Microwave Modeling of Photonic Crystals

Wolfgang Freude and Guy-Aymar Chakam

Outline

- **WDM channel filter for optical communications**
- **Microwave scaling of optical components**
- **Waveguide materials and losses**

- **Coaxial-to waveguide connector with taper**
- **Straight waveguide loss and dispersion**

- **Ring resonator resonances**
- **Ring filter and critical coupling**

- **TE waveguiding in photonic crystal**

- **Summary**

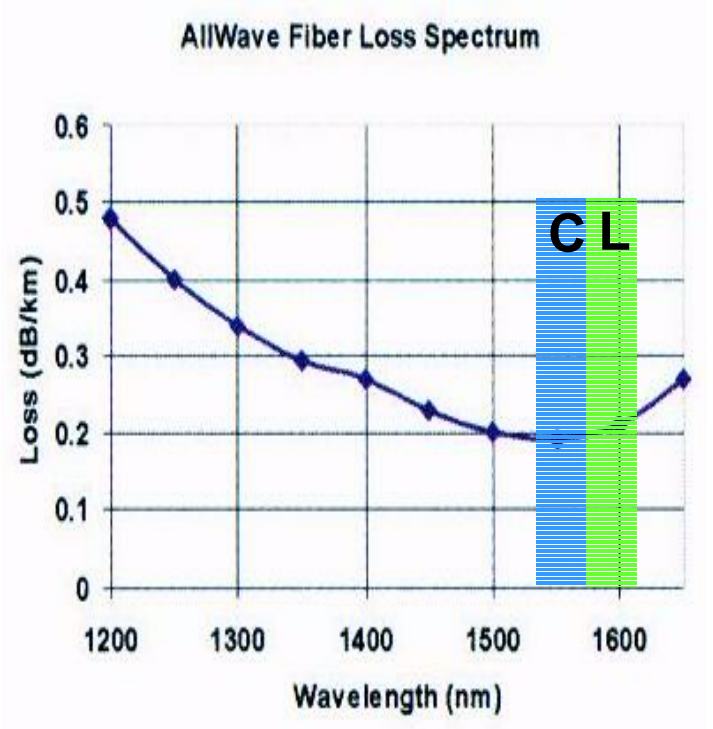
Optical Wavelength Division Multiplexing (WDM)

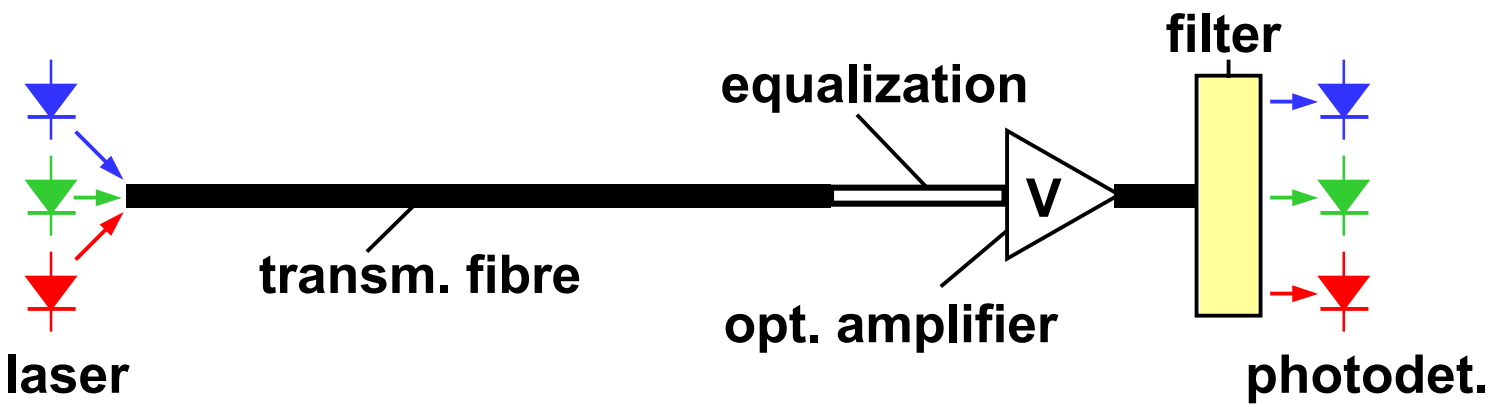
- **Internet: Need for bandwidth B**
- **Optical transmission systems**

  fibres: $B \approx$ 65 THz (450 nm)

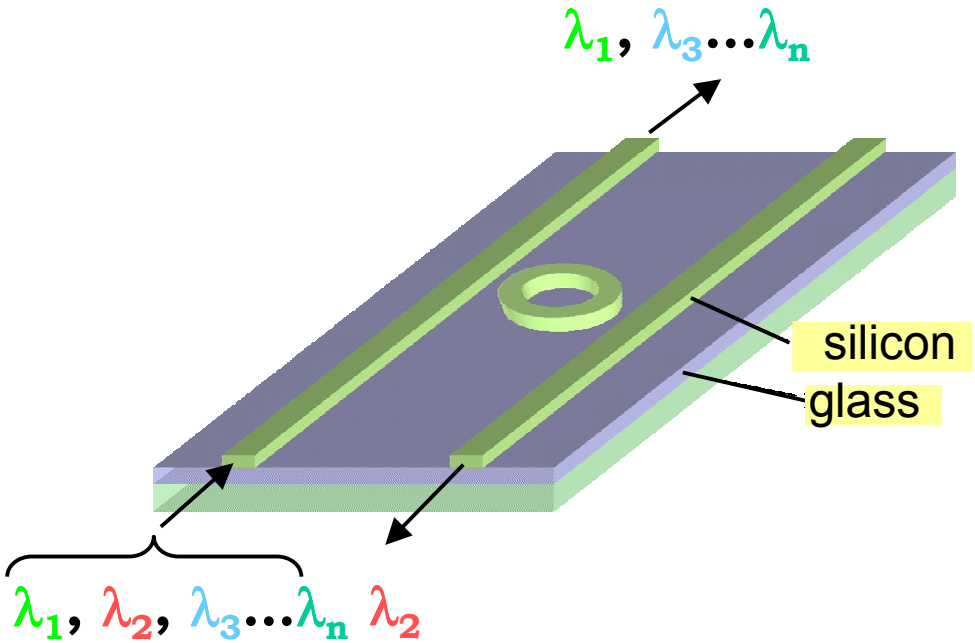
  amplifiers: $B \approx$ 10 THz (80 nm)

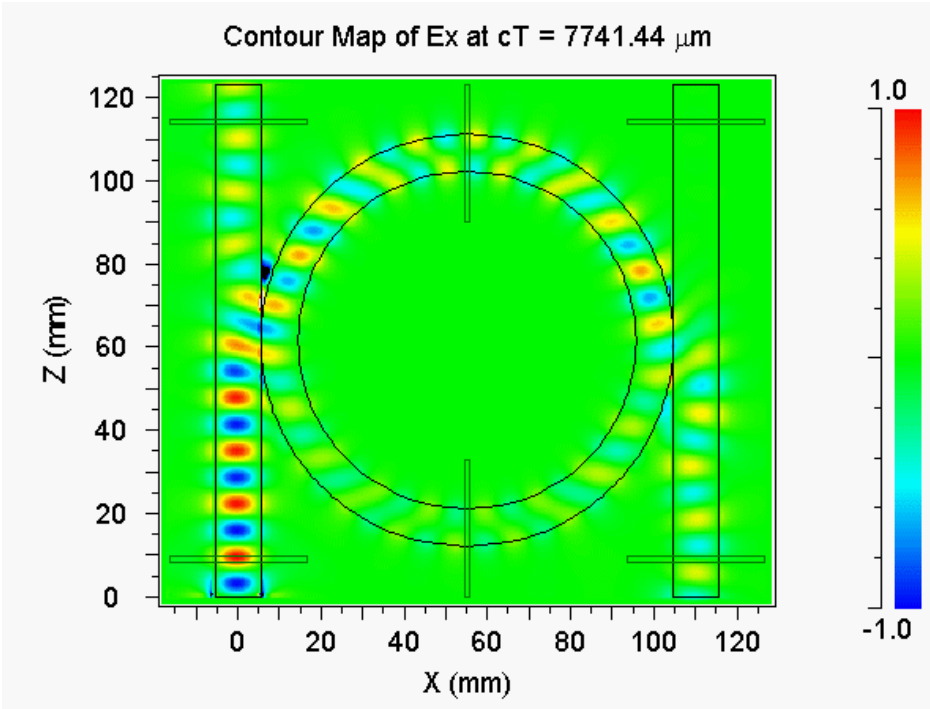
  wavelength division multiplexing





Ring Resonator $2R$ = 90.2 mm f = 9.796 GHz λ = 30.6 mm

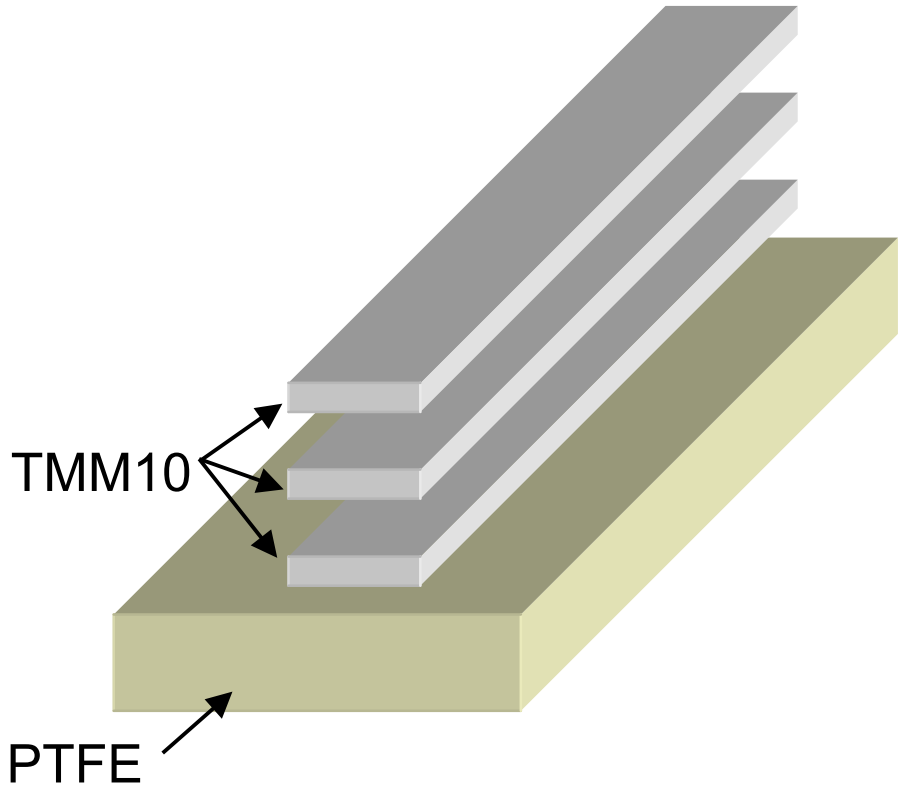




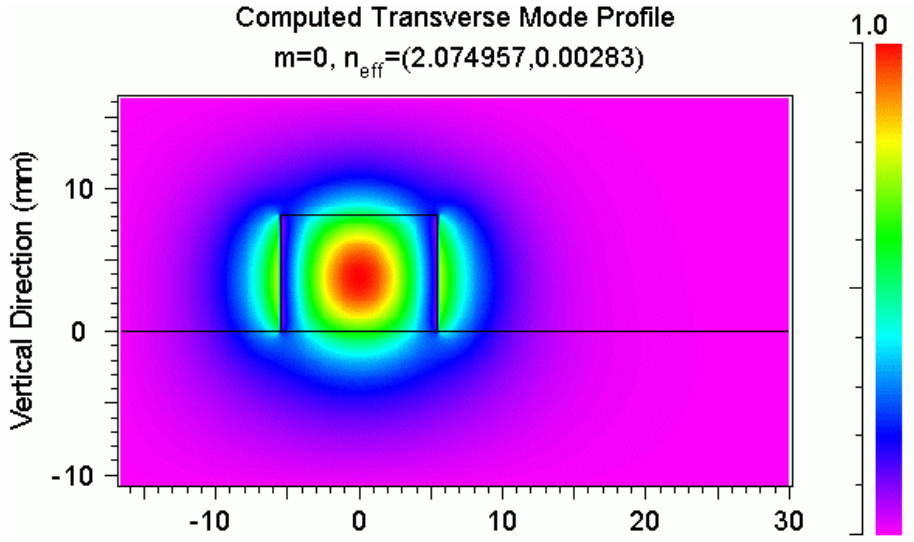
scaling to microwave range 1.5 µm → 30 mm (10 GHz)

