Coupled-Resonator-Induced Transparency in a Fiber System

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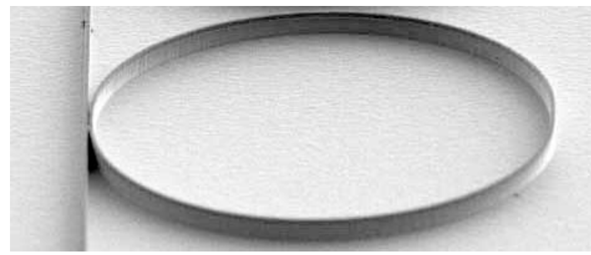
Outline

- Whispering Gallery Mode Resonators (WGMR)
- Coupled-Resonator-Induced Transparency (CRIT)
- Electromagnetically-Induced Transparency (EIT) and CRIT-EIT analogy
- Observation of CRIT in a fiber system
- Numerical simulations of CRIT
- Conclusions

Whispering Gallery Mode Resonators

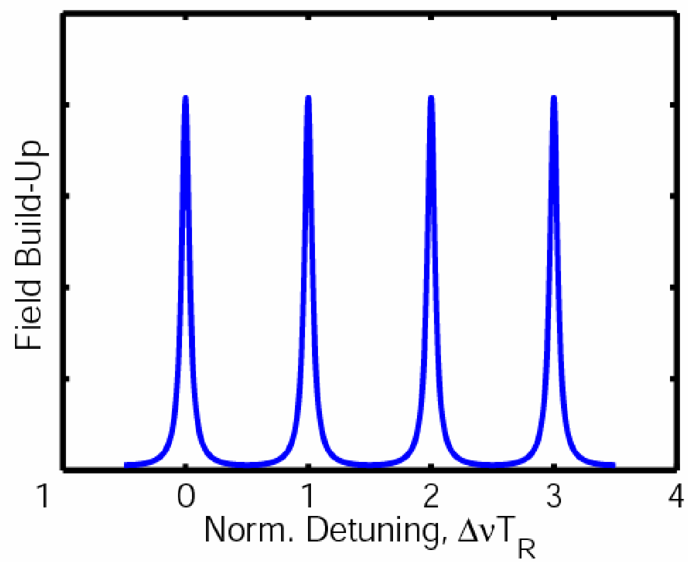
A Real Whispering Gallery

St. Paul's Cathedral, London

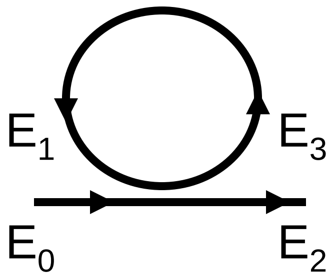


$$2\pi R = m\lambda$$

$$F >> 1$$



Whispering Gallery Mode Resonators



$$E_3(\omega) = rE_1(\omega) + itE_0(\omega)$$

$$E_2(\omega) = itE_1(\omega) + rE_0(\omega)$$

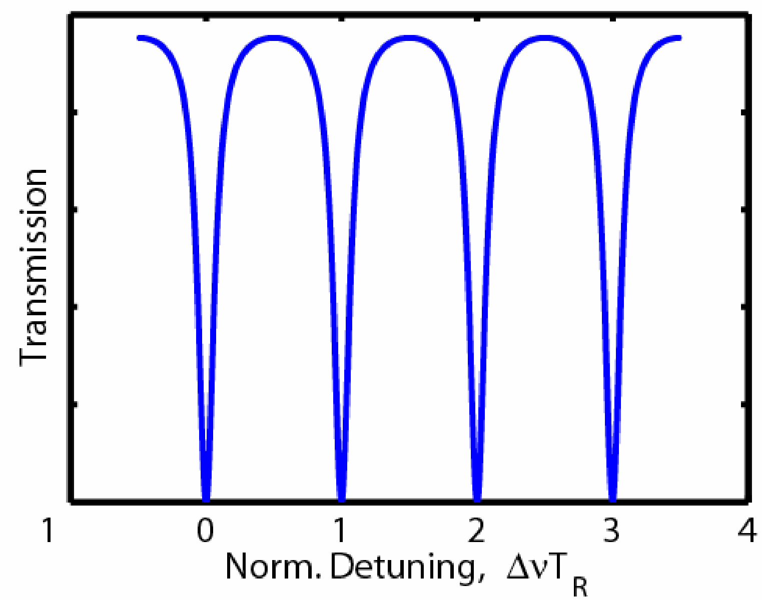
$$E_1(\omega) = ae^{i\phi}E_3(\omega)$$

