Monopole Calibrations in a GTEM Cell

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1. Abstract

Monopole antennas commonly operate anywhere in the range 30 Hz to 100 MHz. One established method for calibrating the antenna is to replace the element with an equivalent capacitor. This models the low frequency performance of the element where the element impedance is mostly reactive, but nearer to the resonant frequency the real component becomes significant and here the model fails. NPL has developed a technique for calibrating monopole antennas, without detaching the element, in a large GTEM cell using calculable passive standard antennas to provide traceability. This method is complemented by an established free-field method which is implemented on a 60 m by 30 m ground plane. This extends the calibration range to cover antennas which operate up to 100 MHz. Estimated measurement uncertainty is ± 1.0 dB for basic designs which have 41 inch elements and ± 1.5 dB for more atypical designs.

2. Introduction

In the original NPL calibration method the low frequency performance was measured up to 10 MHz in a large stripline on the ground plane. The Antenna Under Test (AUT) is placed directly on the ground plane so that good electrical contact is made between the base and ground, and the measured signal is compared to that measured by a passive reference standard which has been modelled in NEC [1]. Above 10 MHz a field is generated by a transmitting monocone and the AUT is positioned at a distance of 20 m, again directly on the ground plane, and compared to the reference standard. This method allows the whole antenna to be tested, and also correctly determines antenna factor around the resonant frequency.

A pair of passive monopole standards were made for this work, comprising 9.6 mm diameter rods. They were 0.875 m high with extra 0.25 m sections which could be screwed on. In commercial antennas the height of bases varies between about 5 cm and 20 cm, therefore the length of the extra sections was chosen so that the different available heights of the standards approximately matched the typical heights of the antennas currently encountered; particularly 41 inch plus base, and 50 inch plus base. The new standards will be referred to as STD0, STD1, STD2, etc., in which the number denotes how many extra sections were added to the base length of 0.875 m

The MEB 1750 GTEM cell which was used for the work is 7.75 m long with enough height between the floor and the septum to accommodate monopoles of up to 1.6 m in height. Four removable panels were placed along the centre axis of the floor through which a N-type bulkhead connector could be inserted, and this allowed the passive standards to be connected at these four different points along the cell. The holes in the GTEM cell floor were labelled Ports 1 to 4, where number 4 had the greatest floor to septum height of 1.69 m.

3. The NEC Model of the Standard Monopoles

Site Insertion Loss (SIL) between two monopoles can be modelled in NEC over an infinite perfect ground plane. The SIL between two standard rods, each of the same height, was measured on the NPL ground plane and the result compared to the NEC simulation. The presence of an actual connector at the feed point was not included in the NEC model, which only contained ideal wires with a specified feed segment at the base. This produced a slight shift in the resonant frequency of the NEC model when compared

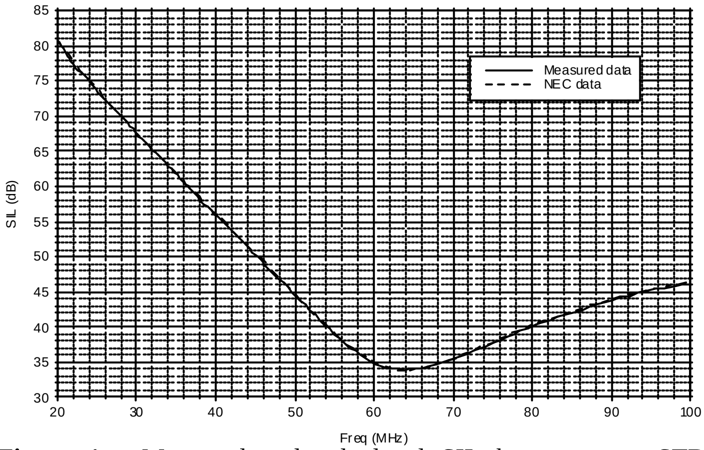

Figure 1 : Measured and calculated SIL between two STD1 monopoles at 28.75 m separation on the NPL ground plane.

to measurement. Some variations in the NEC model were investigated until a generic segmentation scheme was arrived at which produced good agreement at resonance (Figure 1). This scheme produced the best agreement with measurement for all heights of standard antenna. Once the NEC model was verified, the NEC SIL was modelled for each height of passive standard, and the antenna factor calculated from 10 kHz to 100 MHz. Below 10 kHz the GTEM cell is used as a standard field generator (Section 6).