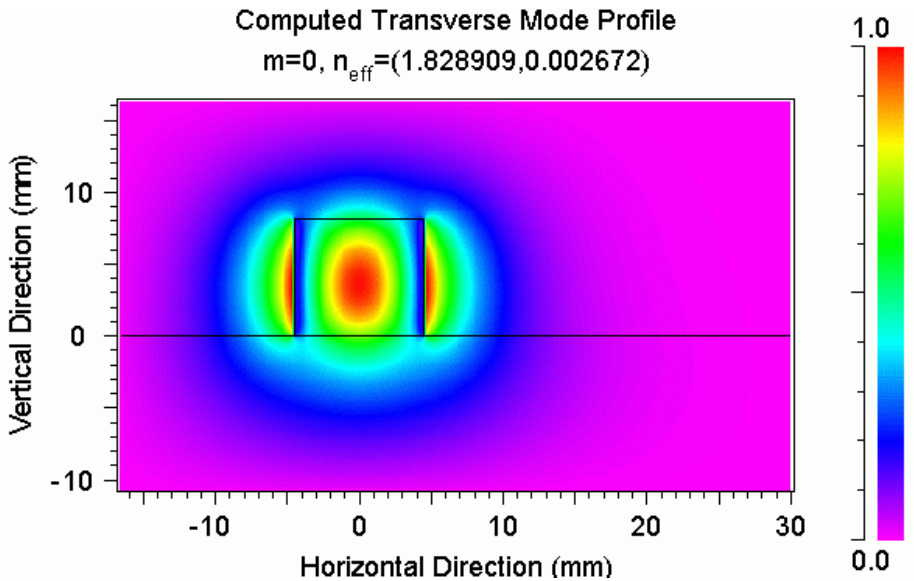
silicon, n = 3.44	quartz glass SiO_2, n =1.45	precision 10 nm
ceramic re-enforced PTFE (TMM10 n = 3.03)	PTFE n = 1.48	0.2 mm

Composite Strip Waveguides and HE_{11} Modes at 7.6 GHz



height	8.1	mm
width straight	11	mm
width ring	9	mm
height glue	< 10	µm





Attenuation in Straight and Bent Waveguides

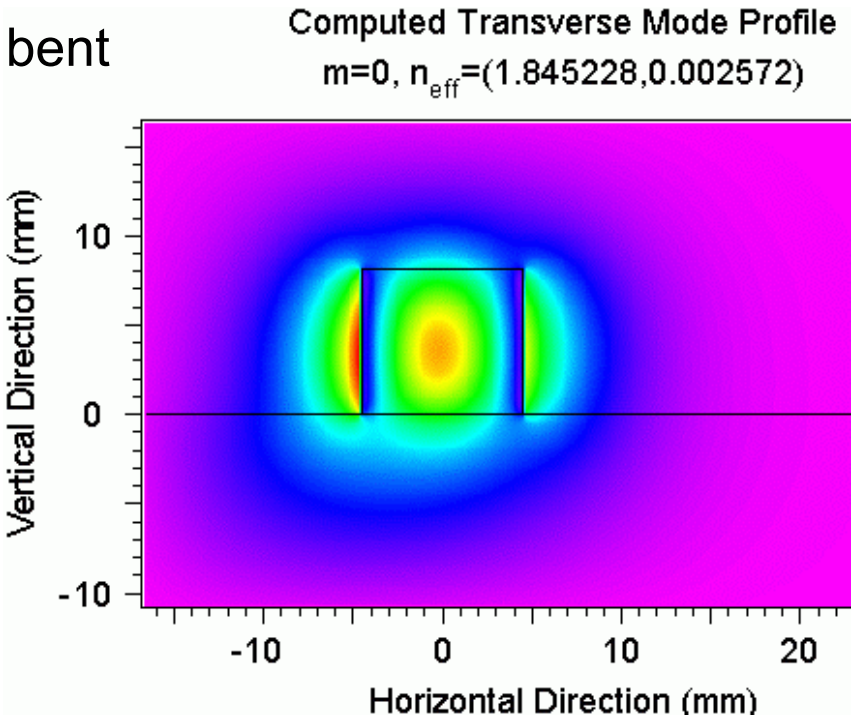
material & structure	attenuation	measured at 10 GHZ
4.0 dB/m	TMM10	
0.1 dB/m	glue	
< 0.001 dB/m	radiation	
4.1 dB/m	**total**	**4.3 dB/m**
	λ_e = 10 mm	**0.04 dB/λ_e**
200 dB/cm	**λ_e = 0.5 µm**	**0.01 dB/λ_e**

7.6 GHz

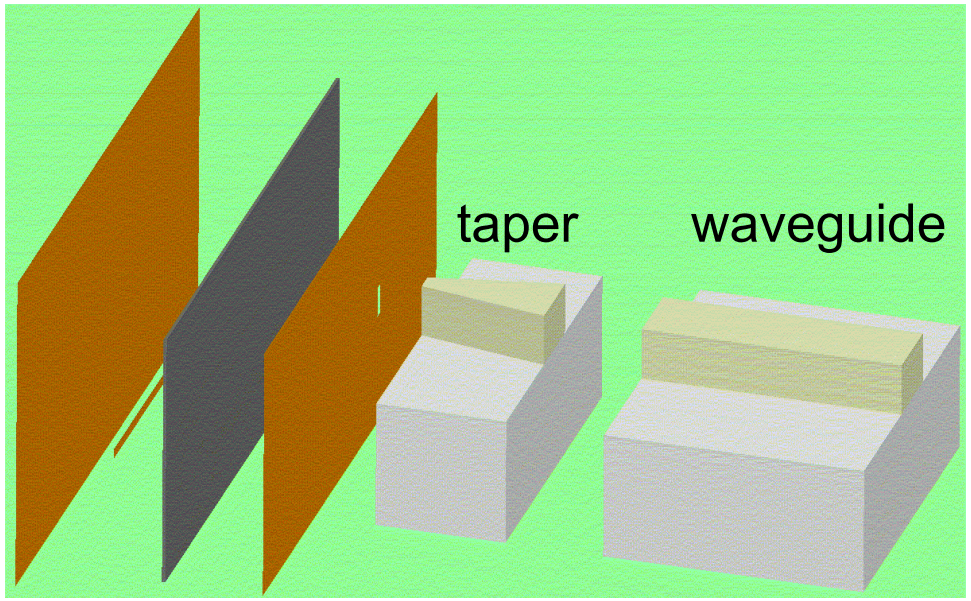
straight

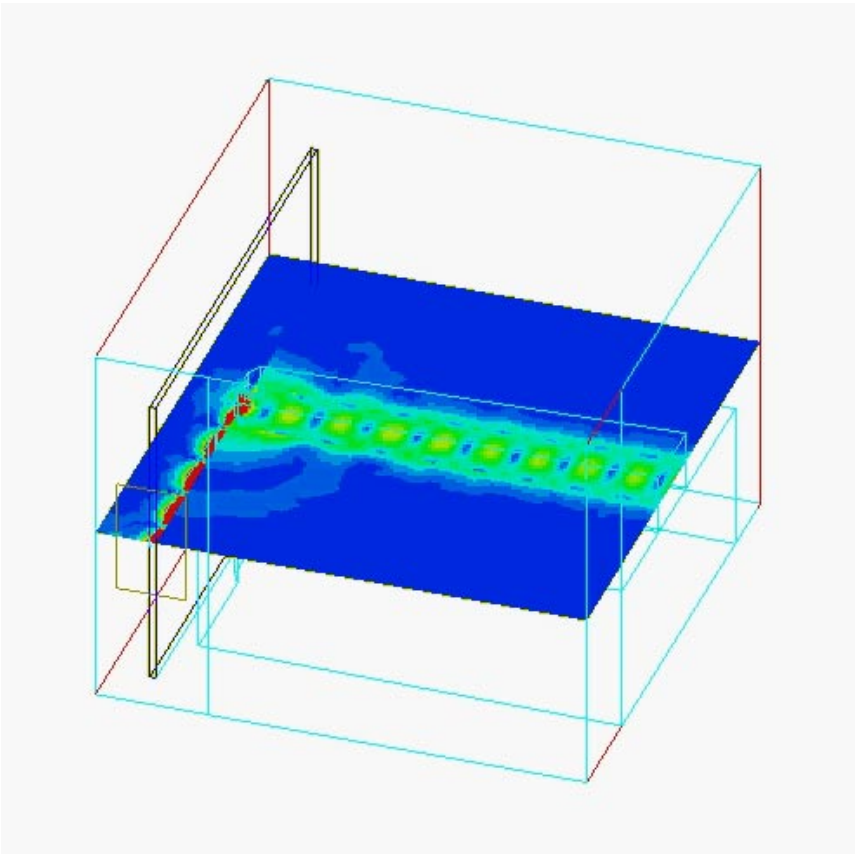
m=0, n_{eff}=(1.828909,0.002672)

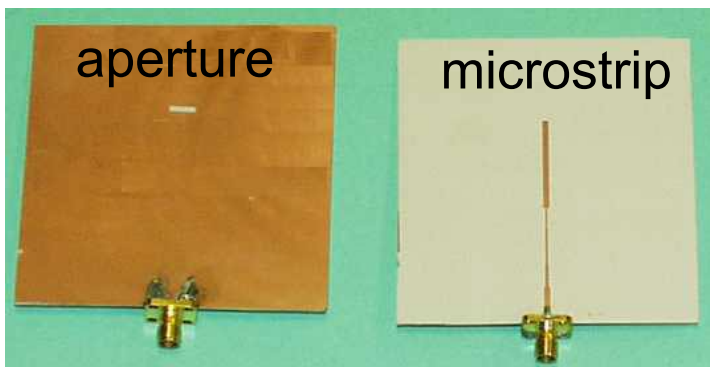
bent



Coaxial-to-Waveguide Connector with Dielectric Taper (1)

