Nested Ring Mach-Zehnder Interferometer (NRMZI)

Photonics Research Centre
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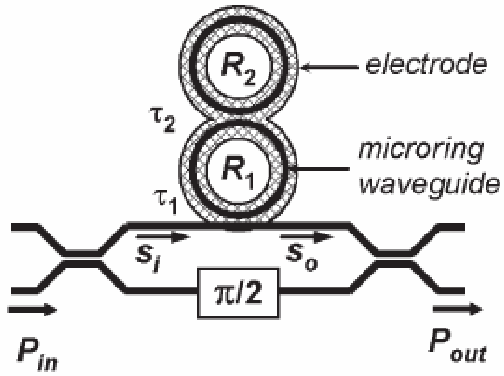
*Special thanks to Landobasa Y. M. for fruitful discussions

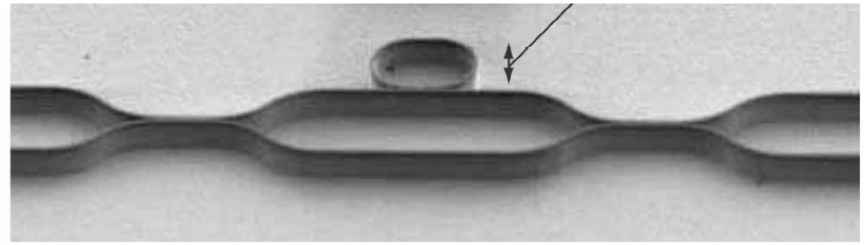
Outline

- Introduction: Some literature review
- Motivation: Why NRMZI?
- Theory: Device modeling
- Results: Box-like output and ultra-sharp resonance
- Conclusion

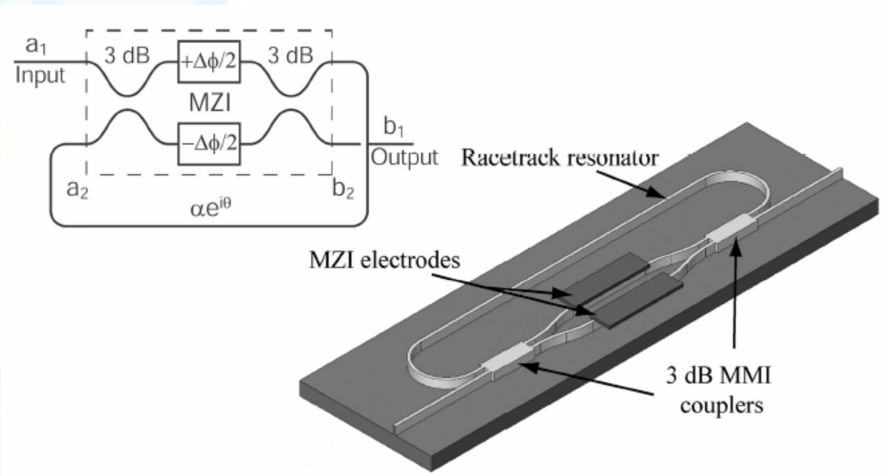
Literature on RR + MZIs



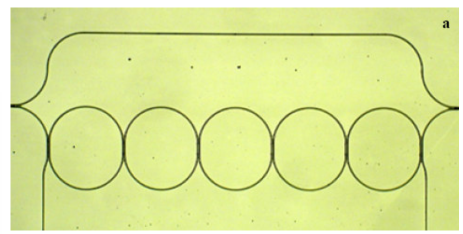
Linearized micro-ring loaded MZI
V. Van etal



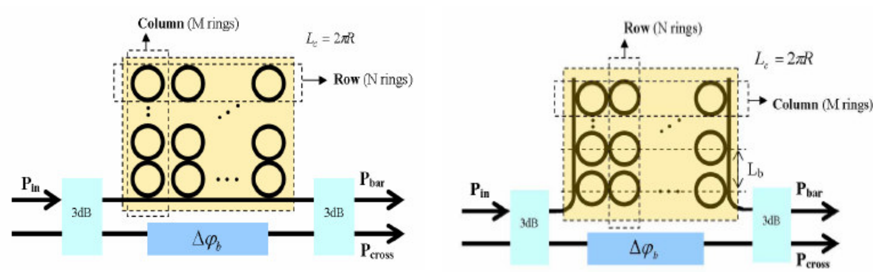
Ring enhanced Mach-Zehnder interferometer (**RE**MZI)
J. E. Heebner, etal ; Y. Lu, etal



Ring feedback Mach-Zehnder interferometer (**RF**MZI)
C.Y. Chao and L. J. Guo
William M. J. Green etal



