Pyramidal Horn Antenna Gain Calculations in Receiving Mode using FDTD Technique

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Abstract

A few widely used incident wave models for pyramidal horn antenna analysis are compared on the basis of gain computations. The finite-difference time-domain (FDTD) technique is applied to compute the gain of horn antennas in this receiving mode. The computed gains are compared with published measured results. The computed results agree well with the measurement for high-gain horn and also for lower gain horn.

1 Introduction

Calculations of antenna gain is interest to a wider group of the researchers. Many authors have proposed different methods to calculate the gain of pyramidal horn antennas. Most of these analyses integrate the fields across the aperture of the horn in transmitting mode. In [1], horn antenna in receiving mode has been analysed based on edge-wave diffraction theory. But in there analysis, calculated gain values of pyramidal horn antennas are very much dependent on the model used for the primary wave incident upon the aperture of the horn, especially for horns with large flare angles.

The FDTD technique which has found extensive use in electromagnetic [2], to the best of the author's knowledge has till now not been used explicitly in analysis of horn antenna in receiving mode. Also, the FDTD has the advantage that a single FDTD simulation can provide for both time domain and frequency domain analysis. Further, the FDTD has the advantage that the problem of modeling a new structure is reduced to a problem of mesh generation rather than the complexity of reformulating an integral equation.

In this work, we compute the gain of pyramidal horn antennas in receiving mode using FDTD technique. Firstly, a waveguide fed pyramidal horn is illuminated by a plane-wave within the FDTD grid. The primary and edge diffracted waves propagate through the horn waveguide structure. As a results, a voltage ($V_L(\omega)$) is developed across the receiver of load 50Ω. Next, the antenna factor (AF) which is the ratio between incident electric field at the antenna and ($V_L(\omega)$) is computed [3], [4]. Since the field strength can, alternatively, be calculated in terms of AF, the antenna gain can be also expressed as a function of AF [4], [5]. Finally, Antenna gain is calculated from computed AF and compared with the measured result available in [1].

2 FDTD Formulation of the Problem

The FDTD model uses a uniform space lattice of cubic Yee cells having $\triangle x = \triangle y = \triangle z = \triangle$. A $10\triangle-$thick unsplit perfectly matched layer (PML) [6] is used as absorbing boundary conditions (ABC) on all six sides of the FDTD lattice. This PML is spaced $5\triangle$ cells from the closest surface of the scatterer. Gaussian pulse [6] is taken as the excitation source.

The complete geometry of the horn antenna is shown in Fig. 1(a). Linearly polarized (along z-axis) perfectly plane wave of Gaussian pulse propagating along y-axis in free space incidents on the open end of the RW-90 waveguide fed horn at y=y_h as shown in the Fig. 1(b). In order to simulate a uniform plane wave within the FDTD lattice, the problem space is divided into the total field and scattered field regions and the

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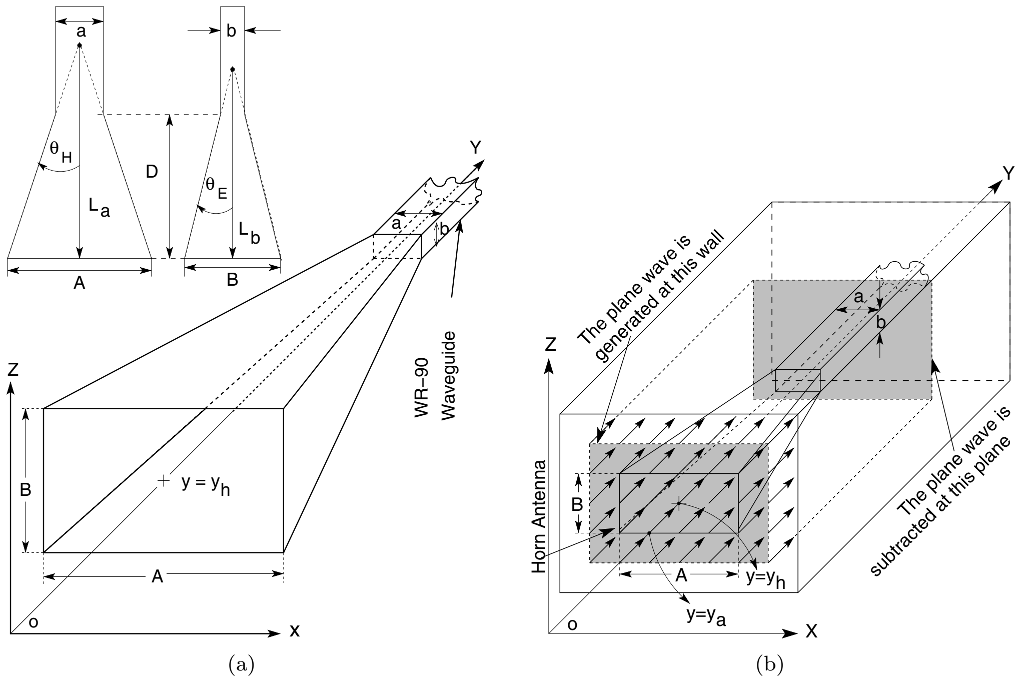