4. Friis Loss between monopoles on an infinite ground plane

In order to calculate the antenna factor of the standard monopoles from the NEC values of SIL it is necessary to understand that the Friis formula is applied slightly differently to monopoles than it is to dipole or aperture antennas which are considered to operate in free-space. Reference [2] contains an expression for the mutual impedance between two antennas, and this may be used to illustrate that the Friis loss between two identical monopoles on an infinite ground plane is the same as that between the two equivalent dipoles in free-space.

Taking the standard expression for the Friis loss in free-space, given in terms of directivity (true gain for loss less antennas), an extra factor of one quarter is needed to account for the fact that the monopole directivity is double that for the equivalent dipole. In the expression below the wavelength is λ, the distance is d, and the directivities are denoted by large D.

$$\text{For monopoles : } \frac{P_{AV}}{P_T} = \left(\frac{l}{4 \cdot p \cdot d}\right)^2 \cdot D_1 \cdot D_2 \cdot \frac{1}{4}$$

Where : P_{AV} = Power available at a conjugately matched load on the receive antenna.
P_T = Power transmitted.

Reference [3] explains how to derive SIL between two antennas in terms of antenna factor, which includes antenna match and conduction losses. Using the modified expression above we arrive at the following expression for SIL which applies to two identical monopoles. Z_0 is the characteristic impedance of the transmission lines (50 Ω); F_M is the frequency in MHz; and AF is the antenna factor in units of dB/m. The only difference to the standard expression used for free-space antennas is the factor of $20 \cdot Log_{10}(2)$ or 6 dB.

$$SIL(dB) = 20 \cdot Log_{10}\left[\frac{5 \cdot Z_0 \cdot d}{2 \cdot p \cdot F_M}\right] + 2 \cdot AF - 20 \cdot Log_{10}[2]$$

5. Standard Antenna Method in the GTEM Cell

Using the floor panels described in Section 2, the response of the passive standards could be measured in the GTEM cell. First, the standard with the nearest height to the AUT height is measured. After removing the standard, the antenna under test (AUT) may be placed next to the plate (on which the standard had been attached), and by comparing the two responses the antenna factor of the AUT is calculated by the Standard Antenna Method (SAM). The AUT is placed in the plane perpendicular to the GTEM cell axis, (later referred to as the measurement plane). Tests conducted at each port showed that the worst case variation in measured signal, caused by moving the AUT in the measurement plane by 30 cm either side of the centre line, was ± 0.3 dB. It is possible to calibrate one standard rod against another at the same position in the GTEM cell. Figure 2 shows one such measurement in which Std1 was used to calibrate Std2 (longer) and Std0 (shorter), and the results are compared to their respective NEC antenna factors. This illustrates the errors introduced when the standard

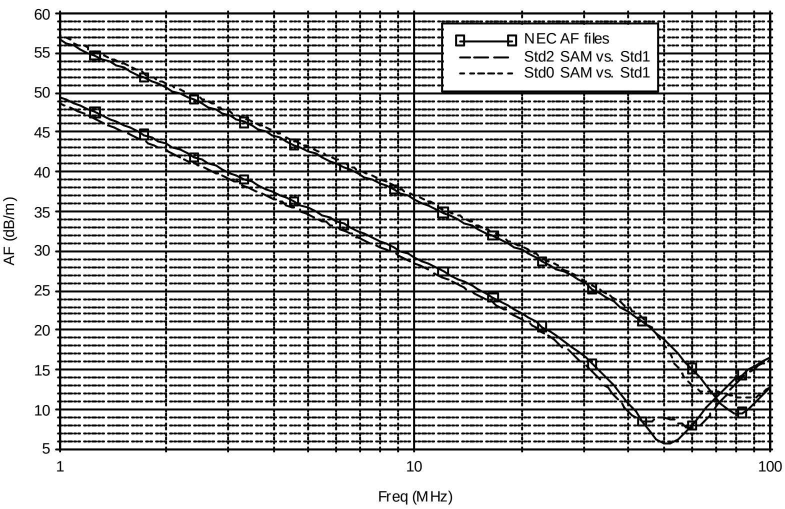

Figure 2 : Example of error caused by 25 cm height difference between standard and AUT.

and AUT (in this case just another standard) are not of the same height. The offset below resonance is about 0.8 dB at worst. In this situation the standard and AUT differ by 0.25 m in height which is much larger than the expected difference in practice, where the standard is chosen to match the AUT height. In most cases the standard should be within 8 cm of the AUT height, resulting in an uncertainty caused by height differences of around ± 0.3 dB. It is thought that these offsets arise because there is a field taper in the vertical plane which means that the different height standards will experience different apparent field strengths when the taper is averaged over the height of each standard.

