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FDTD Model of Wire Antenna with Incident Wave for EM Field Measurement

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Abstract

Electromagnetic Interference (EMI) is becoming a crucial issue in the era of modern electronic systems. For frequency domain EMI measurements, an antenna with wide-band performance in amplitude is desired but for transient field measurements, an antenna with wide-band performance both in amplitude and in phase is desired. The complex antenna factor (CAF) is an appropriate characteristic of such an antenna, which is the ratio of the incident electric field on the antenna surface to the received voltage at the 50 Ω load resistance. In this work, FDTD is applied to predict the performance of wire antenna when it is used as a sensor to measure the Electromagnetic field. The results presented here are compared with the published results.

1 Introduction

All electronic devices must conform to the standards of electromagnetic emission set by different bodies in different countries [1]. Compliance of the devices conforming to the standards(limits) of interference in this range is verified by measuring the radiated electric fields in an anechoic chamber or at an open test range after putting the measurement antenna at a specified distance from the device under test. Wire antennas are widely used as transmitting antenna and also as sensor for electromagnetic interference (EMI) measurements. The term "wire" refers to metallic, highly conducting wire or wire-like structures.

For frequency domain or transient field measurements, it is required to determine the field strength at the point of measurement using a sensor. To use the sensor for this purpose, calibration data is required relating the electric field at the aperture of the receiving antenna to the voltage across the 50 Ω matched detector. The most common performance descriptor of EMI sensors is the complex antenna factor (CAF). CAF is the ratio of the incident electric field on the surface of the sensor to the received voltage at the antenna terminal when terminated with a 50 Ω load [1]. The CAF, which adds phase values to the conventional antenna factor, is equivalent to the reciprocal of the transfer function [2]. The theoretical prediction of the antenna factor of EMI sensors is a very attractive alternative if one takes into consideration the enormous expenditure and time required for calibrating a sensor experimentally. Also, for experimental calibration, each and every sensor is to be calibrated individually, whereas for theoretical calibration all the sensors constituting a particular type can be calibrated at one go using the same approach, it is possible to predict the susceptibility of such antennas to electromagnetic radiation incident from any direction. FDTD method has been used to simulate a wide variety of electromagnetic phenomena because of its flexibility and versatility. Many variations and extensions of FDTD exist, and the literature on the FDTD technique is extensive. But to the best of author's knowledge no appreciable work is available in the open literature where FDTD is used to evaluate the performance of antenna in receiving mode works as an EMI sensor.

In this work Finite Difference Time Domain (FDTD) technique is used to evaluate the CAF of the EMI sensors. For the validation of the theory, FDTD computed Complex Antenna Factor of wire antennas were compared with the published results. First case a CAF of a monopole antenna is evaluated using FDTD technique. FDTD computed magnitude and phase of far-field CAF of a monopole antenna are compared with the measured and low-frequency approximation result of [3]. Secondly, the magnitude of CAF of a ANRITSU MP651A dipole antenna is evaluated using this technique and compared with the data available in the instruction manual [4]. Thirdly, the magnitude of CAF of a disk-loaded thick cylindrical dipole antenna is evaluated using FDTD technique and compared with the measurement [5], MININEC(MoM based commercial software) simulation [5] and MOM based numerical [6] results.

2 FDTD Formulation of the Problem

For FDTD computations a uniform space lattice cubic *Yee* cells having $\triangle x = \triangle y = \triangle z (= \triangle)$ is considered. $10\triangle - thick$ unsplit Perfectly Matched Layer (PML) [7] is used as Absorbing Boundary Conditions (ABC) on all six sides of the FDTD lattice. This PML is spaced $3\triangle$ cells from the closest surface of the scatterer. Gaussian pulse [8, 7] is taken as the excitation source

$$E^{t}_{z_{i,j,k}} = Ae^{-0.5\left(\frac{t-t_0}{t_\omega}\right)^2} \tag{1}$$

where, t_ω is the standard deviation and relates the line width at half-height by the relationship

$$t_{1/2} = \sqrt{8\ln(2)}\, t_\omega = 2.35482\, t_\omega \tag{2}$$

3 Calculation

For a receiving antenna, the open-circuit voltage due to the incident field E_z at the gap between the monopole and the conducting ground plane is [9]

$$V_{oc}|^n = -\triangle z E_z|^n_{i_a,j_a,k_a+1/2} \tag{3}$$

and,

$$V_{oc}(\omega) = F\{V_{oc}(t)\} \tag{4}$$

where, F is define as the Fourier transform. The voltage into a section of transmission line matched ($Z_0 = 50\Omega$) at the far end is [9]

$$V_{50}(\omega) = \left[\frac{50}{Z(\omega)+50}\right] V_{oc}(\omega) \tag{5}$$

Where $Z(\omega)$ is the input impedance of the antenna.