Serially coupled REMZI
George T. Paloczi etal



Ring arrays - MZI
S. Darmawan etal

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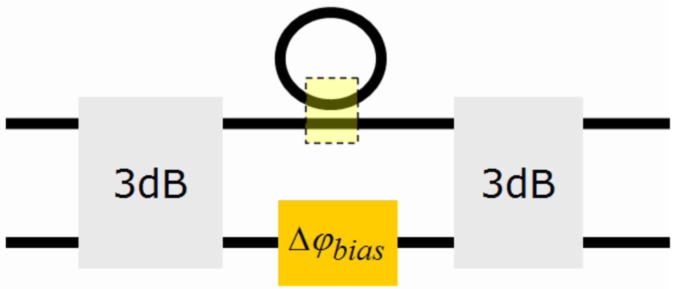
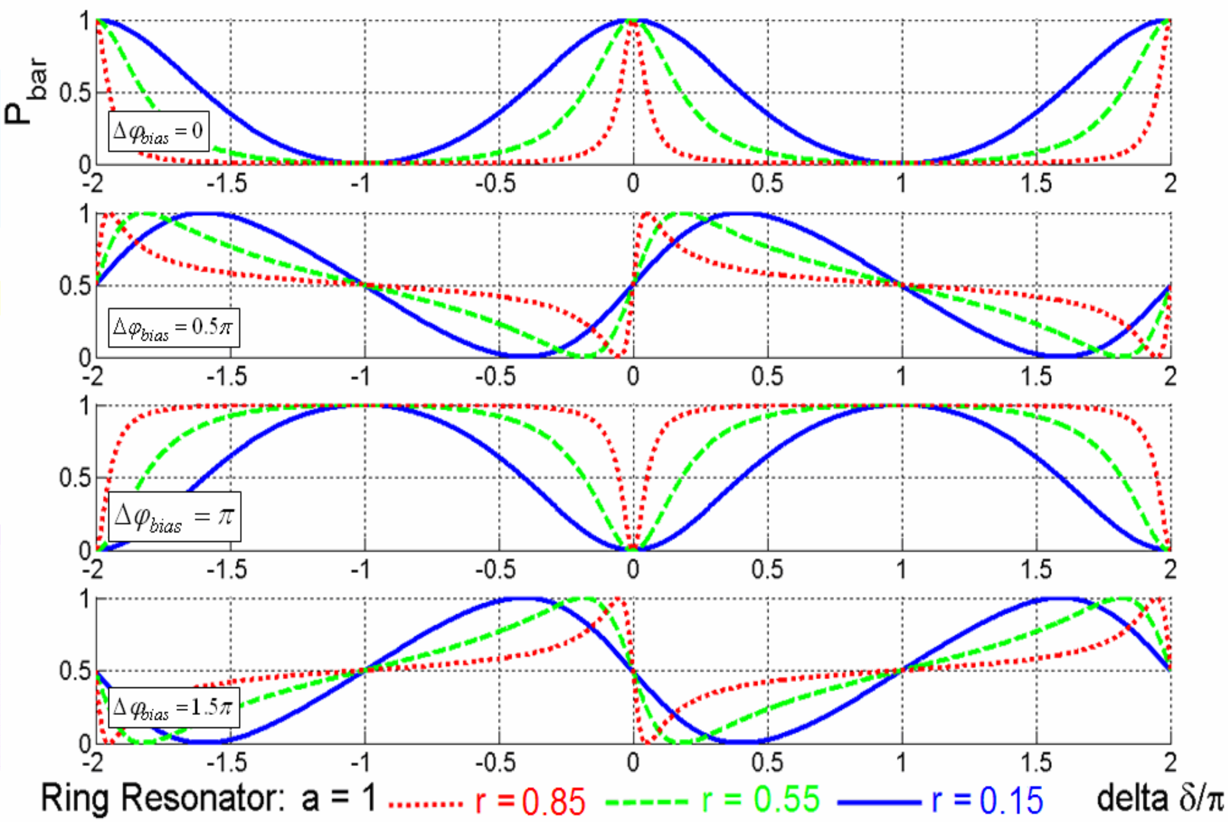
Why REMZI ?

Ring enhanced Mach-Zehnder interferometer (**RE**MZI)
J. E. Heebner, etal ; Y. Lu, etal



$$P_{bar} = \sin^2[(\varphi_{ring} - \Delta\varphi_{bias})/2]$$

$$P_{cross} = \cos^2[(\varphi_{ring} - \Delta\varphi_{bias})/2]$$



May function as:

- Modulator
- Switches
- Sensors

$$\delta = 2\pi n_{eff} L_c / \lambda$$

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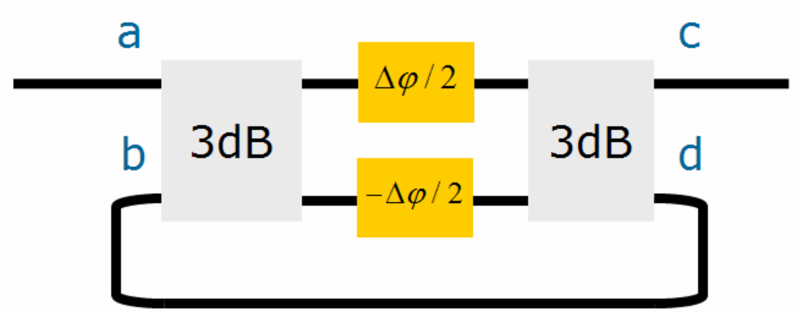
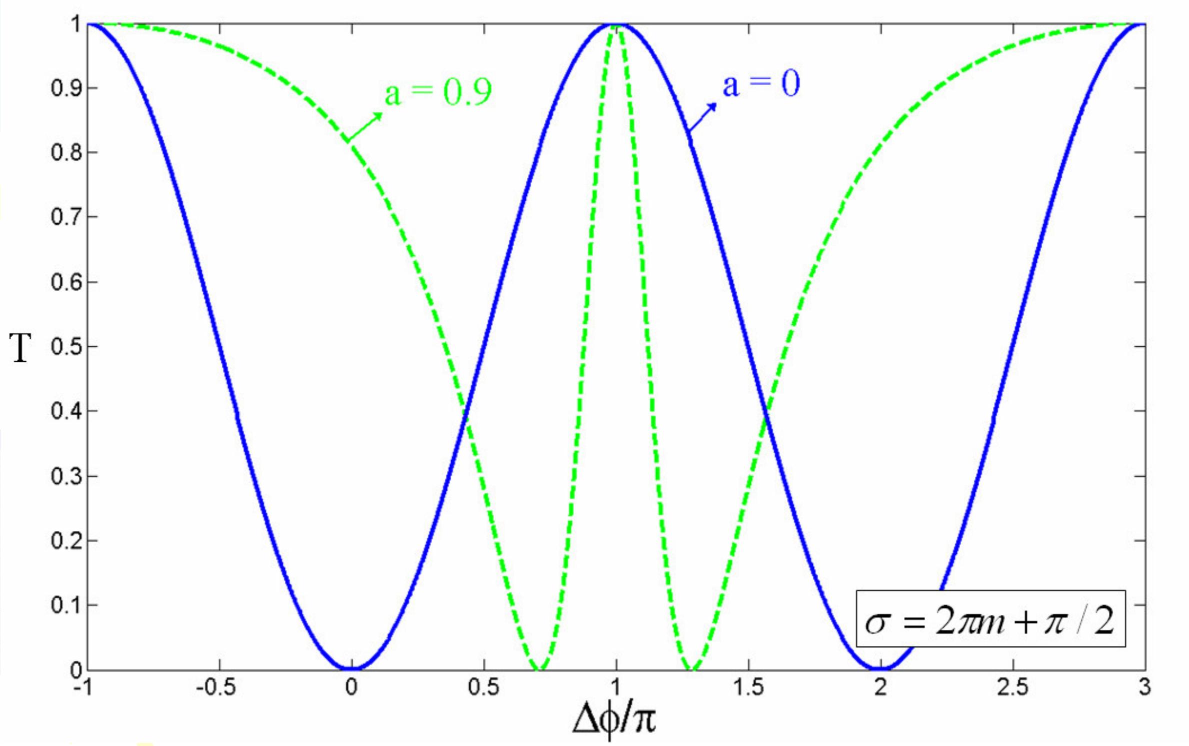
Why RFMZI ?