t - cross-coupling coefficient

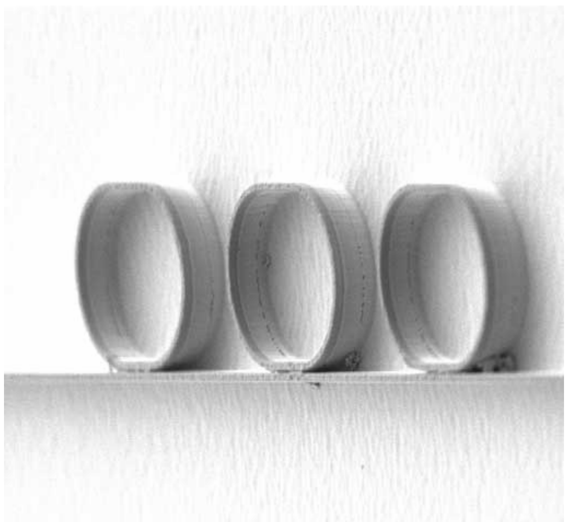
r - self-coupling coefficient

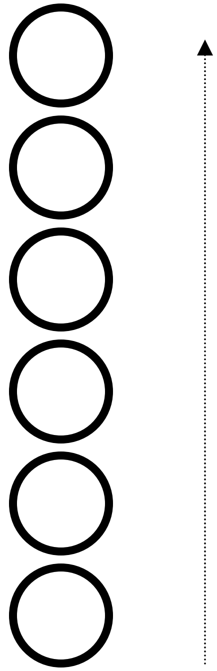
a - single-pass amplitude transmission

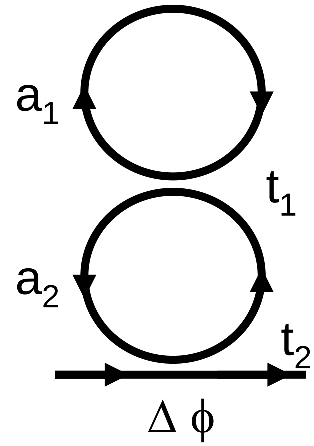
ϕ - single-pass phaseshift



Arrays of WGM resonators







SCISSOR

CROW

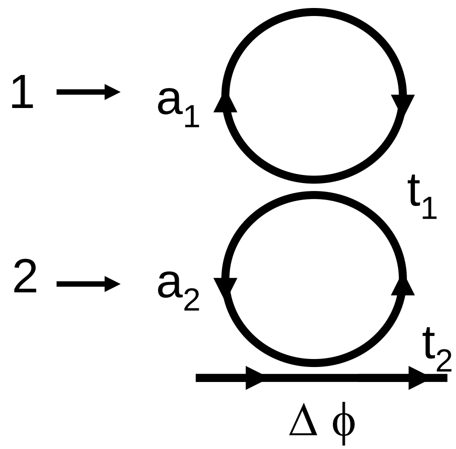
CRIT

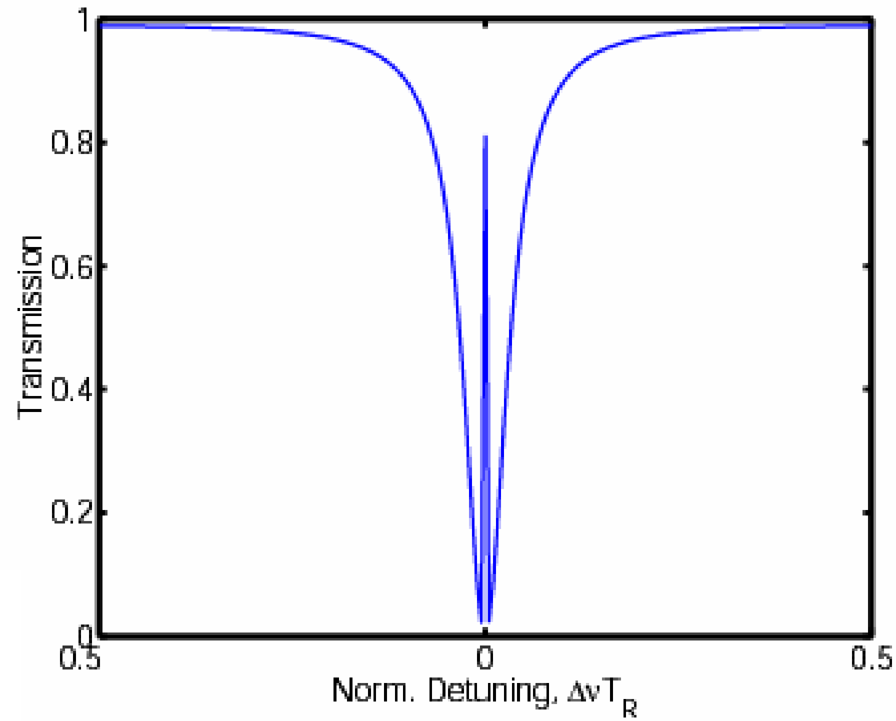
Side-coupled integrated spaced sequence of resonators (SCISSOR)
Heebner et al. , JOSA B, 19, 722 (2002)

Coupled resonator optical waveguides
Yariv et al. ,
Opt. Lett. 24, 711 (1999)

Coupled-resonator-induced transparency
Smith et al.,
Phys. Rev. A 69, 063804 (2004)

Coupled-Resonator-Induced Transparency (CRIT)





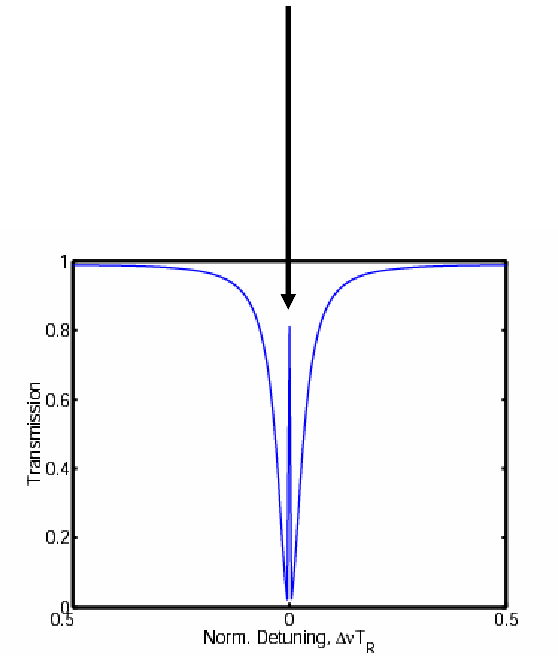
$$t_1(\phi_1) = \frac{r_1 - a_1 e^{i\phi_1}}{1 - r_1 a_1 e^{i\phi_1}}$$