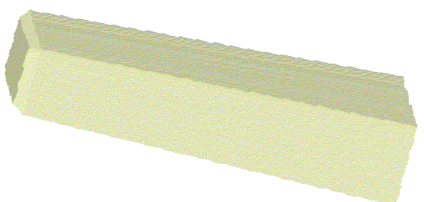




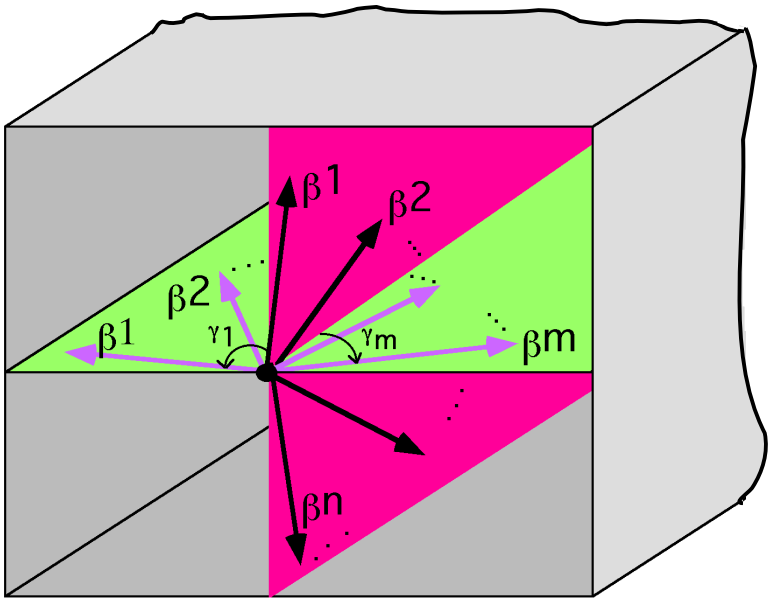


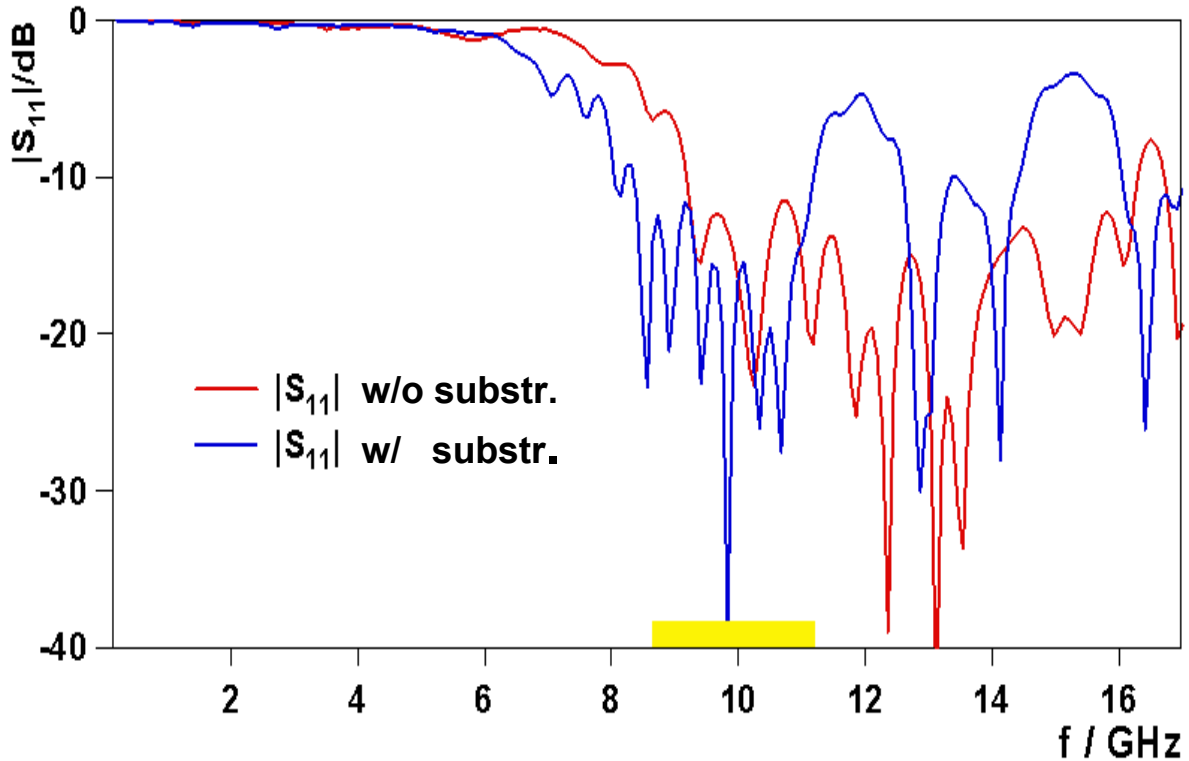
coaxial input

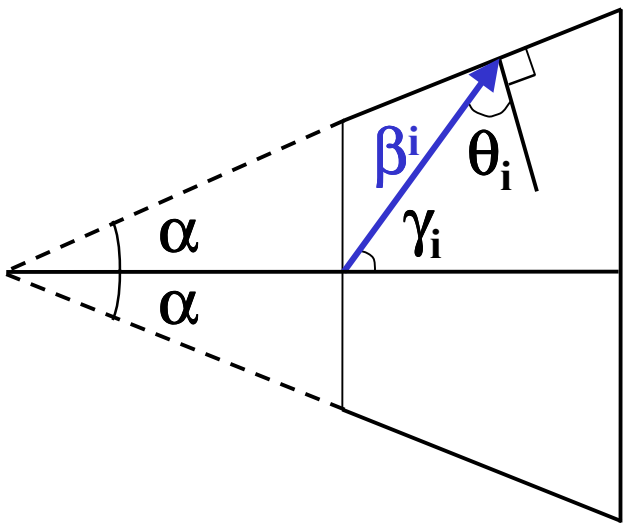
waveguide output

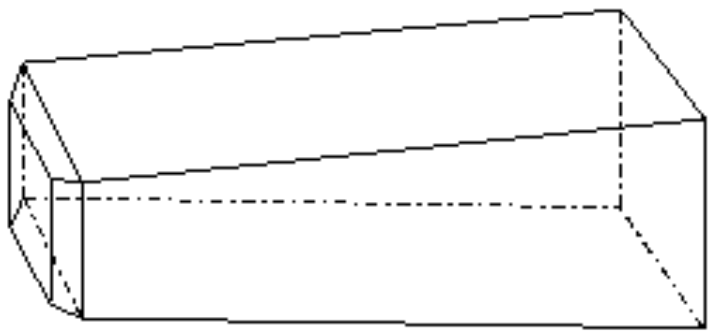


Coaxial-to-Waveguide Connector with Dielectric Taper (2)