$\rightarrow T$

$$b = a\exp(i\theta)$$

$$T = \left| \frac{i\sin(\Delta\varphi/2) - a\exp(i\sigma)}{1 + ia\sin(\Delta\varphi/2)\exp(i\sigma)} \right|^2$$



May function as:

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Ring feedback Mach-Zehnder interferometer (**RF**MZI)

C.Y. Chao and L. J. Guo

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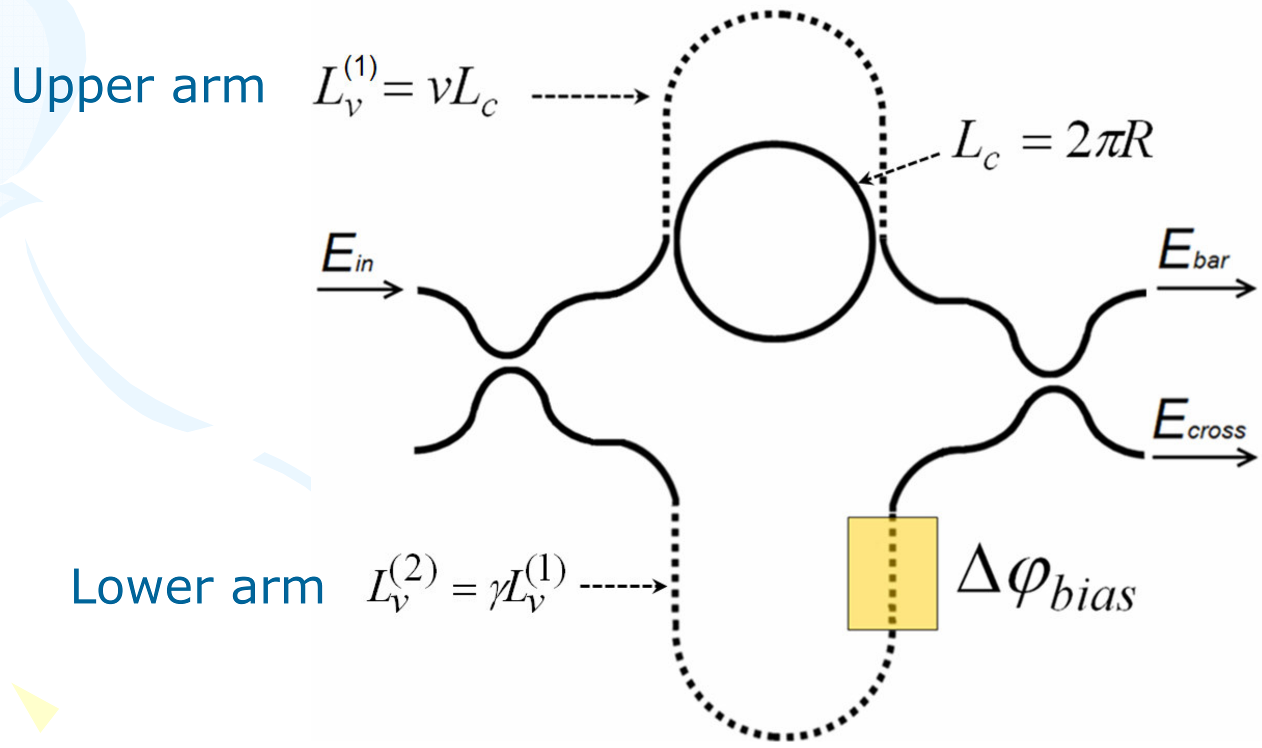
Motivation: Why NRMZI ?

Feature of interest:

- Good linearity with lower pumping power (as Modulator)
- Ultra-sharp resonance (as Sensor)
- Produces a box-like spectrum (as Filter)



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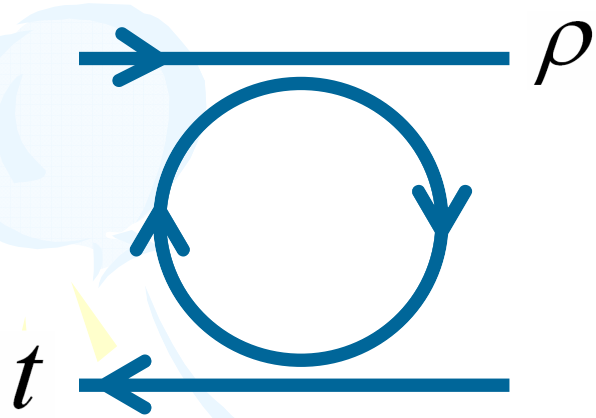
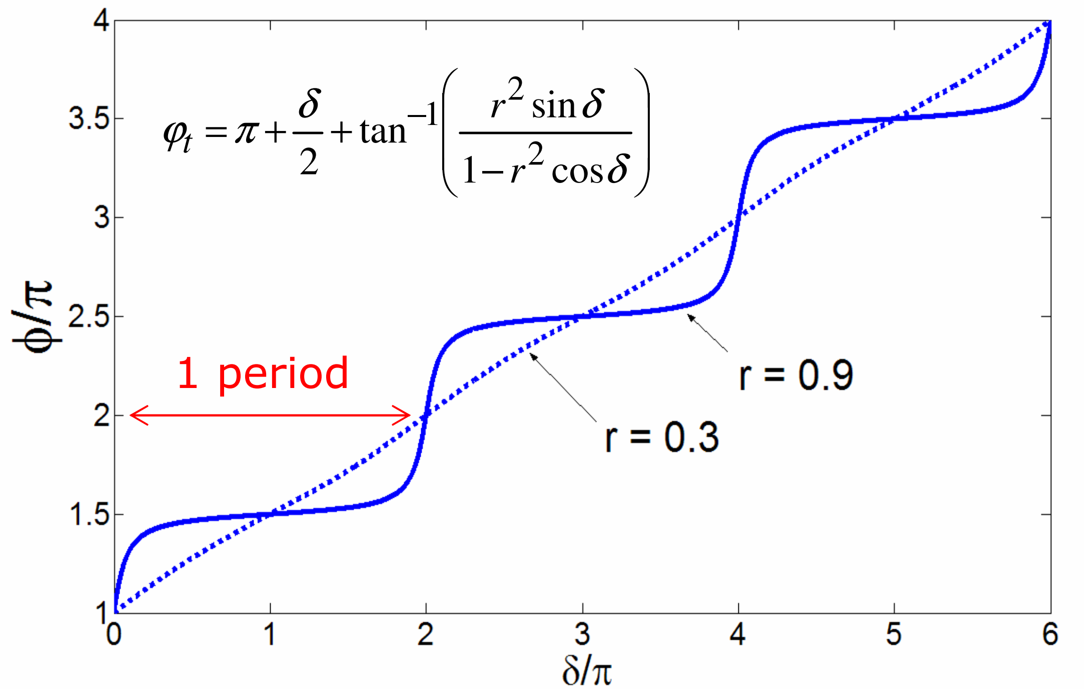
Basic: Dual-bus RR

