Introduction to EMC Antenna Calibration Methods: An overview of new antenna developments, related standards, calibration and what you need to know for efficient and compliant EMC testing

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Antenna Calibration

- **What is calibration**
- **What does it mean to calibrate an antenna**
- **Standards**
- **Specifying**
- **Receiving**

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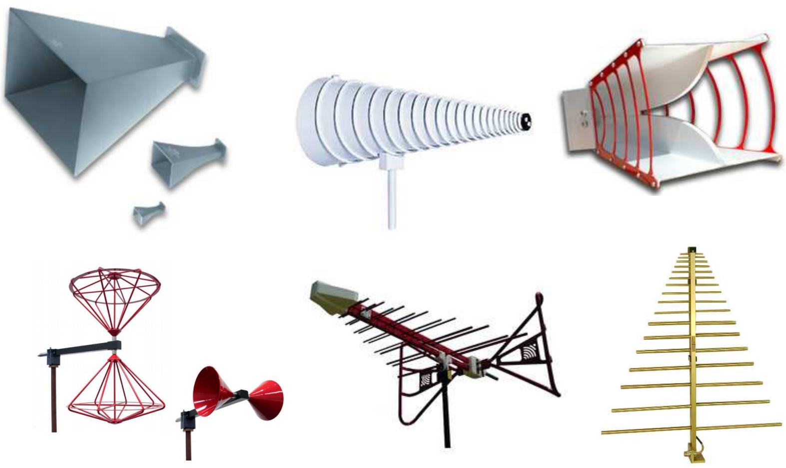
Antenna Calibration



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Key Concepts

- Calibration - Set of operations that establish the relationship between values of quantities indicated by a measuring instrument and a reference standard
- Metrology – "the science that deals with measurement"
- Measure - "to determine the dimension, quantity or capacity of something"
- Verification - Checking the product or process to input requirements
- Validation - Checking that the product or process is suitable for its intended use - does it perform/function in the way intended

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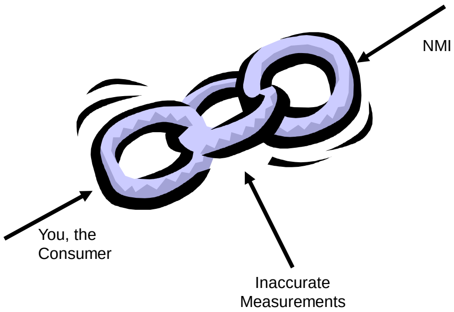
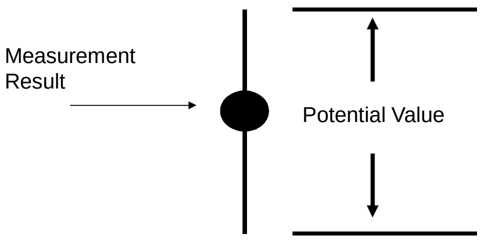
Measurement Traceability

- Traceability - Unbroken chain of comparisons to the SI units, all having stated uncertainties



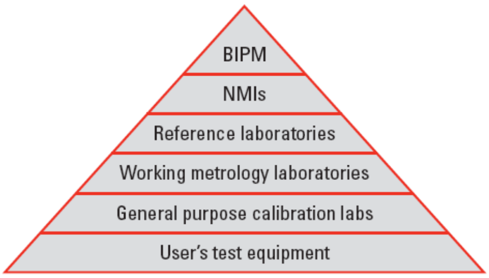
Measurement Traceability

- Uncertainty – "Value assigned to a measurement result that characterizes how well it is known/unknown"



Measurement Traceability

FIGURE 1 Traceability Pyramid



BIPM = Bureau International des Poids et Measures
(International Bureau of Weights and Measures)
NMIs = National metrology institutions

REFERENCE
Jay Bucher, ed., *The Metrology Handbook*, ASQ Quality Press, 2004.

