Electric Fields in a Small Reinforced Concrete House near a Cellular Phone Base Station

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ABSTRACT

Simulation results of electric fields in the small reinforced concrete house are presented and compared with experimental data measured by a Narda Broadband Field Meter. It is shown that simulation results calculated by the FDTD method make a good agreement with those obtained by measurements, for electric field distributions on a test plane with a height of 1 meter above the bottom floor of the reinforced concrete house. It is also found that the maximum power density in the small reinforced concrete house is twenty two thousand times lower than the exposure level recommended by the ANSI/IEEE for an uncontrolled environment at 1795 MHz.

Key words: FDTD, cellular phone base station, electric field.

I. INTRODUCTION

In recent years, there has been an increasing use of cellular phone systems in our society. Therefore, public concerns regarding potential health hazards due to the exposure to RF radiation from cellular phone base stations have also been growing. Especially, there is a great concern about long-term exposure to the RF radiation in residential environments and public areas such as hospitals, clinics, day-care center, and schools. It is therefore necessary to investigate the long-term exposure to RF radiation more comprehensively to determine if safety guidelines for protecting the human body from RF exposure are being met. Such guidelines have been established in various countries, e.g. by the American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) [1]. When cellular phone base station antennas are mounted at rooftop locations, it is possible that RF exposures approaching the safety guidelines could be encountered directly in front of the antennas. This research is intended to calculate and measure the electric fields in a small reinforced concrete house located at a distance of 19 meters from a cellular phone base station. The small reinforced concrete house and the cellular phone base station are constructed on the rooftop of a seven-story building in the Yuan Ze University campus. Electric fields in this small reinforced concrete house calculated by the finite-difference time-domain (FDTD) method [2] and the near zone to far zone transformation technique [3] will be compared with measurement data.

II. THE FINITE-DIFFERENCE TIME-DOMAIN METHOD

The basic FDTD method was first proposed by Yee [2] and later developed by many researchers for antenna analysis, EMI/EMC, shielding applications, microwave engineering, bio-electromagnetic, and many electromagnetic problems. In the FDTD solution procedure, the coupled Maxwell’s equations in differential form are solved for various points of the object as well as its surrounding in a time-stepping manner until the solutions converge. Following Yee’s notation and using centered difference approximation for first-order partial derivatives with respect to both space and time, we obtain six finite-difference equations for six unique field components within a unit cell. In these six
finite-difference equations, electric fields are assigned to half-integer time steps (n+1/2), and magnetic fields are assigned to integer time steps (n) for temporal discretization of fields. The details of the FDTD method may be found in many publications and will therefore not be repeated here.

III. NEAR ZONE TO FAR ZONE TRANSFORMATION

As the electric and magnetic fields on the surface of the radome are determined by the FDTD method, the tangential electric and magnetic current densities can be obtained from boundary conditions expressed by

\[ \mathbf{E}_\text{es} = \mathbf{n} \times (\mathbf{H}_\text{air} - \mathbf{H}_\text{radome}) \bigg|_{r} = -\mathbf{n} \times \mathbf{H}_\text{radome}, \quad \mathbf{J}_\text{ms} = -\mathbf{n} \times (\mathbf{E}_\text{air} - \mathbf{E}_\text{radome}) \bigg|_{r} = \mathbf{n} \times \mathbf{E}_\text{radome} \] (1)

where \( \mathbf{J}_\text{es} \) and \( \mathbf{J}_\text{ms} \) are the electric and magnetic current densities on the surface of the radome, \( \mathbf{E}_\text{air} \) and \( \mathbf{H}_\text{air} \) are the electric and magnetic fields in air, \( \mathbf{E}_\text{radome} \) and \( \mathbf{H}_\text{radome} \) are the electric and magnetic fields in the radome, and \( \mathbf{n} \) is a unit vector outward from the radome to the air. We can find the electric and magnetic fields in the air generated by the electric and magnetic current densities \( \mathbf{E}_\text{es} \) and \( \mathbf{J}_\text{ms} \). The procedure requires that the auxiliary potential functions \( \mathbf{A} \) and \( \mathbf{F} \) generated by \( \mathbf{E}_\text{es} \) and \( \mathbf{J}_\text{ms} \), respectively, are found first. In turn, the corresponding electric and magnetic fields in air are then determined. The potential functions \( \mathbf{A} \) and \( \mathbf{F} \) are expressed by [3].