$$\rho = \frac{r[-1 + a\exp(i\delta)]}{1 - r^2 a\exp(i\delta)} \qquad t = \frac{-\kappa^2 \sqrt{a}\exp(i\delta/2)}{1 - r^2 a\exp(i\delta)}$$

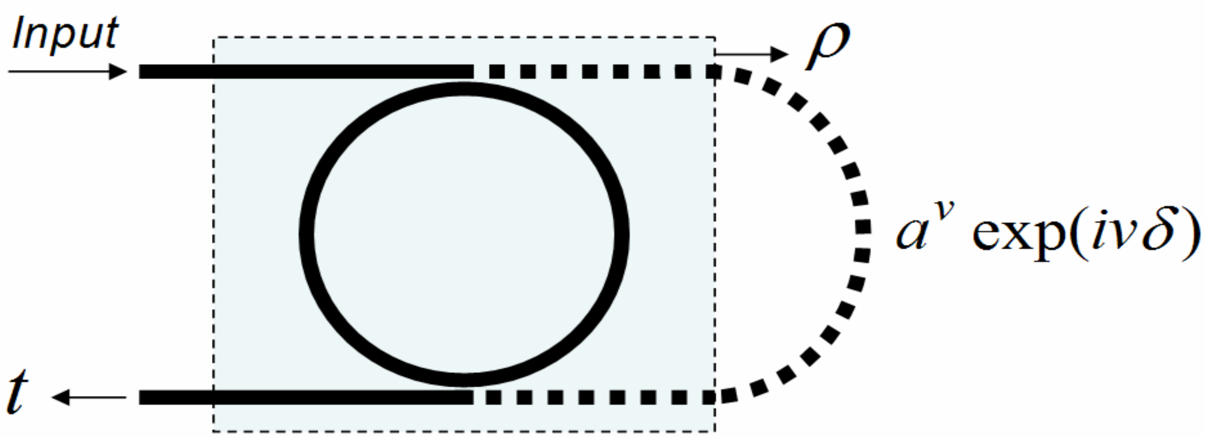


$$r = \sqrt{1 - \kappa^2}$$



Build up factor $B = \frac{\partial\varphi}{\partial\delta}$ is high when (r) is high

Loaded Nested RR (NRR)



$$\delta = \omega n_{eff} L_{\nu}^{(1)}$$

$$L_{\nu}^{(1)} = \nu(2\pi R)$$

Based on the topology of a dual-bus ring with closed loop feedback:

$$t_{ring} = t + \rho^2 a^{\nu} \exp(i\nu\delta)[1 + t a^{\nu} \exp(i\nu\delta) + ...]$$

$$= t + \frac{\rho^2 a^{\nu} \exp(i\nu\delta)}{1 - t a^{\nu} \exp(i\nu\delta)} = \frac{t + (\rho^2 - t^2) a^{\nu} \exp(i\nu\delta)}{1 - t a^{\nu} \exp(i\nu\delta)}$$

Phase response of NRR

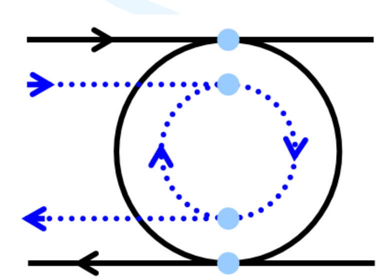
For a lossless case, the loaded phase response of NRR can be expressed as:

$$\varphi_{NRR}^{loaded} = \varphi_t + \varphi_{loading} =$$

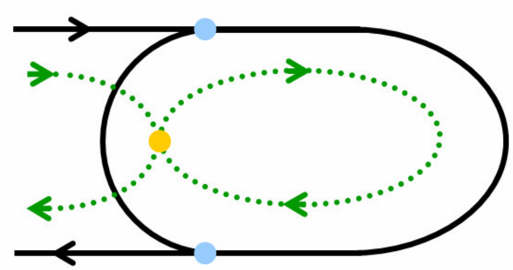
$$\varphi_t - \tan^{-1}\left(\frac{\sin(v\delta + \varphi_t)}{|t| - \cos(v\delta + \varphi_t)}\right) + \tan^{-1}\left(\frac{|t|\sin(v\delta + \varphi_t)}{1 - |t|\cos(v\delta + \varphi_t)}\right)$$

$$\varphi_t = \pi + \frac{\delta}{2} + \tan^{-1}\left(\frac{r^2 \sin\delta}{1 - r^2 \cos\delta}\right)$$

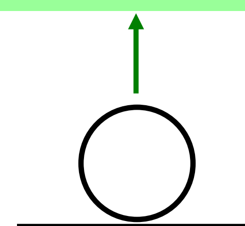
$$\varphi = -\tan^{-1}\left(\frac{\sin\delta}{r - \cos\delta}\right) + \tan^{-1}\left(\frac{r\sin\delta}{1 - r\cos\delta}\right)$$