Measurement Traceability

International System of Measurement

Mass	Kilogram (kg)	Amount of Substance	Mole (mol)
Time	Second (s)	Electric Current	Ampere (A)
Length	Meter (m)	Luminous Intensity	Candela (cd)
		Temperature	Kelvin (K)

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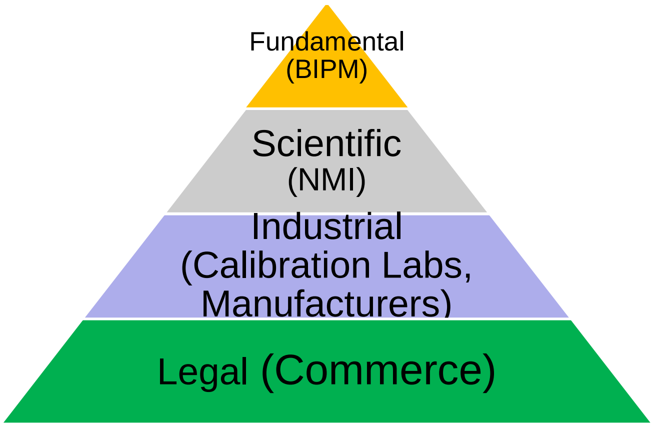
Metology Cases (Levels of Metrology)



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Traceability in Antenna Calibrations

- Achieved through the use of calibrated reference instruments on test sites meeting required performance criteria.
- Uncertainty in calibration relates to the calibration process.

Note: This concept applies to all transducers.

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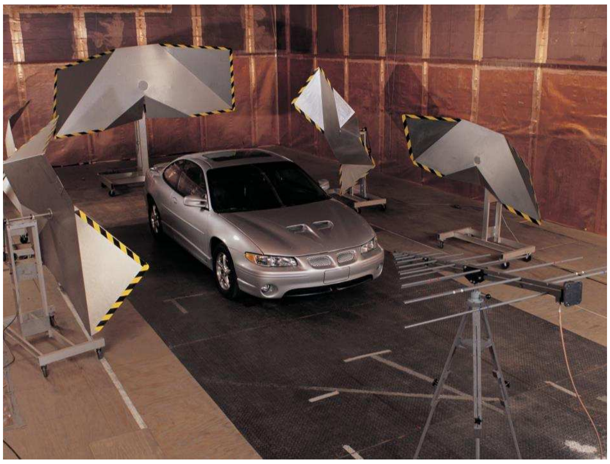
So What…



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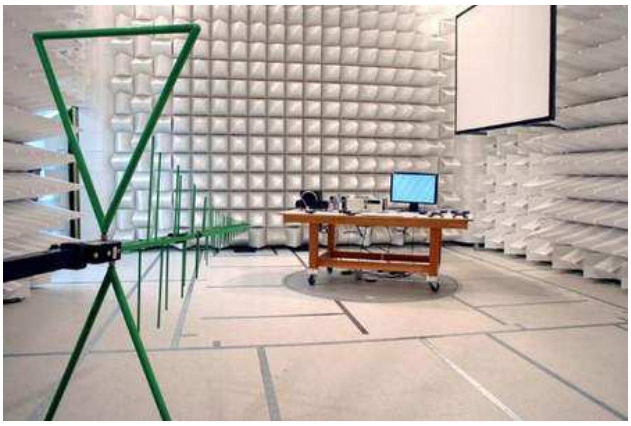
So What…



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So What

- **Regulatory Compliance testing, field strength limits**

FS(dBuV/m) = PL(dB)+R(dBuV)+AF(dB/m)

Where:

FS(dBuV/m): Field Strength for comparison to regulatory limits

PL(dB): path loss from measurement antenna to receiver

R(dBuV): Reading on the measurement receiver using the appropriate detector and bandwidth

AF(dB/m): ….

So What

Antenna Factor*: Ratio of the electric field in the polarization direction of the antenna to the voltage induced across the load connected to the antenna and expressed in decibel form (20 log (E/Vo)), in dB(m^{-1}), is determined:

$$F = E - Vo$$

where, *E* is the field strength in dB(μV/m) of the incident plane wave that illuminates the antenna; *V* is the resultant voltage in dB(μV) across the output terminal of the antenna.

