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Calibration of Antenna for EMI Measurements in Compact Semi-anechoic Rooms

G. Betta[1], D. Capriglione[1], C.F.M. Carobbi[2], M. D. Migliore[1]

[1] *DAEIMI, University of Cassino, Via G. Di Biasio 43, 03043, Cassino (ITALY), Ph:+3907762993629, Fax:+3907762993729, email: {betta, capriglione, mdmiglio}@unicas.it*
[2] *Department of Electronics and Telecommunications, University of Florence, Via S. Marta 3, 50139, Firenze (ITALY), Ph:+390554796268, Fax:+39055494569, email: carlo.carobbi@unifi.it*

Abstract- The accurate knowledge of the antenna factor is a fundamental requirement for reliable electromagnetic compatibility (EMC) measurements in emissions, immunity and human exposure tests. According to international standards, this would imply calibrating antennas in close-to-ideal test sites (calibration test sites), characterized by very large sizes of the ground plane and of the empty space volume above it (free-space behaviour). On the other hand the greater number of EMC test sites is designed for measurements at 3 meters distance, therefore it would be very convenient to calibrate antennas in such facilities at the cost of an acceptable loss of accuracy. In this paper, the authors investigate on the suitability of compact (standard compliant for measurements at 3 m) semi-anechoic rooms for reliable antenna factor calibrations of EMI antennas. As an example, the calibration of a common broadband biconical antenna in the range 200 MHz-1 GHz has been considered. A detailed experimental analysis was performed for estimating all the involved uncertainty components.

I. Introduction

Measurements of Electromagnetic Compatibility (EMC) require the use of proper instrumentations, specific measurement procedures and particular sites for making reliable radiated emission and immunity tests [1]-[2].

With reference to the radiated emissions, the measurement chain is constituted by a suitable antenna to detect the electromagnetic field due to the emission source, by a receiver (or spectrum analyser), and by a coaxial shielded cable for connecting the measurement instrument to the antenna. For each frequency, the measurement result is achieved by adding (in dB scale) the receiver (or spectrum analyser) reading, the cable attenuation, and the free-space antenna factor [3]-[4]. Each component of the measurement chain contributes to the overall uncertainty. This has to be accurately evaluated and taken into account for comparing the measurement results with the applicable standard emission limits.

The free-space antenna factor value and the related uncertainty are the most critical parameters to be evaluated. Accurately calibrated antenna factors would require the use of suitable setups and measurement procedures involving relatively high-cost instrumentation and specific test sites as similar as possible to ideal one (defined as a test site on which the reflective surface is flat and has infinite conductivity and size). The ANSI C63.5-1998 is the international reference which regulates the antenna factor calibrations in the range 30 MHz-1 GHz. It suggests using two main methods: the Standard Site Method (SSM) and the Reference Antenna Method (RAM) [5].

The former requires three site attenuation measurements under identical geometries (height of the transmitting antenna, height of the receiving antenna and their separation distance) using three different antennas taken in pairs. Antenna separations of 10 m and 30 m and large metal ground plane are in particular recommended. The accuracy of antenna factors determined by the SSM mainly depends on the accuracy of the site attenuation measurements.

The latter provides a method of antenna calibration based on the use of a dipole with a well-matched balun and whose construction must follow well specific rules for achieving acceptable accuracies [5], [6]. This yields an antenna whose gain pattern and antenna factors are close to those predicted in theory. The antenna factor of any other antenna may be derived by substitution against the reference dipole antenna. A 10 m separation distance should be employed to eliminate any antenna-to-antenna coupling.

Both methods can provide a similar accuracy, which mainly depends on the quality of the measuring site for the SSM and the accuracy with which the reference antenna is constructed for the RAM. As described above, SSM and RAM would require separation distances (between the transmitting and the receiving antenna) not less than 10 m to assure acceptable accuracies for antenna factor calibrations.

Due to the related high-costs and large spaces required, these wanted setup conditions make difficult the realization and the accreditation of laboratories/sites able to reliably calibrate antenna factors. As a consequence, these operations can result still quite expensive for the customer.

