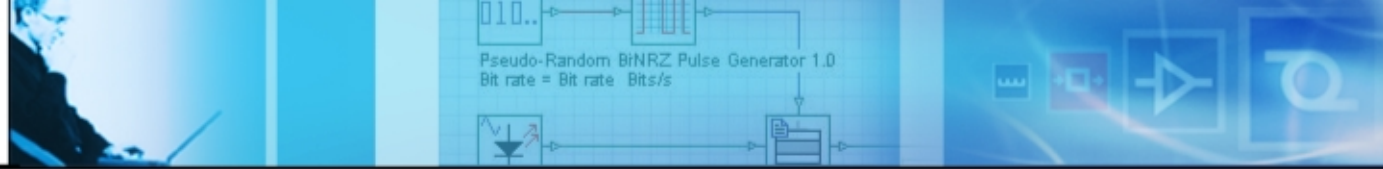


# **Design of WDM Optical Components - Integrated Waveguides, Arrayed Waveguide Gratings, and Fibre Gratings**



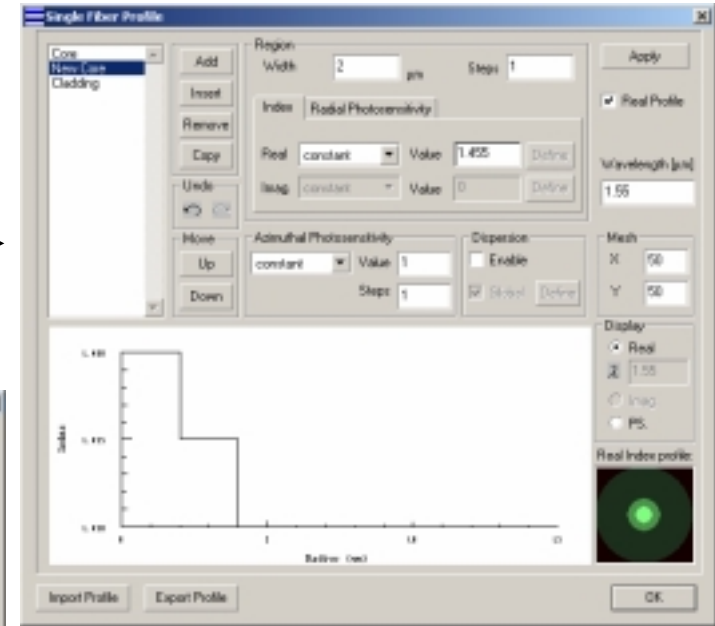
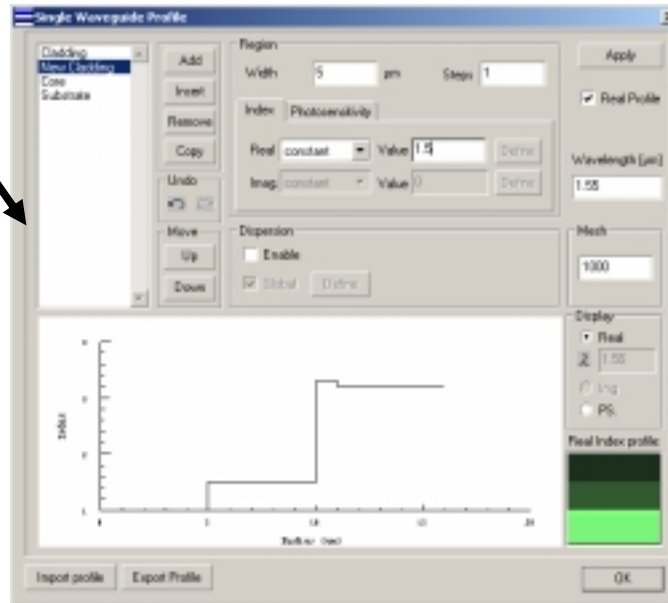
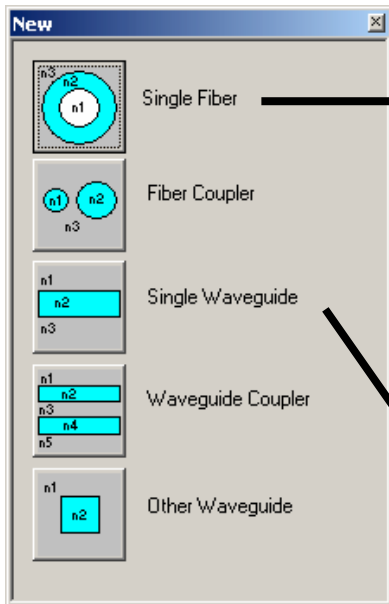
# Introduction

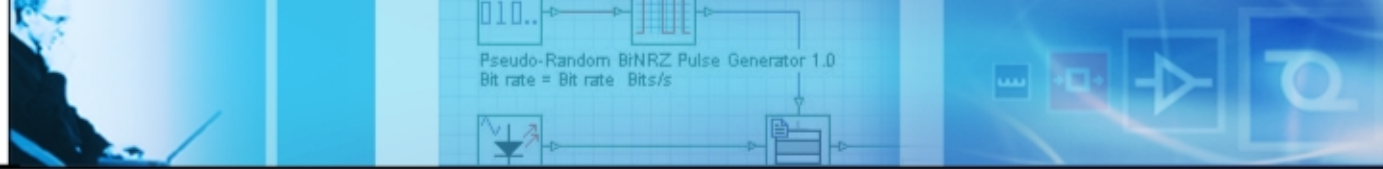
Topics: Design and simulation of

1. Apodized and chirped grating on an optical fibre.
2. 8 channel AWG (Arrayed Waveguide Grating).
3. Optical combiner using integrated waveguides.

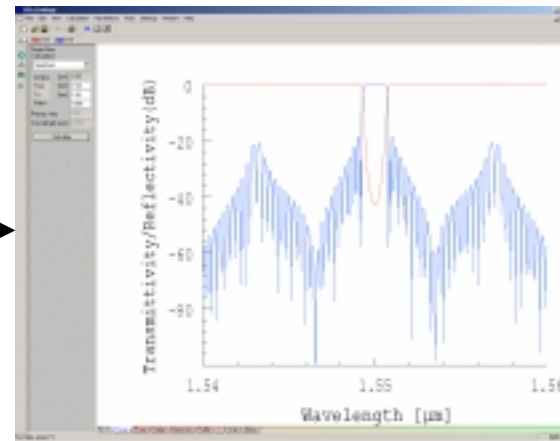
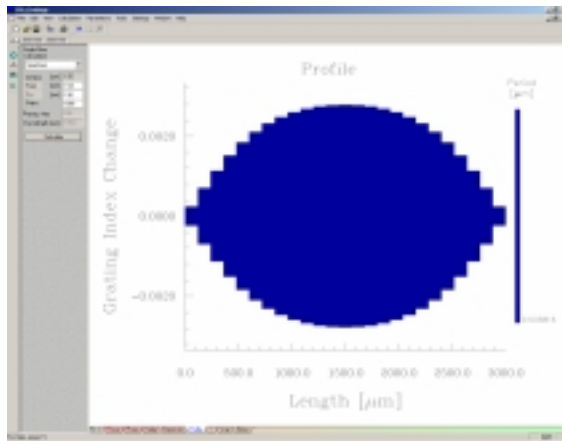
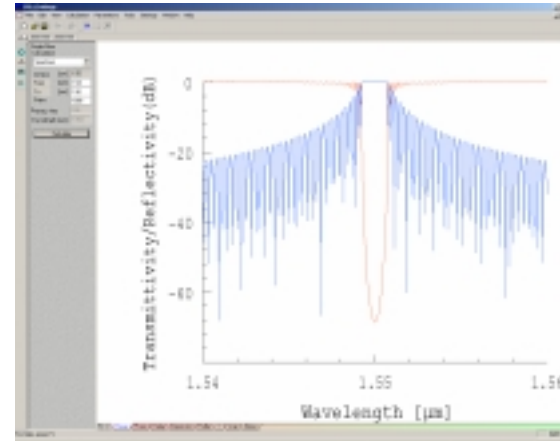
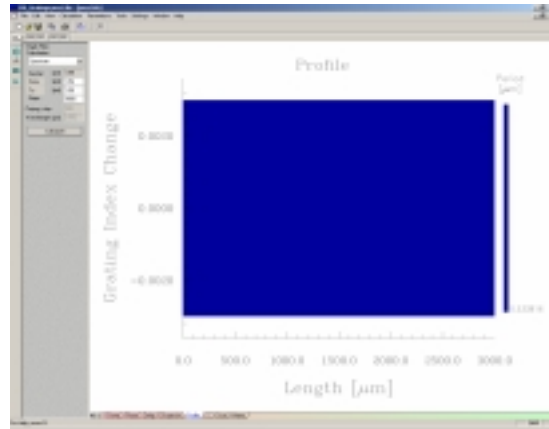
Using Optiwave software

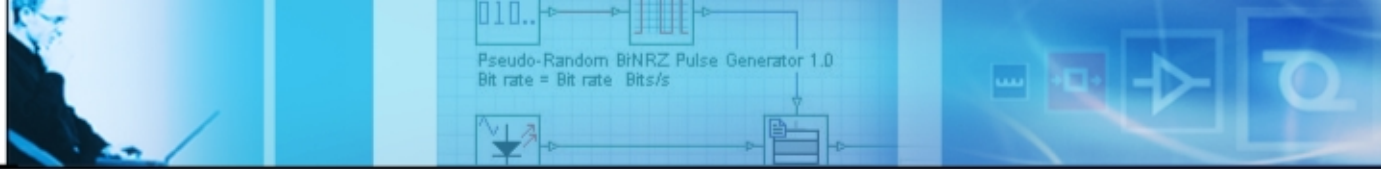
# 1. Optical Fibre Grating



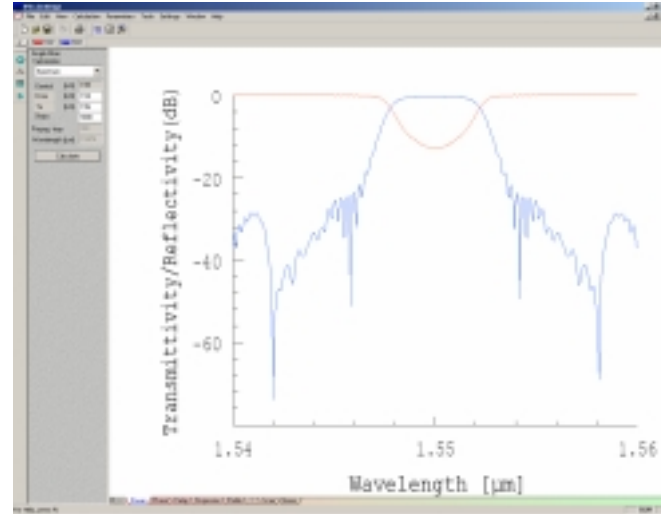
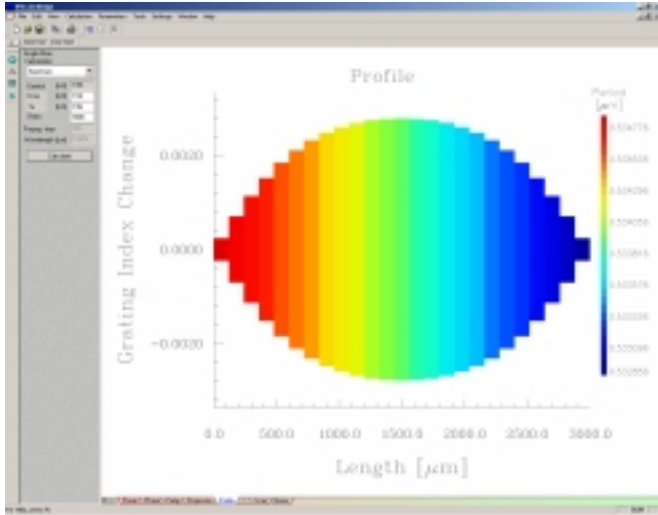


