Utilizing Gain Interpolation for the Removal of Near-Field Coupling Effects during EMC Antenna Calibrations

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***Abstract*—Antenna calibrations for EMC emissions and immunity measurement require gain characterization at reduced distances. The current standards for EMC antenna calibrations do not address the near-field antenna-to–antenna interactions that are present during calibration at these reduced distances. These interactions are not present when using these antennas to measure a device and can result in large measurement errors. Extrapolation measurements have been used for many years to measure the far field gain of antennas at reduced distances. This paper uses both computations and measurements to show how the use of interpolation results in a more accurate assessment of antenna gain at distances required for EMC antenna calibrations.**

***Index Terms*—antenna, calibration, gain extrapolation method.**

I. Introduction

The extrapolation range technique was introduced by Newell et al. in the early 1970s [1,2]. In this paper the term extrapolation range will refer to the measurement technique and the location of the measurements. In the extrapolation range technique the S21 between two antennas is measured versus frequency and versus distance. The antennas are moved progressively further away from each other up to a maximum distance. This maximum distance is not necessarily on the far field of the two antennas, but from the measured data the far field behavior can be extrapolated. Normally the antennas are cross-polarized at the furthest distance and then the cross-polarization of the antennas is measured as the distance between the two antennas are reduced back to the original starting position. Further work has been done on the application of these ranges since their introduction. Mainly the work has been related to reduce errors caused by the supporting structures and the use of time domain gating to reduce the reflections [3, 4]. Several national laboratories and companies use the extrapolation range method to measure gain. However, this method does not seem to have caught the interest of the EMC measurements community and it is not mentioned in the standards as a valid approach for antenna calibration.

In some EMC standards for calibrating antennas, the AF and gain are measured by using other similar or identical antennas, or a rotation of three different antennas [5, 6]. In the case when a secondary antenna is present to measure the gain the values are affected by the near field coupling between the antennas. In the case when a small field probe is used to measure the gain the near field coupling effects are minimal.

In this paper an approach to measure gain is introduced that follows the extrapolation range technique introduced in [1]. The gain is measured over a distance of 10m at discrete steps of 7.6mm. The data obtained can be fitted by a polynomial of a given order and the ripple caused by the near field coupling can be eliminated. Using the polynomial expression, the gain can be calculated for the antenna at any distance of interest. This calculated gain does not contain near field coupling between the antennas used in the calibration process.

II. Numerical Results

To verify the starting assumption that the gain as measured per the typical EMC standards [5,6] includes a series of coupling mechanisms that are not present when the antenna is being used (for emissions or for immunity), a series of numerical experiments were conducted. One of the common calibration methods used for calibrating antennas at 1m is the SAE ARP 958 [5]. This is the preferred method for military EMC testing as described in MIL STD 461F [7], but also the recommended practice for calibrating antennas used on vehicle component testing.

A model was set with two dual ridge horn antennas covering the 200 MHz to 2 GHz range, the antenna is shown in figure 1. These antennas are of the type required by [7] for testing emissions in the 200 MHz to 1 GHz range. It is also a common antenna used in automotive immunity.

The antennas were set 1 m apart and 3 m over an infinite ground plane made out of perfect electric conductor (PEC). The antennas themselves were constructed on PEC. To reduce the computational requirements symmetry was used. Additionally, the antennas were fed with a discrete port. This discrete source has an impedance of 50 ohms. Figure 2, shows the different simulation set ups.

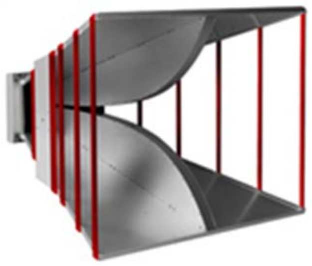

Fig. 1. A Dual Ridged Horn Antenna used in the measurements and the simulations. The antenna aperture is 73cm by 93cm with a 97cm length

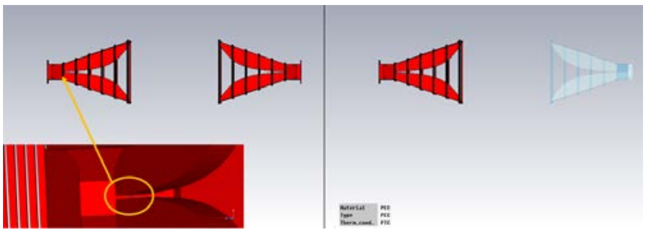

Fig. 2. The two simulations executed. on the left the two antennas present. On the right one simulation with one antenna while the other is modelled as vacuum. in the inset there is picture of the location of the discrete feed.

