# EM-FIELD STANDARDS AND THEIR COMPARISON (IN MEMORIAM OF PROF. MOTOHISA KANDA)

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## ABSTRACT

The Lab is involved in the electromagnetic field (EMF) measurements. EMF standards were here indispensable tools in metrological experiments. Many of the standards found an application as exposure systems in EMC and in biomedical studies. The research in the field is of threefold character, i.e.: new methods of standardization, analysis and increase of the standards accuracy and widening their frequency range. The results of the research were currently published, the frequency limitations are rather dependent upon financial possibilities of the University than conceptual ones. Foreground role here was played by a possibility of the standards comparison.

## INTRODUCTION

The EM Environment Protection Lab has been involved in EMF metrology for many years. The involvement included both propagation measurements and that devoted to the labour safety and the environment protection. The latter has a theoretical part [1] as well as practical one. Within frames of the involvement a set of the meters was designed and manufactured. Presently they are in wide use by Polish sanitary and other services. We may add here that our designs were one of the World-first meters available for the surveying services. The experimental work in the EMF measurements required a possibility to generate an EMF of well-known parameters (frequency, intensity, polarization, spatial distribution, etc.), i.e.: the standard EMF. Our first standards were applied only for metrological experiments and for our EMF probes and meters calibration. Then the former 'side product' was developed to almost independent area of involvement and many of our standard sets were applied for different antennas and probes measurement and calibration as well as exposure systems in investigations related to the electromagnetic compatibility (EMC) tests and in bio-medical investigations. The development of our metrological involvement has been followed, or sometimes outgoing, by the standards development [2]. The research in the field of EMF standards was in general of threefold character, i.e.:
- new standardization methods,
- increase of the standards accuracy,
- widening the standards frequency range.

The latter is the easiest and the most difficult in the university conditions, it mostly does not need concepts or ideas and is limited 'only' by financial factors. At the moment our 'upper corner frequency' is somewhat above 40 GHz, but continuous efforts are done in order to widen it up. However, it may be mentioned that in the Lab was worked out the world-first magnetic field standard working at frequencies above 100 MHz [3]. Below are briefly illustrated our technical attempts and activities as well as the role of the international intercomparison of EMF standards, headed and leaded by the National Institute of Standards and Technology in Boulder, CO (formerly NBS).

## EXAMPLES OF THE NEW PROPOSALS

### Whip antennas calibration

EMF meters with whip antennas usually are used for the electric field measurement at frequencies say below 30 MHz in the far field. Till now these antennas were calibrated on an open area test site (OATS) in the standard EMF generated by another whip antenna. The method is very sensitive to presence of reflections, requires quite large and uniform space (the OATS) and, especially at the lowest frequencies, creates problems with matching the capacitive whip to a source of its excitation. All the disadvantages of the method disappear while in the role of the standard transmitting antenna a loop is applied instead of the whip [4]. Apart of the advantages mentioned the standard is simultaneously the electric- and the magnetic field standard and formulas for both the field components are almost identical.

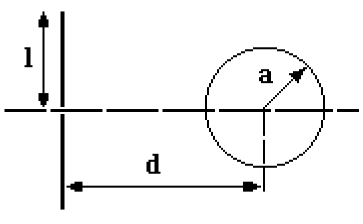


Fig.1 A dipole antenna calibration with a standard loop.

An example of the test set for symmetrical dipole calibration is shown in Fig. 1. E-field in the plane of the loop, averaged at the standardized antenna, is given by:

$$E = \frac{\pi a^2 Z_o I}{2\lambda\, dD}\sqrt{1+k^2D^2} \qquad (1)$$

where: $D = \sqrt{d^2 + a^2 + l^2}$

I - current in the loop,

other indications as in Fig.1

To remind; the magnetic field in similar set is given by:

$$H_r = \frac{60\pi a^2 I}{Z_o D^3}\sqrt{1+k^2D^2} \qquad (2)$$

Both the formulas were introduced with similar assumptions as regards as the accuracy of the field (2-nd order approximation).

