11

The interference between ground plane and receiving antenna and its effect on the radiated EMI measurement uncertainty

Mikulas Bittera, Viktor Smiesko, Karol Kovac and Jozef Hallon
Slovak University of Technology
Slovakia

1. Introduction

Despite the fact that the result of the radiated electromagnetic interference (EMI) measurement is two-valued, i.e. „pass / fail“, the measurement is the most complex and the most time-consuming measurement of all of electromagnetic compatibility (EMC) measurements. The main task of such 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. These limit values are chosen so that no EMI generated by the EUT exceeds the level, which can disturb the operation other electronic devices of commonly used.

Also the interpretation of the radiated EMI measurement is a very complex problem due to many disturbing influences affecting such a measurement. The problem is more difficult because of the necessity to derive the uncertainty budget of EMI measurement of test laboratories. In general, we can recognize three types of negative effects on the uncertainty of the measurement:

- effect of test site equipment (of the measuring chain);
- effect of test site arrangement;
- effect of the tested equipment.

Except for the effect of the tested equipment, which depends mainly on its cable arrangement, the main problem represents the effect of receiving antenna, if a broadband antenna is used. The antenna brings into measurement additional errors, which increase measurement uncertainty. Some errors are also caused by presence of the ground plane in the test site. They are mainly error of antenna factor and of directivity, which can emphasize or suppress the errors of receiving antenna. These errors and their effect on the entire uncertainty of the measurement are investigated in case of broadband Bilog antenna, a typical receiving antenna for radiated EMI measurement, which covers a frequency range of our interest. Since the mentioned effects cannot be quantified by real measurement or by simple calculation, this investigation is based on numerical calculation – simulation based on "method of moments".

2. Radiated EMI measurement

2.1 Principle of measurement

A principle of the radiated EMI measurement given by (CISPR 16-2-3) is shown in Fig. 1. The intensity of electric field, generated by EUT, is scanned by the receiving antenna and measured by a rf measuring receiver. The measurement is executed in an open area test site, but it may be performed also in shielded chambers to suppress ambient disturbing signals. As it may be seen also in Fig. 1 the antenna receives radiated disturbance from EUT directly but also by reflected wave from the reference ground plane, which ensures equivalent conditions for all test sites.

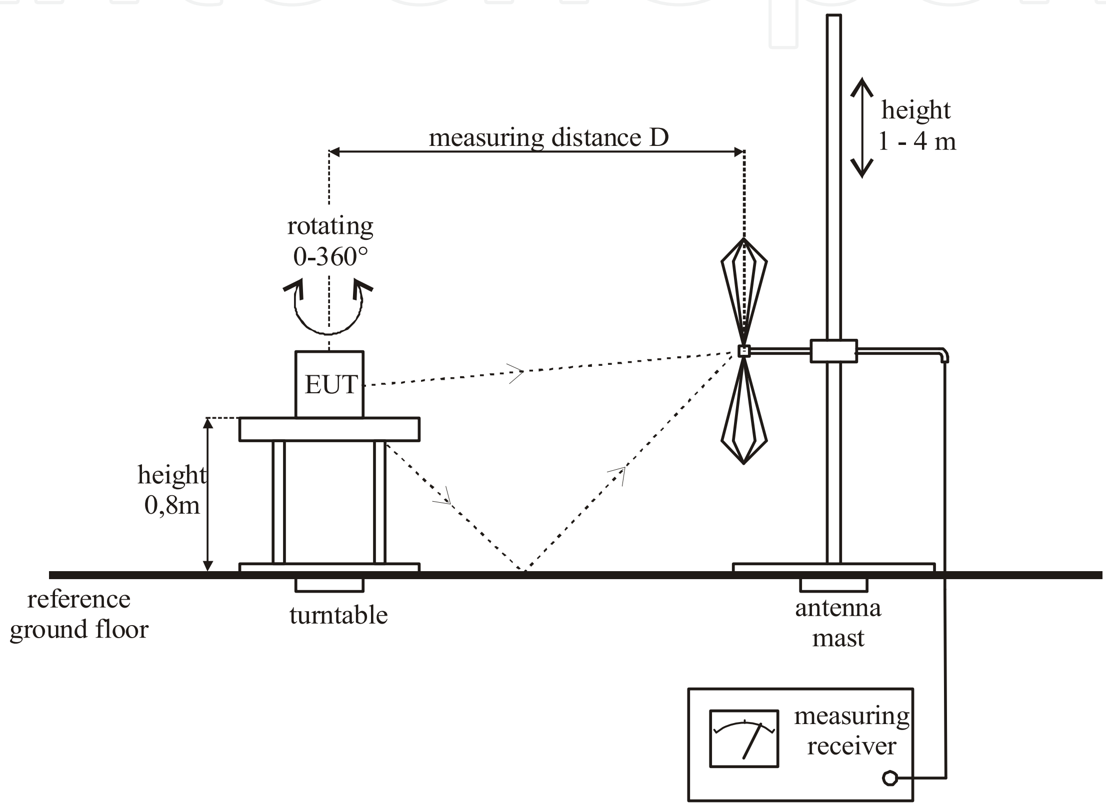


Fig. 1. Scheme of radiated EMI measurement

Measured electromagnetic wave from the EUT is in the point of receiving antenna given by vector sum of direct and reflected wave. Resulting phase of the sum is changing with the varying height over the reference ground plane. Since the maximal radiated disturbance must be found receiving antenna must change its height in the range of 1 m to 4 m and also EUT must rotate to record all directions of possible radiations.
The measurement must be executed for both polarizations of receiving antenna – horizontal and vertical. The radiated disturbance must be recorded in frequency range of 30 MHz to 1000 MHz and a quasi-peak value of this disturbance must be measured by a quasi-peak detector. Such a value does not depend only on amplitude of the measured voltage but also on its repetition frequency, so the resulting value is relative to voltage-time area of disturbing signal.
So, concerning the radiated EMI measurement, it shall be found by the maximal radiated disturbance is given:

- certain arrangement of EUT;
- certain turn of EUT;
- certain height of receiving antenna;
- certain polarization of receiving antenna;
- certain frequency of radiated disturbance.

