realizing the fact that broadband antennas are most widely used for site validation measurements, the working group adopted numerical correction factors for broadband antennas. The NEC2 code [7] was used for the numerical simulation, as its accuracy had been verified extensively in many scientific studies. These correction factors are referred to as geometry-specific correction factors (GSCF) which is not an antenna factor correction, but a correction to NSA.

Site performance issues typically happen in the frequency range of a biconical antenna. EMC biconical antennas from various manufacturers have almost identical physical appearance and dimensions because they followed the original design in MIL-STD-461 (published in 1968) and restated in ANSI C63.5. This is convenient because unified correction factors can be provided. In the standards, some limits are provided on how much an antenna can deviate from these dimensions. Virtually all available biconical antennas meet the requirements.

Additionally, GSCF depends on the impedance of the baluns. ANSI C63.5 provides corrections for both 50 ohm (1:1 impedance transformation ratio) and 200 ohm (4:1 ratio) baluns. These results were verified against a wide range of commercially available antennas [8].

A benefit of the GSCF approach versus the site-to-site comparison method is that only free-space antenna factors are needed for site validation measurements. Geometry-specific influences are all included in the GSCF. With a site-to-site comparison method, one would have to first find a "golden site," and then perform reference measurements in all geometries (currently a total of eight geometries for 3 m and 10 m separations). With the GSCF method, antenna calibration is performed only in a single geometry that is the near-free-space setup (or any alternative method which produces free-space AF). This greatly cuts down the time and hence the cost associated with site validation measurements, as well as reducing the chance for and sources of additional measurement uncertainties.

An often-cited criticism of the SSM, besides the listed shortcomings from the assumptions, is that, for calibrations using three antennas, one antenna is at a fixed height in one measurement, while scanned in height in another measurement. Since antenna factor is height dependent, we are trying to solve four unknowns with only three equations.

This problem, along with the ones caused by other imperfect assumptions, is solved by the introduction of GSCF.

[1] E_d^{max} is a theoretical parameter proposed by Smith for the purpose of calculating theoretical NSA above a conducting ground plane. It represents the maximum E field (dB μV/m) at the receive antenna position during height scanning for a half-wave dipole with 1 pW of radiated power.

Intuitively, it can be understood as follows - the full-wave simulation includes all effects which corrects for any errors in the Smith model. Actually, GSCF bypasses the Smith model. It employs the numerical model as the base instead. When one works out the algebra, any of the $E_d^{max\,1}$ calculations in the Smith model drop out, leaving only the free-space AFs and numerical geometry correction terms. The Smith formulation is not necessary in the GSCF method. It is included as a historical artifact.

The latest edition of ANSI C63.5 provides a measurement approach to obtain GSCF when numerical values are unavailable. This is described in Annex H of C63.5. This method involves measuring the same pair of antennas on a reference site at different geometries. This boils down to a site-to-site comparison with some extra constants present. Unlike the earlier uncontrolled site-to-site comparison method, Annex H requires that the pair of antennas be measured at least five times on different parts of the reference site. The standard deviation from these 5 measurements needs to be within a certain range for the site to qualify as a reference site. In addition, the reference site has to meet several physical specifications including size and flatness.

Log periodic dipole arrays, or log antennas, are also common for EMC applications. Unified correction factors are not feasible, as log antennas vary greatly by manufacturer make and model. A different approach is under consideration, which is modified from the Smith model. This is called complex fit NSA (CFNSA). It fits measured site attenuation data vs. receiving antenna height to a mathematical model in an effort to solve for log antenna phase center positions and antenna patterns. Varying phase center position and antenna pattern deviations from that of a point dipole are the dominant error sources for log antennas in the Smith model. CFNSA does not make assumptions on either parameter. Interested readers are referred to [9, 10] for more information.

Changes, Present Vision and Future Plans

The latest revision of ANSI C63.5 has a number of major changes from previous editions and hence the 2006 edition must be used solely. Most of these were added as normative annexes.

The primary additions relate to free-space antenna factors (FSAF), geometry-specific correction factors (GSCF), the use of a standard antenna calibration site (SACS), and an informative annex on uncertainty. These topics improve the technical accuracy and repeatability of the measurement methods described, and address the compatibility with international standards. However, there still seems to be an occasional misunderstanding as to the proper use of ANSI C63.5 document, which we will now explore.

From the latest version of C63.5, there are two sets of data needed when using EMC antennas. These are related to each other, as explained above. One data set is for product testing and, by international consensus, is the FSAF. This means that there is only one AF for one antenna. The other set of data is used when determining test site validation. FSAF and GSCF are combined to account for the effects of geometry in these NSA measurements.