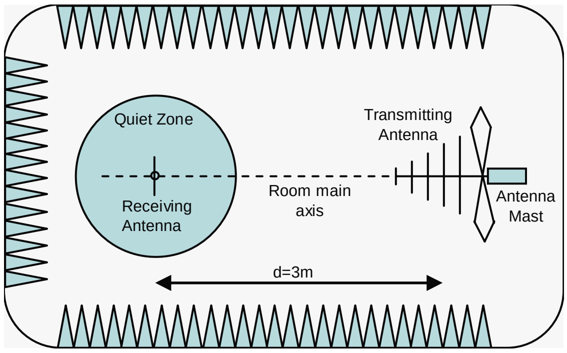


Figure.1 Layout of the measurement setup (top view)

In past, many efforts were addressed to study the dependence of the antenna factor (for typical antennas for EMI measurements) upon both the calibration method adopted and the test site features (geometrical and electromagnetic) [7]-[9]. Other researches were aimed to propose standard method modifications and novel antenna factor calibration methods [10]-[12]. In all the cases some difficulties arise because relatively large ground planes (greater than 8 m x 8 m) and Open Area Test Sites (OATS) are required, or the novel calibration method works in specific frequency range (above 600 MHz).

In [13], [14] antenna factor calibrations on 3 m test sites (both OATS and small fully anechoic chambers were considered) were experimentally evaluated. The achieved results showed a good agreement with the antenna factor provided by the manufacturers, except for the frequency range 30 MHz÷200 MHz, where the coupling phenomena among the antenna (transmitting and receiving) and the ground plane are more relevant.

In this paper, the authors investigate on the suitability of compact (standard compliant for measurements at 3 m) semi-anechoic rooms for reliable antenna factor calibrations of EMI antennas. The RAM method was adopted on a broadband biconical antenna typically employed for EMC applications and electromagnetic environmental fields monitoring. A detailed experimental analysis was performed in order to carefully identifying and estimating the uncertainty components due to the measurement chain, to the site and method imperfections, and to the site reproducibility.

II. The proposed approach

The RAM method was applied for evaluating the antenna factor in the 200 MHz-1 GHz band of a broadband biconical antenna (model EMSAP2000) provided with its cable (model EMSOCF010).

All the tests are carried out in a semi-anechoic room (9.5 m x 5.7 m x 6.2 m), full compliant for 3 m EMI measurements. The simplified layout setup is reported in Figure 1. The receiving antenna is placed in the "quite zone" on a non-conductive support 2.60 m height with aim of containing the mutual coupling with the ground plane, thus avoiding a strong dependence of the antenna factor from the height [15]. The transmitting antenna was a biconilog (Model EM-6917C, 30 MHz-1000 MHz), mounted in horizontal position on a suitable mast for scanning heights from 1 m up to 4 m with a resolution of 0.15 m. The distance, d (evaluated as projection on the ground plane), between the transmitting and receiving antennas was 3 m. As for the reference antenna, a set of four tuned dipoles, model EM-6924-1, characterized by a balun loss < 0.5 dB, was adopted. The electromagnetic field was generated by means of a suitable RF signal generator (external to the chamber) and of a RF power amplifier (75 Watts). The receiving antenna output voltage was picked by the coaxial cable provided by the antenna under calibration manufacturer, and measured by an EMI Receiver (external to the chamber), Rohde & Schwarz ESPC (9 kHz-2.5 GHz). In order to minimize the cable effect, it was arranged not in proximity and not in parallel to the receiving antenna elements. As for the frequency step, as suggested in [5], a 50 MHz-step in the range 200 MHz-300 MHz, and a 100 MHz-step in the range 300 MHz-1000 MHz were considered. For each frequency, the measurement procedure involves the following main steps:

1. place the reference antenna in the receiving position;
2. found the transmitting antenna height which assures the maximum received voltage, V_{REF}, by the reference antenna;
3. replace the reference antenna with the antenna under calibration (AUC) and read the corresponding output voltage, V_{AUC};
4. calculates the AUC Antenna Factor, AF_{AUC}, as follows:

$$AF_{AUC} = AF_{REF} + V_{REF} - V_{AUC} \quad (1)$$

where AF_{REF} is the antenna factor of the reference antenna and the Eq. (1) has been formulated in

