International Symposium on Antennas and Propagation
27 – 30 October 2008, Taipei, Taiwan
Taipei International Convention Center

A Numerical Analysis of Cumulative Probability of Incident Wave Indoor Propagation

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1. Introduction

The digital terrestrial broadcasting services for mobile receivers had already been started in Japan [1]-[3]. The service is effective as communication means at outbreaks of natural disaster. Experimental studies of the reception characteristic in various environments and countermeasures for the deterioration of reception are carried out up to now. A large-scale numerical analysis by using the finite-difference time-domain (FDTD) technique is effective for this purpose [4], [5]. Especially, it is effective to deal with indoor propagation and incident waves in limited areas such as a classroom, a laboratory or a hallway.

In the previous report [6], we considered the incidence plane wave of digital terrestrial broadcasting due to clarifying its indoor propagation characteristics. We carried out a computer simulation about indoor propagation of the incident plane wave toward the rooms and showed the propagation characteristics for the two models, an empty room and a room with a set of furniture. As a result, cross polarized components against the incident wave with the horizontal polarization were relatively increased for the room with a set of furniture.

This paper discusses and evaluates numerically cumulative probabilities for electromagnetic distributions as well as cross polarization characteristics in the room with a set of furniture. Also the spatially high resolution laboratory model will be developed.

2. Analysis Method and Results

Figure 1 shows a numerical model of a room with a set of furniture that we usually use as a laboratory. The dimensions of room are length of 9.83 m, width of 6.85 m and height of 3.02 m. It is surrounded by the concrete walls of 260 mm thick and includes reinforcing rods with the section dimensions of10 mm $\times$ 10 mm regularly arranged in lattice condition. There is a large window of 5.59 m wide and 1.80 m high in front of the room. The incident plane wave goes on the room through the window perpendicularly. We model desks, chairs, bookshelves, household electrical appliances, computers and phantoms as possible faithfully in order to carry out the simulation of the room with a set of furniture precisely. Table 1 lists their relative permittivity and conductivity used in the FDTD calculations.

The FDTD technique is a versatile and efficient tool for the solution of Maxwell's equations in complex structures. It can also treat problem spaces that contain lossy media. In the FDTD analysis, the problem space is quantized by Yee cells (cubical cells). On the outer boundary, the FDTD algorithm employs the absorbing boundary condition to simulate the extension of the field sampling space to infinity by suppressing reflection off the outer boundary. The cell size must be small enough to obtain accurate analytical results. Generally, it is less than one tenth of the wavelength of the frequency for the analysis. Therefore, in the case of analyzing large-scale models such as the room, the computational memory size required becomes extremely large. Then we employed a supercomputer to analyze the EMF in the room. The FDTD analysis based on the total-field / scattered-field formulation [4] is used in order to obtain spatial electric field distributions throughout the inner space of the room. A frequency band of 513.25 MHz to 561.25 MHz is used in the digital terrestrial broadcasting service. To achieve a precise computation, spatial resolution is set to 1 cm^3 in this paper. To analyze the indoor propagation characteristics, the excitation for the plane wave is performed using a Gaussian pulse with the horizontal polarization. In this work, the time step size is chosen as 1.67×10^{-11} sec for the computational stability.

In this report, cumulative distribution related to the indoor propagation for the two indoor models, an empty room and a room with a set of furniture are examined. Figure 2 shows the cumulative probability of the electric field intensity for the horizontal and vertical polarization components where the observation horizontal plane is 1.1 m above from the floor. The total number of the evaluation point is 122,505 since the distance between them is 20 mm. In the figure solid and dashed lines denotes curves for the room with furniture and the empty one, respectively. The EMF distribution in the empty room is thought to be normal distribution because its cumulative distribution almost has the characteristic of the straight line. On the other hand, the vertical polarization component increases conspicuously about 11 dB at the cumulative distribution of 50 % for the room with a set of furniture compared with the empty room. Also, the cumulative distribution of less than -22 dB increases by nearly 1 % for the horizontal polarization component because there is the shadow area which incident wave does not arrive at.

