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Directivity error of broadband antennas at EMI measurement

***Abstract**. Since broadband antennas do not have the same radiation pattern as dipole antenna incidence disturbance may be measured with an error. Models of the broadband antennas for numerical simulations were created and verified. Using these models we obtained the relation between the receiving antenna directivity and measuring distance that leads into the directivity error and also affects uncertainty of the measurement.*

***Streszczenie.** Zostały opracowane modele szerokopasmowych anten dla symulacji numerycznej. Z zastosowaniem tych modeli otrzymano relacje pomiędzy kierunkowością anteny odbiorczej oraz odległością pomiaru powodujące błędy w pomiarach kierunkowości. (**Błąd kierunkowości szerokopasmowych anten przy pomiarach zakłóceń elektromagnetycznych**).*

Keywords: EMI measurement, broadband antenna, directivity, measuring distance
Słowa kluczowe: pomiar zakłóceń elektromagnetycznych, antena szerokopasmowa, kierunkowość, odległość pomiaru.

Introduction

The main task of electromagnetic interference (EMI) measurement is to recognize whether a maximal value of the radiated disturbance from the equipment under test (EUT) exceeds the maximal value given by a standard – a limit value. In order to obtain the radiated EMI measurement we should use antennas of various types. Tuned half-wave dipoles should be used to measure the EMI. Nowadays, it is up to date using broadband antennas in radiated emission measurement. These antennas shall satisfy the standard requirements [1], so they shall be plane polarized, the main lobe of their radiation pattern shall be such that the response in the direction of the direct wave and that in the direction of the wave reflected from the ground do not differ by more than 1 dB and the voltage standing-wave ratio of the antenna with the antenna feeder connected and measured from the receiver and shall not exceed 2.0 to 1. Despite the fact that antennas satisfy the mentioned requirements they bring into measurement additional errors, which increase the whole uncertainty of such a measurement. On the other hands many laboratories do not have recommended test site with a 10 m measuring distance. In such cases they may change the distance between tested device and receiving antenna and use corrections for this distance.

During the measurement may receiving antenna receive disturbing emissions from different directions. The antenna radiated disturbance from EUT directly but also by reflected wave from the reference ground plane, which ensures equivalent conditions for all test sites. Moreover, the receiving antenna is changing its height in the range of 1 m to 4 m over the reference ground plane that affects the direction of disturbance receive. Then the angle of incidence of disturbance depends also on a measuring distance. Therefore, it is necessary to know a relation between the antenna directivity properties and measuring distance. The antenna directivity is also affected by the presence of ground plane, which can cause another errors of measurement [2].

The analysis of the directivity properties of commonly used receiving antennas (biconical, log-periodical and Bilog antennas) on the EMI measurement uncertainty will be presented in the paper.

Antenna models

The whole antenna analysis was executed by means of numerical methods – analytical methods are suitable just for simple problems, while measurement is always affected by auxiliary equipment. Since for antenna analysis the most suitable method are solvers in frequency domain, method of moments [3] was chosen to analyze the problems.

The following antennas were examined:

- biconical antenna (see Fig. 1a) – 1300 mm long, with a cone radius of 260 mm created by 6 wires. Also a crossbar in each cone. The frequency range of such antenna is from 30 MHz to 300 MHz;
- log-periodic dipole array (LPDA) (see Fig. 1b) - 760 mm long and 750 mm wide, with 14 pairs of dipole elements. The scale factor and the spacing factor of log-periodic dipole array elements are 0.85 and 0.126 (the longest dipole element is 750 mm long). The LPDA works in frequency range from 300 MHz to 1GHz;
- Bilog antenna (see Fig. 1c) - 785 mm long and 1660 mm wide, with 15 pairs of dipole elements and a bow-tie part. The scale factor and the spacing factor of log-periodic dipole array elements are 0.855 and 0.13 (the longest dipole element is 640 mm long). The bow-tie element has the flare angle 37°, the height of triangle is 775 mm and height of feed point is 55 mm. The Bilog is intended for frequency range from 30 MHz to 1GHz.

