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**Advances in Radio Science**

# Establishing a link to given radiated emission limits during extending the frequency range above 1 GHz

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**Abstract.** Up to now most limits for radiated emission are given as values for the electrical field strength. Battermann, 2007 has shown that the frequency range extension for radiated emission measurements above 1 GHz generates a lot of problems while performing the test on a classical test site as depicted in Fig. 1. This paper will give a motivation to use an other measurand namely the total-radiated-power than electrical field strength by using alternative test sites like reverberation chambers, TEM-waveguides, Fully Anechoic Rooms (FAR) etc. Nevertheless most of the existing standards still specify electrical field strength limits. This paper will show how to set the parameters in the given algorithm to establish a link between measured total radiated power and equivalent electrical field values.

## 1 Introduction

All standardisation work is devoted to quantify the possible threat from electromagnetic emission to other electronic equipment. In the past the protection of a radio receiver was the most important goal. Therefore the noise voltage at the antenna feeding point has been used as the measurand. Everyone knows, which magnitude of this antenna voltage may generate disturbances on the radio receiver. Justifying which field magnitude will generate the specific antenna voltage gives the field limits which are written down in different standards. Transforming the voltages in field-strength is only valid on a well defined test-site like the open area test-site as depicted in Fig. 1.

The ongoing technological progress changes the historical motivated assumption for the protection goal. First of all it has to be realized that the analogue receiver is not the most important equipment to protect in the frequency range above 1 GHz In this frequency range other radiated coupling processes to the electronic device than the well-known antenna path has to be taken into account. Battermann, 2007 has demonstrated that it is very challenging to pick up the field-strength at a discrete location for very high frequencies because of the rapid changing field over the space. Every field measurement must be seen as a space-integration over a certain area.

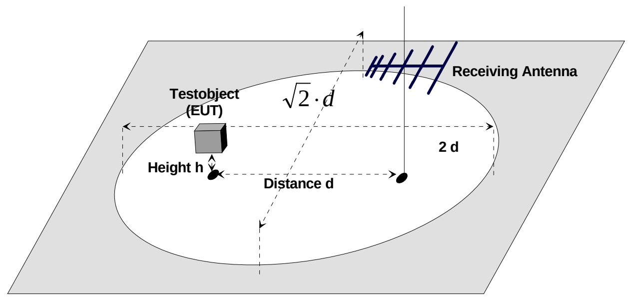


**Fig. 1.** Open Area Test Site (OATS).

Taking into account that energy is the main reason for a disturbance, actual trends in field measurement for frequencies above 1 GHz rely on total radiated power measurements instead of field strength which stands for the amplitude measurements. The intention of this paper is to discuss the transformation from power measurements to equivalent field data with the goal that both approaches will predict a possible interference in the same way.

## 2 Equivalent measurements on different test sites

The relation between the total radiated power $P_{rad}$ and the maximum field strength $E_{max}$ can be found in many textbooks as Eq. (1).

$$E_{\max} = g_{\max} \cdot \sqrt{\frac{D_{\max}\eta_0}{4\pi} P_{\mathrm{rad}}},\ in\, \frac{\mathrm{V}}{\mathrm{m}} \quad (1)$$

Equation (1) is valid for free space as well as OATS. To apply this equation for a specific test site $D_{\max}$ and $g_{\max}$ have to be predefined. $g_{\max}$ describes the geometrical situation of the

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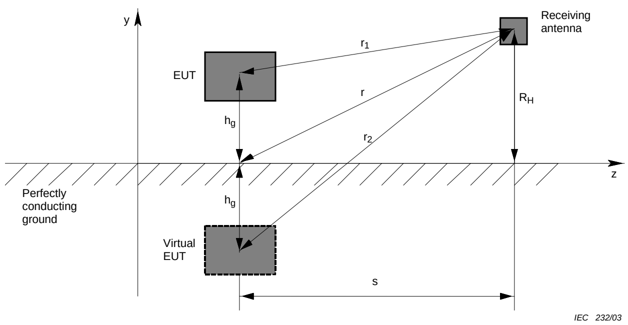



