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Microphotonics

CAD-LAB: Scatter Matrices

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Contents

1 Ring with a single waveguide

1.1 Design of the filter

The ring length of the single-ring single-waveguide filter that has a resonance at 1.55μm, and six other ones - between 1.5 μm and 1.6 μm is given by,

$$2L = \frac{m\lambda}{n_{eff}}, 96 \leq m \leq 120 \tag{1}$$

There are total 25 ring lengths that meet the requirement from 55.111μm to 68.889μm.

Method to calculation

The filter has a resonance at $\lambda = 1.55\mu m$so we have,

$$\lambda = \frac{2Ln_{eff}}{m}, m \in N_+ \tag{2}$$

where $\lambda = 1.55\mu m, n_{eff} = 2.7$. The third and fourth wavelength before or after $1.55\mu m$ when the filter has a resonance is,

$$\begin{aligned} \lambda_1 = \tfrac{2Ln_{eff}}{m+3}, \lambda_1' = \tfrac{2Ln_{eff}}{m+4} \\ \lambda_2 = \tfrac{2Ln_{eff}}{m-3}, \lambda_2' = \tfrac{2Ln_{eff}}{m-4} \end{aligned} \tag{3}$$

We need to make sure that there are exactly seven wavelengths of resonance point between 1.5 μm and 1.6 μm,

$$\begin{cases} \lambda_1 \geq 1.5\mu m, \lambda_1' < 1.5\mu m \\ \lambda_2 \leq 1.6\mu m, \lambda_2' > 1.6\mu m \end{cases} \tag{4}$$

After calculation, we get $96 \leq m \leq 120$ and $55.111\mu m \leq 2L \leq 68.889\mu m$ with $2L = \frac{m\lambda}{n_{eff}}$. The pass

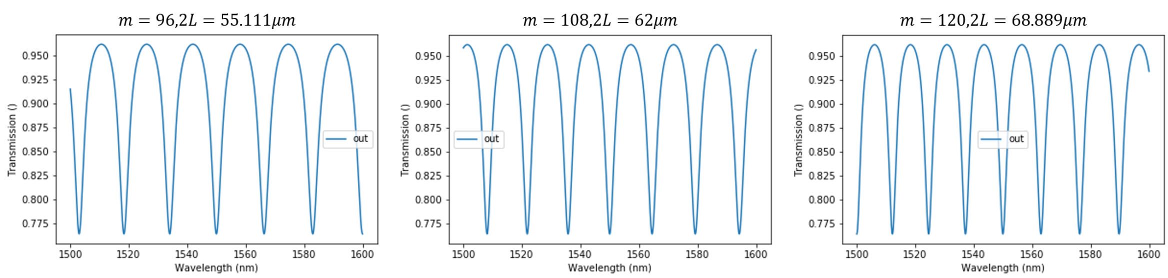


Figure 1: Pass transmission with respect to wavelength

transmission is shown in Figure 1, when the ring length is equal to $55.111\mu m, 62\mu m, 68.889\mu m$,respectly. Obviously, each of them has seven resonances between 1.5 μm and 1.6 μm with one at 1.55μm. So there is a resonance when $\lambda = \frac{2Ln_{eff}}{m}$. 2L is given by 1.

From preparation, we know,

$$\begin{aligned} T_p &= \frac{\tau^2 + A^2 - 2A\tau\cos\phi}{1 + A^2\tau^2 - 2A\tau\cos\phi} \\ &= 1 + \frac{\tau^2 + A^2 - 1 - A^2\tau^2}{1 + A^2\tau^2 - 2A\tau\cos\phi} \end{aligned} \tag{5}$$

$\tau^2 + A^2 - 1 - A^2\tau^2 = \kappa^2(A^2 - 1) < 0$,so when $\cos\phi = 1$,T_p,is minimum.

Free spectral range

$$\Delta\lambda_{FSR} = \frac{\lambda^2}{2n_g L} \tag{6}$$

In fact, the free spectral range(FSR) will change as the wavelength. If choosing λ fixed, this format is not exact so much. When we use the wavelength at the specific FSR to calculate $\Delta\lambda_{FSR}$, it is quite exact. For example, as for the case of$2L = 62\mu m$, it is shown in the center of Figure 1.$\Delta\lambda_{FSR} = 14.29nm$.

Critical coupling

Here, we choose $2l = 62\mu m$. Obviously, only when $|\tau| = \exp -2\alpha L$, $T_p = 0$ at wavelength of resonance,as shown in Figure 2.

