Optimization of apodized tapered fiber Bragg grating parameters

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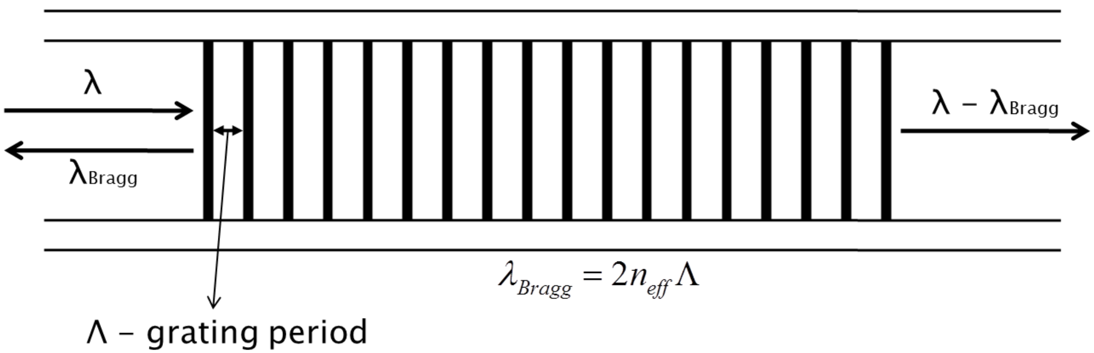
Agenda

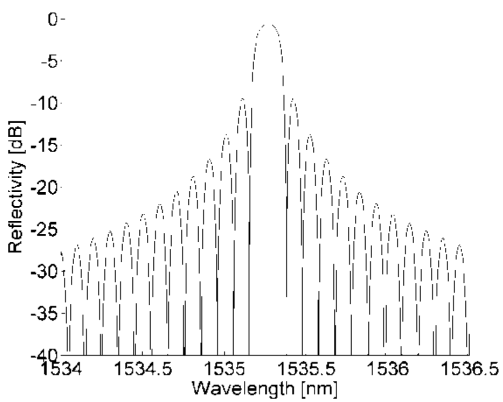
- What fiber Bragg grating is?
- Tapered fiber Bragg gratings
- Coupled mode theory and transfer matrix method
- Idea of apodization
- Optimization of the tanh apodization function

What fiber Bragg grating is?



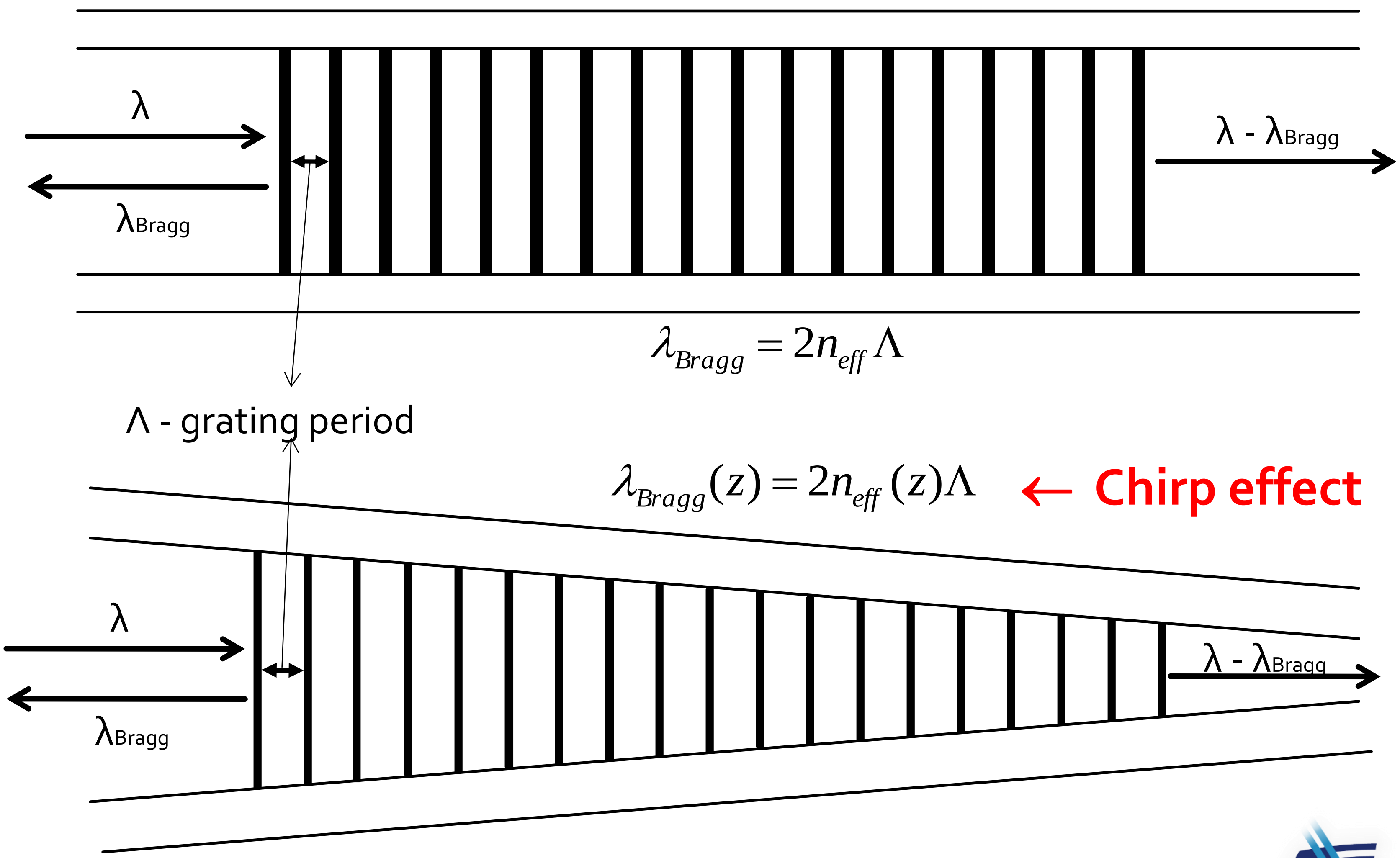
FBG is structure, where periodical fluctuations of the refractivie index within the core, leads to strong coupling of the fundamental mode which ultimately result in change the direction of the propagation of the light.

