

Roughness of the ground-plane and its effect on the antenna calibration in an open-field site

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ABSTRACT

The roughness of the ground-plane has been analytically studied in an open-field antenna calibration site. The proposed formulas present the uncertainty of the measured E-field and by consequent the “Antenna Factor AF” as a closed-form function of the metallic plane roughness. The obtained formulas show that the uncertainty rises exponentially for the higher frequencies. A 3D time-domain simulator has been used to verify the analytical formulations. A complete simulation of the real rough open-site is not possible, however, the partial simulation show good agreement with the analytical formulations.

INTRODUCTION

Radiated emission testing and calibrating of electromagnetic compatibility (EMC) test antennas is based on the electromagnetic waves propagation between device under test (DUT) and antenna or between two antennas.

The EMC tests and calibrations in the frequency range 30 MHz – 1 GHz are generally done in an open-field site [1]. Although, with the recent progress on the open site construction, the higher frequencies could reach 2 to 3 GHz. In general, an open-field site consists of a relatively large high-quality reflector plane, which is far from all the reflecting and scattering objects.

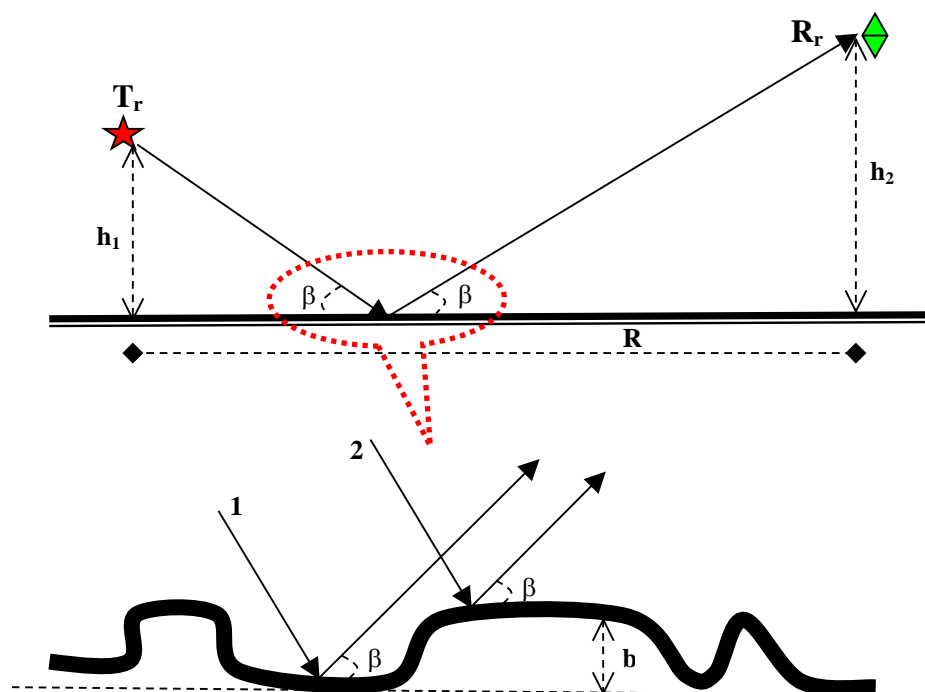


Figure 1. Electromagnetic waves scattering on a rough reflector plane in an open site

The reflector plane size and shape have been the subjects of many studies in EMC domain [2], [3]. The ideal reflector plane is a perfect conductor with infinite dimensions and perfect surface smoothness. A limited-size reflector can perturb the field measurement at low-frequencies and by the way a rough plane disturbs the measurements at high-frequencies.

In this communication, we have investigated the electrical field measurement uncertainties on a real rough metal plane. A rough perfect conductor cannot guaranty a net reflection because of the parasitic scattering waves (Fig. 1). A new equivalent reflection coefficient is introduced here to model a perfect rough conductor. The other cause of uncertainty is the effect of the plane roughness on the transmission and reception antennas heights. These two uncertainty causes have been analyzed to find the global uncertainty imposed by the reflector plane roughness.

THEORY

A. Equivalent reflection coefficient

The Rayleigh roughness criterion is used here basically to find the electrical field density at the reception point to introduce later an equivalent reflection coefficient. The new formulation is based on the evaluation of the different superposed electrical fields at the reception point reflected by the “hills” and “valleys” of the rough reflector surface (Fig. 1).