3.1 Complex Antenna Factor (CAF)

The CAF is the parameter that is used to convert the voltage or power reading of the receiver to the field strength incident on the antenna. In terms of an equation, the CAF is defined as [10]

$$CAF = 20 \cdot \log\left(\frac{E_i(\omega)}{V_{50}(\omega)}\right) \quad \left[dB\left(m^{-1}\right)\right] \tag{6}$$

where, $E_i(\omega)$ is the electric field incident on the antenna, and $V_{50}(\omega)$, is the voltage induced across a 50 Ω load at the feed point of the antenna.

3.2 Calculation of CAF

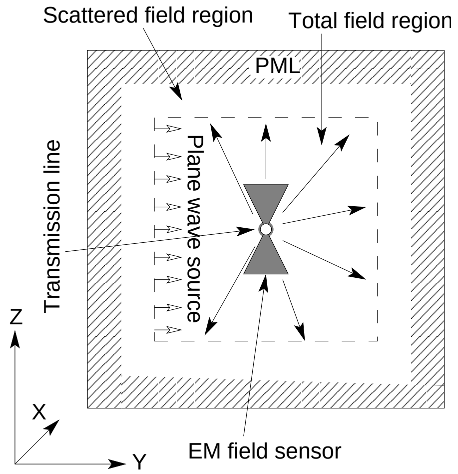


Figure 1. A antenna under plane-wave within FDTD grid.

For the calculation of the far-field CAF, the antenna (along z-axis) is in lossless free space and illuminated by a z-directed linearly polarized uniform plane wave as shown in the Fig.1. In order to simulate a uniform plane wave in a FDTD programme, the problem space was divided into the total field and scattered field regions. Details of this method for three dimensions given in [7], is used in this work. As perfectly plane wave and lossless free space are considered, so there is no need to calculate the incident electric field at the antenna feed position when there is no antenna as like for computing near-field CAF. Time domain electric field at the feed position in absence of the antenna is

$$E^t_{z_{i,j,k}} = Ae^{-0.5\left(\frac{t-t_0+t'}{t\omega}\right)^2} \tag{7}$$

where, t' is the time shift due to the difference in the position of the feed of the antenna and the position where Gaussian pulse applied into the FDTD lattice. During the progress of the FDTD calculations the incident field $E_i(t)$ and time domain open ended voltage $V_{oc}(t)$ are saved for each time step. The FDTD calculations are continued until all transients are dissipated, so that the Fourier transform yields to the steady-state frequency domain response of the antenna. Fourier transform of this time domain open ended voltage $V_{oc}(t)$ gives frequency domain open ended voltage $V_{oc}(\omega)$ at the feed point of the antenna system. Voltage developed across 50 Ω load is $V_{50}(\omega)$ which is obtained from the Eqn. (5). Finally, Complex Antenna Factor of the antenna is evaluated using Eqn. (6). This method takes into account all mutual coupling effects.

For the numerical calculation, a programme based on FDTD technique developed in C using compiler gcc-4.0 was run on a Pentium 2.3 GHz processor based on personal computer supported by LINUX operating system.

3.3 CAF of Monopole Antenna

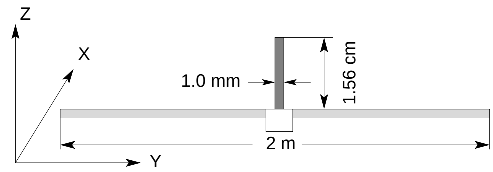
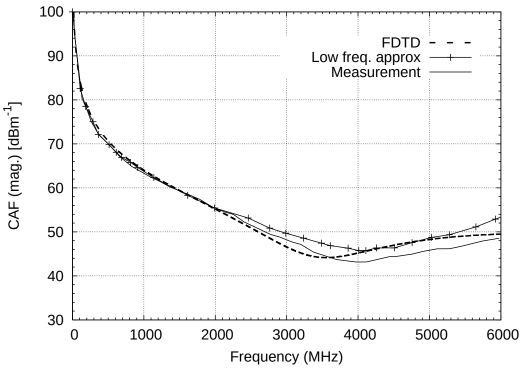


