Experimentální Analýza Napětí 2011
Experimental Stress Analysis

Analysis of the Environment Accuracy and How it Influences Measurement Results Performed in the Near Zone

Ján Ivanka[1], Petr Navrátil[2]

Abstract: Analysis of the accuracy of the relevant environment influencing the results of measurements performed in the near zone gives us a basic knowledge about the measurements of parameters of microwave antennas located in near zone. The objective of the analysis specified below is to provide an overview showing advantages and disadvantages of measurements performed in near zone and comparison of measurements done in near and far zone.

Keywords: Near zone, Far zone, Probe, Basic polarization, Gain errors, Aliasing

1. Introduction

For any measurement technique, the following fundamental requirement must be observed in order to be able to provide a reliable estimate of measurement errors, especially for methods that use high level of mathematical analysis, such as the near zone antenna measurements. Determination of error limits for any combined measuring system antenna / probe / near zone can be a difficult and time consuming task. The mathematical complexity poses the biggest problem. During this procedure measurement results obtained from the near and far zone and differences between those two methods are compared and are considered as the determining factor of measurement errors in the near zone. Limits of this procedure are as follow:

- Partly or maybe mainly, the observed differences exist because of the influence of errors in the far zone.
- It is difficult to generalize one result and apply it to other antenna or to other measuring system.
- The most crucial measurement parameters or contributions of errors received from various sources may not be determined.
- Measurements performed in the far zone may not be practical for certain types of antennas which are suitable for measurements done in the near zone.

We can investigate aliasing in details during measurement errors. Therefore, the biggest number of errors comes from errors occurring due to the measuring system. In this work I have demonstrated detailed theoretical relationships, important for the improvement of the measuring accuracy during measurements done on a surface plane, as well as for measurements done the on a cylindrical surface. Individual sources of errors occurring during measurements done on a plane surface specified in table 1 may be divided into two basic categories. The first inaccuracies are created during measurement of the gain, polarization and radiation characteristics of the probe. These data are used to determine **R´**(**K**) and **R´´**(**K**).

[1] *Ing. Ján Ivanka ;Tomas Bata University in Zlin, Faculty of Applied Informatics, Department of Security Engineering, Nad Stráněmi 4511, 76005 Zlín, Czech Republic; ivanka@fai.utb.cz*
[2] *Ing. Petr Navrátil Ph.D.; Tomas Bata University in Zlin, Faculty of Applied Informatics, Department of Process Control, Nad Stráněmi 4511, 76005 Zlín, Czech Republic; p1navratil@fai.utb.cz*

Other errors are present in the calculated spectrums $I_0'(\mathbf{K})$ and $I_0''(\mathbf{K})$. For example, this means that errors may vary as functions x and y in predetermined and repeatable manner, and due to the influence of Fourier transformation, they will produce an erroneous/incorrect spectrum. In case of radiation characteristics of the probe, these are changing as the **K** and therefore the spectrum is evident. Finally, each of these errors is then considered as independent and uncorrelated with any other error. These errors can therefore be investigated separately and combined together, thanks to their independent characteristics.

2. Probe parameter errors

First, we shall consider the influence of probe errors. This influence will depend on the polarization properties of the probe, in relation to the parameters of the measured antenna. Not all possible combinations may be taken into consideration but the most usual and common cases will be considered. Other cases may be investigated similarly, using the relevant basic relations. We shall consider is that the first probe is mostly linked and connected with the basic element of the measured antenna and the second probe is mostly linked with the cross element. To calculate transfer parameters we may use elements which are perpendicular to the direction of the propagation $t_m = t_m(\mathbf{K})$ for the basic polarization of the measured antenna and $t_c = t_c(\mathbf{K})$ for cross polarization and similarly for the reception/incoming parameters of the probe $r_m = r_m(\mathbf{K})$ a $r_c = r_c(\mathbf{K})$. However, this is not true for circular polarization measurements, but in any case $|r_m'| \geq |r_c'|$ and $|r_c''| \geq |r_m''|$.