Let suppose a little typical differential surface on the plane, which contains a pair of “hill” and “valley”. By supposing a perfect reflection by both “hill” and “valley”, the overall electrical field at the reception point becomes the superposition of two separated rays having two different paths:

Ideal reflector plane:

$$\left| E_1^{\rightarrow} + E_2^{\rightarrow} \right|_{b=0} = 2 \times |E| \quad (1)$$

Rough reflector plane:

$$\begin{aligned} \left| E_1^{\rightarrow} + E_2^{\rightarrow} \right|_{b \neq 0} &= (1 + e^{j\delta\varphi}) \times |E| \\ \delta\varphi &= \frac{4\pi b}{\lambda} \sin \beta \\ \sin \beta &= \frac{h_1 + h_2}{\sqrt{R^2 + (h_1 + h_2)^2}} \end{aligned} \quad (2)$$

Equivalent reflection coefficient:

$$\begin{aligned} |\Gamma_{equ}| &= \frac{\left| E_1^{\rightarrow} + E_2^{\rightarrow} \right|_{b \neq 0}}{\left| E_1^{\rightarrow} + E_2^{\rightarrow} \right|_{b=0}} = \frac{\left| E_1^{\rightarrow} + E_2^{\rightarrow} \right|}{2 \times |E|} \\ |\Gamma| &= \frac{1}{2} \left| 1 + \exp \left(\frac{4\pi b}{\lambda} \frac{h_1 + h_2}{\sqrt{R^2 + (h_1 + h_2)^2}} \right) \right| \end{aligned} \quad (3)$$

The equivalent reflection coefficient of a rough plane shows the relative E-field at the reception point regarding to a perfect smooth plane. This value can be used so, as the E-field measurement uncertainty caused by the reflector plane roughness in a real open-site. Figure 2 demonstrates this uncertainty value as a function of antenna geometries ($h_1 = 2\text{m}$, $R = 3$ and 10m), plane roughness (b) and frequency.

As we can see, for the higher frequencies the uncertainty raises very quickly and for a typical value of b equal to 25mm, the uncertainty can reach 4 dB at 2 GHz for the 3 m horizontal distance between antennas. By the way, a short distance between antennas makes more important the roughness effect on the received E-field at all the frequency range.

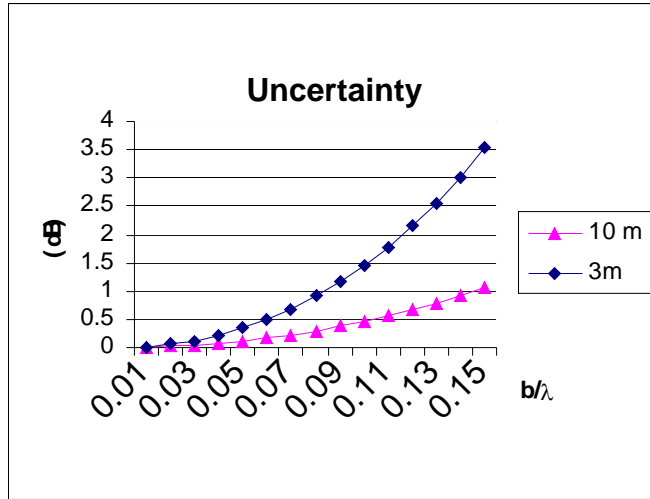


Figure 2. E-field uncertainty versus ground plane roughness and $R = 3$; 10 m

The numerical study of a real rough conductor surface is very difficult because of its unknown and stochastic roughness. Nevertheless, some local roughness at the critical parts of a smooth surface or a regular periodic roughness could be useful for a numerical treatment.

Our numerical study is based on Time-Domain method by supposing some local roughness distributed stochastically on a perfect smooth plan. This numerical simulation is in 3D and the essential variable is the roughness parameter b . A very large reflector plan has been introduced in the numerical treatment to be able to compare the results with an infinite rough plan in the analytical case. The primary numerical results show the exponentially behavior of the uncertainty function which confirms the analytical results.