In the first execution, the two antennas are present as in the measurement method described in [5]. On the second simulation, the secondary antenna is removed by changing its material to vacuum. This approach leaves the structure in place so that the same numerical mesh is used in both simulations. In this second simulation, the field is sampled at 1 m from the aperture of the remaining antenna. For the first simulation the voltage at the feed of the transmitting antenna is recorded along with the voltage at the feed of the receive antenna. Then the gain is computed using the equation in [5].

$$g(dB) = 10 \cdot log_{10}\left(\frac{2\pi f}{c}\frac{V_r}{V_t}\right) \quad (1)$$

Where *Vr* and *Vt* are the voltage at the input of the receive and transmit antennas respectively. For the second simulation, the input power is normalized to 1 watt and the electric field at 1 m is recorded. The gain is computed using the following well known equation:

$$g(dB) = 10 \cdot log_{10}\left(\frac{(r \cdot E)^2}{30 \cdot P}\right) \quad (2)$$

Where *P* is the input power in watts, and r is the distance in m. *E* is the field at the distance *r* in V/m. In figure 3 the results of these simulations are compared to the gain measurement per the method in [5].

The results in figure 3 are extremely interesting. Despite the approximations used in the modeling of the SAE ARP 958 methodology a very close match is observed between the numerical solution and the measurement. This gives validity to

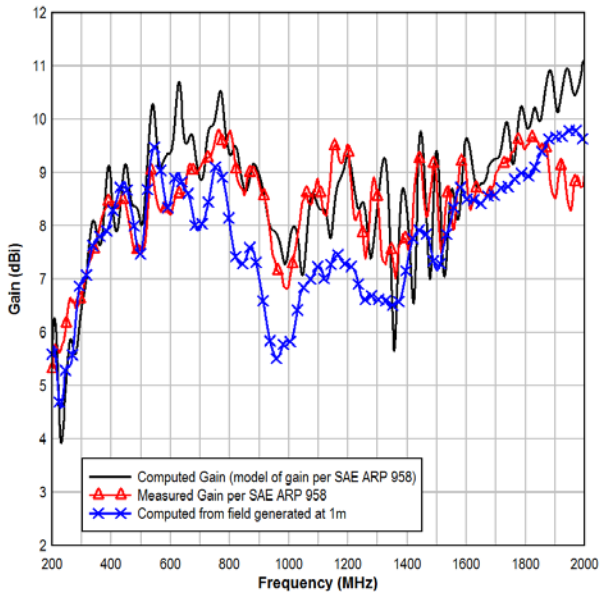

Fig. 3. Numerical results and measurements of the gain of a dual ridge horn covering the range from 200 to 2000 MHz at 1 m distance.

the numerical method. When comparing the SAE APR 958 method data to the gain computed using equation (1) for a single antenna it is found that the curve it is much smother. Also it is slightly lower. The reason is that the near field coupling between the two antennas is not measured. The near field effects are there. This can be seen in the gain dip at 1 GHz, but the mutual coupling between the two antennas is not accounted for in the gain, since the secondary antenna is not present. Mapping the field radiated by the antenna and the field between the two antennas during the SAE ARP 958 calibration shows the near field coupling between the two antennas. Figure 4 shows the field distribution in the two cases.

It can be seen on figure 4 how at 1 GHz there is split on the field and at 1 m distance from the aperture the field in the center line is slightly lower that the field at 1 m from the tips of the ridges.

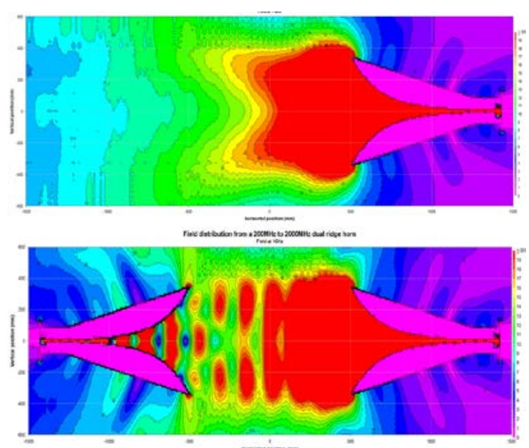

Fig. 4. The electric field distribution shown at 1GHz for the antenna by itself (on the top) and for the antenna in the presence of a secondary unit during the calibration process (on the bottom).

On the bottom of figure 4 we see the field distribution at 1 GHz when the antenna is in the presence of a secondary unit. The standing wave that appears between the antennas is similar to the standing waves measured using the techniques described in [8]. Based on the numerical analysis it is clear that the calibration method causes near field coupling effects between the antennas to be included in the gain. The present results show that interpolation of the data measured in the extrapolation range can be used to eliminate these near field effects and provide a better gain measurement.

