Modelling of Electromagnetic Wave Propagation with the Use of the Ray-tracing Method

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Abstract— The article concerns problems of electromagnetic wave propagation in semi-anechoic chambers. Electromagnetic wave propagation modelling using ray-tracing methodology is described. The analytical equations which are used in ray-tracing methodology are presented. The elaborated program algorithm basing on presented analytical equations is described. The worked out software application basing on the described algorithm is presented. The validation results of elaborated software are presented too.

1. INTRODUCTION

In widely available literature concerning methods of radio-wave propagation modelling [11, 12, 18–24] one can find a series of solutions different from each other in:

- modelled propagation environment (open space, urbanized area, building interior),
- dimensionality (two-dimensional, three-dimensional),
- possible to obtain calculation accuracy.

Only a few of them can be used for modelling of radio-wave propagation in semi-anechoic chambers. Despite the development of numerical methods used for solving electromagnetic problems (method of moments, FDTD) writing a program application implementing specific radio-wave propagation models is still very difficult and sometimes even impossible. We can distinguish a group of methods of radio-wave propagation modelling due to which, after some simplifications, it is possible to obtain simulation results with permissible accuracy in its acceptable duration. This group includes the ray tracing method [1, 2].

2. DESCRIPTION OF THE RAY-TRACING METHOD

The ray-tracing method for electric field strength of i-ray calculation in a particular point use the following dependence:

$$E_i = E_o L_i(d) f_{ti} f_{ri} \Pi_j \Gamma(\theta_{ji}) \Pi_k T(\theta_{ki}) e^{-jkd}, \tag{1}$$

where:
E_i — electric field strength from next ray (V/m),
E_o — electric field strength within the distance of 1 (m) from the source (V/m),
d — length of radio channel (m),
$L_i(d)$ — losses at distance d (channel length),
$\Gamma(\theta_{ji})$ — reflection coefficient,
$T(\theta_{ki})$ — transmission coefficient,
e^{-jkd} — phase shift at length d,
k — wave number ($2\pi/\lambda$),
f_{ti} — distribution of electric field strength of transmitting antenna,
f_{ri} — distribution of electric field strength of receiving antenna.

Total electric field strength in a particular point is vector superposition of fields deriving from particular rays and is expressed as:

$$E = \Sigma_1^i E_i \tag{2}$$

Occurring in Formula (1) coefficient of channel losses is calculated in the following way:

$$L(d) = -10 \log \left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d_o^2} \right) + 10n \log \left(\frac{d}{d_0} \right), \tag{3}$$

where:
G_t, G_r — transmitting and receiving antenna gain,
λ — wave length (m),
d_o — reference distance, usually 1 (m),
d — channel length (total ray path) (m),
n — coefficient dependent on environment, in free space $n = 2$.

3. ASSUMPTIONS FOR MODELLING OF RADIO-WAVE PROPAGATION IN SEMI-ANECHOIC CHAMBERS

During working out the algorithm it was assumed that distribution of electric field strength would be determined in two dimensions. Propagation environment will be semi-anechoic chamber with length 5 (m) and height 3 (m). Ceiling and walls of the chamber are covered with a material absorbing energy of electromagnetic waves in the form of ferrite plates and graphitoidal absorbers. The chamber floor along the entire length is tiled only with ferrite plates and is the plane reflecting electromagnetic waves. Between transmitting and receiving antenna, which for the need of simulation will be represented as single surface points, there are no extra objects (obstacles). As input data for the algorithm application user must introduce: length of wave λ (m) generated by transmitter, height of transmitting antenna position h_1 (m), transmitting antenna gain G_t, relative ground permittivity ε, electric field strength E_o (V/m) within the distance of 1 (m) from transmitting antenna, polarization of generated radio wave (vertical, horizontal). Relative ground permittivity ε can be obtained by using measurement methodology described in literature items [9, 10, 13–17].

As a simulation model two-dimensional implementation of ray-tracing was chosen. Using reciprocity principle allows to determine resultant of electric field strength in the receiving point. For each space point two rays are traced:
- direct,
- reflected from ground.