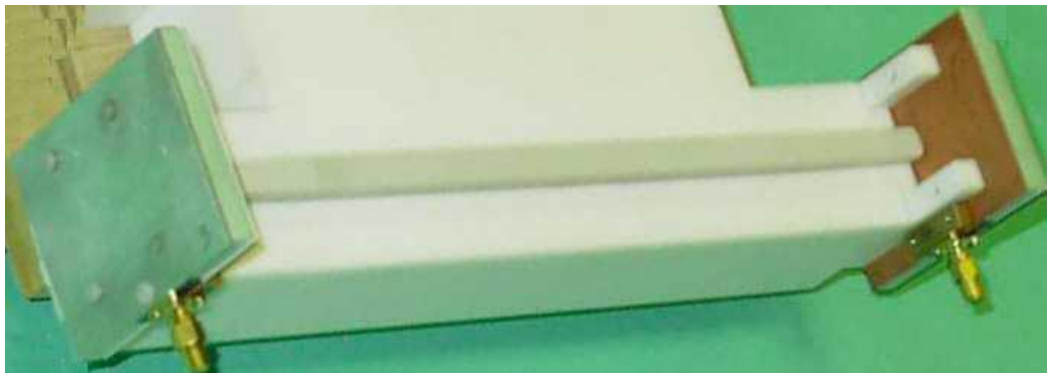


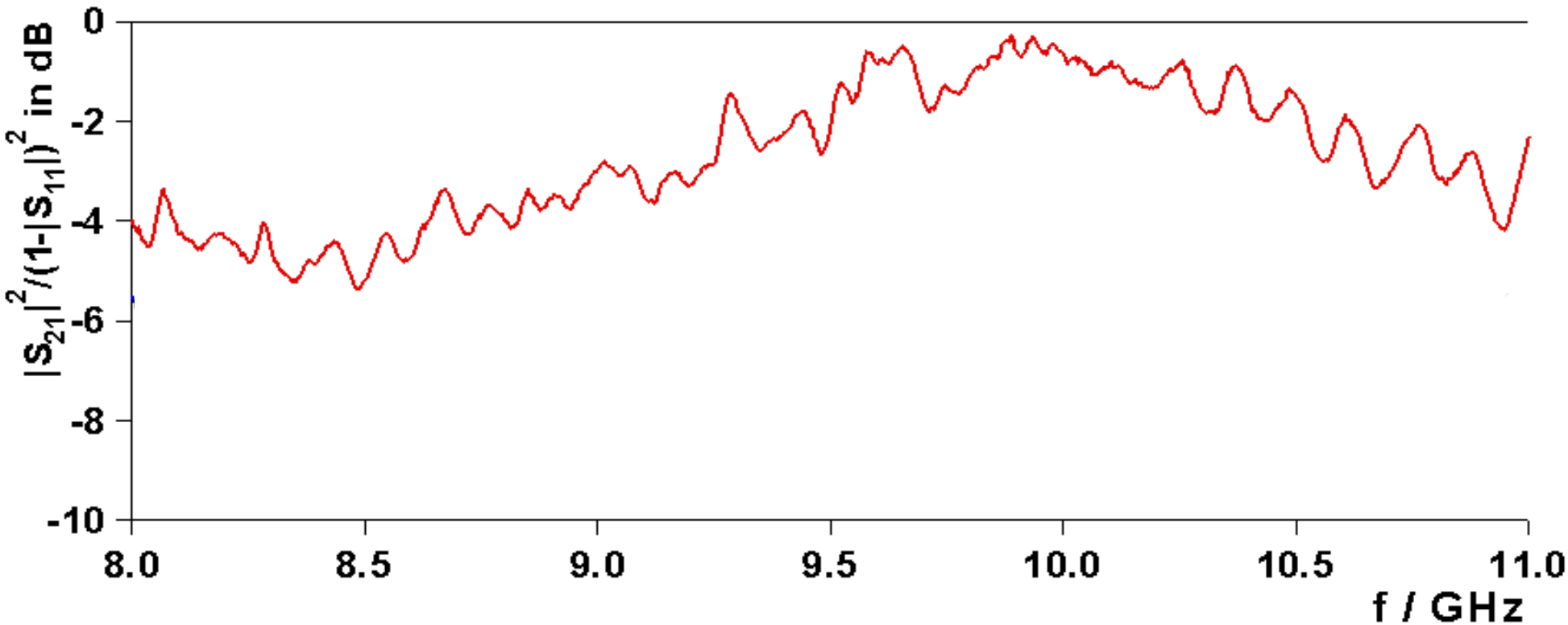




Normalized Power Transmission of Dielectric Strip Waveguide

height 8.1 mm
width 11 mm
length 191 mm

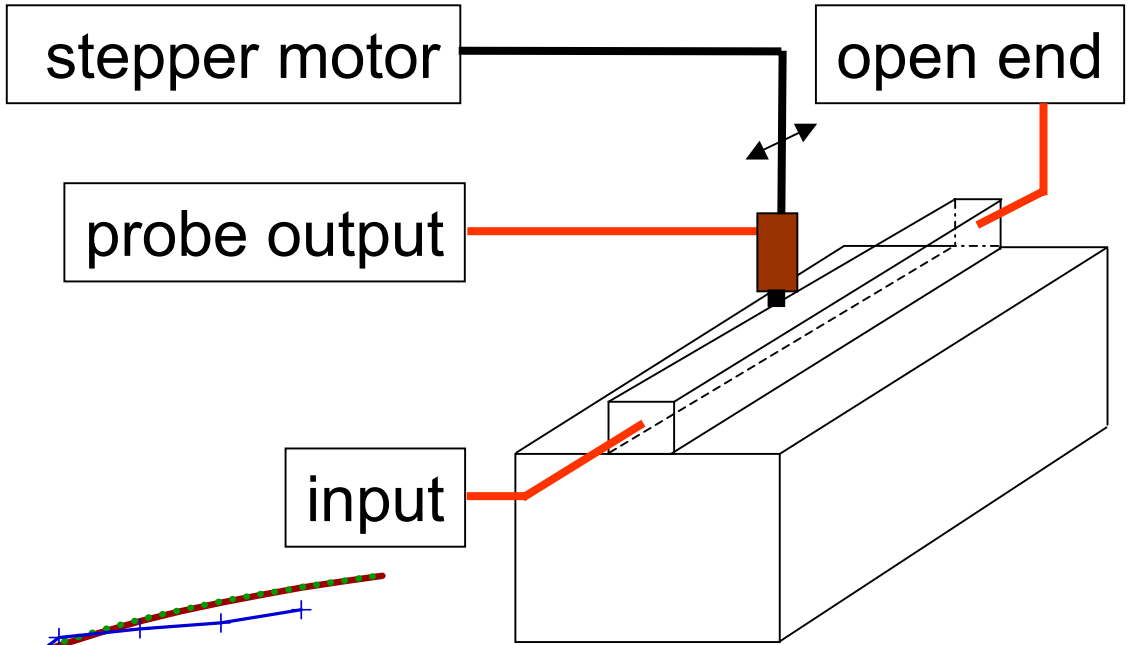


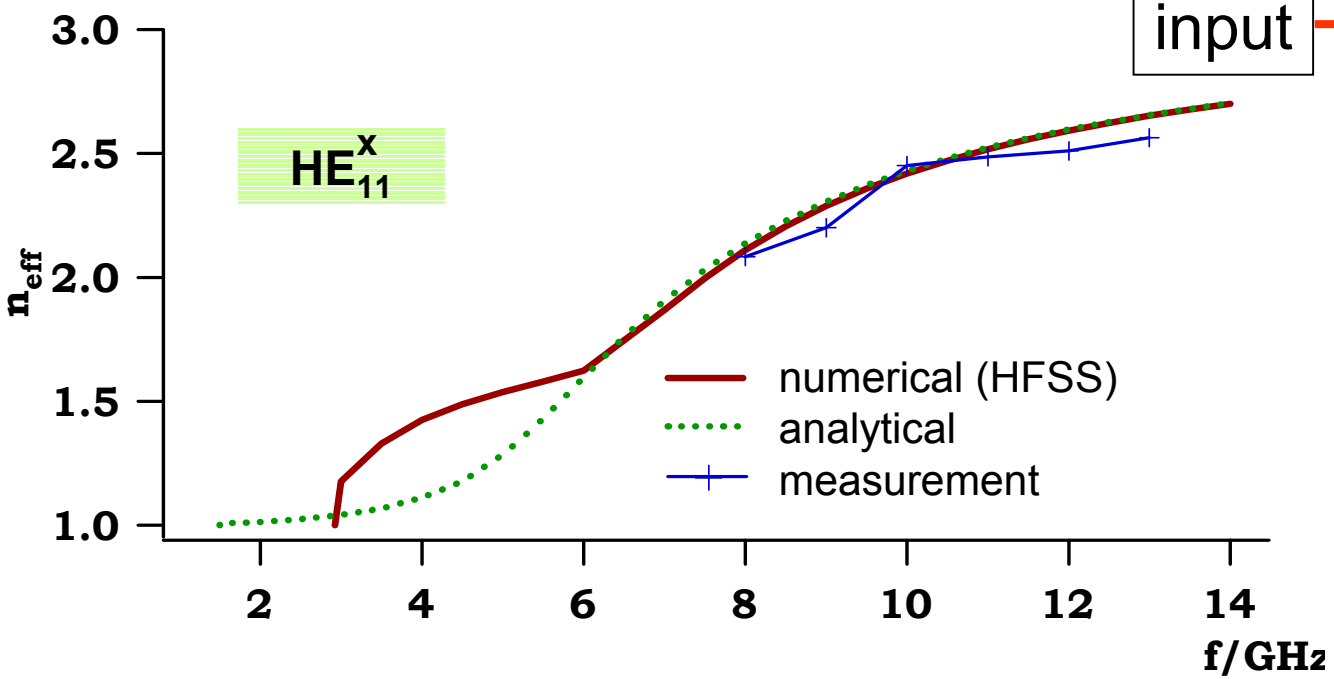


Measured and Calculated Dispersion Diagram

$$n_{\text{eff}} = \beta / k_0 = \beta c / \omega$$

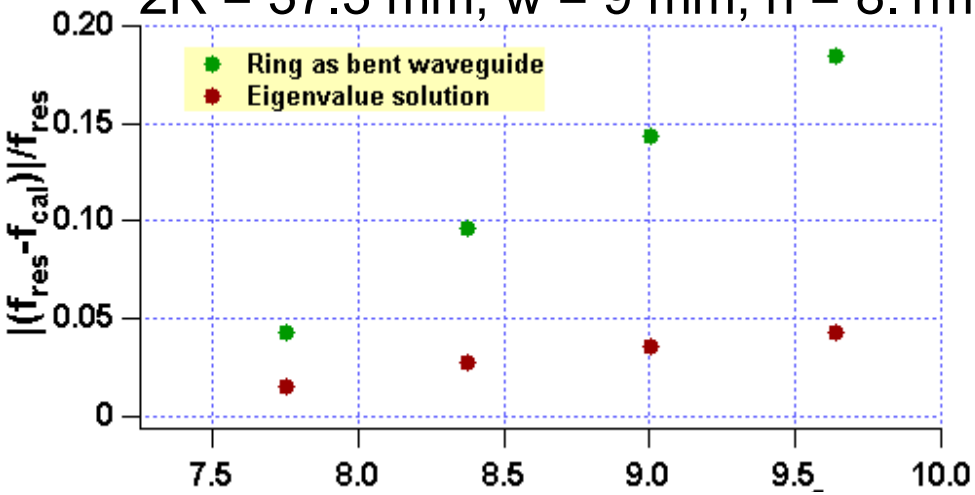
$$\beta = n_{\text{eff}} \omega / c$$



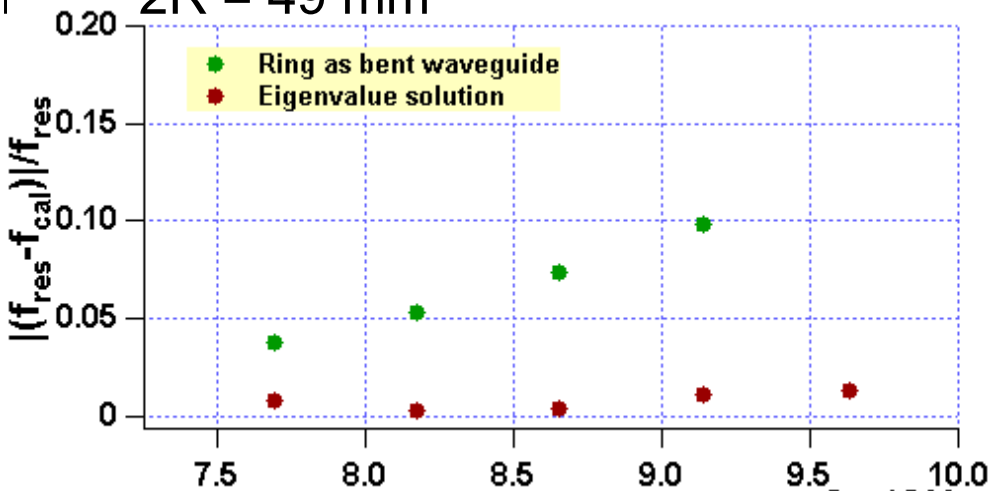


Measured Frequency Deviation for Calculated Hybrid $HE_{\nu\mu 1}$ Modes

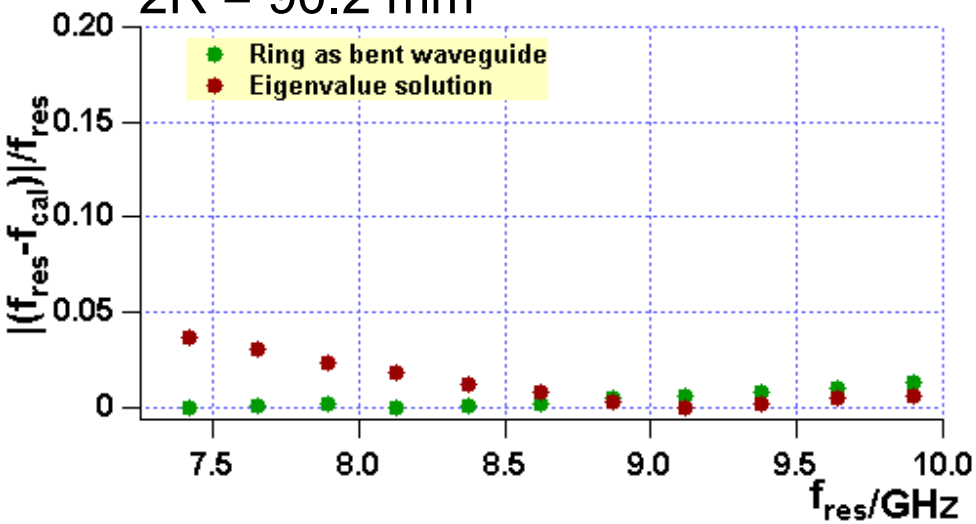
2R = 37.3 mm, w = 9 mm, h = 8.1mm



2R = 49 mm



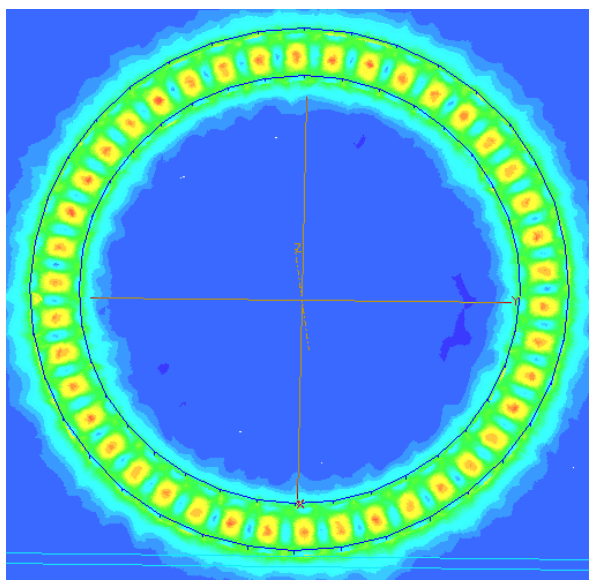
2R = 90.2 mm



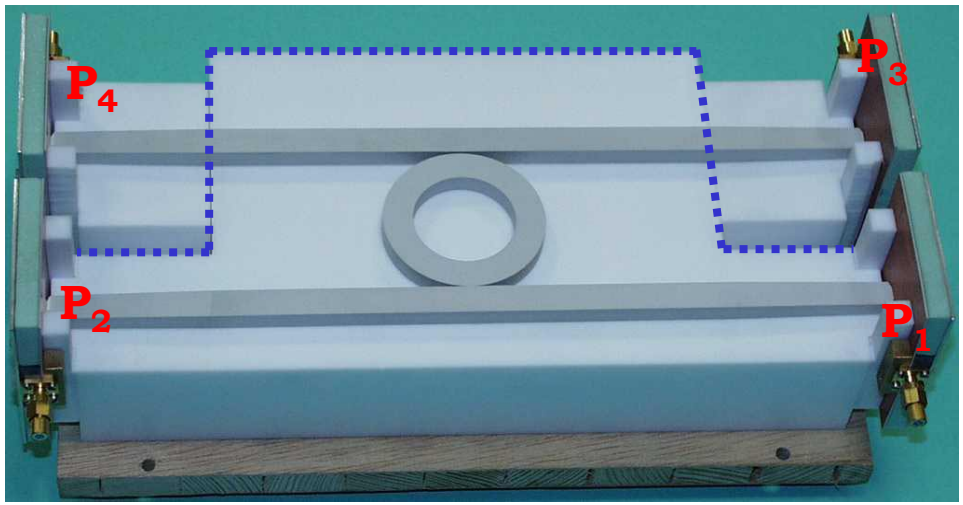
$HE_{21,1,1}$

f = 9.9 GHz

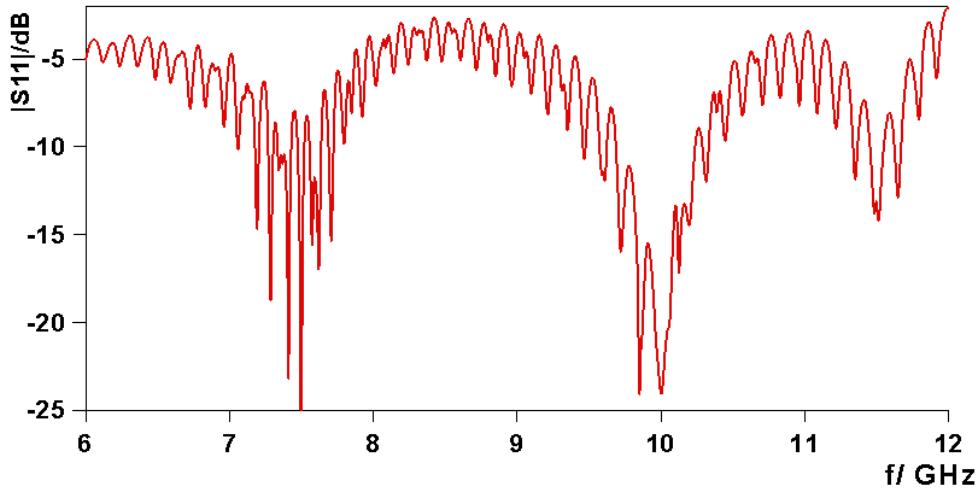
Δf = 249 MHz



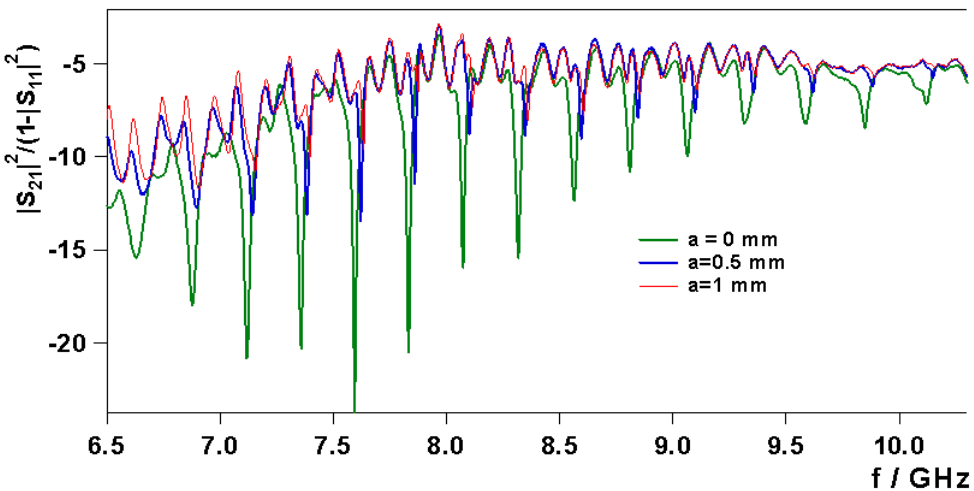
Ring Filter with Varying Coupling Gaps: 0 mm, 0.5 mm, 1 mm



