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Introducing Height Correction Factors for Accurate Measurements with Biconical Antennas above Groundplane

W. Müllner, M. Buchmayr
Austrian Research Center Seibersdorf,
Department of Electronics, A-2444 Seibersdorf
emc@arcs.ac.at

Abstract: The antenna factor of the biconical antenna is a function of antenna height above a ground-plane. Variations in the antenna factor of up to 1.9 dB are observed when the antenna is used in the typical height range of 1 m to 4 m on an open area test site (OATS). The magnitude of this variation depends on the impedance of the antenna balun. From the antenna factor simulations we have derived height correction factors which account for the coupling of biconical antennas above a groundplane. We have demonstrated with antenna calibration measurements what the simulated predictions show.

The new method of height correction can be applied to all measurements with biconical antennas, when the balun impedance of the antenna is known. It removes the systematic error caused by the height dependence of the antenna factor. Examples are demonstrated for precision field strength measurements on an OATS, accuracy enhancement for antenna calibration according to the standard site method given in ANSI C63.5 and conversion of OATS antenna factors to free space antenna factors and vice-versa.

1. Introduction

For radiated emission testing of electronic apparatus according to the basic standard CISPR 16-1 [1], calibrated antennas are required. The uncertainty of the antenna factor has to be less than ±1 dB. Calibration techniques exist to guarantee this accuracy and with some effort excellent antennas can be calibrated down to ±0.15 dB uncertainty in the antenna factor, valid for a certain measurement geometry [2].

We concentrate our investigations on the biconical antenna type which is widely used in the frequency range 30 MHz to 200 MHz. The antenna factor is a function of antenna height above a ground-plane due to mutual coupling. The variation of the antenna factor in the height range of 1 m to 4 m can be up to 1.9 dB. When it is not accounted for, using a correction technique as described in this paper, it contributes to the uncertainty budget as measurement error, additionally to the calibration uncertainty of the antenna factor.

Two measurement types are significantly influenced by the height dependence of the antenna factor. The radiated emission testing on an open area test site (OATS) or in a semi-anechoic chamber and the calibration of the antenna according to the standard site method, ANSI C63.5 [3], also known as 3-antenna method. We have investigated this effect by numerical simulation of the antenna and measurements. A practicable solution for correcting the height dependency of the antenna factor is presented in this paper.

2. The Biconical Antenna

Biconical antennas for the frequency range 30 MHz up to 200 MHz are available from many manufacturers. They all have very similar wire radiation structures which are mounted upon a support containing the balun.

The effect of height dependent antenna factors of biconical antennas has been shown in several publications by measurements [2, 4] and simulations [5]. In this paper we want to show the height dependence as function of polarisation and balun-impedance Z_{Bal} by numerical simulation of the antenna and real measurements. In Figure 1 the definition of Z_{Bal} is given.

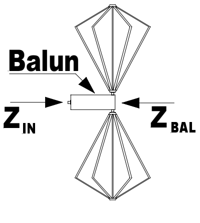


Figure 1: Biconical antenna, definition of input impedance Z_{in} and balun impedance Z_{Bal}.

2.1. Simulations

We use the Numerical Electromagnetics Code (NEC) to simulate the radiators of a biconical antenna. To handle the data input and output for NEC, especially the model generation and the calculation of the antenna factors, we developed a MATLAB-Toolbox. Special care was taken to design the simulation model in order to comply with NEC's design rules for thin wire models. The NEC model segmentation close to the antenna excitation region with its two eight-wire junctions was optimised to improve antenna factor predictions [5].

To calculate the free space antenna factors, the NEC model is excited with a plane-wave having an electric-field strength of 1 V/m. NEC simulation returns the current through the balun impedance Z_{Bal}. From the ratio of field strength to voltage at the load impedance Z we obtain the antenna factor. To calculate the antenna factor above ground-plane, two steps in the NEC simulation are required. First, we determine the electric-field strength at the location of the receive antenna, that is generated by a short dipole in a certain distance. The receive antenna is not present in the first step. Second we place the receive antenna in the field and calculate the voltage at the load impedance The antenna factor of the receive antenna is the ratio of field strength to voltage.