# Grating Apodization

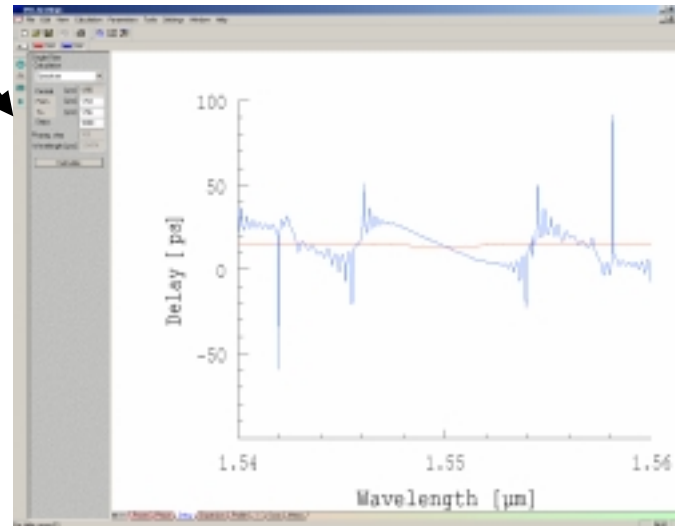




# Grating Chirp

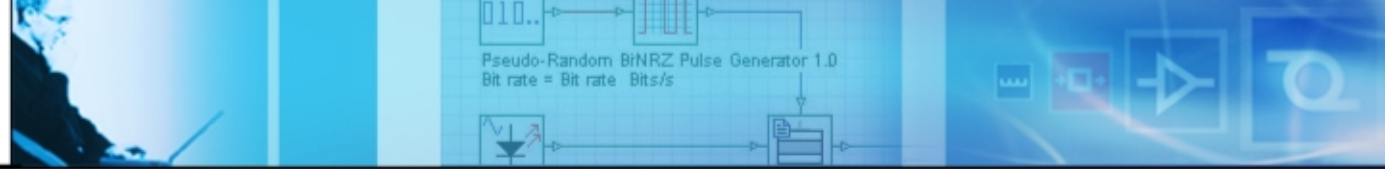


Power

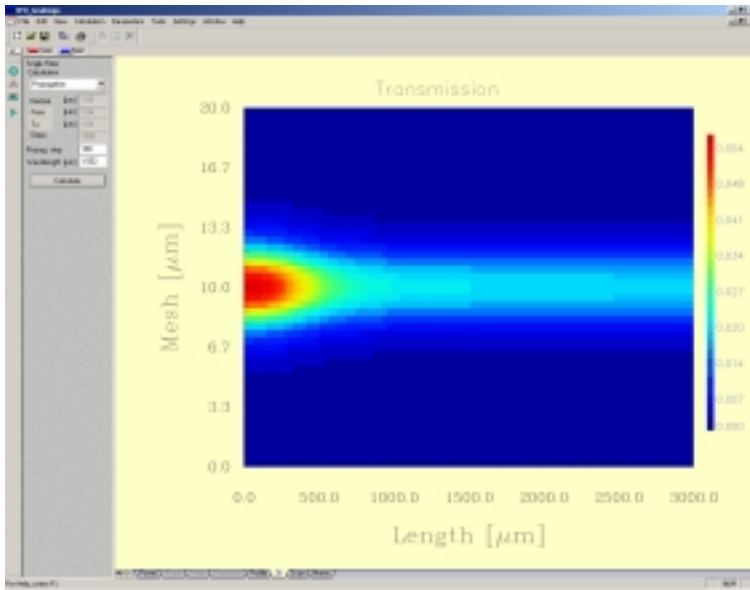


Delay

$\lambda$	Delay (ps)
1.5474	27
1.5520	4.5

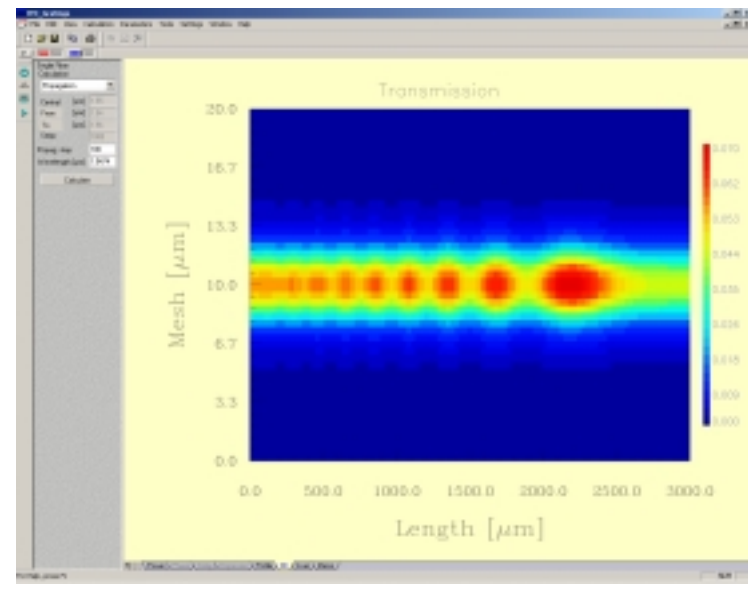


# Differential Delay



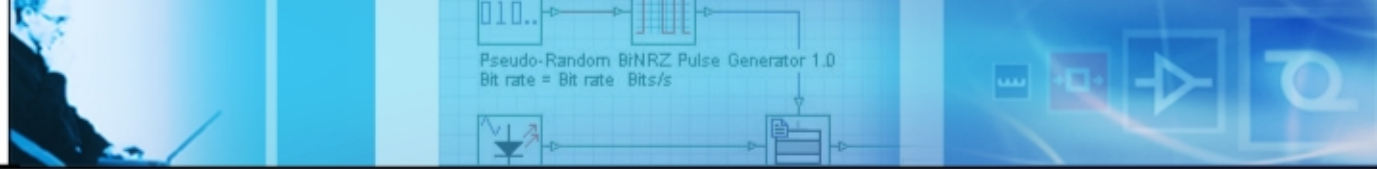
$\lambda = 1552.0$  nm

Reflection delay = 4.5 ps



$\lambda = 1547.4$  nm

Reflection delay = 27.0 ps



# Inverse Problem



Inverse Problem Solver

Define Target Spectrum

Use Defined

From [int]  Bit/Time

To [int]   Phase

Steps   Delay

From File

File Name

Length [int]  Segments  One Sample

Phase Shift

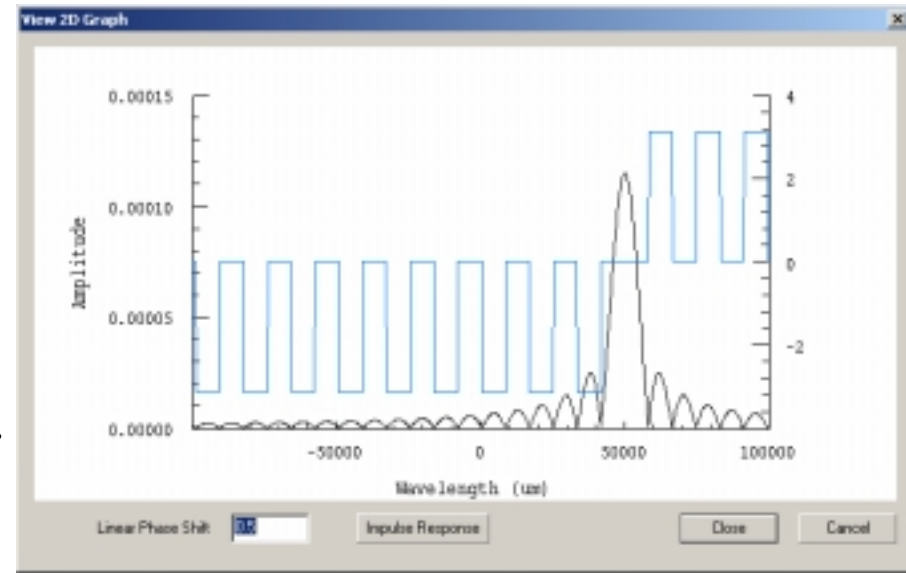
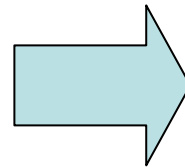
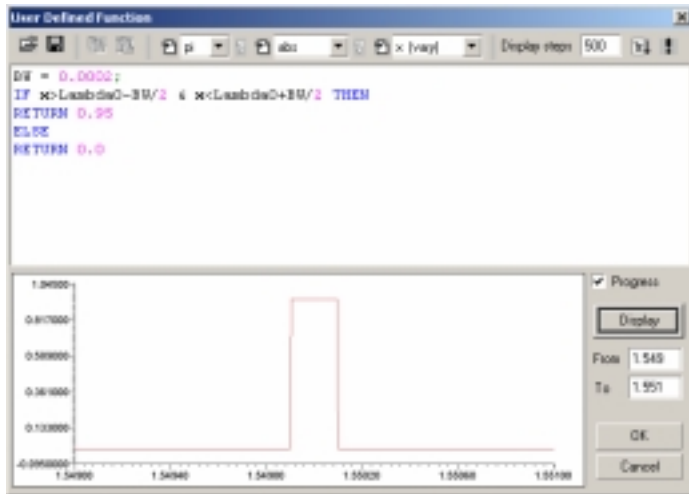
Linear   Auto