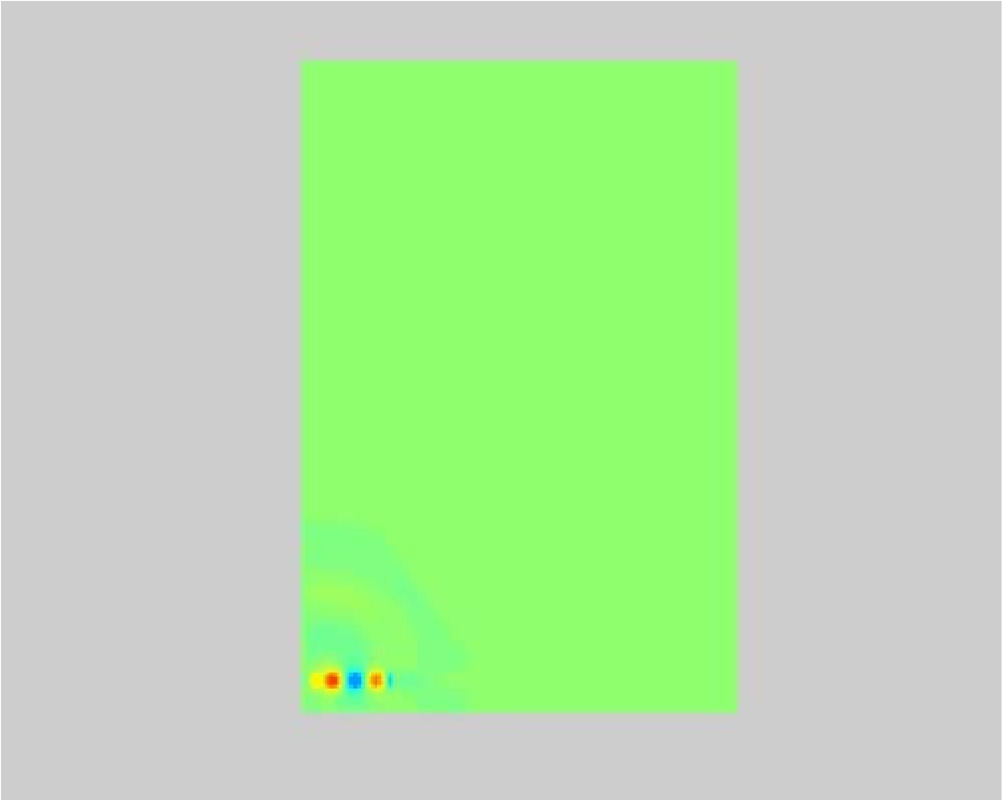
$$t_2(\phi_1, \phi_2) = \frac{r_2 - a_2 t_1(\phi_1) e^{i\phi_2}}{1 - r_2 a_2 t_1(\phi_1) e^{i\phi_2}}$$

ϕ_1, ϕ_2 - single-pass phase shift

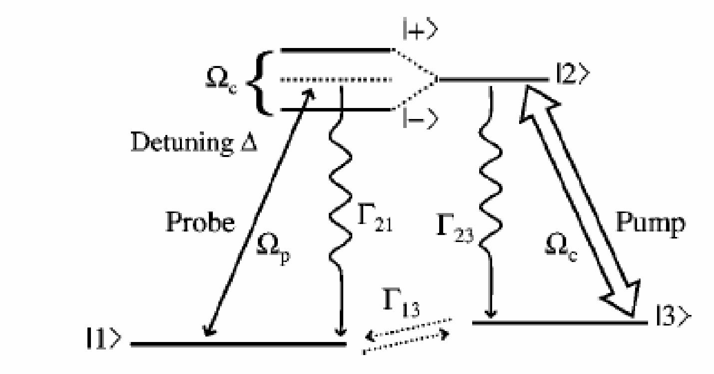
How does it really work?

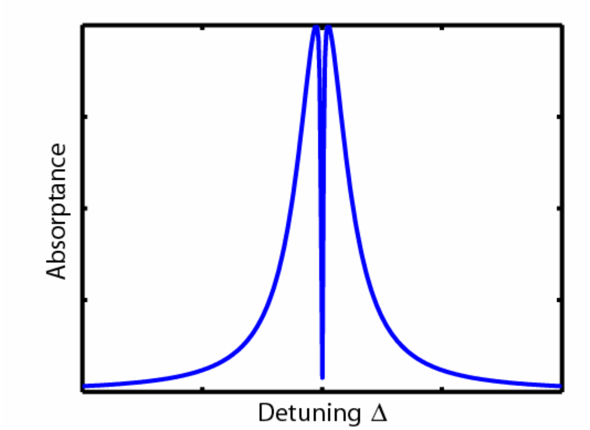
What happens at
this frequency ?





CRIT- EIT analogy

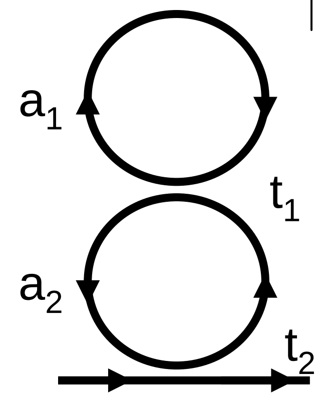


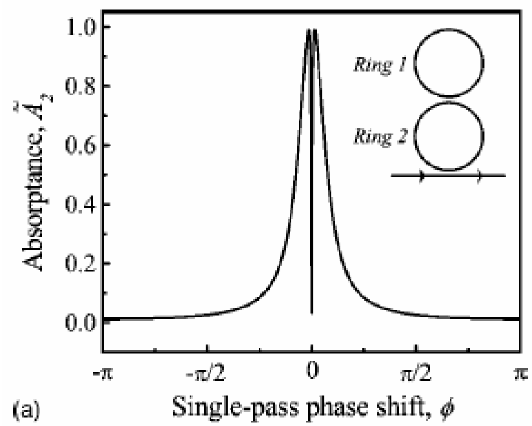


$$W(\Delta) = \frac{[\Omega_p^2/\Gamma]}{1 + \frac{4}{\Gamma^2}\left[\Delta - \frac{(\Omega_c/2)^2}{\Delta}\right]^2}$$

Interference of EM fields vs. probability amplitudes

t_1	Ω_c
t_2	Ω_p
δ	Δ
a_1	Γ_{13}
a_2	Γ





(a)