Only wavelengths that matches the Bragg resonance constrain are reflected! In result, FBG may be characterized as optical band pass filter



Numerically calculated reflectivity of typical uniform FBG

What fiber Bragg grating is?



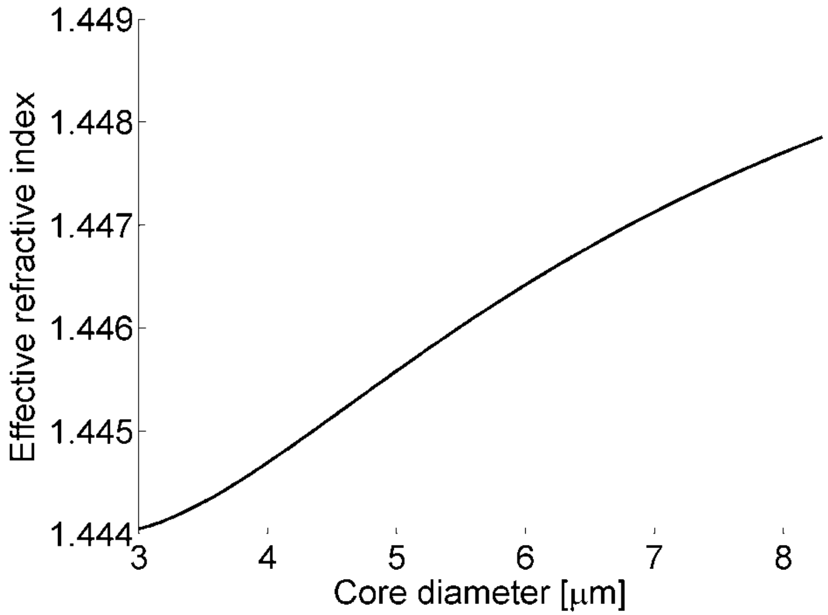
$$\lambda_{Bragg} = 2n_{eff}\Lambda$$

$$\lambda_{Bragg}(z) = 2n_{eff}(z)\Lambda$$

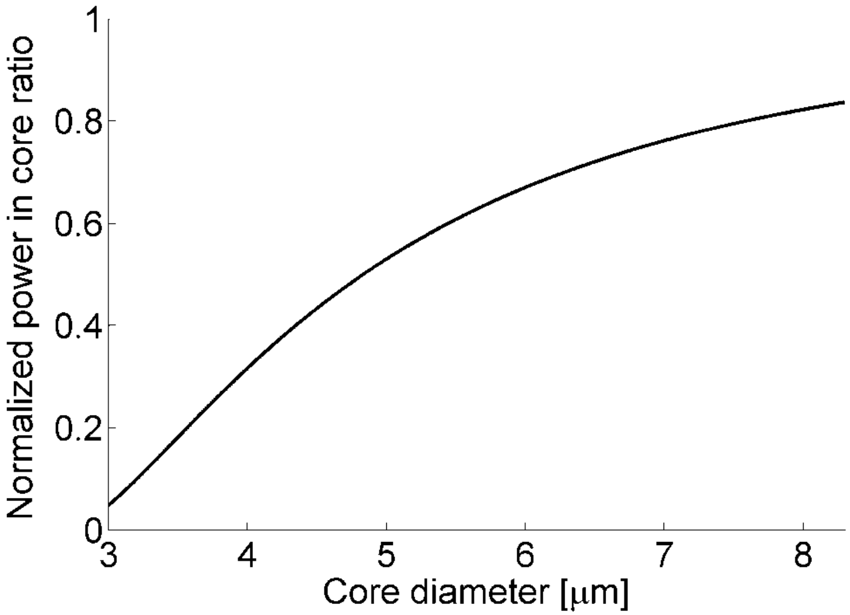
← **Chirp effect**

Tapered fiber Bragg gratings

Beside that, two important effects occurs within the tapered fiber:



Changes of the effective refractive index for LP_{01} fundamental mode



Power in core ratio versus core diameter

Coupled mode theory and transfer matrix method

Ideal mode-approximation is assumed. Transverse component of dielectric field is a superposition of ideal modes in waveguide with no perturbation:

$$\vec{E}^{T}(x,y,z,t)=\sum_j [A_j(z)e^{(-j\beta_j z)}+B_j(z)e^{(j\beta_j z)}]\vec{e}_j^{\,T}(x,y)e^{(j\omega t)}$$

$A_j(z)$ and $B_j(z)$ – amplitude of j_{th} mode