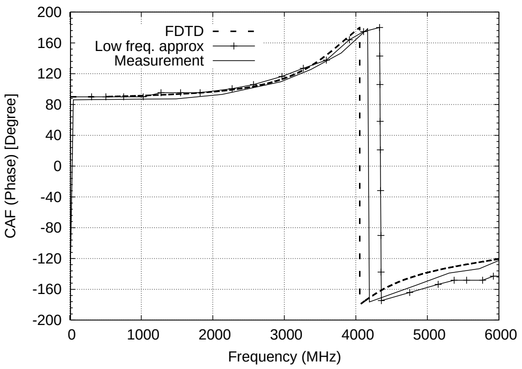
Figure 2. Monopole antenna on PEC ground plane

The geometry of the monopole antenna system [3] is shown in Fig. 2. The length of monopole antennas is 15.6 mm and it is placed in a 4.0 square-meters perfectly conducting square ground plane. The monopole antenna is connected to a 56-ohm chip-resistor in parallel in order to suppress reflection in the low frequency range [3]. And so, 50 Ω load resistance of Eqn. (5) is replaced by 26.42 Ω load resistance.

The FDTD model uses a uniform space lattice cubic *Yee* cells having $\triangle x = \triangle y = \triangle z =$0.25 cm and $\triangle t \simeq$4.17 pico sec. Gaussian impulse of maximum unit amplitude given by the Eqn. (1) with $t_0 = 83.33$ pico sec and $t_\omega = 12.5$ pico sec is taken as the source.



(a)



(b)

Figure 3. CAF of monopole antenna (a) amplitude (b) Phase.

Magnitude of the FDTD computed far-field CAF is compared with the measured and low frequency approximation result [3] shown in the Fig. 3(a). Considering the differences between how the feed regions are modeled the agreement is quite good. R.m.s. deviation between the measurement [3] and the FDTD computed CAF 1.68 dB whereas r.m.s deviation using low frequency approximation of monopole antenna calculating from the Fig. 10. of [3] is 2.64 dB over the frequency rang from 2 GHz to 6 GHz. Below 2.0 GHz the error is not significant. The phase of the far-field CAF is compared with the measured and low frequency approximation of monopole antenna result [3] shown in the Fig. 3(b). FDTD predicted phase of the far-field CAF is much closer to the experimental result [3] than the phase of the far-field CAF derived from the low frequency approximation of the monopole antenna [3].

3.4 CAF of Anritsu MP651A Dipole Antenna

Schematic diagram of a Anritsu MP 651A dipole antenna [4] is shown in the Fig. 4. The length of the antenna is adjustable according to the frequency of operations. The diameter of the arms of the antenna is different for different length. So for a particular frequency mean diameter is taken. As length and mean diameter of the dipole are changing with frequency, so separate FDTD simulation is done for each frequency. In this work CAF of the Anritsu

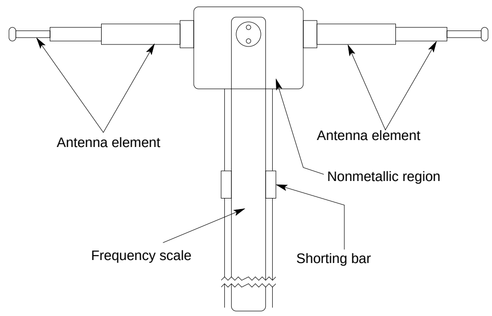


Figure 4. An Anritsu MP651A dipole antenna.

MP 651A dipole antenna is evaluated in different 15 different of discrete frequencies.

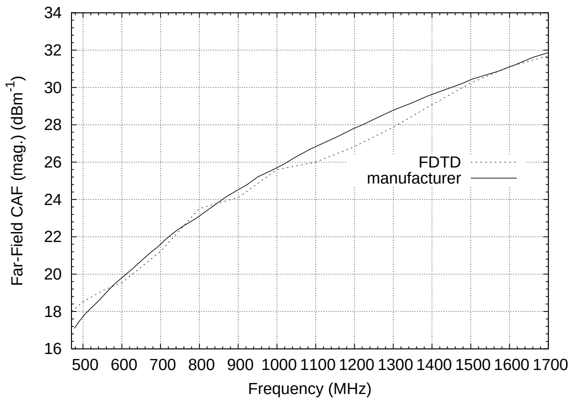


Figure 5. CAF of an Anritsu MP651A dipole antenna.