Then we can write the solution in the following form

$$t_m(\mathbf{K}) = \frac{\dfrac{I'(\mathbf{K})}{r_m'(\mathbf{K})} - \dfrac{I''(\mathbf{K})}{r_c''(\mathbf{K})}\rho_r'(\mathbf{K})}{1-\rho_r'(\mathbf{K})/\rho_r''(\mathbf{K})}$$

$$t_c(\mathbf{K}) = \frac{\dfrac{I''(\mathbf{K})}{r_c''(\mathbf{K})} - \dfrac{I'(\mathbf{K})}{r_m'(\mathbf{K})\rho_r''(\mathbf{K})}}{1-\rho_r'(\mathbf{K})/\rho_r''(\mathbf{K})} \tag{1}$$

where:

$$I'(\mathbf{K}) = \mathbf{t(K)}\cdot\mathbf{r'(K)} = \frac{\exp(j\gamma d)}{4\pi^2 F'A'}\int B_0'(\mathbf{P})\exp(j\mathbf{K}\cdot\mathbf{P})d\mathbf{K},$$

$$B_0'(\mathbf{P}) = \frac{b_0'(\mathbf{P})}{b_0'(\mathbf{P}_0)}, \qquad A' = \frac{a_0}{b_0'(\mathbf{P}_0)}$$

$$\rho_r'(\mathbf{K}) = r_c'(\mathbf{K})/r_m'(\mathbf{K}), \qquad F' = \frac{1}{1-\Gamma_l\Gamma_p'}$$

and similarly, for the other probe (parameters $I''(\mathbf{K})$, $\rho_r''(\mathbf{K}) = r_c''(\mathbf{K})/r_m''(\mathbf{K})$ Therefore, we shall assume that the polarization parameters comply with these relations

$$\left|\frac{r_c'(\mathbf{K})r_m''(\mathbf{K})}{r_m'(\mathbf{K})r_c''(\mathbf{K})}\right| = \left|\rho_r'(\mathbf{K})/\rho_r''(\mathbf{K})\right| << 1,$$

$$\left|\rho_r'(\mathbf{K})\,p_t(\mathbf{K})\right| << 1 \tag{2}$$

where $p_t(\mathbf{K}) = t_c(\mathbf{K})/t_m(\mathbf{K})$. and then (1) is reduced and simplified to

$$t_m(\mathbf{K}) = \frac{I'(\mathbf{K})}{r_m'(\mathbf{K})} \tag{3}$$

$$t_c(\mathbf{K}) = \frac{I''(\mathbf{K})}{r_c''(\mathbf{K})} - \frac{I'(\mathbf{K})}{r_m'(\mathbf{K})\,\rho_r''(\mathbf{K})} .$$

Proportional errors of these elements are:

$$\frac{dt_m(\mathbf{K})}{t_m(\mathbf{K})} = \frac{dI'(\mathbf{K})}{I'(\mathbf{K})} - \frac{dr_m'(\mathbf{K})}{r_m'(\mathbf{K})} , \tag{4}$$

$$\frac{dt_c(\mathbf{K})}{t_c(\mathbf{K})} = \left(1 + \frac{1}{p_t(\mathbf{K})\,\rho_r''(\mathbf{K})}\right)\left(\frac{dI''(\mathbf{K})}{I''(\mathbf{K})} - \frac{dr_c''(\mathbf{K})}{r_c''(\mathbf{K})}\right) + .$$

$$\frac{1}{p_t(\mathbf{K})\,\rho_r''(\mathbf{K})}\left(\frac{d\rho_r''(\mathbf{K})}{\rho_r''(\mathbf{K})} - \frac{dI'(\mathbf{K})}{I'(\mathbf{K})} - \frac{dr_m'(\mathbf{K})}{r_m'(\mathbf{K})}\right)$$

