Full-Vector Beam Propagation Methods for 3D Optical Waveguides

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Introduction

An optical waveguide is a dielectric structure which confines and guides light waves to propagate along a pre-determined path. An optical fiber is a well-known optical waveguide. The beam propagation method (BPM) is the most widely used numerical tool for simulating the propagation of light in 3D optical waveguides. We develop a wide-angle full-vector BPM based on alternating direction implicit (ADI) pre-conditioner. The exponential of a square root operator (the propagator) is first approximated by a rational function of the transverse differential operator *X*. The linear equations involving the operator *X* are solved by a Krylov subspace method with an ADI pre-conditioner. To show the validity and usefulness of our methods, waves propagating in a Y-branch rib waveguide is numerically simulated.

Basic Formulations

1.) Consider the one-way equation for the transverse components of the magnetic field,

$$\frac{\partial u}{\partial z} = ik_0 n_* \sqrt{1+X}\,u \qquad (1)$$

where $u = [H_y, -H_x]^T$ is a vector related to the *x* and *y* components of the magnetic field, *X* is a 2×2 transverse differential operator, k_0 is the free space wave number and n_* is a reference refractive index.

2.) Equation (1) is discretized in the propagation direction z. For a propagation step from z_j to $z_{j+1} = z_j + h$,

$$u_{j+1} = P u_j \quad \text{for} \quad P = e^{is\sqrt{1+X}} \qquad (2)$$

where *P* is the propagator, *h* is the step size, $s = k_0 n_* h$, *X* is evaluated at the midpoint $z_j + h/2$, u_j approximates *u* at z_j, etc.

3.) The [*p*-1/*p*] Padé approximants of *P* can be used and this requires solving the linear equation

$$(1 + bX)w = f \qquad (3)$$

where *b* is a given constant, *f* is a given vector of two functions and *w* is a vector of two unknown fucntions.

4.) Reformulate equation (3) as in the ADI iterative scheme for elliptic problems, then solve the new equation by a Krylov subspace method called BICGSTAB. Also, the optimal value of a parameter is calculated form eigenvalue estimates of the related operators.

Numerical Example

- ❖ The Y-branch is excited by the fundamental mode field for λ = 1.55 μm.
- ❖ Propagates from $z = 0$ to 40 μm with $\Delta z = 0.1$ μm.
- ❖ Computational domain: $|x| < 4$ μm and $|y| < 2$ μm.
- ❖ Discretized with grid sizes $\Delta x = \Delta y = 0.05$ μm.
- ❖ Perfectly Matched Layer with thickness = 0.3 μm.
- ❖ [3/4] Padé approximants of *P* is used with $n_* = 3.3885$
- ❖ Magnitude of Hy at z = 0, 24 and 40 μm are shown below: