An Alternative Method for Determining the Antenna Factor of a Monopole

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Abstract - **In this study, the standard methods of monopole antenna calibration are interrogated and the use of alternative methods is investigated. For this purpose, the GTEM cell has been used for two standard identical monopole antenna calibrations. The dummy antenna (≈10pF by ANSI, ≈12pF by CISPR), which is suggested as standard methods in ANSI C.63.5 and CISPR 16.1.4 are not appropriate to simulate the actual monopole. So Manufacture Antenna Simulator (MAS) has been used as an alternative equivalent circuit substitution method (ECISM) of the rod. Good agreement between GTEM measurement and ECISM is observed. Calibrations with standard and alternative methods are performed and the reliability of these methods is discussed in the frame of the measurement results**.

Keywords - **Antenna calibration, GTEM cell, monopole antenna, equivalent circuit substitution method.**

I. INTRODUCTION

Monopole antennas are commonly used for radiated emission measurements in the frequency range 10 kHz to 30 MHz. In EMC compliance testing, the accuracy of calibration plays an important role in the rod antenna range. Determining the antenna factor (AF) is a major step in making accurate field strength measurements for EMC compliance. There are well-established antenna calibration methods [1] (ANSI C.63.5/1998) to calculate these antenna factors at open area test sites (OATS). However, alternative methods utilizing different test setup and sites, like GTEM Cell (**G**igahertz **T**ransverse **E**lectro**M**agnetic) [2, 3] and Full Anechoic Chamber (FAC), (SAE ARP 958,1999) are also brought forth in recent years [4].

The most common method of calibrating rod antennas is the **E**quivalent **C**apacitance **S**ubstitution **M**ethod (ECSM). In this method, a dummy antenna consisting of a capacitor equal to the self-capacitance of the rod or monopole is used instead of the actual rod. The value of the capacitor should be calculated according to the CISPR 16-1-4 [5]. It is not possible to simulate the right interaction of the rod antenna (including monopole, ground plane, coupling/amplifier unit) with the site ground using the dummy antenna. The insertion loss of capacitor decreases as the value of capacitor decreases. That is the point that the correct value of capacitor plays important key role on the antenna factor. In practice, calibration procedure of the radiated emission test (RE102) according to MIL-STD-461E [6] requires the substitution of the rod element of the monopole antenna with 10 pF capacitor and

application of a signal at a level 6 dB below the limit. The measured signal level in the receiver should, in this method, be between ± 3 dB amplitude range of the applied signal level. However, this is not the case in many calibration measurements performed. That is, calibration with 10 pF capacitor does not fit the manufacture data. In most cases the capacitor method is accurate to within ± 2dB, but breaks down above about 10 MHz [7].

Other method of monopole calibrations given by at the **N**ational **I**nstitute of **S**tandards and **T**echnology (NIST) at open area test site is based on using a transmitting monopole to generate a known electromagnetic field at the site of the antenna under test (AUT). If the separation distance is not large enough, the incident field is not constant along the length of the AUT; this introduces the non-planarity error in the determination of the antenna factor. There is also another effect known as mutual impedance coupling of the antenna [8].

Once upon a time, TEM cells have been used for determining antenna factors for low frequency antennas, monopoles, loops and higher frequency probes. This calibration method has some limitations because of the upper cut-off frequency of the Cell indeed.

II. ALTERNATE CALIBRATION PROCEDURES AND MEASUREMENTS

With deficiencies of these methods in mind one has to take other methods should in to account. These methods are GTEM cell and **E**quivalent **CI**rcuit **S**ubstitution **M**ethod (ECISM) The aim of this work is to investigate the possibility of alternative calibration methods for monopole. This paper shows an alternate method determining antenna factor of a monopole in GTEM cell, and gives consistent comparative data.

As an alternative test site, GTEM cells have been proposed for small antenna measurements [9]. Since the field strength inside the GTEM cell is well correlated to the input power, the antenna factor can be measured accurately provided that the antenna size is not bigger than the test volume, at a point where the field strength is uniform and can be precisely determined. The procedures of antenna calibration for monopole in GTEM 1750 cell (MEB GTEM 1750, the height of maximum test volume is 1.75 m, DC to 1 GHZ, nominal impedance is 50 ohm, VSWR is 1:1.5, field uniformity; <±4 dB) is to place the monopole antenna at the center of the test

volume, aligned in such a way that the linearly polarized antenna is oriented vertically (perpendicular to the septum) in the linearly polarized test volume between the septum and the floor of the GTEM cell (Fig. 1).
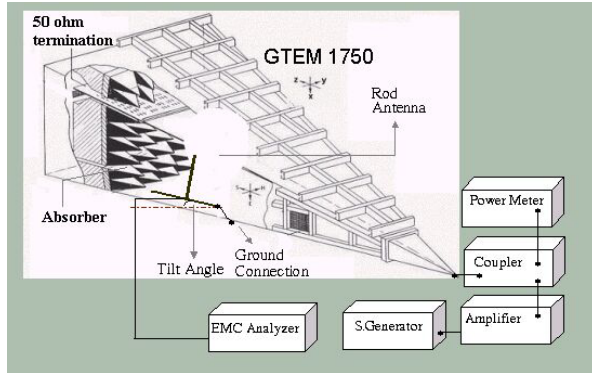

Fig. 1. Test setup for determining the antenna factor in GTEM cell.

The field strength inside GTEM Cell is given by

$$E = \frac{V_i}{h} \qquad (1)$$

where
E : Electric Field Strength (Volts/meter),
V_i : Input RF Voltage (Volts),
h : Septum Height (meter),
and the definition of antenna factor is

$$AF = 20 \log(\frac{E}{V_0}) \qquad (2)$$

where
AF: Antenna Factor (m^{-1}),
V_0: Antenna output voltage (Volts).

Combining (1) and (2) yields
$$AF = 20 \log(V_i) - 20 \log(V_0) + 20 \log(1/h) \quad . \qquad (3)$$

Whereby equation (3) gives the antenna factor of the rod. An EMC Analyzer (Agilent 7405), a signal generator (R&S SMY01), a power meter (R&S NRVD), a power amplifier (AR), a directional coupler and MEB GTEM 1750 were used in calibration process. Two identical 41 inch R&S antennas (Rod#1, Rod#2) have been calibrated in the frequency range 10 kHz to 30 MHz. For the verification of the antenna factor obtained using GTEM cell and ECISM Measurements, the same antennas were also calibrated using standard methods (Fig. 2).

We also checked the dummy antenna consisting of a capacitor equal to the self-capacitance of the rod or monopole used in place of the actual rod by using SNEC (Super Numerical Electromagnetic Code Ver. 2.55) for the reliability of ECSM Method (Fig. 3). We observe good agreement between SNEC data and CISPR data. ANSI data is approximately 2 dB lower than other data in this frequency range.

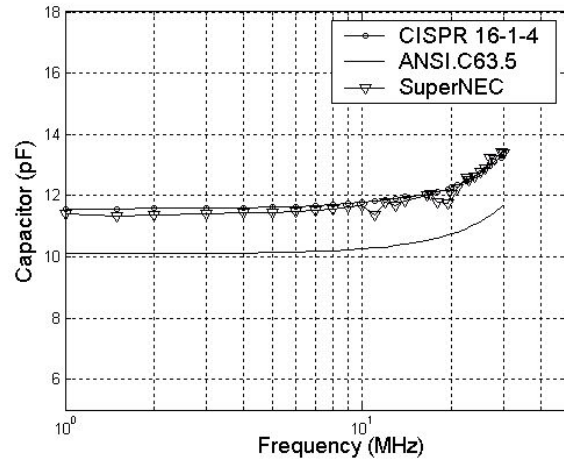Fig. 2. Test setup of ECSM calibration method.

Fig. 3. Capacitance of dummy antenna (calculated - simulated).

It is observed that the capacitor value increases with the frequency. The results yield 2 dB uncertainty above 15 MHz. Another uncertainty comes from the variation of the effective length of the rod with the frequency.

ECISM is based on the insertion loss measurement of antenna matching network (AMN) with antenna simulator used instead of the actual rod. Using Manufacture Antenna Simulator (MAS) (Fig. 4) instead of dummy capacitor in order to make another effective check on the GTEM cell data. In addition, s-parameters of MAS circuit have been calculated using Microwave Office V. 2.66. A Network Analyzer was used to measure the related parameters. Measurement and calculation results were found to be very close (0.1 dB) (Fig. 5.) It has been understood that this circuit is very well matched at 50 ohm.