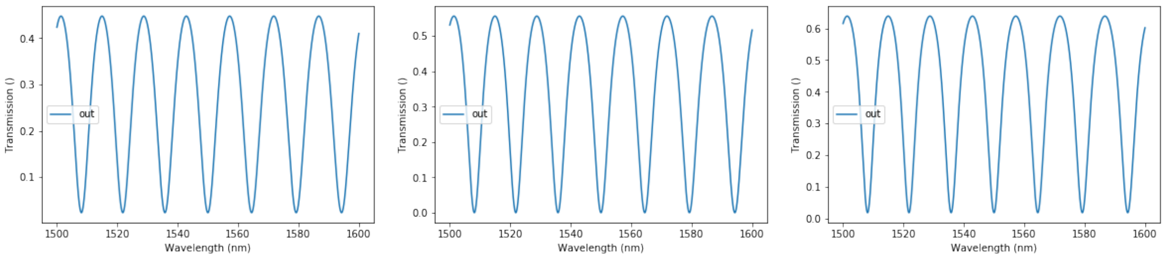


Figure 2: Pass transmission with respect to wavelength.When $\exp -2\alpha :< |\tau|$(left);When$\exp -2\alpha := |\tau|$(center);When $\exp -2\alpha :> |\tau|$(right)

2 Ring with two waveguides

2.1

The figure 3 illustrates that maximum drop transmission and minimum pass transmission is at wavelengths , such as about 1500nm , 1514nm, 1528nm, 1542nm, 1558nm.

2.2

As we solved in the preparation,the condition to obtain maximum T_d is$2\beta L = 2\pi m$ (m is positive integer). Therefore,the ring length $2L = (m_0)/n_{eff}$. For $_0 = 1.55\mu m, n_{eff} = 2.7$, I choose m=104,which makes

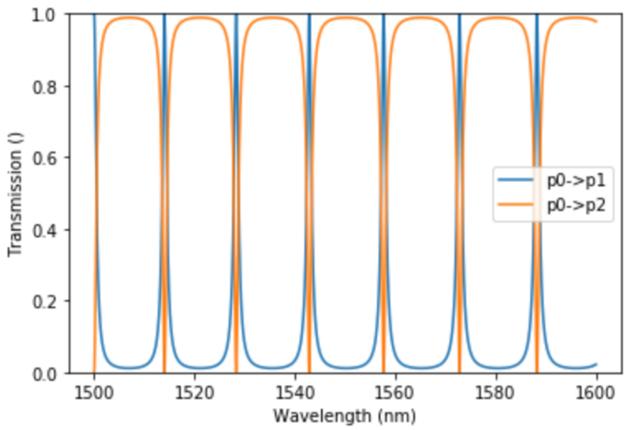


Figure 3: Transmission distribution of drop (blue) and pass (orange),ring length=60 μm

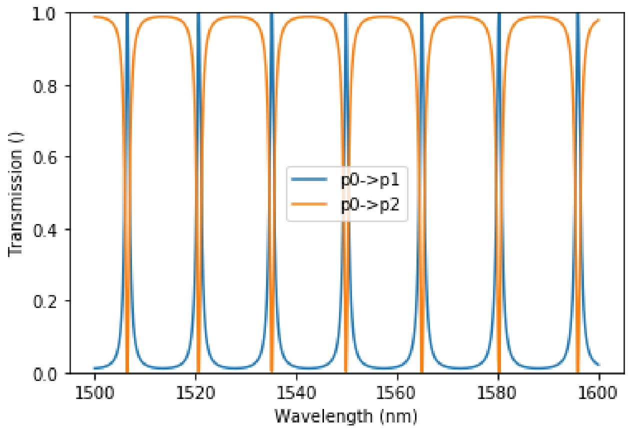
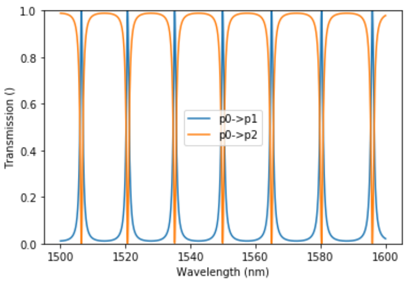


Figure 4: Transmission distribution of drop (blue) and pass (orange),ring length=59.7μm

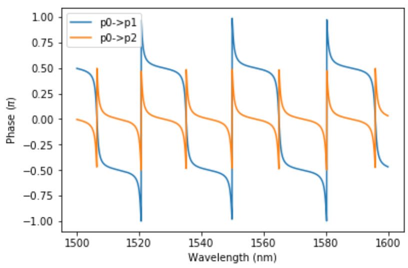
2L=59.7um .From figure 6,we can see resonance is around 1.55 μm.