Or

In terms of the linear gain of the antenna (G) and wavelength (λ), value that can be measured:

$$AF = \frac{9.73}{\lambda\sqrt{G}}$$

*Definition from ANSI c63.5:2006

EMC Antenna Calibration Standards

- **IEEE 291:1991**
  - Default historical reference
- **SAE ERP 958:2003**
  - 1m or 3m antenna calibration
- **ANSI C63.5:2006**
  - DeFacto “Standard”
  - 10m Horizontal only
- **CISPR 16-1-6:** Specification for radio disturbance and immunity measuring apparatus and methods – Part 1 -6: Radio disturbance and immunity measuring apparatus – EMC-antenna calibration

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IEEE 291:1991

- **Includes references to all other methods**
- **NOT state-of-the-art**
- **ESCM (as covered in c63.5)**
  - Conducted calibration of antenna
  - Uses calibration fixture
- **Loops**

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SAE ERP 958

- **Automotive, Aerospace, MIL**
- **Nearest point approach to separation measurement**
- **2 identical antenna method, 1m distance, 3m height, over a ground plane**
  - 3 antenna method, 3m distance, 1-4m scan receive antenna height to 1m height of transmitting antenna (needed for the gain determination for 1 of the 2 antenna in the 2 antenna method)

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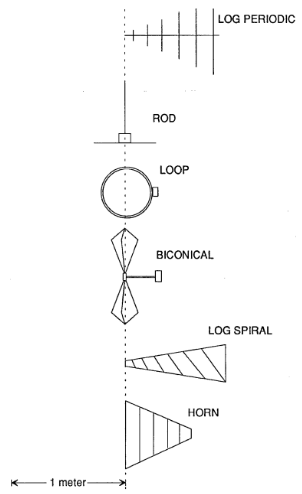

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ANSI c63.5

- **Changes over the years**
  - Previously V and H
  - Distances, measured from midpoint
  - Calibration Sites, site meeting NSA per c63.4 with +/-2dB

Table 1—Calibration methods for antennas

Antenna Type	Antennas for Product Test				Antennas for Normalized Site Attenuation			
	Clause 5	Clause 5 + Annex G	Clause 6	Clause 7	Clause 5	Clause 5 + Annex G	Clause 6	Annex H
Monopole				X				
Tunable Dipole	X		X		X		X	
Biconical Dipole		X	X			X		X
Log Periodic Array	X		X		X		X	X
Broadband Hybrid	X		X					X
Horn	X						X	
Other	X							

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ANSI c63.5:2006

- **Separation distance, *R*, the horizontal distance between antennas when the antennas are at the same height.**
  - Dipole and Biconical dipole antennas: measured from the midpoint of the dipole elements.
  - Log-periodic array antennas: measured from the midpoint of the elements along the longitudinal axis of each antenna.
  - Horn antennas: measured from the front face of the antennas.

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CISPR 16-1-6, the newcomer

- The standard provides procedures and information on the calibration of antennas for determining antenna factors (AF) that are applicable to antennas intended for use in radiated emission measurements in accordance with CISPR 16-2-3.
- The frequency range addressed is 9 kHz to 18 GHz. The relevant antenna types covered in this standard are monopole, loop, dipole, biconical, log-periodic dipole-array (LPDA), hybrid and horn.

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CISPR 16-1-6, the newcomer

- The standard provides multiple methods for determining free-space AFs or height-dependent AFs used for product emissions measurements.
  - F_a and F_a: antenna factor and antenna factor for a monopoles calibrated in plane wave conditions
  - F_{ac}: antenna factor for monopoles, ECSM
  - $F_a(h,p)$ and $F_a(h)$: height and polarization dependent factors
  - F_{aH}: magnetic antenna factors
- **For >30 MHz, two types of sites are used**
  - Over metal ground plane
  - Free-space (absorbing material on the ground)

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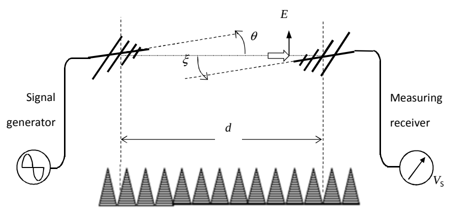
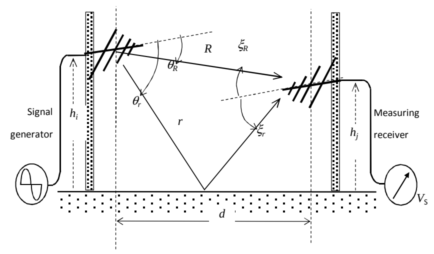
CISPR 16-1-6, the newcomer





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CISPR 16-1-6, the newcomer

- Calibration Sites, CALTS
- Similar to c63.5
- Phase corrections
- Uncertainty details
- Loops

