

# EDUCATION PROGRAM FOR FIBER BRAGG GRATINGS SIMULATION

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## ABSTRACT

This paper discusses the education program for fiber Bragg gratings modeling. The goal of this work is acquaint students with fiber Bragg gratings issue. This program makes possible spectral characteristics simulation of gratings, which are commonly used as band pass filters or chromatic dispersion compensators in telecommunications and in-fiber sensors in modern sensor systems.

## 1. INTRODUCTION

Fiber Bragg gratings (FBGs) have become a key technology in many optical systems [1] where they enable a realization of essential devices such as narrow band filters [2], chromatic dispersion compensators [3], in-fiber sensors [4] or external cavity semiconductor lasers [5].

It is important to acquire students with basic principles and usage of FBGs. It was realized by laboratory exercise based on simulation of FBGs. The base of exercise is program with graphic user interface (GUI). Using this GUI, it is possible to easily set input parameters of FBGs and watch output characteristics.

The essence of program was taken from Matlab-based program, earlier made for science purposes [6]. GUI was created in Borland Delphi, especially for education use. The program contains sets of many input parameters describing the grating profile. Students are acquired with advanced gratings and improvement of modern devices. By this way, students will be able to design suitable gratings for modern optical devices, frequently used in telecommunications and sensor systems.

## 2. THEORY

The heart of program is calculation unit (CU). CU calculates grating spectral characteristics from input parameters. CU uses for calculation methods based on layered dielectric media and transfer matrix [6]. It is important to know basic theory of FBGs and calculation methods to understand how program works.

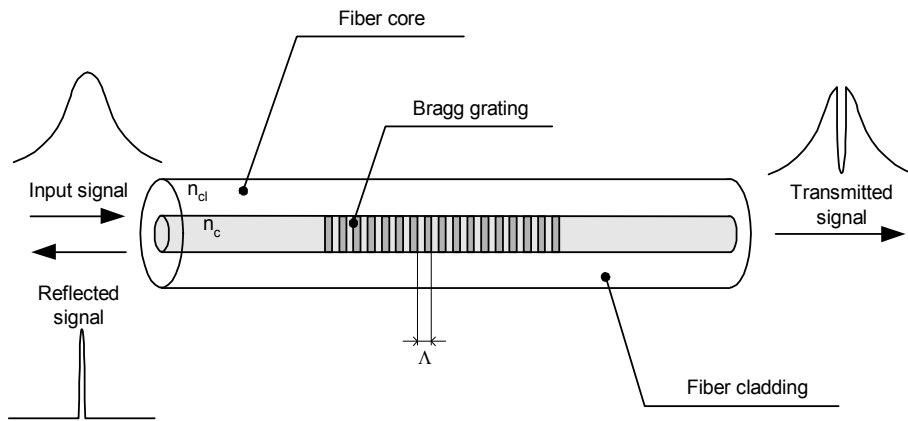
A grating is a device that periodically modifies the phase or the intensity of a light wave reflected on, or transmitted through, it [7]. The grating in fiber is represented by periodic

change of the core refractive index with the period,  $\Lambda$  and the amplitude,  $\delta n$ , along the fiber axis. The propagating wave is reflected, if its wavelength equals Bragg resonance wavelength,  $\lambda_{Bragg}$ . Otherwise, the wave is transmitted. Typical layout of a fiber Bragg grating with input and output signal indicated is on Figure 1. The advanced grating features improving grating characteristics are apodization and chirp profiles, also included in program. Apodization means modulation of the amplitude,  $\delta n$ , along the grating length,  $L$ , and chirp means modulation of period,  $\Lambda$ , along the grating length,  $L$ . Apodization of FBG has advantages in many systems because it provides suppressing of the side lobes in the grating spectral properties. Chirp profile leads to defined group delay dependence on wavelength. Chirped gratings can be well used in optical systems to chromatic dispersion compensation.

The equation relating the grating spatial periodicity and the Bragg resonance wavelength is given by [7], [8]:

$$\lambda_{Bragg} = 2n_{eff}\Lambda \quad (1),$$

where  $\lambda_{Bragg}$  is Bragg resonance wavelength,  $n_{eff}$  is effective mode index and  $\Lambda$  is grating period.



**Figure 1:** Fiber Bragg grating

The combination of methods based on layered dielectric media (LDM) and transfer matrix can be used for calculation of FBGs. LDM method is based on sequence of thin films of dielectric media assembled in direction of wave propagation. This structure can describe arbitrary shape of grating.