Hence it is clear that the proportion of polarizations of the first probe complies with conditions (2), uncertainty ρ_r'' (**K**) does not have any significant impact on the determination of any element. Because the main element of the measured antenna as well as the partial gain are equal $t_m(\mathbf{K})$, the main errors, occurring due to the influence of the probe errors, are proportional to each other with a ratio one to one. That means that these errors have the same value as errors $r_m'(\mathbf{K})$ and the result in the relevant direction **K** is influenced by the probe diagram in the same direction. This is the difference between scanning done on a cylindrical and spherical surface, where the result in one direction is affected by the probe diagram in a wider field of directions. The effect of the probe on the cross polarization of the measured antenna depends on the relative polarization proportions of the measured antenna and on the second probe. For a field where:

$$p_t(\mathbf{K})\,\rho_r''(\mathbf{K}) >> 1 \tag{5}$$

is true, the relation for proportional errors of cross polarization (4) is reduced down to the same form as for the relations for the main polarization, and t_c errors are created only under the influence of I'' and r_c''. This situation probably exists in the side lobes of the measured antenna, where p_t may reach 1, but p_r'' may still be great. In case where (5) is true, the probe is polarized "better" than the measured antenna. Around the main field pack/set/ the following may be true

$$(p_t(\mathbf{K})\,\rho_r''(\mathbf{K})\,) \approx 1, \tag{6}$$

because both the cross polarized probe and the measured antenna have similar axial ratio, but they are orthogonally polarized. In this scenario, all elements of the second relation (4) are important. In both cases, probe parameters inaccuracies may be obtained during the calibration and then used in both relations (4). If we consider the polarization ratio of the measured antenna we will get:

$$p_{t\varepsilon}(\mathbf{K}) = \frac{t_c(\mathbf{K})}{t_m(\mathbf{K})} = \frac{I''(\mathbf{K})\,r_m'(\mathbf{K})}{I'(\mathbf{K})\,r_c''(\mathbf{K})} - \frac{1}{\rho_{r\varepsilon}''(\mathbf{K})} . \tag{7}$$

Index ε in p_t and ρ_r'' is used as we want to consider error influence ρ_r'' on the polarization of the measured antenna. The ratio between the measured and actual polarization ratio is

$$\frac{p_{t\varepsilon}(\mathbf{K})}{p_t(\mathbf{K})} \approx 1 + \frac{1}{p_t(\mathbf{K})\,\rho_r''(\mathbf{K})} - \frac{1}{p_t(\mathbf{K})\,\rho_{r\varepsilon}''(\mathbf{K})} . \tag{8}$$

The use of (8) will be illustrated on two typical examples, which are related to the measured antenna with nominal linear polarization and on probe with E pole and coordinate axes, which are roughly the same. The p ratio is then identical as errors in the axes ratio. In the first case a total probe correction is used, but we also have to consider the ρ_r'' error. Then the worst case occurs for arg $[p_t(\mathbf{K})] \cong -\pi/2$ and arg $[\rho_r''(\mathbf{K})] \approx$ arg $[\rho_{r\varepsilon}''(\mathbf{K})] \approx \pi/2$. This corresponds with the assumption of polarization. For linear polarization, it is generally value ρ_r'' , which is incorrect and it is not a phase. Next, we shall consider the impact of the assumption, that both probes are perfectly polarized and therefore, only one correction component is used. This is equivalent to assumption that $\rho_r'(\mathbf{K}) = 0$ and $\rho_{r\varepsilon}''(\mathbf{K}) = \infty$, so the error is equal to the two members in the relation (8). Other two samples that are related to the measured antenna with nominal circular polarization of the measured antenna and probes are shown in [9].

3. Gain errors

First, we consider sources of errors which continuously affect the radiation characteristics, that is, they are not the K function. These errors only affect the maximum gain and other parameters which depend on the output / performance. By application and using the relation demonstrated in 6 we will get:

$$\frac{\Delta G_m(\mathbf{K}_0)}{G_m(\mathbf{K}_0)} = \frac{\Delta M}{M} + \frac{\Delta\left|\sum_i B_0(\mathbf{P}_i)\exp(j\mathbf{K}_0\cdot\mathbf{P}_i)\right|^2}{\left|\sum_i B_0(\mathbf{P}_i)\exp(j\mathbf{K}_0\cdot\mathbf{P}_i)\right|^2} - \frac{\Delta G_p(\mathbf{K}_0)}{G_p(\mathbf{K}_0)} - \frac{\Delta\left|A_n\right|^2}{\left|A_n\right|^2}, \tag{9}$$

where (M and M are related to the non-adaptation and Δ in every member marks an error of this expression and A_n refers to the normalization constant.