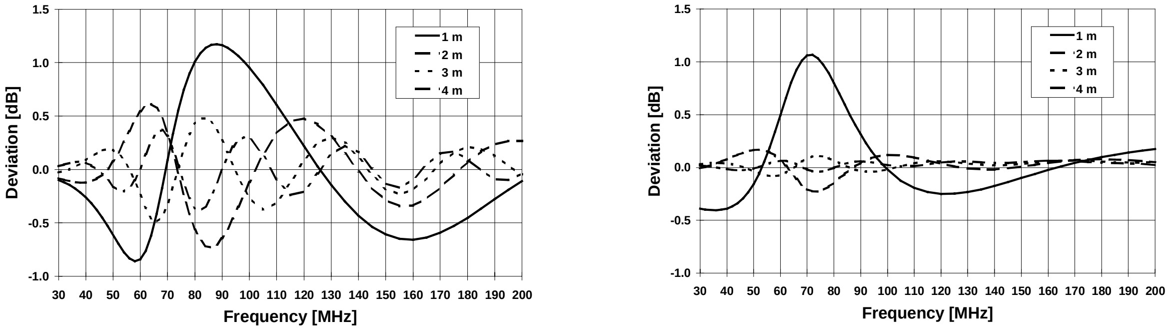
We have run simulations with different balun impedance Z of 50 Ω, 73 Ω, 100 Ω, 150 Ω and 200 Ω at the feedpoint of the antenna for antenna heights h of 1 m to 4 m in 20 cm steps on an OATS and in free space (FS) conditions. The difference between antenna factors on the two test site types ΔAF is calculated as function of height h, polarisation p and impedance Z:

$$\Delta AF(\mathrm{h,p,Z}) = AF_{\mathrm{OATS}}\,(\mathrm{h,p,Z}) - AF_{\mathrm{FS}}\,(\mathrm{Z}) \qquad (1)$$

Thus the antenna factor on the OATS in a certain height and polarisation equals the antenna factor in free-space plus a correction factor ΔAF which accounts for coupling with the groundplane on an OATS. Figure 2 shows selected results of this simulation.

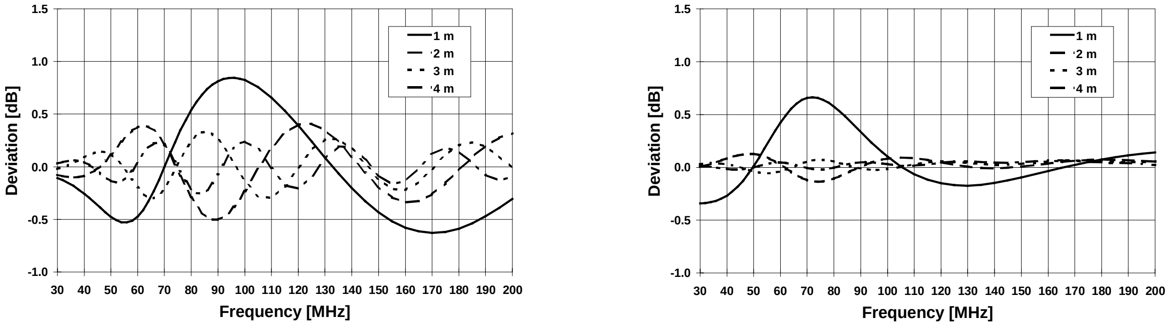
a) 50 Ohm, horizontal polarisation

b) 50 Ohm, vertical polarisation



c) 100 Ohm, horizontal polarisation

d) 100 Ohm, vertical polarisation



e) 200 Ohm, horizontal polarisation

f) 200 Ohm, vertical polarisation

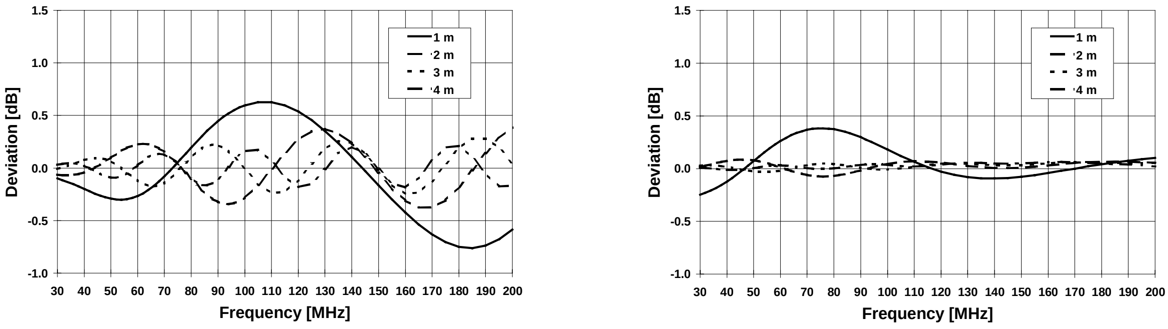


Figure 2: Deviation between free-space antenna factor and antenna factor on an OATS as function of height (1, 2, 3 and 4 m), balun impedance and polarisation