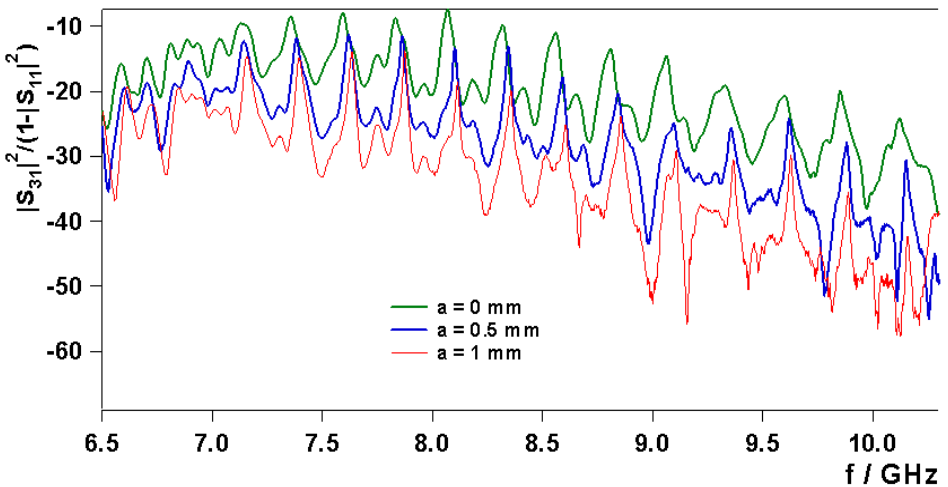
Reflection P_1



Transmission $P_1 \rightarrow P_2$



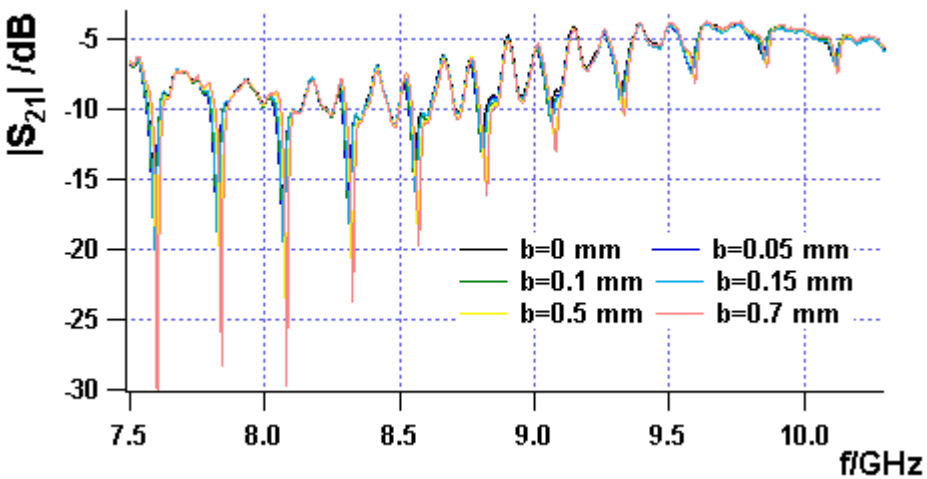
Coupling $P_1 \rightarrow P_3$

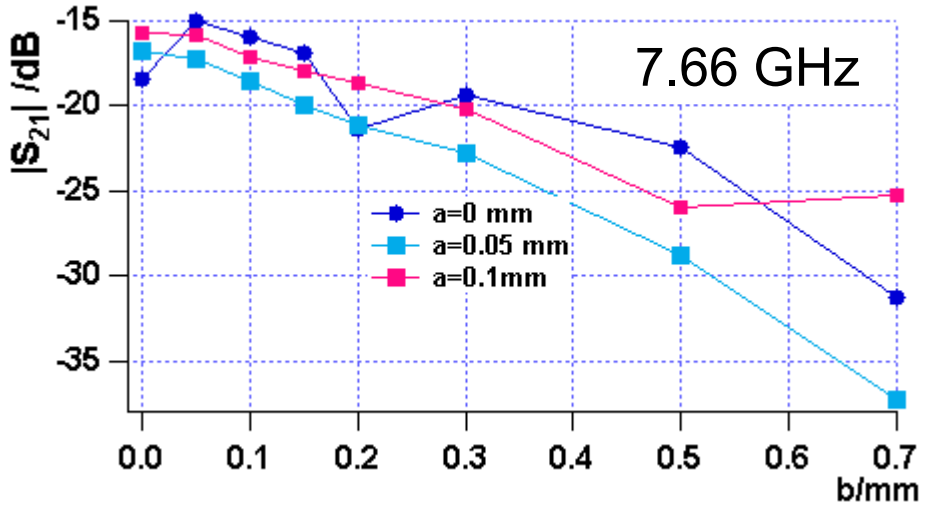


Transmission and Coupling for Ring Filter with Varying Gaps

a = 0.05

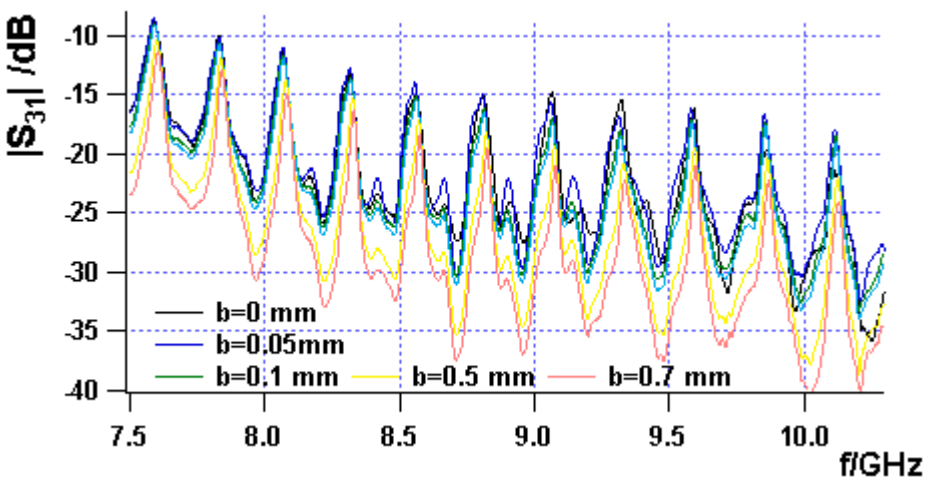
Transmission $P_1 \rightarrow P_2$

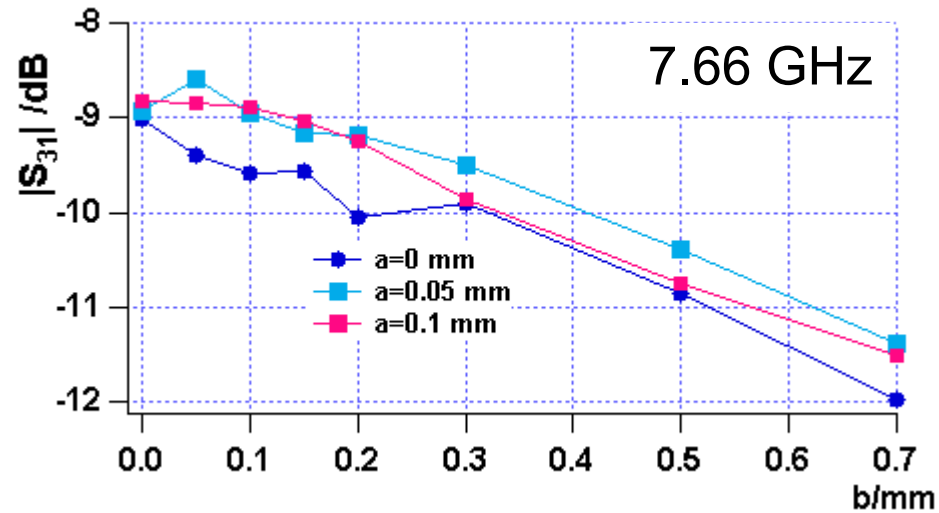




a = 0.05

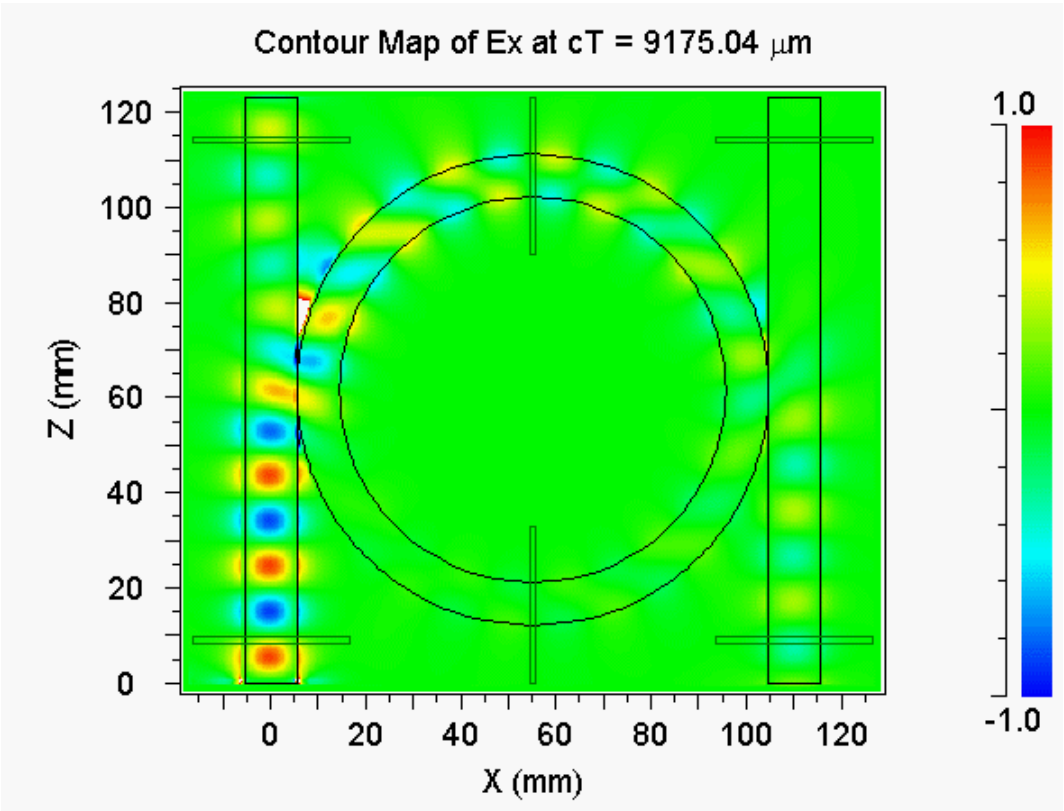
Coupling $P_1 \rightarrow P_3$

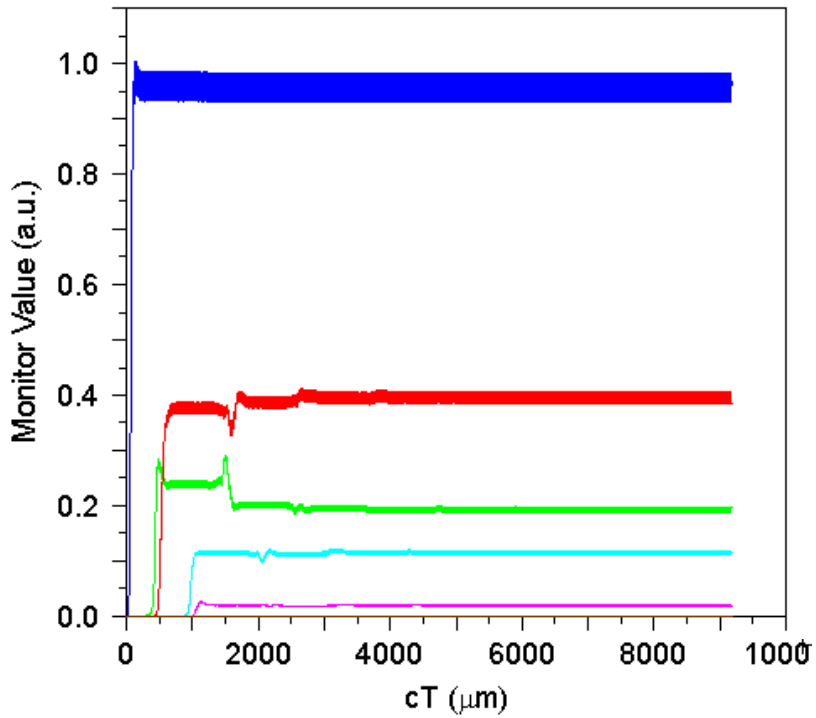




E_x and Monitor Powers at 7.663 GHz with Gaps = 0.05 mm

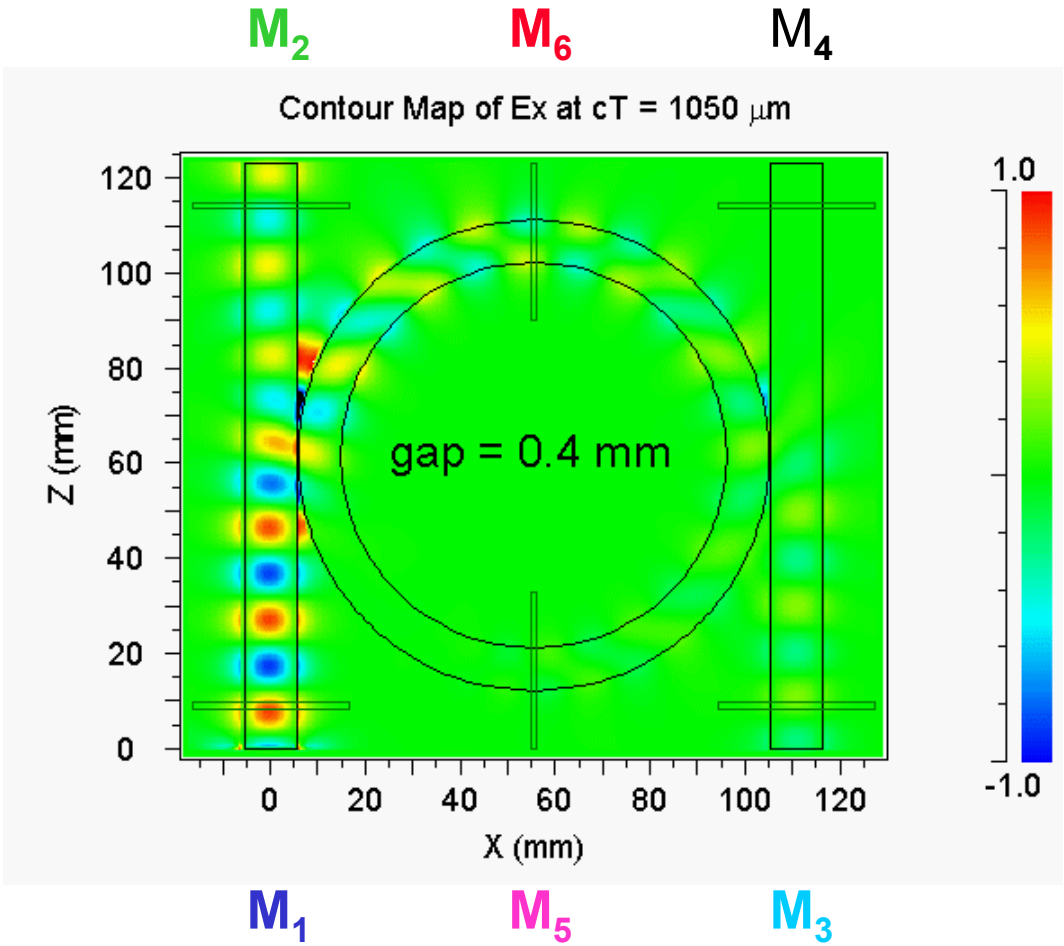
M_2 M_6 M_4