Filters

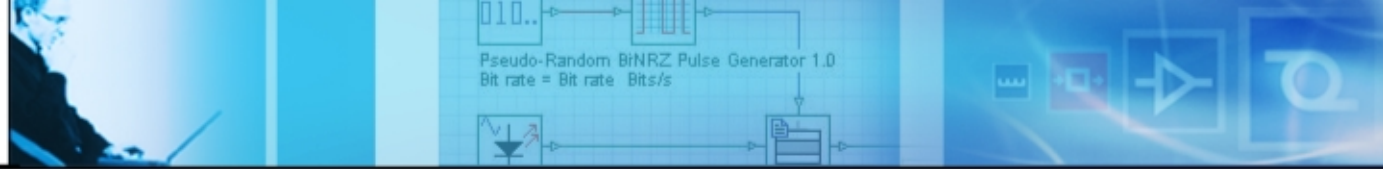
Input Function

Scaling/Profile

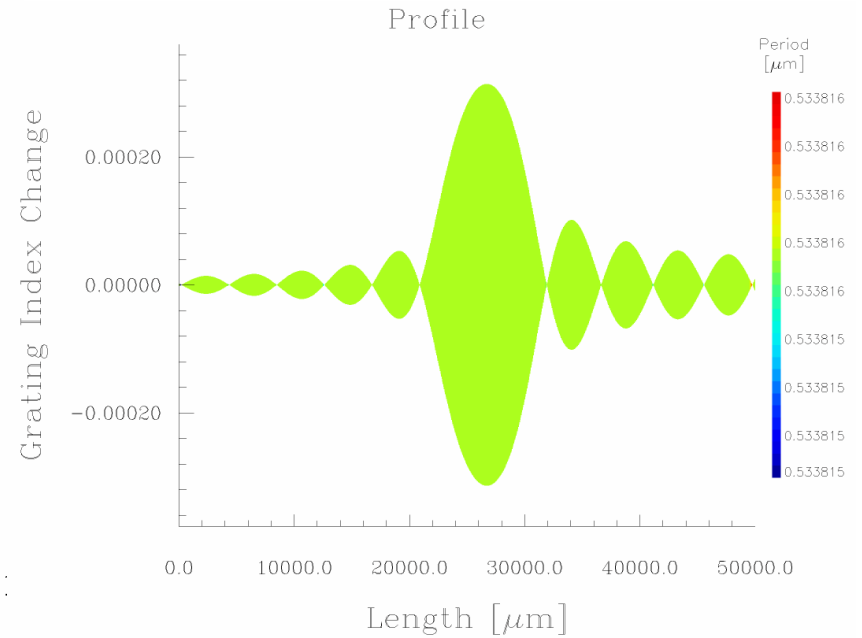
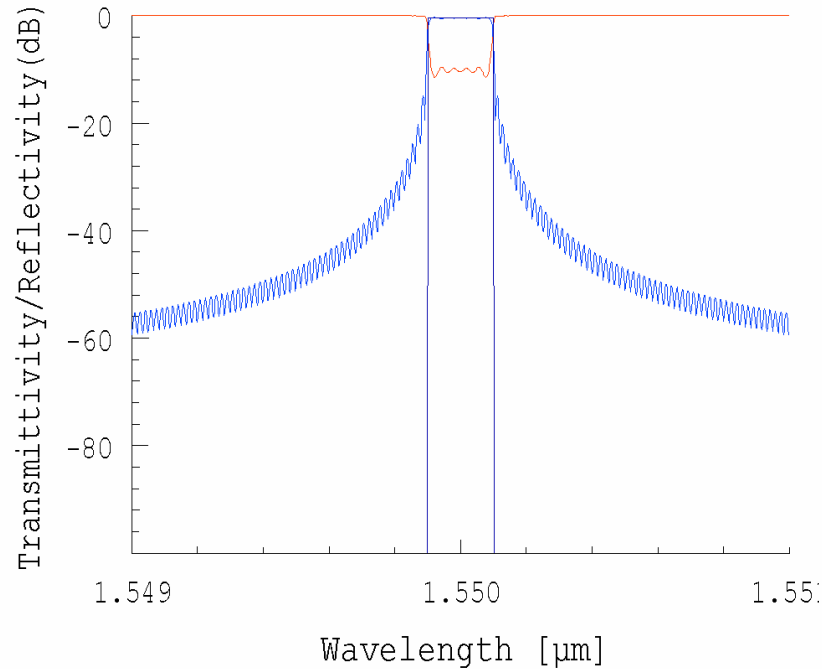
Desired Spectrum



Optical Impulse Response of Desired System

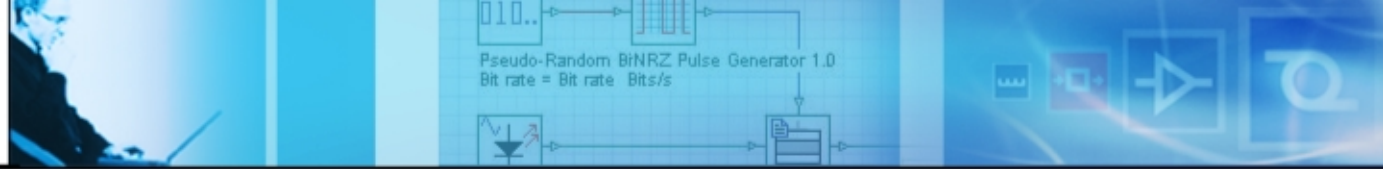


# Reconstruction

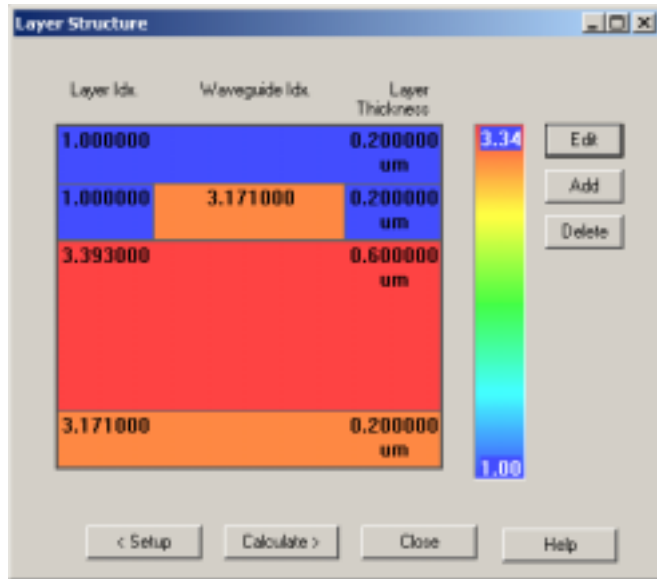


Desired and Realized Spectrum

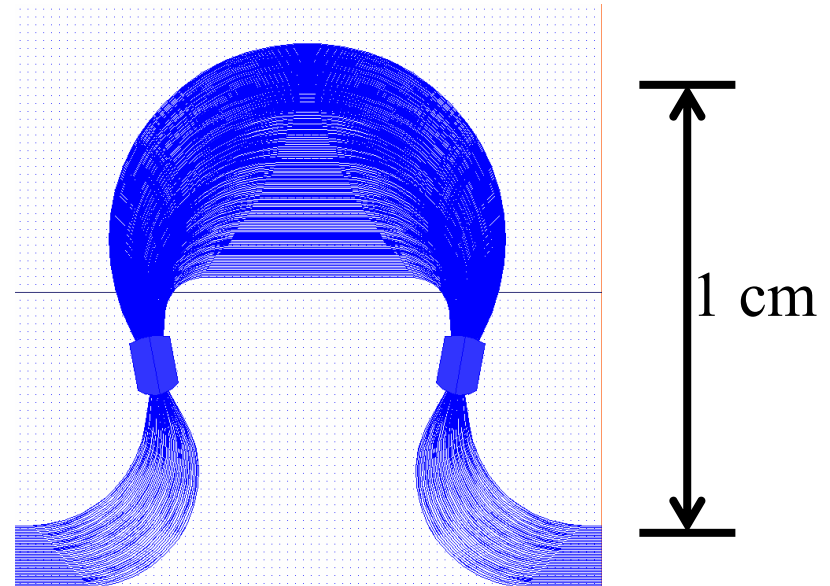
Reconstructed Profile



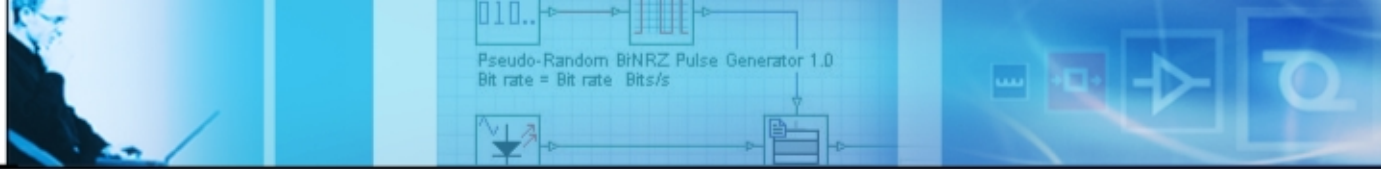
## 2. Arrayed Waveguide Gratings (AWG)



Rib Waveguide Cross Section



40 Channel AWG



# AWG Design Wizard

**WDM Parameters**

Water Effective Index	3.32735	Input/Output Waveguides	1.5	Phased Array Waveguides	1.5
Wavelength [μm]	1.55	Waveguide Width [μm]	1.5	Max. Crosstalk Level [dB]	-35
Polarization		Waveguide Effective Index	3.36101	Phased Array Waveguides Effective Index	3.36101
<input checked="" type="radio"/> TE <input type="radio"/> TM					

< Back   Next >   Cancel   Help

**WDM Parameters**

Minimum Separation [μm]	4.35	FPR Effective Index	3.36101
Input/Output Waveguides	4.35	Nonuniformity [dB]	0.5
Phased Array Waveguides	4.35	Output Channels	8

< Back   Next >   Cancel   Help

**WDM Parameters**

Calculated Free Propagation Region

Minimum Length	485.489 μm	Far Field Half Angle	0.1308 rad
----------------	------------	----------------------	------------