The deviations between AF_{OATS} and AF_{FS} are largest for lowest heights of the antenna for both polarisations: +1.18 dB / -0.85 dB for horizontal polarisation, 1 m height, 50 Ω balun impedance. For horizontal polarisation the coupling to the groundplane has a strong effect on the antenna factor for all heights. The variation is up to ± 0.4 dB for 4 m height, horizontal polarisation, 50 Ω. In vertical polarisation the variation is only ± 0.2 dB for 2 m height and less than ± 0.1 dB for 4 m height, 50 Ω. The impedance at the antenna feedpoint strongly effects the height dependence of the antenna factor. In the simulated impedance range of 50 Ω to 200 Ω the height sensitivity decreases with growing impedance.

2.2. Measurements

The complex balun impedance is needed to calculate the height dependent antenna factors for real biconical antennas. But for available biconical antennas it is practically not possible to determine the balun impedance with sufficient accuracy. Therefore we have developed a precision biconical antenna (PBA320) which comprises a special balun with a stable, frequency independent impedance of 100 Ω, an excellent phase symmetry of ± 0.2° and an amplitude symmetry of less than ± 0.2 dB. The ports of the balun are accessible for coaxial impedance measurements.

On our reference OATS we have set up a pair of PBA's, co-polarised, in 10 m distance to perform four transmission loss measurements. The transmit antenna is operated at a fixed height of 1 m and 2 m in horizontal polarisation and of 1 m and 1.5 m in vertical polarisation. The receive antenna performs a height scan in the range of 1 m to 4 m in order to find the minimum transmission loss between the 2 antennas. Then we calculate the sum of the antenna factors according to ANSI [1]:

$$AF_1(h_1) + AF_2(h_2) = 20\log(f_M) - 48.92 + E_D^{max} + A \quad (2)$$

where
f_M = *frequency in MHz*
E_D^{max} = *maximum received field [1]*
A = *measured transmission loss [dB]*

The measurement results are given in Figure 3. A large deviation in the two horizontal antenna factors (1 m height and 2 m height) of up to 2 dB can be observed. This effect is typical for biconical antennas. The heights of the receive antenna at which the minimum transmission loss is found, is given in Figure 3b.

2.3. Verification of Simulations

Using Eq. (1), the measured antenna factor sum can be written as

$$\mathrm{AF1(h1) + AF2(h2)} = \mathrm{(AF1,FS + \Delta AF1(h1))} + \mathrm{(AF2,FS + \Delta AF2(h2))} \quad (3)$$

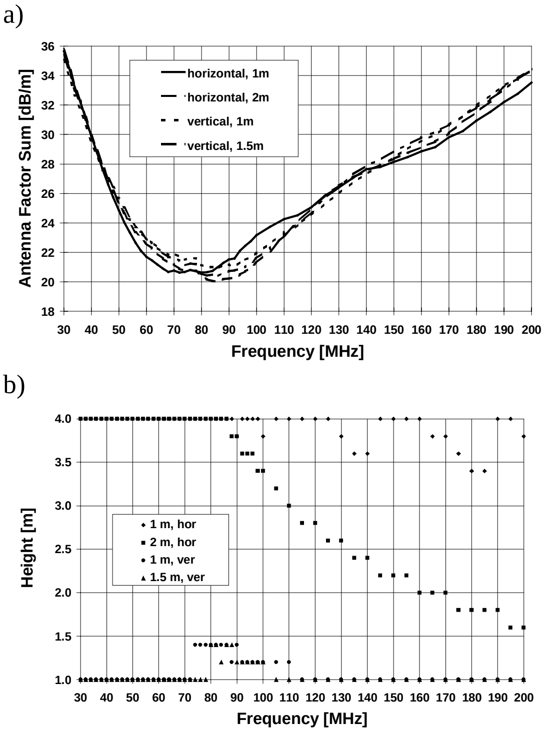


Figure 3: Four measured antenna factor sums of a Precision Biconical Antenna pair in 10 m distance on our reference OATS (a) and corresponding heights of receive antenna for minimum transmission loss (b).

assuming 2 identical antennas:

$$AF(h_1) + AF(h_2) = 2 * AF_{FS} + \Delta AF(\mathrm{h}_1) + \Delta AF(\mathrm{h}_2) \quad (4)$$

When we solve Eq. 4 to get the free-space antenna factor

$$AF_{FS} = (AF(h_1) - \Delta AF(\mathrm{h}_1) + AF(h_2) - \Delta AF(\mathrm{h}_2)) / 2 \quad (5)$$

On applying Eq. 5 to our four measurements, we expect to get four identical antenna factors: the free space antenna factor of our antenna.

