FDTD simulation in wireless sensor antenna application

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In this paper an own developed FDTD simulation environment is employed for antenna analysis in a wireless sensor network for traffic monitoring. The analyzed antenna is part of a WSN node that is placed in the street. The node is protected by being placed in a plastic tube with a lid. Since this in-road implementation differs from the conventional use, properties of the applied commercially available antenna don't match the ones specified by the manufacturer. For this reason it is necessary to investigate how much this specific installation influences radiation properties of the applied antenna configuration and perform parameter analysis. It is shown that the influence of surrounding material and the change of weather conditions (which are represented through the change of relative electric permittivity and specific electric conductivity) doesn't affect significantly antenna operation in the applied design. Mounting of the antenna on PCB favorably affects matching properties of the antenna.

Introduction

A rapid advancement in computer technology today has made the computational electromagnetics (CEM) in general a powerful tool for antenna analysis and design, radar signature prediction, EMC/EMI analysis, design of electrical and medical devices and the prediction of radio propagation. One of the CEM methods that receive increasing attention in the literature is certainly the finite difference time domain (FDTD) method [1], [2]. Since this is a time-domain method, it is possible to obtain the system response in large frequency range with only one simulation run. It is particularly suitable for preliminary tests and parameter analysis in antenna design applications. However, one should be aware of its limitations. Namely, in the case of highly resonant structures the method suffers from lower accuracy and has long simulation times and a slow decay of the time-dependent electromagnetic (EM) fields [3]. Since wireless sensor application requires narrow band antenna, the modeling in FDTD was an additional challenge. Thus, it requires careful selection of parameters and cautious interpretation of the obtained results.

In this paper an own developed FDTD simulation environment is employed to analyze antenna and propagation properties of a specific wireless sensor network (WSN) for traffic monitoring that is developed at the Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH (IMMS), Ilmenau, Germany [4]. In this application scenario, detectors utilizing magnetic field sensors are placed in the road surface to detect passing vehicles. The detectors function as WSN nodes communicating with a local gateway pole-mounted at a height of 4 metres. Besides line-of-sight obstructions due to traffic and the influence of seasons and weather, the typically low angle resulting from the communication between nodes and the gateway at intended distances of up to 100 metres poses issues which initiated the research discussed in this article. Additional details on the application context have been given in [5].

The commercially available antenna configuration, previously proven to be the most suitable solution for the particular application, was tested in the FDTD simulator and a parameter analysis is performed.

FDTD formulation

As a simulation tool, an own developed FDTD simulation environment is used. The exact update equations for H and E field components can be presented as (for the brevity only equations for H_x and E_x field components are presented)

$$H_{x(i,j+1/2,k+1/2)}^{n+1/2} = a_{x,H} H_{x(i,j+1/2,k+1/2)}^{n-1/2} + \tag{1}$$
$$+ b_{x,H} \frac{E_{y(i,j+1/2,k+1)}^{n} - E_{y(i,j+1/2,k)}^{n}}{\Delta z} -$$
$$- b_{x,H} \frac{E_{z(i,j+1,k+1/2)}^{n} - E_{z(i,j,k+1/2)}^{n}}{\Delta y}$$

$$E_{x(i+1/2,j,k)}^{n+1} = a_{x,E} E_{x(i+1/2,j,k)}^{n} + \tag{2}$$
$$+ b_{x,E} \frac{H_{z(i+1/2,j+1/2,k)}^{n+1/2} - H_{z(i+1/2,j-1/2,k)}^{n+1/2}}{\Delta y} -$$
$$- b_{x,E} \frac{H_{y(i+1/2,j,k+1/2)}^{n+1/2} - H_{y(i+1/2,j,k-1/2)}^{n+1/2}}{\Delta z}$$

where $a_{v,E}$, $b_{v,E}$, $a_{v,H}$ and $b_{v,H}$ ($v = x, y, z$) - update coefficients. Implementation details can be found in [6].

System and antenna model

The analyzed antenna is a part of a WSN node that also includes an industry-standard microcontroller, a programmable flash memory and 2.4 GHz transceiver. Based on the signal quality analysis (in terms of losses, LQI, RSSI) the commercial antenna that has been chosen as the most suitable for this application is a patch antenna. The electronic part of the WSN node is inserted into a plastic tube and buried in the street. Since this antenna installation differs from the conventional one (open air), there is a need to investigate in which way and to which extent it influences the radiation characteristics and the wave propagation. In the scenario considered in this paper the inner surface of the plastic tube is metalized. The simulation model of the antenna mounted on the PCB plate is presented in Fig. 1. The simulation model of the entire antenna installation is presented in Fig. 2.

