Agnieszka CHOROSZUCHO, Bogusław BUTRYŁO

Białystok Technical University, Faculty of Electrical Engineering

Local attenuation of electromagnetic field generated by wireless communication system inside the building

Abstract. *The aim of this paper is an analysis of propagation of a high frequency electromagnetic wave (f=1.8 GHz) in a part of the building. Three typical technologies (i.e. the brick, the reinforced slabs, and the passive building), commonly used in construction of buildings are evaluated. Some phenomena connected with interaction of electromagnetic field with the complex, non-ideal material structures are presented and discussed. The influence of physical properties of materials, and the effect of obstacles such as additional wall are examined. A discussion connected with the influence of the reinforcement and the additional walls on the distribution of electromagnetic field is useful for designers of wireless networks.*

Streszczenie. *Celem publikacji jest analiza propagacji fali elektromagnetycznej wewnątrz części budynku. Analiza dotyczy trzech powszechnie stosowanych typów konstrukcji budowlanych, w których wykorzystuje się: cegły, zbrojone płyty betonowe lub beton komórkowy. Artykuł zawiera dyskusję dotyczącą zjawisk fizycznych związanych z polem elektromagnetycznym występujących w złożonych konstrukcjach. Badany jest wpływ fizycznych właściwości materiałowych i konstrukcji ścian działowych na rozkład pola elektromagnetycznego. Wnioski mogą być źródłem wiedzy dla projektantów bezprzewodowych sieci. (**Lokalne tłumienie pola elektromagnetycznego generowanego przez system komunikacji bezprzewodowej wewnątrz budynków**).*

Keywords: electromagnetic wave propagation, finite difference time domain method (FDFD), wireless communication, building materials (brick, aerated concrete, reinforced concrete).
Słowa kluczowe: propagacja fali elektromagnetycznej, metoda różnic skończonych w dziedzinie czasu (FDTD), komunikacja bezprzewodowa, materiały budowlane (cegła, beton piankowy, zbrojony beton).

Introduction

The analysis of the phenomena connected with the propagation of high frequency electromagnetic waves inside the buildings is of a great importance. construction of a good quality, reliable wireless communication system must include a wide spectrum of factors determining the electromagnetic (EM) field distribution, including geometry and construction of a building, as well as properties of some complex material structures that are found between the a transmitter and a base station. It has been the subject of a number of investigations [1-7, 11]. The implementation of the modern wireless communication systems must consider different negative, local effects (e.g. multiple reflections, diffractions, wave interferentions, fading and attenuation) that may deteriorate the distribution of EM field. These effects usually lead to lower quality of the data transmission. The problem results directly from the wave propagation in the building structures containing some dielectric and metal elements (e.g. reinforcement, additional partition walls) [5, 8-10].

In this study the distribution of the high frequency electromagnetic field inside a brick building construction is investigated. The geometry of the analysed part of building remains unchanged, and the precise, large-scale model of the reinforcement inside the walls is prepared. A comprehensive assessment of some different building technologies is presented. The partition wall had been erected with the help of three typical, commonly used building technologies: the brick, the passive building technology composed of aerated concrete and the reinforced concrete [7]. The access point of the local, short-range wireless communication system is a source of the EM field. Conclusions concerning the influence of the building construction on the distribution of high frequency electromagnetic field are presented.

Formulation of the numerical model

The distribution of the electromagnetic field in the analysed system is determined using the finite difference time domain (FDTD) method [12]. In the classical approach for 3D problems the examined area is divided into elementary Yee cells [12-13]. Every Yee cell is described by electric permittivity, magnetic permeability and electric conductivity (e.g. ε, μ, σ). The method is based on the direct numerical integration of the Maxwell's curl equations [12] in the time and space. Owing to its methodological simplicity and easy mapping of the geometry of the analysed model, the method is particularly useful in the calculations of some broadband and high frequency time dependent electromagnetic fields. The mathematical background of the applied formulation is presented in [12-13].

Construction of the analysed room

The geometry of the analysed part of the building is approximated by three-dimensional model. The presented case study concerns the distribution of the EM field in a room measuring 2.6×3.7 m in *X*, *Y* directions respectively. In the direction of axis *Z* only the part of the room is modelled. It is a horizontal segment at the height 0.405 m (Figs. 1-2). The external walls are built of the common brick. The room is partitioned by an additional wall 0.13 m thick, covered with the 0.01 m plaster board on each side. The length of the analysed model along *Y* axis is 4 m whereas the additional wall is located *Y*=1.7 m (Fig. 2) from the door made of wood.