**Doubly standardized EMF**

On the ground of the above solution we'll demonstrate an idea of the doubly standardized field (Fig.2). The idea of the concept is based upon a simultaneous use of the standard EMF method (the standard transmitting antenna) and the standard antenna method (the standard receiving antenna). A standard transmitting antenna ($A_t$) is placed at the same distance (d) between a standardized antenna ($A_s$) and the standard receiving antenna ($A_r$). The approach was in use in the case of a dipole-, loop-, and whip antennas calibration. Its use makes it possible to increase calibration accuracy and, what is of primary importance in calibration procedures, assures a measuring team that a gross error does not appear while the calibration is performed.

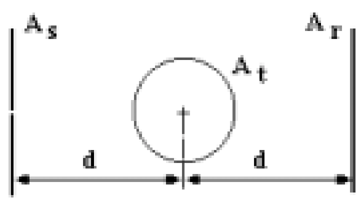


Fig.2 Doubly standardized EMF.

**Directional antennas calibration**

Some doubts were formulated in the literature as regards as a possibility to calibrate directional antennas on an OATS. The problem was analysed on the ground of a logo-periodic (LP) antenna calibrated on an OATS [5] in geometry of propagation as shown in Fig. 3. Radiation pattern of the LP antenna was approximated in analytical form in order to make it possible a presentation of closed-form formulas. The use of SRA (substitution) method was here suggested.

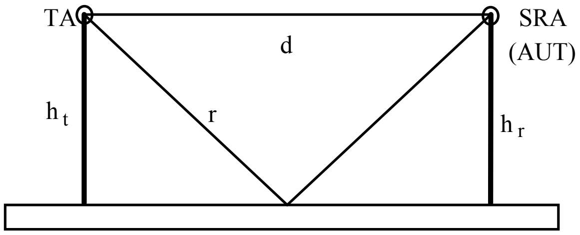


Fig.3 Geometry of propagation on an OATS

The analyses were performed for two cases, i.e.: while the transmitting antenna (TA) was a dipole and while identical LP as the calibrated one. The uncertainty of the method is shown in Fig.4 as a function of distance between antennas. Continuous line expresses the uncertainty in the first case while dashed the latter.

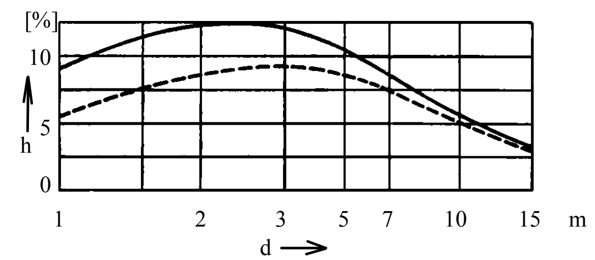


Fig.4 Uncertainty of the method versus separation

The considerations were performed for LP antenna, however, the method is valid for analysis of the calibration procedure uncertainty in the case of any other antenna type. The curves in Fig.4 were obtained in pure theoretical way. Their correction is possible if use measured radiation pattern of the directional antenna instead of that approximated in analytical form. Of course, if the calibration is performed in an unechoic chamber the error discussed vanishes as does not exist a reflected ray. It is place here to remind that with no regard to fully correct (within frames of the analysis) calibration of directional antennas, their application in real environment requires appropriate experience.

Other new proposals of the calibration methods include: magnetic field probes calibration in wide frequency range in a travelling wave device, sets for calibration E- and H-field probes in conditions of arbitrarily polarized EMF, i.e.: the sets make it possible to generate linearly, circularly, ellyptically, spherically and ellypsoidally polarized fields.

## ACCURACY LIMITATIONS

In the opinion of the authors the majority of the accuracy analyses of EMF standards, presented in the literature, are very optimistic ones. The analyses take into account only the most evident factors limiting accuracy of the standards and do not take into consideration more subtle ones. A few examples of such factors are presented below.