2.3

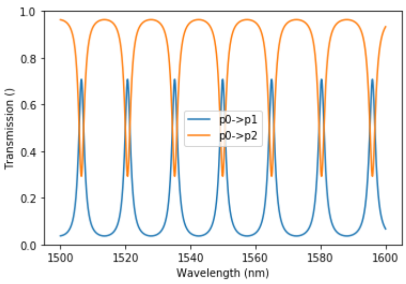
From Figure 5 (a) and (c), we can know the ’unbalanced’ ring induces the maximum drop transmission decline sharply . Figure5 (b) and (c) illustrate the same contribution. Thus ,when we get an ’unbalanced’ figure like (b) and (c) in practice, we can’t confirm which coupler have fabrication errors. But it can be confirmed easily by check the phase distribution. When bottom τ = top τ , the phase of difference between the maximum and minimum is π . When bottom τ < top tau or bottom $\tau >$ toptau, the phase of difference between the maximum and minimum is respectively larger than π orsmaller than π.



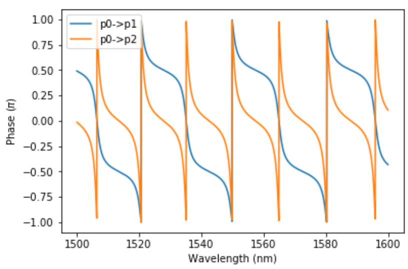
(a) Bottom τ=0.9 ,top τ=0.9



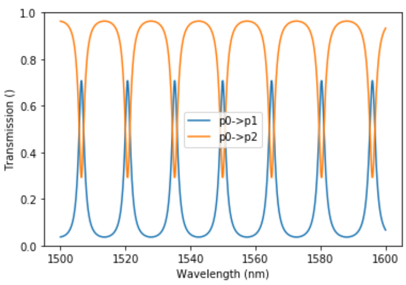
(b) Bottom τ=0.9 ,top τ=0.9



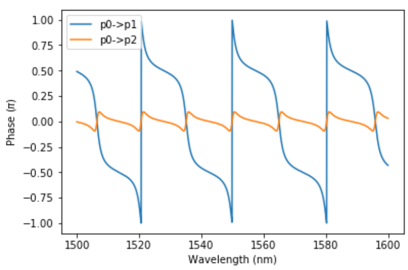
(c) Bottom τ=0.7 ,top τ=0.9



(d) Bottom τ=0.7 ,top τ=0.9



(e) Bottom τ=0.9 ,top τ=0.7



(f) Bottom τ=0.9 ,top τ=0.7

Figure 5: Transmission(left) and phase(right) distribution of dfifferent 'unbalanced' rings

2.4

For ring_loss_dB_m=0,we can get A=0.The formula of $\Delta\lambda\_3dB$ can be simplified as:

$$\Delta\lambda_{3dB} = \frac{(1-\tau^2)\lambda^2}{\tau\pi 2Ln_g} \tag{7}$$

For no dispersion will be included so the effective index equals the group index,$n_{eff} = n_g = 2.7$. And 2L=59.7um,=0.9, =1.55um.Take parameters in the formula we get :

$$\Delta\lambda_{3dB} = 1.00158nm$$

From figure 2.4 ,we can see the bandwidth ,the distance between orange curve, is the same as the theoretical value of $\Delta\lambda_{3dB}$.

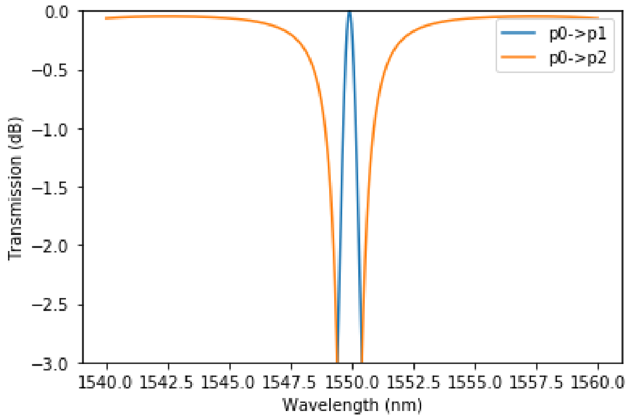


Figure 6: Transmission distribution (dB) of drop (blue) and pass (orange),ring length=59.7um,wavelength (1.54um, 1.56um)