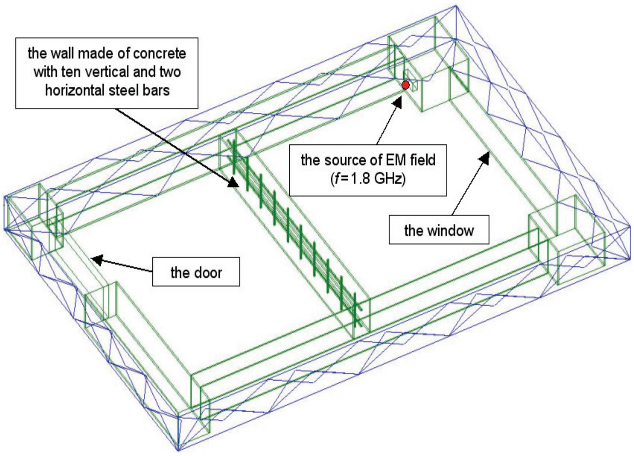

Fig.1. The 3D model of the room with the partition wall. (The presented version of the inner separating wall is made of reinforced concrete.)

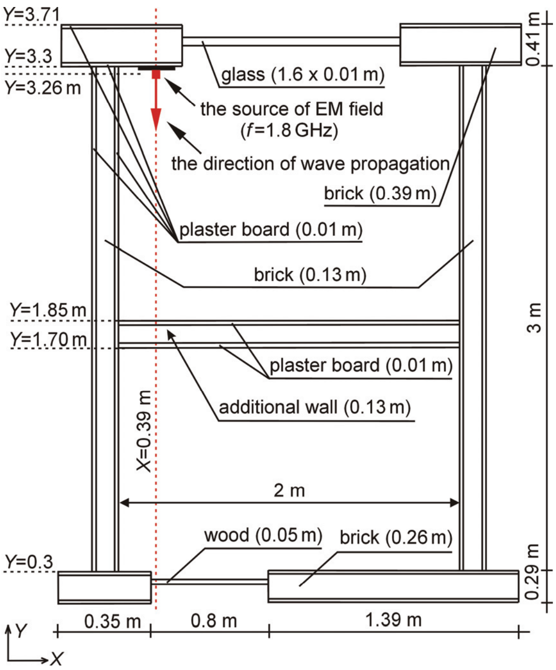

Fig.2. The geometry and dimensions of the analysed room

The three different structures of the additional wall are analysed: the common brick, the aerated concrete and the reinforced concrete with the mesh (0.2×0.2 cm ≈ 0.66λ) of steel bars (diameter ϕ=10 mm). Owing to the dimensions of the analysed room, the additional wall is strength by ten vertical bars and two horizontal ones (Fig. 1). The reinforcement is additionally used in the form of metal bars, stirrups or steel meshes of various sizes, in order to protect concrete structures against tensile stresses. The structure of the reinforcement depends, among others, on the design plans and the type of the concrete [1, 8]. The nominal diameter of the reinforcement bars in the common buildings is ϕ=5.5-40 mm. The structure and geometry of the reinforcement is precisely approximated in the presented FDTD model. Both the actual mounting of the reinforcement and the spaces between the steel bars are taken into account for each constructional element.

The discussed results of computation concern the isotropic, linear materials. The electrical properties of these materials are presented in [1-7].

The EM field is excited by a transmitter that generated a harmonic wave at the frequency of f=1.8 GHz. An isotropic point source is assumed. The source is switched on at t=0, and it is modelled by a term representing an incident electric current, independent of the calculated EM field.

The source of the field is placed inside the room, on the left column close to the window (Figs. 1, 2). The X and Y coordinates for the transmitter are 0.39 m and 3.26 m respectively. It is placed at the level 0.27 m from the ceiling. This kind of a location is frequently used because it enables to spread the signal towards the interior part of the room. As mentioned earlier the horizontal segment of the room is analysed, and the antenna of transmitter is placed in the centre of the left column.

