Novel Approach to Uncertainty of Antenna Factor Measurement

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*Abstract-*Different method to calculate uncertainty of antenna factor measurement is presented in this paper. This approach does not break the rules of standard uncertainty calculation approach, but reduces the entire uncertainty. It is obtained by performing the measurement with two reference dipole antennas and considering frequency dependent contributions of the uncertainty as well as the possible covariance between them.

I. Introduction

A radiated emission measurement belongs to such tests of the electromagnetic compatibility (EMC) of electrical equipments, which are performed in common for electrical devices. The measurement requires a measurement of electric field strength, which is compared with a limit level [1]. A measuring chain consists of a rf voltmeter, an antenna, which converts electric field strength to the voltage and a cabling. In EMC area, the most important parameter of the antenna is so called antenna factor, via which measured output voltage of the antenna is converted to electric field strength. Two types of the antenna factors are known :
– a free space antenna factor – used at the measurement in free space,
– a standard site method antenna factor – used at the measurement at test site, i.e. space with reference ground
  plane.
Both antenna factors are used in EMC area, in consideration of their advantages or disadvantages.

Nowadays, an essential condition for accrediting a calibration laboratory is that the laboratory has included the relevant uncertainty components in its implementation of the measurement methods, such as deviations from the measurement model implied by the standard. The uncertainty shall be calculated according to the international standard [2]. The same situation is in EMC area [3, 4], even though decibel units are used (due to known properties of log-normal distribution [5]). The standard approach leads to a relatively high value of the uncertainty, also mutual influence of the uncertainty contributions – covariances – are neglected. In the case of antenna factor measurement, such a parameter is frequency dependent; also the contributions are frequency dependent. In addition, antenna factor are obtained by relatively complicated process of three measurements of site attenuations.

The aim of this paper is to design such a process of evaluation of the standard site method antenna factor measurement uncertainty, obtained from measured values of site attenuations and considering all the disturbing effects, their frequency dependence and mutual influence among the contributions. The task is also to find such a process which leads to decrease of the entire uncertainty value.

II. Problem description

Antenna factor *AF* is defined as the ratio of incident electromagnetic field strength *E* to the voltage *V* on the line of the connection of an antenna:

$$AF = \frac{E}{V} \qquad (1)$$

Also it can be determined as [6]:

$$AF = \sqrt{\frac{4\pi\eta}{Z\lambda^2(1-\Gamma^2)G}} \qquad (2)$$

where η is impedance of free space, *Z* load (generally 50Ω), λ wavelength, Γ reflection coefficient of potential impedance mismatch on an antenna output and *G* is antenna gain. So, the antenna factor contains not only transmission ratio but also losses due to impedance mismatch. According to (2) it is also directly proportional to frequency of a measured signal.
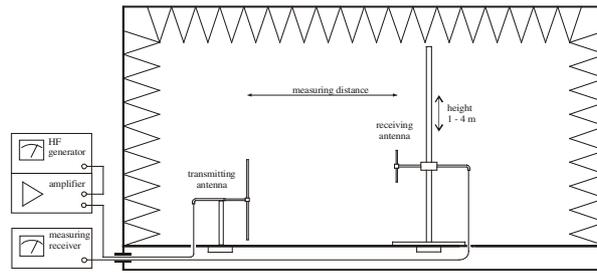
Figure 1. "Standard site measurement" antenna factor measurement system

The antenna factors values should be obtained by three-antenna methods [7]. Its principle is based on performance of three measurements of the site attenuation, given by the difference between a voltage on transmitting antenna input and a received voltage on measuring antenna output, for different pairs of antennas. These measurements can be executed in free space or at standard test sites with a reference ground plane. If antenna factor is measured at the test site given parameter is called as standard site measurement antenna factor. Such an antenna factor is different from free-space antenna factor (up to 2 dB) [8] and may be obtained by three measurement of site attenuation SA [6]:

$$SA_1 = 48.92 + AF_1 + AF_2 - 20\log f - E_{D\max}$$
$$SA_2 = 48.92 + AF_2 + AF_3 - 20\log f - E_{D\max} \qquad (3)$$
$$SA_3 = 48.92 + AF_3 + AF_1 - 20\log f - E_{D\max}$$

where f is frequency and E_{Dmax} is theoretically obtained value of electromagnetic field strength at given frequency, measuring distance and polarisation of an antenna. Parameter E_{Dmax} in (3) is assumed in uncertainty calculation as a constant. Site attenuation values SA may be simply obtained as:

$$SA = V_{dir} - V_{site} \qquad (4)$$

where V_{dir} is a measured voltage when a signal generator is directly connected with the rf voltmeter. V_{site} is measured voltage when antennas, by which the site attenuation is measured, are added in measuring chain. From (3) we can determine required values of antenna factors AF:

$$AF_1 = \frac{1}{2}(SA_1 + SA_3 - SA_2) - 24.46 + 10\log f + \frac{1}{2}E_{D\max}$$

$$AF_2 = \frac{1}{2}(SA_1 + SA_2 - SA_3) - 24.46 + 10\log f + \frac{1}{2}E_{D\max} \qquad (5)$$

$$AF_3 = \frac{1}{2}(SA_2 + SA_3 - SA_1) - 24.46 + 10\log f + \frac{1}{2}E_{D\max}$$

The uncertainty of such a antenna factor measurement may be calculated by standard approach according to the ISO document [2]. The entire uncertainty is given by integration of type A evaluation and type B evaluation. Since values of antenna factor (as well as other parameters) are in decibels, using theory of log-normal distribution [5] it is possible to use approach of [2] in this case.