φ_t Dual-bus RR



$\varphi_{loading}$



Single-bus RR

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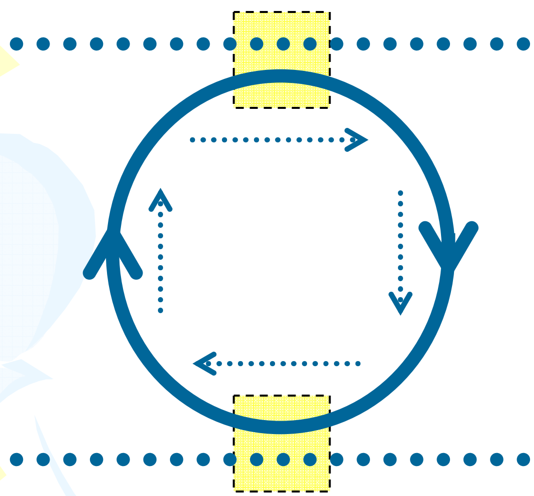
Two ‘competing’ resonant loops

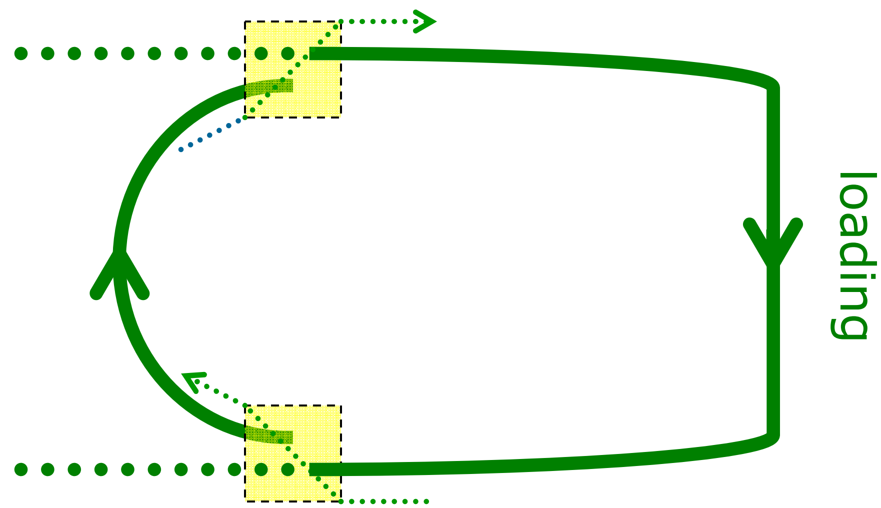
Inner resonant loop



$$r = \sqrt{1-\kappa^2}$$

‘Reflection’ based resonance

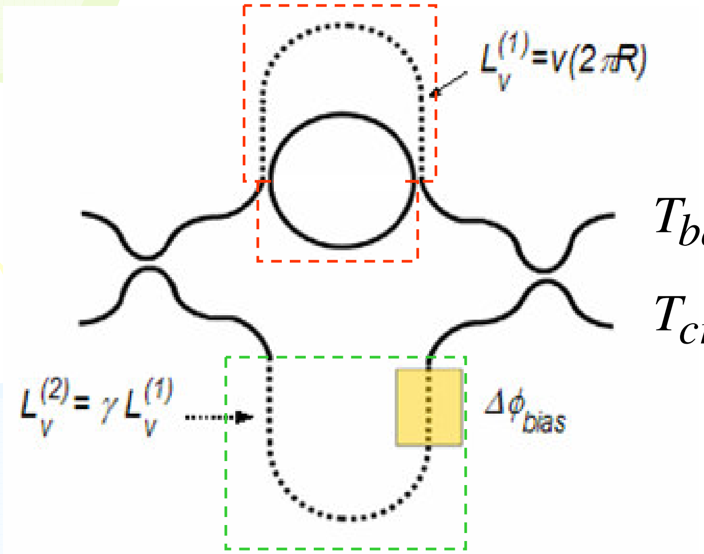
Outer resonant loop



$$\kappa = \sqrt{1-r^2}$$

‘Coupling’ based resonance

Engineering a box-like transmission

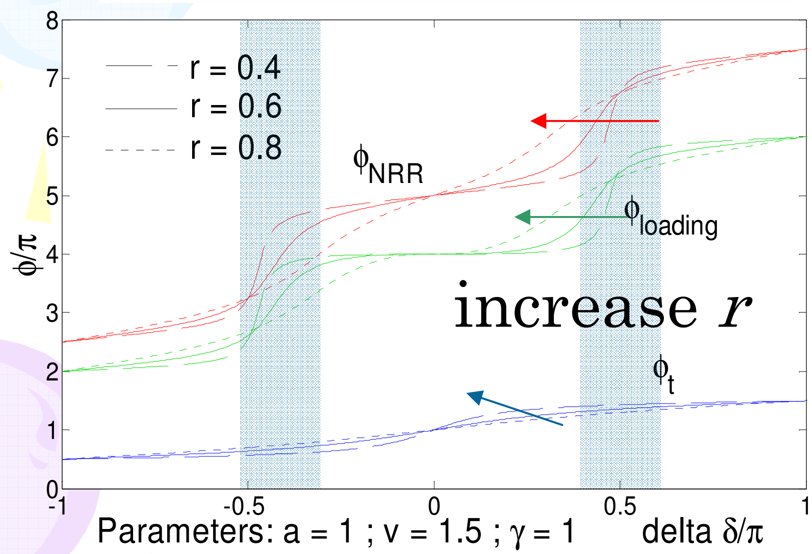


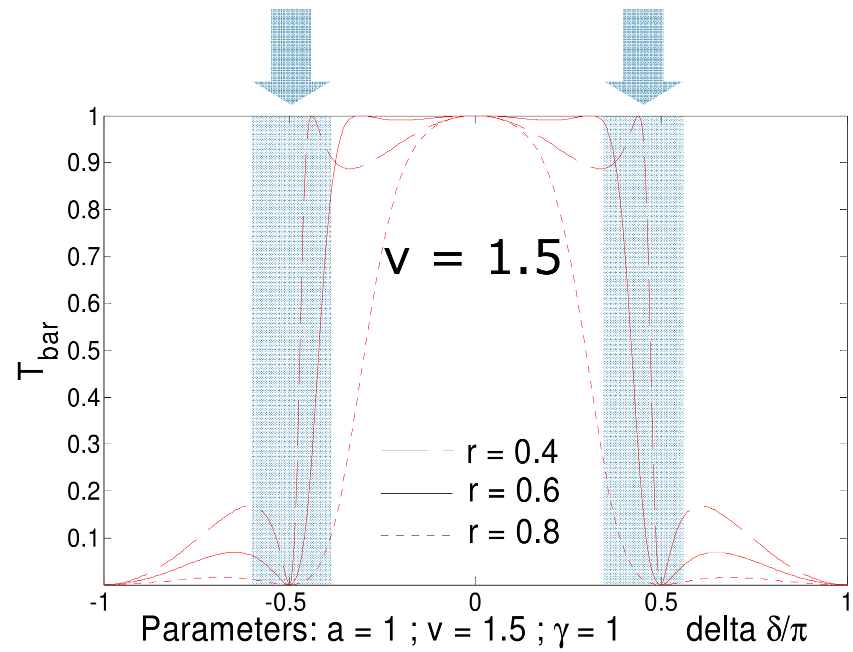
By optimizing (v) and (r) values !

