Calibration of Calculable Wideband Direct Feed Biconical Antenna for EMC Measurements

Syarfa Zahirah Sapuan#, Mohd Zarar Mohd Jenu#, Alireza Kazemipour#

#*Center for Electromagnetic Compatibility*
Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia (UTHM)
Batu Pahat, Johor, Malaysia

[1]syarfa@uthm.edu.my
[2]zarar@uthm.edu.my
[3]alireza@uthm.edu.my

Abstract— **An optimized wideband biconical antenna is presented for EMC measurement which potentially can be used as a standard-reference antenna. The antenna is "direct-fed" (no Balun is needed) with optimized dimension to match with 50 Ω coaxial cable from 200 MHz to 2 GHz. Radiation pattern of the antenna indicates that the common mode current existing on the coaxial cable is negligible . Meanwhile, the biconical antenna has a fixed phase-center for the various frequencies and the related uncertainties can be improved. The antenna factors (AF) of the antenna have been evaluated using analytical and numerical methods. Experimental "Standard Antenna Method SAM" has been used to verify the theoretical results and good agreements were observed.**

***Keywords*— Standard Antenna, Biconical Antenna, Antenna Factor, Calculable Antenna, EMC Measurement**

I. Introduction

E-field and magnetic field measurements are the basis of identifying the radiated emission characteristics of equipment or device under test in the domain of Electromagnetic Compatibility (EMC). The measuring device is generally an antenna which itself should be calibrated for accurate measurements. The antenna can be calibrated by using different methods such as standard antenna method (SAM) and standard site method (SSM). The SAM requires a reference antenna and the SSM requires a reference site. Usually, the calibration techniques are used to determine the antenna factor (AF), antenna gain (G) and input impedance Z_{ant}. The most important antenna parameter for EMC is the AF which is defined as the ratio of the electric-field (E) of a plane-wave incident on the antenna to the detected output voltage (V):

$$E = AF.\ V \qquad (1)$$

The calibration process is time consuming and expensive and the accuracy is highly dependent on the quality of the reference antenna and site. Therefore, a highly accurate calculable antenna is preferable as a reference antenna to achieve reliable and low cost calibration.

Half-wavelength dipole has established calculable radiation characteristic and can be used as a "calculable antenna" for EMC calibration with low uncertainty level [1-3]. However, dipole antenna is a narrowband antenna and for different frequencies its length should be adjusted to the relevant half-wavelength. This fact increased the calibration time and cost. Therefore, it is useful to focus on development of calculable wideband antenna.

The proposed biconical antenna presented in this paper is a "direct-fed" antenna with no Balun is needed as shown in Fig. 1. The dimensions are optimized to match to 50 Ω coaxial cable from 200MHz to 2GHz. The absence of balun has a major contribution on E-field measurement uncertainty which can improve the measurement accuracy. In addition, the antenna has a fixed phase-center for the various frequencies which further removed the related uncertainties.

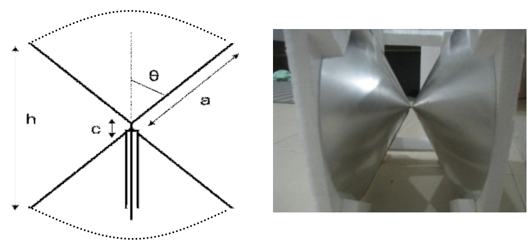


Fig.1 The Proposed Direct Feed Biconical Antenna

II. Theory

The input impedance and radiation pattern of a conical antenna as shown in Fig.2 have been modified to suit with the biconical antenna and is evaluated analytically by using Bessel's functions [4, 5]. The input impedance ($R_{in} + jX_{in}$) of the biconical antenna is deduced as a function of antenna size (*a*) and flare angle (θ) as shown in Fig.1 by simplifying the Bessel's functions.

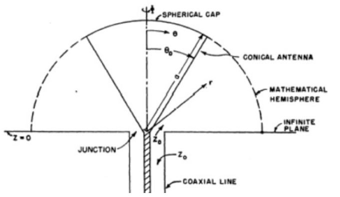


Fig.2 A conical antenna

A finite biconical antenna has an input impedance as a function of antenna height, *a* and flare angle, θ, in contrary to an infinite biconical (very large *a*) where the input impedance depends only on the flare angle, θ. Therefore, to determine the antenna dimensions for 50 ohm input impedance, equations (2) to (5) can be used.