If such a maximal value does not exceed the given disturbance limit value for the given electric device, the EUT can be stated as electromagnetic compatible in terms of radiated disturbance.

2.2 Uncertainty of measurement

In general, uncertainty of the measurement is as important as the result of measurement itself. The term uncertainty represents a region about an observed value of a measured quantity, which is likely to contain the true value of that quantity. The uncertainty describes deficiencies of quantity knowledge. There are many potential uncertainty contributions, which influence the uncertainty of measurement and which cannot be independent.

The standard CISPR 16-4-2 (CISPR 16-4-2) knows and quantifies following 17 uncertainty contributions that influence the radiated EMI measurement:

- receiver reading;
- attenuation between antenna and receiver;
- antenna factor;
- receiver corrections for sine-wave voltage;
- receiver corrections for pulse amplitude corrections;
- receiver corrections for pulse repetition rate response;
- receiver corrections for noise floor proximity;
- mismatch between antenna and receiver;
- antenna factor frequency interpolation;
- antenna factor height deviations;
- directivity difference of antenna ;
- phase centre location of antenna;
- cross-polarisation of antenna;
- balance of antenna;
- test site imperfections;
- measuring distance between EUT and antenna;
- table or EUT height.

It is important to note, that despite the fact that most of these contributions do not influence the result of measurement, they affect its uncertainty. The combined standard uncertainty may be computed using Gauss's law on the distribution of uncertainty:

$$u_c = \sqrt{\sum_i c_i^2 u^2(x_i)} \quad (1)$$

where c_i is the sensitivity coefficient and $u(x_i)$ the standard uncertainty in decibel of i-th contribution x_i. The expanded measurement uncertainty may be calculated as:

$$U = 2u_c \quad (2)$$

and it should be less than U_{CISPR}, which is given by standard CISPR 16-4-2 and which is 5.2dB. If the uncertainty U is greater than U_{CISPR} all the measurement results have to be increased by the difference (U-U_{CISPR}).

3. Receiving antennas

In order to obtain the radiated EMI measurement we should use antennas of various types. An antenna transforms intensity of electromagnetic field to voltage, which is measurable by the measuring receiver. To get the exact value of field intensity, tuned half-wave dipoles shall be used. The dipoles represent basic type of line antennas, more details can be found in (Balanis, 1997).

But nowadays, it is customary to use broadband antennas (biconical, log-periodic, Bilog or horn antenna) to save measurement time. These antennas shall satisfy the standard requirements (CISPR 16-1-4):

- the antennas 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;
- 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.

Broadband Bilog antennas are widely used in radiated emission measurements. They represent combinations of biconical antenna and log-periodic dipole array, so they are able to cover the frequency range from 30 MHz to 3 GHz (Van Dijk, 2005). By using the proper geometry it is possible to achieve small dimensions of the antenna also at lower frequencies, which is given by the bow-tie part of antenna. On the other hand the log-periodic part determines the antenna properties at higher frequencies (usually over 200 MHz).

In presence of E field, voltage V is induced across a 50 Ω load at the feed point of the antenna. Then antenna factor AF represents the ratio between the field strength of an incident plane wave E_{in} and induced voltage V:

$$AF = \frac{E_{in}}{V} \tag{3}$$

or expressed in dB terms:

$$AF(dB) = 20\log_{10}\frac{E_{in}}{V} = E_{in}(dB) - V(dB) \tag{4}$$

Generally antenna factor AF may be expressed also by its parameter:

$$AF = \sqrt{\frac{480\pi}{Z\lambda^2 G}} \tag{5}$$

where Z is load impedance of antenna, l is a wavelength and G is a gain. Such an AF is free space antenna factor determined on basis of the assumption that the antenna is located in free space. In practice, radiated EMI measurements are always performed in presence of a perfectly conducting ground plane. Since antenna like Bilog has large dimensions, there is a not negligible effect of ground plane on antenna properties and also on antenna factor. In this case antenna factor is known as a standard site method antenna factor. This parameter may be obtained theoretically from the standard site attenuation $A(dB)$ using the following expression (Kodali, 1996):

$$AF_{SSM}(dB) = 10\log f - 24.46 + 0.5\left[E_D^{\max}\left(dB\mu Vm^{-1}\right) + A(dB)\right] \quad (5)$$

where f is frequency in MHz, E_D^{max} is the maximum E field at the receiving antenna position during scanning (from 1 m to 4 m height) for a half-wave dipole with 1 pW of radiated power.

Other important parameter is the radiation pattern. It refers to the directional (angular) dependence of radiation from the antenna. It is generally known that radiation pattern of 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:

$$F(\theta,\varphi) = \frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta} = \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \quad (6)$$

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

4. Modelling

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. Numerical methods can be divided into three categories: frequency domain, time domain and eigenmode or modal solvers. For antenna analysis the most suitable method are solvers in frequency domain. The method of moments (Harrington, 1993) was chosen to analyse the problems.

The numerical model must be created at first to implement analysis by means of numerical simulations. Interaction between dipole antenna and ground plane is known generally, so we focused on popular broadband Bilog antenna. The Bilog antenna analysed in this contribution is 785 mm long and 1660 mm wide, with 15 pairs of dipole elements and a bow-tie part. The scale factor τ and the spacing factor σ 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 numerical model of such an antenna is shown in Fig. 2. The presented model is a wire model – wire replacement of antenna – so the model consists just of wire segments.