Channel Spacing [GHz]: 100

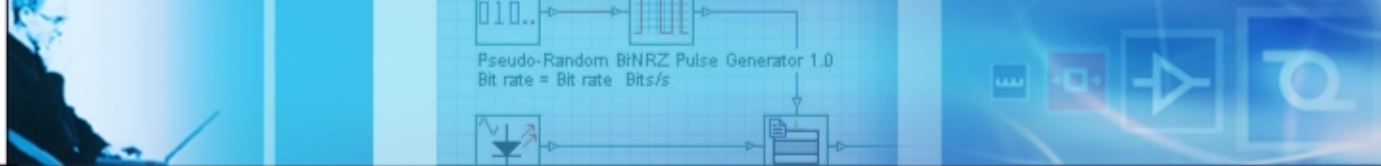
Array Maximum Transmission [dB]: 0.2

< Back   Next >   Cancel   Help

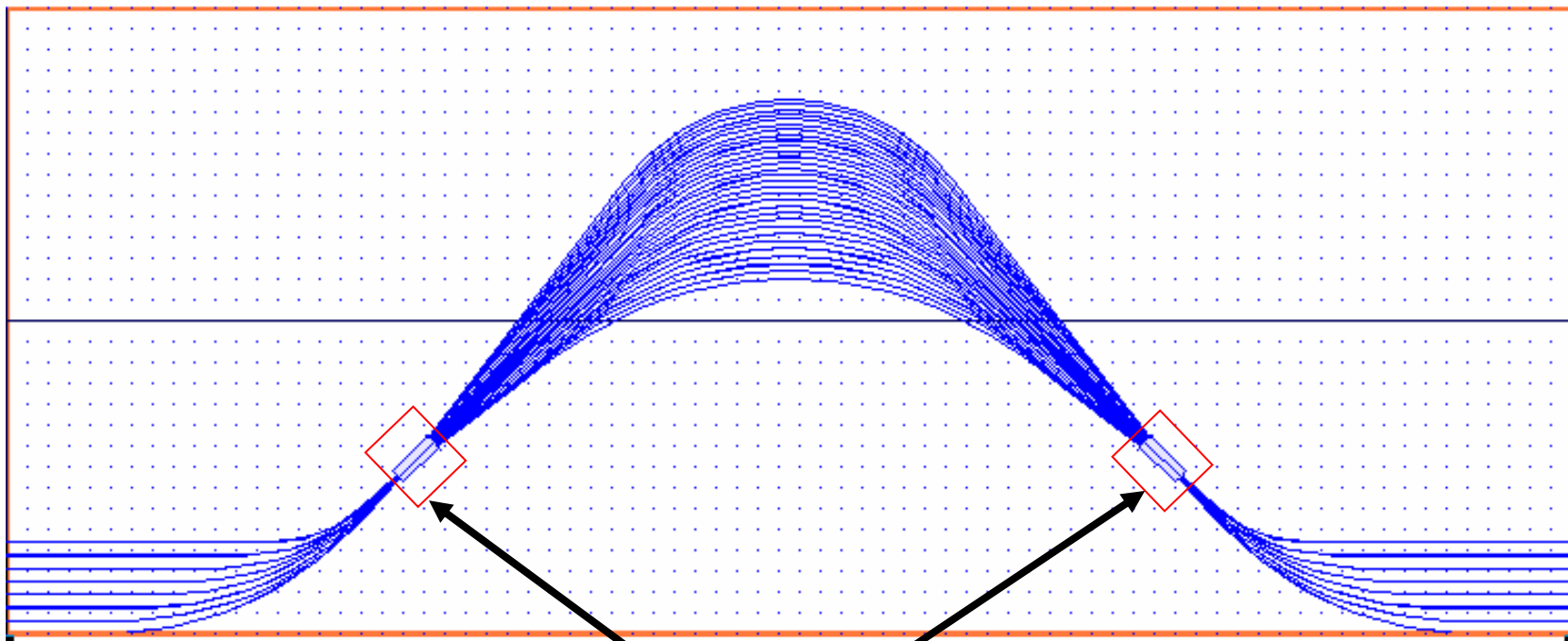
**WDM Parameters**

Modal Index	3.3479931	Array Waveguides Length	75.45 μm
Output Waveguides	3.3479931	Nr. of Waveguides	30
Array Waveguides	3.3479931	Far Field Half Angle	0.1312 rad
Free Propagation Region		Order	163
Minimum Length [μm]	485.489		

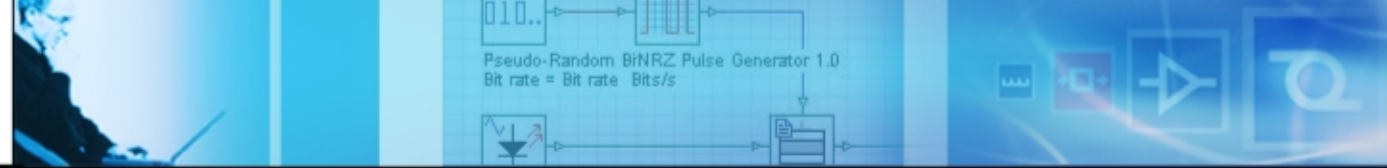
< Back   Finish   Cancel   Help



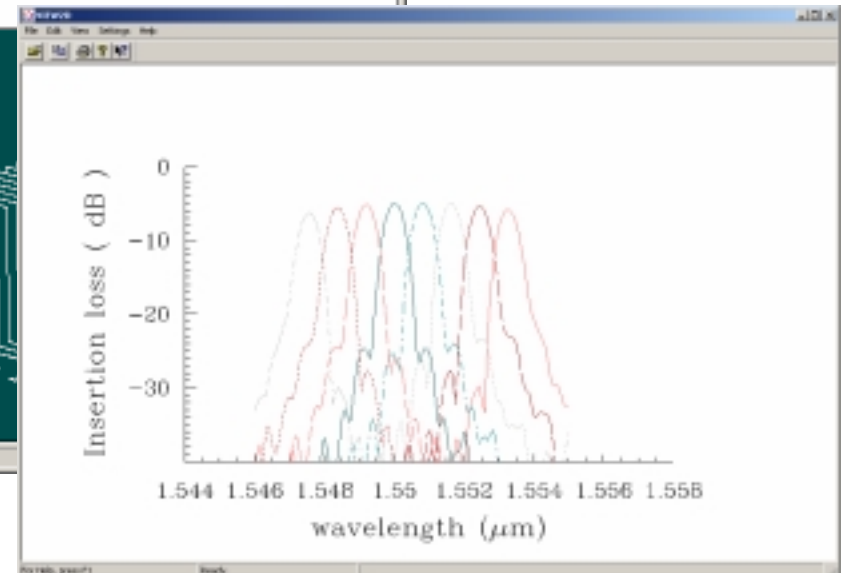
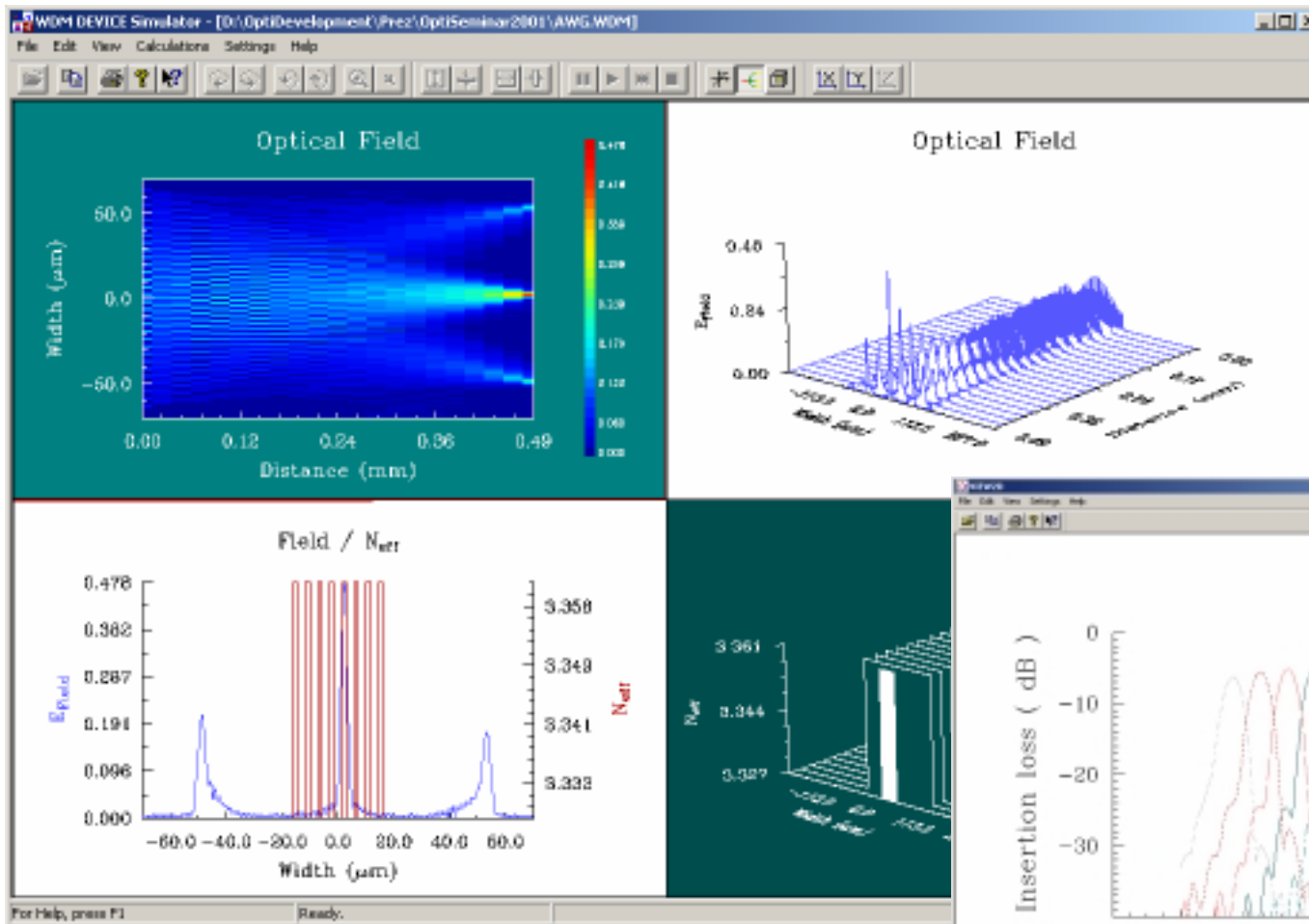
# AWG Layout

