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EVALUATION OF ANTENNA CORRECTION FACTORS FOR EMC MEASUREMENTS

Mohamed A. H. Eleiwa (Ph.D.)
Egyptian Armed Forces

ABSTRACT

The fundamental parameters of the EMC (Electromagnetic Compatibility) antennas, which are used for EMC measurements, are the antenna correction factors, or simply the antenna factor (AF), and a related parameter, the transmit antenna factor (TAF), provides a clearer understanding of radiated emissions and immunity measurements.

This paper provides mathematical derivations of the antenna factors AF and TAF in terms of the effective length parameter (h). The antenna factors for dipole and loop antennas are then calculated and analyzed. A new procedure is suggested for obtaining the antenna factor and hence the gain (G) of Log Periodic Dipole Antennas (LPDA), which are used for emission and susceptibility testing. A simple technique is also devised to calculate the antenna factors for biconical antennas used in site attenuation measurements. The proposed procedures are then verified by comparing the calculated AF and G for different LPD and biconical antennas with their corresponding published data.

KEYWORDS

EMC Antenna factors; Analysis, Log Periodic and Biconical Antennas.

1. INTRODUCTION

EMC antennas [1] are used for two types of measurements: radiated emission (RE) and radiated susceptibility or immunity (RI) measurements. In the first case, the maximum level of EM field that may be generated by Equipment Under Test (EUT) is measured, while the minimum level of interference that equipment can tolerate without malfunction is the measured value in the second EMC measurement.

For immunity and emission testing, the antenna should be broadband. Broad bandwidths are driven by the broad frequency spectrum covered in the performance of EMC measurements. For all the importance of the bandwidth, however, the antenna parameter most often used, is the antenna factor AF. For radiated emission measurements, the AF is used to convert the reading of the receiver to the incident field strength, while in susceptibility testing, the TAF relates the value of the field strength radiated by an antenna as a function of its input. The antenna factors are also used for the calculation of site attenuation, which determines the ability of a semi-anechoic chamber to simulate an ideal OATS (Open Area Test Site) for performing emission measurement [2].

Although antenna factors are widely used, the analysis of such factors has not received a great deal of attention in the literature. The antenna factor expressions derived in [3,4] do not account for impedance or polarization mismatch losses, while the derived E- field antenna factor in [5] accounts for losses.

This paper presents a comprehensive analysis of all known (E and H) field antenna factors and their related transmit antenna factors TAF. The E and H factors of dipole and loop antennas are then derived and analyzed. Two different techniques are finally proposed to calculate the antenna factor and gain for typical EMC antennas (LPD and biconical antennas). The results are discussed and found to be in good agreement with the available published data.

2. DERIVATION AND EVALUATION OF ANTENNA FACTORS

The IEEE dictionary [6] defines the antenna correction factor as a factor that is applied to convert the reading of the receiver to the field strength. Thus

$$\mathrm{AFE} = \frac{|\vec{E}_i|}{|V_r|} \tag{1}$$

Where AFE is the electric field antenna factor, $\vec{E}_i$ is the field strength of the incident wave, and V_r is the input voltage to the measuring receiver. Similarly the magnetic field antenna factor AFH is given by

$$\mathrm{AFH} = \frac{|\vec{H}_i|}{|V_r|} \tag{2}$$

The transmit antenna factor TAF, which relates the radiated electric field strength E_r at a distance r away from the transmitting antenna with the input voltage V_{in} is written as

$$\mathrm{TAF} = \frac{|\vec{E}_r|}{|V_{in}|} \qquad (3)$$

Consider the equivalent circuit of the receiving antenna, as shown in Fig. (1-a), the developed voltage V_r across the receiver with total load impedance Z_l is given by

$$V_r = \frac{Z_l V_{oc}}{Z_a + Z_l} \qquad (4)$$

Where Z_a is the antenna impedance and V_{oc} is the antenna open circuit voltage, which is given by [7] as

$$V_{oc} = \vec{h}.\vec{E}_i = |\vec{h}||\vec{E}_i|\cos(\psi_p) \qquad (5)$$

Where $\vec{h} = h_\theta a_\theta + h_\phi a_\phi$ is the complex antenna effective length parameter. Substituting Equation (5) into Equation (4) and then using Equation (1) to get

$$\mathrm{AFE} = \frac{|Z_a + Z_l|}{|\vec{h}||Z_l||\cos(\psi_p)|} \qquad (6)$$

From Equation (6), minimum AFE is obtained at maximum V_r, which requires matched polarization (ψ_p=0) and matched impedance (Z_l=Z_a) conditions. Substituting these (matched conditions) values into Equation (6) to get the minimum AFE at resonance (X_a=X_l=0) as