This model is composed of 191 segments, and elements of antenna are connected to each other by non-radiating transmission lines.

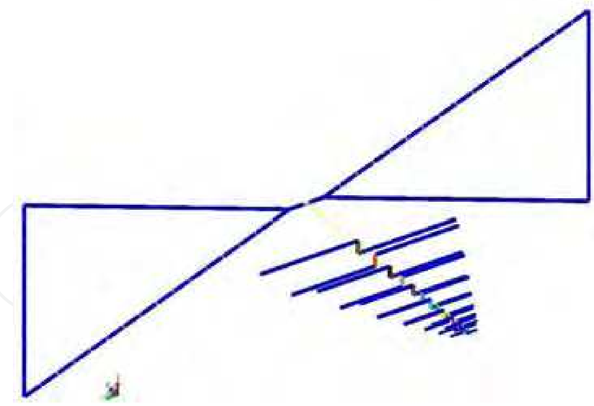


Fig. 2. The numerical model of analysed Bilog antenna.

To use these models, at first we have to validate the numerical model of the Bilog antenna. That means to verify that the obtained results copy sufficiently the properties of real antenna. The antenna factor values are obtained by simulation by placing a source of electromagnetic field e.g. short dipole antenna at adequate distance (ca. 100 m) away from the receiving Bilog antenna. Then antenna factor is given as ratio between known E field values E_{in} and computed induced voltage at antenna output V (Chen & Lin, 2003). The comparison of obtained simulated values of free space antenna factor with the measured values provided by manufacturer is shown in Fig. 3. There is a good correlation between measured and simulated antenna factor values, the small differences below 200 MHz can be caused by omission of balun (balanced-unbalanced network) in case of simulations. At higher frequencies, the effect of sequential activation of log-periodic dipole elements may be seen.

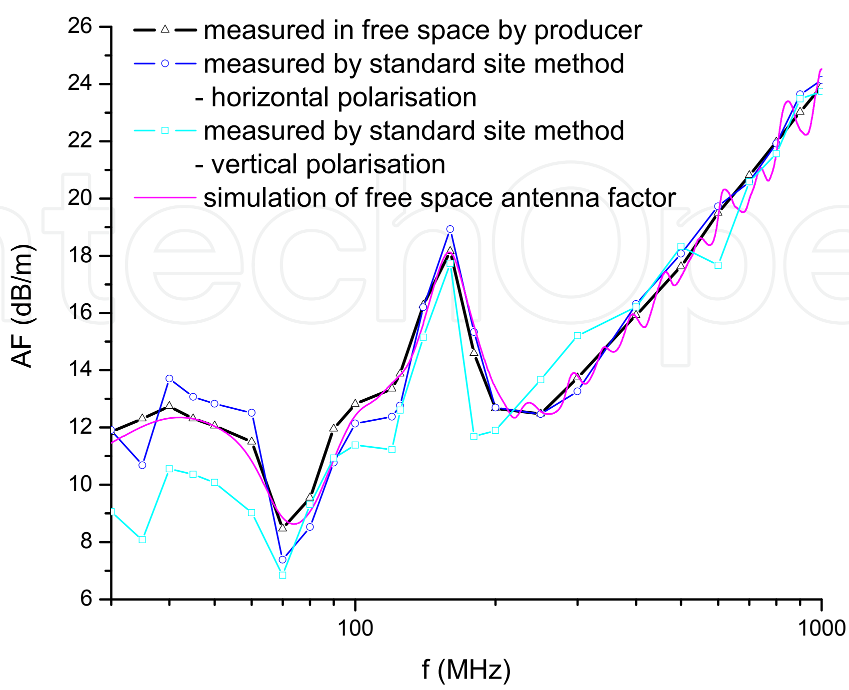


Fig. 3. Comparison of measured and simulated values of antenna factor of Bilog antenna.

Also the simulated radiation patterns of Bilog antenna were compared with measured ones at discrete frequencies. The differences are mainly in back lobe (see Fig. 4), which may be caused by antenna feeder presence during the measurement, or by small errors in numerical computation.

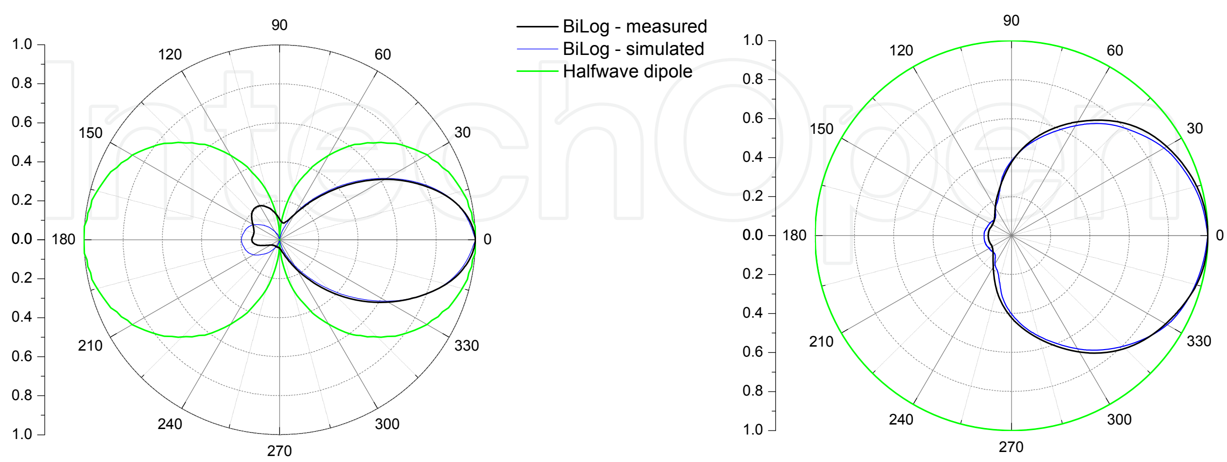


Fig. 4. Comparison of measured and simulated radiation patterns of Bilog antenna at 200 MHz (a) in E plane, (b) in H plane.

