Multiple Slot Array with Near Zero Refractive Index Substrate

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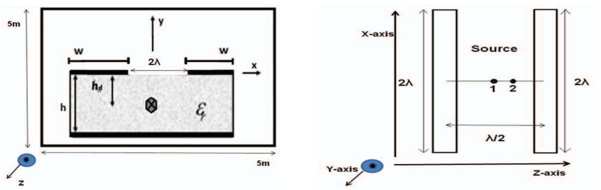
***Abstract*—Near zero refractive index based materials have been useful for building antennas with high directivity at the broad side direction. We demonstrate a directive multi slot antenna structure with a near zero refractive index substrate that is capable of directing the main lobe of the radiation pattern away from the broad side. The tilt of the main lobe is a function of the position of the source excitation, within the substrate, with respect to the two slot apertures.**

I. INTRODUCTION

As per Snell - Descartes law, incident waves from a point source embedded in a near-zero refractive index material will be refracted close to the normal direction in a homogeneous right hand medium [1]. For instance, if we consider the Lorentz/Drude model with homogeneous plasma-like dispersive permittivity (ϵ) and permeability (μ) as shown in (1),

$$\mu = \mu_0\left(1-\frac{\omega_p^2}{\omega^2}\right), \epsilon = \epsilon_0\left(1-\frac{\omega_p^2}{\omega^2}\right) \tag{1}$$

the refractive index of the material is close to zero at the plasma frequency (ω_p). Therefore highly directive emission from a source embedded in this medium can be realized at plasma frequencies. This property has been exploited towards designing antennas with high directivity [2]–[4]. However, in all of these cases, the main beam is directed towards the broad side. The unique contribution of our paper is to demonstrate, through simulations, a directive antenna that radiates away from the broad side. Such an antenna will be especially useful for realizing on-chip antennas in Silicon-On-Chip applications where near-zero refractive index substrates have been identified as the means towards mitigating the losses due to surface wave propagation through the silicon [5]. We first, consider a single slot antenna with a zero refractive index substrate as shown in Fig.1(a) and then extend the analysis to two slots shown in Fig.1(b). Though we have considered a simple two-dimensional slot antenna, the principles of this work apply equally to more realistic three-dimensional structures (results not shown here). When the position of the source excitation within the substrate is such that it is not equidistant from the two slot apertures (position 2 in Fig.1(b)), then there is unequal phase excitation of the magnetic current sources across the slot apertures. This results in the shift of the main lobe away from the broadside. We demonstrate the functioning of the antenna using finite difference time domain (FDTD) simulations.



(a) (b)

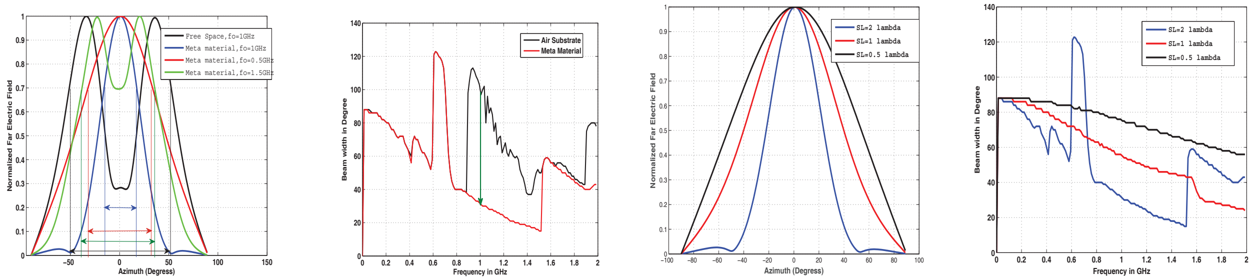
Fig. 1. (a) FDTD simulation model of a slot antenna with a metamaterial substrate (b) 2 slot array

II. EXPERIMENTAL RESULTS

In Fig.1(a), we model the dispersive material properties of (1) using Z transform techniques described in [6]. The antenna is excited by a TM mode Gaussian pulse source of $0.25ns$ width. The plasma frequency of the substrate is $f_p = 1GHz$. The simulation space is enclosed by a perfectly matched layer [7]. Using Fourier transform, we obtain the electric field $\vec{E}_a(\omega)$ at every point in the aperture. From field equivalence principles, the far field radiation pattern is obtained from (2), where $\vec{M} = 2\vec{E}_a \times \hat{y}$, is the magnetic current source across the aperture.