$$Z_{in} = Z_n \frac{1-\frac{\beta}{\alpha}}{1+\frac{\beta}{\alpha}} \quad (2)$$

where,

$$Z_n = 2(60 \ln \cot \frac{\theta_o}{2}) \quad (3)$$

$$\frac{\beta}{\alpha} = e^{-2ika} \frac{1 + i\frac{60}{Z_o}\sum_{n=1}^{\infty}\frac{2n+1}{n(n+1)}[P_n(cos\theta_o)^2\zeta_n(ka)}{-1 + i\frac{60}{Z_o}\sum_{n=1}^{\infty}\frac{2n+1}{n(n+1)}[P_n(cos\theta_o)^2\zeta_n(ka)} \quad (4)$$

$$\zeta_n(ka) = \frac{h_n^{(2)}(ka)}{h_{n-1}^{(2)}(ka) - \frac{n}{k}h_n^{(2)}(ka)} \quad (5)$$

$$a$$

and $h_n^{(2)}$ is the spherical Hankel function of the second kind and P_n (cos θ_o) is the Legendre polynomial of order n.

An optimized 50Ω wideband antenna was achieved at flare-angle 65 degrees. The analytical results are compared with numerical simulation together with the experimental results as shown in Fig. 3. Both simulation and experimental results show a good agreement with the analytical formulation. Fig. 4 shows the measured return loss (S_{11}) of the biconical antenna compared with simulation.

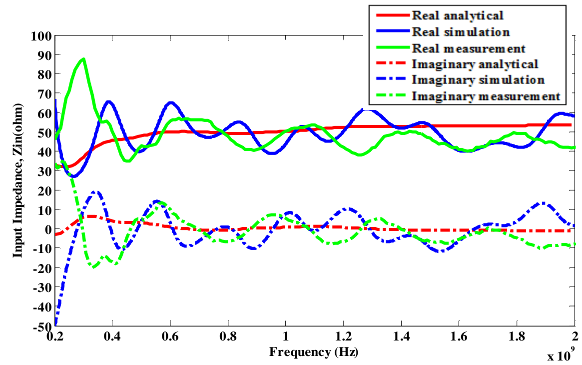


Fig.3 Input Impedance of biconical antenna

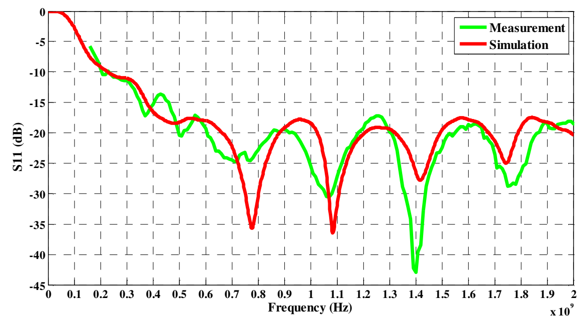
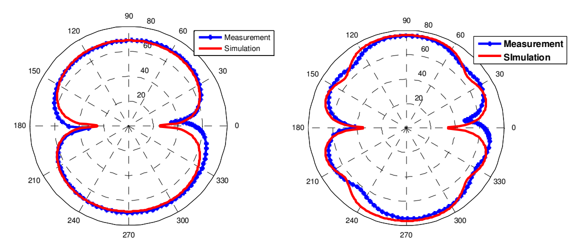


Fig. 4 Return Loss (S_{11}) from 200MHz to 2GHz

It is to be stated that the effect of the gap between the two cones of the antenna was not taken into account in the analytical calculation. At low frequencies, the coupling effects between antenna and ground plane and at higher frequencies the feed-gap effects can affect the measurement results of impedance and AF. Figure 5 shows the measurement and simulation radiation pattern for 200 MHz and 600 MHz. From the radiation pattern, it can be concluded that the effect of common mode current from the antenna can be neglected.



(a) (b)

Fig.5 Radiation pattern (a) 200 Mhz (b) 600 Mhz

It is well established that for a perfectly match 50 Ω antenna, the AF can be evaluated based on the effective-length (L_e) and the antenna gain (G) as equation (6).

$$(AF)^{-1} \sim Le = \frac{\lambda}{\pi}\sqrt{\frac{GR_r}{120}} \qquad (6)$$

For a real antenna which the input impedance is a complex value (R_{in} + jX_{in}) and not perfectly matched to 50Ω, the AF formula should be corrected to take into account the internal power reflections.

$$AF = \frac{|E|}{V} = \frac{2\pi}{\lambda}\sqrt{\frac{120}{D\,|1-\Gamma^2|R_{load}}} \qquad (7)$$

where, R_{load} is usually a 50 Ω coaxial connector, D is the antenna directivity and Γ is the input reflection-coefficient of the antenna.