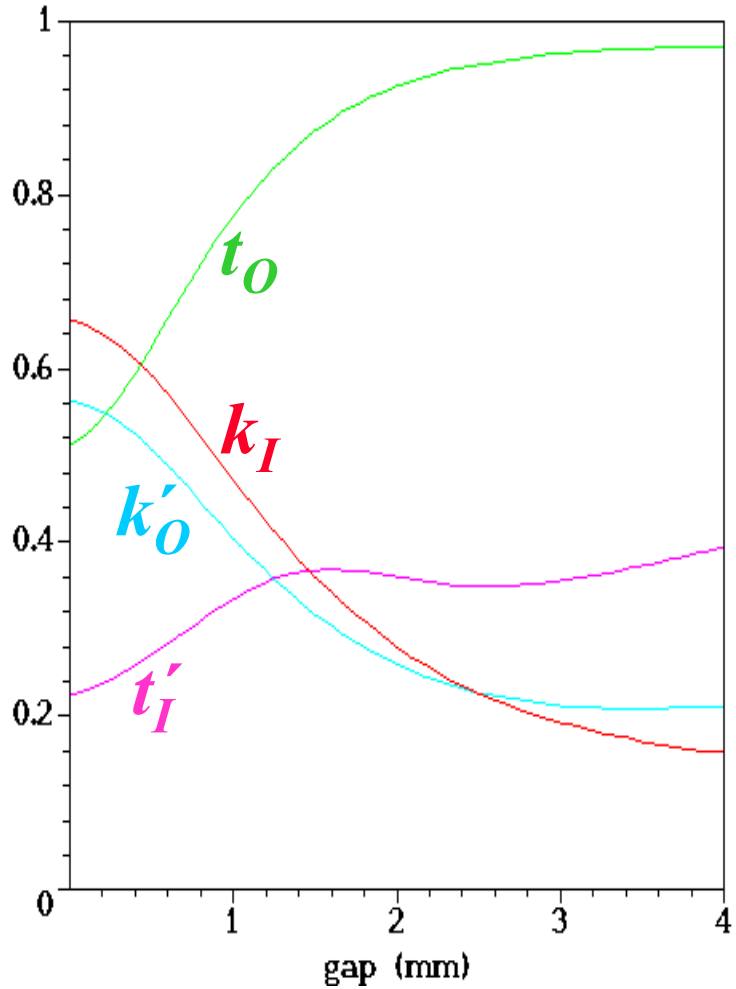




M_1 M_5 M_3

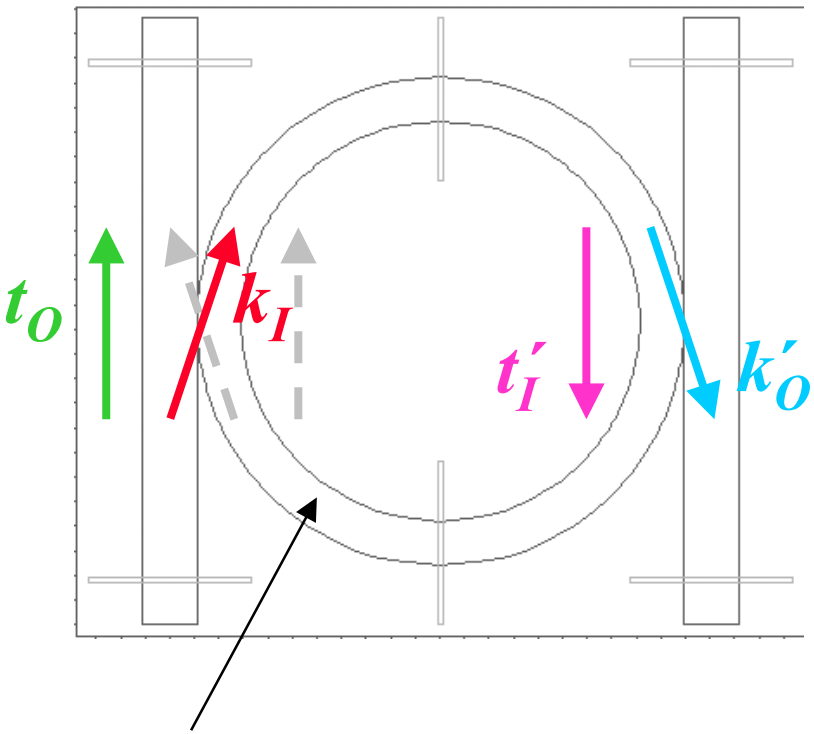
E_x and Monitor Powers at 7.663 GHz for Gap = 0, .4, .8, 1.6, 3.2 mm



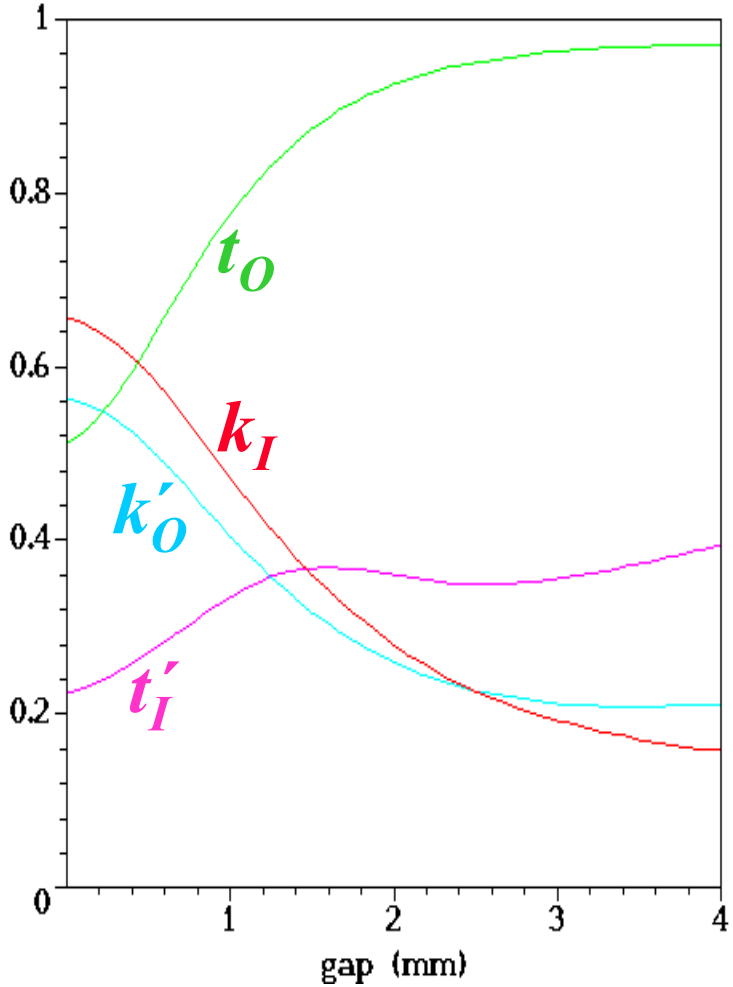


Amplit. Transmission & Coupling at 7.6 GHz. Lossy Coupling Zone

$$|b_2|^2 = \frac{\left[\left(|t_O t_I| + |k_O k_I|\right)|t'_I s| - |t_O|\right]^2}{\left(1 - |t_I t'_I s|\right)^2}|a_1|^2$$



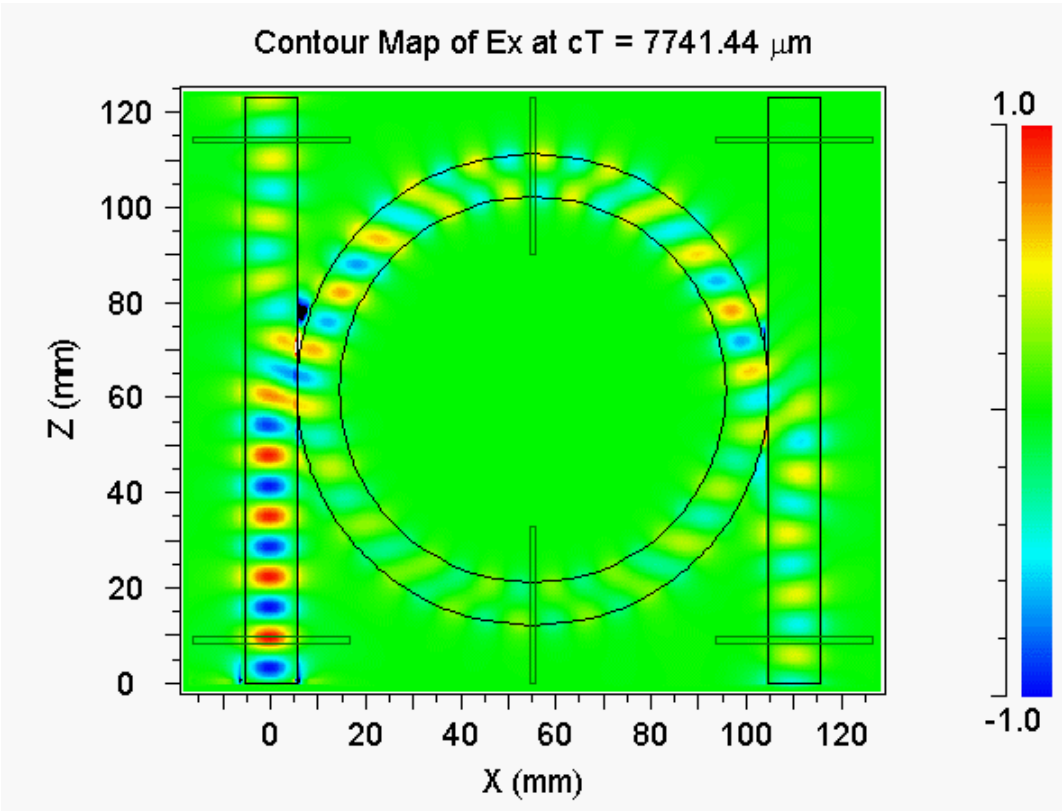
No zero = no critical coupling

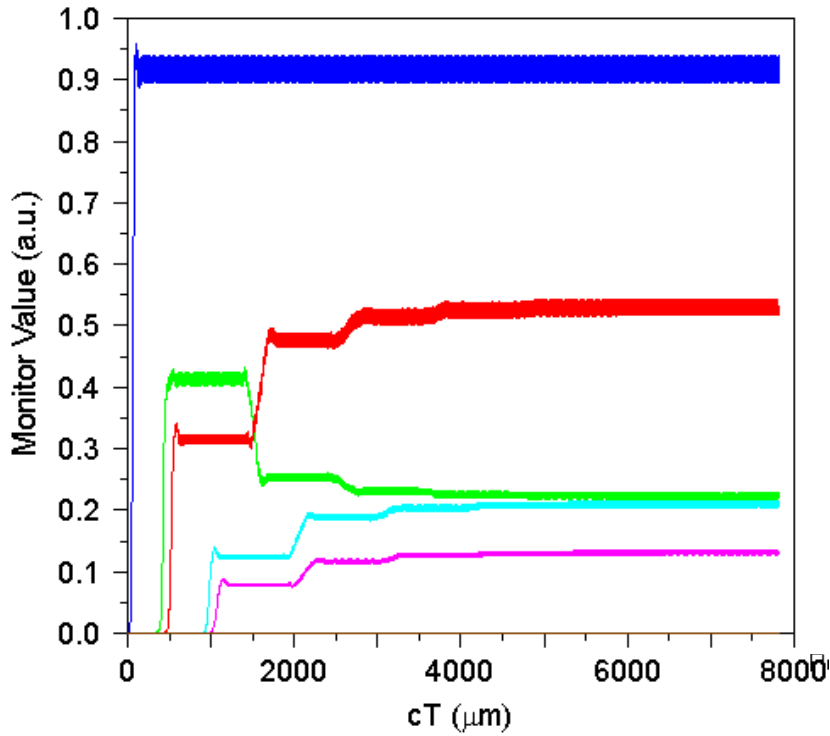


$$s = |s|\exp(\mathrm{j}2\pi R\beta) \qquad |b_4|^2 = \frac{|k_O k'_I|^2 |s|}{\left(1 - |t_I t'_I s|\right)^2}|a_1|^2$$ at resonance

