INCREASING THE QUALITY OF TEACHING OF THE STUDENTS BY A NEW METHOD OF DESIGN OF OPTIC FIBRES AND ANALYSIS OF THEIR PARAMETERS

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Introduction in the problems

Telecommunications using fibers as the transmission media is now a major industry. Choosing appropriate fiber parameters is an important issue for a given optical system. Cross-sectional dimensions, material composition, and refractive index profile all influence the losses, dispersion and the nonlinearities of the fiber and must be chosen carefully to achieve a satisfactory tradeoff for a given application.

All these parameters of existing fiber samples could be experimentally measured and then the fiber manufacturing process adjusted towards an optimized production. However, this trial and error approach is extremely slow, expensive and unreliable. Moreover, some important fiber parameters, for example the total group-velocity dispersion and the effective nonlinear coefficient, are not directly measurable with compact tabletop devices. Because of that, the number of professionals who use an appropriate fiber design and modeling software is growing constantly across the photonics industry.

The high quality of the teaching of the students is one of the basic tasks standing in front of the teaching team of the Burgas Free University. The fulfilment of this task demands opportunely the teaching lessons connected with the obtaining of skills for self-dependent creative and practical work to be renovated. At the center of engineering, technical and natural sciences from subjects "Communicational technics and technology", "Computers' technics and technology" and "Electronics" at Burgas Free University at the subject "Optoelectronics and optic communications" are thought the basic principles of the diffusion of the lighting energy in the optic fibers, the receiving and the transmitting optical modules, the principles of the building of the optic devices for the optic communication and optic nets. In the last two years, in this subjects were introduced exercises in which the students are thought to design self-dependant optic fibers after an area of application of the fiber assigned in advanced. The aim of the task is to obtain deeper knowledge at the area of the optic communications as well as to be well grounded with the basic parameters of the optic fibers, the mutual connections between this parameters and the influence of the construction of the fiber and the admixture-alloy on his exite parameters.

For this purpose was choosan a demonstrating software of the firm OptiWave - FiberCad. It is a powerful tool that blends numerical mode solvers for fiber modes with calculation models for group delay, group-velocity dispersion, effective mode area, losses, polarization mode dispersion, effective nonlinearity, etc.

Among the most powerful features are abilities to predict how any given fiber could be optimized versus a design goal, for example small, but non-zero dispersion and maximal mode area. WE can supplement and extend the fiber characterization capabilities of real laboratory devices, such as EXFO's NR-9200 Optical Fiber Analyzer, by importing and analyzing the refractive index profiles of real fiber samples.

This is indispensable tool for engineers, scientists and students who design fibers, fiber components and optical communications systems.

At the area of the exersices are assigned tasks connected with the exploring of some of the following parameters:

- Design a multilayer fiber with an arbitrary 2D refractive index profile by either:
- Defining the profile, using a library of built-in functions or a using a user-specified formula
- Assign material dispersion based on Sellmeier model or user-defined functions
- Model material losses based on known experimental formulas
- Calculate the following characteristics of any supported mode, fundamental or higher order:
- Effective refractive index and the propagation constant
- Group delay
- Three types of group-velocity dispersion (material, waveguide, total)
- Mode field diameters according to various definitions and eff. mode area
- Estimations of the cutoff wavelengths
- Macrobending, microbending and splicing losses
- Optimize the dependence of these characteristics on numerous technological parameters of the fiber: geometry, profile shape, composition.
- Calculate and visually compare the parameters of an arbitrary group of modes vs. the mode number
- Calculate birefringence effects induced by intrinsic or extrinsic perturbations
- Estimate the PMD based on stochastic model

To change the refractive index of optical fiber, pure silica is often doped with dropants. For example, adding germanium can result in an increase in the refractive index, while adding fluorine reduces it. The refractive index of doped material can be determined by the linear relationship between the doped material's mole percentage and permittivity.

Assume that n_0 is the refractive index of the host material and n1 is the refractive index of m1 mole-percentage doped material. Then, the refractive index n of m mole-percentage doped material can be interpolated as:

$$n^2 = n_0^2 + \frac{m}{m_1}\left(n_1^2 - n_0^2\right)$$

(1)

Currently have two methods for defining the geometry and the material composition of the fiber:

- Direct definition of the refractive index profile: the abscissa values n(x) in the formulae above are interpreted directly as refractive index values at a user specified wavelength. Wherever needed, the dropant concentration in each region is internally calculated by interpolating the given value between the refractive index values of two materials using the formula (1). The material dispersion and dispersion of the profile are calculated from the known Sellmeier coefficients. The parameters of the materials can be different for each region or global for the whole profile.