\[ \mathbf{A} = \frac{\mu_0}{4\pi} \int_\mathcal{S} \mathbf{J}_\text{es} \frac{e^{-jk_0 R}}{R} \, ds' \] , \[ \mathbf{F} = \frac{\varepsilon_0}{4\pi} \int_\mathcal{S} \mathbf{J}_\text{ms} \frac{e^{-jk_0 R}}{R} \, ds' \] (2)

In equation (2), \( R \) is the distance of any point in the source from the observation point, \( \mathcal{S} \) is the surface of the radome, \( k_0 \) is the wave propagation constant of free space, \( \varepsilon_0 = 8.854 \times 10^{-12} \text{ F/m} \) is the permittivity of free space, and \( \mu_0 = 4\pi \times 10^{-7} \text{ H/m} \) is the permeability of free-space. The electric field \( \mathbf{E} \) and magnetic field \( \mathbf{H} \) radiated form current sources \( \mathbf{J}_\text{es} \) and \( \mathbf{J}_\text{ms} \) are then given by

\[ \mathbf{E} = -j\omega \mathbf{A} - j \frac{1}{\omega \mu_0 \varepsilon_0} \nabla (\mathbf{A} \cdot \mathbf{A}) - \frac{1}{\varepsilon_0} \nabla \times \mathbf{F} \] , \[ \mathbf{H} = \frac{1}{\mu_0} \nabla \times \mathbf{A} - j \omega \mathbf{F} - j \frac{1}{\omega \mu_0 \varepsilon_0} \nabla (\mathbf{A} \cdot \mathbf{F}) \] (3)

IV. SCATTERED FIELDS RADIATED FROM CONCRETE WALLS

The induced electric fields in the walls of the small reinforced concrete house constructed on the rooftop of a seven-story building can be obtained by using the computation procedure described in Section III with boundary conditions. From the boundary conditions, the tangential component of an electric field is continuous and the normal component of an electric flux is discontinuous across an interface. However, the normal component of an electric flux is enforced to be continuous since the surface charge density on the walls is negligible. As the induced electric fields in the walls are obtained, the equivalent free-space current density \( \mathbf{J}_\text{eq} \) in the walls can be computed by

\[ \mathbf{J}_\text{eq} = [\sigma + j\omega \varepsilon_0 (\varepsilon - 1)] \mathbf{E}(r') \] (4)

where \( \mathbf{E}(r') \) is the electric field in the walls, \( \omega \) is the angular frequency, and \( \sigma \) and \( \varepsilon \) denote the conductivity and relative dielectric constant of the walls, respectively. Therefore, the electric field \( \mathbf{E}' \) scattered from the walls can be obtained from the equivalent free-space current density expressed as [5]

\[ \mathbf{E}'(\mathbf{r}) = -j \eta_0 k_0 \int_\mathcal{S} \mathbf{J}_\text{eq}(r') \cdot [\mathbf{I} + \frac{\nabla}{k_0^2}] G_0(\mathbf{r}, \mathbf{r'}) \, ds' \] (5)

where
\[ G_o(\vec{r}, \vec{r}') = \frac{\exp(-jk_0 R)}{4\pi R}, \quad R = |\vec{r} - \vec{r}'| = \sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2} \]  \tag{6}

\[ \eta_0 = \frac{\mu_0}{\varepsilon_0}, \quad k_0 = \omega \sqrt{\mu_0 \varepsilon_0} \]  \tag{8}

In the above equations, \( \hat{I} \) is the identity tensor, \( \varepsilon_0 = 8.854 \times 10^{-12} \text{ F/m} \) is the permittivity of free space, \( \mu_0 = 4\pi \times 10^{-7} \text{ H/m} \) is the permeability of free-space, \( k_0 \) is the wave propagation constant of free space, \( \vec{r} (x, y, z) \) and \( \vec{r}' (x', y', z') \) are field position vector and source position vector, respectively. The scattered far-field components \( E_\theta \) and \( E_\phi \), can easily be found by calculating the far-field radiated from currents distributed in the walls as presented in [5].

\[
\vec{E}^\ast (\theta, \phi) = E_\theta \vec{a}_\theta + E_\phi \vec{a}_\phi = \frac{-j \eta \mu_{0} k_{0}}{4\pi} \int \left\{ \vec{a}_\theta [J_x (\vec{r}') \cos \theta \cos \phi \\
+ J_y (\vec{r}') \cos \theta \sin \phi - J_z (\vec{r}') \sin \theta \right\} d\vec{r}' \\
+ \vec{a}_\phi \left[ -J_x (\vec{r}') \sin \phi \right] \exp \left[ jk_0 (x \sin \theta \cos \phi + y \sin \theta \sin \phi + z \cos \theta) \right] d\vec{r}'
\]
\[
\left[ jk_0 (x \sin \theta \cos \phi + y \sin \theta \sin \phi + z \cos \theta) \right] d\vec{r}'
\]

where \( \eta_0 \) is the wave impedance, \( k_0 \) is the wave propagation constant, and \( J_x (\vec{r}') \), \( J_y (\vec{r}') \), and \( J_z (\vec{r}') \) are the current densities flowing in the x-, y-, and z-axis inside the walls, respectively.

