The Importance of Antenna Calibration

by Ron Bethel, ETS-Lindgren

In the United States and many parts of the world, antennas are calibrated per the American National Standards Institute C63.5: American National Standard for Electromagnetic Compatibility—Radiated Emission Measurements in Electromagnetic Interference (EMI) Control—Calibration of Antennas (9 kHz – 40 GHz). A standard sets uniform methods, processes, and practices for the industry. Some standards may be mandatory while others are voluntary.

Example of an OATS

When standards are required in contractual or regulatory regimes, then they are mandatory. For example, in the widely used ANSI C63.4 standard on measuring emissions, antennas shall be calibrated using ANSI C63.5 in performing radiated emissions measurements per FCC Part 15 for low-power devices such as those for information technology equipment.

Antenna calibration standards are consensus standards that define methods and practices recommended by and agreed as best practices to be used to ensure consistent results. The user of the item or service has the responsibility of validating the suitability of available standards and specifying and using the correct one.

ANSI C63.5 was accepted by consensus in the United States while in Europe, Asia, and other countries, alternate antenna calibration standards are being implemented and developed. Yet many still are using ANSI C63.5.
as these developments mature. ANSI ASC C63® membership represents industry, regulatory bodies, military, universities, and consultants located in the United States, so a wide range of users impacted by ANSI standards has direct input.

With the global economy driving the market, there is an increasing need to harmonize the various antenna calibration standards where appropriate. Work began over a decade ago specifically to bring the Standard Site Method (SSM) of ANSI C63.5 into the European standard CISPR 16 as the method of antenna calibration to be used. However, parts of the standard did not meet the view of the CISPR working group then assigned this task.

In the SSM method, the antenna factor was derived at a particular antenna height above the ground plane. There also was discussion on the accuracy and uncertainty of such antenna calibrations that still is being argued, namely what ANSI C63.5 provides vs. what the other proposed calibrations require.

Of course, the needs of the user must be better defined in the accuracy and uncertainty of the calibrations. For example, is it absolutely necessary to have an antenna calibration that has the lowest uncertainty if the other techniques have uncertainties slightly larger?

**Common Terms**

Here is a listing of the most common terms related to antenna calibration:

**Near Free-Space Antenna Factor (NFSAF)**

Antennas calibrated under NFSAF over a conducting ground plane are specified with horizontal polarization, $R=10\ m$, $h_1=2\ m$, and $h_2=1$ to 4 m. Under this geometry, antenna factors are minimally affected by the test environment.

This is what you have been getting with your antenna calibration for years, and it should match up with previous calibration data. The calibration is performed on a high-quality antenna test site defined in both ASC C63.5-2006 and CISPR Pub 16-1-5 (2003).

**Free-Space Antenna Factor (FSAF)**

Ideally, FSAF is an environment having no reflections or couplings to the antennas. It is not very realistic.

In the case of biconical antennas, to get the FSAF using ANSI C63.5-2006, a correction factor is applied to the actual calibration that produced the NFSAF. The FSAF shall be used for product testing and site validation measurements in conjunction with the geometry-specific correction factors (GSCF).

In the case of broadband horn antennas that are highly directional (Figure 1), there is an option for the FSAFs. These are measured using a technique where the antenna does not see signal reflections or the reflections are so small they have little or no effect on the calibration.

**GSCF**

GSCFs are provided by the standard or measured for each frequency at a specific geometry. These correction factors are for a pair of antennas for test-site validation and are not geometry-specific antenna factors.

**SSM**

The SSM is the most commonly used method for antenna calibration over a conducting ground plane and highlighted in ANSI C63.5. Usually three pairs of measurements are needed which involve three antennas.
Maintaining Calibration

The importance of maintaining calibration for antennas used frequently for product compliance measurements cannot be over-emphasized. For example, if the calibration changes due to antenna damage or misuse, the compliance data will be suspect, and the compliance measurements may well have to be repeated. Figure 2 shows the history of calibration for a biconical antenna over time and the effect the lack of maintenance had on the antenna’s performance.

New Emphasis on Measurement Uncertainty

Many factors impact the accuracy of antenna calibration, hence contributing to the term measurement uncertainty. Examples include properly matching the connection of the antenna to the cable and the cable to the receiver as well as taking into account cable insertion loss related to temperature.

According to Bob DeLisi, senior staff engineer at Underwriters Laboratories and chair of the C63.23 Working Group in ASC C63® on Measurement Uncertainty, the ambient temperature impact of testing at an open area test site (OATS) can be very important. For example, if testing is done at a time of year that provides a significantly varying temperature range over the antenna calibration interval, the heating or cooling of the cable can introduce errors. These errors must be factored into the uncertainty budget.