$$T_{bar} = \sin^2([\varphi_{NRR} - (\gamma v\delta + \Delta\varphi_{bias})]/2)$$

$$T_{cross} = \cos^2([\varphi_{NRR} - (\gamma v\delta + \Delta\varphi_{bias})]/2)$$

Double-Fano resonance





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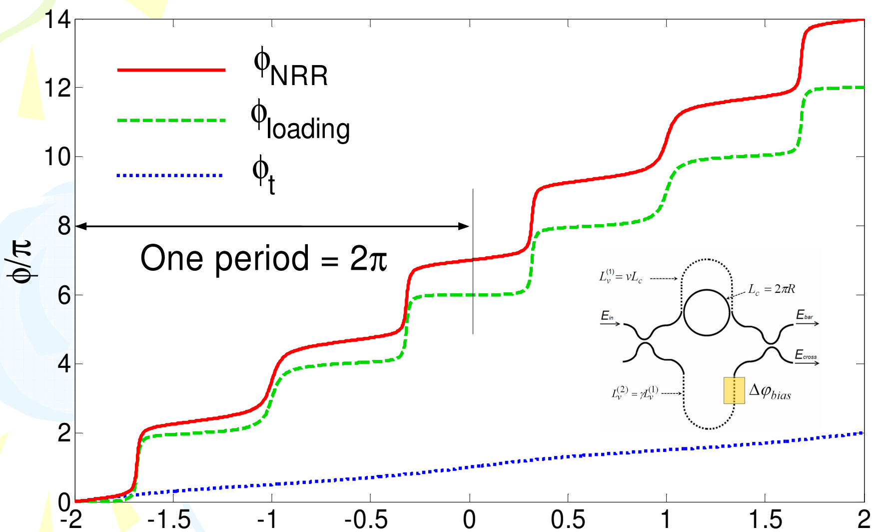
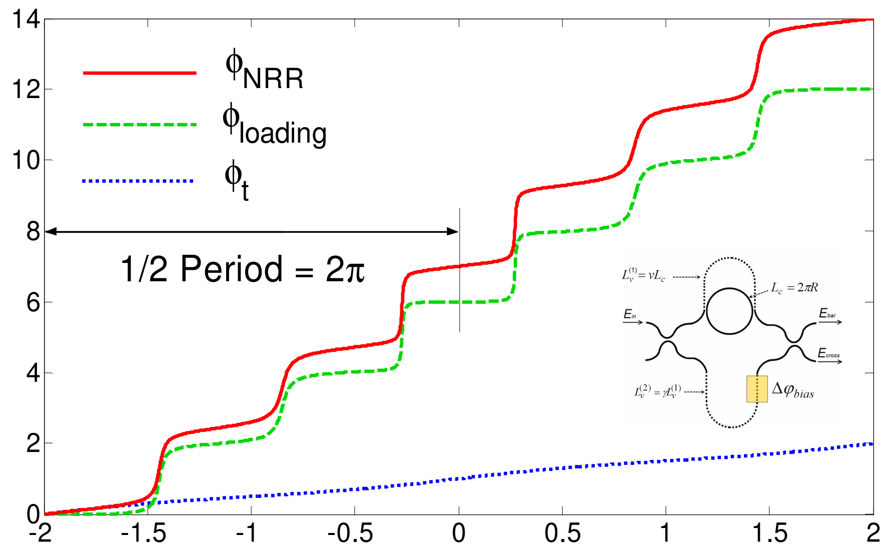
Conditions of (v) for box-like transmission

- Box-like only at: v = m-1/2 → 2pi period and v = m → 4pi period



Parameters: a = 1 ; r = 0.4 ; v = 2.5

(v = m-1/2)



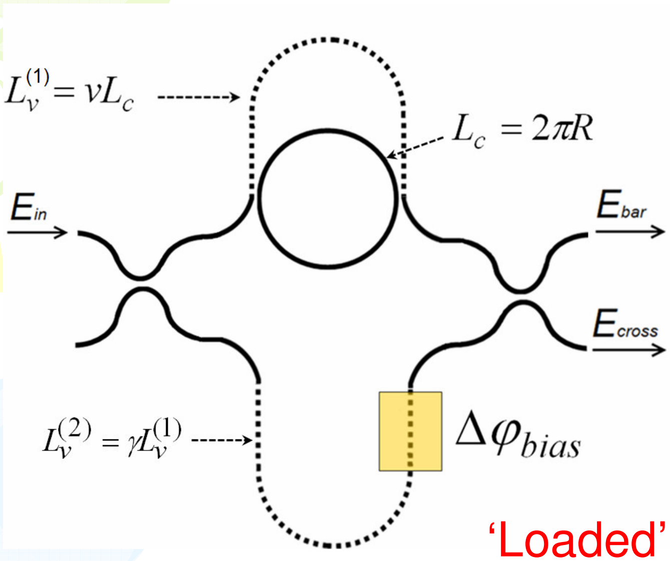
Parameters: a = 1 ; r = 0.4 ; v = 3

(v = m)