III. MEASUREMENTS

In the extrapolation range approach a large amount of data is recorded. The antennas being measured start close together and slowly they are moved apart. At each separation a frequency sweep is performed. For each discrete frequency a curve can be plotted as the distance changes. This plot shows the near field coupling effects and the far field behavior. In figure 5 the extrapolation range is shown. In figure 6, the coupling between a pair of antennas is shown. During the measurement the antennas are moved apart to a point close to the far field at the highest frequency of operation, but not necessarily in the far field region. For this range the maximum separation is 10 m.

At the furthest point the antennas are cross polarized and they are moved close together. Hence, the extrapolation range provides cross polarization information about the antennas. Figure 6 shows the distance scans for three different frequencies, the near field coupling effects are clearly seen at 1 GHz. for 500 MHz the effects are also clear. However, at 200 MHz the wavelengths are longer and the ripple much slower so it is not clearly seen.

Figure 7 shows the 1 GHz scan in the near field region. The data shown is a small fraction of the overall 10m scan. The plot shows the coupling up to a 1m distance. The plot also shows a 6th order fitting polynomial, the complete set of data up to 10m distance is used to generate the polynomial curve fit. This polynomial gets rid of the ripple caused by the near field effects and coupling between the antenna pair. In figure 8, the measurement from the extrapolation range is compared with the computed SAE ARP 958 method and the computed gain from the field generated. These are the same computations that

Fig. 5. Gain extrapolation range.

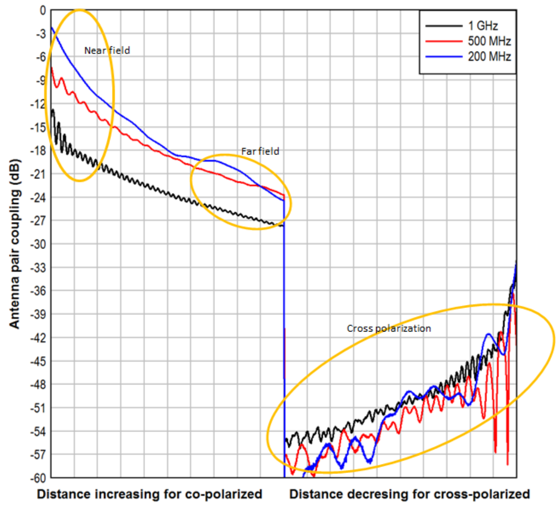

Fig. 6. Antenna pair coupling at different frequencies versus distance for the co-polarized and cross-polarized scans measured in an extrapolation range. The distance is not shown on the x-axis, but the maximum distance of separation in the range is 10m. The plot is given as a typical sample of the data that is gathered during the sample

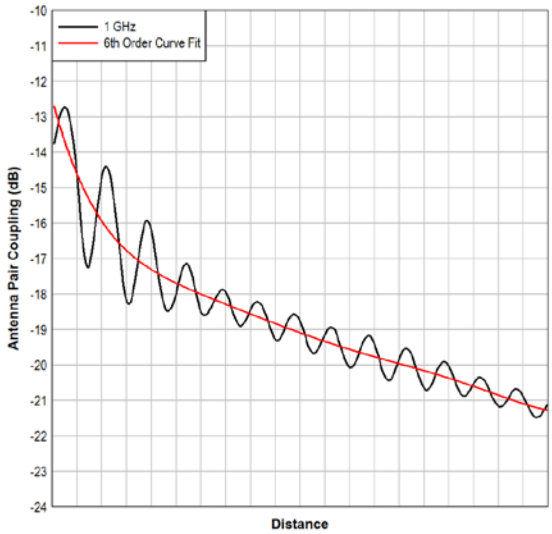

Fig. 7. Polynomial approximation to the measured data in the extrapolation range at 1 GHz.

were performed in the previous section but these were performed for an earlier version of the antenna. The differences between the earlier design and the new design are discussed in [9]. As it can be seen, the extrapolation range provides values that are very close to the single antenna simulation up to 700 MHz. We also see that this curve is has less ripples than the SAE measurement approach gain. As we move higher than 700 MHz in frequency we observe that the extrapolation range measurements closely match the SAE approach. The far field distance has been plotted in the same graph. The purpose of plotting the far field boundary of the antenna is to show that the better results are obtained when some of the data measured in the range falls in the far field of the antenna under test. The extrapolation range used has a maximum distance of 10 m. At 700 MHz the far field distance for the antenna being measured is 6.5 m. So part of the scan was measured in the far field of the antenna. Further measurements are needed where the range measurement is extended closer to the far field at these frequencies. This will