3 Multiple rings

3.1

Set $m_1 = 110$ in $2\beta L = 2\pi m_1 \lambda$ of the first filter, m_2 in $2\beta L = 2\pi m_2 \lambda$, which respectively correspond to the ring length $2L_1 = 63.15\mu\mathrm{m}$ and $2L_2 = \frac{m_2}{m_1} \times 63.15\mu\mathrm{m}$. Assume there is no loss, the free spectral range and the 3dB-bandwidth of the first ring are given by:

$$\Delta\lambda_{FSR1} = \frac{\lambda^2}{2n_g L_1} \tag{8}$$

$$\Delta\lambda_{3dB} = \frac{\left(1-\tau^2\right)\lambda^2}{\tau\pi 2L_1 n_g} \tag{9}$$

and in the same way we can get $\Delta\lambda_{FSR2}$. In order to filter the lights of which wavelengths are near $1550\mathrm{nm}$, consider the free spectral range of the second filter $\Delta\lambda_{FSR2}$ is at least smaller or longer of $3\Delta\lambda_{3dB}$. The relations are represented by:

$$\begin{aligned} &\Delta\lambda_{FSR2} > \Delta\lambda_{FSR1} + 3\Delta\lambda_{3dB}, \mathrm{or} \\ &\Delta\lambda_{FSR2} < \Delta\lambda_{FSR1} - 3\Delta\lambda_{3dB} \end{aligned} \tag{10}$$

Then we get

$$m_2 \le 91 \quad \mathrm{or} \quad m_2 \ge 138 \tag{11}$$

Figure 7 shows the filtering results when $m_2 = 91, L_2 = 52.55\mu\mathrm{m}$ or $m_2 = 138, L_2 = 79.09\mu\mathrm{m}$. Obviously resonances next to $\lambda = 1.55\mu\mathrm{m}$ are effectively removed.

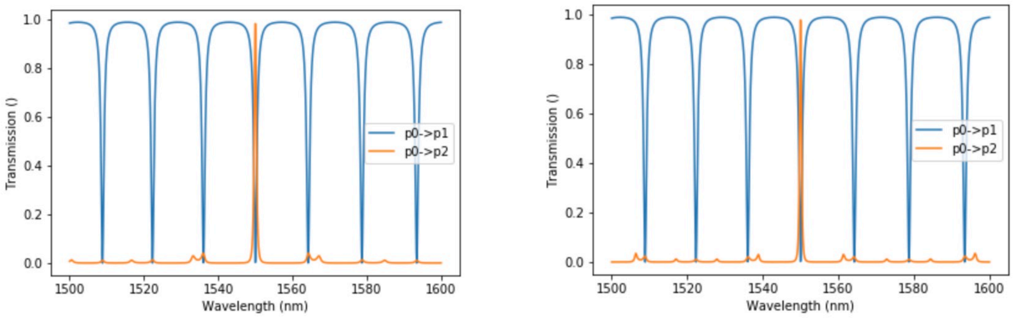


Figure 7: The transimission when $L_2 = 52.55\mu\mathrm{m}$(left) or $L_2 = 79.09\mu\mathrm{m}$(right)

3.2

When $\tau = \tau_{\mathrm{middle}} = 0.9$, we observe the appearence of two peaks in Figure 9

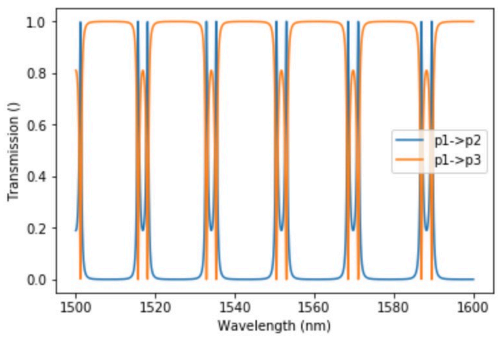


Figure 8: The transimission when $\tau = \tau_{\mathrm{middle}} = 0.9$

By changing both tau and τ_{middle} we get the results in Figure **??**. When τ becomes smaller, the positive peak near the two peaks become smaller and finally disapears; while there are no obvious difference when changing τ_{middle} but not tau. So we can get aflat, steep filter response by keeping $\tau \to 0$.

