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FDTD analysis of diffraction efficiency in a hologram for application in optical fiber communication

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ABSTRACT

Finite Difference Time Domain (FDTD) algorithm is developed and implemented for the first time in this paper to investigate the diffraction efficiency of a holographic coupler. FDTD simulation is found to be in better agreement with the results of diffraction efficiency for holographic coupler reported in literature using other theories. Further this algorithm is used to investigate the variation of diffraction efficiency with respect to wavelength at different grating period and angle of incidence in three different optical communication windows. It is found that First window is the most suitable for holographic coupler.

1. Introduction

Holograms are gaining interest due to their reduced dimension, light weight and low replication cost. Thus holograms are attractive elements for various applications like image display, optical security, metrology and optical sensing [1]. Holograms are used to effectively couple power between two fibers. For example in reference [2] two holograms are used to couple power in between two fibers. While using a hologram as a coupler, one has to optimize the coupling efficiency. And this is done using different approaches. For example Tripathy et al. [2], investigated, the coupling efficiency using Kogelnik coupling theory for optimizing the efficiency of the hologram and eikonal approximation for calculating intrinsic efficiency of fibers. And in reference [3], Kogelnik coupling theory in conjunction with aperture antenna analysis is used to analyse the diffraction efficiency of a holographic coupler w.r.t angular divergence. Above investigations, thus use either eikonal approximation or aperture antenna analysis with Kogelnik coupling theory to investigate the coupling efficiency between two fibers. However recently FDTD (Finite Difference time domain) technique has emerged as a powerful technique to analyse the behaviour of electromagnetic field in different structures. For example in ref [4,5], interference and diffraction analysis of holographic gratings are reported using finite difference time domain method. Interestingly there is a good agreement between the results obtained in ref [4] and the characteristic matrix method. Further in the same reference FDTD simulation results for hologram diffraction efficiency with thickness of the hologram, matches reasonably well. Motivated by above investigations, we here in this paper attempted to use FDTD algorithm in analysis of holographic coupler. The merits of this investigation is that, this serves as a single step procedure to analyse the coupling efficiency, instead of using two different theories as in references [2,3].

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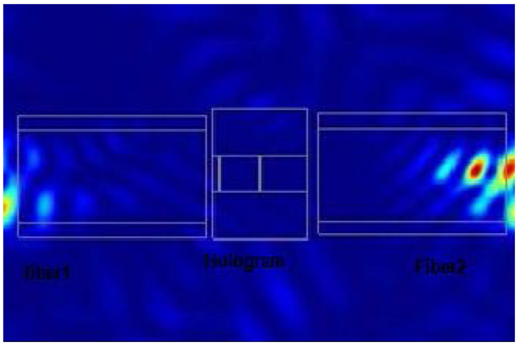

Fig. 1. Electric field of a transmission hologram using the above method. Parameters: d = 11.08 μm, Λ = 0.22 μm, n1 = 0.025, λ = 633 nm.

2. Theory

we have employed the FDTD method based on Yee's algorithm [6], to study electromagnetic wave propagation, because the computational time and memory requirements are reduced [7,8]. A region of space is selected for field sampling in space and time. At t = 0, all the fields in the sampling region are zero. Mode radiation is investigated by implementation of central difference approximation. We use the following update equations in our simulation.

$$\tilde{D}_Z|_{i,j}n+1/2=\tilde{D}_Z|_{i,j}n-1/2+\frac{\Delta t}{\Delta y\sqrt{\mu_0\omega_0}}(H_y|^n i+1/2,j-H_y|^n i-1/2,j)$$
$$-\frac{\Delta t}{\Delta x\sqrt{\mu_0\omega_0}}(H_x|^n i,j+1/2+H_x|^n i,j-1/2) \tag{1}$$

$$H_x|^{n+1}i,j+1/2=H_x|^{n-1}i,j+1/2-\frac{\Delta t}{\Delta z\sqrt{\mu_0\omega_0}}(E_Z|_{i,j+1}n+1/2-E_Z|^{n+1/2}_{i,j}) \tag{2}$$

$$H_x|^{n+1}i+1/2,j=H_x|^{n-1}i+1/2,j+\frac{\Delta t}{\Delta z\sqrt{\mu_0\omega_0}}(E_Z|_{i+1,j}n+1/2-E_Z|^{n+1/2}_{i,j}) \tag{3}$$

Here Δx and Δy are respectively, the lattice space increments in the x and y coordinate directions. i and j are integers that denote the position of sample points in the x and y directions respectively. The time increment is represented by Δt and is related with the integer n to localize a determined observation interval.

A perfectly matched layer (PML) has been applied to ensure uniqueness and validity of the numerical solution of Maxwell's equations inside the computation domain. In this study, the temporal step Δt is 2×10^{-17} s, the spatial step (Δx, Δy) is $\lambda/40$, where λ is the wavelength of the signal. The condition of stability is also achieved as it fulfils:

$$\Delta t<\frac{1}{c}\left(\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}\right)^{-1/2} \tag{4}$$

where c is the velocity of light. It may be mentioned here that, we have not considered the loss, in the holograms, due to absorption or scattering that might have occurred, during transmission, hence a correction factor is introduced in the simulation, which can take care of this losses.

If we assume that the refractive index varies sinusoidally with amplitude n_1 about a mean value n_0, the diffraction efficiency of the grating at the Bragg angle is θ_B is:

$$\eta_B^T=\sin^2(\Phi)$$

Where $\Phi = \pi n_1 d/\lambda\cos\theta_B$ is known as the modulation parameter, where d = Grating thickness, θ_B=Bragg angle.

The electric field of a transmission hologram using FDTD method is shown in Fig. 1.

In this simulation a single hologram is used in between two fibers and a Gaussian signal is introduced at the input of fiber1

3. Model

In this work transmission through different holograms (transmission) have been studies using FDTD method. As the diffraction efficiency of a hologram depends on, its thickness, Bragg period, angle of incidence. We simulate the field emerging out of the hologram, with different thickness, angle of incidence and grating period. The variation of diffraction efficiency with deviation from Bragg angle of incidence is important in practical applications like photovoltaics and holographic coupler. A flat response is usually desired for such applications. FDTD simulation is also made to study the variation of efficiency with