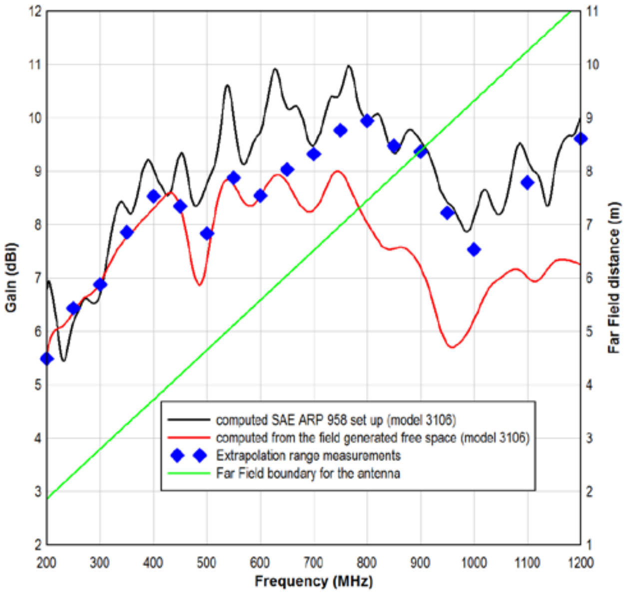

Fig. 8. Comparison of the computed SAE approach and the single antenna gain measurement to the Extrapolation range interpolation measurement.

increase the points on the far field to generate the polynomial curve that will help eliminate the near field coupling that appears to still be present in the measurements above 700MHz.

IV. CONCLUSION

Numerical analysis has shown the potential errors in gain caused by the standard methods used in EMC to calibrate antennas. The ripple on the gain curves can be as high as ±1.5 dB and the levels could be potentially off by 1 dB. Numerical results also show how the field distribution around the antenna is affected by the presence of the secondary antenna. Measurements of gain performed on an extrapolation range have been analyzed. As a starting point to this research the gain was calculated at some discrete frequencies.

There is much more work to be performed. The methodology seems to be able to eliminate the near field coupling between the antennas used in the measurement and to provide a closer value to the actual gain of the antenna. In the preliminary measurements presented in this paper results below 650MHz match very well with the computed results for the antenna. Further study is needed to evaluate if the differences seen above 700MHz are related to the near field coupling extending further away as frequency increases or if they are related to the modeled results for the single antenna. The final goal will be for committees and engineers involved in developing standards to recommend the inclusion of this methodology in the approved methods to measure AF and gain for EMC applications.

ACKNOWLEDGMENT

The authors will like to thank their employers, past and present for their support during the completion of this paper. The authors will also like to thank the Calibration Lab staff at ETS-Lindgren and their manager Doug Kramer for their support of obtaining some of the measurements for this paper.

REFERENCES

[1] A. C. Newell, R. C. Baird, and P. Wacker “Accurate Measurement of Antenna Gain and Polarization at reduced distances by an extrapolation technique” IEEE Transaction on Antennas and Propagation. Vol. 21, No 4, July 1973 pp. 418-431.

[2] A.G. Repjar, A. C. Newell, and D. T. Tamura “Extrapolation Range Measurements for Determining Antenna Gain and Polarization” National Bureau of Standards NBS Technical Note 1311,United States Department of Commerce, U.S. Government Printing Office, Washington, D.C. August 1987.

[3] M. Ameya “Antenna Gain Calibration Using Time-Domain Gating in Extrapolation Ranges for V-Band Pyramidal Horn Antennas” 2010 Conference of Precision Electromagnetic Measurements (CPEM)Daejeon, Republic of Korea, 13-18 June 2010.

[4] E. Van Lil, P. Govaerts, and A. Van de Capelle “Improved Extrapolation Methods for Antenna Gain Measurements” 20th European Microwave Conference, 1990, Vol. 2. Budapest, Hungary, Sept 9-13, 1990.

[5] SAE ARP 958 Rev C “Electromagnetic Interference Measurement Antennas Standard Calibration Method.” Society of Automotive Engineers Standard. Surface Vehicle EMC Standard: Warrendale, PA 1999.

[6] ANSI/IEEE C65.3-2006 “American National Standard for Electromagnetic Compatibility – Radiated Emission Measurements in Electromagnetic Interference (EMI) Control – Calibration of Antennas (9kHz to 40 GHz)” IEEE New York, New York: April 2006

[7] MIL STD 461 F “Requirements for the Control of Electromagnetic Interference Characteristic of Subsystems and Equipments” Department of Defense Interface Standard, United States Department of Defense, Dec 2007.

[8] Metzger, D.W. Norgard, J.D. and Sega, R. M. “Near-field patterns from pyramidal horn antennas: numerical calculation and experimental verification” IEEE transactions on Electromagnetic Compatibility. Vol 33, No. 3 pp. 188-196.

[9] V. Rodriguez “Improvements to Broadband Dual Ridge Waveguide Horn Antennas” 2009 IEEE International Symposium on Antennas and Propagation and USNC/URSIG.