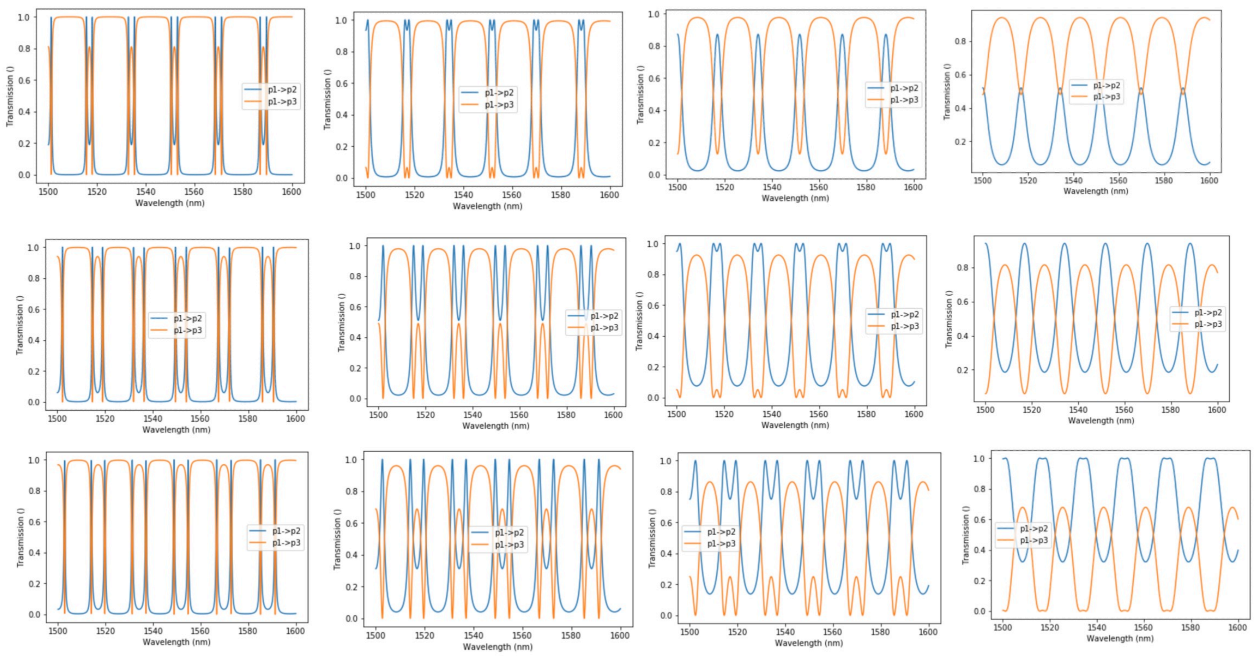


Figure 9: The transimission when τ changes in $0.9, 0.7, 0.5, 0.3$ along the row and τ_{middle} changes in $0.9, 0.7, 0.5$ along the vertical columns

The difference between the vernier effect and the series-rings is that there are two peaks appearing around the main wavelength in the series-rings while just one peak in the vernier effect.

4 Bonus question

We choos the fileter lossless, and ring length with $2L = 80 \times \frac{\lambda}{n_{neff}}$. If we want to make steeeper edges, we could make τ smaller, as shown in Figure 10. It has steepter edges than Figure 6.

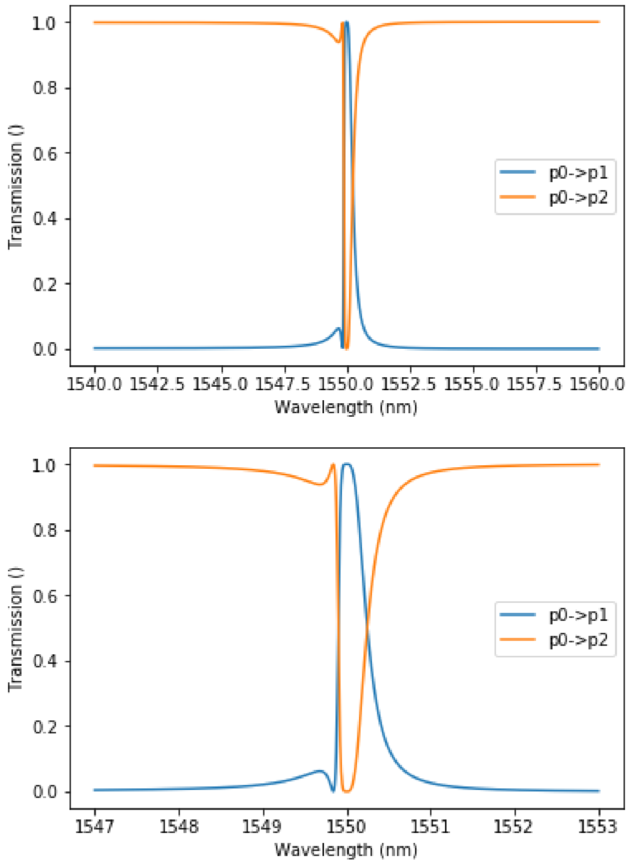


Figure 10: Transmission distribution (dB) of drop (blue) and pass (orange),ring with $\tau = 0.98$