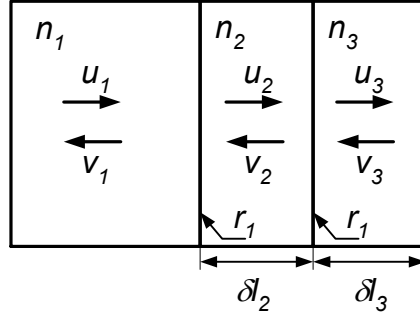
Figure 2 shows a thin film structure with indicated input and output fields and refractive indexes of each layer. The reflectivities,  $r_1$  and  $r_2$ , at each interface depend purely on the refractive indexes of the two dielectric materials on either side. The field in each region,  $E_j$ , is the sum of the forward,  $u_j$ , and backward,  $v_j$ , traveling fields:

$$E_j = u_j + v_j \quad (2)$$

Applying the continuity of the transverse field components at the first layer and assuming propagation in nonmagnetic medium, the equations are given by:

$$u_1 + v_1 = u_2 + v_2 \quad (3)$$

$$n_1(u_1 - v_1) = n_2(u_2 - v_2) \quad (4)$$



**Figure 2:** Structure of layered media

Equations (3) and (4) can be expressed by algebraic manipulation in the following matrix form:

$$\begin{bmatrix} u_1 \\ v_1 \end{bmatrix} = \frac{1}{t_1} \begin{bmatrix} 1 & r_1 \\ r_1 & 1 \end{bmatrix} \begin{bmatrix} u_2 \\ v_2 \end{bmatrix} \quad (5)$$

The reflectivity,  $r_1$ , at the substrate interface and the transmission coefficient,  $t_1$ , are:

$$r_1 = \frac{n_1 - n_2}{n_1 + n_2} \quad (6)$$

$$t_1 = \frac{2n_1}{n_1 + n_2} \quad (7)$$

Once again applying the field continuity at the second interface the reflected and transmitted fields are described as:

$$\begin{bmatrix} u_2 \\ v_2 \end{bmatrix} = \frac{1}{t_2} \begin{bmatrix} e^{j\varphi_2} & r_2 e^{j\varphi_2} \\ r_2 e^{-j\varphi_2} & e^{-j\varphi_2} \end{bmatrix} \begin{bmatrix} u_3 \\ v_3 \end{bmatrix} \quad (8)$$

The phase  $\varphi_j = \beta_j \delta_j = 2\pi n_j \delta_j / \lambda$ , where  $\delta_j$  is length of the  $j$ -th layer and  $\lambda$  is wavelength.

Using the transfer matrix method, combining equations (5) - (8) leads:

$$\begin{bmatrix} u_1 \\ v_1 \end{bmatrix} = \begin{bmatrix} T^{11} & T^{12} \\ T^{21} & T^{22} \end{bmatrix} \begin{bmatrix} u_n \\ v_n \end{bmatrix} = [T] \begin{bmatrix} u_n \\ v_n \end{bmatrix} \quad (9),$$

where T is overall transfer matrix,  $T = \frac{1}{t_1 t_2 \dots t_n} [T_1][T_2] \dots [T_n]$ .

The overall grating reflectivity is given by [8]:

