Incident Wave Models of Monopole Antenna on Perfectly Conducting Ground Plane

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ABSTRACT
A few widely used incident wave models for antenna analysis are compared on the basis of antenna factor (AF) computations. The finite-difference time-domain (FDTD) technique is applied to compute the complex AF of monopole antenna placed on conduction ground plane in the receiving mode. The computed AFs are compared with published measured results.

Keywords
antenna factor, FDTD, gain, monopole antenna, ground plane

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.

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 (AF), 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.

Finite difference time domain (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 [3]. 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 FDTD technique is used to evaluate the CAF of the EMI sensor. For the validation of the theory, CAF of a monopole antenna on a conducting ground plane is evaluated using FDTD technique and computed magnitude and phase of the CAF are compared with the measured and low-frequency approximation result of [4].

2. FDTD FORMULATION OF THE PROBLEM
For FDTD computations a uniform space lattice cubic Yee cells having Δx = Δy = Δz(=Δ) is considered. 10Δ−thick unsplit Perfectly Matched Layer (PML) [5], [6] is used as absorbing boundary conditions (ABC) on all six sides of the FDTD lattice. This PML is spaced 3Δ cells from the closest surface of the scatterer. Gaussian pulse [5] is taken as the excitation source.

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

$$V_{oc}|^n = -\Delta z E_z|^n_{i_a, j_a, k_a + 1/2}, \quad --- (1)$$

and let, V_{oc} (ω) is the Fourier transform of $V_{oc}|^n$. The voltage into a section of transmission line matched (Z_0 = 50 Ω) at the far end is [7]

$$V_{50}(\omega) = \left[\frac{50}{Z(\omega) + 50}\right] V_{oc}(\omega) \quad --- (2)$$

Where, Z (ω) 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 [8], [9]

$$CAF = 20 \log\left(\frac{E_i(\omega)}{V_{50}(\omega)}\right) \quad [dB(m^{-1})] \quad --- (3)$$

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

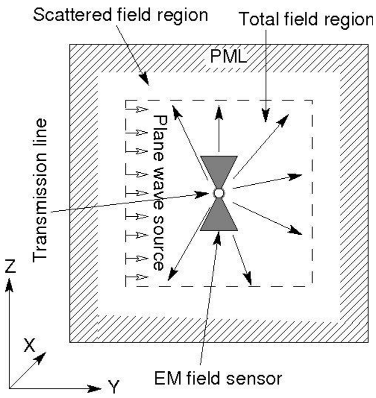

Fig. 1. Receiving antenna case. A antenna under plane-wave illumination within the FDTD grid [5].

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. Details of the method are given in [5].

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. (2). Finally, Complex Antenna Factor of the antenna is evaluated using Eqn. (3). This method takes into account all mutual coupling effects [10].

3.3 CAF of Monopole Antenna

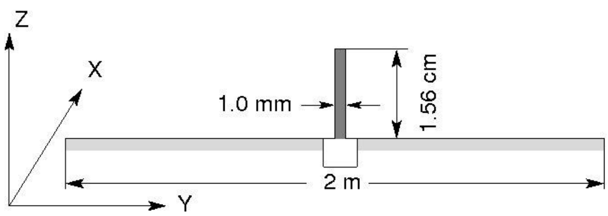

Fig. 2. Monopole antenna on perfectly conducting ground plane.

The geometry of the monopole antenna system of [4] 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 [4]. And so, 50 Ω load resistance of Eqn. (2) is replaced by 26.42 Ω load resistances.

The FDTD model uses a uniform space lattice cubic Yee cells having Δx =Δy=Δz =0.25 cm and Δt≈4.17 pico sec. Gaussian impulse of maximum unit amplitude with t_0 = 83.33 pico sec and t_ω= 12.5 pico sec is taken as the source [5].

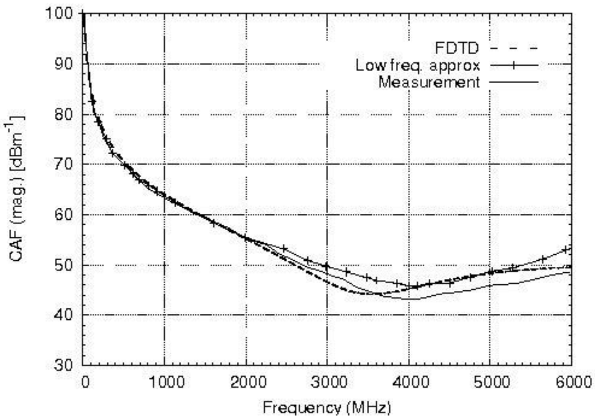

Fig. 3. FDTD computed amplitude of CAF of the monopole antenna is compared with measured and low frequency approximation results of [4].

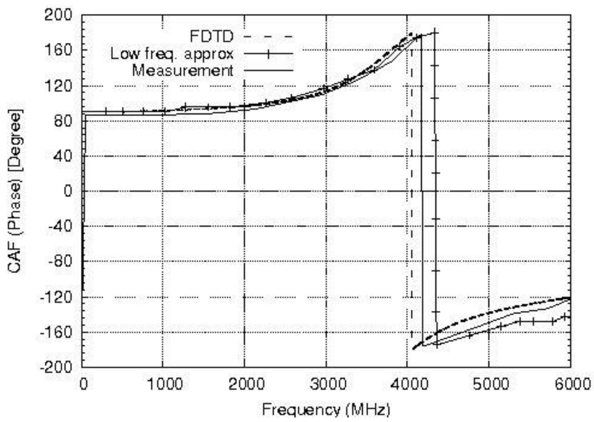

Fig. 4. FDTD computed phase of CAF of the monopole antenna is compared with measured and low frequency approximation results of [4].

Magnitude of the FDTD computed far-field CAF is compared with the measured and low frequency approximation result [4] shown in the Fig. 3. Considering the differences between how the feed regions are modeled the agreement is quite good. R.m.s. deviation between the measurement [4] 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 [4] is 2.64 dB over the frequency range 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 [4] shown in the Fig. 4. FDTD predicted phase of the far-field CAF is much closer to the experimental result [4] than the phase of the far-field CAF derived from the low frequency approximation of the monopole antenna [4].

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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