This method is convenient whenever the distribution of the refr. index is known from experimental measurements, estimations, etc.

- Definition of a dopant concentration profile: the abscissa values n(x) in the formulae are interpreted as molar concentration of a certain dopant. The material dispersion and dispersion of the profile are calculated from the known Sellmeier coefficients of the dopant,

This method is convenient when the dopant concentration distribution of the fiber or at least of it's perform are known with sufficient accuracy.

Using some of these methods for modulling the index of the refraction of the core, we can, indentifying one profile to count all more important parameters of the fiber. They are count:

a) Scalar fiber modes

The designation of Linearly Polarized (LP) Fiber modes is based on the assumption of weak guidance. Weakly guiding fibers have a small difference between core and cladding refractive index.

Two numbers designate the LP (m, n) modes:

m - azimuthal number

n - orbital number where m = 0, 1, 2, … and n = 1, 2…

Both guided and cladding modes of arbitrary circular symmetric refractive index profile are calculated either by the accurate finite difference method or by the analytical method (step index profile).

b) Vector fiber modes

The designation of vector fiber modes TE, TM, EH, and HE follows the convention:

TE (0,n) - transverse electric family of modes

TM (0,n) - transverse magnetic family of modes

EH (m, n) - hybrid family of modes

HE (m, n) - hybrid family of modes

where m and n = 1, 2…

The vector modes are calculated only for the step-index fiber. The step-index calculations are based on the analytical approach. The fundamental mode of step-index fiber is HE (1,1).

Next we can calculate for example:

- Total dispersion of the fiber

The total dispersion is the total effect of material and waveguide dispersion. It is calculated in a similar way as for calculating waveguide dispersion. In this case, the fiber refractive index profile depends on wavelength. The material dispersion effect should be calculated first. Then the mode effective index Neff is calculated by the mode solver. The total dispersion of a fiber is:

$$D_{total} = -\frac{z}{c}\lambda\frac{d^2N_{eff}}{d\lambda^2}$$

(2)

- The cutoff wavelength for any mode is defined as the maximum wavelength at which that mode will propagate. The cutoff wavelength λ_c of LP_{11} is an important specification for a single-mode fiber. The operation wavelength must be greater than the cutoff wavelength of LP11 to operate the fiber in a single mode regime. λ_c can be determined analytically for some specified fiber profiles. For a general fiber profile, a highly accurate numerical mode solver should be involved to calculate cutoff wavelength.

- A 'Theoretical' cutoff value - This is the wavelength above which the given mode can not propagate even in short and unperturbed samples of this fiber. This value is calculated using the general numerical mode-solvers of Fiber_CAD. It is defined as the wavelength, above which the eigenvalue problem formulated for the current fiber design and for the given mode does not have real solutions.

- The total fiber loss can be divided into material losses and fiber induced losses. Material losses include Rayleigh scattering, ultraviolet (UV), infrared (IR) absorption, and hydroxyl (OH) absorption losses. Material losses are the limiting losses in fibers.

Fiber loss is defined as the ratio of the optical output power P_{out} from a fiber of length L to the optical input power P_{in}. The symbol α is commonly used to express loss in decibels per kilometer:

$$\alpha = \frac{10}{L}\log\left(\frac{P_{in}}{P_{out}}\right)$$

(3)

- Mode field diameter and area importance - The Mode Field Diameter (MFD) is an important parameter related to the optical field distribution in the fiber. It has been shown that MFD provides useful information about the cabling performances, such as possible joint, macrobending, and microbending losses. The effective area of the fibers has a direct relation to the nonlinear distortions in long fiber links.

- Effective diameter definition

effective Mode Field Diameter (eff. MFD), defined as :

$$d_{eff} = \frac{2\sqrt{2}\int E_i^2\, r\, dr}{\left[\int E_i^2\, r\, dr\right]^{\frac{1}{2}}}, \quad d_{eff} = \frac{2}{\sqrt{\pi}}\sqrt{A_{eff}}$$

(4)

where E(r) is the optical mode field distribution. A_{eff} is the effective Mode Area (eff. MA)

- Macrobending loss;
- Microbending loss;
- Splice loss;
- Fiber birefringence

and other parameters.

Bibliography

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