

Numerical Calculation of Electric Fields in Housing Spaces Due to Electromagnetic Radiation from Antennas for Mobile Communication

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The influence of electromagnetic radiation from mobile antennas on humans is under discussion in various groups of scientists. This paper deals with the impact of electromagnetic radiation in a housing space. The space is assumed to be bordered by 5 walls of ferroconcrete and a door-window combination on the 6th side, the latter to be electromagnetically transparent. The transparent side of the housing is exposed to an electromagnetic wave. As the source of radiation is considered to be far away from the housing, the radiation is regarded to be from a plane wave. Due to the high signal frequency and ferroconcrete walls, 5 sides of the housing space are considered to be perfect conductors. The electric field inside the housing is calculated numerically by the method of finite differences for different angles of incidence of the radiated electromagnetic wave. The maximum value of the calculated electric field is outlined in a diagram.

Keywords: numerical calculation, finite difference, electric fields, mobile communication.

1 Introduction

The aim of this paper is to calculate the electric fields which are caused by the impact of electromagnetic waves inside a housing space. The calculation is performed numerically with the finite-difference time-domain method (FDTD). The method of finite differences is based on discretisation of infinitely small time and space steps by finite small time and space steps. The code applied for this investigation approximates the time and space dependencies of magnetic (H) and electric (E) – fields by central differences.

Eq. 1a–c shows discretisation along dimensions (x, y, z) of the Cartesian grid. Eq. 2 shows discretisation of time.

$$\frac{\partial}{\partial x} F^n(x, y, z) = \frac{F^n\left(x + \frac{1}{2}, y, z\right) - F^n\left(x - \frac{1}{2}, y, z\right)}{\Delta x} \quad (1a)$$

$$\frac{\partial}{\partial y} F^n(x, y, z) = \frac{F^n\left(x, y + \frac{1}{2}, z\right) - F^n\left(x, y - \frac{1}{2}, z\right)}{\Delta y} \quad (1b)$$

$$\frac{\partial}{\partial z} F^n(x, y, z) = \frac{F^n\left(x, y, z + \frac{1}{2}\right) - F^n\left(x, y, z - \frac{1}{2}\right)}{\Delta z} \quad (1c)$$

$$\frac{\partial}{\partial t} F^n(x, y, z) = \frac{F^{n+1/2}(x, y, z) - F^{n-1/2}(x, y, z)}{\Delta t} \quad (2)$$

F : E, H , respectively

n : time step

x, y, z : location in cartesian dimensions

As only electromagnetic waves are considered, Maxwell's equations are approximated, omitting current density.

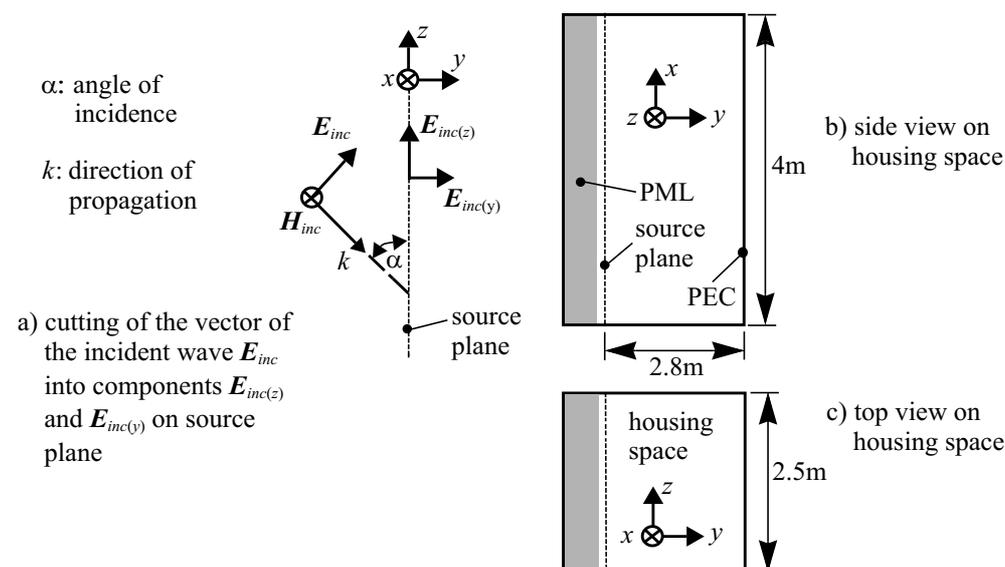


Fig. 1: Simulation of wave propagation and housing space dimensions

FDTD requires the computational domain to be limited by boundary conditions. Two boundary conditions are used here, perfectly-electric conductors (PEC) and perfectly-matched layers (PML). PEC's are implemented by forcing the tangential component of the electric field along the boundaries to be zero ($E_{\text{tangential}} = 0$). In the PML-technique, an artificial layer of absorbing material is placed around the outer boundary of the computational domain. The goal is to ensure an electromagnetic wave incident into the PML region at an arbitrary angle to be absorbed without reflection. The PML region is realized by implementing a new degree of freedom into the formulas of the FDTD code, which is done by splitting the field components [1].