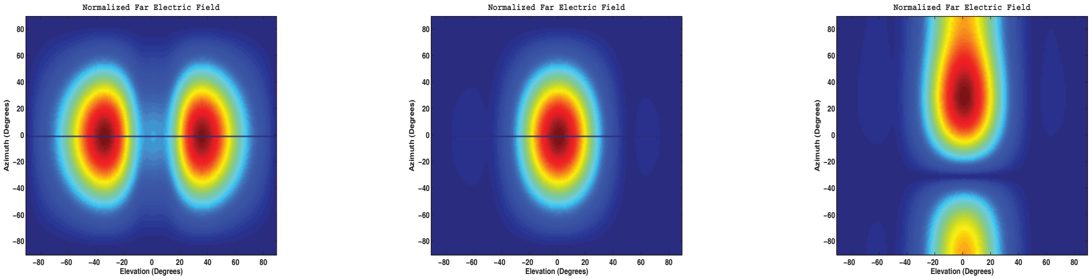
$$\vec{E}_{ff} = \frac{-jk}{4\pi R}\int_C (\vec{M}(r') \times \hat{r})e^{-jkR}dl' \tag{2}$$

Here k is the propagation constant, R is the far field radius and C is the aperture. Fig.2(a) compares the radiation patterns of the slot antenna with the air substrate at 1GHz and the metamaterial substrate at 3 frequencies. At 1GHz, the beamwidth for the metamaterial substrate is clearly lower than that of the air substrate. In the case of a metamaterial substrate, the beamwidth is lowest at the plasma frequency (1GHz) as compared to frequencies above (1.5GHz) and below the plasma frequency (0.5GHz). This is because, at different incident angles, the refracted rays are in-phase and normal to the slot aperture at $f_0 = f_p$. At other frequencies, the refracted waves bend either away or towards the normal at different angles depending on the incident angle. Fig.2(b) shows the half power beamwidth of the single slot antenna for different excitation frequencies. We can observe that there exists a band of frequencies about the plasma frequency where the directivity is high due to low refractive index. Next, we consider different slot lengths in Figs.2(c) and 2(d). The half



(a) (b) (c) (d)

Fig. 2. (a) One dimensional far field radiation patterns and (b) directivity versus frequency, for single slot antenna with air and metamaterial substrate. (c) Radiation patterns and (d) directivity versus frequency for varying lengths of the slot aperture with metamaterial substrate.



(a) (b) (c)

Fig. 3. Two dimensional far field radiation patterns for 2 slot antenna with (a) air substrate and source excitation at position 1 (b) metamaterial substrate and source excitation at position 1 and (c) metamaterial substrate and source excitation at position 2.

power beamwidth reduces as the slot length increases until it converges for a slot length of $2\lambda_p$ where λ_p is the wavelength corresponding to f_p. For lower slot lengths, we do not obtain a broad band of frequencies where the beamwidth is low. Next, we consider a case with two-slot antennas where the antennas are perfectly aligned along the XY plane but are separated by $0.5\lambda_p$ along the Z axis as shown in Fig.1(a). Each slot is $2\lambda_p$ long along the X dimension and very short along the Z dimension. The radiation of each slot still remains oriented along the broad side direction at plasma frequency even when the source excitation is moved away from the center of the slot. The combination of the array factor due to the two slot antennas and their elemental pattern results in beam patterns as shown in Fig.3 where the azimuth beamwidth is governed by the element pattern while the elevation beamwidth is governed by the array factor. Fig.3(a) shows the beam pattern of the two slot structure with the air substrate when the source is at position 1 in Fig.1(b). Fig.3(b) shows the beam pattern realized for a 2 slot antenna array with a metamaterial substrate when the source is at position 1. Superior directivity is achieved when compared to the free space case. Fig.3(c) shows the beam pattern when the source excitation is at 2. Here, the beam is steered away from the broad side along the elevation.

III. CONCLUSIONS

Directive emission, away from the broadside, is achieved using a two slot array antenna with a near zero refractive index substrate.

ACKNOWLEDGEMENT

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