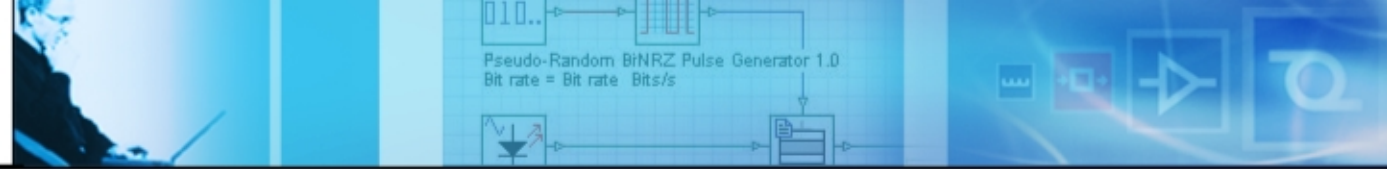


BPM simulation zones

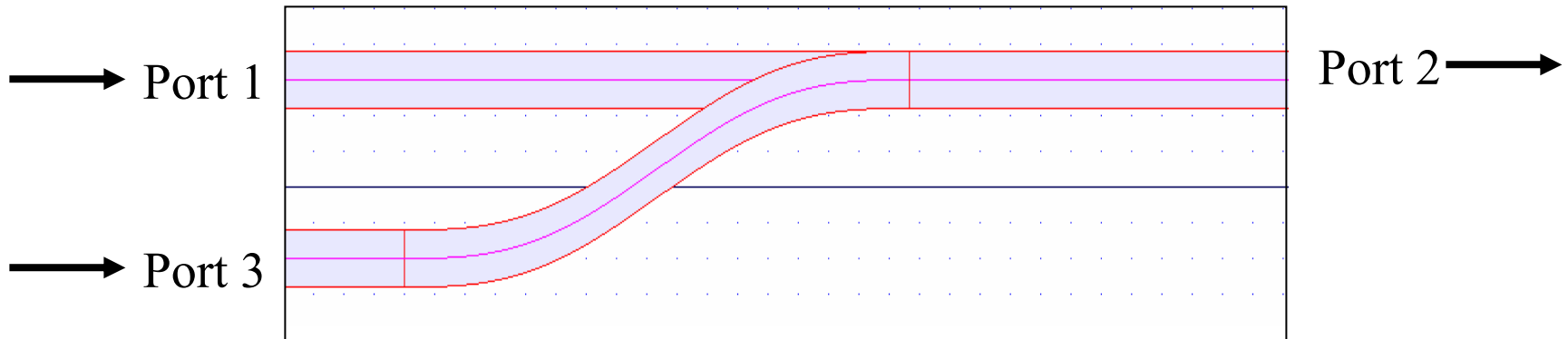


# AWG Simulation

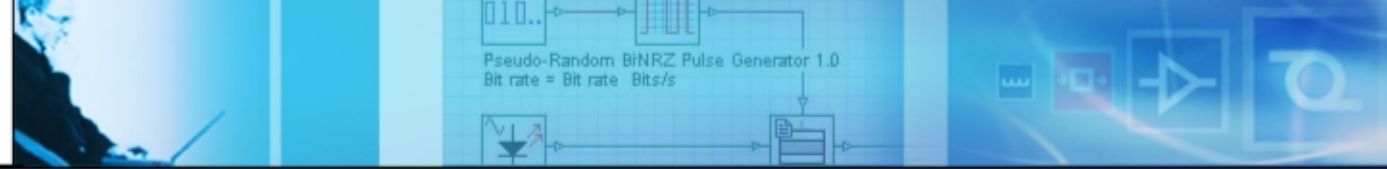




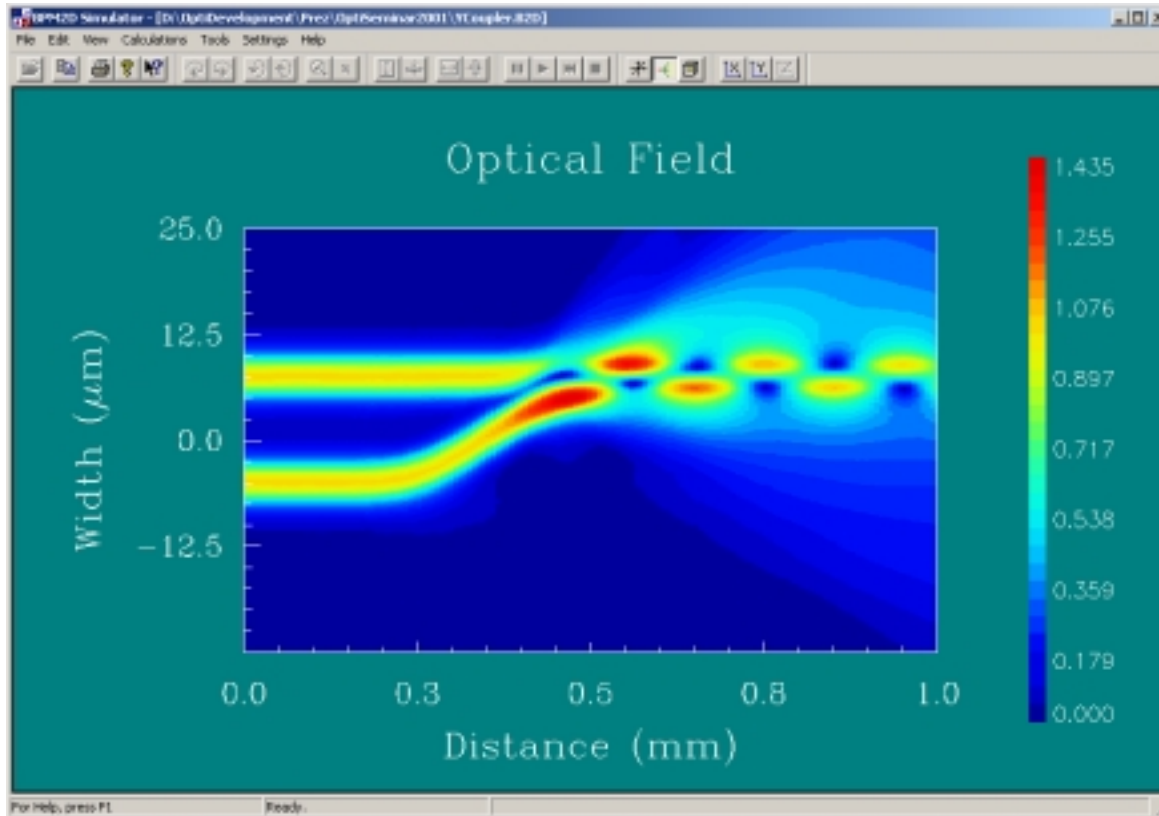
### 3. Optical Power Combiner

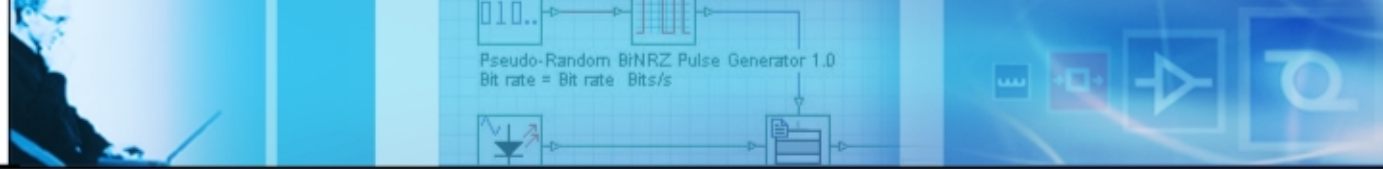


- Design a waveguide junction which takes power coming in Port 1 and Port 3 and combines them into Port 2 with no loss.

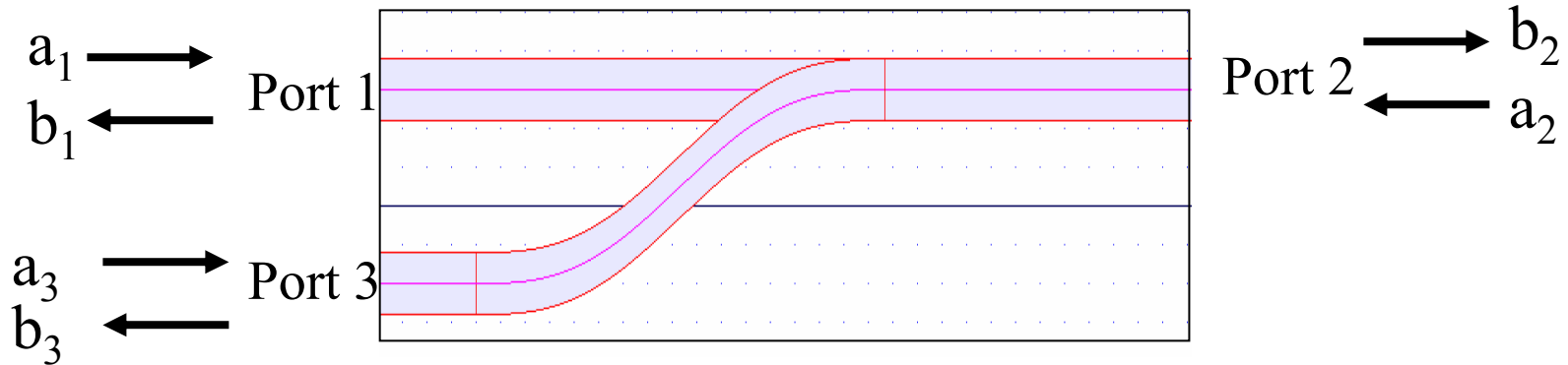


# Simulated Y Coupler





# 3 Port Networks



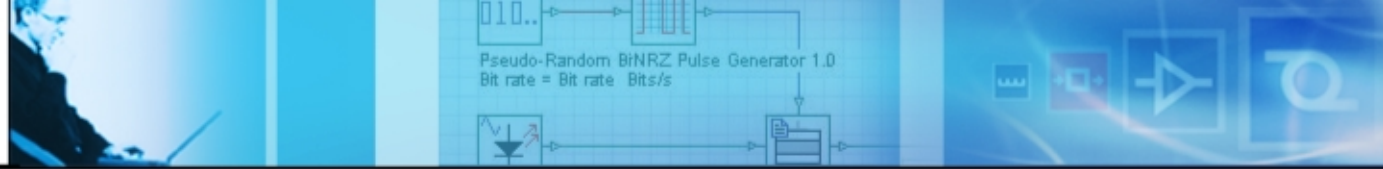
S matrix is the relation between Waves entering and waves exiting

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

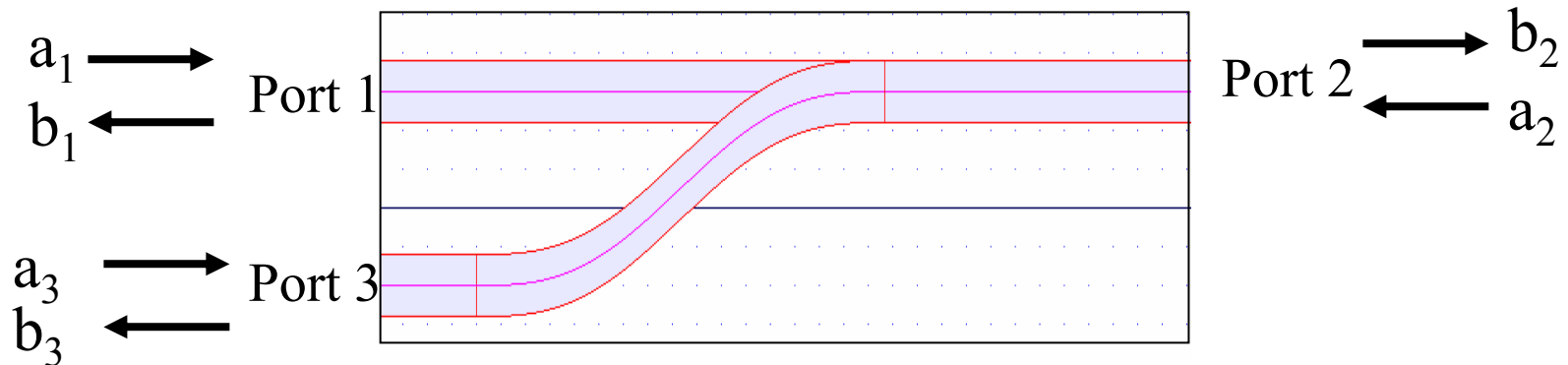
Basic results from Electromagnetic theory:

