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

\[ 2\pi R = m\lambda \]

\[ F \gg 1 \]
Whispering Gallery Mode Resonators

\[ E_3(\omega) = rE_1(\omega) + itE_0(\omega) \]

\[ E_2(\omega) = iT E_1(\omega) + rE_0(\omega) \]

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

- \( t \) - cross-coupling coefficient
- \( r \) - self-coupling coefficient
- \( a \) - single-pass amplitude transmission
- \( \phi \) - single-pass phaseshift
Arrays of WGM resonators

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

Coupled resonator optical waveguides

Coupled-resonator-induced transparency
Coupled-Resonator-Induced Transparency (CRIT)

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

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

\( \phi_1, \phi_2 - \text{single-pass phase shift} \)
How does it really work?

What happens at this frequency?
CRIT- EIT analogy

Interference of EM fields vs. probability amplitudes

Smith et al.

\[
W(\Delta) = \frac{4}{\Gamma^2} \frac{[\Omega_{\text{p}}^2/\Gamma]}{1 + \frac{4\left(\Delta - \frac{\Omega_{\text{c}}}{2}\right)^2}{\Delta^2}}
\]

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<td>(t_1)</td>
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<td>(a_1)</td>
<td>(\Gamma_{13})</td>
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<td>(a_2)</td>
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\[
\tilde{A}_2(\delta) = \frac{A_{2(\text{env})}}{1 + \frac{4\left(\delta - \frac{\Delta \omega}{2}\right)^2}{\gamma^2}}
\]
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

- Tunable diode laser
- Frequency modulation
- 1550 nm
- Couplers
- 90/10
- Tunable
- 0.97 m
- 1.22 m
- Thermal stabilization
- Oscilloscope
- Detector
Single resonator transmission

FSR – 170 MHz
F~12

\[ a_1 = 0.98 \]
\[ r_1 = 1.0 \]
\[ a_2 = 0.82 \]
\[ r_2 = 0.95 \]
CRIT (weak coupling)
CRIT (weak coupling)

\[
\begin{align*}
1% & \quad a_1 = 0.98 \\
90/10 & \quad r_1 = 0.995 \\
& \quad a_2 = 0.82 \\
& \quad r_2 = 0.95
\end{align*}
\]
CRIT (weak coupling)

\[
\begin{align*}
\text{Norm. Transmission} & \\
\text{Detuning, MHz} & \\
0 & 200 & 400 & 600 & 800
\end{align*}
\]

\[
\begin{align*}
a_1 & = 0.98 \\
r_1 & = 0.99 \\
a_2 & = 0.82 \\
r_2 & = 0.95
\end{align*}
\]
CRIT (mode-splitting)

![Graph showing normalized transmission against detuning in MHz, with modes labeled 8% and 90/10, and parameters $a_1 = 0.98$, $r_1 = 0.96$, $a_2 = 0.82$, $r_2 = 0.95$.](image)
Mode-splitting and mode profiles

Symmetric mode

Anti-symmetric mode

$a_1 = 0.98$
$r_1 = 0.96$

$a_2 = 0.82$
$r_2 = 0.95$
CRIT (strong-coupling limit)

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

\[ a_1 = 0.98 \]
\[ r_1 = 0.1 \]
\[ a_2 = 0.82 \]
\[ r_2 = 0.95 \]
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