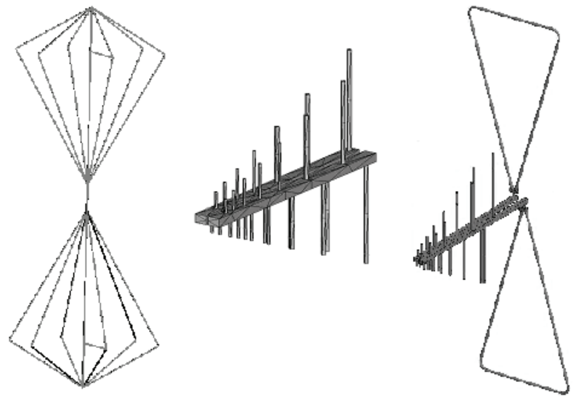

Fig.1. Models of biconical, LPDA and Bilog antenna

To use these models, at first we have to validate them, that means to verify that the obtained results copy sufficiently the properties of real antenna. The antenna factor values are obtained by simulation where we placed a source of electromagnetic field e.g. short dipole antenna at adequate distance (ca. 100 m) away from the analyzed antenna. Then antenna factor is given as ratio between known E field values E_{in} and computed induced voltage at antenna output *V* [4]. The comparison of obtained simulated values of free space antenna factors of Bilog antenna with the measured values provided by manufacturer is shown in [5]. There is a good correlation between measured and simulated antenna factor values. Some small errors are caused by omission of balun in the Bilog model. Also the normalized directivity patterns of the antennas were compared with measured ones at discrete frequencies [6]. The differences in Bilog and LPDA antennas are mainly in back lobe, which can be caused by antenna feeder presence during the measurement [2].

Methods

The most important parameter of the antennas for our analysis is the radiation pattern. It refers to the directional dependence of radiation from the antenna. It is generally known that radiation pattern of an ideal half-wave dipole is constant in H plane, but in E plane it is a figure-of-eight pattern. So the directivity F given by sphere angles (θ,φ) can be expressed as:

$$F(\theta,\varphi)=\frac{\cos\left(\frac{kl}{2}\cos\theta\right)-\cos\left(\frac{kl}{2}\right)}{\sin\theta}=\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \quad (1)$$

where k is wave number ($k=2\pi/\lambda$) and l the length of the dipole (in case of half-wave dipole $l=\lambda/2$) [7]. Unfortunately, the radiation patterns of broadband antennas are not known. In addition they vary with changing frequency.

The variation of radiation pattern may be expressed as the error of antenna factor. If the source of radiation is not situated in front of analyzed antenna in direction of maximal radiation (zero angle-wise), but it is moved so that radiation from itself affects the analyzed antenna with angles (θ, φ), we obtain the real antenna factor of antenna AF:

$$AF(\theta,\phi)=AF(dB)+F(\theta,\phi) \quad (2)$$

where $AF(\mathrm{dB})$ is known antenna factor and F is directivity of analyzed antenna. Then the error, obtained by replacing the half-wave dipole antenna by broadband antenna, may be expressed as error of antenna factor ΔAF defined as:

$$\Delta AF(dB)=AF(\theta,\phi)-AF_D(\theta,\phi)-K \quad (3)$$

where AF and AF_D are antenna factors at the same angles of incidence given by angles (θ, φ). The parameter K is a correction for neglecting the difference between the values of antenna factors of these antennas.

Since receiving antenna varies its height with respect to height of tested equipment from 1 to 4 m, angles of incidence of disturbing electromagnetic waves on measuring antenna vary their values as well. If tested object is assumed to be in 1 m height and the measuring distance is standard [1] recommended 10 m the angle of incidence of direct wave varies from 0° to 17°. In case of shorter distances e.g. 3 m these angles may increase up to 45°, in case of 1 m till 72°. If we consider not only the direct wave incident on the antenna, but also the wave reflected from the reference ground plane, angles of incidence are from 0° up to 27°. Similarly for 3 m measuring distance we have to consider a range of possible angles of incidence up to 60° or for 1 m up to 79°.