Figure 3 shows the cumulative distribution of the cross polarization ratio (XPR) which is the strength ratio of the horizontal polarization component to the vertical one at the measurement points. The probability that electric field strength reverses is 0.03 % and 2.28 % for the empty room and the room with a set of furniture, respectively. The difference of XPRs at the cumulative distribution of 50 % is 11 dB corresponding to the above mentioned.

3. Conclusions

The paper discusses the indoor propagation of the plane wave incident from outside such as the digital terrestrial broadcasting service and numerically estimates the electromagnetic field distribution by using the FDTD technique. The two kinds of indoor model, the empty room and the room with a set of furniture are developed and used in the numerical analysis of the cumulative distribution. As a result, we conclude that the vertical field components are slightly observed for the horizontal incident field in the empty room although they are evidently detected in the room with a set of furniture. The difference between the XPRs for the two models is 11 dB at the cumulative distribution of 50 %.

Acknowledgments

Computations were performed using the resources provided by the High Performance Computing System at Information Initiative Centre, Hokkaido University.

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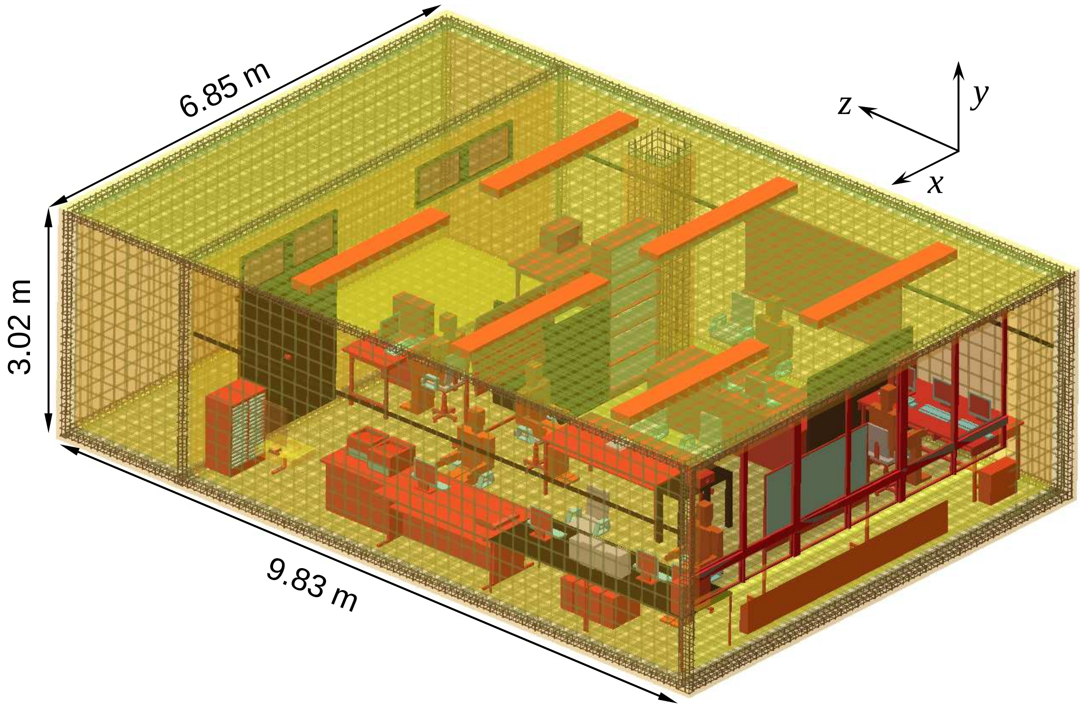

Figure 1: An analytical model for a room with a set of furniture.