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CISPR 16-1-6, the newcomer

Antenna type, frequency, MHz	Suggested method	Alternative method, frequency, MHz	Method not requiring an STA
Biconical, 30 to 300 Biconical part of hybrid, 30 to 240	8.4 SSM CALTS	9.3 VP CALTS 9.1 SAM FAR B.4.2 HP SAM height-averaging	B.4.3 HP TAM height-averaging
LPDA, 200 to 3 000[a] LPDA part of hybrid, 140 to 3 000[a] Horn, ≥ 1 000	9.4.2 TAM high above ground	9.4.3 SAM high above ground 9.4.4 TAM or SAM in FAR or with absorber on ground 8.4 SSM CALTS, 140 to 1 000 9.5.1.3 TAM in FAR, 1 000 to 18 000[b]	9.4.2
Horn, 1 000 to 18 000 LPDA, 1 000 to 18 000	9.5.1.3 TAM in FAR	9.5.2 SAM in FAR 9.4.2 TAM high above ground	9.5.1.3
Tuned dipole	B.5.2 SAM at "free-space" height using calculable dipole	B.4.2 HP SAM height-averaging 8.4 SSM CALTS, 30 to 1 000	B.5.3 TAM at "free-space" height

[a] The upper frequency depends on the manufacturer's specification.

[b] Applies only to LPDA antennas.

Methods Used

- Standard site method, SSM, Reference site method, 3 antenna method, TAM, 3AM
- Standard antenna method, SAM, Reference antenna method, RAM, substitution antenna method
- Equivalent Capacitance Substitution Method (ECSM)

Methods Used, SSM

Pre-defined test location

3 similar antenna

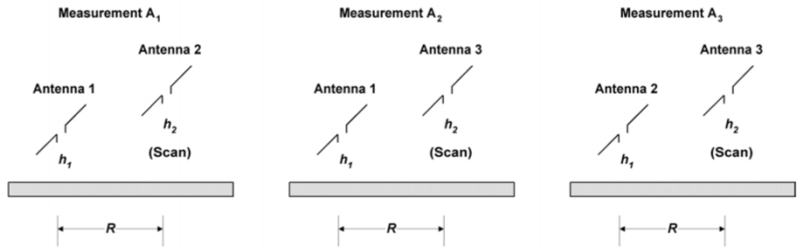
$$AF_1\ (dB) = 10 \log_{10} (f_M) - 24.46 + .5 \times (E_D^{max} + A_1 + A_2 - A_3)$$

$$AF_2\ (dB) = 10 \log_{10} (f_M) - 24.46 + .5 \times (E_D^{max} + A_1 + A_3 - A_2)$$

$$AF_3\ (dB) = 10 \log_{10} (f_M) - 24.46 + .5 \times (E_D^{max} + A_2 + A_3 - A_1)$$

Methods Used, SSM

Measurement procedure



Methods Used, SSM

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ANSI c63.5:2006

- Calibration Site Requirements
  - NSA of +/-2 dB or better (4.3)
    - Measured using techniques in C63.4
      - ANSI/IEEE c63.4:2009 (NSA)
      - CISPR 16-1-4 (NSA and sVSWR)
  - Annex H requirements
- Antenna Symmetry (4.4.1)

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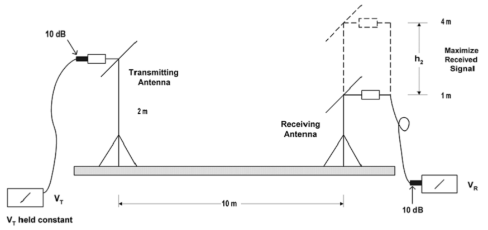
ANSI c63.5:2006

- **Standard Site Method (SSM)**

  The Standard Site Method (SSM) (based solely on horizontally 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. For either use, the measurement distance is 10 m, the transmitting antenna height is 2 m, and the receiving antenna search heights are from 1 m to 4 m. (5.1)

ANSI c63.5:2006

- **How the measurement is made:**
  - Clause 5, Standard Site Method
    - 10m, H polarization (bicon, LPA, hybrid)
    - Horn: distance equal to or greater than $R = 2D^2/\lambda$; not at a distance less than $R = 0.5D^2/\lambda$. *D (m)* is the largest dimension (e.g., width or height) of the aperture of the antenna and λ (m).



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ANSI c63.5:2006

- **Antenna for Normalized Site Attenuation**
- **Appendix G**
  - Biconical dipole antennas, corrections to free space shall be applied for product measurements and are provided in Annex G.