5. Methods

From all mentioned uncertainty contributions two of them affected by ground plane presence were chosen for further analysis:

- antenna factor height deviations;
- directivity difference of antenna.

It is known that the presence of ground plane affects the input impedance *Z* of every antenna. The change of impedance cause change of induced voltage *V* on antenna, and consequently according to (3) also change of antenna factor *AF*. This variation may be expressed as error of antenna factor ΔAF:

$$\Delta AF = AF_h - AF_{FS} \tag{7}$$

where AF_{FS} is antenna factor of antenna in free space and AF_h antenna factor of the same antenna, calculated by the same conditions, in the height *h* over the reference ground plane. It is necessary to ensure the identical height of both antennas (transmitting short dipole and receiving analysed antenna) during the antenna factor calculation. Unfortunately, the error ΔAF is not constant. It changes with varying height of antenna and also with frequency. Therefore it is necessary to consider with range of errors, obtained as intersection of all the errors for height interval from 1 m to 4 m.

Note that the change of antenna impedance due to height variation may cause also additional error in mismatch between antenna and receiver.

Broadband antennas have radiation patterns different from the half-wave dipole and they are additionally frequency dependent. At lower frequencies, the radiation pattern of Bilog antenna is similar to the pattern of half-wave dipole. But with increasing frequency of radiation the main lobe of radiation pattern becomes more dominant, so there is less similarity between two radiation patterns (see Fig. 5). Hence, there is higher probability that error 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.

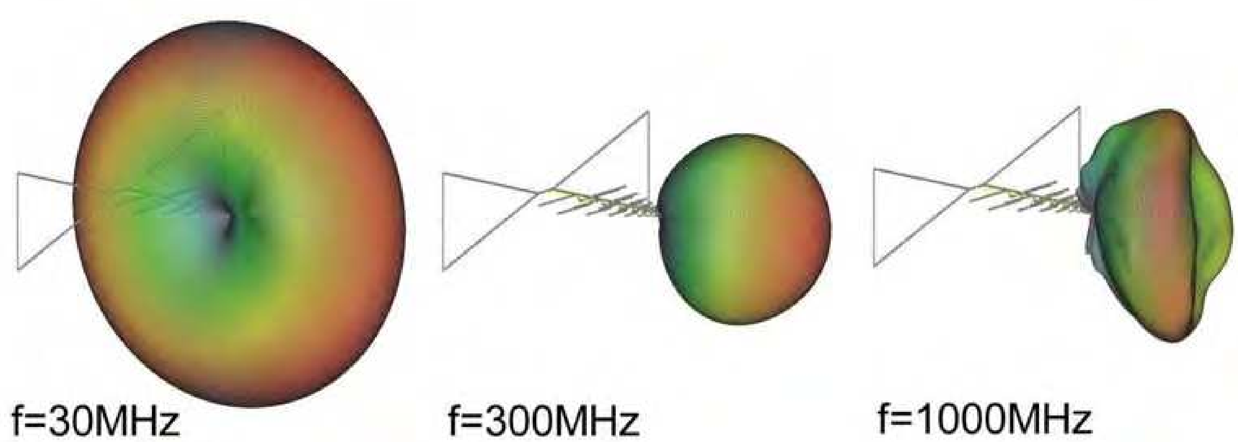


Fig. 5. Radiation pattern of Bilog antenna at frequencies 30 MHz, 300 MHz and 1000 MHz.

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

$$AF(\theta,\phi) = AF(dB) + F(\theta,\phi) \tag{8}$$

where *AF*(dB) is known antenna factor and *F* is directivity of analysed 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:

$$\Delta AF(dB) = AF(\theta,\phi) - AF_D(\theta,\phi) - K \tag{9}$$

where *AF* and AF_D are antenna factors at the same angles of incidence given by angles (θ, φ). The dependence of antenna factor of half-wave dipole antenna may be obtained by substituting (6) into (8). 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 during the measurement 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 (CISPR 16-1-4) 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°. 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 30 m just up to 9.5°. The possible errors of antenna factor, which may be included into the entire uncertainty, are shown in Fig. 6 and 7. It is necessary to consider the range of errors, because the real error may vary in value according to angle of incidence, which is unknown.