$\vec{e}_j^{\,T}$- transverse mode fields (describes LP radiation modes)

The presence of perturbation in dielectric constant lead to coupling of the modes.

$$K_{kj}^{T}=\frac{\omega}{4}\iint_{\infty}\Delta\varepsilon(x,y,z)\vec{e}_k^{\,T}(x,y)\vec{e}_j^{\,T*}(x,y)dxdy$$

K_{kj}^{T}- transverse coupling coefficient between modes j and k

and thus amplitude of j_{th} mode in z and –z direction can be written as:

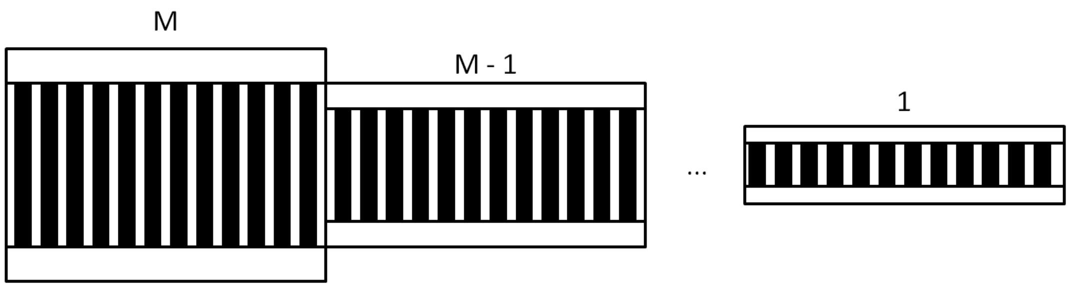
$$\frac{dA_j}{dz}=-j\sum_k [A_k e^{j(\beta_j-\beta_k)z}+B_k e^{j(\beta_j+\beta_k)z}]K_{kj}^{T}(z)$$

$$\frac{dB_j}{dz}=j\sum_k [A_k e^{-j(\beta_j+\beta_k)z}+B_k e^{-j(\beta_j-\beta_k)z}]K_{kj}^{T}(z)$$

Solving these equation leads to matrix elements in Transfer Matrix Method used in simulation.

Coupled mode theory and transfer matrix method

Tapered FBG can be described as multiplication of the series of uniform FBGs with constant coupling ratio, constant efective refractive index, etc.