Because the radiation pattern of the tested equipment and consequently also the incidence angle are mostly unknown, we assume that the disturbing electromagnetic field can be received at any angle from the given range with the same probability. Hence, it is necessary to rotate the source of radiation around the analyzed measuring antenna with these angles and to record the maximal variations as compared with a zero angle of incidence. This process was performed in multiple discrete points of frequency range from 30 to 1000 MHz, which is interesting for us, and for both polarizations of the antenna. The result is value ΔAF, or its frequency dependence, which represents one of the contributions to the entire uncertainty of the radiated EMI measurement. ΔAF is not single-valued. It may be arbitrary error from the interval of the maximal and minimal range.

Results

The directional pattern of biconical antenna and a bow-tie part of the Bilog is similar to the pattern of the dipole. However mainly in case of LPDA and also log-periodic part of Bilog, the main lobe of radiation pattern becomes more dominant with increasing frequency of radiation, so there is less similarity between radiation patterns of dipole and broadband antenna. Hence, there is higher probability that ΔAF caused by the real radiation pattern of Bilog antenna is higher than at lower frequencies and the using of such antennas introduces additional error into the measurement.

According to [2], the perfect ground plane presence nearby the antenna influences its directivity pattern in addition. To obtain ΔAF of the analyzed antennas, which is influenced by the presence of the ground plane, we modified the models of the antenna. Instead of inserting the ground plane into the models, we made use of the mirror principle and we situated their mirror images below the antennas in the distance of its double height over the ground plane. There are evident changes in directional patterns of analyzed antennas. While in case of log-periodic antennas the main lobe of the pattern is just crinkled at low heights of antenna, in case of bow-tie part of Bilog or biconical antenna one can say evident change of the directional patterns, which lead to higher errors at some frequencies up to 300 MHz. In Fig. 2 and 3 possible errors of vertically polarized antennas are shown, which is the worse case analysis.

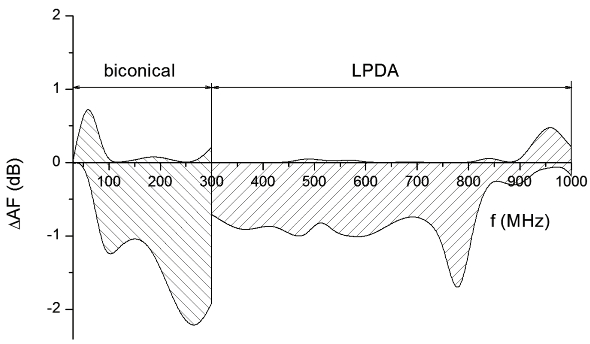

Fig.2. Possible errors of biconical and log-periodic antenna for distance 10 m

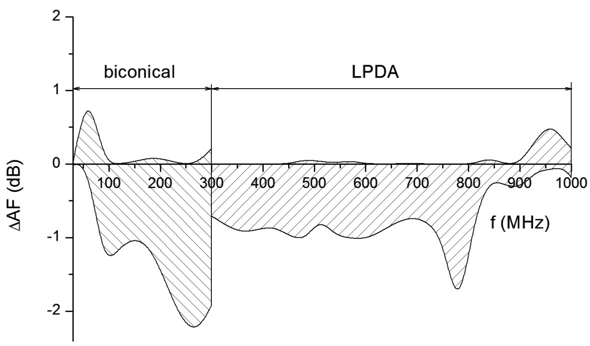

Fig.3. Possible errors of Bilog antenna for distance 10 m

In such cases, it is necessary to get the maximal and minimal values of ΔAF at different angles of incidence, which are dependent on the antenna height over the ground plane. While at zero angle of incidence the error is zero due to the correction K, with an increase of angles of incidence ΔAF also increases its value.