Table 1 Comparison of antenna factors

Frequency [MHz]	**AF_{AUC} [dB/m]**	**AF_{MAN} [dB/m]**	**$\Delta = AF_{AUC}-AF_{MAN}$ [dB]**
200	30.8	33.0	-2.2
250	30.1	28.5	1.6
300	26.4	27.9	-1.5
400	21.8	22.3	-0.5
500	23.6	23.4	0.2
600	25.8	26.2	-0.4
700	29.5	29.5	0.0
800	29.8	31.0	-0.2
900	30.7	31.3	-0.6
1000	31.7	33.9	-2.2

logaritimic scale.
To verify the suitability of the method in providing reliable results, the measured antenna factor was compared with one provided by the manufacturer, taking into account the related uncertainties.
All the uncertainty components involved in the measurement chain have to be considered [15]-[17], among which the contributes due to: the electromagnetic field source stability, the receiver (resolution, and accuracy), the cable (connector repeatability, attenuation variation due to the temperature), the impedance mismatch, the positioning errors, the reflection from the antenna mast and cables, the reference antenna factor, and the site imperfections. The evaluation of such quantities was made on the basis of the instruments specification and calibration data, and by considering either reference values suggested in [15]-[17] or experimental analyses performed on the field.
In addition, to verify the repeatability and the reproducibility of the results, a number of experiments was repeated in a short-term period and in a different day.

III. Experimental results

Following the measurement steps described in the previous section, the AF_{AUC} was evaluated and compared with the value provided by the manufacturer, AF_{MAN}.
Table 1 reports the corresponding deviation in the range 200 MHz-1 GHz: generally a good agreement between AF_{MAN} and AF_{AUC} is observed, with the exception of frequencies 200 MHz and 1 GHz, where the highest biases (-2.2 dB) arises.
To validate these results, two kinds of experimental analyses were performed by evaluating the measurement's repeatability and reproducibility:

A. all tests were run five consecutive times in the same experimental conditions. For each frequency the maximum deviation among the five AF_{AUC} was observed. A maximum deviation equal to 0.2 dB was obtained at 500 MHz, whereas maximum differences always less than 0.1 dB were achieved for the other frequencies (see Figure 2a);

B. further experiments were performed in a different day by repeating all the measurement operations and setup arrangements. In this way, an absolute maximum deviation equal to 0.3 dB was observed at 1000 MHz, whereas maximum differences always less than 0.2 dB were achieved for the other frequencies (see Figure 2b).

These results prove the good repeatability and reproducibility of both the measurement method and the site. However, the antenna factor deviations observed in the above analyses have to be taken into account to quantify the overall measurement uncertainty, because they have a critical role in the EMC

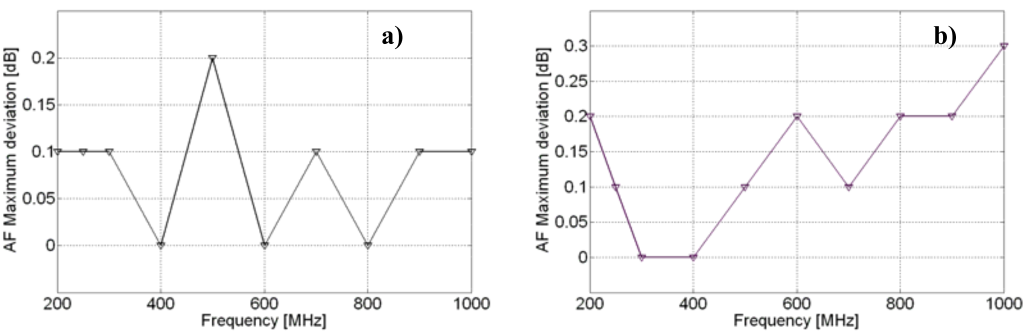


Figure 2. Maximum deviation of AF_{AUC}: a) evaluated over five consecutive measurements, b) evaluated as difference between measurements performed in two different days.

Table 2 Measurement chain uncertainties

Uncertainty source	Probability Distribution Function	Standard Uncertainty [dB]
Receiver Accuracy	Normal	0.10
Connector repeatability	Normal	0.10
Cable attenuation variation due to the temperature	Rectangular	0.11
Antenna Factor of the reference antenna	Rectangular	0.29
Reflections from mast And cables	Rectangular	0.03
Error in free-space assumption	Rectangular	0.09
Mismatch error	U-shape	0.08
Polarisation Mismatch	Normal	0.03
Antenna alignment	Normal	0.10
Combined uncertainty (u_M)	**Normal**	**0.38**

context [19].