Table 1: Electric constants of media

Items	Relative permittivity	Conductivity
Free space	1	0
Metal	-	∞
Concrete	5.5	0.023
Wooden material	2.5	0.001
Window glass	5.0	0.003
Plastics material	3.2	0.008
Rubber material	2.4	0.005
Phantom	50.0	2.2253
Seat polyfoam	2.0	0.001
Paper	2.9	0.008

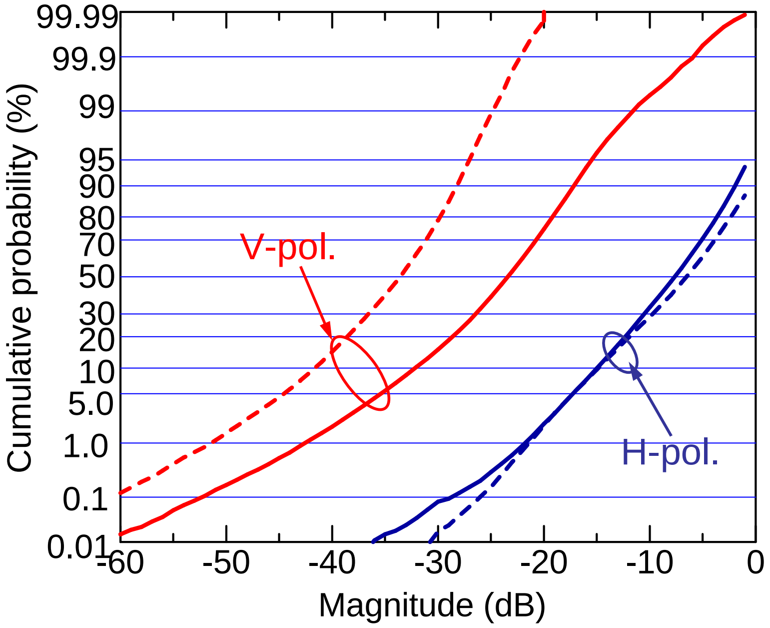

Figure 2: Cumulative probability at the frequency of 537 MHz for the horizontally polarized incident wave. Solid and dashed lines denote the characteristics for the room with a set of furniture and the empty room, respectively.

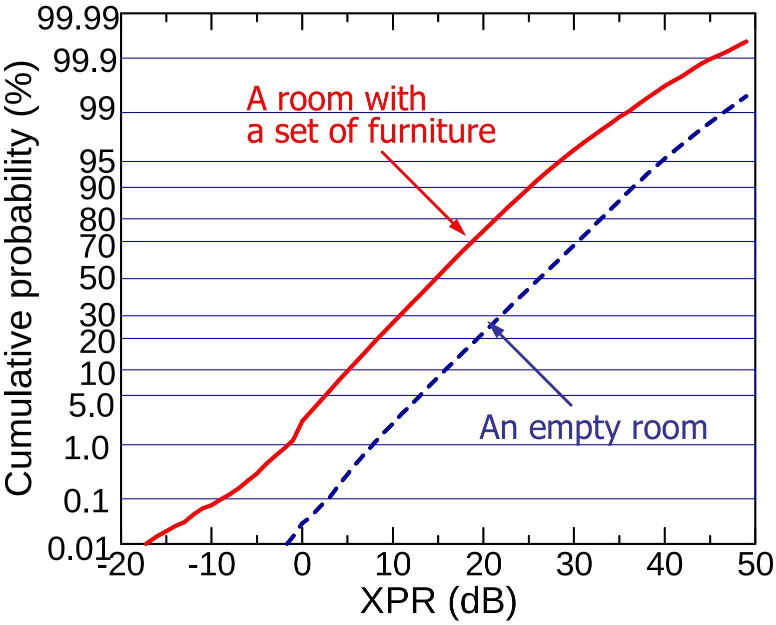

Figure 3: XPR cumulative probability at the frequency of 537 MHz.