Figure 1: Pyramidal horn antenna (a) details of geometry (b) under plane-wave illumination within the FDTD grid (Receiving antenna case).

antenna is placed within the total field regions. Details of this method given in [6] are used in this work. The plane wave is generated in the $XZ-$plane, at $y = y_a$. As primary and edge diffracted waves propagate through the horn waveguide structure, the subtractions in the $XZ-$plane at $y = y_b = y_h + 1$ take place like [6] but without the area $(A \times B)$ inside the horn at $y = y_b$. As perfectly plane wave and lossless free space are considered, time domain electric field at the aperture of the horn antenna is

$$E_{z_{i,j,k}}(t) = Ae^{-0.5\left(\frac{t-t_0+t'}{t_\omega}\right)^2} \quad (1)$$

where, t' is the time shift due to the spacial difference between the antenna aperture and the position where Gaussian pulse is applied into the FDTD lattice. Fourier transform of $E_{z_{i,j,k}}(t)$ gives the frequency domain incident electric field, which is

$$E_i(\omega) = F\{E_{z_{i,j,k}}(t)\} \quad (2)$$

where, $F\{\ \}$ denotes the Fourier Transform.

3 Gain Calculations of Pyramidal Horn Antenna in Receiving Mode

The time average complex power flowing through the waveguide is given by [7]:

$$P^c(\omega) = \int_0^a\int_0^b \frac{1}{2}\left[E(\omega) \times (H(\omega))^*\right] dx\ dz \quad (3)$$

Although many modes are generated inside horn and enter into the waveguide after travelling few λ distance through the waveguide all the modes will die down except TE_{10} mode. Neglecting all components except E_z and H_x^*, time average power flowing through the waveguide along y-direction is real part of $P^c(\omega)$ which is given by:

$$P_y(\omega) \approx Re\{P^c(\omega)\} \approx Re\{\int_0^a\int_0^b \frac{1}{2}E_z(\omega)H_x(\omega)^*\Big|_{y=y_0} dx\ dz\} \quad (4)$$

where, y_0 is the point in which all other modes are died down except TE_{10} and minimum 3 cell before the PML start in the FDTD space lattice. Since, most measuring devices have an input impedance of 50 Ω, the voltage measured by these is given by:

$$V_L(\omega) = \sqrt{50 \times P_y(\omega)} \quad \text{Volts} \tag{5}$$

on the condition that the waveguide transporting this power is well matched with the measuring device.

The antenna factor (AF) 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 AF is defined as [3]

$$AF = \frac{E_i(\omega)}{V_L(\omega)}\ m^{-1} \tag{6}$$

Since the field strength can, alternatively, be calculated in terms of AF, the antenna gain can be also expressed as a function of AF. From [4, eq. (4)] & (6), antenna gain can be written as

$$G = \frac{94.751}{\lambda^2}\frac{1}{AF^2} = \frac{94.751}{\lambda^2}\left(\frac{V_L(\omega)}{E_i(\omega)}\right)^2 \tag{7}$$

During the progress of the FDTD calculations time domain incident field $E_{z_{i,j,k}}(t)$ at $y = y_h$ and time domain electric field $E_z(t)$ and magnetic field $H_x(t)$ at $y = y_0$ on the surface area $a \times b$ 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. The frequency domain incident electric field is calculated from the (2). Power flowing through the waveguide is obtained from the (4) and voltage developed across 50Ω load $V_L(\omega)$ is obtained from the (5). Finally, gain of the horn antenna is evaluated using (7).