III. Solution

The values of uncertainties of rf voltage measurement $u(V)$ and site attenuation measurements $u(SA)$ should be known at first to get the uncertainty of standard site method antenna factor measurement. The process of the uncertainty $u(V)$ calculation is known [9], while the uncertainty $u(SA)$ should be determined. The following model of measurement of site attenuation SA may be built up (according (4)):

$$SA = (V_{dir} + \delta PSV_{dir}) - (V_{site} + \delta PSV_{site} + \delta D + \delta h_1 + \delta PC + \delta Z_h + \delta F) \qquad (6)$$

This model is extended with parameters which has zero value but affects the uncertainty of the measurement: δPSV is correction of impedance mismatch of given measuring chains, δD correction of measuring distance, δh_1 correction of height of transmitting antenna, δPC correction of phase centre location, δZ_h correction of antenna's input impedance height variation and δF is correction of antenna's directivity. Corrections δPC, δZ_h and δF are sums of contributions of both (transmitting and receiving) antennas. Then we can determine the uncertainty of site attenuation measurement as:

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$$u(SA) = \sqrt{u(V_{dir})^2 + u(V_{site})^2 + \frac{M_{dir}^2 + M_{site}^2}{2} + \frac{u_D^2 + u_{h1}^2 + u_{PC}^2 + u_{Zh}^2 + u_F^2}{3} + 2.u(V_{dir}, V_{site})} \qquad (7)$$

where u_D, u_{h1}, u_{PC}, u_{Zh} and u_F are maximal variations caused by given effects with rectangular probability distribution and M_{dir} and M_{site} are maximal errors caused by impedance mismatching according [10]:

$$M = 20\log(1 \pm \Gamma_a \Gamma_r) \qquad (8)$$

Γ_a and Γ_r are reflection coefficient of antenna and receiver, respectively. U-shaped probability distribution [10] is assumed in case of M. It is evident from (7) that all the sensitive coefficients are assumed to be one. Due to weak interdependence (close to zero), the parameters of (7) may be considered as independent.

It is advisable to use dipole antennas, which has zero values of u_{PC} and u_F, to obtain low values of uncertainties $u(SA)$. Also u_{Zh} can be considered as zero, if height of transmitting antenna over ground plane is kept constant. So final uncertainty of site attenuation measurement is given:

$$u(SA) = \sqrt{u(V_{dir})^2 + u(V_{site})^2 + \frac{M_{dir}^2 + M_{site}^2}{2} + \frac{u_D^2 + u_{h1}^2}{3}} \qquad (9)$$

If antenna factor AF is measured by three antenna method (5) the uncertainty of such a measurement may be calculated as:

$$u(AF) = \sqrt{\left(\frac{u(SA_1)}{2}\right)^2 + \left(\frac{u(SA_2)}{2}\right)^2 + \left(\frac{u(SA_3)}{2}\right)^2 + 2u(SA_1, SA_2) + 2u(SA_1, SA_3) + 2u(SA_2, SA_3)} \qquad (10)$$

where the covariance are determined:

$$u(SA_i, SA_j) = \pm \frac{r_{ij}}{4} u(SA_i) u(SA_j) \qquad (11)$$

The sign in equation (11) is changing with regard to choice of antenna factor AF in (5). If substituting (6) into (5), the antenna factor measurement uncertainty changes:

$$u(AF) = \frac{1}{2}\left(3u(V_{dir})^2 + 3u(V_{site})^2 + \frac{3M_{dir}^2}{2} + \frac{M_{site12}^2}{2} + \frac{M_{site13}^2}{2} + \frac{M_{site23}^2}{2} + u_d^2 + u_{h1}^2 + \right.$$
$$\left. + \frac{2u_{PC1}^2}{3} + \frac{2u_{PC2}^2}{3} + \frac{2u_{PC3}^2}{3} + \frac{u_{Zh1}^2}{3} + \frac{u_{Zh2}^2}{3} + \frac{u_{Zh3}^2}{3} + \frac{2u_{F1}^2}{3} + \frac{2u_{F2}^2}{3} + \frac{2u_{F3}^2}{3} + C*\right)^{\frac{1}{2}} \qquad (12)$$

where M_{siteij} is maximal error caused by the impedance mismatch if i-th and j-th antenna is included into measuring chain at the site attenuation measurement, u_{PCi}, u_{Zhi} and u_{Fi} are contributions of phase centre variation, input impedance height variation and directivity of i-th antenna. Parameter C* represents all possible covariances (between the same values in (12), e.g. the voltage measured with the same rf voltmeter, etc), which are expected in contrast to other works of uncertainties in EMC area. In such case we considered strong dependence between the parameters ($r = 1$), otherwise we considered no dependence ($r = 0$).