The magnitude of far-field free space CAF of an Anritsu dipole MP 651A has been evaluated using FDTD and compared with the data available from the chart supplied by the manufacturer [4] shown in Fig. 5. The agreement is quite good considering the different approximations and assumptions made in the FDTD approach relative to the manual data, especially in modeling the feed region and nonmetallic region as shown in the Fig. 4. R.m.s. deviation between the manufacturer's [4] and the FDTD computed magnitude of CAF is 0.6 dB over the frequency rang from 470 MHz to 1700 MHz, which is quite good enough.

3.5 CAF of Disk-Loaded Thick Cylindrical Dipole Antenna

Dimensions of different parts of a broadband dipole i.e., dipole loaded with circular disc [5] is shown in Fig. 6. The FDTD model uses a uniform space lattice cubic *Yee* cells having $\triangle x = \triangle y = \triangle z$ =4.488 cm and $\triangle t$ =0.0748 ns. This fine spatial resolution permits direct modeling of the 2.244 cm radius wire, assumed to be PECs. The dipole is illuminated by a plane wave of Gaussian impulse of max-

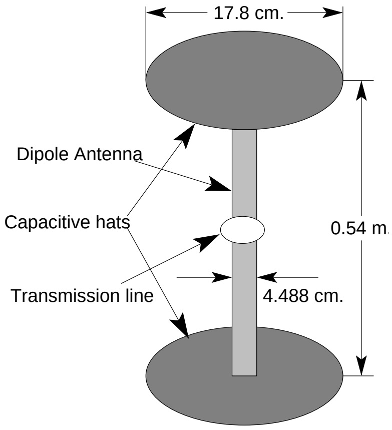


Figure 6. Disk-loaded thick cylindrical dipole antenna.

imum amplitude $A = 1.0\ V/m$ given by the Eqn. (1) with $t_0 = 1.496$ ns and $t_\omega = 0.44880$ ns.

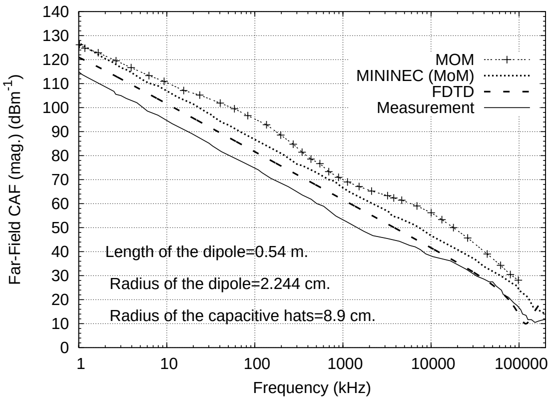


Figure 7. Magnitude of CAF of a broadband dipole.

The magnitude of CAF of broadband dipole obtained using FDTD is compared with experimental [5], MININEC (MoM based commercial software) simulation [5] and MoM based numerical, [6] results in Fig. 7. Considering the differences in how the feed region is modeled the agreement is quite good. FDTD predicted magnitude of CAF is much closer to the experiment result, than the other available in the literature [5], [6]. R.m.s. deviation between the measurement [5] and the FDTD computed magnitude of CAF is 6.31, whereas this deviations between the measurement [5] and MININEC simulation result, calculating from the Fig. 3. of [5] is 10.43 dB and MOM is 15.40 calculating from the Fig. 12. of [6] over the frequency rang from 1 KHz to 200 MHz.

4 Conclusions

To conclude it is said that FDTD predicts CAF very easily and accurately. For far-field CAF the programme needs to be run twice for a particular antenna structure, first for input impedance and second for open-circuit voltage. Being time-domain technique, FDTD directly calculates the impulse response of an electromagnetic system. Therefore, a single FDTD simulation can provide either ultra wide band temporal waveforms or the sinusoidal steady state response at any frequency within the excitation spectrum. In case of FDTD, specifying a new structure to be modelled is reduced to a problem of mesh generation rather than the potentially complex reformulation of an integral equation. For example, FDTD requires no calculation of structure-dependent Green functions. This technique can easily be extended to determine the antenna factor of any other types of antennas.

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