B. Uncertainty on antenna height

The roughness of the ground-plane can also cause a certain uncertainty on the T_r and R_r antenna heights (Fig. 3)

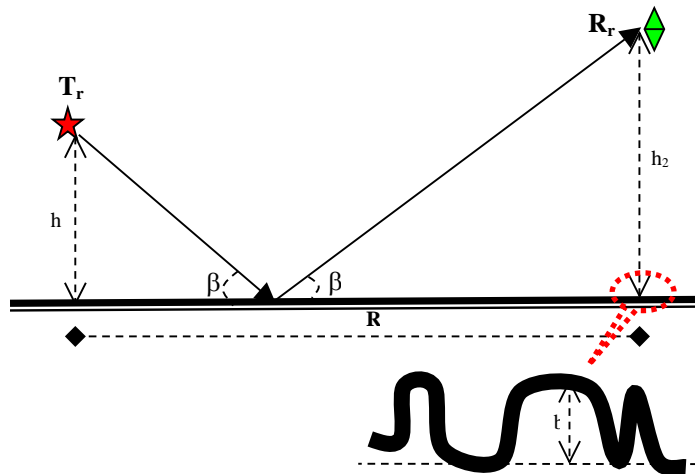


Figure 3. Antenna height uncertainty caused by the reflector plane roughness

To study this effect we calculate the E-field uncertainty at the reception point by differential method on the general expression of the received electrical field [1]:

$$|E_R| = \frac{V_0}{d_1 \times d_2} \sqrt{|\Gamma|^2 d_1^2 + d_2^2 + 2|\Gamma| d_1 d_2 \cos\{\beta(d_1 - d_2) + \theta_\Gamma\}}$$

$$d_1 = \sqrt{R^2 + (h_2 - h_1)^2} \quad ; \quad d_2 = \sqrt{R^2 + (h_2 + h_1)^2}$$
(4)

$$\frac{\delta|E_R|}{|E_R|} = \left\{ \frac{h_1 - h_2}{2} \left(\frac{1}{d_1} - \frac{d_1 + d_2 \cos[\beta(d_1 - d_2)] - \beta d_1 d_2 \sin[\beta(d_1 - d_2)]}{d_1^2 + d_2^2 + 2d_1 d_2 \cos[\beta(d_1 - d_2)]} \right) \right\} \frac{\delta h_2}{d_1}$$

$$- \left\{ \frac{h_1 + h_2}{2} \left(\frac{1}{d_2} - \frac{d_2 + d_1 \cos[\beta(d_1 - d_2)] + \beta d_1 d_2 \sin[\beta(d_1 - d_2)]}{d_1^2 + d_2^2 + 2d_1 d_2 \cos[\beta(d_1 - d_2)]} \right) \right\} \frac{\delta h_2}{d_2}$$
(5)

As we can see in general formulas (4) and (5), the E-field variations are important because of the direct presence of the applied frequency β . This dependence can disappear if the reception point is adjusted at an optimum height where the electrical field is maximal and evidently its variations are minimal:

$$|E_R|_{\max} = V_0 \frac{d_1 + d_2}{d_1 d_2}$$

$$\delta|E_R|_{\max} = V_0 \frac{h_1 - h_2}{\left(\sqrt{R^2 + (h_2 - h_1)^2}\right)^3} \delta h_2$$

$$\frac{\delta|E_R|_{\max}}{|E_R|_{\max}} = \left\{ \frac{h_1 - h_2}{2d_1} \frac{d_2}{d_1} - \frac{h_1 + h_2}{2d_2} \frac{d_1}{d_2} \right\} \frac{\delta h_2}{d_1 + d_2}$$
(6)

According to formulas (5) and (6), by choosing the optimal height for the reception point, the measured E-field uncertainty issued of antenna height uncertainty becomes minimum. By the way, these formulas show, for the shorter distances between antennas (small d_1 and d_2), the measurement uncertainty is more important.

The numerical study of the reception antenna height h_2 uncertainty on the measured electric field at the reception point has been done by MoM 1D simulation. The field variations in this case could be evaluated by the Monte-Carlo method at each applied frequency. These results show that at the higher frequencies and shorter distances between antennas, the field variations versus the antenna height are considerably important [4]. The numerical results confirm completely the analytical formulations.

CONCLUSION AND PERSPECTIVES

The new closed-form formulas have been presented to relate directly the E-field to the reflector plane roughness in an open-field antenna site. These formulas are very useful to evaluate analytically the antenna calibration uncertainties. This study show that for the higher frequencies and the shorter distances between antennas the plane roughness causes more uncertainties on antenna calibration procedure in an open site.

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