### V. ELECTRIC FIELDS IN THE SMALL HOUSE

The cellular phone base station antenna is constructed from a copper reflector screen and 32 transmitters that are protected by a flat fiberglass radome. The 32 transmitters are divided into two equal groups that are fed by two identical feeding lines with different excitation phases of + 45° and -45°, respectively. Each feeding line has an impedance of 50 ohms operating at frequencies of 1710~1880 MHz. The cellular phone base station antenna is designed to have a radiation power of 20 watts. The conducting case of the cellular phone base station antenna is DC grounded. The cellular phone base station antenna is constructed with 6,071,100 cubic cells of 1.0 mm on each side. The excitation source is a sinusoidally modulated Gaussian pulse wave over the gap between the two arms of each transmitter by \( E = E_0 \exp(-[(t-t_0)/T]^2 \sin 2\pi f_0(t-t_0)) \), where \( E_0 = (V/d) \) is the amplitude of the excited electric field, \( t_0 = 3T, T = 2.32 \times 10^{-9}, f_0 = 1795 \text{ MHz}, V = 1.625 \text{ volts}, d = 38 \), and \( \delta = 1 \text{ mm} \) is the cell size used in the FDTD. The relative dielectric constants and electrical conductivities of conducting cases (iron), transmitters, and radome are adopted to be \( (\varepsilon_r = 1.0, \sigma = 1.0 \times 10^7 \text{ S/m}), (\varepsilon_r = 1.0, \sigma = 5.8 \times 10^7 \text{ S/m}), \) and \( (\varepsilon_r = 2.5, \sigma = 7.01 \times 10^{-4} \text{ S/m}) \), respectively. As the electric fields in the radome are calculated by the FDTD method, the scattered electric fields radiated from the walls of the small reinforced concrete house can be obtained by using the computation procedures described in Section III and IV. In the calculation of the scattered electric fields, the relative dielectric constants and conductivities of the reinforced concrete walls, glass window, and metallic door are adopted to be \( (\varepsilon_r = 2.96, \sigma = 2.095 \times 10^3 \text{ S/m}), (\varepsilon_r = 5.5, \sigma = 1.0 \times 10^{12} \text{ S/m}), \) and \( (\varepsilon_r = 1.0, \sigma = 1.0 \times 10^7 \text{ S/m}) \) at frequencies 1795 MHz, respectively. The small reinforced concrete house is located at a distance of 19 meters from a cellular phone base station. The seven-story building has a height of 28.21 meters above the ground plane. Measurements of the field strengths in the small reinforced concrete house were obtained by using a Narda Model NBM-550 digital electromagnetic field survey meter. Figs. 1 and 2 show that the simulated and measured electric field strengths on a test plane with a height of 1 meter above the bottom floor in the small reinforced concrete house are in the range of 0.1~0.57 and 0.15~0.64 V/m, respectively.

### VI. CONCLUSIONS

The FDTD method implemented with the near zone to far zone transformation technique is used to calculate electric fields in a small reinforced concrete house constructed on the rooftop of a seven-story building. Simulation results of electric fields in the small reinforced concrete house are presented and
compared with experimental data. From electric field distributions on a test plane with a height of 1 meter above the bottom floor of the small reinforced concrete house, it is shown that there is a good agreement between simulated and measured data. The maximum electric fields obtained by calculations and measurements are 0.57 and 0.64 V/m, respectively. From simulated and measured data, it is clear that the maximum power density level of 0.54 mW/m² in the small reinforced concrete house is twenty two thousands of time less than the exposure level of 11.97 W/m² recommended by the ANSI/IEEE for an uncontrolled environment at 1795 MHz.

REFERENCES

1. IEEE, Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz, IEEE Standard C95.1, 2005.

Fig. 1  Simulated electric fields distributed on a test plane with a height of 1 meter above the bottom floor in the reinforced concrete house.

Fig. 2  Measured electric fields distributed on a test plane with a height of 1 meter above the bottom floor in the reinforced concrete house.