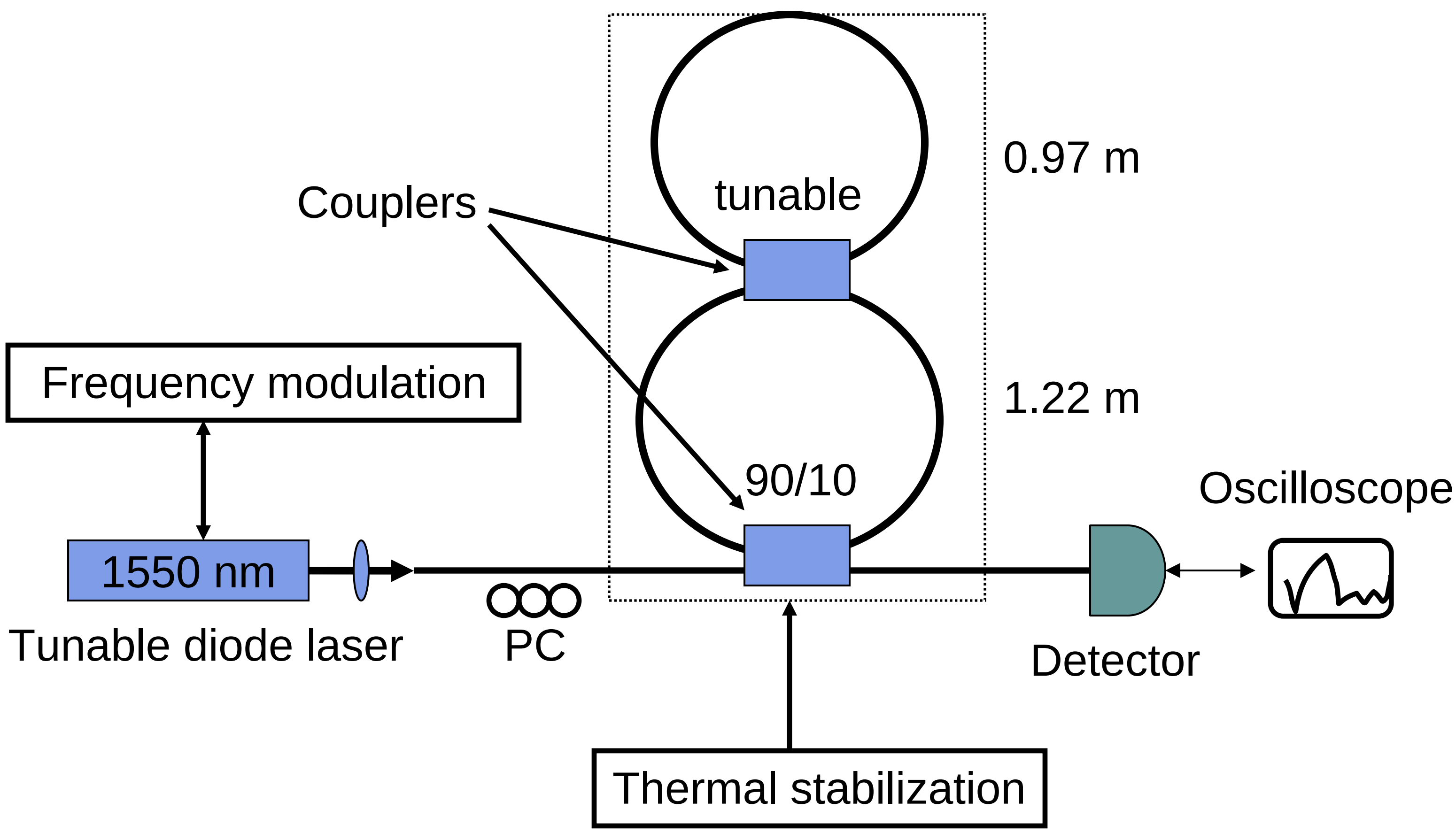
$$\tilde{A}_2(\delta) = \frac{A_2^{(\mathrm{env})}}{1 + \frac{4}{\gamma^2}\left[\delta - \frac{(\Delta\omega/2)^2}{\delta}\right]}$$

Smith et al.
Phys. Rev. A 69, 063804 (2004)

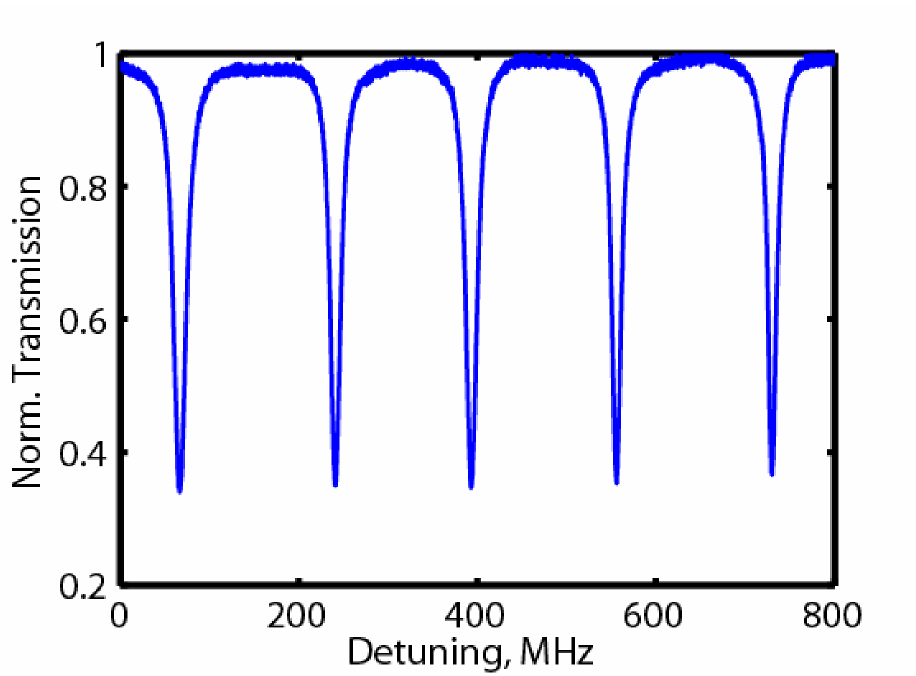
What material system to use?