We measured insertion loss of the Antenna Matching Network (AMN) with MAS The resulting data gives the rod antenna factor.
In all measurements, traceable devices have been used and all cable attenuations have been taken into account.
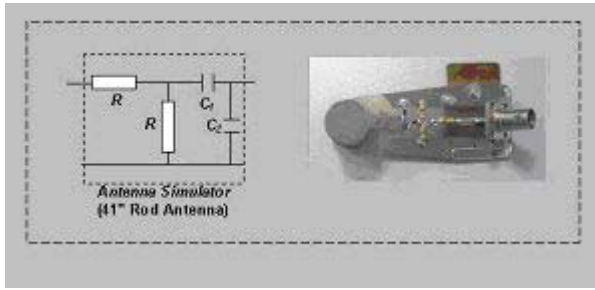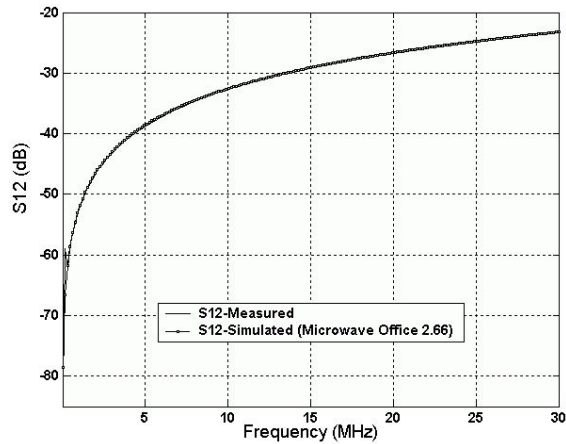
Fig. 4. Manufacture antenna simulator (MAS).

Fig. 5. S$_{12}$ of MAS.

In order to make better comparison of the results, and also to check the general curve of AMN response we have obtained the insertion loss (IL) curve of the AMN and then calculated antenna factor by adding contribution of effective length of the rod .

Antenna factors of Rod#1 and Rod#2 are obtained by using AF-ECSM, AF-ECISM (**E**quivalent **CI**rcuit **S**ubstitution **M**ethod), AF-IL (**I**nsertion **L**oss of AMN) and AF-GTEM (measured and calculated).

It has been observed that antenna factor values obtained using GTEM and ECISM methods were very close in the frequency range 10 kHz – 25 MHz (Fig. 6 and Fig. 7). However, it has been also observed that results obtained using these methods are approximately 2 dB different from the ECSM and IL results (2.6 dB above 25 MHz). The difference between GTEM calculated and GTEM measured data may come from the raised location of feed point on the floor of GTEM and the tilt angle. In high frequency range (above 25 MHz), IL curve of antenna matching circuit is similar in GTEM and ECSM methods. The difference between GTEM and ECSM may come from the instability of the 10-pF capacitance (it should be 12.5 pF as given in Fig. 3) values through the frequency range, the high production tolerance of the capacitor and effective length of the antenna. Small changes on the effective length of the antenna may result large error to the antenna factor. For example the 5cm change is gives approximately 1 dB error.
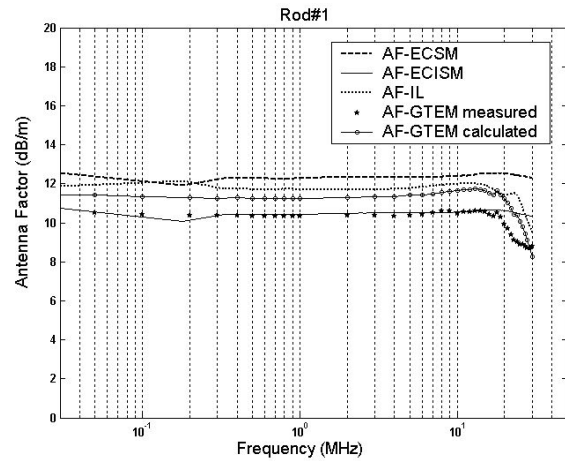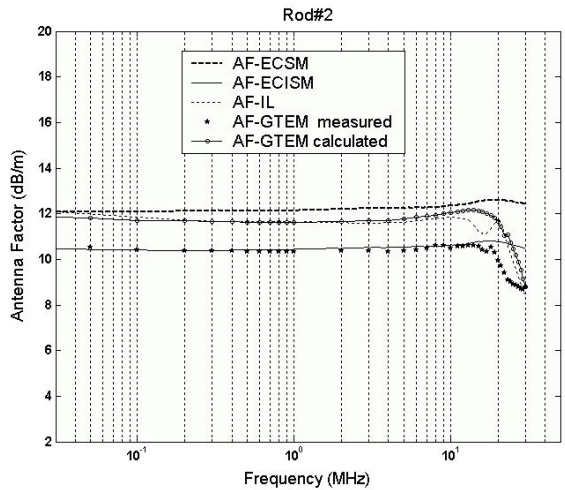

Fig. 6. Antenna factor (Rod#1).

Fig. 7. Antenna factor (Rod#2).