E_x and Monitor Powers at Resonance 9.796 GHz. Gaps = 0.05 mm

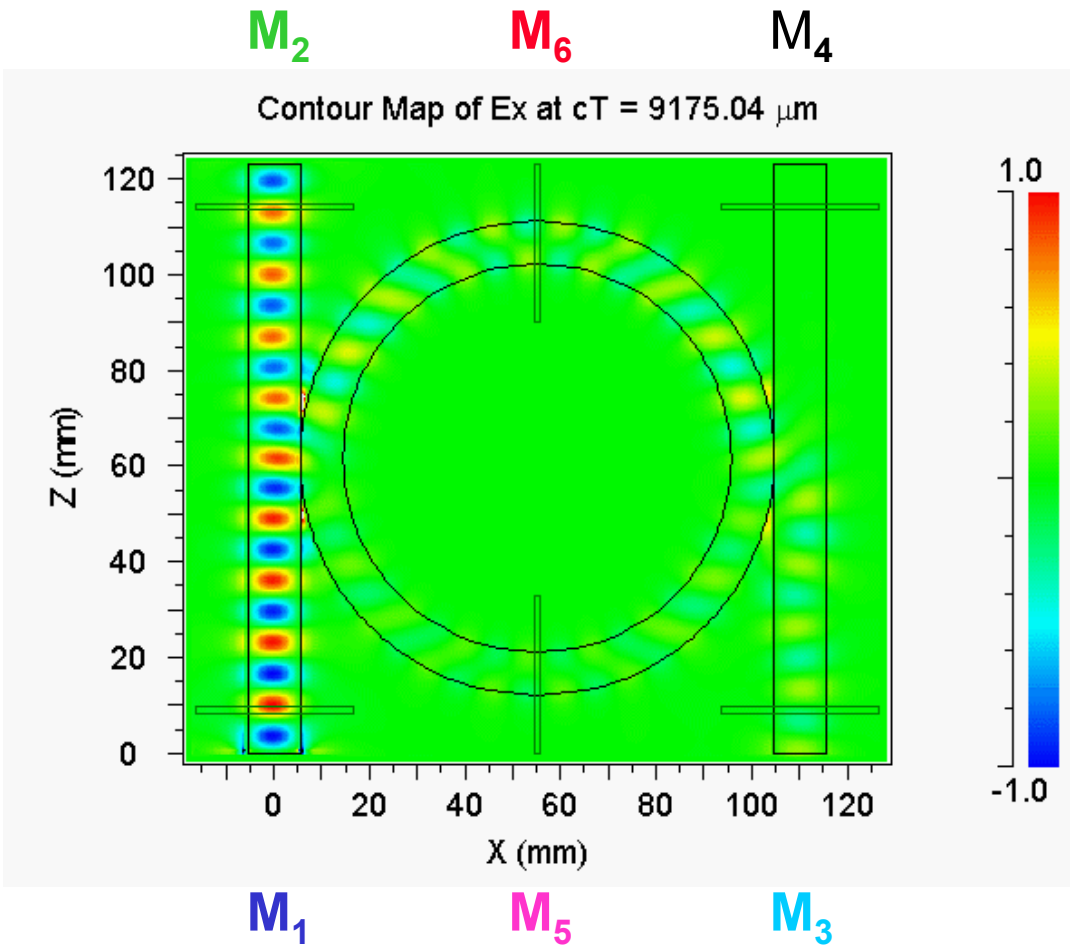
M_2 M_6 M_4

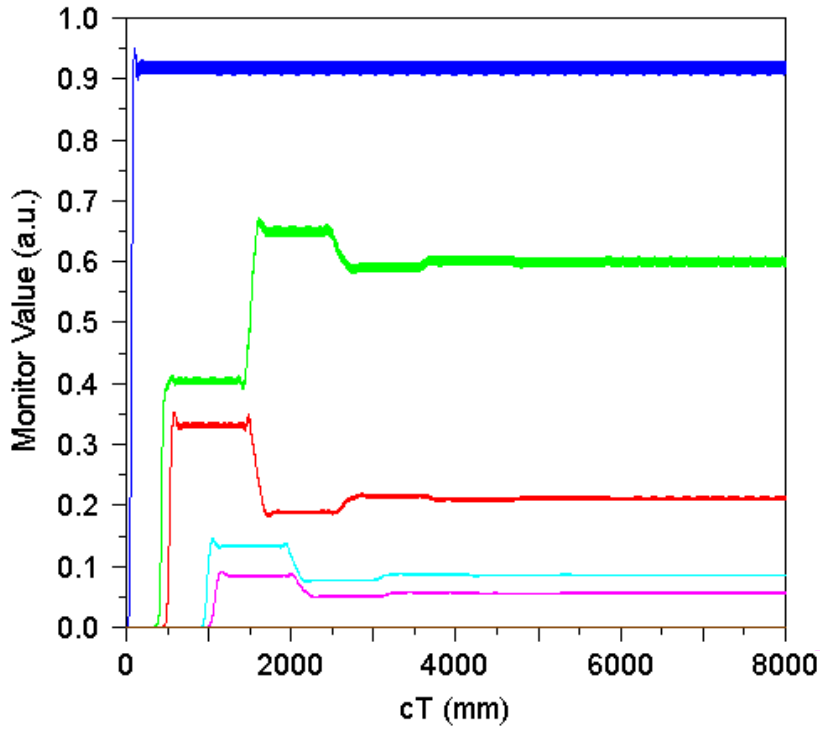




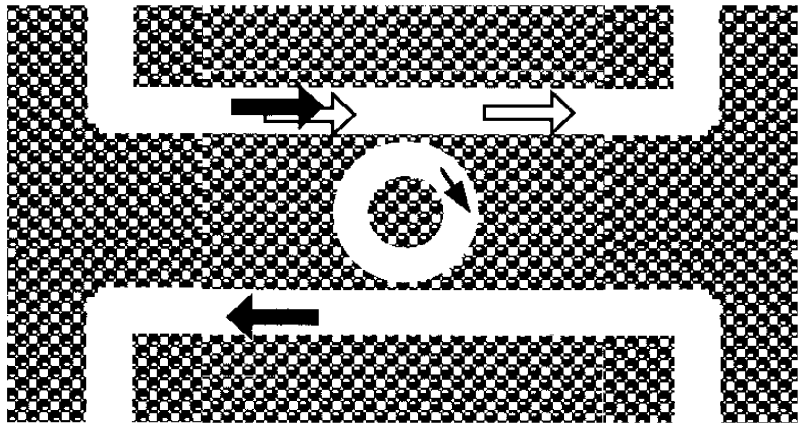
M_1 M_5 M_3

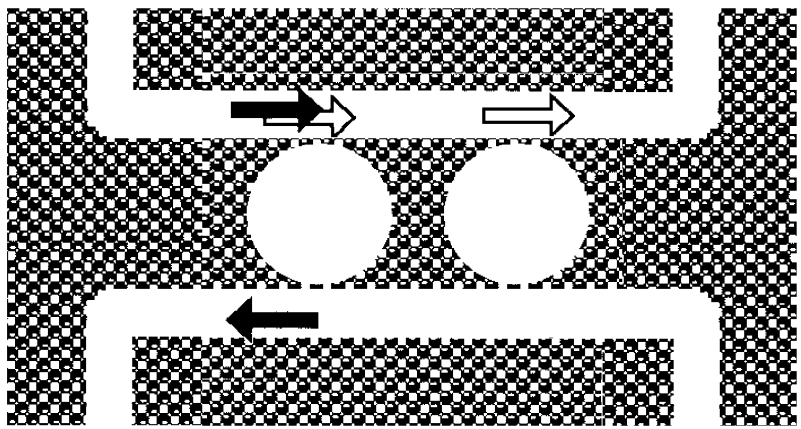
E_x and Monitor Powers Off-Resonance 9.672 GHz. Gaps = 0.05 mm