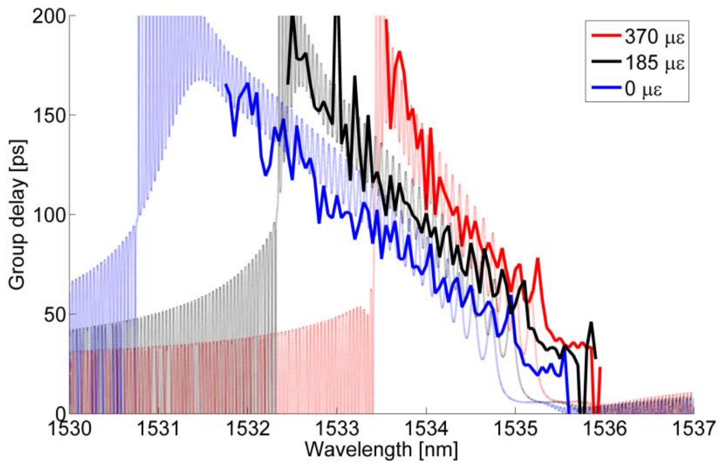


$$\begin{bmatrix} \cosh\sqrt{\hat{\sigma}_k^2-\kappa_k^2}z_k+\frac{i\hat{\sigma}_k}{\sqrt{\hat{\sigma}_k^2-\kappa_k^2}}\sinh\sqrt{\hat{\sigma}_k^2-\kappa_k^2}z_k & \frac{i\kappa_k}{\sqrt{\hat{\sigma}_k^2-\kappa_k^2}}\sinh\sqrt{\hat{\sigma}_k^2-\kappa_k^2}z_k \\ \frac{-i\kappa_k}{\sqrt{\hat{\sigma}_k^2-\kappa_k^2}}\sinh\sqrt{\hat{\sigma}_k^2-\kappa_k^2}z_k & \cosh\sqrt{\hat{\sigma}_k^2-\kappa_k^2}z_k+\frac{-i\hat{\sigma}_k}{\sqrt{\hat{\sigma}_k^2-\kappa_k^2}}\sinh\sqrt{\hat{\sigma}_k^2-\kappa_k^2}z_k \end{bmatrix}$$

In that case, by manipulation of the section parameters, it is possible to analyse different types of gratings and TFBG under influence of external conditions (i.e. axial strain, temperature).

And by appling axial strain TFBG provides functionality of the tunable delay line, which may be used in microwave systems (for example: phase-arrays antenas technology)

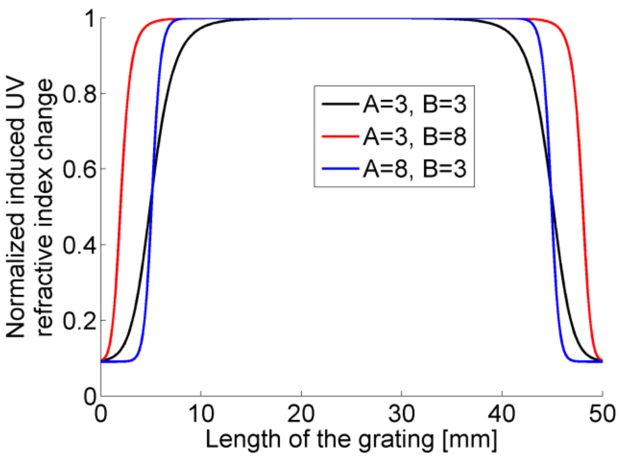
Idea of apodization



TFBG under the influence of axial strain

Unfortunatly, group delay characteristic of typical TFBG is jagged and strongly oscillates.