Reciprocity:  $S = S^T$   
 i.e.  $S_{21} = S_{12}$  and  $S_{23} = S_{32}$

Loss-less:  $SS^{\bar{T}} = I$



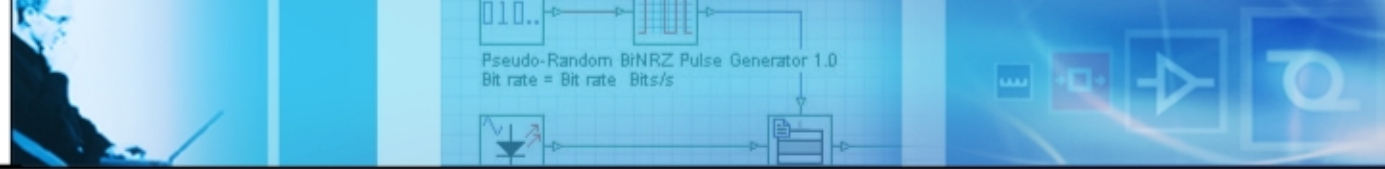
## Trouble with 3 Ports



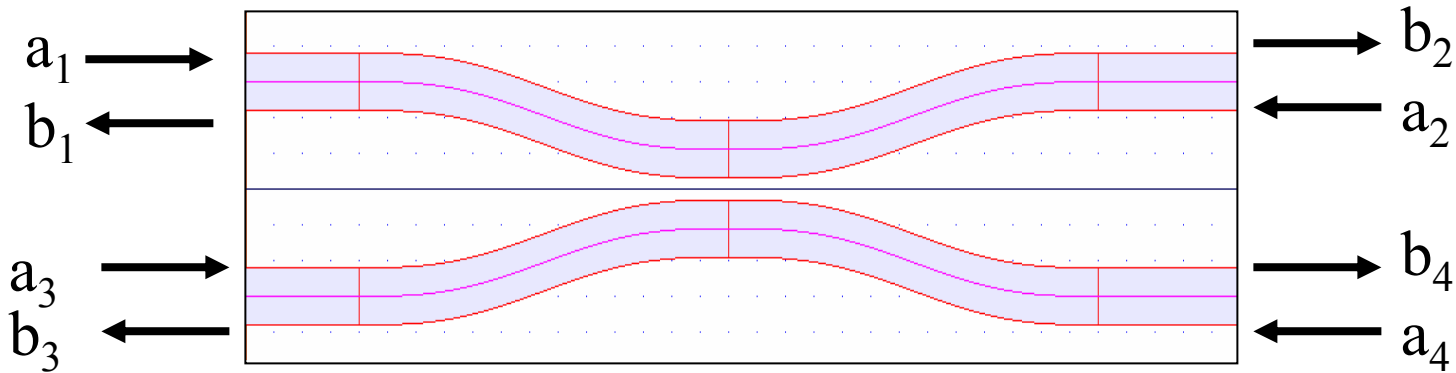
Ideal power combiner would have  $|S_{21}|^2 = 1$  and  $|S_{23}|^2 = 1$

and Reciprocity would imply  $|S_{12}|^2 = 1$  and  $|S_{32}|^2 = 1$

But this is impossible!



# 4 Port Networks

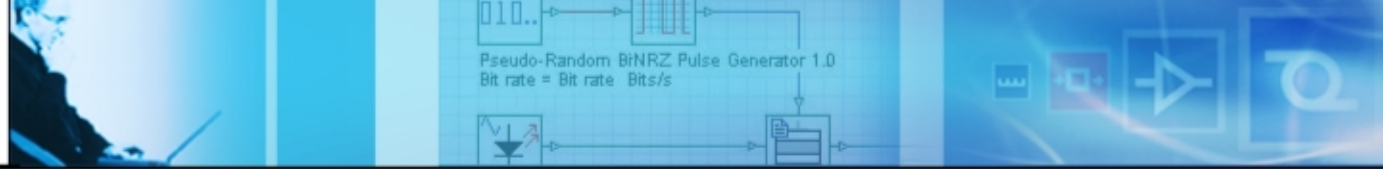


$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} 0 & t & 0 & jc \\ t & 0 & jc & 0 \\ 0 & jc & 0 & t \\ jc & 0 & t & 0 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}$$

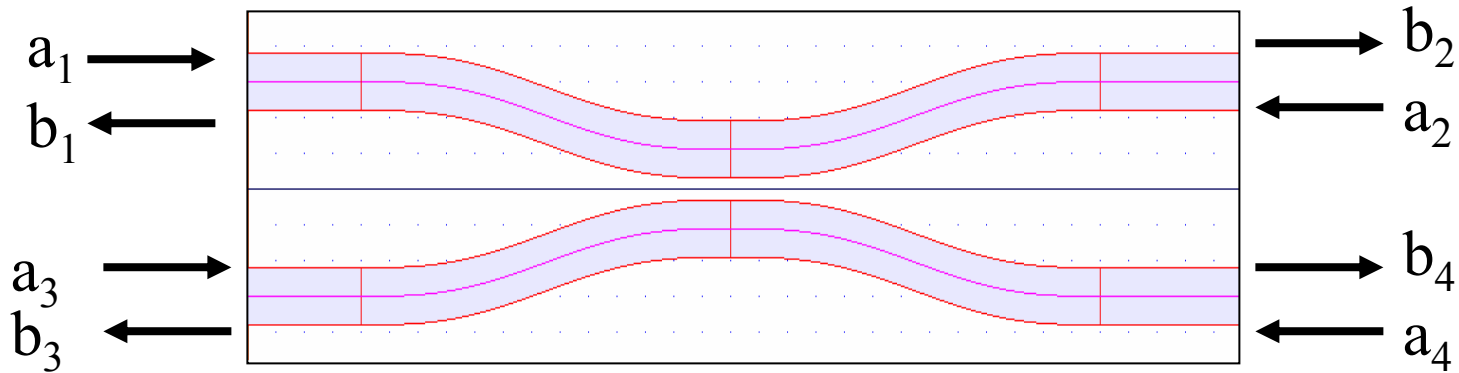
$$t = \sqrt{P_{\text{transmitted}}}$$

$$c = \sqrt{P_{\text{coupled}}}$$

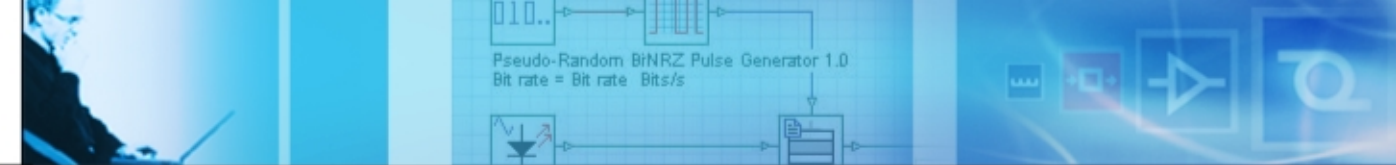
$$t^2 + c^2 = 1 \quad j = \sqrt{-1}$$



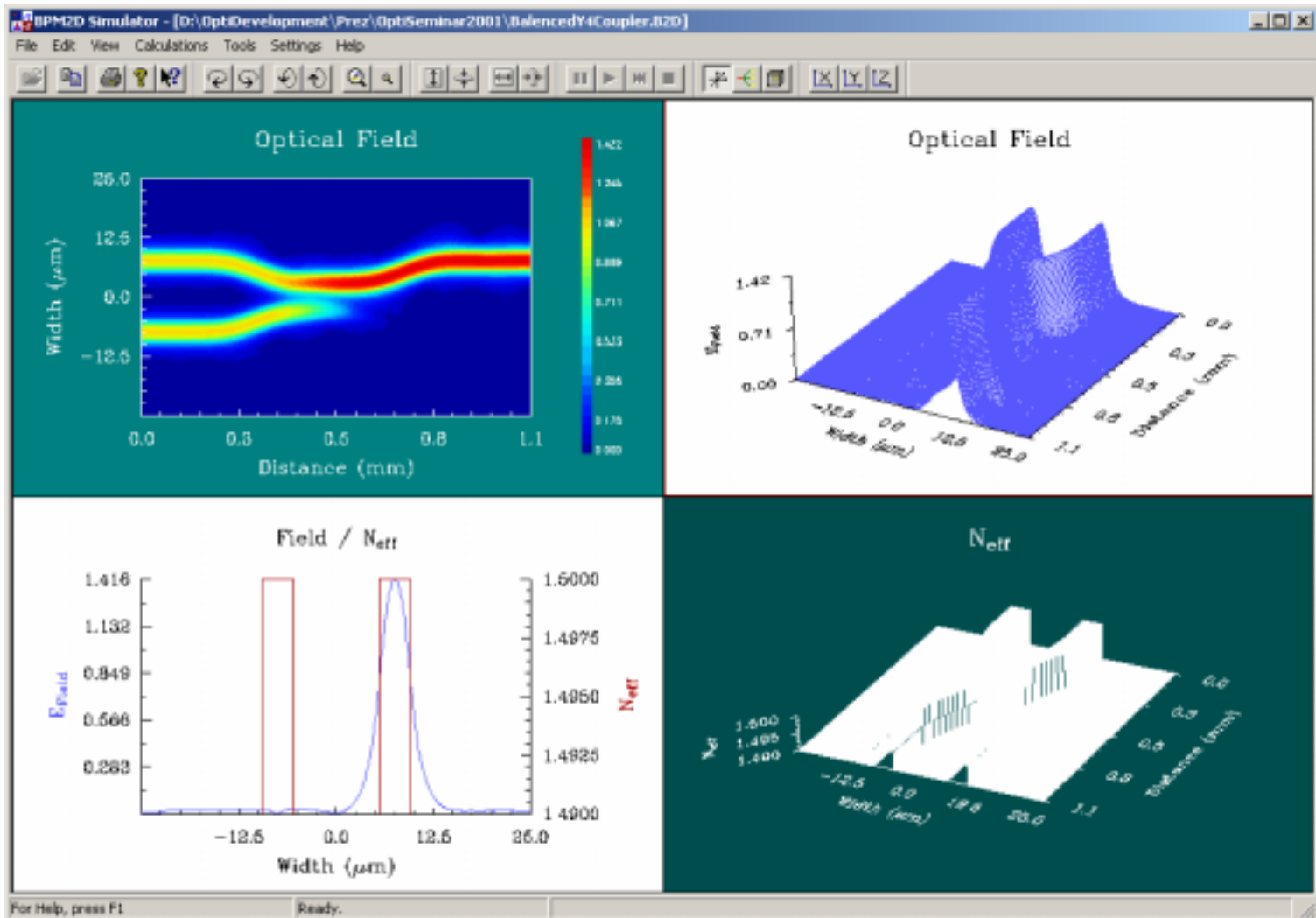
# 4 Port Combiner

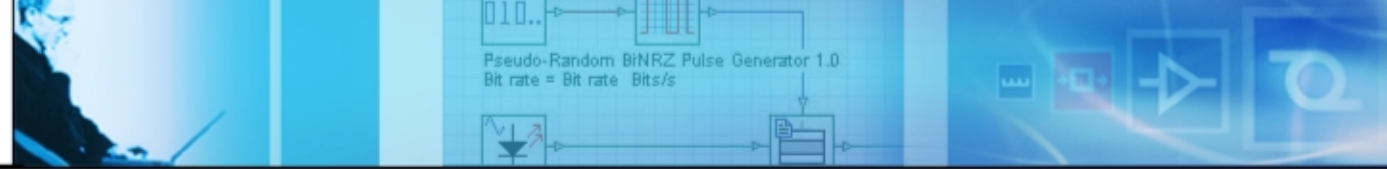


$$\begin{bmatrix} 0 \\ \sqrt{2} \\ 0 \\ 0 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 0 & j \\ 1 & 0 & j & 0 \\ 0 & j & 0 & 1 \\ j & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ -j \\ 0 \end{bmatrix}$$