III. FEASIBILITY CONSIDERATIONS AND UNCERTAINTIES

The obvious error sources in GTEM cell are reflections from the termination section. Since the antenna is placed in the testing volume it will receive signal directly from the port of the cell and another signal from termination section where there is reflection with a power reflection coefficient of typically –25 dB for the TEM mode. Another source of error is higher order GTEM wave-guide modes, which cause unwanted field fluctuations in the test volume inside GTEM cell [10]. This error can be cancelled at the low frequency measurements.

We present the uncertainty of antenna calibrations in the frame of the conventional uncertainty estimation where partial derivates of the fundamental formula constitute the basis of uncertainty budget [11]. Parameters acting in this budget are impedance discontinuity (antenna-cable, GTEM cable), signal generator/EMC analyzer specifications, cable attenuation, direction coupler and repeatability. The overall expanded

uncertainty is calculated to be ± 1.01 dB in the frame of these parameters. The uncertainty of GTEM 1750 field uniformity has not been added in the uncertainty budget.

IV. CONCLUSIONS

- Two identical monopole antennas covering the frequency range 10 kHz-30 MHz were calibrated by using GTEM cell and ECISM.
- Good agreement between the GTEM and ECISM was observed.
- Capacitance and effective length of the dummy antenna varies with frequency. This variation brings an additional 2 dB uncertainty above 10 MHz. This uncertainty does not include the tolerance of 10-pF capacitor.
- Antenna is an element that converts electric field to voltage and AF identifies the rate of this conversion. In GTEM calibration AF is determined by making measurements, hence precluding uncertainties arising from dummy antenna. Note that capacitor used instead of the antenna in ECSM method cannot fully simulate the antenna.
- If the separation distance is not large enough in NIST method, the incident field is not constant along the length of the AUT, this introduces the non-planarity error in the determination of the antenna factor. And NIST calibration method gives free space antenna factor of monopole antenna. Practically monopole antennas are used in EMC compliance measurements, in which there is a 1-meter distance (especially for Military Standards) from EUT (Equipment Under Test). It is well-known free space antenna factor and 1m-antenna factor are different at each other so we suggest the GTEM results to be used reliably for 1m EMC measurements.
- In the previous works, GTEM cell has been used for antenna calibration in the frequency range 300 MHz to higher frequency [2,3] This works shows to assure the suitability of the GTEM for antenna calibration in the lower frequency range.
- Additional work is performed to determine transmit antenna factor of the passive rod antenna, using the reciprocity property of the GTEM.

REFERENCES

[1] ANSI C63.5 American National Standart for Electromagnetic Compatibility-Radiated Emission Measurements in Electromagnetic Interference (EMI) Control-Calibration of Antennas (9 kHz-40 GHz), *The Institute of Electrical and Electronics Engineers, Inc,* New York, USA, 1998.

[2] Branaugh E.L., Osburn J.D.M., "Measuring EMC Antenna Factors in The GHz Transverse Electromagnetic Cell," *IEEE Symposium Records*, pp.229-231, Anaheim, Calofornia, USA, 1992.

[3] Türetken B., Yürekli A.İ., and M.Yazici, "Determining Antenna Factors for EMC Measurements," *Turkish Journal of* Telecomunication, vol. 1, no. 2, pp.59-66, 2002.

[4] SAE ARP 958, Electromagnetic Interference Measurement Antennas, Standard Calibration Requirements and Methods, Society of Automotive Engineers (SAE), 1999.

[5] CISPR 16-1-4: Specification for radio disturbance and immunity measuring apparatus and methods, Edititon 1.1. 2004-05, IEC, 2004.

[6] MIL-STD 461 E, Requirement for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, Department of Defence, USA, 1999.

[7] Alexander M.J., "Calibration and Use of EMC Antennas," NPL, April 1977.

[8] Randa J., " Correction Factor for Nonplanar Incident Field in Monopole Calibrations" *IEEE Transactions on Electromagnetic Compatibility,* vol. 35, no. 1, 1993.

[9] Hui P., "Small Antenna Measurements Using a GTEM Cell" *IEEE Antennas and Propagation Society International Symposium,* vol. 4, pp. 715 - 718, pp. 22-27, June 2003.

[10] Icheln C., Vainikainen P., and Haapala P., "Application of GTEM Cell to Small Antenna Measurements," *Antennas and Propagation Society* vol.1, pp. 546 – 549, pp. 13-18, July 1997.

[11] Foegelle M.D., "A statistical Approach to Measurement Uncertainty," *Antenna Catalog Essential Equipment for EMC Testing*- EMCO, 1998.

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