$$\mathrm{AFE}_{min} = \frac{2}{h_e} \qquad (7)$$

Where h_e is the maximum antenna effective length, which is related to the maximum antenna effective aperture A_e by the following relation [8]

$$h_e = 2\sqrt{\frac{A_e R_a}{\eta}} \qquad (8)$$

Substituting $\eta = 120\pi$ for free space and $A_e = \lambda^2 G_r / 4\pi$ into the above equation to get an alternative expression for AFE, in terms of other antenna parameters (gain G and wavelength λ) as,

$$AFE_{min} = \frac{68.83}{\lambda\sqrt{G_r R_a}} \quad (9)$$

Substituting $R_a = 50\Omega$, for a 50Ω system, into Equation (9) and rewriting it to get the antenna gain in dB as

$$G_{r(dB)} = 19.76 - 20\log_{10}\lambda - AF_{(dB/m)} \quad (10)$$

3. THE TRANSMIT ANTENNA FACTORS

Consider Fig.1-b., the power delivered to the antenna is given by

$$P_{in} = \frac{|V_{in}|^2 R_a}{2|Z_a + Z_s|^2} \quad (11)$$

The radiated power density W_r at a distance r form the transmitting antenna with gain G_t is given by

$$W_r = \frac{P_{in} G_t}{4\pi r^2} = \frac{|E_r|^2}{2\eta} \quad (12)$$

Substituting Equation (11) into Equation (12) and then using Equation (3) to yield the transmit antenna factor as

$$TAF = \frac{\sqrt{30 R_a G_t}}{r|Z_a + Z_s|} \quad (13)$$

Substituting the matched impedance condition (Z_a=Z_s) into Equation (13) to get the minimum TAF as

$$TAF_{min} = \frac{2.74\sqrt{G_t}}{r\sqrt{R_a}} \quad (14)$$

Substituting R_a=50Ω and taking 2o $\log_{10}$ of both sides of Equation (14) to yield the TAF in (dB/m) as

$$TAF_{(dB/m)} = G_{t(dB)} - 20\log_{10} r - 8.23 \quad (15)$$

As can be seen from Equation (9) and Equation (14), the AF and TAF are neither identical nor reciprocal. They are connected by the fact that the gain is identical for both expressions, which allows TAF to be computed from AF. Therefore, substituting Equation (10) into Equation (15) to get

$$TAF_{(dB/m)} = 11.53 - AF_{(dB/m)} - 20\log_{10}\lambda - 20\log_{10} r \quad (16)$$

This conversion is valid for similar conditions from which either the AF or TAF is measured.

4. ANTENNA FACTORS CALCULATIONS

The antenna factors are derived for dipole, loop, LPD and biconical antennas. The method of obtaining the antenna factors is based on the determination of the antenna effective antenna length h from the radiated field expression, and then substituting h into Equation (7) to yield the AF, while the AF for biconical antennas is calculated in terms of G and according to Equation (10).

FINITE LENGTH DIPOLE

The far radiated field E by any antenna with input current I_{in} may be expressed relative to that which a unit current element would radiate as follows [7]

$$\vec{E} = \frac{j\eta I_{in} k e^{-jkr}}{4\pi r}\vec{h} \qquad (17)$$

For a dipole of length l and input current I_o, the far-zone radiated field is given by [8]

$$E_\theta = \frac{j\eta I_o e^{-jkr}}{2\pi r}\left(\frac{\cos(kl\cos\theta/2) - \cos(kl/2)}{\sin\theta}\right) \qquad (18)$$

Comparing Equation (18) with Equation (17) to yield h as

$$h_\theta = (2/k)\left(\frac{\cos(kl\cos\theta/2) - \cos(kl/2)}{\sin\theta}\right) \qquad (19)$$

Substituting the maximum value of Equation (19), which is h_e , into Equation (7) to get the AF for the dipole antenna as

$$AFE = \frac{2\pi}{\lambda(1 - COS(\pi l/\lambda)} \qquad (20)$$

SMALL LOOP ANTENNA

Substituting $|\vec{E}_i| = \eta|\vec{H}_i|$ into Equation (1), and then using Equation (2) to yield AFH = AFE/ η , which is then substituted into Equation (7) to have

$$AFH = \frac{2}{\eta h_e} \qquad (21)$$

The radiated electric field from small loop with $I_{in}=I_o$ and radius a $(E_\phi = \eta (ka)^2 \sin(\theta) e^{-jkr}/4r)$ is then compared with Equation (17) to yield $h_\phi = -jk\pi a^2 \sin\theta$. The maximum h is finally substituted into Equation (21) to get the minimum AFH for the small loop antenna as

$$AFH = \frac{2}{k\eta\pi a^2} \qquad (22)$$

The same result may be obtained by using Faraday's law to calculate the open circuit voltage V_{oc} induced in the loop antenna illuminated by a uniform, normally incident magnetic field H_i to the loop area. Thus $V_{oc} = -d\psi/dt = 2V_r = -j\omega\mu H_i \pi a^2$.