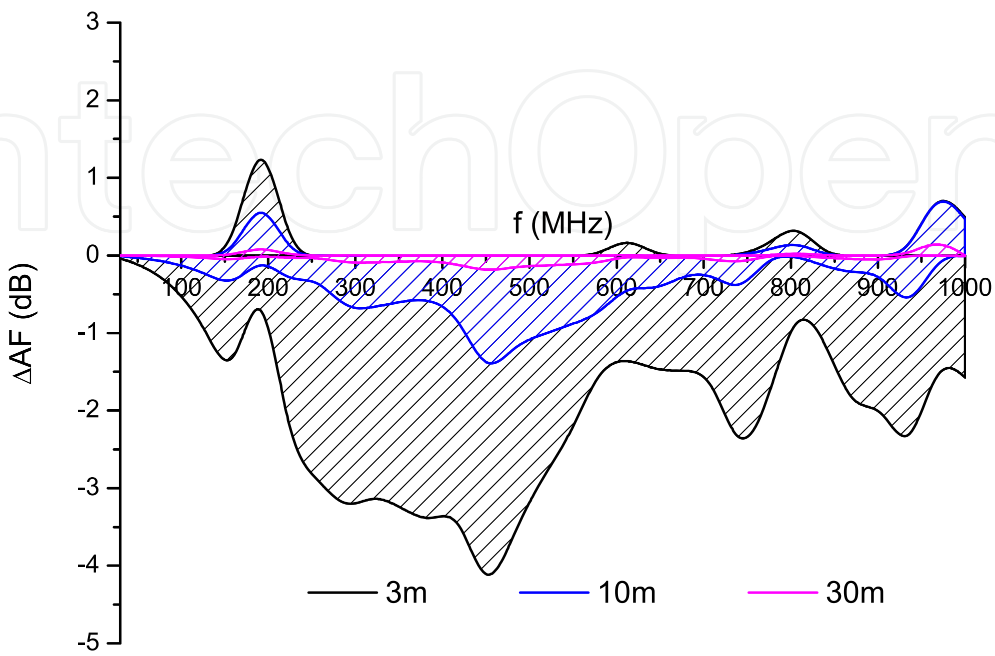


Fig. 6. Possible errors of antenna factor caused by directivity for horizontally polarised Bilog and for different measuring distances

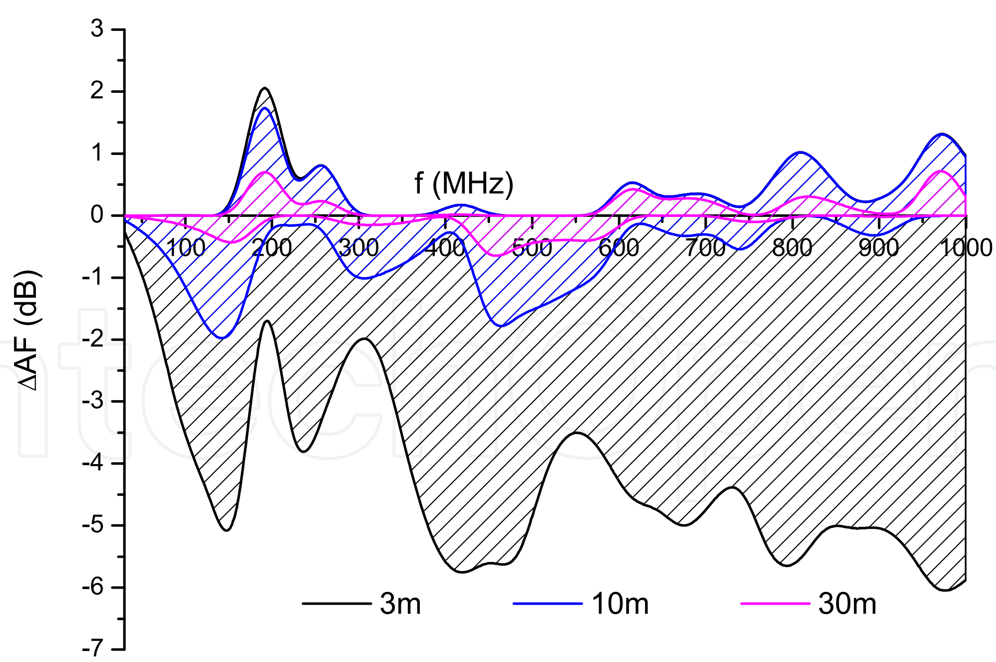


Fig. 7. Possible errors of antenna factor caused by directivity for vertically polarised Bilog and for different measuring distances

Since the radiation pattern of tested equipment and then also the angle of incidence are mostly unknown, we take into account that disturbing electromagnetic field may be received by measuring antenna with the same probability with any angle from given range. Hence, it is necessary to rotate the source of radiation around the analysed measuring antenna with these angles and record the maximal variations (positive and negative) in comparison with zero angle of incidence. This process was performed at multiple discrete points of frequency range of our interest from 30 to 1000 MHz and for both polarizations of antenna. The result is the error of antenna factor ΔAF, respectively its frequency dependence, which represents one of contributions to entire uncertainty of the radiated EMI measurement. The error ΔAF is not single-valued, it may be arbitrary between maximal and minimal range, but we have to consider the maximal error in order to calculate the measurement uncertainty.

6. Results

The perfect ground plane presence near the Bilog antenna affects its input impedance as well as its antenna factor. But it also affects its radiation pattern of Bilog antenna. To obtain the error ΔAF of Bilog antenna, which is influenced by ground plane presence, we have to modify the numerical model of the antenna. Instead of inserting the ground plane into the model, we make use of the mirror principle and below the Bilog we locate its mirror image in distance of double height over the ground plane. In such cases it is necessary to get the maximal and minimal values of error ΔAF at different angles of incidence, which are dependent on the antenna height over the ground plane.