It is appropriate using a pair of dipole antennas combined with measured antenna to minimize the uncertainty of antenna factor measurement. The equation (12) is changing for measured antenna "1":

$$u(AF) = \frac{1}{2}\sqrt{4u(V)^2 + M_{dir}^2 + \frac{M_{site12}^2 + M_{site13}^2 + M_{site23}^2}{2} + u_D^2 + u_{h1}^2 + \frac{u_{Zh1}^2 + 4u_{F1}^2}{3}} \qquad (13)$$

In equation (13) we do not consider neither with value of u_{PC1}, which is possible to reduce if other two antennas are dipoles antennas [8]. The value of uncertainty of antenna factor measurement may be calculated generally, for the entire frequency range considering maximal contributions, errors, in (13), or individually for discrete frequencies. In the second approach we can reduce the influence of some contributions, which effects may be evident at various frequencies.

IV. Results

The advantages of such an approach were examined in case of Bilog antenna. Tested Bilog antenna used in this

paper is 785 mm long and 1660 mm wide, with 15 pairs of dipole elements and a bow-tie part. All the measurements, mentioned above, were executed in semi-anechoic chamber of EMC Laboratory of Slovak University of Technology. All the uncertainty contributions were obtained in our previous work [11] (all these contributions are frequency dependent).
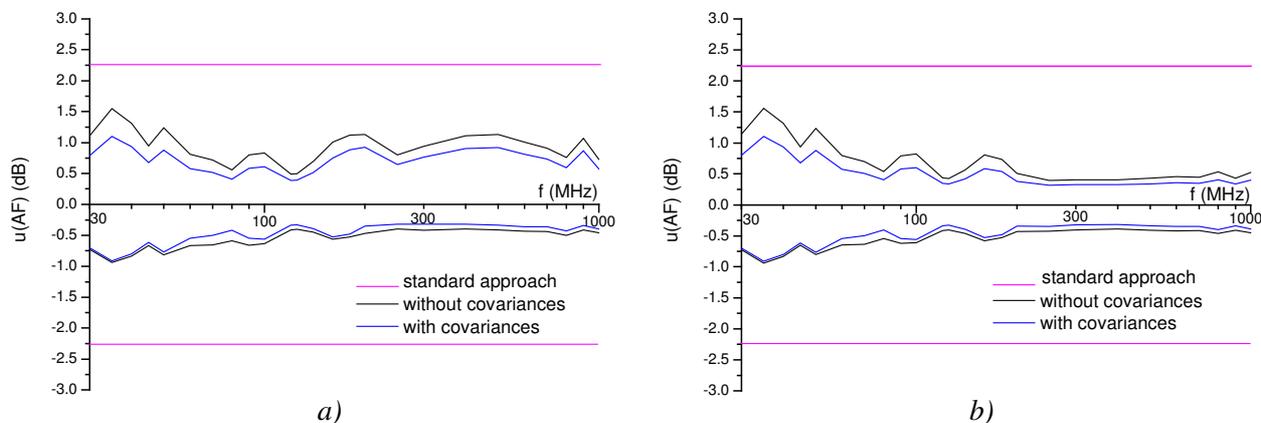

Figure 2. Antenna factor measurement uncertainties of various calculation for horizontal *a)* and vertical *b)* polarizations of antenna

The comparison of calculated uncertainties is shown in Fig. 2. Standard approach according [3] count with maximal values of uncertainty contributions in the entire frequency range and therefore we get only one value of both sign ± 2.24 dB (pink line). Such uncertainty is much higher than values of the frequency dependant uncertainties.

Assuming process of calculating uncertainties in discrete frequencies (black line), the entire uncertainty can be decreased due to restriction of two most evident uncertainty sources – the directivity of Bilog antenna [12], which causes errors mainly at higher frequencies, and the impedance mismatch of Bilog antenna, which increases the uncertainty at lower values of frequency. In such case the final uncertainty is not single valued nor it is symmetrical (equal for both signs). Maximal positive value of uncertainty is +1.55 dB and negative one – 0.94 dB for both polarisations. The main difference between the polarizations is at higher frequencies due to antenna directivity.

Considering also correlations between uncertainty contributions, other reduction of the uncertainty may be achieved (blue line). Maximal uncertainties are a bit smaller +1.1 dB or –0.91 dB.

V. Conclusions

Different view to the calculation of the antenna factor measurement uncertainty is described in this paper. Although the calculation is based on standard process of uncertainty calculation, some improvements were applied, which reduce the entire uncertainty. It was achieved by using of pair of the dipole antennas in combination with the measured antenna, assuming of frequency dependence of uncertainty contributions and assuming of covariances. The entire uncertainty was reduced from 2.24dB to max. 1.1dB. However, such a reduction is on the expense of time of uncertainty calculation.

Acknowledgment

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