- Integrated devices – difficult to fabricate
- Micro-spheres – difficult to use
- Fiber rings – easy to fabricate and use

CRIT in a fiber system



Single resonator transmission

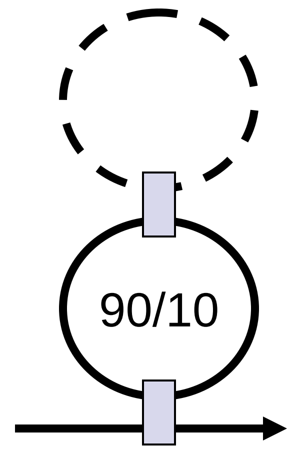


$a_1 = 0.98$

$r_1 = 1.0$

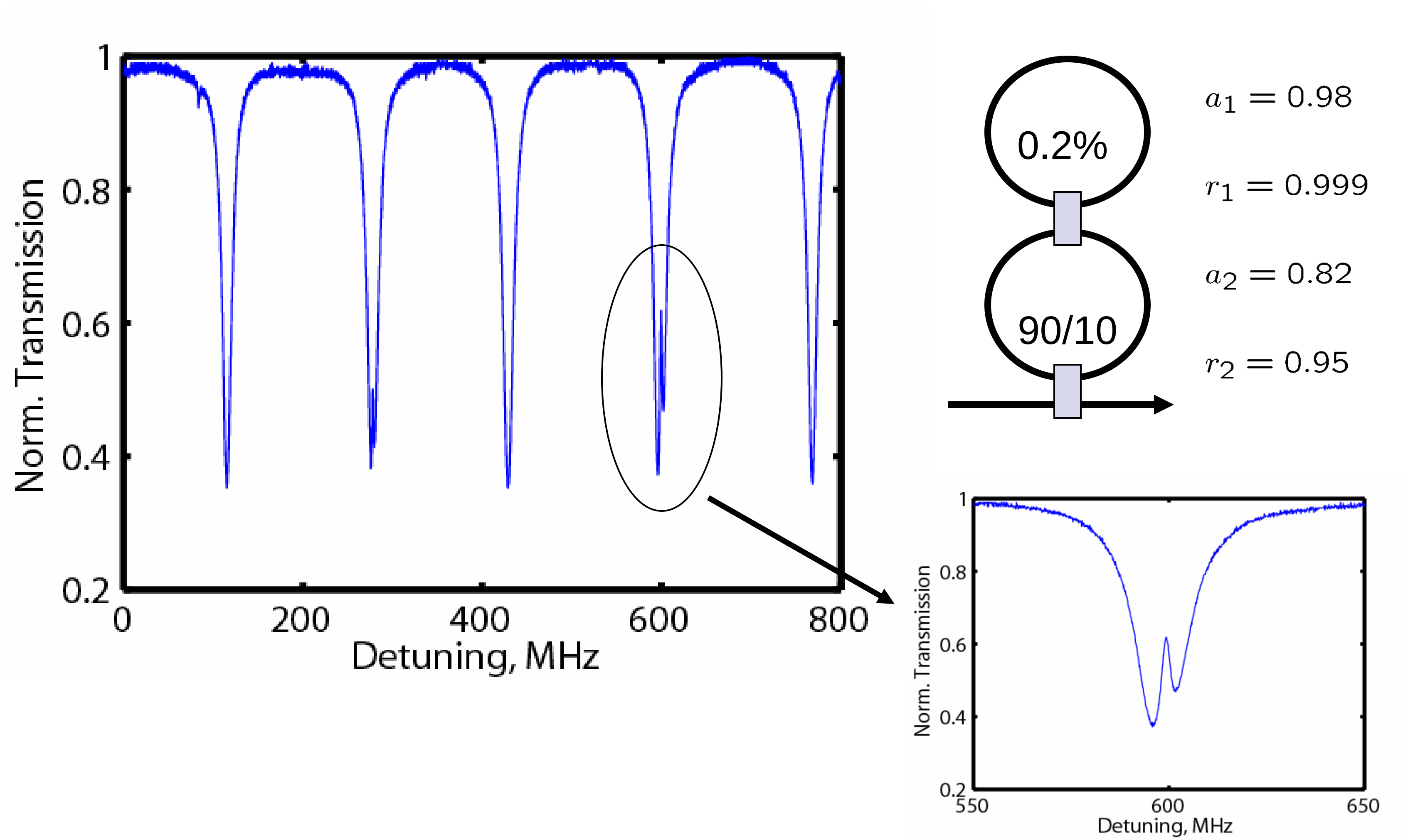
$a_2 = 0.82$

$r_2 = 0.95$

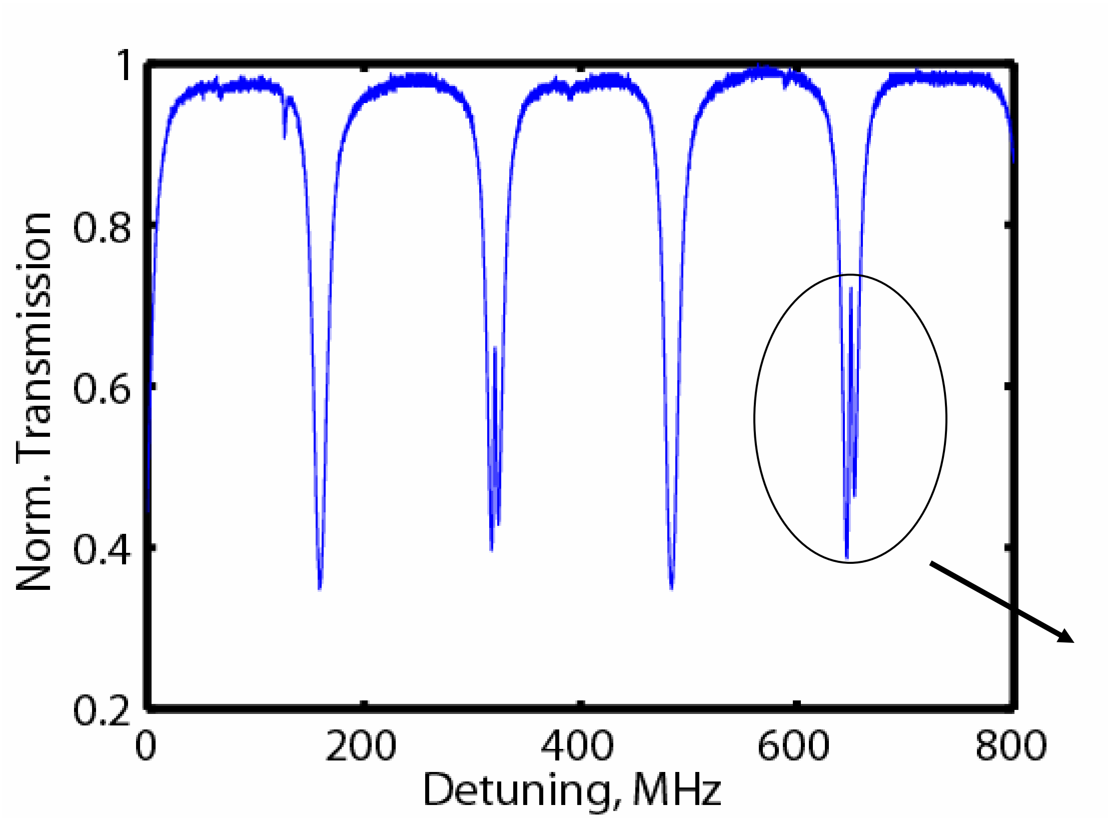


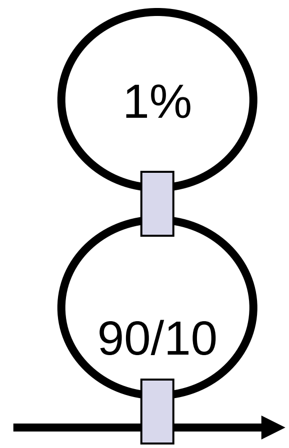
FSR – 170 MHz
F~12

CRIT (weak coupling)



CRIT (weak coupling)