LOG PERIODIC DIPOLE ANTENNAS

Log periodic antennas [7,8] are too complex to analyze by theoretical methods to get the radiated field in a closed form, which is suitable for h determination and hence the antenna factors. Therefore a procedure is proposed to determine the AF for LPDA. This procedure is based on viewing the ideal LPDA operation as being similar to an adjustable $\lambda_n/2$ dipole antenna at discrete frequencies f_n, which requires that the antenna should expand and contract in proportion to the wavelength in order to be frequency independent over the desired bandwidth. This concept may explain the broad band operation of LPDA, as well as the flatness of the obtained antenna factors.

The steps of calculations may be summarized as follows: dividing the frequency band $\Delta f = f_u - f_l$ into equal intervals. A certain frequency $f_n = f_l + (n-1)\Delta f/(N-1)$ is specified for every element no. n, n =1;...,N. The element lengths are then calculated starting from $l_1 = \lambda_1/2,\ l_2 = \tau l_1; ..., l_N = \lambda_N/2$, where $\tau = (l_N/l_1)^{(1/N-1)}$ is an approximate scaling factor and N is the number of LPDA elements. Finally, substituting the obtained dipole length l_n into Equation (20) to get its AF at frequency f_n, which is approximately equal to the LPDA antenna factor at the same frequency.

To verify the above proposed procedure, the AFE and hence the antenna gain G (according to Equation (10)) are calculated for typical EMC LPD antennas, which are used for EMC measurements. The first antenna is (LPD-310/A) with 10 elements designed for a (3.3:1) bandwidth, as shown in Fig.2. The calculated and published antenna gain are compared in Fig.3., while AFE is not published for that model. The second one is LPD-8130/A for a (16:1) bandwidth using 30 elements, as shown in Fig.4. The calculated and published AFE and G for LPD-8130/A are plotted vs. frequency in Fig.5. The manufacturer's published data [9] are also listed for purposes of comparison.

BICONICAL ANTENNAS

Wide-angle biconical antennas [10] are frequently used as broad band antennas. Equation (10) is used to calculate the biconical antenna factors in terms of λ and G. The

directivity Do = 4π (maximum radiation intensity) / (total power radiated) is first derived from the infinite biconical antenna radiation pattern $F(\theta) = \sin\theta_h / \sin\theta$ to get

$$D_o = \frac{1}{\sin^2\theta_h \ln|\cot(\theta_h / 2)|} \qquad (23)$$

Substituting $Z_o = R_r = (\eta / \pi)\ln|\cot(\theta_h / 2)|$ and the half cone angle $\theta_h = 60^o$; to match approximately the 50 line, into Equation (23) to yield Do = 160/R_r for free space propagation. Neglecting ohmic losses, the radiation resistance R_r of the finite biconical antenna with length 2l is approximately given by twice the real part of the input impedance for its equivalent conical monopole with length l. Measured input impedance Z_{in} curves of the conical monopole vs. its electrical length for various θ_h are found in [10]. The gain is finally calculated as $G = (1-|\Gamma|^2)D_o$, where $\Gamma = (Z_{in} - 50)/(Z_{in} + 50)$ is the reflection coefficient between the antenna and a 50Ω line. Substituting the obtained gain values at different frequencies in Equation (10) to get the required AF as function of frequency

To assess the accuracy of this technique, the antenna factors for a typical biconical antenna (tip to tip length = 2l=1.3m), used in site attenuation measurements, are calculated over the frequency range 80 - 200 MHz, and compared with their corresponding published data in [11], as shown in Fig.6. The noted 1dB (in average) discrepancy is probably due to the inaccuracy of Z_{in} values. However, the calculated frequency response of AF using the proposed technique is smoother, as expected for such broad band antennas.

CONCLUSION

The different antenna factors AFE, AFH and TAF have been derived and studied extensively. The derivation relies on the definition of the effective antenna length parameter $\vec{h}$. Applying the equivalent circuit principle for receiving and transmitting antennas has also derived alternative expressions for the antenna factors.

Two different techniques have been proposed for obtaining the antenna factor and the gain of LPD and biconical antennas. The numerical calculations of AFE and G for different LPD and biconical antennas, which are used in emission and susceptibility testing, have been shown to agree well with those supplied by the manufacturers.