### Mutual interaction of a standard and an OUT

The problem of mutual interaction of a standard and a standardized object was taken into account only in the case of probes' calibration in a TEM cell. The analyses were usually summarized with a statement that the effect is negligible while the sizes of the probe are less than 1/3 of the distance between the cell walls. It is true, however, an increase of the frequency, at which the cell can correctly operate, requires construction of cells of smaller and smaller sizes. Thus, the space within them is more and more limited. An effective use of the cell implies strict analysis that would indicate a relation between sizes of the cell and the OUT. Such an analysis was performed [6]. The analysis took into account mutual impedance of the calibrated probe's antenna and infinite set of its mirror reflections, as shown in Fig.5. The impedance affects the probe's sensitivity in the relation to the free space conditions, and as a result affects the calibration accuracy. Because of deterministic character of the phenomenon the analysis makes it possible to estimate appropriate correction factors and increase the accuracy of the procedure.

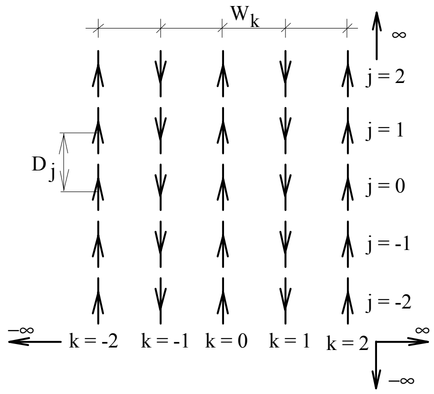


Fig.5. The set of couplings between an antenna and its mirror reflections

Apart from the analysis and its outcomes it is possible to generalize the problem to the case of any other object calibration (investigation) in a waveguide standard or exposure system: presence of the phenomenon alternates significantly results of any EMC and bio-medical experiment performed with a use of a waveguide due to affect of the system upon the OUT. As a result a susceptibility of investigated device or biological object to EM exposure may be different in the real conditions than measured in the system. The phenomenon seems to be important in particular in bio-medical investigations. Unfortunately, it is never take into account and usually investigated animals are placed in very narrow cages – waveguides.

### Excitation measurement

Excitation measurement of a EMF standard is loaded with an error. In the majority of cases the error is equivalent to uncertainty of the excitation meter applied. In the case of a waveguide type standard, however, more important is an allocation of voltage (current) in a point of system. The voltage distribution in the system is affected by a mismatching caused by an OUT. Although it is possible to fully match the system to an excitation source, however, it does not affect nonuniform field distribution inside it. Even time domain reflectometry is unable to solve this problem radically. In order to find mutual relation between mismatching of a system, a method

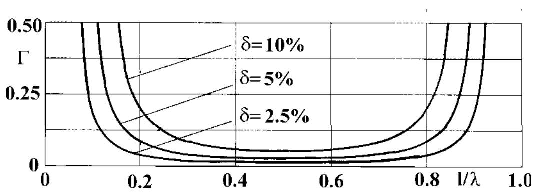


Fig.6. Results of error estimations while measured input voltage

of the excitation measurement and required calibration accuracy was analysed. The results of the analysis are shown in Fig.6. The analysis was performed for the case while an input voltage in a cell is measured. The figure shows mutual relations between electrical length of the system (l/λ) reflection factor at the input of the cell (Γ) and assumed uncertainty (δ). As it may be seen from the figure in the case discussed a particular attention has to be paid while total length of the calibration system is around 0.5λ.

### Spectral purity

The role of the spectral purity of the standard exciting source has never been analysed before. It is usually assumed than the source is 'ideal' in the aspect. It is not true, especially in the case of power generators and power amplifiers as well as while generators with frequency synthesis are in use. Their spectral purity is often unknown. Sometimes, especially in nontechnical labs, due to attempts to increase the output power of the generators, the purity of their spectrum may be remarkably reduced. Similar story is while a microwave oven plays a role of ‘the exciting generator’. As a result the accuracy of the standard (exposure system) may be remarkably degraded. An analysis shows that the most intensive degradation takes place in the case of wideband magnetic field probes calibration. The reduction of the standard's accuracy in the case may exceed the clearfactor of the exciting signal.