If the antenna is to be used for product testing, then the free-space AF is used to determine the emission levels for both horizontal and vertical polarizations. The SSM provides near free-space AFs that are acceptable as-is if no corrections are provided. C63.5-2006 [11] currently has corrections for biconical dipoles, and is working on application of free-space corrections for other types of antennas.

The rationale for having a stricter NSA requirement than the usual ±4 dB is for the antenna calibration site to conform tighter to theoretical NSA, since any error that the site might introduce from the theoretical value would propagate through all of the calibration process. If the ±2 dB NSA requirement is not met, the site shall not be used for antenna calibrations. There are three requirements for validation of the antenna calibration site:

1. The test site shall be constructed in accordance with C63.7 [12].

2. Measured NSA shall be within ±2 dB of an ideal site.

3. The NSA shall be evaluated over a volume (e.g., as an alternate test site).

If the antenna is to be used for test site validation, then geometry-specific correction factors are also needed. In Annex G, there are tables containing GSCFs for biconical antennas. These GSCF terms can be measured for all types of EMC antennas, and the method is provided in Annex H. These GSCF terms combine with the FSAF to provide a site-to-site comparison of the antenna calibration site (SACS) with the user's test site.

The calibration site has additional requirements that help specify its design and control its environment that are also specified in Annex H. There are three requirements for validation of the antenna calibration site to use for GSCF:

1. NSA shall be measured using biconical dipoles or tuned dipoles.
2. The test site shall be constructed in accordance with C63.7 and Annex H of C63.5.
3. NSA shall comply with the statistical criteria described in this Annex.

New advances being considered in the next revision of this standard are an option for time-domain gating to improve antenna calibrations, guidance on a complex-fit NSA for log-periodic antennas, and a limit on the type of antenna to use in this testing based on maximum variations of vertical to horizontal NSA.

The use of time-domain gating to determine free-space AFs is discussed in [13]. This method will provide FSAF for any type of antenna, provided that its time-domain pulse length is short compared to the period needed for the reflected signals to be detected. This means that the antenna type will dictate the measurement geometry. Time domain gating can also be used for site validation, as described in [14]. Much of this work was derived from earlier efforts documented in [15].

Antennas used for test site validation will need to have limitations imposed, due to the variations between horizontal and vertical polarization NSA. The goal here is to address the hybrid antennas, which have strong ground plane coupling in one polarity--usually vertical--and much less coupling in horizontal orientation. The standard requires the antenna be calibrated only in the horizontal polarity at a 2-meter transmitting height to establish a near free-space condition.

The industry consensus has been that the use of all antennas in other geometries, such as vertical polarization at receiving height of 1-meter, introduces only minor variations in the antenna performance. This was true when the antennas were dipoles and dipole like designs (log periodic and biconical dipoles). This is no longer true for larger hybrid antennas with very large low-frequency elements that are orthogonal to the ground plane in the vertical polarity. The influence of the ground plane on the antenna must be limited to ensure the results correlate to dipole-like antennas.

Summary

ANSI C63.5-2006 is the latest revision of the U.S. standards document available to provide methods of calibration for antennas used in EMC measurements. While this version has addressed issues of concern and incorporated technical advances, several new items have arisen that will need to be considered in this standard.

For the next revision of this document, additional text is being added to improve user's understanding of these concepts and the explanation of their usage. Discussion of standard gain horns and their requirements for calibration is ongoing and will result in more specific requirements for this antenna type. Several text additions for clarification and ease of use include a redesign of Table 3, addition of the E_d^{max} equation for the vertical polarization into Annex A, and specification of the minimum frequency resolution needed. An addition of a table for site specific corrections for dipole antennas will be included in this revision (similar to Annex G for biconicals).

This standard is revised to improve understanding, promote comprehension, incorporate technical advances, and add corrections as needed since the last version. There are several sources for these changes, including feedback from the users of the document, and harmonization with similar international standards and other national standards. When technical advances are made, they too are incorporated into the standard. Removal of any typographical errors and further clarifications of existing text and figures are continual components in the revision/maintenance cycle.

In this current cycle, about one third of the proposed changes relate to clarifications and typographical corrections or additions to existing text. Approximately one fourth of the current work is related to harmonization with other standards. The remaining changes are for technical advances with EMC antenna measurement methodologies.

Since the last revision of this standard was published in 2006, the completion of this next revision is being targeted for 2009. While overall goals are currently scripted, specific details are being molded by the working group. If you have comments on these topics, or wish to assist in the development of this standard, contact C63® at www.c63.org. This U.S. national standards committee always welcomes new members that have an interest in seeing this standard, or its other standards, developed with newer and more accurate details in a timely manner. ☐

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