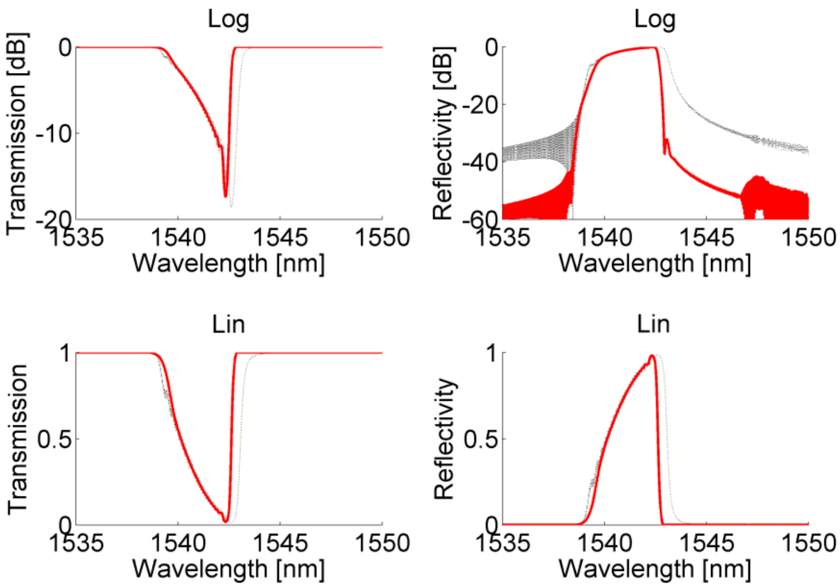
This problem may be solved by appling well known, in terms of FBG with chirped pattern, apodization technique. Term apodization refers to the grading of the refractive index to approach zero at FBGs ends.

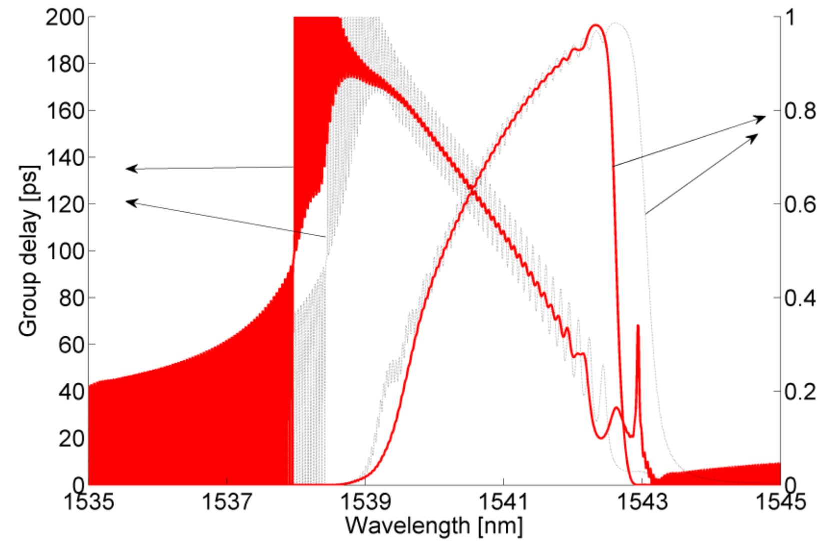


$$g(z) = \begin{cases} 1 + tanh\left[A\left(1 - 2\left(1 - \frac{2}{L}z\right)^{B}\right)\right], & z \in \left(0, \frac{L}{2}\right) \\ 1 + tanh\left[A\left(1 - 2\left(\frac{2z - L}{L}\right)^{B}\right)\right], & z \in \left(\frac{L}{2}, L\right) \end{cases}$$

Typical apodization function is hyperbolic tangent.