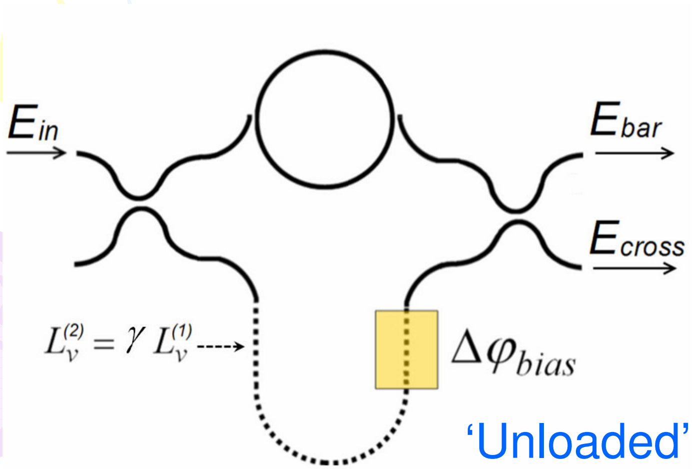
$$\varphi_{NRR}^{loaded} = \varphi_t + \varphi_{loading} =$$

$$\varphi_t - \tan^{-1}\left(\frac{\sin(v\delta+\varphi_t)}{|t|-\cos(v\delta+\varphi_t)}\right) + \tan^{-1}\left(\frac{|t|\sin(v\delta+\varphi_t)}{1-|t|\cos(v\delta+\varphi_t)}\right) \rightarrow (v+1/2)\delta + cc \text{ term}$$