Antenna Factor recorded (SSM) - ΔAF (Table G.1) = FSAF, dB.

$$A_N = V_{Direct} - V_{Site} - FSAF_T - FSAF_R - GSCF$$

Mutual coupling correction factors for tuned dipoles shall be applied and are provided in ANSI C63.4-2003. The near free-space antenna factors for the remainder of the listed antennas shall be used without further correction for emission measurements as specified in ANSI C63.4-2003.

Two measurements are needed to determine GSCF for a pair of antennas:

(1) measure the SA in the near-free-space geometry and

(2) measure the SA in any additionally required geometry. These SA values are applied as shown in Equation (H.1).

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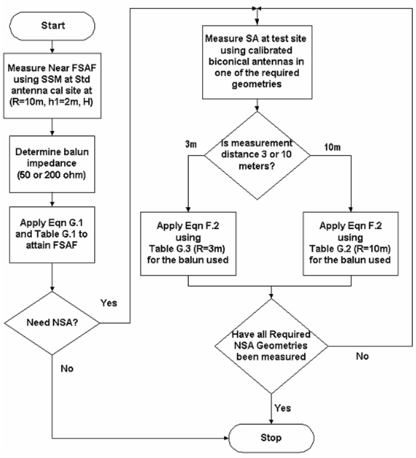
ANSI c63.5:2006

- **Appendix G**



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Methods Used, SAM

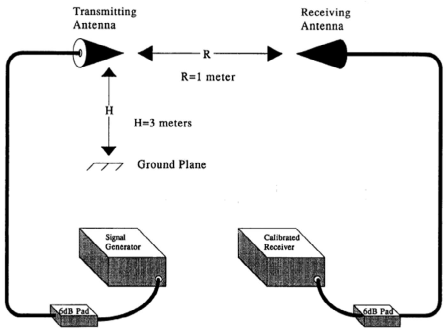
Known antenna used in comparison

Oriented to minimize nulls

$$AF_1 = A_1 + 20 \log f_M - 48.92 + E_D^{max} - AF_2$$

Methods Used, SAM

SAE ERP 958



$$AF_1\ (dB) = 10\log_{10}(f_M) - 24.46 + .5 \times (E_D^{max} + A_1 + A_2 - A_3)$$
$$AF_2\ (dB) = 10\log_{10}(f_M) - 24.46 + .5 \times (E_D^{max} + A_1 + A_3 - A_2)$$
$$AF_3\ (dB) = 10\log_{10}(f_M) - 24.46 + .5 \times (E_D^{max} + A_2 + A_3 - A_1)$$

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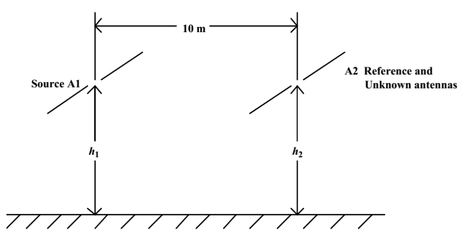
ANSI c63.5:2006

- **How the measurement is made:**
  - Clause 6, Reference Antenna Method (30MHz to 1GHz)
    - NOT important to position the antenna to max signal, but it is important to avoid the region around a null, height of 2.5m to 4m



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Methods Used, SAM

- **Loops**
  - Standard receiving loop
    - Substitution
  - Standard transmitting loop
    - Known field

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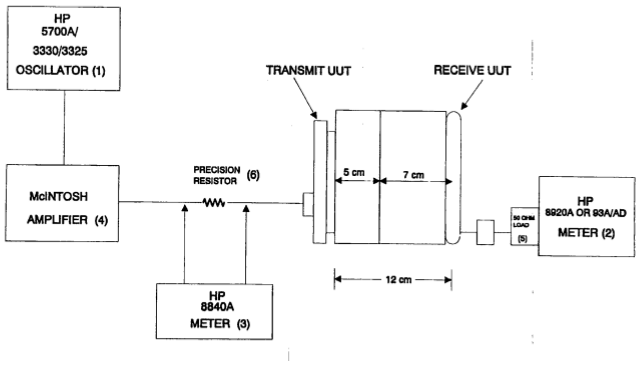
- **Small Loops**