# Combiner Simulation

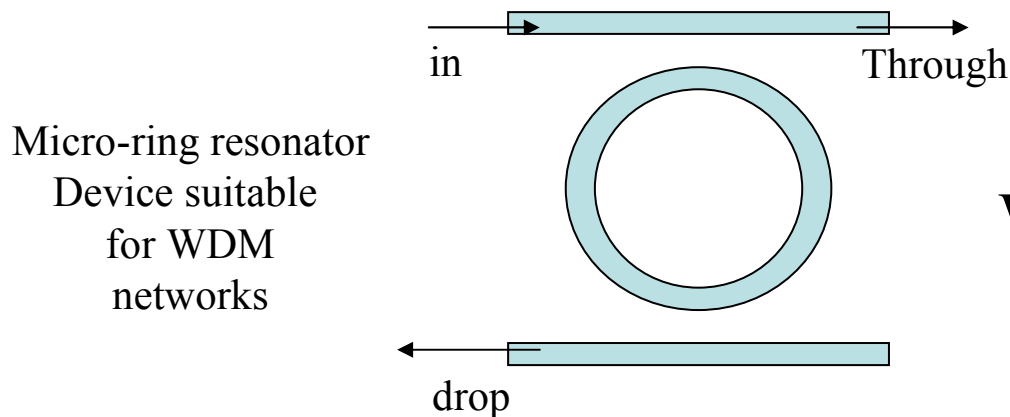




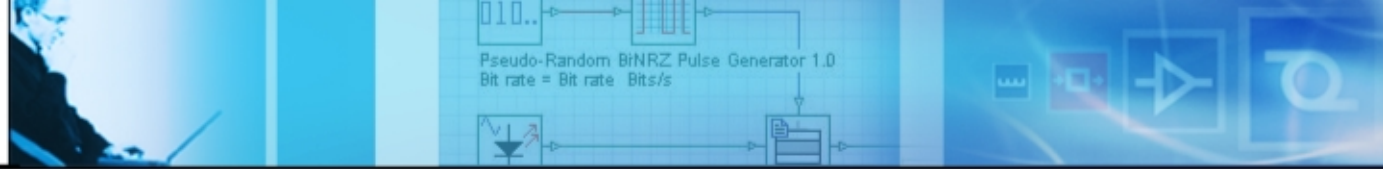
# Micro-ring Resonator (Couplers and Beyond)

BPM is a unidirectional simulation tool. Typical applications: Mach Zehnder interferometer, couplers, Y junctions, ...

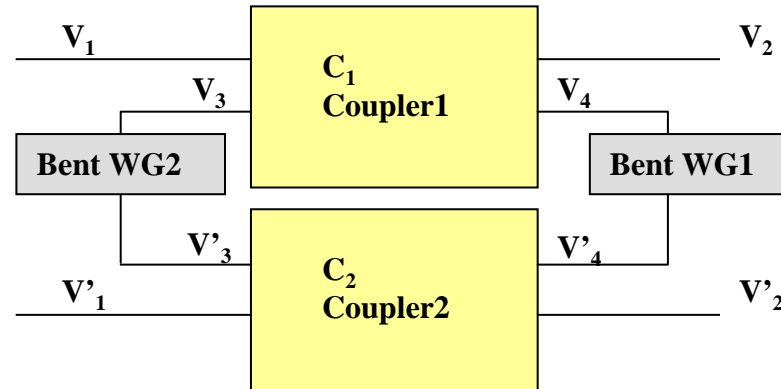
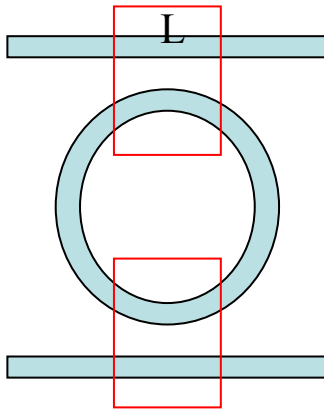
Modeling of devices like micro-ring resonators, Cylindrical Micro-cavities, photonic bandgap crystals, requires Omni-directional modeling tools ( FDTD, Helmholtz FEM solver)



Why not use BPM ?



# Segmentation of the Problem

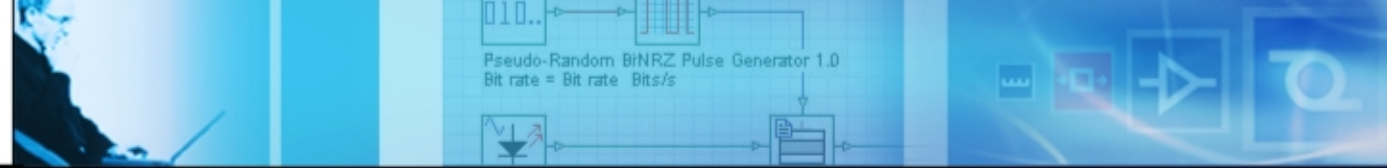


Coupling between the waveguide and the ring occurs over a finite length  $L$

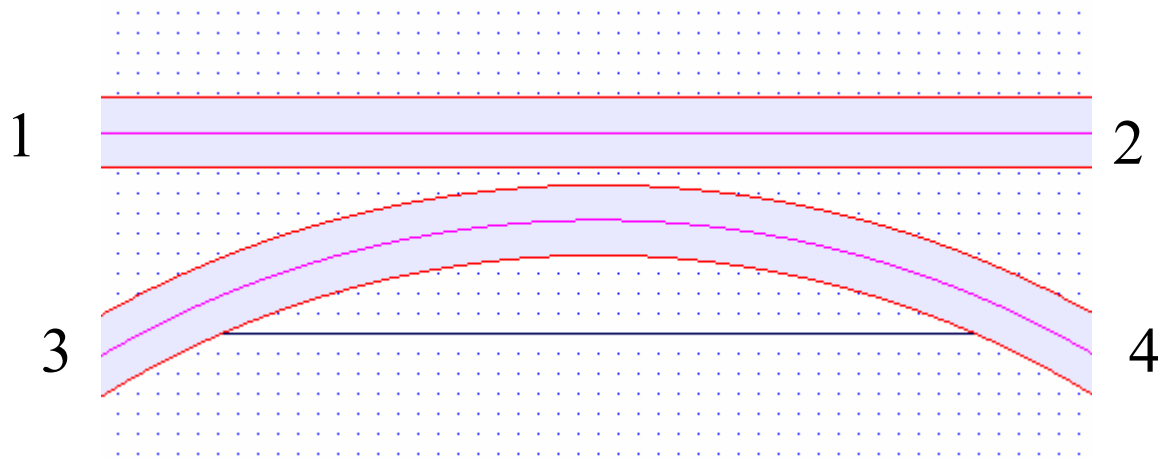
→ The problem can be split into smaller problems regarding the beam propagation in the coupler and the straight and bent waveguides, as long as we are able to match the interfaces.

BPM provides means for analyzing both couplers, straight and bent waveguides.

Is there a way to use the available resources?  
circuit theory with devices as N-ports?



# Micro Ring Coupler



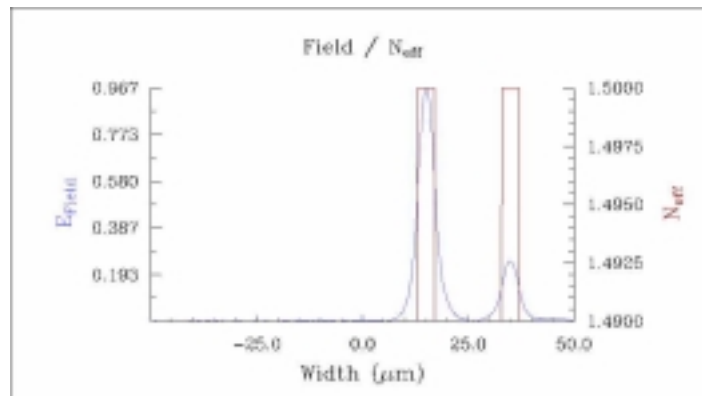
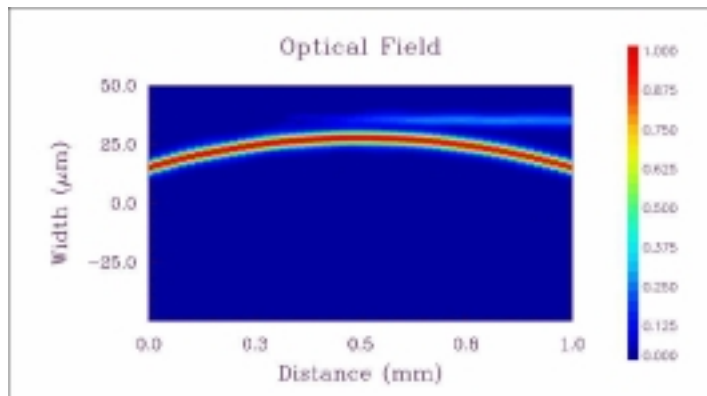
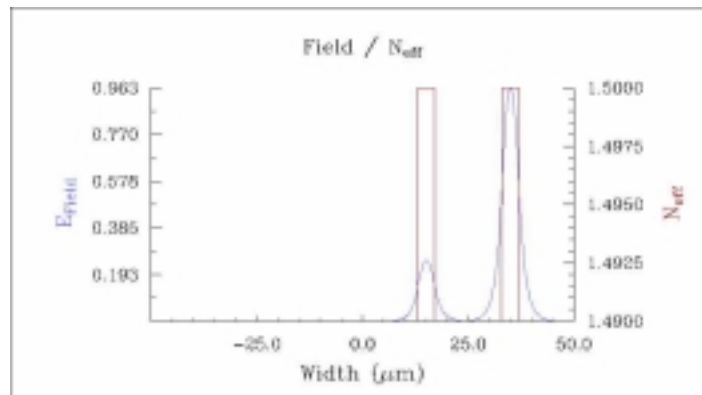
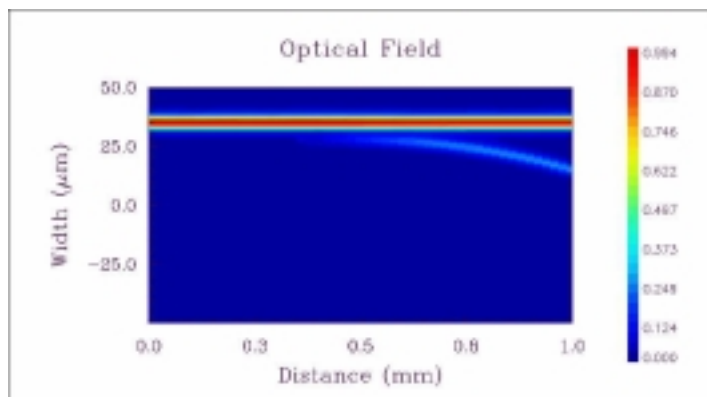
$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} 0 & t & 0 & jc \\ t & 0 & jc & 0 \\ 0 & jc & 0 & t \\ jc & 0 & t & 0 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}$$