For the first time, the proposed revision to ANSI C63.5 will contain text on the elements of uncertainty and the definitions and equations describing how a lab calculates its measurement uncertainty and provisions on how to reduce the overall error contributions. It will be presented in a format enabling those performing antenna calibrations to readily enter data necessary for the calibration.

The importance of measurement uncertainty when applied to antenna calibration sometimes is underestimated or ignored according to Dennis Lewis, lead engineer for RF/microwave and antenna metrology for The Boeing Company. For instance, if two laboratories calibrate antennas, you expect to have nearly the same result within the measurement uncertainty of their test setups, instrumentation, and procedures. If their measurement uncertainties are not comparable, you will get different results on that fact alone. How can you decide which calibration lab to use?

Industry is moving toward the use of global suppliers, which makes it more critical to harmonize global antenna calibration standards. It also is important to understand the traceability path to a recognized national standards lab.

For many companies, using an accredited calibration lab is all that is required. However, it is important to understand the lab’s scope of accreditation and verify that the scope is adequate for the service being requested. Accredited labs are required to participate in interlab comparisons (ILC) where a standard artifact, in this case an antenna, is sent around to various labs to be measured. The results are shared among the labs in an effort to validate each lab’s calibration process and help identify areas for improvement to processes and standards. Most

Figure 2. History of Calibration for a Biconical Antenna

Golden Antennas

by Daniel D. Hoolihan, Hoolihan EMC Consulting and NIST/NVLAP Lab Assessor

Reference standards are called out in ISO/IEC 17025: General Requirements for the Competence of Testing and Calibration Laboratories.

The term reference standards appears in Clause 5.6, titled Measurement Traceability, specifically, Clause 5.6.3.1.

The laboratory is required to have a program and procedure for calibrating its reference standards. They shall be calibrated by a body that can provide traceability as described in Subclause 5.6.2.1. These reference standards of measurement should be held by the lab and used for calibration only and for no other purpose unless it can be shown that their performance as reference standards would not be invalidated. Finally, reference standards must be calibrated before and after any adjustment.
Revisions to ANSI C63.5

Changes and improvements have been made to ANSI C63.5 from the first publication in the 1980s. The most recent editions were in 1988, 1998, 2004, and 2006. In the present edition, the most notable addition was that specified biconical antenna calibration data should be reported as NSAF and corrected to FSAF to be used for product testing and Normalized Site Attenuation (NSA) measurements. The NSA calibration requires that geometry-specific antenna factors be added to the FSAFs.

In general, the 2006 standard provides a means of measuring antenna factors for most types of antennas used in emissions testing. The parameters specified for the calibration are horizontal polarization at a separation distance of 10 meters and a transmitting antenna height of 2 meters, and the receiving antenna search heights are from 1 to 4 meters.

Other key provisions of the 2006 version include the following:

- The antenna factors can be used for either vertically or horizontally polarized measurement at separation distances of 3 meters or more.
- Calibration measurements at 3 meters included in previous versions of ANSI C63.5 were considered unacceptable and removed.
- Previous versions of ANSI C63.5 included information on calibration using vertical polarization; this was removed.
- The SSM based solely on horizontally polarized measurements provides one antenna factor that is used for both polarizations from 30 MHz to 40 GHz.
- Antenna factors obtained for biconical antennas are NSAF; the standard requires they be corrected to FSAF using the correction factors provided in Table G.1 of the standard.
- Biconical antennas used for NSA measurements will be calibrated at a 10-meter separation, horizontal polarization, and then Table G.1 will be used to obtain the FSAF. Table G.2 or Table G.3, which lists the GSCF, is used together with the FSAF in performing normalized site attenuation measurements (30 MHz to 200 MHz). It is important to note the frequency limitation.

Current Status of ANSI C63.5

by Dennis Camell, NIST and the ANSI-ASC C63® Subcommittee 1

ANSI C63.5-2006: American National Standard for Electromagnetic Compatibility—Radiated Emission Measurements in Electromagnetic Interference (EMI) Control—Calibration of Antennas (9 kHz to 40 GHz) provides methods of calibration for antennas used in EMC measurements. While this version has addressed issues of concern in the past and incorporated technical advances, several items are proposed for the next revision.

Since 2006, a working group in Subcommittee 1 of ASC C63® has been developing the next revision. This group is composed of knowledgeable individuals whose work is related to the use of this standard.

Changes to this standard are done periodically to improve understanding, promote comprehension, incorporate technical advances, and correct mistakes since the last version. The time needed for a complete revision cycle is minimally two years.

There are several sources for these changes including feedback from the users of the document and harmonization with similar national and international standards. When technical advances are made, they, too, are incorporated into the standard. Corrections to any typographical errors and clarifications of existing text and figures are a continual component in the revision cycle.

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

The last revision had a large change relating to FSAF and GSCF and included an informative annex on measurement uncertainty. Additional text is proposed in the next revision to improve the understanding of these concepts and the explanation of their usage.