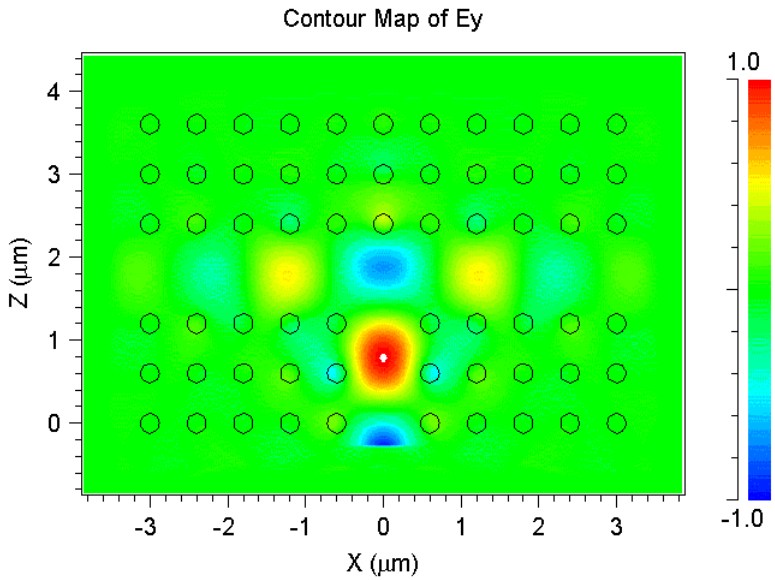




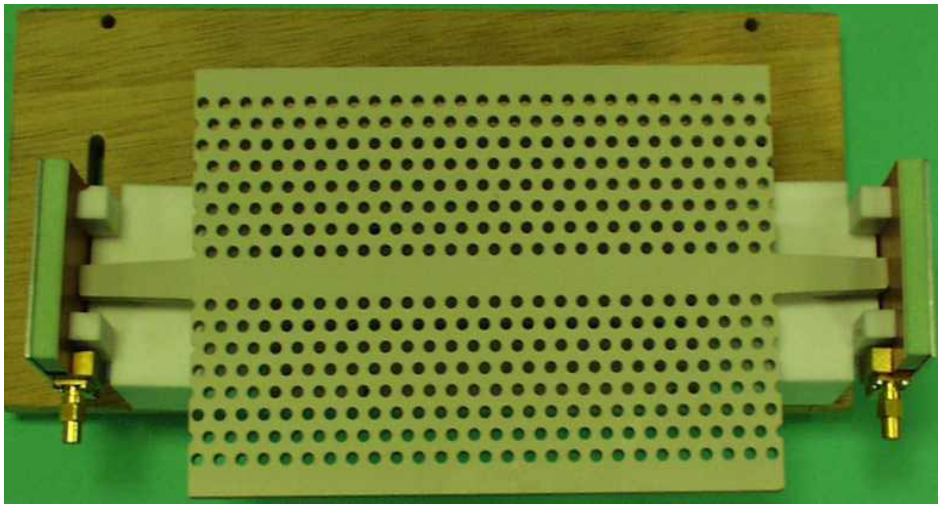
2D Bandgap High-Q Ring Filter

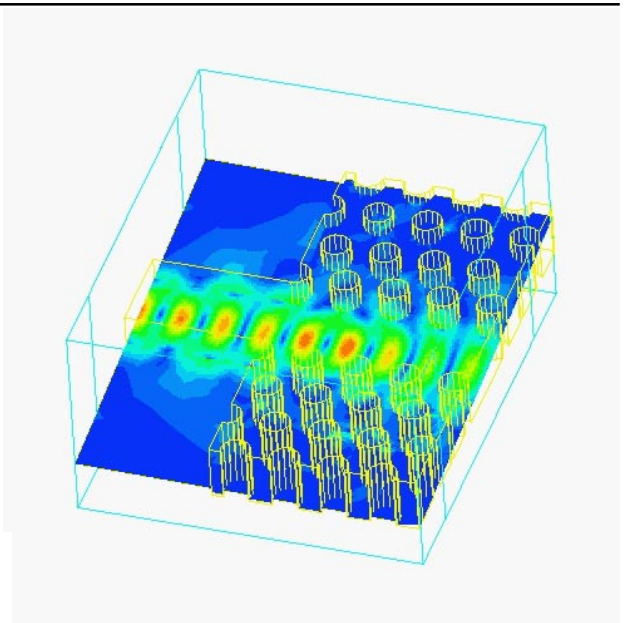


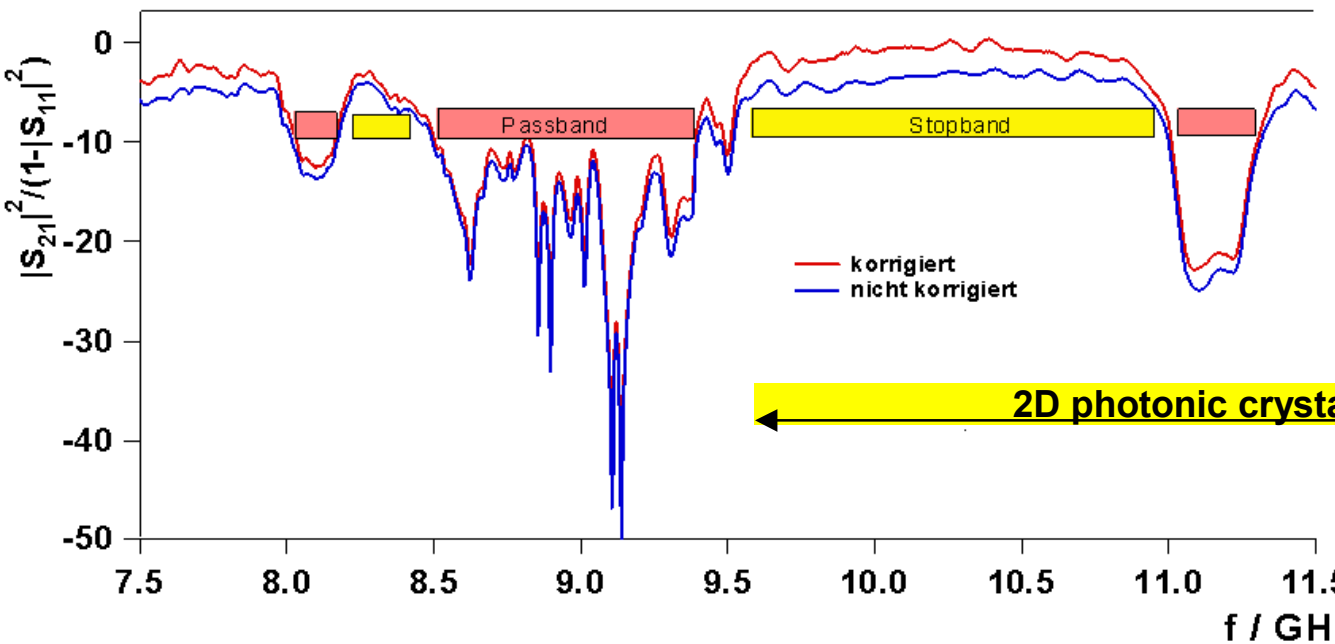




TE Waveguiding in Photonic Crystal





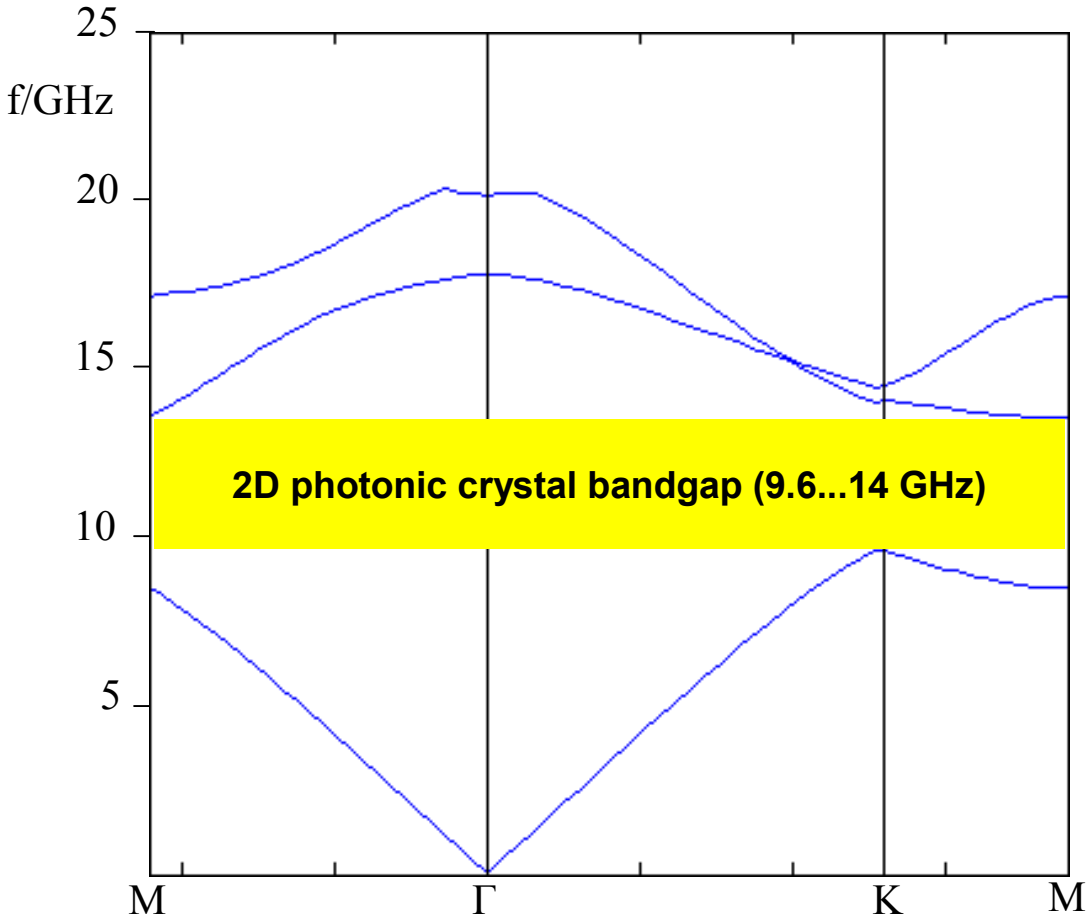


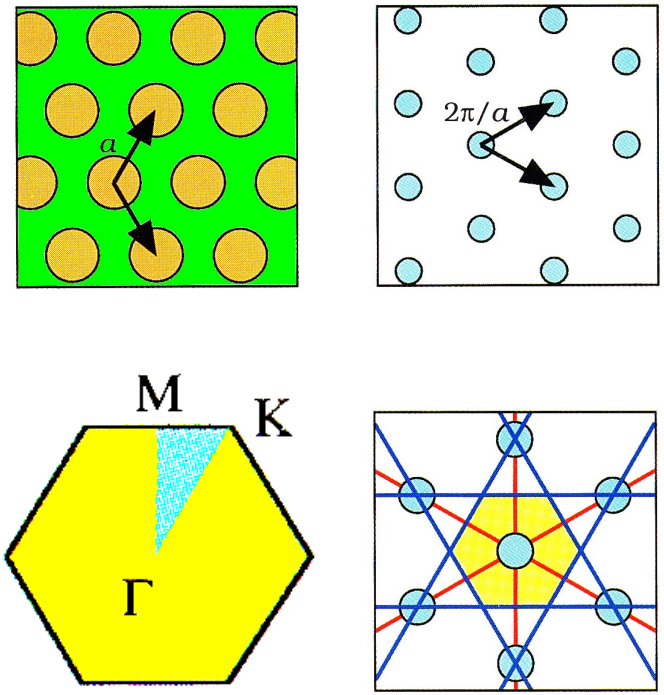
2D photonic crystal bandgap (9.6...14 GHz)

r / a = 0.30

ε_r = 9.2

TE-Modes Band Structure of 2D Crystal



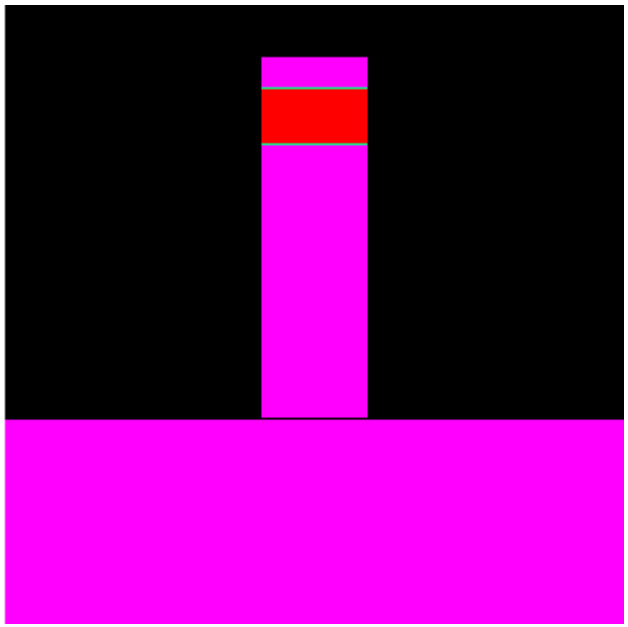


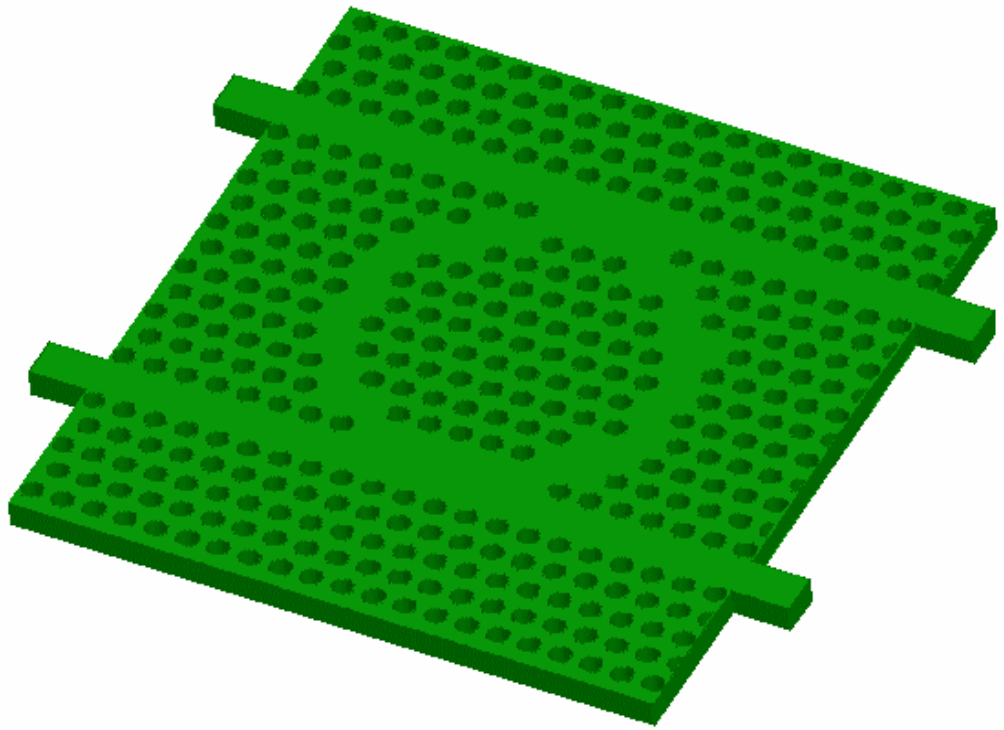
r / a = 2.1 mm / 7.1 mm = 0.30

$\varepsilon_r = 9.2$

Pedestal waveguide

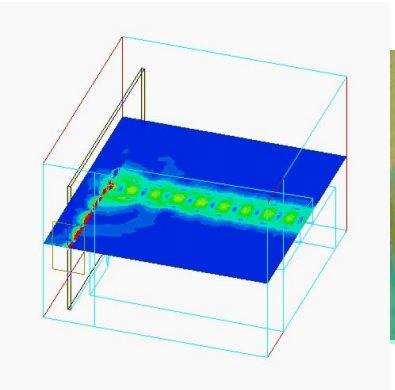
2D Bandgap High-Q Ring Filter

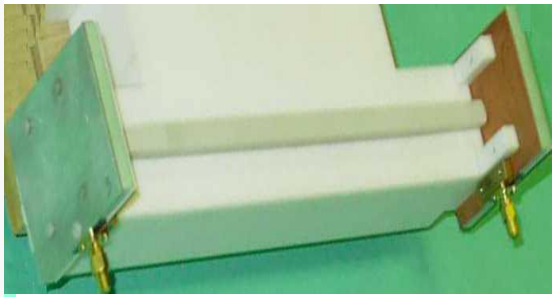




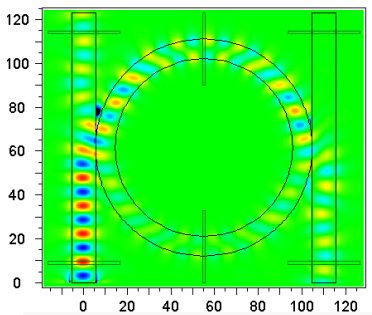
Summary

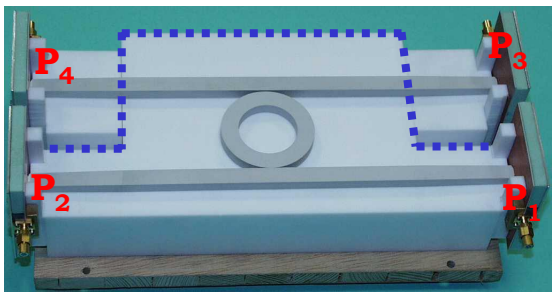
- **Connector and waveguide**
  - **Design**
  - **Measurement**



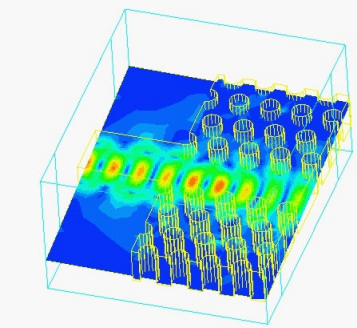


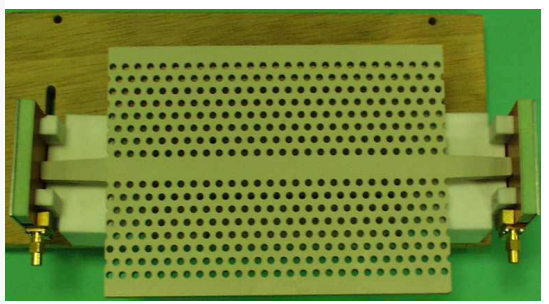
- **Ring resonator and coupling**
  - **Resonances**
  - **Coupling**





- **2D PBG TE waveguide**
  - **Band structure**
  - **Measurement**





- **To do: Pedestal waveguide, TM propagation, 2D PBG ring filter**