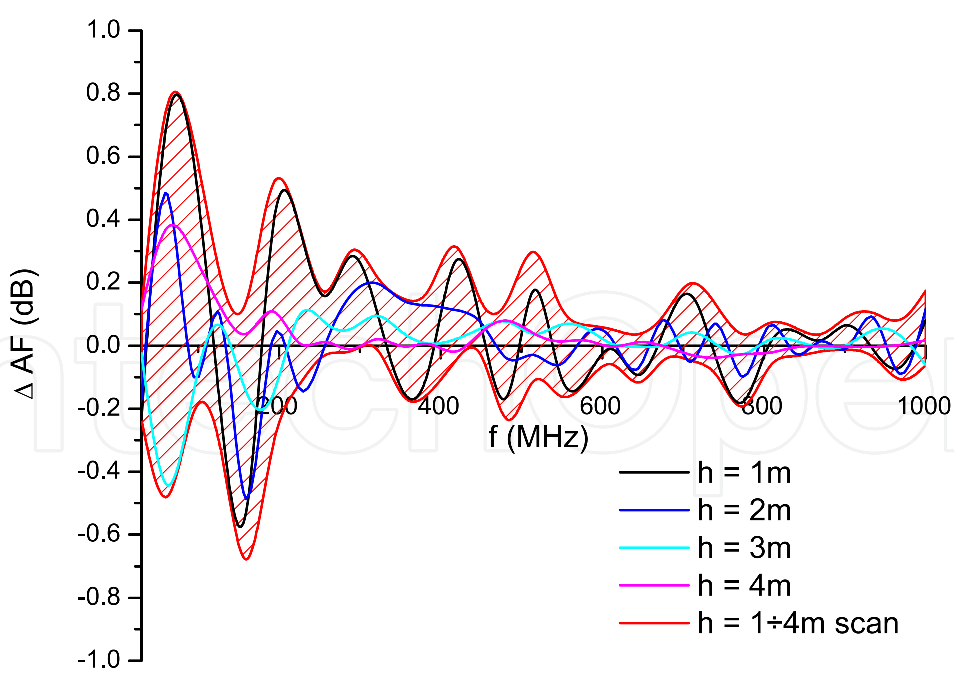


Fig. 8. Possible errors of antenna factor for a horizontally polarized Bilog placed in height h over the ground plane

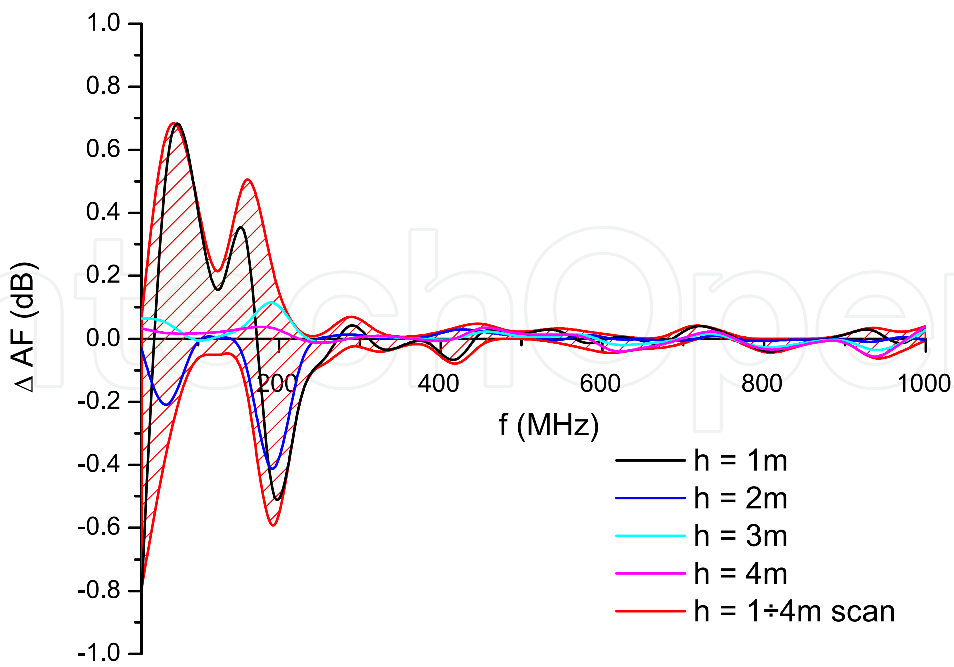


Fig. 9. Possible errors of antenna factor for a horizontally polarized Bilog placed in height *h* over the ground plane

As the antenna varies its height above the reference ground plane, its antenna factor varies as well. This variation *ΔAF* is shown in Fig. 8 and 9 according to (7). The error is strongly frequency dependant and it is maximal ±0.8 dB in case of the lowest height of antenna *h* = 1 m. This is when the mutual coupling between the antenna and the ground plane is maximal. The error is large in the frequency range below 200 MHz, which is the active range of bow-tie part of antenna. The log-periodical part causes a smaller error when mainly vertically polarised. It is consistent with the previous analysis of biconical or log-periodical antennas (Chen & Foegelle 1998), (Chen et al. 1999).

The error *ΔAF* is dependent also on the angle of incidence. While at zero angle of incidence the error is zero due to correction *K*, with increasing angles of incidence the error *ΔAF* also generally increases in value. As we can see in Fig. 6 and 7 the worst situation occurs at short measuring distances of 3 m. A better situation occurs in case of horizontally polarized antenna, the possible error is up to ±1.4 dB. In case of vertical polarized antenna the error is up to ±2 dB. With increasing measuring distance the values of error *ΔAF* descends, at 10 m the maximal error is ±4.1 dB or ±6 dB and at 30 m distance ±0.2 dB or ±0.8 dB for both polarizations. Such errors are visibly frequency dependent and mostly negative, which means that received signal is smaller than expected

The effect of ground plane presence on directional patterns of Bilog antenna we may be seen in Fig. 10. With increasing height over the ground plane the directional pattern of Bilog antenna becomes smoother – it resembles the directional pattern in free space. On the other hand at low heights also the main lobe of the pattern is crinkled. Even though the ground plane influence on radiation pattern of Bilog cannot be overlooked, this effect is not so evident on frequency characteristics of error *ΔAF* as a whole, as it is seen in Fig. 11 and 12. More significant is the interference of bow-tie part of Bilog with ground plane in the frequency range from 100 to 200 MHz that causes higher error of antenna factor. The effect of presence of ground plane increases the maximal error of approximately 0.4 dB at horizontal polarization and of 1.2 dB at vertical polarization. This increase is just in mentioned frequency range, in case of shorter measuring distances and vertically polarized antenna there is even the error *ΔAF* drop at higher frequencies (Bittera et al., 2008).