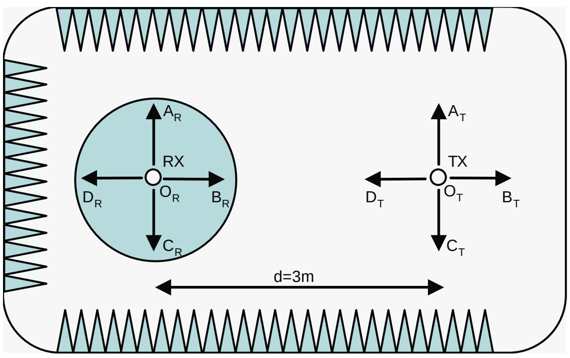
As previously described, the measurement of the AF_{AUC} is affected by several uncertainty causes that can be grouped in the following main classes:

i) *measurement chain uncertainties*, u_M: due to source filed instability, receiver accuracy, cable accuracy, impedance mismatching, accuracy of the reference antenna factor. These components was estimated starting by instrument calibration data, manufacturer specifications and some reference values suggested in [15]-[17]. Table 2 reports the considered values together with the combined uncertainty, $u_M = 0.38$ dB;

ii) *uncertainty due to the antennas positioning errors*, u_{PE}: due to the measurement of distance used between the transmitting and the receiving antennas. Accepting a positioning error of ±0.02 m, this uncertainty component was experimentally evaluated by repeating the antenna factor measurements at two other different distances, $d_1=d+0.02\ m$ and $d_2=d-0.02\ m$. The obtained maximum absolute deviations (calculated as difference with respect to the antenna factor measured in *d* over the whole frequency range) were $\Delta_{P1MAX} = 0.3$ dB and $\Delta_{P2MAX} = 0.3$ dB, respectively. Therefore, assuming a rectangular probability distribution and defining $\Delta_{PMAX} = \max(\Delta_{P1MAX}, \Delta_{P1MAX})$, the standard uncertainty, u_{PE}, is assumed given by:

$$u_{PE} = \frac{\Delta_{PMAX}}{\sqrt{3}} = 0.17dB \quad (2)$$

iii) uncertainty due to the site imperfections, u_S: mainly due to the difference between theoretical site attenuation and the measured one. Generally, this contribution is overestimated because the relatively high uncertainty due to the measurement procedure and experimental apparatuses would provide a standard uncertainty not less than 1.63 dB [16], [18]. Therefore, to improve the estimation of this uncertainty component, a recently proposed experimental procedure was applied [5], [18]. It consists in directly comparing the behaviour of the site under investigation with the basic property of the ideal reference site which is its absolute invariance with respect to horizontal motion. Concisely, two identical antennas (transmitting and receiving) are translated along the ground plane without letting anything else change during the motion. This rigid horizontal translation should give rise to *zero variation* in the ideal site, the accuracy of the probing apparatus being in this case irrelevant. In the our case two biconilog antennas (30 MHz-1000 MHz) horizontally polarized were



Measurement positions
TX: O_T, RX: O_R
TX: O_T, RX: A_R
TX: O_T, RX: C_R
TX: A_T, RX: A_R
TX: A_T, RX: O_R
TX: A_T, RX: C_R
TX: B_T, RX: B_R
TX: C_T, RX: C_R
TX: C_T, RX: O_R
TX: C_T, RX: A_R
TX: D_T, RX: D_R

Figure 3. Measurement setup for the evaluation of the site imperfection.

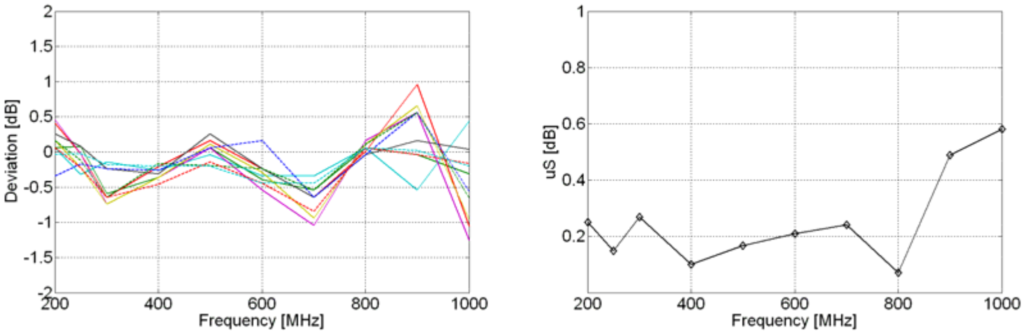


Figure 4. a): Deviations of the ten new measurements from the reference configuration (TX:O_T, RX:O_R), b): variability interval at 68.3 % with ten degrees of freedom.