Extracting the height corrections from the 100 Ω simulation (Fig. 2c,d) using the height information from Fig. 3b and applying it according Eq. 5 to the antenna factors on the OATS (Fig. 3a) results in the free-space antenna factors of Fig. 4. We get four nearly identical antenna factors with a maximum variation of only 0.3 dB around 80 MHz.

3. Application of Height Correction

To apply a height correction, information on the antenna height, balun impedance and polarisation is required. With the geometric dimensions of the antenna a NEC-model is generated and the correction table is calculated using the Matlab NEC Toolbox.
The calibration of the antenna can be done in free-space or on an OATS. The results are convertible as demonstrated in the previous chapter.

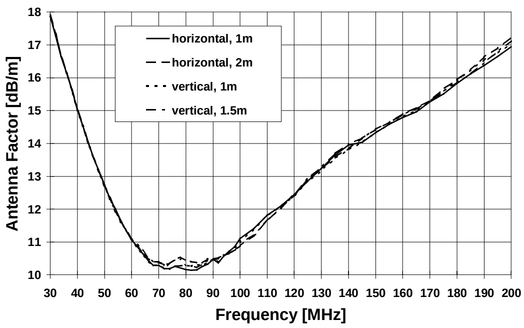


Figure 4: Measured antenna factors from Fig. 3 with applied height correction. In ideal case this results in 4 equal traces: the free space antenna factor.

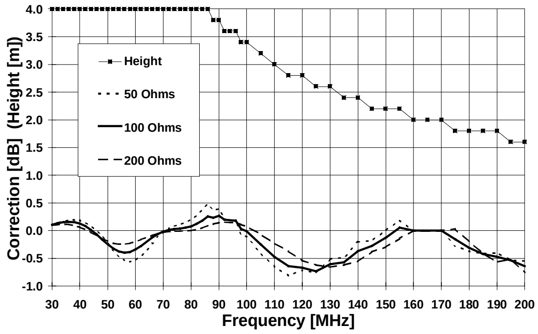


Figure 6: Correction factor for ‘Antenna 2’ for antenna calibration according to the standard site method. Given is the height of receive antenna for minimum transmission loss, when the transmit antenna is in 10 m distance, 2 m height, horizontal pol. The correction factors are given for different balun impedance.

3.1. Radiated Emission Testing

For measuring the radiated emissions of an EUT on an OATS or in a semi anechoic chamber it is required by the basic standard CISPR 16-1 to perform a height scan in the range of 1 m to 4 m in order to find the maximum field strength emitted by the EUT. The received voltage V is corrected by the cable loss and the antenna factor to obtain the field strength E(h) at the location of the antenna. In the course of height scan the antenna factor of the biconical antenna varies with height (see Fig. 2). For precision measurements it is therefore required to compensate for this by applying the height correction factor at each height of the receive antenna as given in Eq. 6. The maximum search has to be performed with E(h) and not with the received voltage V.

$$E(h) = V(h) + C + AF + \Delta AF(h) \qquad (6)$$

with
E = *Field strength at the location of the antenna [dBµV/m]*
V = *measured voltage at the receiver [dBµV]*
C = *cable loss of the receive cable [dB]*
AF = *Free space antenna factor [dB/m]*
ΔAF = *height correction factor for the receive antenna[dB]*
h = *height of receive antenna above groundplane*

3.2. Antenna Calibration

The standard site method, given in ANSI C63.5 [1] suffers from an inherent problem: it doesn't take the height dependence of the antenna factor into account: The ‘antenna 2’ is operated as transmit antenna at a certain height (e.g. 2 m) and as receive antenna in a height between 1 m and 4 m wherever the maximum of the field-strength is received (Fig. 5). For both operating conditions the antenna factor is different, up to +0.35 dB and –0.75 dB at 100 Ω. But the formulas given in the standard assume only **one** antenna factor for ‘antenna 2’. When the height dependence of ‘antenna 2’ is known a correction of this systematic error is possible.