4. ALGORITHM OF RADIO-WAVE PROPAGATION MODELLING

In Fig. 1 the algorithm of calculation of electric field strength distribution has been presented. Analysing the below algorithm one should bear in mind that variable y represents the height of receiving antenna suspension in centimetres and variable x — the distance (in straight line)

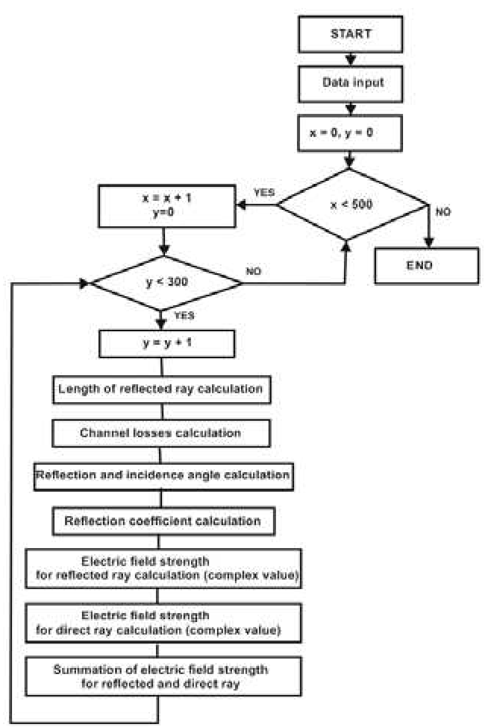
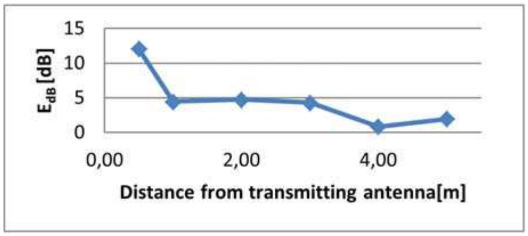
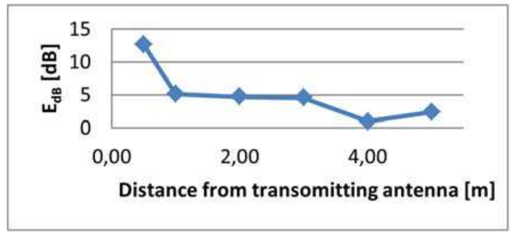


Figure 1: Algorithm calculating electric field strength — implementation of two-dimensional ray-tracing method.

of receiving antenna from transmitting antenna in centimentres. Software modelling radio-wave propagation and implementing the ray-tracing method was conducted on the platform JavaFX in Java language.



(a)



(b)

Figure 2: Accuracy of simulation results for HPEM generator (a) without reflector and (b) with reflector.

5. VALIDATION OF SIMULATION SOFTWARE

In order to verify the designed simulation software levels of electric field strength obtained with the computer simulation method were compared with results received from measurements conducted in semi-anechoic chamber. As the source of test signal the generator HPEM DS-110 was used. Two range measurements of the HPEM generator were conducted. The first measurement was carried out for the HPEM generator without reflector, the second for the HPEM generator with reflector. The measurements were conducted at frequency $f = 350\,\text{MHz}$, vertical electric field polarization and along direct ray. Both transmitting and receiving antennas were located at height $h = 1\,(\text{m})$. As receiving antenna can be used optional antenna [3–8] tuned to the frequency of the test signal. During computer simulations environment close to the environment in semi-anechoic chamber was simulated. The measurement results were compared with results obtained with the use of designed simulation software. Two test scenarios simulating range measurement of the HPEM generator were conducted. In the first one measurement without aerial reflector was simulated, in the second — measurement with reflector.

Each value obtained as a result of simulation E_{sim} was compared with corresponding measurement result E_{meas} according to the below dependence:

$$E = |10 \log(E_{sim}/E_{meas})|, \tag{4}$$

6. CONCLUSIONS

In the above presented Fig. 2 we can notice that for measuring points placed within the distance bigger than one meter from transmitting antenna, the obtained simulation results differ from the measurement results in not more than 5 (dB). The obtained differences between simulated and measured values fall into ranges published in specialist literature obtained for models of simulated channel according to models: Seidel and Rapaport, Holt, Pahlavan and Lee and McKown.

Moreover those differences do not depend on the structure of transmitting antenna — value $E\,(\text{dB})$ is approximately the same for both tested scenarios. Thus we can assume that implementation of the ray-tracing method was performed correctly. It is worth noticing that along with increase of the distance from transmitting antenna the designed implementation of ray-tracing allows to obtain results closer to measured values.

ACKNOWLEDGMENT

The project is financed from NCBiR means within the Agreement No. 0024/R/ID2/2012/02 in the years 2012–2015.

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