A. Validation

Antenna factor calibration for EMC measurements can be obtained using three different methods namely Standard antenna method (SAM), Standard site method (SSM), and standard field method (SFM). However, SAM and SSM are generally used as recommended in CISPR 16-1-4 and ANSI C63.5.

SAM was conducted in 3 meter Semi Anechoic Chamber with absorbers on the ground plane as depicted in Fig. 6. In this measurement, log-periodic antenna was used as the transmitting antenna for both reference and antenna under test (AUT) measurements to ensure consistent E-field can be achieved. Dipole and horn antennas were used as reference antenna to cover frequency range from 200MHz to 2GHz.

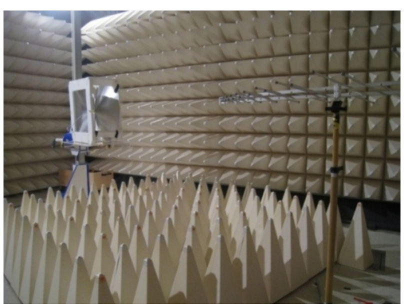


Fig. 6 Standard Antenna Method Measurement

B. Sensitivity to uncertainty contributions

Sensitivity analysis is concerned with the propagation of uncertainties in mathematical models [6]. The main task of sensitivity analysis is to identify critical parameter dependences. A sensitivity coefficient is basically the ratio of changes in output to the changes in input while all other parameters remain constant.

This paper presents an analytical evaluation of the Antenna Factor of a biconical antenna, where it is important to ensure which parameter (Directivity or Input Impedance) has higher influence to the AF equation. This is important for future references to reduce uncertainty.

The partial derivative of AF with respect to D and Γ are given as:

$$\frac{\partial AF}{\partial D} = -\frac{\pi}{\lambda}\left[\frac{120}{R_l}\right]^{1/2} D^{-1.5} \qquad (8)$$

$$\frac{\partial AF}{\partial \Gamma} = \frac{2\pi\Gamma}{\lambda}\left[\frac{120}{DR_l}\right]^{1/2} [1-\Gamma^2]^{-1.5} \qquad (9)$$

Table I
Uncertainty of AF due to variation in D

F (MHz)	$\partial AF/\partial D$	D (in linear)	ΔD	$\|\Delta AF_D\|$
300	-3.11	1.35	0.05	0.16
500	-2.31	2.31	0.05	0.11
700	-4.60	1.83	0.05	0.23
900	-4.36	2.24	0.1	0.44
1100	-3.29	3.09	0.1	0.33
1300	-4.13	2.96	0.1	0.41
1500	-4.53	3.07	0.1	0.45
1700	-3.99	3.63	0.1	0.40
1900	-4.53	3.59	0.1	0.45

Table II
Uncertainty of AF due to variation in Γ

F (MHz)	$\partial AF/\partial\Gamma$	Γ (linear)	$\Delta\Gamma$	$\|\Delta AF_\Gamma\|$
300	1.24	0.14	1x10-2	$1x10^{-2}$
500	0.22	0.02	$5x10^{-3}$	$1x10^{-3}$
700	$4.6x10^{-3}$	$-2.74x10^{-4}$	$1x10^{-4}$	$4.6x10^{-7}$
900	$9.3x10^{-2}$	$4.8x10^{-3}$	$1x10^{-4}$	$9.3x10^{-6}$
1100	0.26	$1.27x10^{-2}$	$1x10^{-3}$	$2.6x10^{-4}$
1300	0.67	$2.75x10^{-2}$	$1x10^{-3}$	$6.7x10^{-4}$
1500	0.79	$2.8x10^{-2}$	$1x10^{-3}$	$7.9x10^{-4}$
1700	0.87	$3.0x10^{-2}$	$1x10^{-3}$	$8.7x10^{-4}$
1900	1.07	$3.3x10^{-2}$	$1x10^{-3}$	$1.1x10^{-3}$

Table I and II show the results for AF uncertainty due to changes in D and Γ for selected frequencies. It can be seen that the antenna factors are more sensitive to Directivity uncertainty as compared to return loss uncertainty. Consequently, directivity accuracy should be improved when calculating the antenna factor of this calculable biconical wideband antenna because any small changes in Directivity will contribute towards higher AF uncertainties. Therefore, any factors that affect the accuracy of the directivity of the antenna must be fully understood.

III. RESULTS

It is now clear that D and Γ can be obtained from analytical and/or simulation methods and the AF can be calculated from equation 7. The results are compared with experimental data generated using Standard Antenna Method (SAM). The results of AF for the biconical antenna from analytical, simulation and measurements are tabulated in Table III and plotted in Fig. 6.