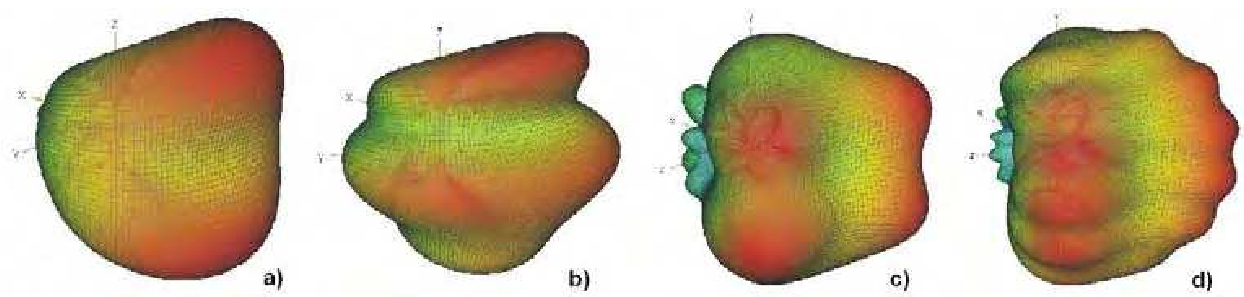


Fig. 10. Radiation pattern of Bilog for 200 MHz : (a) in free space, (b) 1 m over ground plane vertical polarization, (c) 1 m over ground plane horizontal polarization, (d) 4 m over ground plane horizontal polarization

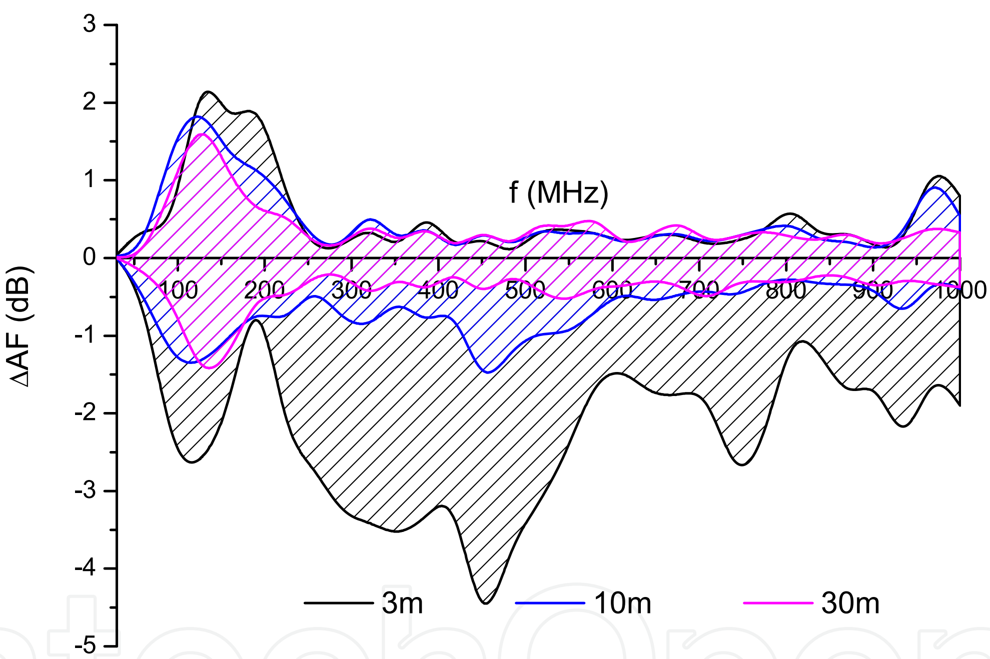


Fig. 11. Possible errors of antenna factor over ground plane caused by directivity for horizontally polarised Bilog

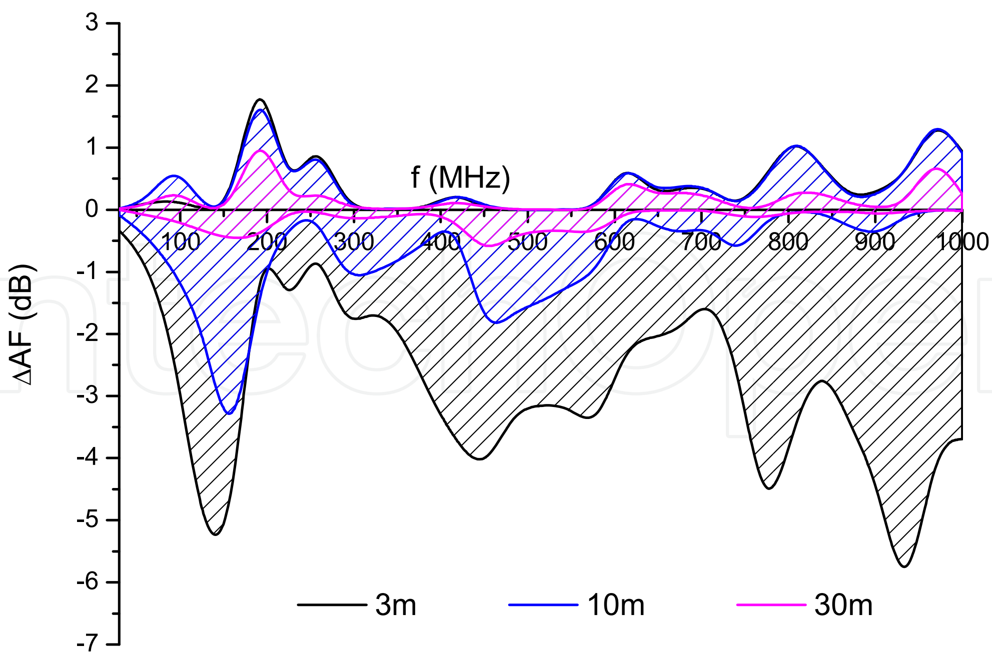


Fig. 12. Possible errors of antenna factor over ground plane caused by directivity for vertically polarised Bilog