Discussion on standard gain horns and their requirement 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 Table 3 redesign, addition of the $E_{\text{max}}$ equation for vertical polarization into Annex A, and specification of the minimum frequency resolution. An expansion of the calibration site correction table similar to the present annex G for biconicals will be included for dipole antennas in the next revision.

Also, new are an option for time-domain gating to achieve free-space results, a use for complex-fit NSA for log-periodic antennas to account for specific geometries, and a limitation on the antenna type for NSA based on the maximum variation in the comparison of vertical to horizontal NSA. Finally, the description of measurement uncertainty may be moved into the upcoming ASC C63® uncertainty standard which has been given the number ANSI C63.23. This is in draft form and will not be available before mid 2009.

The completion of this revision of ANSI C63.5 is targeted for 2009. While overall goals are currently scripted, details still are being molded by the ASC C63® Subcommittee 1 working group on antenna calibrations.

If you have comments on these topics or wish to assist in the development of this standard, contact ASC C63®. This U.S. national standards committee always welcomes new members that have an interest in seeing this standard or its other standards developed with new and accurate details in a timely manner.
• No corrections are applied to the calibration results (NFSAF) for broadband antennas such as the log periodic used for product testing. This is the same as previous versions of the standard.
• GSCFs for broadband antennas such as the log periodic dipole arrays are measured in all geometries required for NSA measurements at 3- and 10-meter separation. This is similar to previous versions of the standard. There are more restrictions on the site that will be used for measuring GSCF. In addition, several measurements over different parts of the ground plane are needed for each geometry.
• Broadband horn antennas may be calibrated using the SSM with the exception that height search is not necessary when there is no ground reflection. Although this is not new, very few people are aware of this FSFAF measurement option.

The changes have removed 3-meter calibrations for most antennas and eliminated references to vertical calibrations.

Usage Options

Since the 3-meter calibration has been removed from ANSI C63.5, for most antennas you still can have the calibration performed under SAE/ARP 958. Although this is known for 1-meter calibrations, Annex C provides the same method for determining antenna factors at 3 meters that was previously in ANSI C63.5.

If you are conducting testing per ANSI C63.4, you must use the antenna factors derived from calibrations as specified in ANSI C63.5. It is your responsibility to specify the calibration to be performed.

Horn antennas may be calibrated at a distance of less than 10 meters, but the antenna factors can only be used at that distance. This is a very simplified statement. For exact details, refer to ANSI C63.5-2006 5.2 pages 10-11.

2009 ANSI C63.5 Workshop

The ANSI C63.5 Workshop, scheduled in conjunction with the 2009 IEEE International Symposium on EMC, will feature a series of lectures on ANSI C63.5 by Don Heirman, chair of the ANSI ASC C63® Committee; Mike Windler of Underwriters Laboratories, chair of ANSI ASC C63® Subcommittee 1 where this standard resides; and Dennis Camell of NIST, chair of the working group addressing revisions to the standard. Following the lectures, hands-on demonstrations will supplement the material presented using the ISO 17205-certified OATS and A2LA-accredited lab at ETS-Lindgren.

Summary

Accurate and repeatable antenna calibration is becoming increasingly important as antenna technology has advanced. Revisions to ANSI C63.5 are taking into account new impact factors such as measurement uncertainties and new technology developments such as seen with the log periodic, biconical, and horn antenna types.

Bottom line, the antenna is the first piece of a radiated emissions measurement system, and its impact on test results cannot be understated. Accordingly, proper and timely antenna calibration is essential to maintaining the optimal measurement system. While the changes incorporated in ANSI C63.5-2006 have had a significant effect on biconical antenna calibrations used for product testing and site validation, they have removed 3-meter calibrations for most antennas and eliminated references to vertical calibrations.

Remember, calibration providers are an excellent resource for information, but you know your business best. Always ensure that you are up to date and request the test that fits your requirements and be very specific about the calibration that you are purchasing and that the calibration standard is specified.

References/Additional Reading

• ANSI C63.4-2003: Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.
• CISPR 16-1-5: Specification for radio disturbance and immunity measuring apparatus and methods—Antenna calibration test sites for 30 MHz to 1,000 MHz, November 2003
• ANSI C63.5-2006: Electromagnetic Compatibility—Radiated Emission Measurements in Electromagnetic Interference (EMI) Control—Calibration of Antennas (9 kHz to 40 GHz)
• SAE/ARP958-2003 Aerospace Recommended Practice: Electromagnetic Interference Measurement Antennas; Standard Calibration Method

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About the Author

Ron Bethel is the calibration manager for ETS-Lindgren. He has been employed by the company for more than 12 years. ETS-Lindgren, 1301 Arrow Point Dr., Cedar Park, TX 78613, e-mail: ron.bethel@ets-lindgren.com

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