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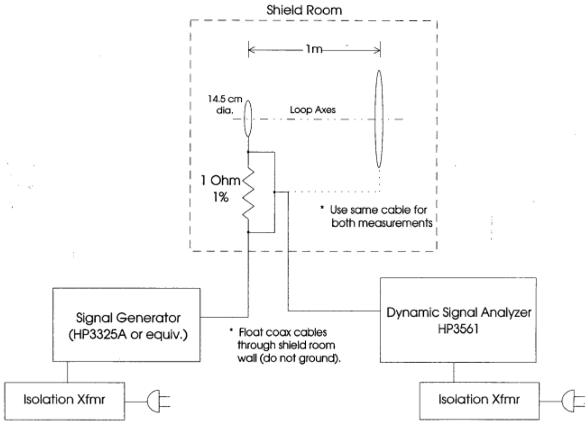
- Loops Freq. < 10kHz



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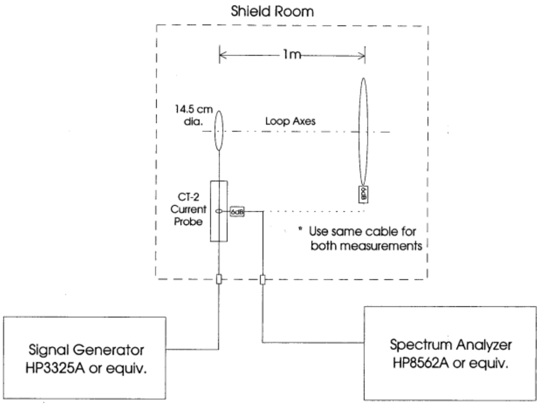
- Loops Freq. > 10kHz and <10MHz



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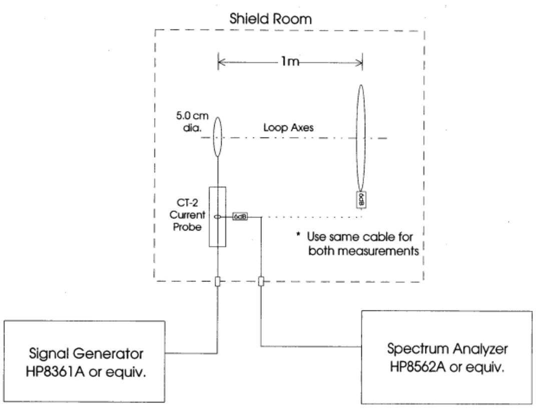
- **Loops Freq. > 10MHz**



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CISPR 16-1-6

- **Loops**
  - TEM Cell
    - Predeterministic field
    - Shielded loops only
  - Helmholtz Coils

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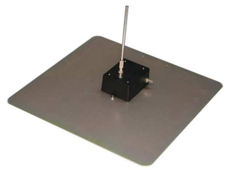
Methods Used, ECSM

- **ECSM Summary**
  - Mono-pole antenna
  - Capacitor used to couple energy
    - Value based on the length and diameter of the antenna element
    - Correction value added to measurement



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IEEE 291, the grandfather

- **Measurement Generalities**
- **ECSM**

AF(dB)=V_D-V_L+L_{eff}

$$L_{\text{eff}} = \frac{\lambda}{2\pi}\tan\frac{\pi h}{\lambda}$$

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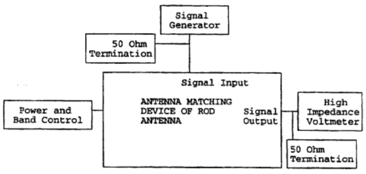
SAE ERP 958

- **ECSM**

  10pF coupling capacitor for a 1m rod; 6dB correction factor



NOTES:
1. At selected frequencies (4.3(g)) adjust the signal generator for a level which is sufficient for an accurate reading on the voltmeter. Insure that the level is below over-load.
2. Calculate the antenna factor (AF) where
   AF = 20 Log (Input Voltage / Output Voltage) + 6 dB
3. Repeat at the frequencies of 4.3(g).
4. Manufacturers should be consulted on implementation of this technique for a particular antenna due to variations between antennas.
5. All cables except for power and band control are 50 Ω coaxial cables.