The low frequency limit for this method is about 10 kHz where the signal to noise ratio becomes too low for the passive NEC standards. The upper limit for SAM in the GTEM cell will occur just beneath resonant frequency for each height of standard, at which point the coupling with the GTEM cell side walls becomes significant. For STD1 this limit is approximately 35 MHz.

6. GTEM cell as Electric Field Standard

For completeness we wanted to extend the method to allow antenna factor to be measured down to 100 Hz. The standard expression for calculating antenna factor in TEM cells is given by:

$$AF(dB/m) = 10 * Log_{10}\left[\frac{P_{IN}}{P_M}\right] - 20 * Log_{10}(H)$$

P_{IN} = Power delivered to the cell
P_M = Power from monopole output
H = Septum to floor gap (m)

Using an amplifier the response of the passive standard rods could be measured down to 100 Hz, but we could not use the same power to measure commercial active AUTs because the high field would saturate the antenna circuits. We found that when the antenna factor of the standard rods was calculated at each position with the above expression there was a constant offset between the measured antenna factor and the NEC data (Figure 3). It is suspected that this is caused by the same field taper discussed in Section 5 on SAM measurements, and as such the effect will be very nearly the same for all monopoles of a given height.

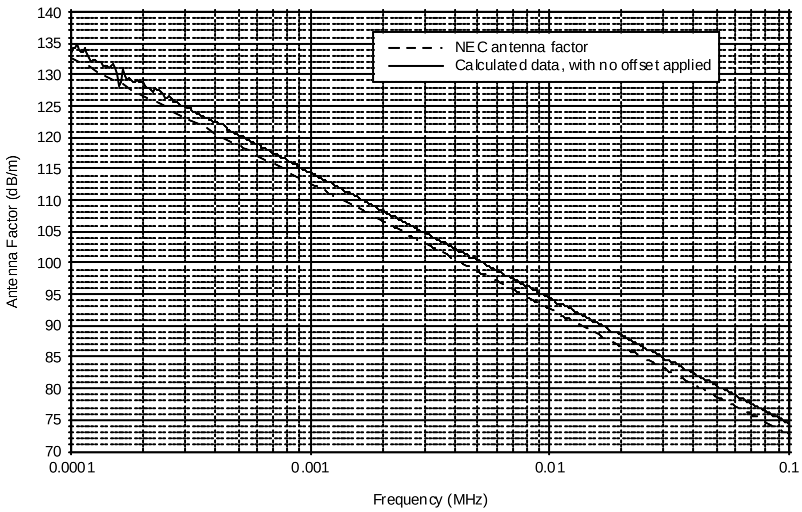

Figure 3 : Offset seen when derived antenna factor of STD1 was calculated at Port 2. The offset here is about 1.8 dB.

From this observation a table of experimentally determined offsets for each height of standard (at each Port) was produced. For any given AUT placed next to one of the bulkhead ports, the offset for that port, corresponding to the standard with the closest height, could be subtracted from the AUT antenna factor calculated from the above expression (referred to later as the derived antenna factor). Since commercial antennas which work below 10 kHz have powered circuits in their bases they will produce an easily measurable signal down to their lowest operating frequency without needing an external amplifier (such as the one used when measuring the passive standard rods). This method was used to measure the antenna factor of AUTs down to 100 Hz.

Because of ambient interference, particularly at 50 Hz, measurements below 100 Hz were unrepeatable, and therefore the lower limit for this work was set at 100 Hz.

7. Calibration Results

Figure 4 shows the agreement achieved between this GTEM cell calibration method and previous data measured on the NPL Open Field Site (OFS). The derived offset for STD1 at Port 2, i.e. the standard used for the SAM measurement here, is 1.8 dB. This figure is therefore also applied to the derived antenna factor of the AUT to get the low frequency data. For these 41 inch antennas the method gives a good calibration over the common EMC test frequency range of 10 kHz to 30 MHz. Above this range the existing OFS method may be used to extend the measurement to 100 MHz.

