# FINITE-DIFFERENCE TIME-DOMAIN ANALYSIS OF A DUAL-RESONANCE AND SHIELDED CELLULAR ANTENNA

Bahadir S. Yildirim, El-Badawy El-Sharawy, Senior Member IEEE

Department of Electrical Engineering
Arizona State University, Tempe 852 87-7206

## Abstract

This paper presents a dual-resonance shielded antenna suitable for cellular phone applications. The antenna is shielded with a metallic wall to reduce possible health hazards towards user. Unlike other cellular antennas, new antenna's operating bandwidth spans between the first two resonances of the antenna and an almost 50 ohms flat input resistance can be obtained within a bandwidth of 824-896 MHz, using proper antenna dimensions. A proto-type of the dual resonance shielded antenna has been built and input impedance, near and far field measurements have been performed. Near field measurements showed that excessive electromagnetic radiation towards user is blocked by 90% without significantly sacrificing the omnidirectional characteristics required for cellular phone devices. Input impedance measurements are compared with the numerical results and a good agreement has been achieved. The new antenna uses all copper wires and shield which makes it easy and inexpensive to build.

## 1 Introduction

This research work initiated from the development of a cellular phone antenna which aimed to reduce excessive electromagnetic (EM) radiation towards user. It has been showed by Jensen [1] that almost half of the radiated energy is absorbed by user's head and hand. The amount of absorbed energy can be hazardous at high power output levels. Besides, antenna characteristics such as radiation pattern, gain and input impedance are greatly influenced by the presence of humans [2]. Recent progress in cellular technology and widespread availability of cellular phones generated a hot spot in antenna research to develop a better antenna for cellular systems. Ideally, such an antenna should have no radiation towards user and antenna characteristics should not be altered by the presence of user.

As an initial step of solving the ideal cellular antenna problem, a magnetically shielded cellular phone antenna was proposed in [3]. In this study, an ordinary monopole antenna mounted on a finite ground plane and a metallic shield coated by an isotropic magnetic material were located very close to each other. It has been showed that, such configuration reduces EM radiation towards user considerably. However, magnetic materials for cellular phone applications are heavy and expensive. Consequently, even though the magnetically shielded antenna performed well, need for a cheap and easy to manufacture antenna arises. New design does not require any coating material other than copper; making the new antenna inexpensive and easy to manufacture.

Finite-Difference Time-Domain (FDTD) method has been chosen to investigate input impedance of the antenna. FDTD method was introduced for EM field analysis problems by K. S. Yee in 1966 with the application of Yee's algorithm [4]. Mathematical details of solving Maxwell's curl equations using finite differences and stability considerations can be found in [5] in detail.

## 2 Theory of Dual Resonance and Modeling with FDTD

Fig. 1 shows the antenna. Due to the open and shorted configuration of the wires, multiple resonances occur. First two resonances and the frequency bandwidth between them can be adjusted such that an almost 50 ohms flat input resistance between 824-896 MHz can be obtained, while input reactance of the antenna is minimized. Obviously, dual-resonance shielded antenna inherently matches to 50 ohms transmission lines. The wire looking down and open at end mutually couples to the wire looking up and shorted at end to the shield. The mutual coupling between

0-7803-4603-6/97/$5.00 (c) IEEE

two wires generates a weak third resonance between the first two resonances, which can be used to lower the input reactance within the bandwidth.

In all FDTD calculations, PML absorbing boundaries are used. PML works on the basis of a lossy non-physical media that surrounds the FDTD computational domain. The wave propagating in normal direction to PML media will be attenuated so rapidly that only exponential updating coefficients can be used inside the PML medium. While the wave is traveling thru the PML region, impedance of the medium is set to vacuum impedance of 377 Ω and therefore reflections due to impedance mismatch are avoided. A PML reflection coefficient of $R(0) = 10^{-5}$ is used in all numerical calculations.