**Fig. 2.** Open-area test site geometry from IEC.

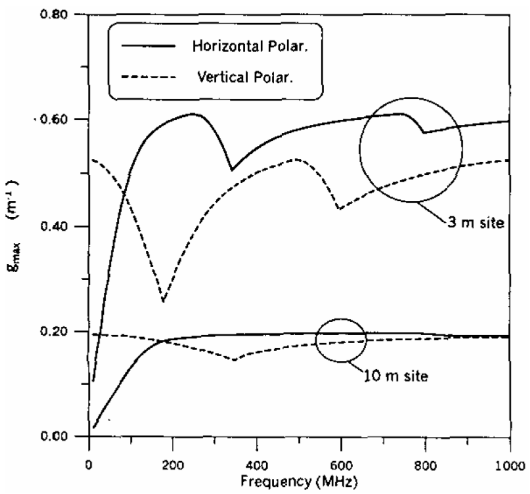



**Fig. 3.** Geometry factor $g_{max}$ by Holloway, 2003.

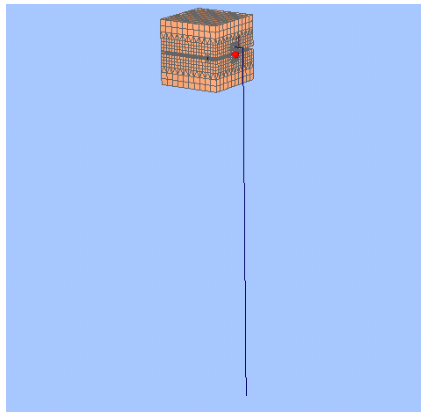


**Fig. 4.** Model of a realistic test-object for numerical simulations.

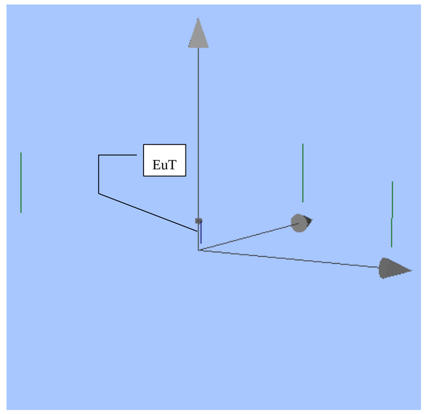



**Fig. 5.** Locations to calculate $E_{max}$.

specific test site and $D_{max}$ introduces the antenna pattern of the equipment under test. The appropriate choice of these two values will be discussed in the following chapters.

## 2.1 $g_{max}$: Effect of the Test Site Geometry

The geometry factor $g_{max}$ is given for free space by

$$g_{max} = \frac{1}{r} \tag{2}$$

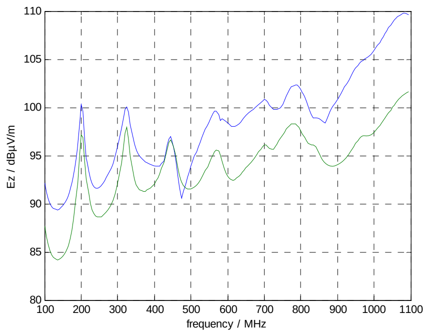
with $g_{max}$ in 1/m.

Switching to a test site with a perfect conducting ground plane, the effect of the plane has to be considered. A well known way to consider the ground is to introduce an image of the EuT below the ground as depicted from Fig. 2. The fields may be calculated over the equivalent height scan of the receiving antenna as required by the OATS method. The maximum signal from the two polarizations gives the maximum possible electrical field strength. The geometry factor $g_{max}$ from Eq. (3), which is determined by the height-scan of the receiving antenna, gives an estimate for the maximum field $E_{max}$ on an OATS.

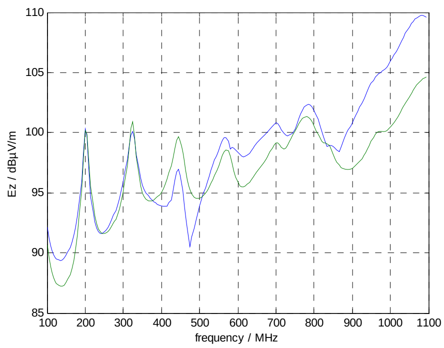
$$g_{max} = \begin{cases} \left| \frac{e^{-jk_0 r_1}}{r_1} - \frac{e^{-jk_0 r_2}}{r_2} \right|_{max} \\ = \left| \frac{1}{r_1 r_2} \sqrt{r_2^2 + r_1^2 - 2 r_1 r_2 \cos k_0 (r_2 - r_1)} \right|_{max} \\ \text{horizontal pol.} \\ \left| \frac{s^2}{r_1^2} \frac{e^{-jk_0 r_1}}{r_1} + \frac{s^2}{r_2^2} \frac{e^{-jk_0 r_2}}{r_2} \right|_{max} \\ = \left| \frac{s^2}{r_1^3 r_2^3} \sqrt{r_2^6 + r_1^6 + 2 r_1^3 r_2^3 \cos k_0 (r_2 - r_1)} \right|_{max} \\ \text{vertical; pol.} \end{cases} \tag{3}$$

Wilson, 1995 showed, that the EUT emissions over a ground plane (measurement on an OATS) under far-field conditions are simulated by assuming that the same total radiated power is emitted by a short dipole (replacing the EUT).