As shown in Table III, the analytical AF shows good agreement with simulation and measurement results. However, it can be seen that the AF discrepancies can vary up to 4dB especially at low frequencies due to the coupling effect, the reference antenna uncertainty and semi-anechoic chamber conditions. Good agreement at frequencies above 1GHz is due to the usage of horn antenna as the reference antenna which has good accuracy for AF and fixed phase center. The coupling effect to the ground is also reduced at these frequencies. It is obvious from the results that our direct feed biconical antenna which has calculable AF can be used as reference antenna for AF calibration due to the good accuracy of the AF compared to simulation and measurement results.

Table III
Tabulated Data of AF Using Analytical Simulation and Measurement Methods.

F (MHz)	AF (Analytical)	AF (Simulation)	AF (measurement)
200	15.8	16.1	15.6 ± 1
300	17.7	17.6	21.5 ± 1
400	19.9	21.8	22.3 ± 1
500	21.9	21.9	22.6 ± 0.5
600	24.1	24.0	23.6 ± 0.5
700	25.1	25.3	25.8 ± 0.5
800	24.6	24.7	25.8 ± 0.5
900	24.9	25.0	26.2 ± 0.5
1000	27.0	27.1	25.3 ± 0.5
1100	26.7	26.5	27.2 ± 1
1200	26.7	27.1	27.4 ± 1
1300	27.7	27.9	28.6 ± 1
1400	28.0	28.4	27.7 ± 1
1500	28.0	28.4	28.3 ± 1
1600	28.5	28.8	28.9 ± 1
1700	29.1	29.5	28.8 ± 1
1800	29.2	29.9	30.3 ± 1
1900	29.6	30.1	29.7 ± 1

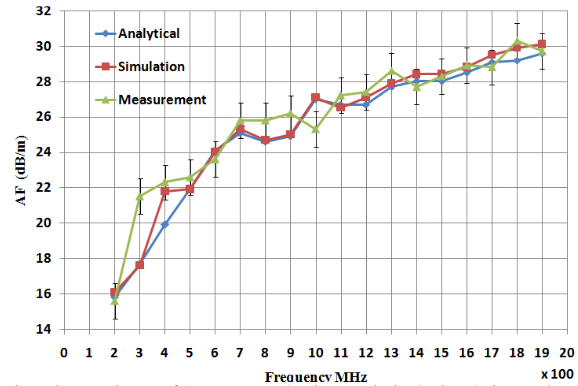


Fig.7 Comparisons of AF generated using analytical, simulation and measurement techniques.

IV. CONCLUSIONS

An optimized wideband biconical antenna is presented for EMC measurement which can be used as a standard-reference antenna because of its calculable characteristics. The antenna is optimized to match with 50 Ω coaxial cable from 200 MHz to 2 GHz. Theoretical and experimental results of the antenna input impedance and the Antenna-Factor show a good agreement especially at high frequency and less accuracy at low frequency due to the coupling effect. Therefore, the effect of the antenna-ground coupling must be taken into account on the AF and the related uncertainties.

From the uncertainty analysis, the antenna factors are more sensitive to D uncertainty as compared to return loss uncertainty. Consequently, D accuracy should be improved when calculating the antenna factor of this calculable biconical wideband antenna because any small changes in D will contribute towards higher AF uncertainties.

REFERENCES

[1] M. Alexander, "Using the calculable dipole antenna for antenna calibration and validation of EMC test sites," Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC), pp. 782-785, 2010

[2] M. Alexander, M. Salter, B. Loader, and D. Knight, "Broadband calculable dipole reference antennas,", IEEE Transactions on Electromagnetic Compatibility, vol. 44, pp. 45-58, 2002.

[3] A. Kazemipour and X. Begaud, "Calculable dipole antenna for EMC measurements with low-loss wide-band balun from 30 MHz to 2 GHz," Journals on Electromagnetics, vol. 25, pp. 187-202, 2005.

[4] C. H. Papas and R. King, "Input impedance of wide-angle conical antennas fed by a coaxial line," Proceedings of the IRE, vol. 37, pp. 1269-1271, 1949.

[5] C. H. Papas and R. King, "Radiation from wide-angle conical antennas fed by a coaxial line," Proceedings of the IRE, vol. 39, pp. 49-51, 1951.

[6] A. Ostermann, "Sensitivity analysis," Analyzing Uncertainty in Civil Engineering, p. 101, 2004.