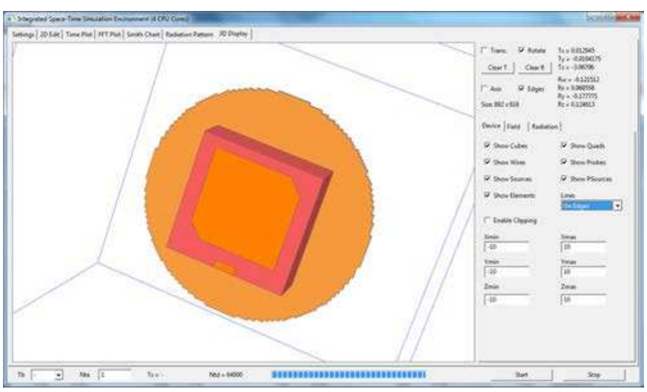

Fig.1. Model of antenna on PCB plate.

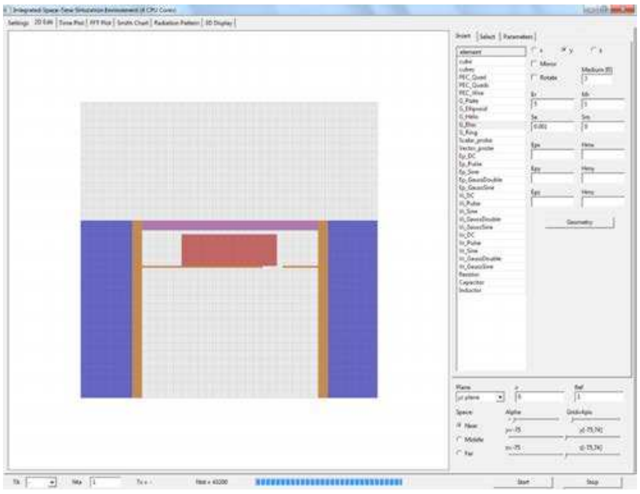

Fig.2. Model of the antenna installation in the plastic tube.

Simulation results

The results presented here are part of the joint work between the Faculty of Electronic Engineering, University of Nis, Serbia and the IMMS. Thus, this paper is a sequel to the work “Wireless sensor solution for traffic monitoring” reported at PES 2015 conference as well.

Since the antenna is electrically connected to the printed circuit board (PCB), its shape and dimensions affect the resonant frequency and the matching properties of the antenna. In Fig. 3 $|z_{11}|$ and $|s_{11}|$ parameters versus frequency can be observed for the antenna operating in the open air and in Fig. 4 for the case when it is mounted on PCB. It can be noticed that the reduction of PCB surface (in borderline case no PCB) causes significant shift of resonant frequency. Namely, this frequency shift ranges to approximately 100 MHz, which is more than the wireless signal bandwidth. Also, the magnitude of return losses is changed. This implies that an unconventional implementation may require some additional modifications, such as impedance compensation.

Normalized radiation patterns for the single antenna and the antenna on PCB are presented in Fig. 5 and Fig. 6, respectively. It can be noticed that the mounting of the antenna on PCB leads to the reduction of the radiation in undesirable direction (in azimuth plot it is direction of 90° and in elevation plot it is direction of 180°).

Since the WSN node together with antenna is placed in the ground, the radiation and matching properties of the antenna in such an installation differs from the one in open air. The WSN node is placed in the plastic tube with the plastic lid and it is buried in the street. In installation that is considered here, the side walls of the plastic tube are metalized on the inner side.

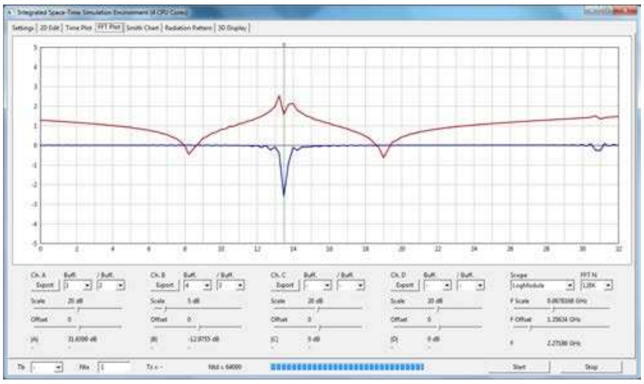

Fig.3. z and s parameters of the single antenna in free space (red line – $|z_{11}|$, blue line - $|s_{11}|$).