For using $g_{max}$ in real life applications the maximum of the equations from Eq. (3) have to be found for each frequency step. This requires a lot of calculation time so an estimation

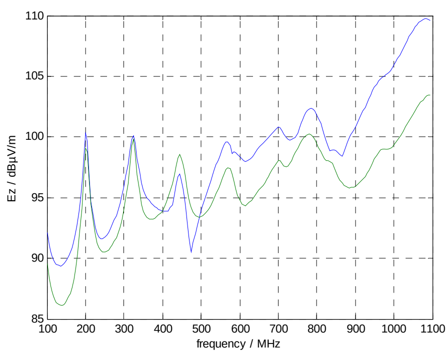



$D_{max} = 1$




$D_{max} = 2$

**Fig. 6.** Simulated field strength (blue) vs. predicted field strength (green).




$D_{max} = 1.55$

**Fig. 7.** Simulated field strength (blue) vs. predicted field strength (green).

of $g_{max}$ should be found. Figure 3 shows $g_{max}$ for a 3 m- and a 10 m-test-site. An upper-bound can be found with

$$g_{max} \approx \frac{2}{r} \qquad (4)$$

**Table 1.** Directivity $D_{max}$ in free space.

| **Antenna** | **Directivity $D_{max}$** |
|---|---|
| isotropic | 1 |
| Hertzian dipole | 1.5 |
| Half-wave dipole | 1.64 |
| Combined electric magnetic dipole from Wilson, 1995 | 3 |

This seems to be reasonable because it is expected that the maximum would be not more than double of the value for free space.

Summarizing this chapter it can be said that a very good approximation for $g_{max}$ is

– for free space: $g_{max} = \frac{1}{r}$

– for perfect conducting ground plane: $g_{max} \approx \frac{2}{r}$

### 2.2 $D_{max}$: Directivity of the EuT

The factor $D_{max}$ describes the complexity of the EuT radiation pattern. Some numbers for canonical antennas can be found in Meinke, Gundlach, 1968. These numbers are given in Table 1.

A lot of papers (Wilson, 2004; Koepke, 2000; Harrington, 2000) have been published on this topic. Most papers like IEC are coming back to the assumption $D_{max}$=1.55, the directivity of a Hertzian Dipole. Taking into account, that most of these test sites are validated by using dipoles, it seems to be a reasonable approach to use this directivity. Wilson uses this value for the low-frequency range. This is reasonable because the approximation for $g_{max}$ underestimates this frequency range.

## 3 Verification for an unintentionally radiating EuT

Choosing the "appropriate" $D_{max}$ for an unintentionally radiating EuT confuses the issue for increasing frequency. To illustrate the problem a realistic test-object as depicted in Fig. 4 is simulated. This model has been set up by Dr. Kappel from EMC Test NRW GmbH. It consists of a cube 20 cm×20 cm×20cm and an attached wire with the length of 1.5 m. The wire ends 5 cm above ground. The EuT is fed by an ideal voltage source marked with a red dot in Fig. 4.

According to the procedure for OATS-measurements the maximum field strength was calculated and along three lines in a distance of 10 m running from z=1 m to z=4 m as shown in Fig. 5 with the numerical field simulation tool CONCEPT II. Another advantage of this numerical code is the fact that the total-radiated-power $P_{rad}$ is given for each frequency step. This gave as the opportunity to get $E_{max}$ according to the

OATS-procedure from the three lines calculation and to predict $E_{max}$ from $P_{rad}$ with Eq. (1).

For all simulations $g_{max}$ has been chosen to 0.2 according to Eq. (4) $D_{max}$ has been chosen to 1 as the directivity of an isotropic radiator, 1.55 for a dipole and 2 as recommended by some other papers. Figure 6a, b and c compare the maximum field strength obtained by simulation with the predicted field strength using Eq. (1).

A dipole assumption of $D_{max}$=1.55 seems to be a good solution for the frequency range up to 600 or 800 MHz. If we focus on higher frequencies above 1 GHz, we have to be aware of an increasing $D_{max}$. Krauthäuser, 2007 as well as Wilson and others have discussed some approximations for $D_{max}$ for unintentional radiators in the high frequency range. These approximations depend on the electrical size of the EuT. Further work is going on to predict the electrical size of an EuT over ground and in free space without knowing the radiation pattern

## 4 Conclusions

Summarising this paper we can say, that it is possible with a small error bound to convert total radiated power measurements to equivalent field strength on an open area test sites or to free space conditions. Following Eq. (1) the geometry factor $g_{max}$ und the directivity of the EuT $D_{max}$ have to be predefined. $g_{max}$ can be approximated for free space with $1/r$ and for an OATS with $2/r$. For the frequency range below 800 MHz the standard dipole assumption for an unintentionally radiating EuT is reasonable. For higher frequencies a more sophisticated description of $D_{max}$ is necessary.

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