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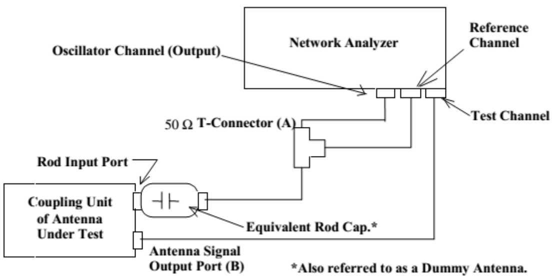
ANSI c63.5:2006

- **ECSM**

  $AF(dB) = V_D - V_L + 6.02 = V_D - V_L + L_{eff}$

$$L_{\text{eff}} = \frac{\lambda}{2\pi}\tan\frac{\pi h}{\lambda}$$

$$C_a = \frac{55.6h}{\ln\frac{2h}{a} - 1}\,\frac{\tan\frac{2\pi h}{\lambda}}{\frac{2\pi h}{\lambda}}, pF$$



$$h_e = \frac{\lambda}{2\pi}\tan\frac{\pi h}{\lambda}, m$$

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CISPR 16-1-6, the newcomer

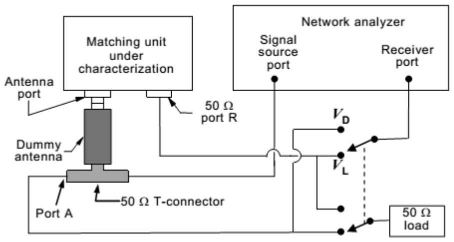
- **ECSM**

$$F_{ac} = V_D - V_L - L_h$$

$$h_e = \frac{\lambda}{2\pi} \tan \frac{\pi h}{\lambda}$$

$$C_a = \frac{55{,}6 h}{\ln(h/a) - 1} \frac{\tan(2\pi h/\lambda)}{2\pi h/\lambda}$$

$$L_h = 20 \lg(h_e)$$



h_e is the effective height of the antenna (m);
h is the actual height of the rod element (m);
λ is the wavelength (m);
C_a is the self-capacitance of the rod antenna (pF);
a is the radius of the rod element (m);

How to specify antenna calibration

- **There is NO one size fits all text**
- **Frequency range; standard to be used; measurement distances**
- **Up/down, orientation of elements**
  - **Have the calibration orientation match your use**

Key: Make sure that you are requesting what YOU NEED.

How to specify antenna calibration

- What is the testing requirement, what does the test standard require?
- What is the QMS requirement?
- What other business requirements?
- What antenna factors do you need?
- Electronic data

How to specify antenna calibration

Additional items to consider:

Balance

Symmetry

Cross pol. isolation

Pattern

More data = more $

QMS & Accreditation

Accreditation

- Accreditation is used to verify that laboratories have an appropriate quality management system and can properly perform certain test methods and calibration parameters according to their scopes of accreditation. Upon satisfactory assessment, the laboratory is issued a Certificate of Accreditation along with a Scope of Accreditation listing the test methods or calibration parameters that the laboratory is accredited to perform.
  - At ETS-L, labs are Accredited (A2LA, NVLAP) for testing for a given scope of operations, additionally the quality system is registered (DNV).

Certification

- Certification is used for verifying that personnel have adequate credentials to practice certain disciplines (ISO 900x), as well as for verifying that products meet certain requirements (Guide 65).
- Persons and products are certified.

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QMS & Accreditation

- **ISO/IEC 17025**
  - International Standard for Quality Management Systems (QMS) for Laboratories
    - Clause 4: Management System Requirements (15 Clauses)
    - Clause 5: Technical Requirements (10 Clauses)
  - Compliments ISO 9001
    - Laboratories that comply with 17025 operate a QMS that also meets the principles of ISO 9001.
    - Covers technical competence requirements that are not covered by ISO 9001
  - 2 Types of Users of the Standard
    - Test Labs
    - Calibration Labs

    Both most likely providing services to external customers in an international market

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What to look for in a calibration certificate

17025:2005 requirements:
Clause 5.10

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ISO 17025, Clause 5.10 Reporting the Results