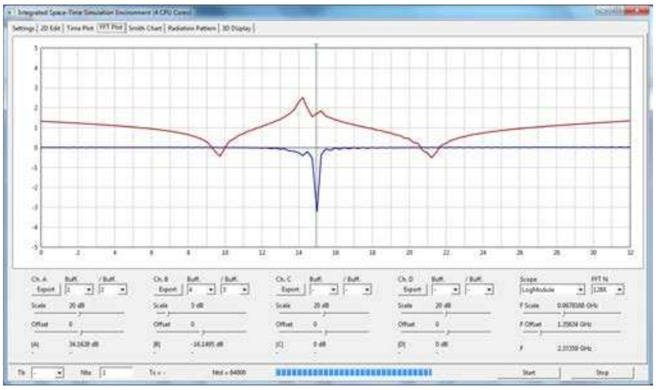

Fig.4. z and s parameters of the antenna on PCB in free space (red line – $|z_{11}|$, blue line - $|s_{11}|$).

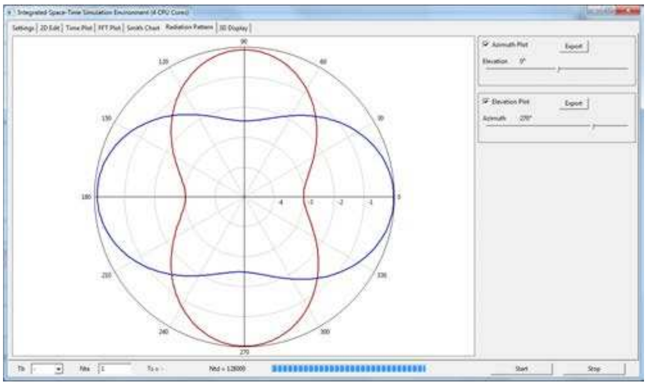

Fig.5. Normalized radiation pattern of the single antenna in free space (blue line – elevation plot, red line – azimuth plot).

In Fig. 7 $|z_{11}|$ and $|s_{11}|$ parameters are presented for this specific antenna installation. Electric properties of the surrounding asphalt are given through its relative electric permittivity and specific electric conductivity: ε_r=5, σ=0.001S/m. Electric properties of the plastic tube and the lid are set to be: ε_r=4, σ=0S/m. The thickness of the lid is 1.25mm. Antenna is placed 0.5mm below the lid. It can be noticed that operation of the antenna in this unconventional environment causes a shift of the resonant frequency and affects the matching properties of the antenna. Namely, this frequency shift ranges to approximately 48MHz, which is comparable with the wireless signal bandwidth. On the other hand, selectivity of the antenna is reduced, which allows signal in wider frequency range to be transmitted.

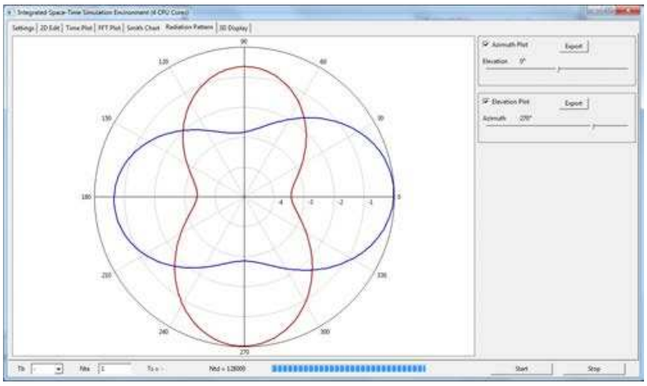

Fig.6. Normalized radiation pattern of the antenna on PCB in free space (blue line – elevation plot, red line – azimuth plot).

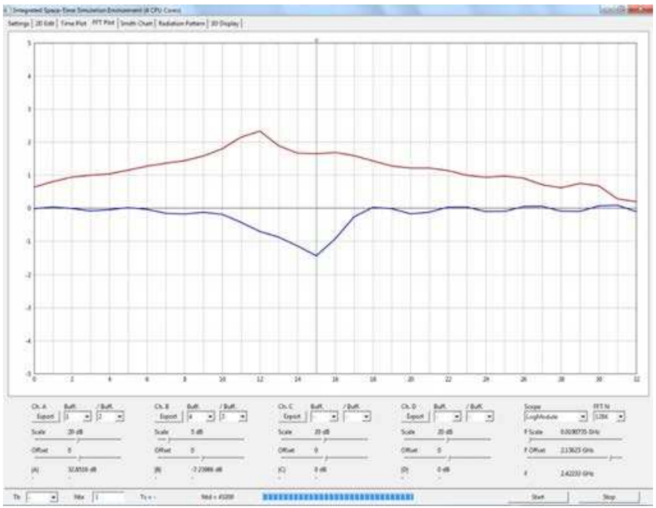

Fig.7. z and s parameters of the antenna installation in the ground (red line – $|z_{11}|$, blue line - $|s_{11}|$) for ε_r=5, σ=0.001S/m.