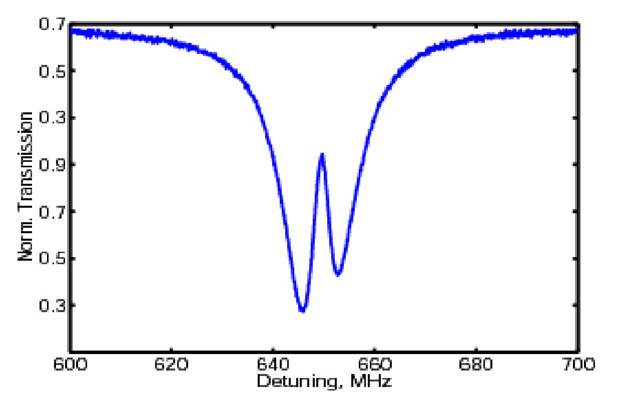


$a_1 = 0.98$

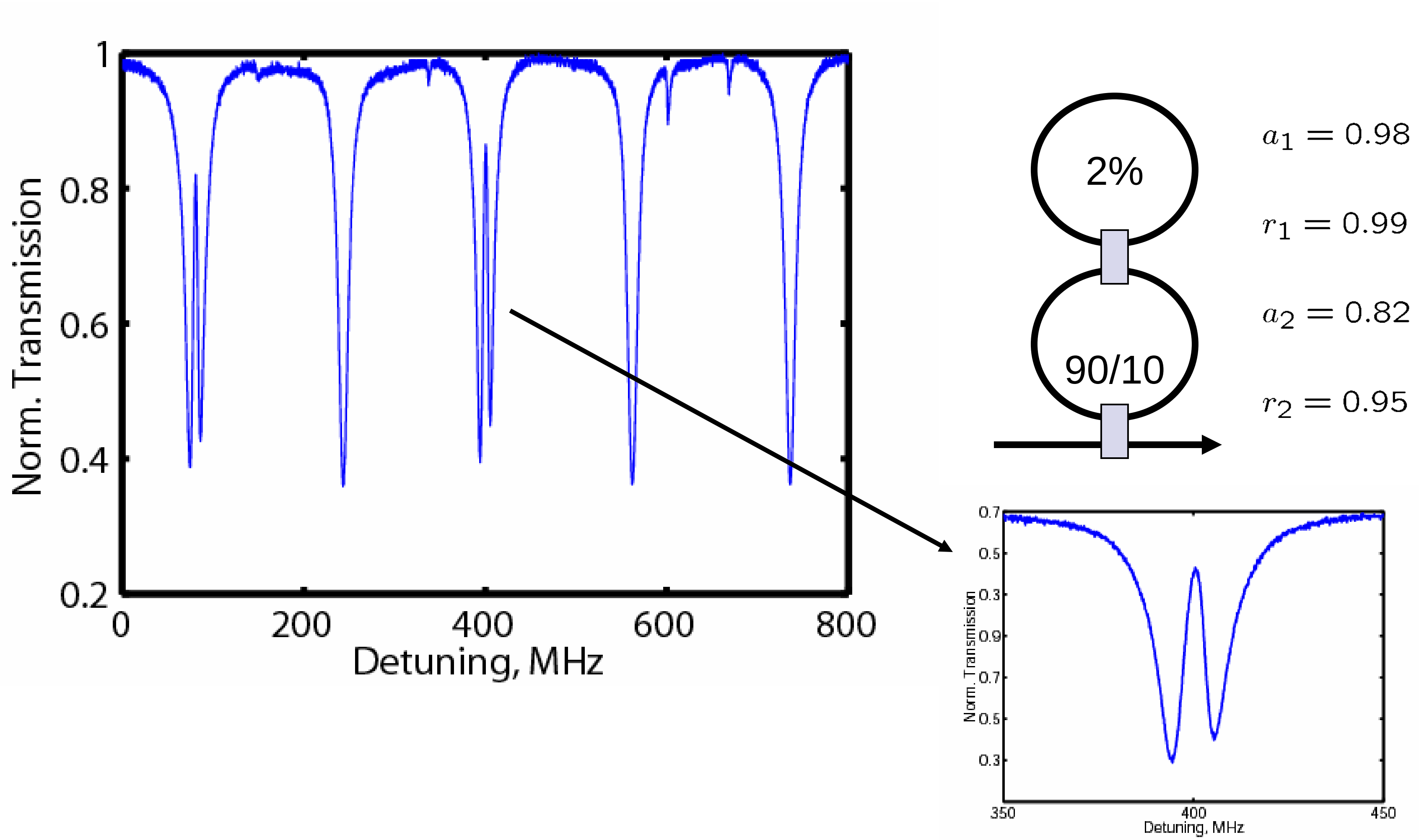
$r_1 = 0.995$

$a_2 = 0.82$