Weak coupling

$$c \ll t$$



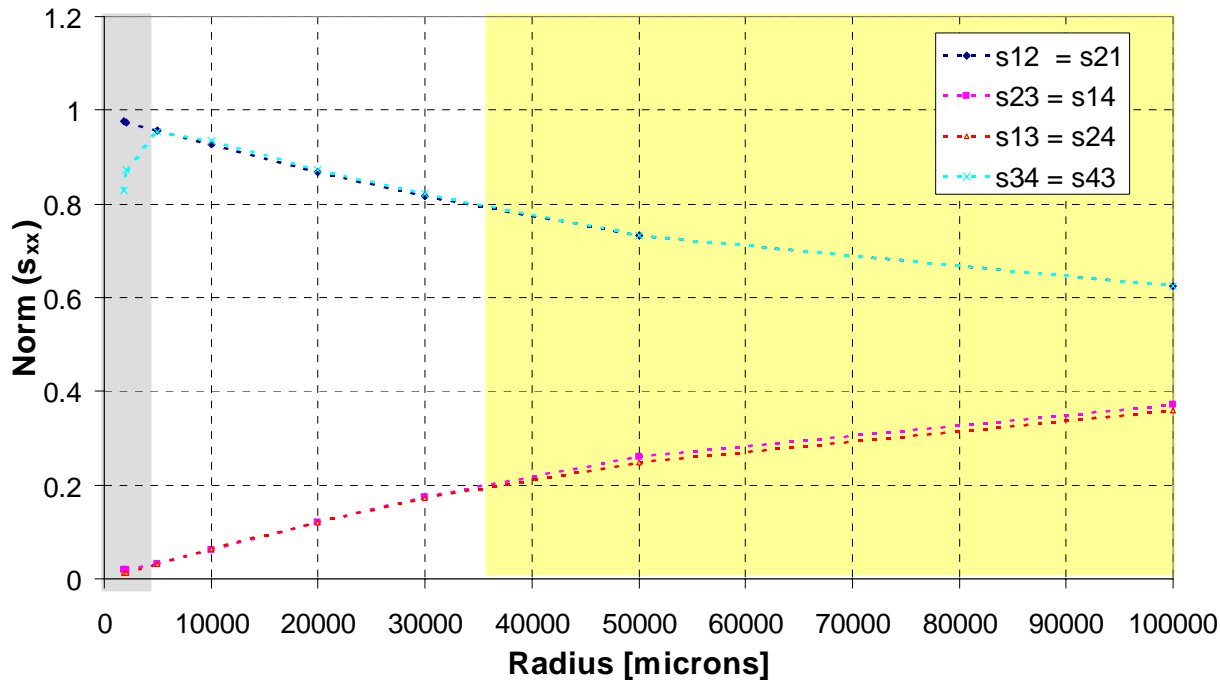
# Ring BPM Zone



Fields in waveguides at end of BPM propagation zone

# Micro Ring Simulation

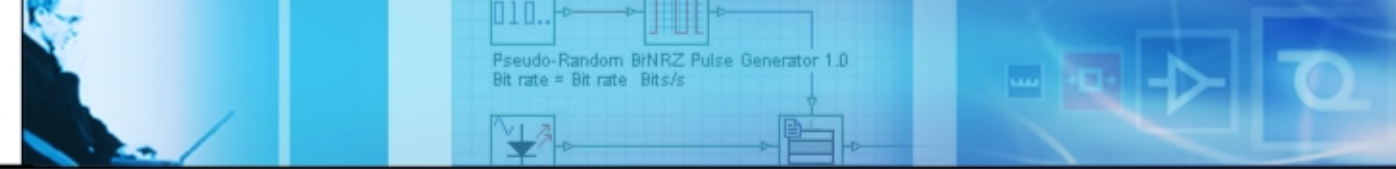
norm of the scattering matrix coefficients



Gray region – large bending losses; Scattering matrix asymmetrical

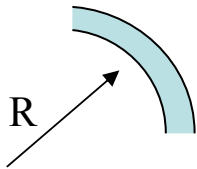
White region – scattering matrix almost symmetrical;  $P_2 + P_4 \sim 1$ ;  $P_1 - 2 \sim P_3 - 4$

Yellow region – not suitable for 4-port presentation; still coupling between waveguides



# Ring Circuit Analysis

Bent Waveguide



Propagation through both straight and bent waveguides can be simulated by a simple phase shift and attenuation, using the factor:

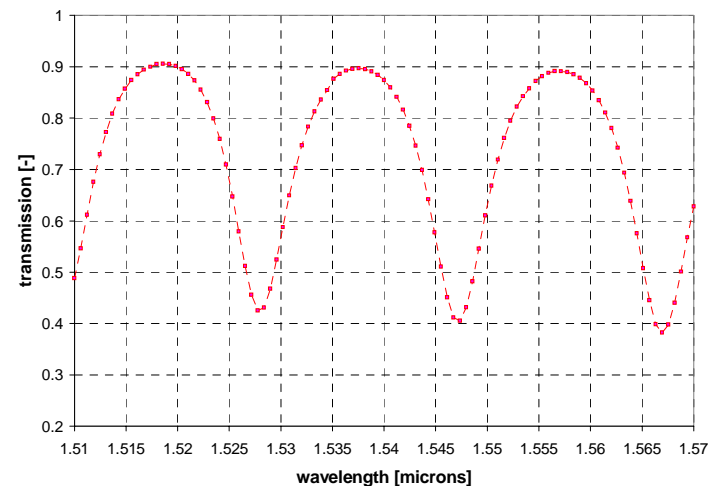
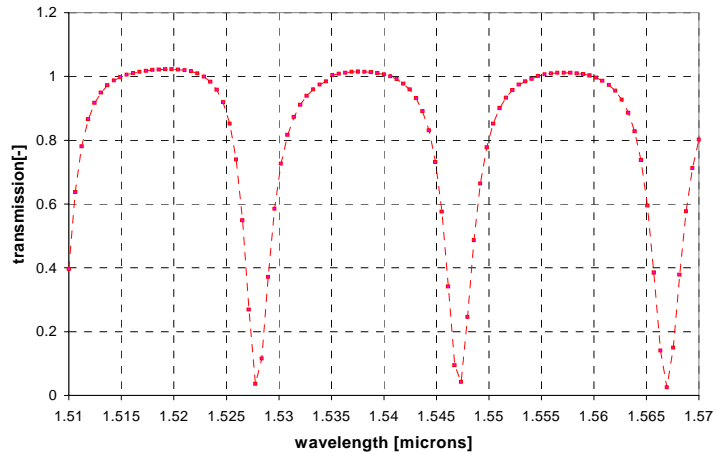
$$e^{-j\beta L}$$

Where  $\beta$  is a complex propagation constant.

Based on the 4-port description of the couplers and simplifying the waveguide propagation as an induced phase shift, we arrive at an expression for the output of the through port:

$$b_2 = \left[ t - \frac{c^2 t' e^{-2j\beta L_b}}{1 - t' t e^{-2j\beta L_b}} \right] a_1$$

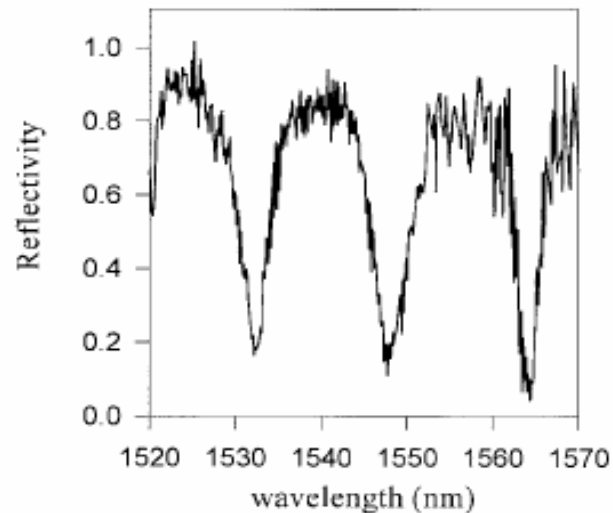
# Transmission Spectrum

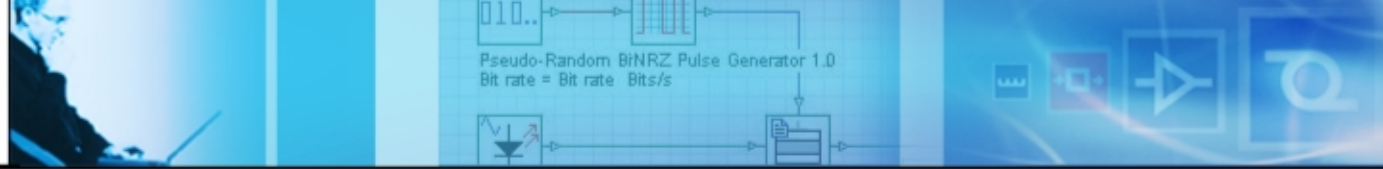


- Final transmission characteristic of the Micro Ring resonator with
1. no attenuation in the bends
  2. with attenuation of 0.36/cm

## Measured transmission of similar structure

( Rafizadeh, D, Zhang, JP, Tiberio, RC, Ho, ST, 'Propagation loss measurements in semiconductor microcavity ring and disk resonators', J.Lightw.Technol., vol.16, no.7, pp.1308-1314, July 1998 )





# Conclusions

This presentation has demonstrated the use of Optiwave software in the design of

1. Gratings in optical fibres
2. Arrayed Waveguide Gratings
3. Integrated waveguides

The software is useful for both proof of concept and Optimization.

By breaking problems into smaller parts, sometimes the limitations of the methods can be overcome.