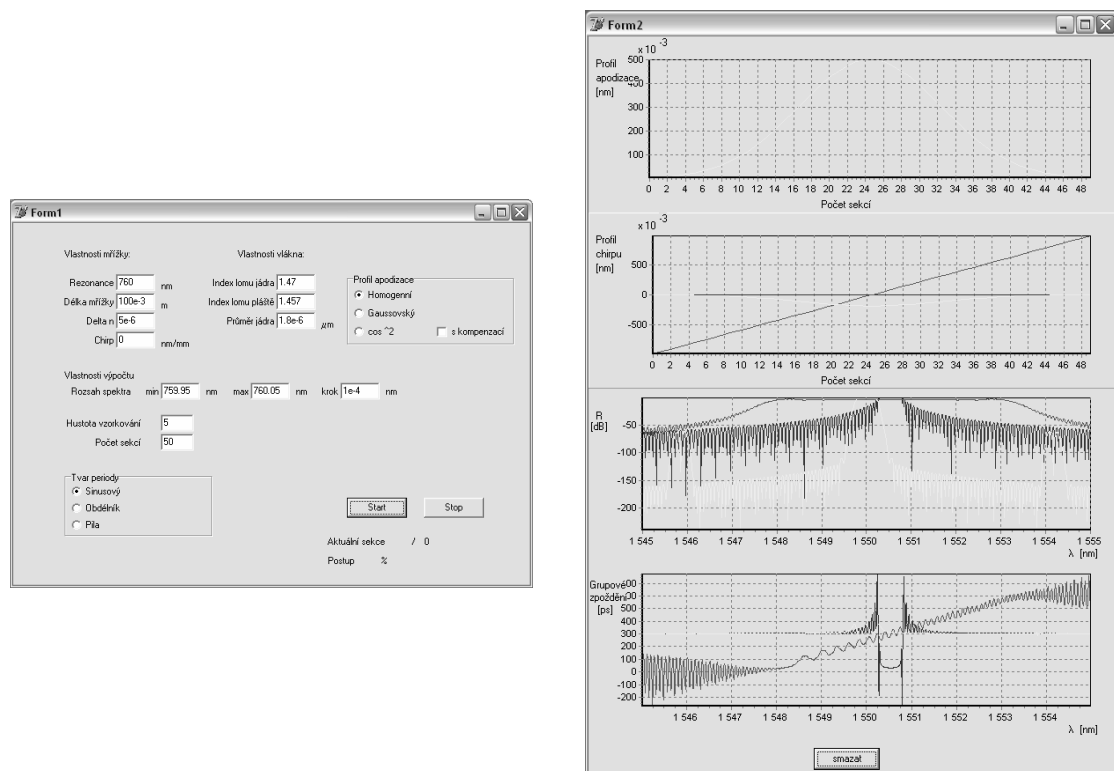
$$\rho = \frac{T^{21}}{T^{11}} \quad (10)$$

The group delay of the reflection coefficient is derived as:

$$T_g = -\frac{d}{d\omega} \phi_\rho(\omega) = -\frac{d}{d\omega} \arg(\rho(\omega)) \quad (11)$$

### 3. PROGRAM DESCRIPTION

Program for FBGs calculation was made in Borland Delphi. The program consists of two parts, graphic user interface and calculation unit. GUI gives input values to CU which makes calculations of grating response. After CU completes calculations, the vectors of grating reflectivity and group delays in dependence on wavelength are returned to GUI to draw graphs. GUI consists of two windows. First window, illustrated on Figure 3a, is used for setting input parameters. First group of parameters is used to setting properties of grating – Bragg resonance wavelength, grating length, amplitude of refractive index modulation and step of linear chirp. Second group of parameters sets properties of the fiber, in which is grating inscribed. These parameters are fiber core diameter and refraction indexes of fiber core and cladding. Next parameters group consists of calculation parameters, like interval of calculated wavelengths, sampling frequency and number of calculated grating sections. The last groups of parameters are advanced grating properties. User can choose apodization profile (uniform, Gauss or raised cosine) and shape of grating periods.



**Figure 3:** a) GUI – input parameters window, b) graph window

After calculation start, input parameters are given to CU to calculate reflectivity and group delay dependences on wavelength. The characteristics are then drawn in graph window.

Graph window, Figure 3b, consist of four graphs. First graph illustrates apodization profile. It is dependence of modulation strength in each section of grating. In this case, grating has length 10 mm and is divided into 50. Each section represents grating region of length 0.2 mm. Second graph illustrates chirp profile of grating. Chirp profile means dependence of grating period on actual position. Third graph is dependence of grating reflectivity on wavelength and the last illustrates dependence of grating group delay on wavelength.

As can be seen from Figure 3b, there can be drawn many characteristics of arbitrary grating into one graph. This feature was made for better comparison of characteristics of simulated gratings. Students can better compare characteristics of (for example) uniform, linearly chirped and apodized gratings.

Calculation speed depends on grating length and number of points in characteristic. For commonly used grating and sufficient resolution take calculation few minutes. Calculation progress is also included in input window.

#### 4. CONCLUSIONS

There were made GUI based program for calculation of FBGs spectral characteristics. This program was made for education purposes. The program uses for grating characteristics calculations methods based on layered dielectric media and transfer matrix. This program can be used for simulation of common gratings, especially gratings for use in telecommunications and sensor systems. Together with documentation will be program used as laboratory exercise in laboratory of optoelectronics.

#### ACKNOWLEDGEMENT

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