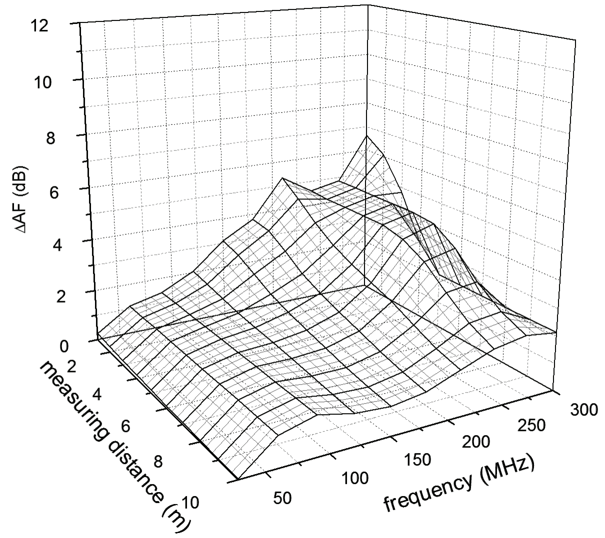

Fig.4. Maximal errors of vertically polarized biconical antenna

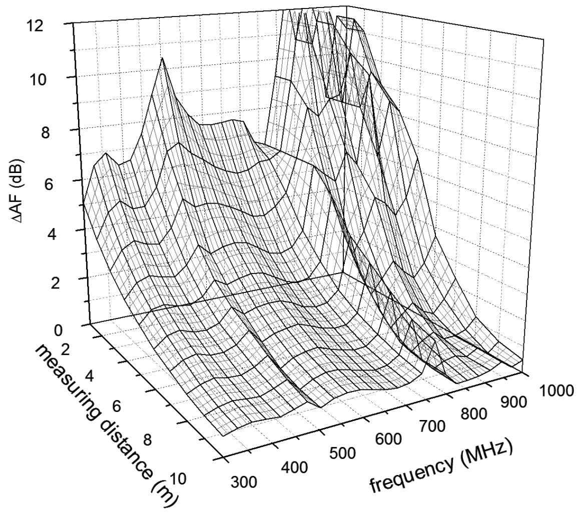

Fig.5. Maximal errors of vertically polarized LPDA

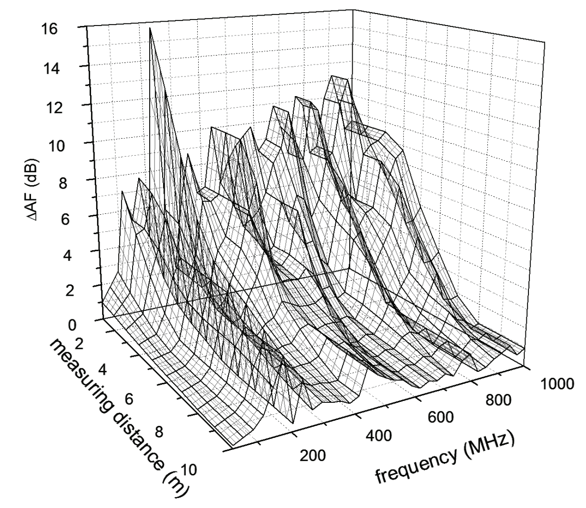

Fig.6. Maximal errors of vertically polarized Bilog antenna

As may be seen in Fig. 4-6, the worst situation occurs in case of short measuring distances. In these figures dependences the maximal possible error is shown. We may observe better results in case of horizontally polarized antennas. The short measuring distance can ruin the EMI measurement because of high error of used antenna directivity. With increase of the measuring distance, the values of directivity error descend. The lowest values of error for short measuring distance occur in case of biconical antenna, however such antenna has high enough errors also for longer distances. Log-periodic antennas have a strong dependence between measuring distance and directivity error. With decreasing measuring distance the errors increase noticeably. The errors are noticeably frequency dependent and most often they are negative, which means that the received signal is smaller than expected.

Conclusions

In comparison with half-wave dipoles, broadband antennas are more popular among test engineers due to their properties – it is not necessary to change them during the radiated EMI measurement. On the other hand they may introduce additional errors into measurement with greater contributions to uncertainty. The entire uncertainty is thus bigger.

The effect of directivity pattern of broadband antennas were examined. This analysis was focused on obtaining of the error value caused by directivity of the antennas and used for uncertainty estimation. The directivity error may be more evident due to presence of the ground plane in antenna vicinity. From the analysis based on numerical simulation, it follows that these errors are strongly frequency-dependent. This error also depends on measuring distance; such antennas, as it can be seen, are not suitable for short distances, mainly due to their directional properties.

Acknowledgement

This research was financially supported by the project VEGA VG 1/0963/12.

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