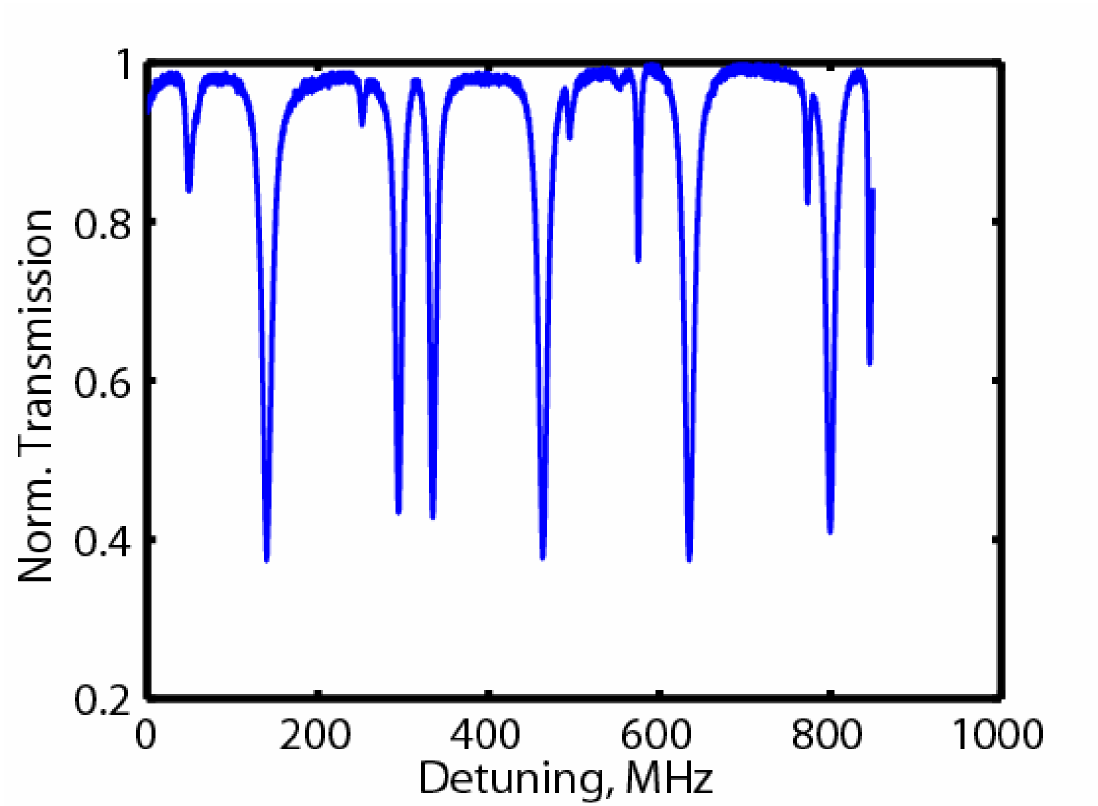
$r_2 = 0.95$

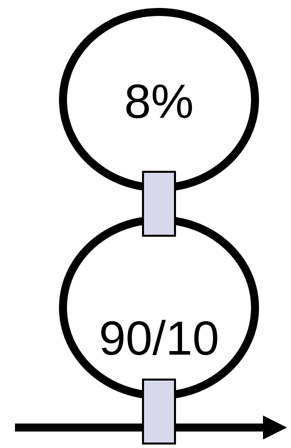


CRIT (weak coupling)



CRIT (mode-splitting)