4. Data sampling (aliasing)

In principle, it is possible to selected distances between sampling points (steps δ_x, δ_y) in a certain way, so that aliasing errors are arbitrarily small, however noise and quickly changing systematic errors determine the practical bottom limit. Theoretically, the summary of integrals using the discrete Fourier transformation (DFT) is precise (no error occurred due to aliasing), if the Fourier transformation of the measured data has a limited spectrum with limits k_1 and k_2 and the distances between data comply with sampling theorem $\delta_x \leq \pi / k_1$ and $\delta_y \leq \pi / k_2$. If no limits exist, or if the sampling theorem is violated by the use of larger sampling distances, errors will occur due to the influence of aliasing. If there is no aliasing, this spectrum will consist of two parts:

$$F(\mathbf{K}) = I(\mathbf{K})\exp(-j\gamma d) + \varepsilon(\mathbf{K}), \tag{10}$$

where the first expression corresponds with the multiplied product of probe spectrums and the measured antenna, and the other expression corresponds with the noise and other sources of errors of the measured data. Because in real life we use DFT, the result is the sum of periodically repeated components, which overlap each other in $(2m-1)k_1$ and $(2n-1)k_2$:

$$\begin{aligned} F_e(\mathbf{K}) &= \sum_{m,n=-\infty}^{\infty} F(k_x + 2mk_1, k_y + 2nk_2) = \\ &= \sum_{m,n=-\infty}^{\infty} I(k_x + 2mk_1, k_y + 2nk_2)\exp(-j\gamma_{m,n}d) + \varepsilon(k_x + 2mk_1, k_y + 2nk_2) \end{aligned}, \tag{11}$$

where $(_{m,n} = [k^2 - (k_x \pm 2mk_1)^2 - (k_y \pm 2nk_1)^2]^{1/2}$. Aliasing causes error in $m \neq 0$, $n \neq 0$ inside intervals $|k_x| \leq k_1$, $|k_y(\leq k_2$. Error due to elements containing $\exp(-j\gamma d)$ may be arbitrarily small due to the use of δ_x, δ_y and therefore, only the spectrum is the limiting factor - due the error influence. Usually only components $m=n=\pm 1$ represent significant contribution and therefore from estimates $I(\mathbf{K})$ - either from measured or from theoretical probe values and from the characteristics of the measured antenna, we can reliably determine the upper limit of the sampling influence. If we are interested only in characteristics in the limited angular extent, we may increase the sampling beyond the limit established by the sampling theorem and then we can lower the time needed for scanning and calculations. To estimate errors caused by aliasing, we shall measure or estimate the $F(\mathbf{K})$, or both of its parts. This may be often done with data measured on the axis, or through theoretical characteristics together with the system noise and error level measurements.

5. Conclusion

This article in its shortened form specifies theoretical relations which are important for the increase in measurement accuracy. Detailed analysis showed that the main source of errors comes from errors occurring due to the influence of the measuring system. This article only considers errors that are not related to the scanning mechanism, or to errors occurring due to the setup of the measured antenna. Professional literature basically does not provide any references to the accuracy of transformations on the antenna surface. Because this is a very new source, it cannot be assumed that this problem is theoretically solved and closed. Furthermore, several problems were not address yet (e.g. probe correction influence).

Acknowledgements

This work was supported by the Ministry of Education of the Czech Republic under grant MSM 7088352102

References

[1] Vaculíková, P., Vaculík, E., Elektromagnetická kompatibilita (Electromagnetic Compatibility), Grada Publishing, Praha 1998, ISBN 70-7082-85-21

[2] ROHDE & SCHWARZ, Radiomonitoring and Radiolocation, Catalog 2008/2009, PD 0758.0368.52

[3] ROHDE & SCHWARZ, Radiomonitoring and Radiolocation, Catalog 2009/2010, PD 0758.0368.52

[4] Repjar, A. G., Newell, A. C. and Francis, M. H., Accurate determination of planar near- field correction parameters for linearly polarized probes. IEEE Trans. Antennas Prop., AP-36, No. 6, pp. 855-768.