7. Conclusion

In comparison with half-wave dipoles, Bilog antennas are more popular among test engineers due to their broadband properties – it is not necessary to change them during the radiated EMI measurement. On the other hand they introduces additional errors into measurement with greater contributions to uncertainty. The entire uncertainty is thus larger. The effect of ground plane on Bilog antenna pattern and consequently the effect of its interference to measurement uncertainty are not measurable. To examine this influence the numerical simulation based on method of moments has been used. The incurred error is computed as the difference between antenna factor of ideal antenna in free space and antenna factor influenced by ground plane presence respectively. In case of directivity effect analysis ideal antenna is represented by half-wave dipole. Due to varying the antenna height over the reference ground plane the uncertainty contribution has to be expressed as maximum of errors at all heights in a scanning range from 1 m to 4 m.

Due to high mutual coupling between antenna and ground plane we get the maximum error when the antenna is in height of 1 m. In case of directivity difference the error is also dependent on the measuring distance. Though ground plane presence affects the radiation pattern of Bilog, its entire effect on the uncertainty is not as significant. It is mainly affected by the Bilog radiation pattern difference itself. Resulting from the analysis, using Bilog antenna is more suitable for larger measuring distance to get lower uncertainties.

From the analysis it is evident that both analysed effects - antenna factor height deviations and directivity difference of antenna are strongly frequency dependent. Therefore we may use the maximal error value as well as frequency dependence of the error for uncertainty calculation. The first consideration is suitable for simpler calculations while in other cases we need to know all errors as being frequency dependent. However then we may minimize uncertainty of the measurement.

8. References

CISPR 16-1-4 (Ed.2.0). Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-4: Radio disturbance and immunity measuring apparatus – Ancillary equipment – Radiated disturbances. *IEC Standard,* May 2005, 179 p.

CISPR 16-2-3 (Ed.2.0). Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity –Radiated disturbance measurements. *IEC Standard,* December 2006, 185 p.

CISPR 16-4-2 (Ed.1.0). Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Uncertainty in EMC measurements. *IEC Standard,* November 2003, 43 p.

Balanis, C.A. (1997). *Antenna Theory – Analysis and design,* John Wiley & Sons, ISBN 0-471-59268-4, New York

Harrington, R.F. (1993). *Field computation by moment method*, IEEE Press, ISBN 0-7803-1014-4, Piscataway

Kodali, V.P. (1996) *Engineering electromagnetic compatibility – Principles, measurements and Technologies*, IEEE Press, ISBN 0-7803-1117-5, New York

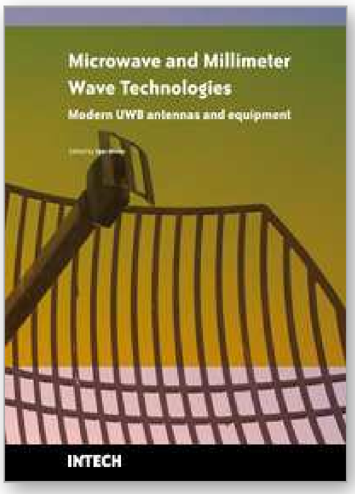
Bittera, M.; Smiesko, V.; Kovac, K. & Hallon, J. (2008). Interference between ground plane and Bilog antenna and its effect on EMI measurement uncertainty, *Proceedings of Asia-Pacific Microwave Conference*, pp. 611-614, ISBN 978-1-4244-2642-3, Hong Kong

Chen, Z.; Foegelle, M.D. & Harrington, T. (1999). Analysis of log periodic dipole array antennas for site validation and radiated emissions testing, *Proceedings of the 1999 IEEE International Symposium on EMC*, pp. 618-623, ISBN 0-7803-5057-X, Seattle, August 1999, IEEE Press, Piscataway, NJ

Chen, Z. & Foegelle, M.D. (1998). A numerical investigation of ground plane effects on biconical antenna factor, *Proceedings of the 1998 IEEE International Symposium on EMC*, pp. 618-623, ISBN 0-7803-5015-4, Denver, August 1998, IEEE Press, Piscataway, NJ

Chen, H.F. & Lin, K.H. (2003). A numerical analysis of antenna factor of Bilog antennas for normalized site attenuation and EMC measurements, *Proceedings of the 2003 IEEE International Symposium on EMC*, pp. 817-821, ISBN 0-7803-7835-0, Boston, August 2003, IEEE Press, Piscataway, NJ

Van Dijk, N. (2005). Uncertainties in 3-m radiated emission measurement due to the use of different types of receive antennas. *IEEE Transactions on Electromagnetic compatibility,* Vol. 47, No. 1, (February 2005) pp. 77 – 85, ISSN 0018-9375



Microwave and Millimeter Wave Technologies Modern UWB antennas and equipment
Edited by Igor Mini

ISBN 978-953-7619-67-1
Hard cover, 488 pages
Publisher InTech
Published online 01, March, 2010
Published in print edition March, 2010