IMPORTANT ITEMS

- 5.10.1, The results of each test, calibration, or series or series thereof SHALL be reported accurately, clearly, unambiguously and objectively, and in accordance with any specific instructions in the test or calibration methods.
- 5.10.1, Results SHALL be reported, usually in a test report/certificate or a calibration certificate/report, and SHALL include all the information requested by the customer and necessary for the interpretation of the results and all information required by the method used.
- 5.10.2, Each test report or calibration certificate SHALL include at least the following information, *unless* the laboratory has valid reasons for not doing so.
- 5.10.4.2, The calibration certificate shall relate only to quantities and the results of functional tests. If a statement of compliance with a specification is made, this shall identify which clauses of the specification are met or not met.
- 5.10.4.3, When an instrument for calibration has been adjusted or repaired, the calibration results before and after adjustment or repair, if available, shall be reported.
- 5.10.4.4, A calibration certificate (or calibration label) shall not contain any recommendation on the calibration interval except where this has been agreed with the customer. This requirement may be superseded by legal regulations.
- 5.10.8, The format shall be designed to accommodate each type of test or calibration carried out and to minimize the possibility of misunderstanding or misuse.

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Incoming Calibration Review Checklist for Accredited Calibrations

Calibration Certificates shall be evaluated for compliance in accordance with this form and the requirements specified by ISO 17025, Z540.1, A2LA, CTIA and applicable industry requirements.

The results of each calibration or tests shall be in accordance with this document and the requirements specified in the contract and /or Purchase Order.

All reports shall be reviewed and accepted before releasing the equipment for use. The person responsible for performing the activities will document the review by placing a checkmark by each required item on the certificate and a corresponding checkmark on the checklist. A signature, initials or other suitable means will be placed on the certificate indicating compliance with process controls and contractual requirements.

Calibration reports that do NOT contain an accredited symbol will not be released without the approval of the Area Manager or Quality Assurance Manager.

1. Each calibrated device, including in-house calibrations, will include a Calibration Certificate and data package which includes but is not limited to the following information:

a.☐ Calibration Laboratory identification - vendor name, physical address, and phone number
b.☐ A2LA Accredited symbol including certificate number and type of accreditation (calibration/testing) when appropriate. (or other MRA recognized Accreditation Body)
c.☐ Each report is clearly identified with a unique number used for identifying the report and recording or reporting traceability.
d.☐ To ensure that each page of the data documents are recognized as part of the report set, a unique identification is provided on each data sheet (normally “page” of “pages”) which identifies the specific model and serial number matching the instrument identification on the Certificate of Conformance.
e.☐ Identification of the calibration or test method standard used or an unambiguous description of any non-standard method used;
f. ☐ A statement of the environmental conditions under which the calibration was performed.
g.☐ Specific identification of the instrument to which the report pertains including:
h.☐ Manufacturer, Model, Type Instrument/Nomenclature, Serial Number/ID:
i. ☐ Authorizing Signatures; a signature of the technical management representative which endorsed/attested the calibration measurements is provided.
j. ☐ The date the report was generated for issue and attested shall also be provided.
k.☐ The specific date in which individual measurements were conducted will be recorded on each data sheet.
l. ☐ A statement of the estimated uncertainty of the calibration or measurement result will be recorded. Ordinarily this will be identified with a 95% confidence level; the uncertainty is stated as the actual uncertainty, not as the accredited best uncertainty unless the best uncertainty applies, actual uncertainties cannot be smaller than the uncertainty listed on the accredited scope.
m.☐ A traceability statement indicating that the measurements are traceable to an appropriate National Laboratory (e.g. NIST),
n. ☐ A listing of the critical M&TE used to conduct the calibration measurements will be identified by the Make, Model, Serial Number, and current recall date will be recorded.
o. ☐ Any deviations or corrections applied during the measurement process will be recorded on the certificate when appropriate.
p. ☐ The condition of the item for calibration or test as received and will be provided. As found data is to be provided for units as applicable.
i.☐ “In Tolerance” ii.☐“Out of Tolerance” - initiate investigation
q. ☐ The condition of the item for calibration or test as released will be provided. As found data is to be provided for units as applicable.
i.☐ “In Tolerance” ii.☐ “In Tolerance-Limited” iii.☐“Out of Tolerance” - initiate investigation
r. ☐ Tables and graphs will contain the appropriate descriptive titles, column headings, labels, legends, etc. to clarify the data presented.

2.☐ Incoming functional check permed as appropriate for specific instrument

12 May 2015

ETS·LINDGREN
An ESCO Technologies Company

Extra Items to be Checking

- **Maintain good packing materials**
- **Connector quality**
  - Cleanliness
  - Pin depth
  - Connector age (insertions)
- **Element joints**
  - Loose rivets
- **Loose elements**

12 May 2015

Questions?

12 May 2015