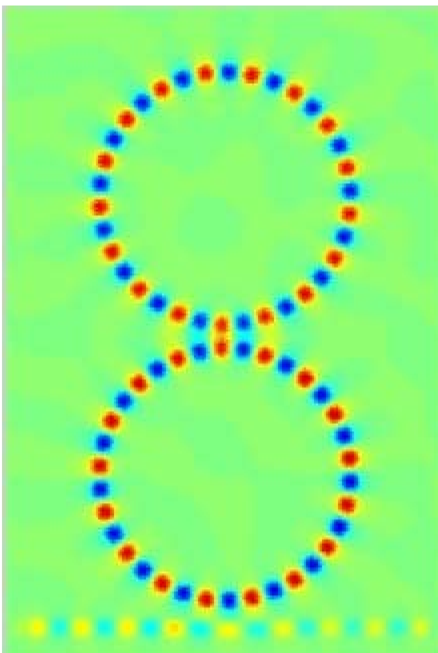
$a_1 = 0.98$

$r_1 = 0.96$

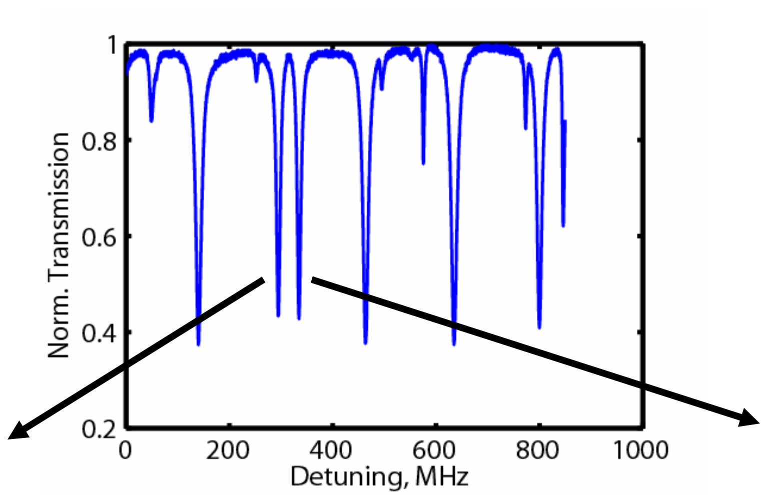
$a_2 = 0.82$

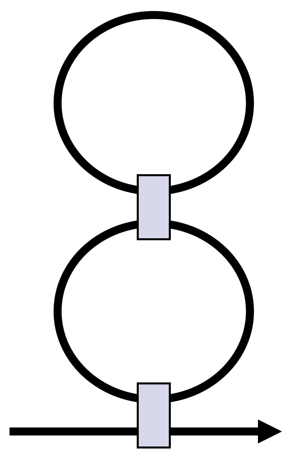
$r_2 = 0.95$

Mode-splitting and mode profiles



Symmetric mode



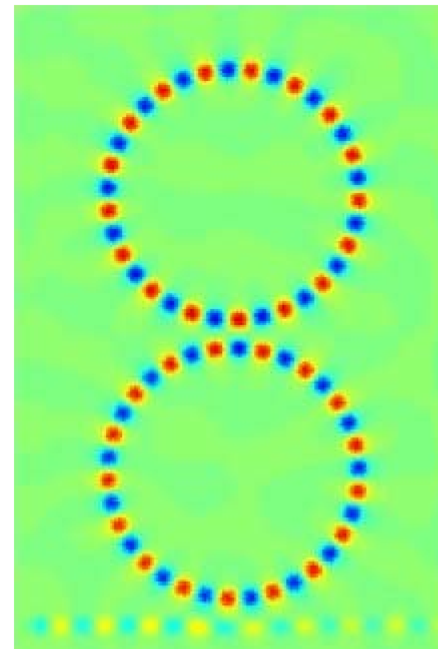


$a_1 = 0.98$

$r_1 = 0.96$

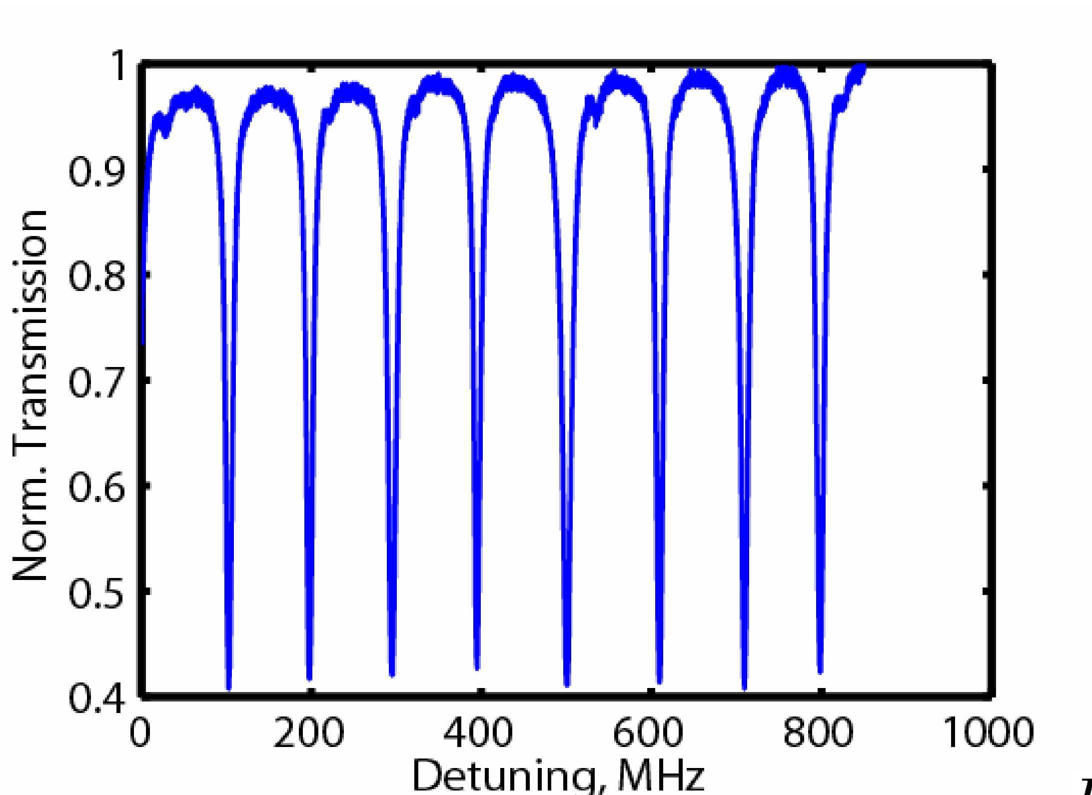
$a_2 = 0.82$

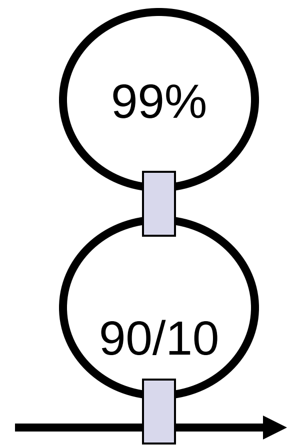
$r_2 = 0.95$



Anti-symmetric mode

CRIT (strong-coupling limit)





$a_1 = 0.98$

$r_1 = 0.1$

$a_2 = 0.82$

$r_2 = 0.95$

$$FSR \approx \frac{c}{(L_1+L_2)n}$$

Conclusions

- CRIT-EIT analogy
- Observation of CRIT in a fiber system
- Narrow (sub-radiative) spectral features for

1. Sensing applications
2. Dispersion control
3. Slow light