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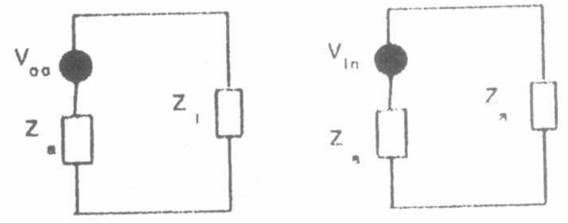
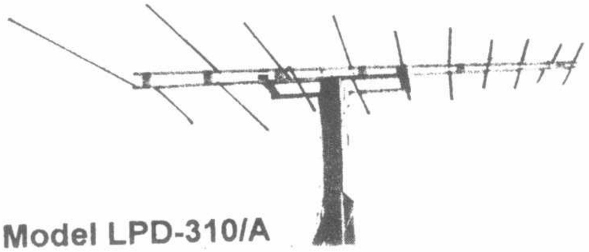


(a) (b)

Fig.(1) Equivalent circuits of (a) receiving antenna, and (b) transmitting antenna.



Typical Gain (dBi)	
Frequency (MHz)	LPD-310/A
30	6.2
40	6.8
50	7.4
60	6.9
70	6.3
75	6.4
80	6.2
90	6.7
100	6.7

Fig.(2) Model LPD-310/A and its typical gain.

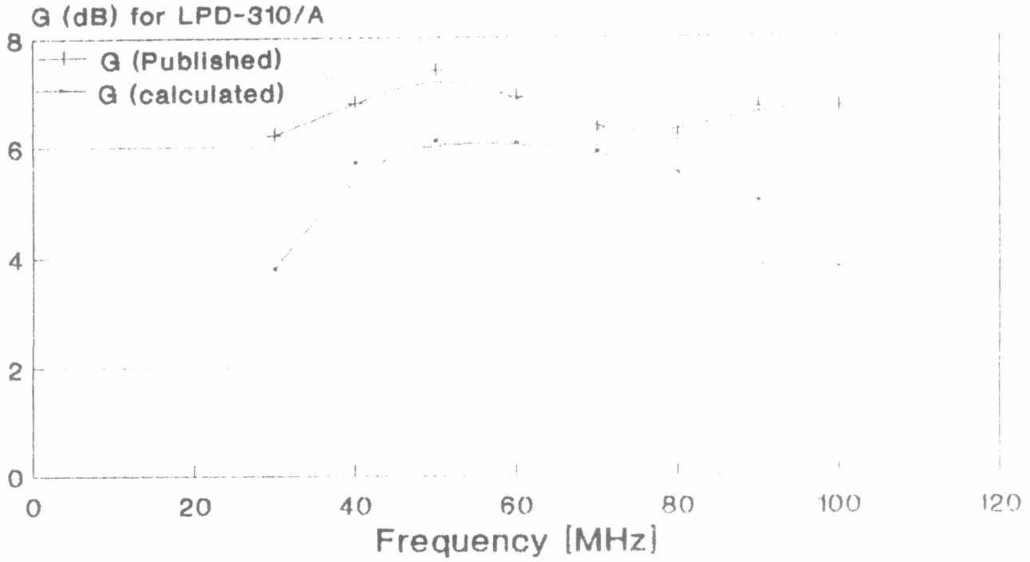


Fig.(3) Calculated and published G for LPD-310/A.

Model LPD-8130/A
Typical Antenna Factor and Gain

Frequency (MHz)	AFE (dB m-1)	Gain (dBi)
80	2.4	5.9
100	3.8	6.4
150	7.3	6.5
200	9.5	6.8
250	11.2	7.0
300	12.5	7.3
400	14.8	7.5
500	16.1	8.1
600	18.0	7.8
700	19.9	7.2
850	20.7	8.1
1000	21.5	8.7
1100	23.4	7.7
1200	24.4	7.4
1300	26.1	6.4