The first order Mur's absorbing boundary conditions (ABC) is assumed on the external surfaces of the model [14]. In this study we decided to investigate the direct propagation of EM wave through the complex structures of the wall. Therefore, the reflections from both the ceiling and the floor do not take into account in the presented case.

The Courant-Friedrichs-Lewy condition (CFL) is commonly recognized and it is used as an indicator of stability and quality of the numerical simulation [12]. In the analysed cases the wavelength is 0.17 m and the area is composed of cubic Yee cells measuring 0.01×0.01×0.015 m. Each of the three models consists of 2 912 448 Yee cells. The Maxwell equations are directly integrated in time domain with the assumed time step Δt=0.116 ns.

Results of the analysis

The reflections of electromagnetic wave caused by the non-ideal dielectrics (i.e. the concrete) and some phenomena connected with the interaction between the EM field and the mesh of metal bars (i.e. reinforcement) are analysed. The distributions of the EM field on different XY planes are examined.

The results of calculation are shown in the XY plane and Z=0.17 m therefore the results of computations are compared in the steady state.

Figures 3-5 show the distribution of E_z component at the same time step and at the level Z=0.17 m below the transmitter. The weakest signal, after the penetration of the additional wall, is recorded in the reinforced concrete construction (Fig. 8b, Table 1). Comparing figures 3-5 there are some distinct differences in the distribution of the EM field intensity. The quality of the signal in the part of the room located inside the part of room without the transmitter (Y=0.3-1.7 m) is greatly influenced by the properties of the concrete and the steel bars in the wall. The local reflections of the waves and some resultant wave interactions are enhanced. Such an obstacle additionally causes local fading that have influence on the quality of data transmission. Since the electric properties e.g. of the brick (ε_r=4.44) and the aerated concrete (ε_r=3.0) [7] are almost the same, the significant differences in the distribution of the electromagnetic field are not observed.

Figures 5-6 show the phenomenon of multiple reflections from steel bars and their correlations with concrete causing local increase of the values of EM field inside the part of room with transmitter (the near the additional wall).

The signal considerably decreases near the surrounding walls due to the wave phenomena that occur in building structures. In the case of the reinforcement steel bars whose number and size increase will deteriorate the EM field distribution, which finally results fading.

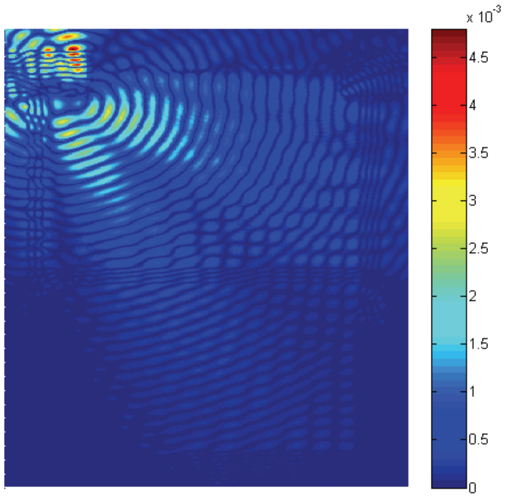

Fig.3. The distribution of E_z component [V/mm] inside the room (the partition wall is made of brick)

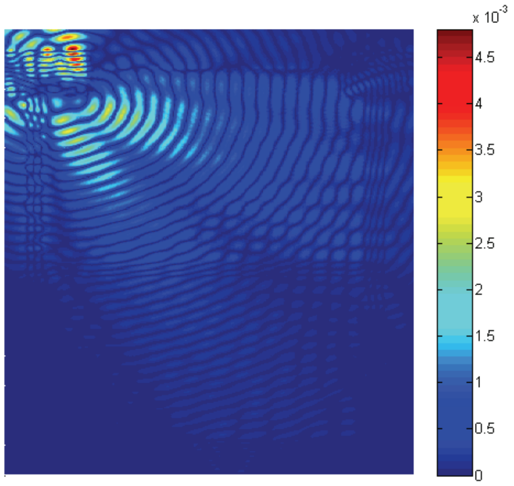

Fig.4. The distribution of E_z component [V/mm] inside the room (the partition wall is made of aerated concrete)