# 3 Experimental Verification

A proto-type of the dual-resonance shielded cellular antenna has been built and tested at Arizona State University's Anechoic Chamber in terms of input impedance, near and far fields. Fig. 3 shows the antenna and the cellular phone. Cellular box is covered by a 2.3 mm thick dielectric layer ($\epsilon_r = 2.5$) except the top surface. Cellular box dimensions (mm) are $64.8 \times 34.8 \times 102.4$ in x, y, and z directions, respectively. Antenna is located centrally on the cellular box. For fine details of the antenna and shield configuration Fig. 2 should be referred. Metallic shield is approximated to a curve-like shape using staircased cells and wires have square cross sections rather than circular. The dimensions of the proto-type antenna are given in the following table and can also be referred to Fig. 1.

| Dimensions of the cellular antenna (mm) | |
|---|---|
| H | 127.0 |
| L1 | 80.0 |
| L2 | 77.5 |
| L3 | 25.4 |
| L4 | 2.54 |
| D1 | 5.08 |
| D2 | 2.78 |

FDTD analysis is carried out using a non-uniform grid architecture in x-y plane as shown in Fig. 4. The computational domain in x-y plane is divided into two regions, a high resolution cell region formed by uniform high resolution cells and an expanding grid region to handle large objects compared with antenna dimensions. Meanwhile, cell size in z direction is kept uniform. It is clear that without the application of non-uniform mesh, handling large objects like the cellular phone box would cost a huge memory requirement and an extremely long computation time. Cell size in high resolution x-y plane is 0.565 mm and $\Delta x = \Delta y$. Antenna is located in this region. Away from the antenna, cell size expands with an expansion coefficient $p$ as given

$$\Delta_m = \Delta_{m-1}\,(m-1)^p$$

where m is the spatial index variable either i or j, and $\Delta$ is the cell size in either x or y direction.

The shield has a radius of 5.08 mm and the wire diameter is 2.33 mm. The thick wire is subject to skin depth phenomenon and need to be modeled precisely. For accurate modeling, a cell size of 0.565 mm is chosen in fine-mesh area and the wire is modeled by 16 cells in 4×4 matrix resolution. The antenna is excited by a Rayleigh pulse using the $E_z$ field components at the bottom of the wire. This type of feed model is known as delta-gap source. Time domain input current of the antenna is found using circulating magnetic field components around input terminal. Then, taking the Fast Fourier Transforms of input voltage and current, and dividing voltage by current at each frequency point yields the input impedance. Fig. 5 and Fig. 6 shows the comparison between input impedance measurements and numerical results obtained from FDTD calculations and good agreement has been achieved.

In the far field measurements, a 1.5 dB more gain than the conventional monopole antenna is observed in H-plane in the absence of user as shown in Fig. 7. In the presence of user, far field gain of the monopole antenna dropped by 2.6 dB down while the shielded antenna's gain dropped about 1 dB which is not significant. This implies that in the presence of user radiation pattern is altered significantly. Human head is modeled simply by a dielectric block of $\epsilon_r \approx 50$ to account for the presence of user as shown in Fig. 8. Near field measurement show that radiation towards user is reduced by over 90% as shown in Fig. 9 without significantly sacrificing the omnidirectional characteristics required for cellular phone devices.

# 4 Conclusions

A dual-resonance shielded cellular phone antenna has been presented. Unlike the conventional cellular antennas, new antenna blocks excessive EM radiation

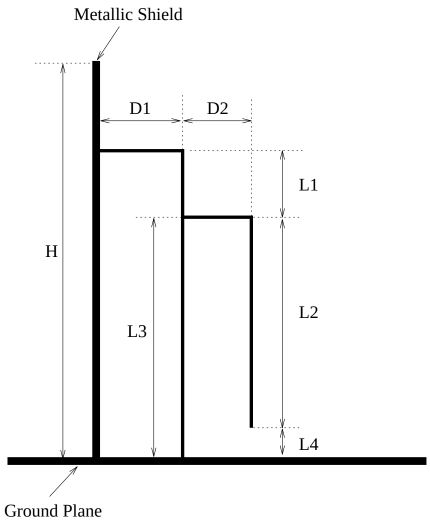


Figure 1: Dual-resonance shielded antenna on a finite ground plane.