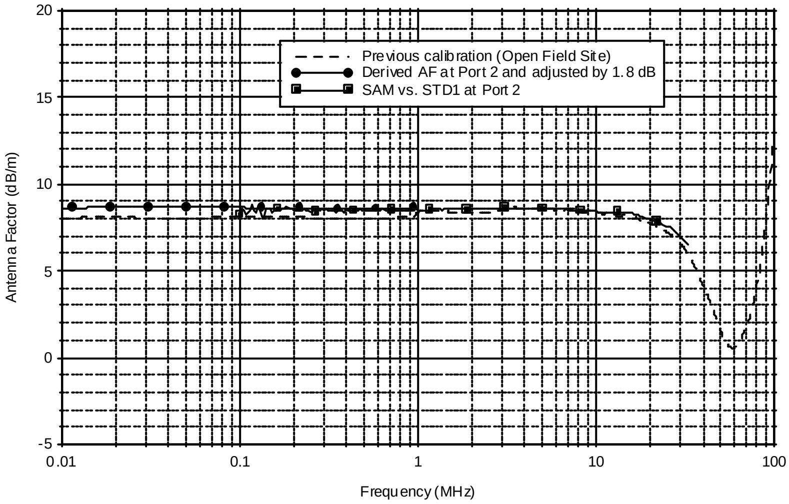

Figure 4 : Calibration results for a typical 41 inch monopole antenna, measured at Port 2.

Figure 5 shows the results for a taller antenna; in this case a 1.6 m antenna which operates down to 100 Hz. The previous data from 100 Hz to 10 kHz was measured on the OFS using an active standard monopole antenna that had previously been calibrated in a TEM cell. The agreement between the GTEM cell method and previous data is within 1dB, which is within the uncertainty for the previous OFS data (± 1.5 dB).

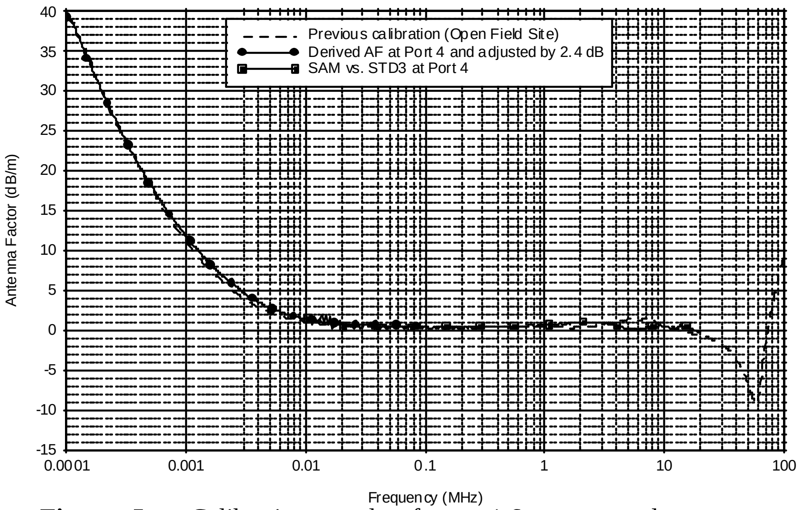

Figure 5 : Calibration results for a 1.6 m monopole antenna, measured at Port 4.

8. Conclusions

The calibration scheme works well for 41 inch monopoles and shows only a slight increase in uncertainty for taller ones up to 1.6 m. Results so far indicate that the overall uncertainty has not increased from the ± 1.5 dB previously achieved for calibrations on the Open Field Site, and hopefully the more controlled environment in the GTEM cell will improve repeatability and allow us to reduce this level of uncertainty. Commercial monopoles come in a variety of sizes and confidence in this new technique will improve as more types are measured. We believe that this GTEM cell method gives a more accurate calibration at the higher frequencies than the capacitor substitution method. For a calibration house one draw back of the capacitor substitution method is that the element connectors on the monopole base units come in varied forms so an adaptor would be required to attach the capacitor on each type.

9. References

[1] Numerical Electromagnetic Code: LOGAN J.C. and BURKE A.J., 1981. Naval Oceans Systems Centre, CA, USA.

[2] Principles of antenna theory: by Kai Fong Lee, 1984. Published by Wiley ISBN 0471-901-679.

[3] Calculation of site attenuation from antenna factors: by Smith A.A., German R.F., Pate J.B. IEEE Transactions on Electromagnetic Compatibility, vol. EMC-24, August 1982.