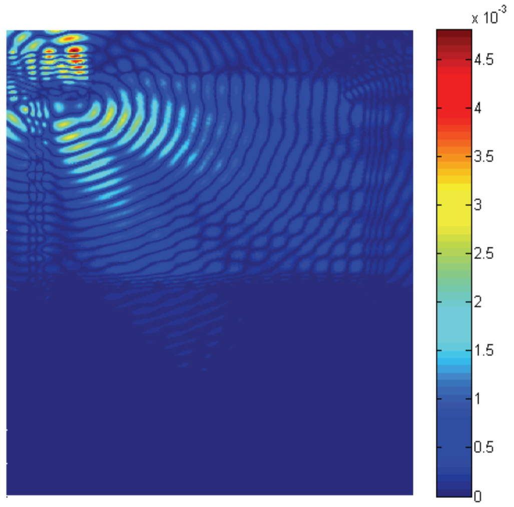

Fig.5. The distribution of E_z component [V/mm] inside the room (the concrete partition wall with cross reinforcement)

Some characteristic values of the EM field intensity for E_z component at the level of transmitter and at the horizontal XY surface below it (Z=0.17 m) are compared in Table 1.

Table 1. The comparison of the EM field intensity values for E_z component [V/mm]

Type of material of the additional wall	Inside the room with the transmitter, X=0.39 m, Y=1.86 cm		Inside the room without the transmitter, X=0.39 m, Y=1.69 m	
	below the transmitter, Z=0.17 m	on the level of the transmitter	below the transmitter Z=0.17 m	on the level of transmitter
brick	0.00017	0.00029	0.00005	0.00006
aerated concrete	0.00011	0.00027	0.00009	0.00010
reinforced concrete	0.00013	0.00025	0.00001	0.000007

Figures 6 and 8b show the distributions of the E_z component and their dependencies from the distance and the type of material of which the partition wall is made. Figure 6 gives a comparison of the values near and inside the additional wall. The layer of the plaster board due to its electric properties causes no significant changes of EM field. The considerable changes of field intensity are observed inside the wall. The intensity of electric field becomes lower after the penetration of analysed wall. The value of the field intensity at the height of the transmitter is significantly decreased for the reinforced wall. In this case its value is damped 35 times. For the brick and the aerated concrete walls these values are smaller, i.e. 4.8 and 2.7-fold respectively. However, the intensity of the field at height of 0.17 m below the transmitter do not show such sudden drops especially in the case of the reinforced concrete (13-fold smaller). For the brick wall the values are 3.4-fold smaller whereas in the case of modern building technology (passive building) the value of attenuation is are the smallest i.e. only 1.2–fold.

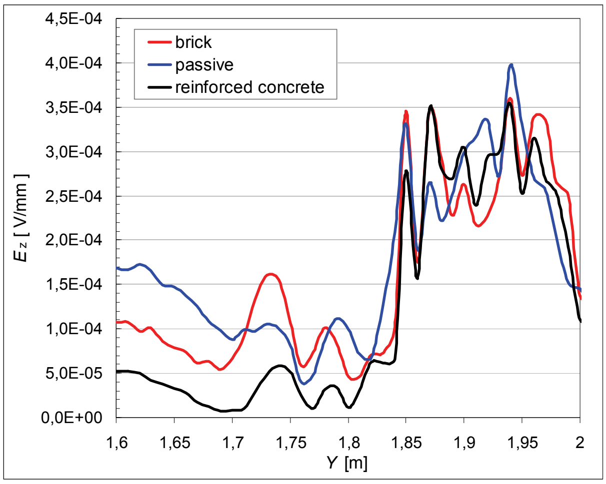

Fig.6. The comparison of the maximum values of E_z component near the additional wall (at the level of the transmitter)

Figure 7 presents the distribution of the maximum values E_z component inside a part of the room without the transmitter (Y=0.3-1.7 m) and the values in the room with the transmitter near the wall (Y=1.85-2.2 m). At a distance of 1 m from the analysed wall (Y=0.3-0.7 m) the values for all three cases are almost the same and it does not depend on the height where the transmitter was located. However, for the reinforced concrete the amplitude of the EM wave is smaller and the profile of the E_z intensity is irregular in shape. Its value drops again after passing through another wall (Y=0 m). The observed envelope value, i.e. maximum recorded value of the field, is also distorted at a distance of Y=0.3-0.7 m due to wave reflections from the surrounding wall.