Influence of different types of the surrounding material (soil, asphalt etc.) and the change of weather conditions (humidity, temperature, etc.) is modeled through the change of parameters ε_r and σ. In Fig.8 $|z_{11}|$ and $|s_{11}|$ parameters of the in-road antenna installation are presented for ε_r=5, σ=0.1S/m. Comparing the results in Fig.8 with the ones in Fig. 7, one can observe the influence of specific electric conductivity.

In Fig.9 $|z_{11}|$ and $|s_{11}|$ parameters of the in-road antenna installation are presented for ε_r=25, σ=0.1S/m. Comparing the results in Fig. 9 with the ones in Fig. 8, one can observe the influence of relative electric permittivity. It seems that change of ε_r and σ parameters doesn't affect the position of the resonant frequency in this design, but slightly changes its matching properties.

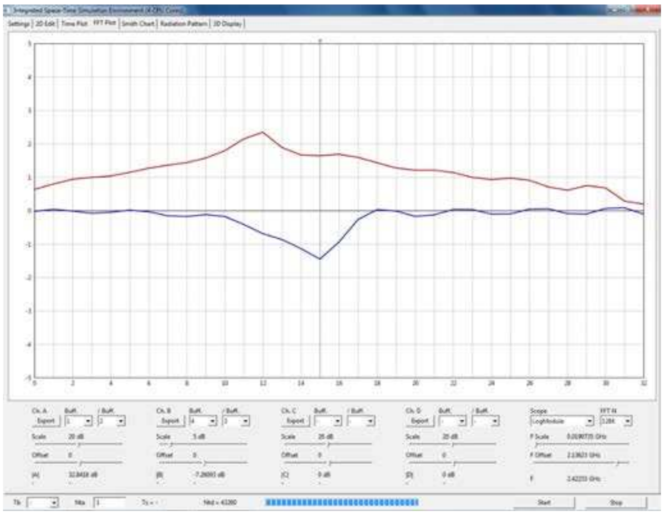

Fig.8. z and s parameters of the antenna installation in the ground (red line – $|z_{11}|$, blue line - $|s_{11}|$) for ε_r=5, σ=0.1S/m.

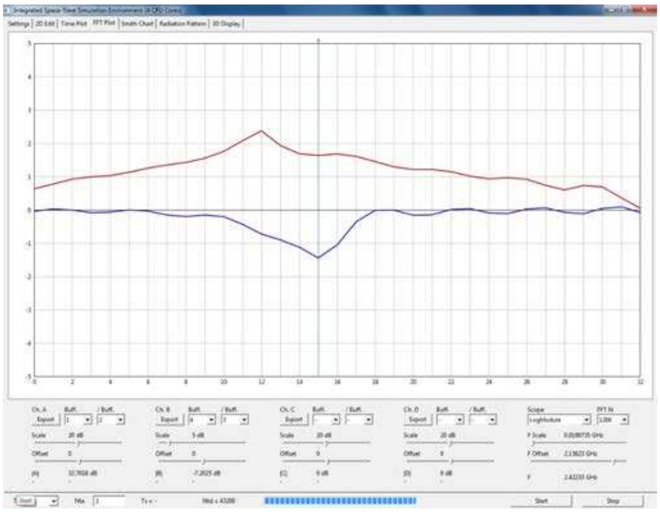

Fig.9. z and s parameters of the antenna installation in the ground (red line – $|z_{11}|$, blue line - $|s_{11}|$) for ε_r=25, σ=0.1S/m.

Conclusion

In this paper an own developed FDTD simulation environment is used to characterize the behavior of the chosen antenna configuration under very specific installation conditions of wireless sensor nodes for traffic monitoring.

It is shown that the mounting of the antenna on PCB causes significant shift in resonant frequency and improves matching properties of the antenna.

In comparison to the operation in the open air, in-road installation of the antenna affects the resonant frequency and the matching properties of the antenna. On the other hand, it reduces the selectivity of the antenna.

Influence of the surrounding material and the change of weather conditions is modeled through the change of parameters ε_r and σ. It is noticed that the analyzed design allows the resonant frequency to stay stable when relative electric permittivity and specific electric conductivity of the surrounding material change.

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