Applying Eq. 1 to the ANSI C63.5 formulas for calculating the antenna factor, we present new formulas, for the standard site method, including a correction for the height dependent antenna factor of 'Antenna 2':

$$AF_1 = \tfrac{1}{2} * (A_1 + A_2 - A_3 - c + \mathrm{k}) \qquad (7)$$

$$AF_2 = \tfrac{1}{2} * (A_1 + A_3 - A_2 - c + \mathrm{k}) \qquad (8)$$

$$AF_3 = \tfrac{1}{2} * (A_2 + A_3 - A_1 + c + \mathrm{k}) \qquad (9)$$

where
AF_1, AF_2, AF_3 = *antenna factors of antennas 1, 2 and 3 [dB/m]*
A_1, A_2, A_3 = *measured site attenuations [dB]*
c = *height correction term [dB]*

$$c = \Delta AF(\mathrm{h}_{1,\ \mathrm{fixed}}) - \Delta AF(\mathrm{h}_{2,\ \mathrm{variation}}) \qquad (10)$$

$$k = 20\log(f_M) - 48.92 + E_D^{max} \qquad (11)$$

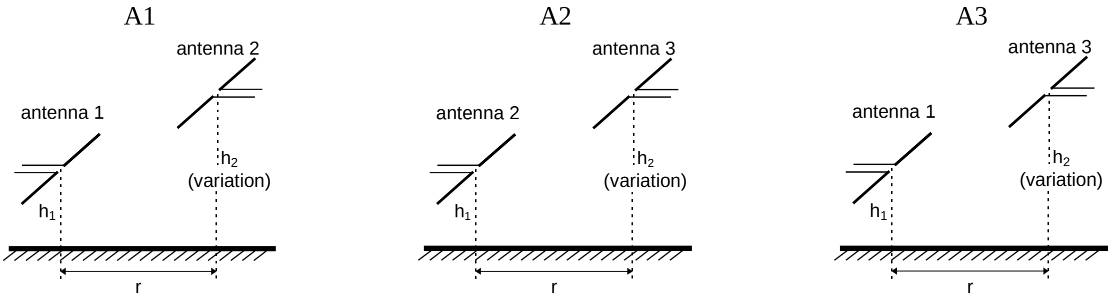


Figure 5: Standard site, 3-antenna method for calibrating antennas on an OATS according to ANSI C63.5.

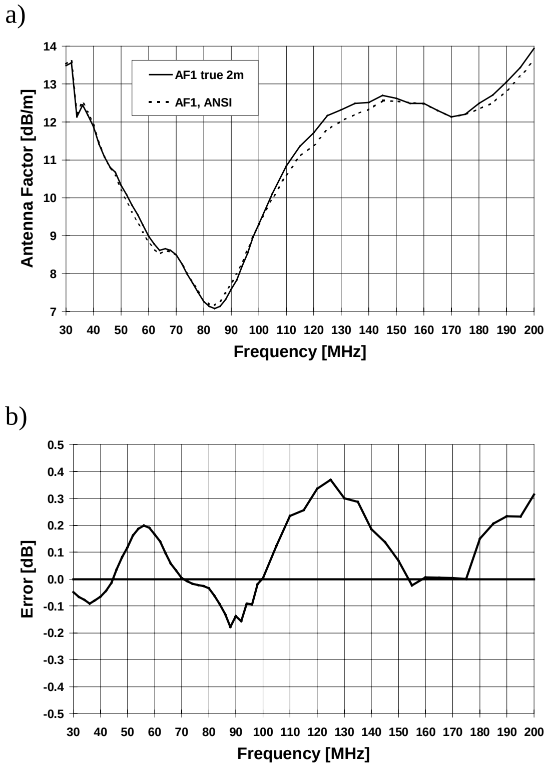


Figure 7: Results of antenna calibration according to the standard-site method given in ANSI in comparison with the applied height correction to ’Antenna 2’

a) Antenna factors of ’Antenna 1’, 2 m height, horizontal pol., 100 Ohms

b) Error without the correction method

In Figure 6 the correction term is given for different balun impedances, 2 m height of transmit antenna and horizontal polarisation. It can be seen, that the general shape of the correction is similar, but the exact value of the correction factor depends on the balun impedance of the ’antenna 2’

In Figure 7 we show the calibration result of a biconical antenna according to the standard site method and a calibration result using the height correction technique. The improvement in accuracy is up to 0.37 dB.

4. Conclusion

We have simulated the antenna factor of biconical antennas on different types of test sites as function of balun impedance and polarisation. Height correction factors are introduced which account for the coupling of the antenna on an OATS. They depend on the impedance of the balun. Therefore it is essential to use antennas where this parameter can be measured with sufficient accuracy. We have demonstrated with practical antenna calibrations on an OATS that the simulated predictions prove.

The method of height correction allows an accuracy improvement for precision field strength measurements on an OATS or semi anechoic chamber. Furthermore it removes the systematic error caused by the height dependence of the antenna factor in the standard-site, 3-antenna method.

We focused on the biconical antenna but recent developments as the biconical-logarithmical antenna have the same principal properties in the frequency range of 30 MHz to 200 MHz.

5. References

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