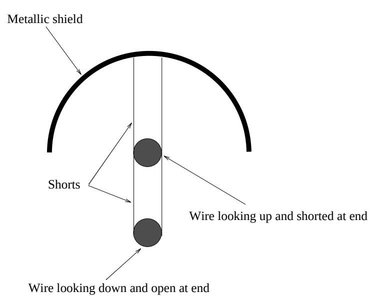


Figure 2: Cross sectional areas of the actual shielded antenna (left) and staircase approximation used in FDTD simulations (right).

towards user over 90%. Matching to 50 ohms transmission lines is not a problem because the new antenna is inherently matched to 50 transmission lines. This simplifies the design and eliminates additional matching circuitry. In the absence of user, the new antenna has 1.5 dB more gain than the conventional monopole antenna in far zone. In the existence of user, far zone gain does not drop significantly and the radiation pattern seems to be unaltered. Input impedance measurements show that shielded antenna is wideband and an almost 50 ohms input resistance can be obtained in the range of 814-908 MHz. Good agreement has been achieved between FDTD calculations and measurements of input impedance.

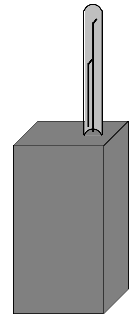

Figure 3: Dual-resonance shielded antenna mounted on a cellular phone.

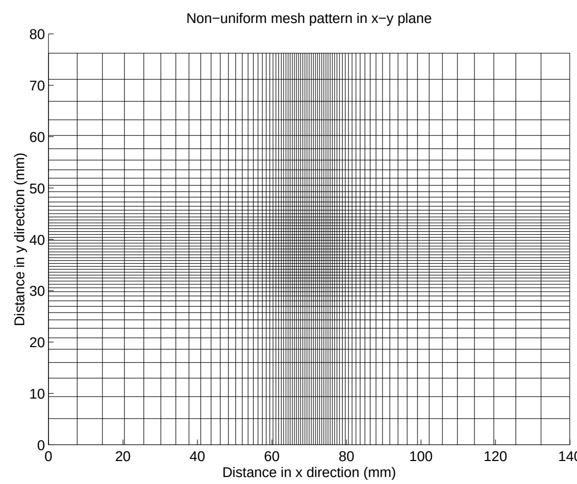


Figure 4: Non-uniform mesh pattern in x-y plane.

# References


[1] M. A. Jensen and Y. Rahmat-Samii, "EM interaction of handset antennas and a human in personal communications," *Proceedings of the IEEE*, vol. 83, pp. 7–17, Jan. 1995.

[2] J. Toftgard, S. N. Hornsleth, and J. B. Andersen, "Effects on a portable antennas of the presence of a person," *IEEE Trans. Antennas Propagat.*, vol. 41, pp. 739–746, June 1993.

[3] B. Yildirim and E. El-Sharawy, "Analysis of a magnetically-shielded cellular phone antenna using Finite-Difference Time-Domain method," *IEEE Int. Microwave Symposium Digest*, vol. 2, pp. 979–982, June 1996.

[4] K. S. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media," *IEEE Trans. Antennas Propagat.*, vol. 17, pp. 585–589, May 1966.

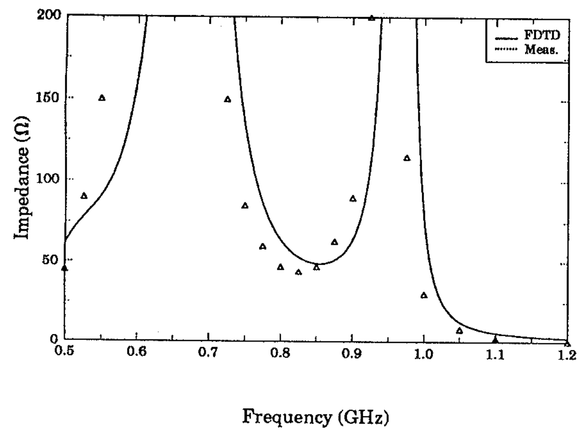


Figure 5: Input resistance of the dual-resonance shielded cellular phone antenna.