## INTERCOMPARISON OF THE STANDARDS

EMF standards these are one of the least accurate standards of the physical magnitudes. Although in the literature may be found suggestions that the standards uncertainty may be on the level of 1%, however, these estimations may be summarized as incredible, non-realistic and optimistic too much. Real accuracy of an EMF standard may be given on the level of 4-5%, and the most advanced labs usually give these values. The optimism mentioned may be resulted from inability to experimentally verify the standards, impossibility to intercompare several methods of standardization and neglecting a role of factors limiting the standard's accuracy, for instance as in above presented examples or others. Apart from a possibility to internal intercomparison of the standards within one laboratory a crucial role may be played here by a possibility to perform a comparison of own sets with that from other labs. First our involvement in similar action took place in early 70s [7]. The action was initiated and coordinated by doctors Altschuler, Baird and Wacker from National Bureau of Standards in Boulder. All of them are well known as leaders and active participants of the URSI Commission A. The lattes intercomparison was initiated and performed, under auspices of the International Institute of Weights and Measures, by Prof. Moto Kanda, the head of the URSI Commission A at that time. Apart from the NIST, in the action took a part the following institutes: National Physical Laboratory (NPL) from UK, NMi Van Swinden Laboratorium (Nmi VSL) from the Netherlands, Instituto Elettrotecnico Nazional (IEN) from Italy, Laboratorie Central des Industries Electriques (BNM) in France, Electrotechnical Laboratory (ETL) from Japan, Korea Research Institute of Standards and Science (KRISS) and the Technical University of Wroclaw (TUW) [8]. A part of the results of the comparison is set-up in Fig.7. The figures show results of measurement of the NIST transfer standard in indicated laboratories. Measurements at 27 MHz are shown in upper figure, at 500 MHz in the medium and at 2.45 GHz in the lower. The measurements were performed at three levels at each frequency. With no regard to the long breaks between separate measurements and resulted from it ageing effects on the transfer standard the results seem to confirm general agreement between the institutions. An attention may be focused on different estimation of the standard accuracy. It is resulted from more or less rigorous approach to the accuracy limiting factors as well as to conditions of the standards work. It is to be stressed that such an action should be continued in the future.

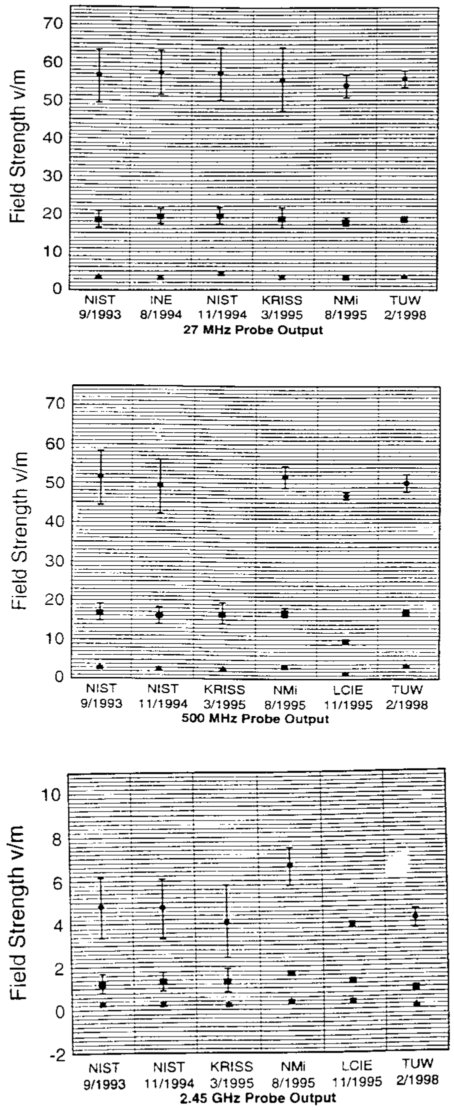


Fig.7 Results of standards comparison [8].

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