4 Results and Discussions

Simulations are carried out FDTD spatial grid with uniform cell size of $\triangle x = \triangle y = \triangle z = \triangle(\cong \lambda_{min}/24) = 1.0\ mm$ where $\lambda_{min} = 24.0\ mm$ is the wavelength at the frequency of 12.4 GHz. $\triangle t\ (= 1.67\ ps)$ is calculated from [6, eq. (11.1)]. A linearly polarized (along z-axis) perfectly plane wave of Gaussian pulse having significant frequency content in a frequency range from 8 GHz to 12.5 GHz of maximum amplitude $A = 1.0\ V/m$, $t_0 = 80.65$ ps & $t_w = 10.08$ ps of (1), falls upon the open end of the horn at $y = y_h$. The AF of two WR-90 waveguide fed horns of different size are computed and compared with the experimental results in [1].

The dimensions of the first horn (large flare angles) use to calculate the gain in receiving mode are $A = 19.2\ cm$, $B = 14.6\ cm$, $D = 15.0\ cm$, $\theta_H = 29.423°$ & $\theta_E = 24.355°$. The FDTD computed gain from (7) are compared with the experimental results of [1, Fig. 2] shown in the Fig. 2(a). The dimensions of the second horn (small flare angles) use for gain calculation in receiving mode are $A = 19.45\ cm$, $B = 14.4\ cm$, $D = 28.9\ cm$, $\theta_H = 16.539°$ & $\theta_E = 13.037°$. The FDTD computed gain from (7) are compared with the experimental results of [1, Fig. 3] shown in the Fig. 2(b).

The results in Fig. 2 show that the gain of long horn (small flare angles) is higher than that of small horn (large flare angles). The medium horn in [1] is considered as a large horn for this paper. From this results, it is seen that flare angles of the horns does not effect on FDTD gain computation like [1] and the results are well agreed with the measured values. FDTD computed results in Fig. 2(b) are agreed more than that's of in Fig. 2(a) because of the fact that the measured results of [1, Fig. 3] (in Fig. 2(b)) are more accurate than those of [1, Fig. 2] (in Fig. 2(a)) as stated in [1].

The amplitude oscillation in FDTD computed gain is due to the oscillation of amplitude in power flowing through the fed waveguide, calculated from (4), represent a standing wave component resulting from

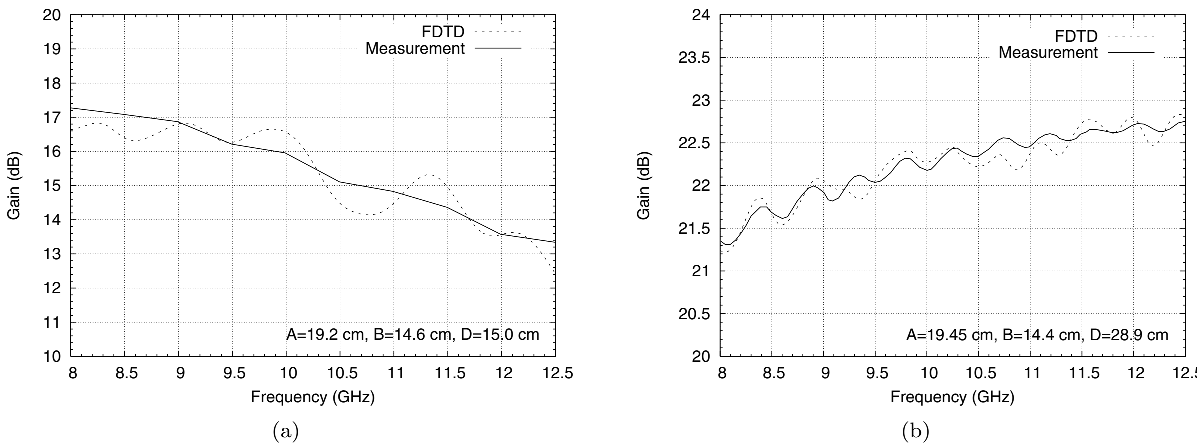

Figure 2: Gain of pyramidal horn computed using FDTD technique compared with the measurement of [1] (a) horn with larger flare angles (b) horn with smaller flare angles.

interference between the primary wave and the edge diffracted waves. Same variation is also observed in the measurements and the FDTD technique reproduces them very well.

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