Fig. 1 shows the dimensions of the house spacing under consideration from a top and side view.

The house space under consideration is restricted to a volume of $V = 4 \text{ m} \cdot 2.8 \text{ m} \cdot 2.5 \text{ m}$. Five boundaries are considered to be walls of ferroconcrete and therefore good reflectors for high-frequency signals, as used for mobile communication. Hence these walls are simulated by PEC's. The 6th boundary is considered to be a window/door combination and therefore electromagnetically transparent. In order to simulate the incidence of electromagnetic waves from radiating antennas far away from the housing, the window/door boundary is simulated as source plane. For calculation, the direction of propagation needs to be taken into account, so the electric field vector of the incident wave is simulated on the source plane by decomposition into components. Simulation is performed by setting the components of the electric field strength $E_{\text{inc}(z)}$ and $E_{\text{inc}(y)}$ on the source plane according to the electric field strength E_{inc} of the incident electromagnetic wave on the window/door combination. The time-dependence is taken into account by setting the values of the components of the electric field strength on the source plane sinusoidally. Setting of the magnetic component was omitted, as magnetic and electric fields are related by the impedance of free space. Impedance-matched simulation of free space along the window/door combination (source plane) is assured by implementing PML's. The PML structure numerically absorbs the energy of the electromagnetic wave traveling from the interior of the housing space towards the environment.

2 Results

As shown in Fig. 1a, numerical calculation was performed for an electromagnetic wave with magnetic and electric field vectors H_{inc} and E_{inc} and direction of propagation k related to the dimensions of the defined Cartesian system. Investigation of the electric field strength inside the housing space was based on different angles of incidence within a range of $5^\circ \leq \alpha \leq 85^\circ$ in steps of $\alpha_{\text{step}} = 5^\circ$. For each angle of incidence a calculation was performed, until a steady state of the electric field inside the housing space could be observed.

Data analysis was restricted to the last time interval in a steady state. The last time interval was divided into 10 time-points with equal time spacing.

Fixing the angle of incidence of the propagating electromagnetic wave, the maximum absolute value of the electric field strength E_{max} was detected within the housing space and within the chosen time points for steady state. In addition E_{max}

was referred to the amplitude of the incident electric field strength E_{inc} .

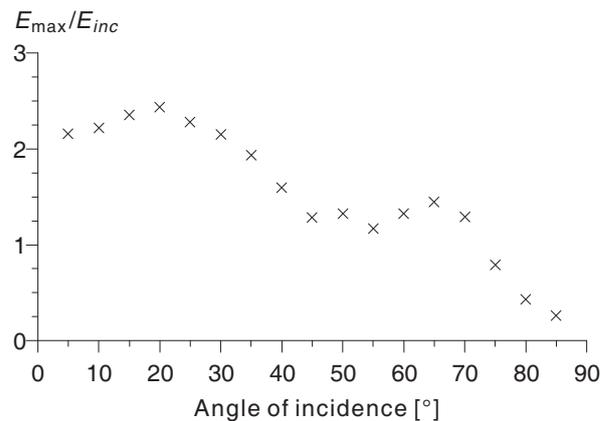


Fig. 2: Dependency of maximum electric field strength inside a housing space referred to incident electric field strength ($E_{\text{max}}/E_{\text{inc}}$) over angle of incidence (α)

Fig. 2 shows $E_{\text{max}}/E_{\text{inc}}$ over α . As may be seen, the maximum electric field strength depends strongly on the angle of the incident electromagnetic wave, and the maximum value of the electric field strength inside the housing exceeds the value of the electric field strength of the incident wave. The maximum may be observed for $\alpha = 20^\circ$ with a ratio

$$\frac{E_{\text{max}}}{E_{\text{inc}}} \approx 2.5.$$

This may be explained by reflections and superposition on the perfectly conducting walls of the housing space, particularly in corners and edges where superposition with reflected electric fields from several walls may occur. Taking into account the density of the electromagnetic energy being quadratically dependent on the electric field strength, it may be argued that the density of the energy may be in the worst case about 5 times higher than the energy density of the incident electromagnetic wave on the source plane.

Conclusion

From Fig. 2 it may be concluded that the effects of electromagnetic radiation from antennas for mobile communication should not only be judged by their electric field strength in free-space or boundaries between free-space and housings. As electromagnetic waves with high frequencies may have negative effects on humans, attention should be paid to legal limits for electromagnetic radiation from radio transmitters for mobile communication in the vicinity of housings. Legal limits referring to free space propagation of electromagnetic waves should be regarded with care, as under unfavourable conditions humans inside housings may be subjected to electric field strengths which exceed the allowed limits. It should be taken into account that the effects of electromagnetic radiation on humans are quadratically dependent on the electric field strength, as these effects are mainly related to the energetic density of the electromagnetic waves, and therefore the negative impacts on humans increase disproportionately with electric field strength.

References

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