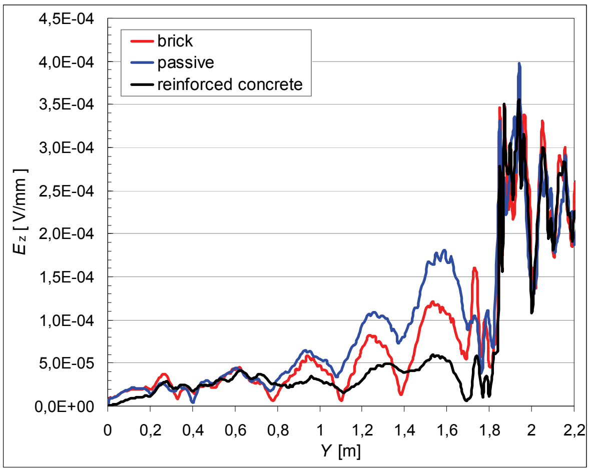

Fig.7. The comparison of the maximum values of E_z component behind the additional wall, i.e. inside the room without the transmitter (at the level of the transmitter)

Figure 8 presents the charts of E_z component in the logarithmic scale for the whole analysed area. The highest values of the EM field are in the room with the aerated concrete wall (the passive building technology). The introduction of any steel elements such as reinforcement cause an appearance of undesirable wave phenomena, e.g. wave attenuation or diffractions that either increases or decreases its values behind the wall.

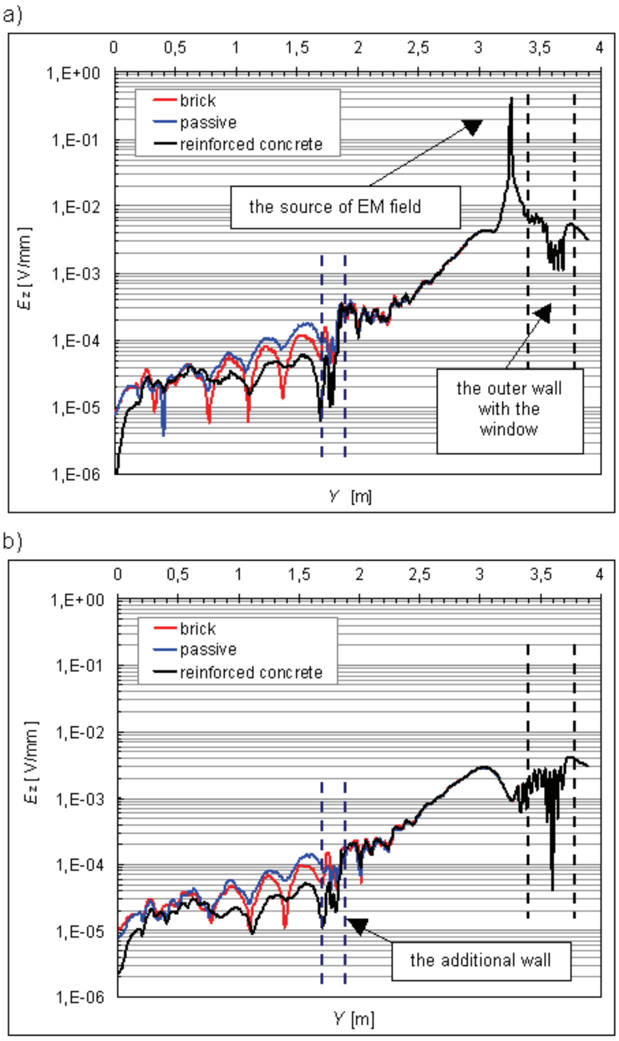

Fig.8. The comparison of the maximum values of E_z component inside the whole area of the analysed room: a) at the level of the transmitter b) at the level of 0.17 m below the transmitter along *Z* axis

Conclusions

The numerical analysis of some large and complex buildings requires a homogenisation of the structure and material properties of components. Detailed analysis of data as well as an implementation of optimisation methods will make it possible to design and install transmitters in complex constructions composed of building materials possessing various physicals properties.

The analysis of the obtained results have indicated that each obstacle on the way of the EM wave especially the one made of a heterogeneity material with metal elements (reinforced concrete) significantly decreases intensity of EM wave. In order to ascertain a high quality signal and undisturbed transmission of data the transmitters should be located on the walls with no reinforcements so as to avoid negative effects connected with wave reflections. As regards partition walls, they should be made of a homogenous building material, for instance aerated concrete, because its permittivity is lower than the value of ε_r of concrete or brick.