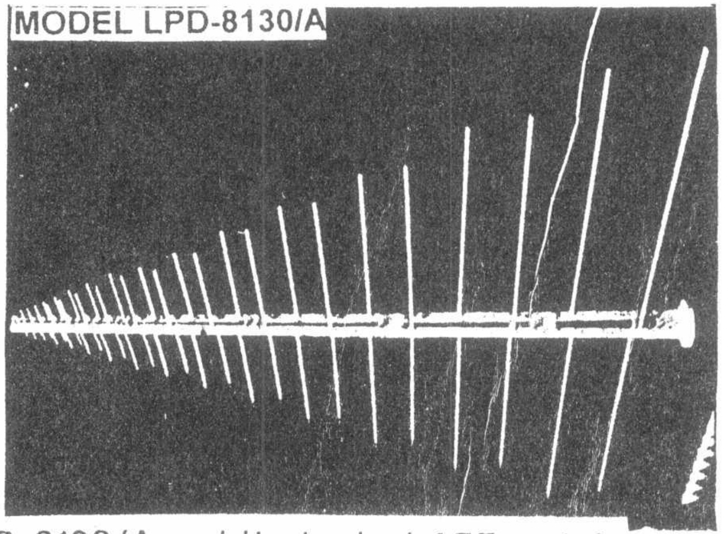


Fig.(4) Model LPD-8130/A and its typical AFE and G.

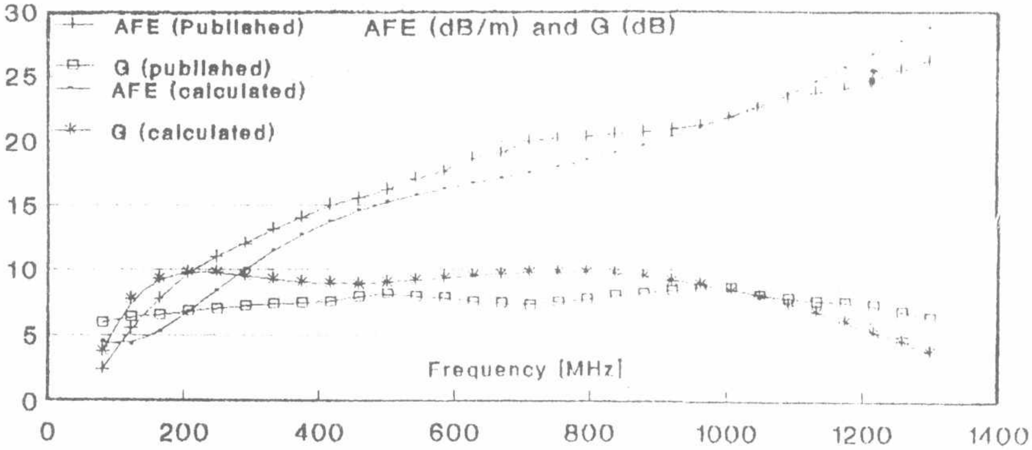


Fig.(5) Cal. and pub. AFE and G for LPD-8130/A.

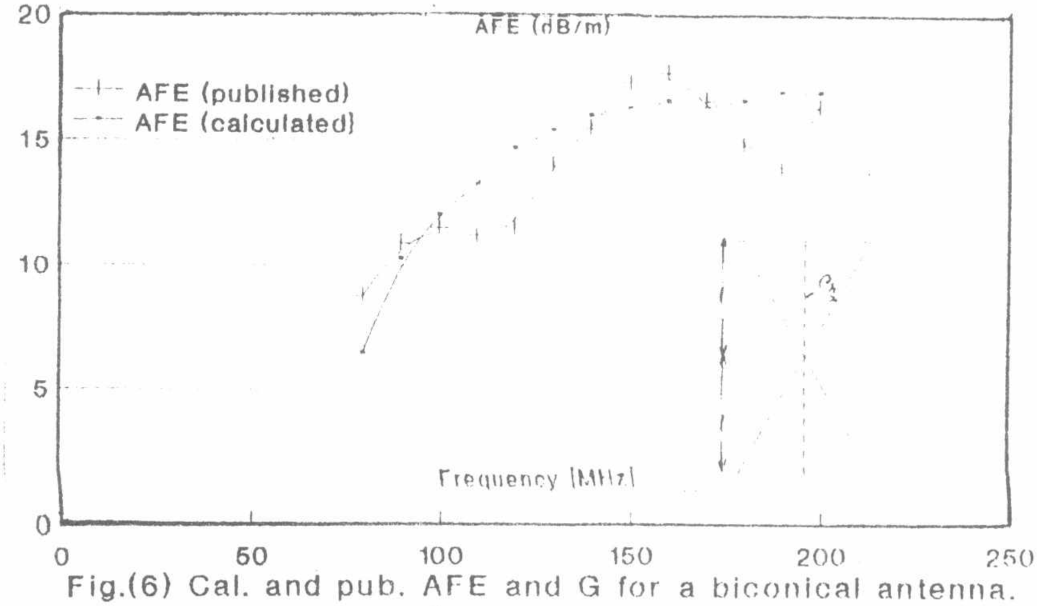


Fig.(6) Cal. and pub. AFE and G for a biconical antenna.