Idea of apodization

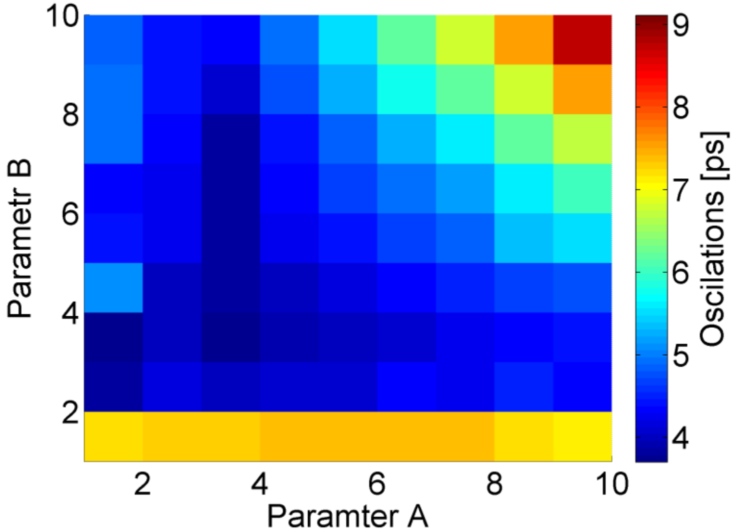




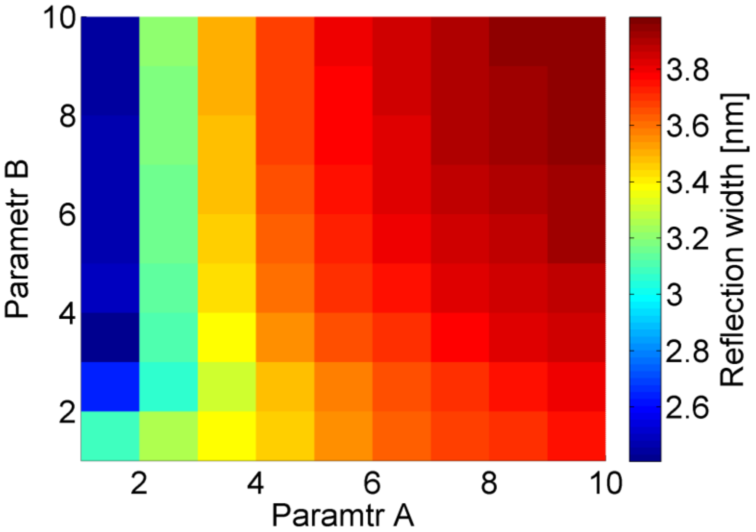
Gratings with the apodized changes of UV induced refractive indices has smother reflectivity, transmission as well as group delay characteristics.

Unfortunately, with the smother characteristic, reflection width slightly decreases.

Optimization of the tanh apodization function



Minimum value of the group delay oscillations has been achieved for A=3 and B=3



Maximum value of the reflection width has been achieved for A=10 and B=10

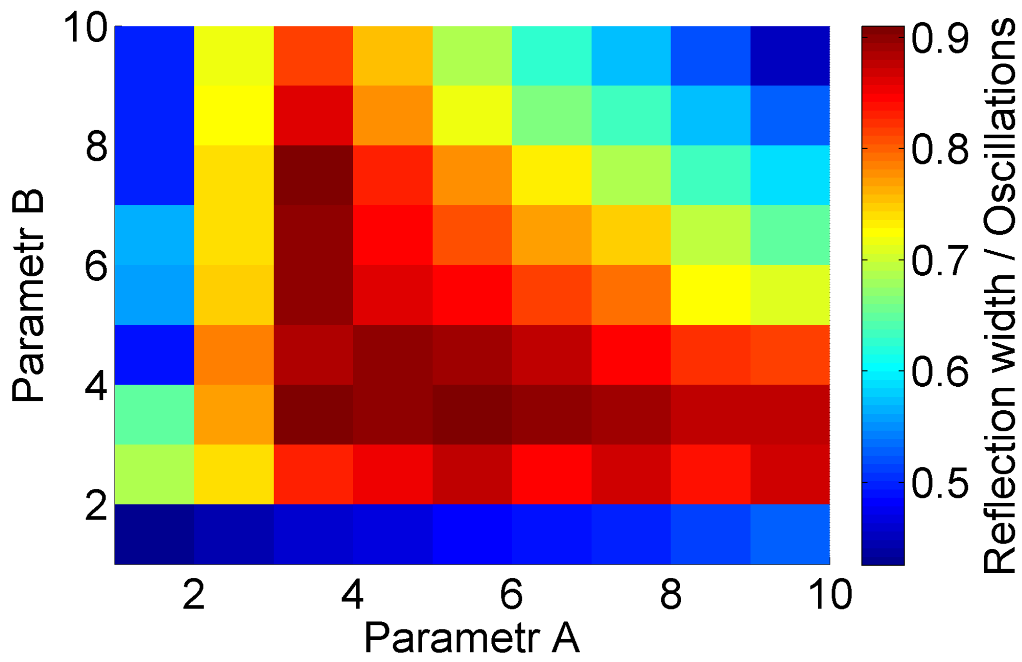
$$\bar{\tau}_g = \frac{1}{N-1}\sum_{i=1}^{N-1}|\tau_i - \tau_{i+1}|$$

Formula used to determine group delay oscillation factor for TFBG

Optimization of the tanh apodization function

The final step, in order to optimize parameters of the TFBG is to qualitative comparison of its attributes. For this purpose, it appears to be useful to determine ratio of the spectral width to the oscillation factor

Colormap reaches its maksimum at A=3 and B=3, what can be considered as optimized value for tanh apodization function



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