The obtained results of the numerical analysis enable to understand the wave phenomena connected with the electromagnetic wave inside the complex buildings made of various heterogeneous materials used in civil engineering. Further research will focus on the influence of the size and architecture of rooms on the distribution of the electromagnetic field generated by the transmitter. Comparisons will be made concerning the changes resulting from the transmitter location and the influence of ceilings on the EM field distribution.

REFERENCES

[1] Richalot E., Bonilla M., Wong M., Fouad-Hanna V., Baudrand H., Wiart J., Electromagnetic Propagation into Reinforced-Concrete Walls, *IEEE Transactions on Microwave Theory and Techniques*, 48 (2000), No. 5, 357-366

[2] Cuinas I, Sanchez M.G., Permittivity and Conductivity Measurements of Building Materials at 5.8GHz and 41.5GHz, *Wireless Personal Communications*, 20 (2002), 93-100

[3] Stavrou S., Saunders S.R., Review of constitutive parameters of building material, *IEEE Transactions on Antennas and Propagation*, Vol. 1 (2003), 211-215

[4] Antonini G., Orlandi A, D'elia S., Shielding Effects of Reinforced Concrete Structures to Electromagnetic Fields due to GSM and UMTS Systems, *IEEE Transactions on Magnetic*, 39 (2003), No. 3, 1582-1585

[5] Dalke R.A., Holloway Ch.L., McKenna P., Johannson M., Ali A.S., Effects of Reinforced Concrete Structures on RF Communications, *IEEE Transactions on Electromagnetic Compatibility*, 42 (2000), No. 4, 486-496

[6] Liu Ping, Chen Gui, Long Yun-liang, Effects of reinforced concrete walls on transmission of EM Wave in WLAN, *Proceedings of the ICMMT 2008, International Conference on Microwave and Millimeter Wave Technology*, Vol. 2 (2008), 519-522

[7] Choroszucho A., Pieńkowski C., Jordan A., Electromagnetic wave propagation into building constructions, *Przegląd Elektrotechniczny*, 84 (2008), nr 11, 44-49

[8] Holloway Ch.L., Perini P.L., DeLyser R.R., Allen K.C., Analysis of composite walls and their effects on short-path propagation modeling, *IEEE Transactions on Vehicular Technology*, 46 (1997), No. 3, 730-738

[9] Dalke R.A., Holloway Ch.L., McKenna P., Johannson M., Ali A.S., Effects of Reinforced Concrete Structures on RF Communications, *IEEE Transactions on Electromagnetic Compatibility*, 42 (2000), No. 4, 486-496

[10] Weiping Q, Shenggao D., Yerong Z., FDTD Calculation of the Effects of Reinforced Concrete Wall on Short Path Propagation of UWB Pulse, *IEEE Microwave Conference Proceedings*, 2005. APMC 2005. Asia-Pacific Conference Proceedings (2005)

[11] Tan S.Y., Tan Y., Tan H.S., Multipath Delay Measurements and Modeling for Interfloor Wireless Communications, *IEEE Transactions on Vehicular Technology*, 49 (2000), No. 4, 1334-1341

[12] Taflove A., Hagness S.C., Computational Electrodynamics, The Finite – Difference Time – Domain Method. Boston, *Artech House*, Inc. 2005

[13] Luebbers R.J., Kunz K.S., The Finite Difference Time Domain Method for Electromagnetism, CRS Press Inc., *Boca Raton*, 1993

[14] Mur G., Absorbing Boundary Conditions for the Finite – Difference Approximation of the Time – Domain Electromagnetic Field Equations. *IEEE Trans. on Biomed. Eng.*, Vol. BME-34, No. 2 (1987), 148-157

***Authors**:*
mgr inż. Agnieszka Choroszucho,
E-mail: a.choroszucho@we.pb.edu.pl,
dr inż. Bogusław Butryło, E-mail: bogb@pb.edu.pl;
Politechnika Białostocka, Wydział Elektryczny, Katedra Elektrotechniki Teoretycznej i Metrologii, ul. Wiejska 45D, 15-351 Białystok.