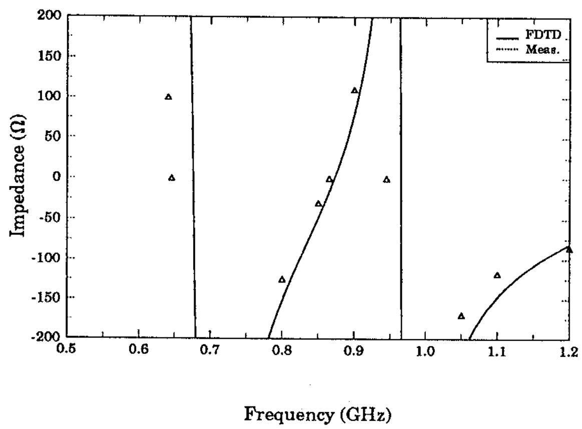


Figure 6: Input reactance of the dual-resonance shielded cellular phone antenna.

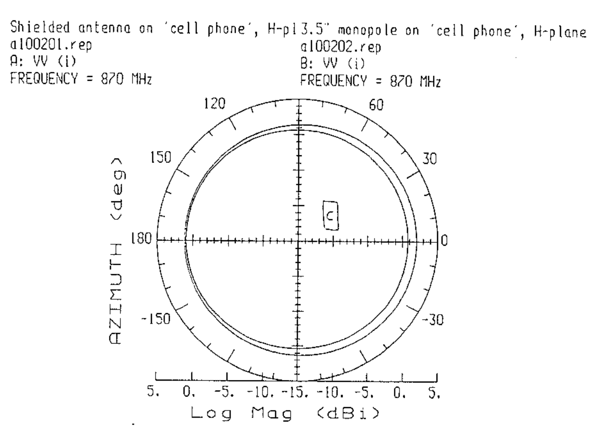


Figure 7: Far field patterns of the shielded antenna and the monopole in the absence of user.

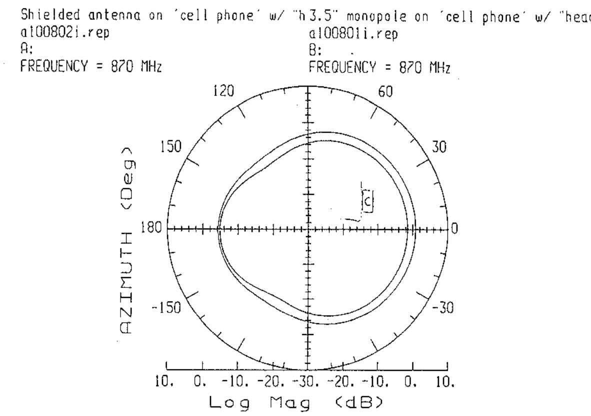


Figure 8: Far field patterns of the shielded antenna and the monopole in the presence of user.

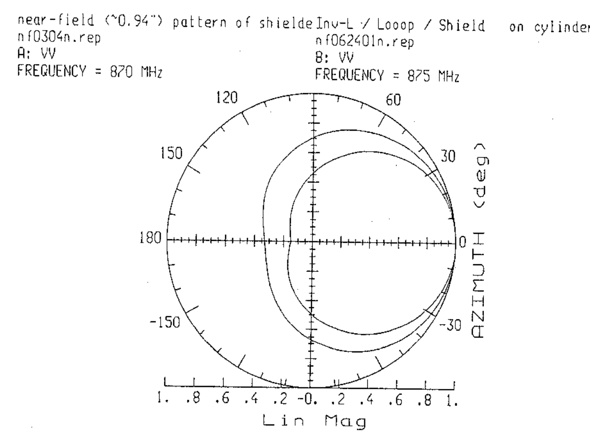


Figure 9: Near fields in the absence of user.