placed at 3 m, heights of 2 m and of 1.7 m were fixed for the transmitting and receiving antennas respectively. Starting from the reference configuration (transmitting antenna, TX, placed in O_T and the receiving antenna, RX, placed in O_R) ten new measurements were collected by moving both antennas across the ground area to be explored and following the scheme reported in Figure 3 in which, for each measurement the distance between TX and RX was kept to 3 m. Figure 4 reports the deviation of the ten measurements from the reference configuration, together with the corresponding variability interval at 68.3 % of confidence level, u_S, estimated by considering ten degrees of freedom.

The relatively small values observed for the deviations (always constrained in 1.3 dB) and the variability intervals (always constrained in 0.60 dB) prove the good behaviour of the site, with worst performance for frequencies > 800 MHz.

Considering the worst case, the site imperfections will contribute to the uncertainty budget with a value, u_S, equal to the maximum observed variability interval, i.e. 0.60 dB;

iv) *uncertainty due to the measurement repeatability*, u_R: it includes the measurement chain and the measurement method contributions caused by short-term variations. Starting from the results achieved with the above-described analysis (A.), for each frequency, the standard uncertainty, u_R, has been calculated as variability interval at 68.3 % of confidence level with five degrees of freedom. Once again, u_R depend on the frequency, nevertheless it will be considered constant and equal to u_{RMAX} (worst case, achieved at 500 MHz), i.e. 0.10 dB;

v) *uncertainty due to the measurement reproducibility*, u_D: it takes into account the setup and measurement variability that could be arise whenever the experiments are performed in a different day. Starting from the results achieved with the above-described analysis (B.), u_D was calculated assuming a rectangular probability distribution with the semi-interval given by the greatest observed deviation, ΔD_{MAX} (0.3 achieved at 1000 MHz). As a consequence:

$$u_D = \frac{\Delta_{DMAX}}{\sqrt{3}} = 0.17dB \tag{3}$$

Finally, the combined uncertainty, u_{AF}, is given by:

$$u_{AF} = \sqrt{u_M^2 + u_{PE}^2 + u_S^2 + u_R^2 + u_D^2} = 0.74dB \tag{4}$$

Taking into account the expanded uncertainty (at 95 % of confidence level), $U_{AFMAN} = \pm$ 1.8 dB, provided by the manufacturer, one can verify the full compatibility of the obtained antenna factor values with the expected ones (see Figure 5).

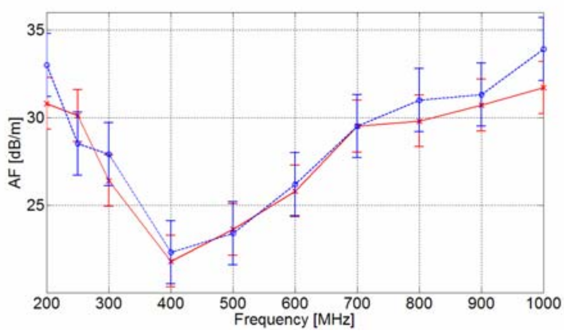


Figure 5. Antenna factor comparisons: AF_{MAN} (-), AF_{AUC} (--).

IV. Conclusions

The experimental analyses carried out in this paper were aimed at studying the suitability of compact semi-anechoic rooms for reliable antenna factor calibration. A number of experiments have been carried out for estimating the antenna factor of a common biconical broadband antenna in the range 200 MHz-1 GHz, by applying the RAM method inside a 3 m standard compliant site. The estimation of the measurement uncertainty has been made by taking into account several components such as the measurement chain, the measurement repeatability and reproducibility, and the site imperfections, achieving an expanded uncertainty (at 95 % of confidence level) less than 1.5 dB (an acceptable value for this kind of application). Comparing the measured antenna factor with the value provided by the manufacturer a full compatibility appears, thus confirming the goodness of the obtained results.
Further research will concern with an extension of the study to other kind of antennas and frequency ranges.

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