‘Loaded’ NRMZI vs. ‘unloaded’ dual-bus coupled REMZI

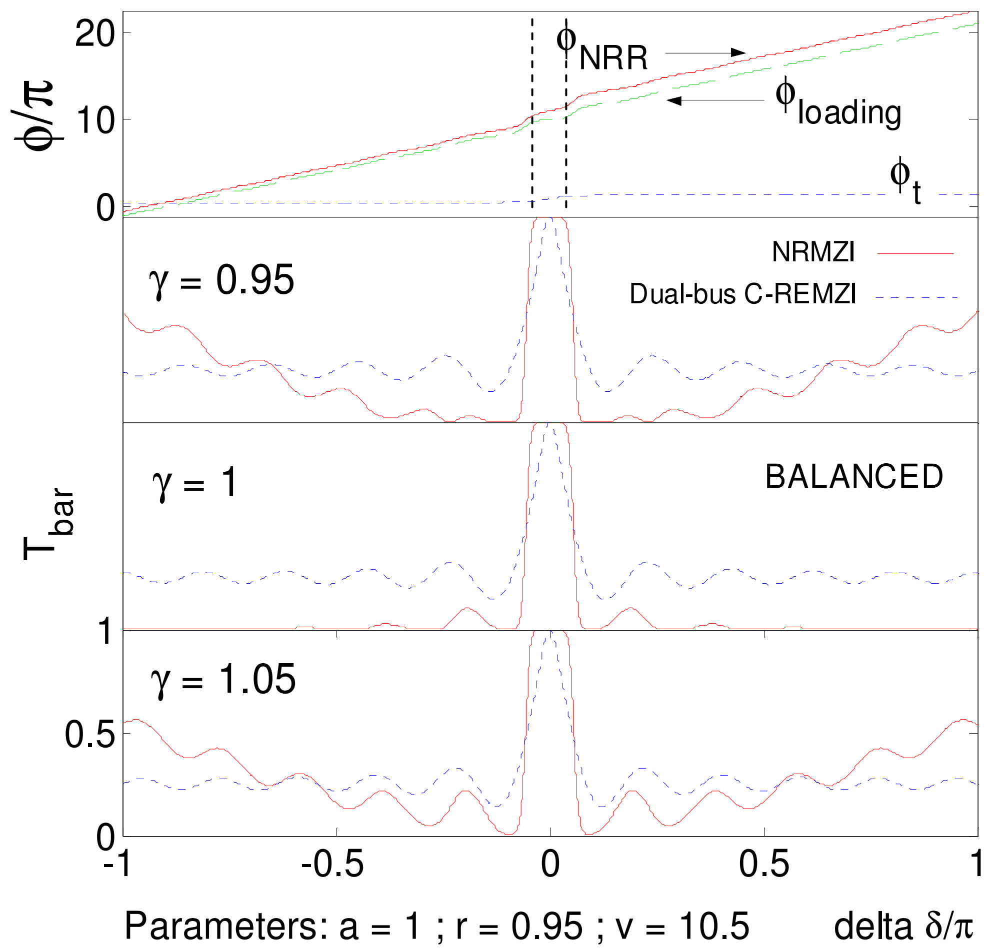


‘Loaded’ NRMZI



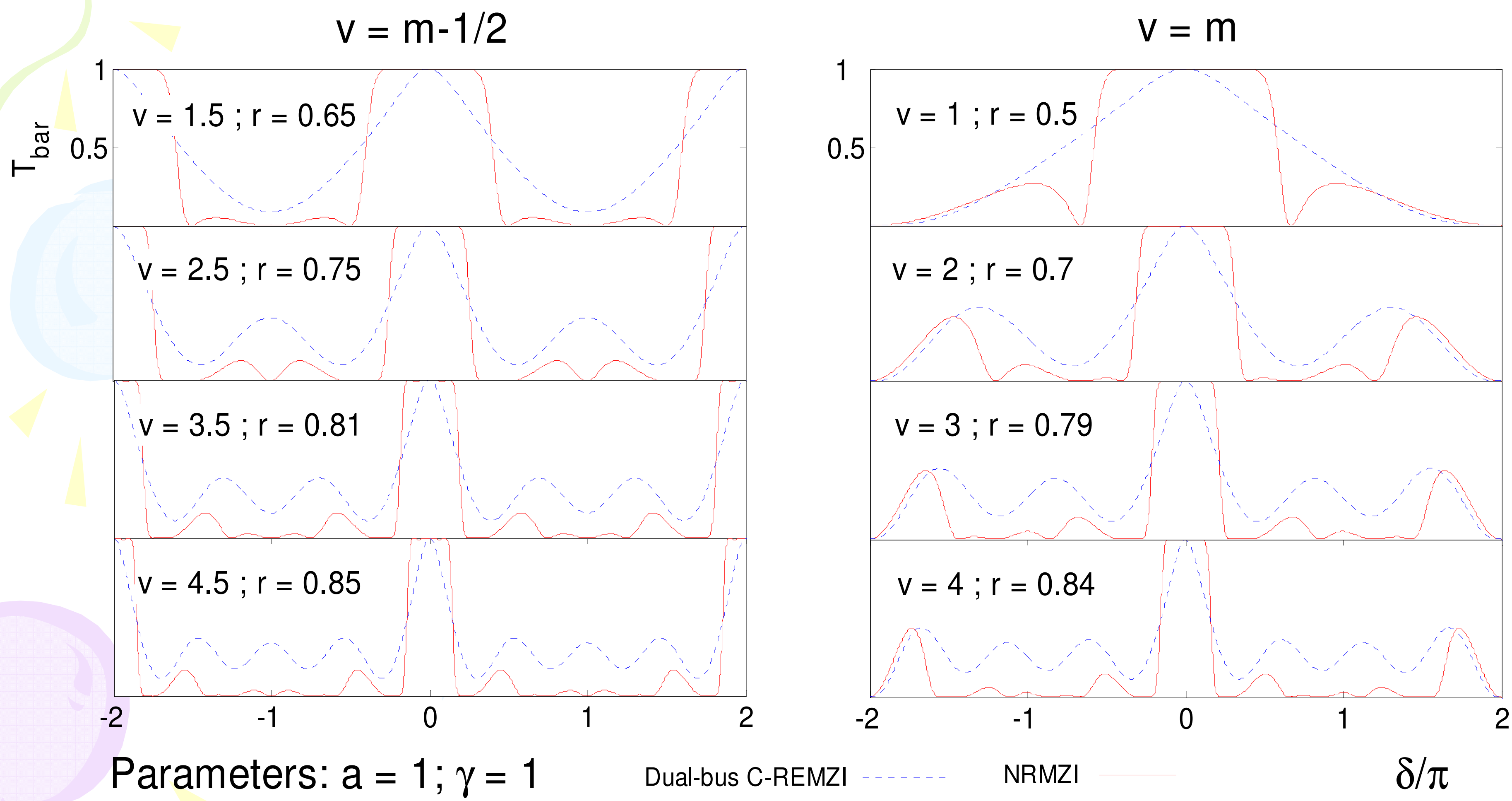
‘Unloaded’ Dual-bus CREMZI

v = 10.5

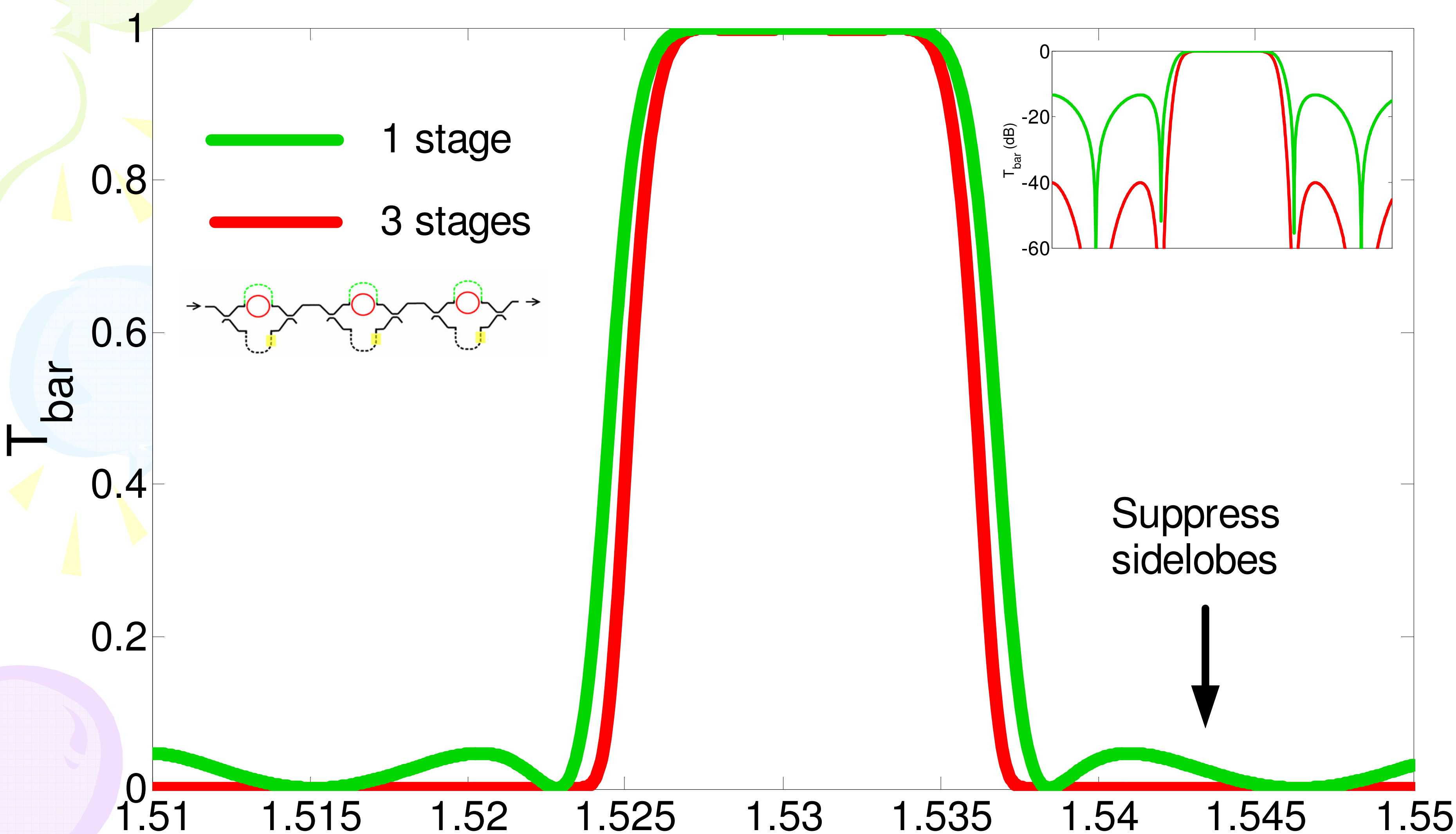


Box-like output of loaded NRMZI

→ v controls the effective bandwidth ; r controls the Fano lineshape

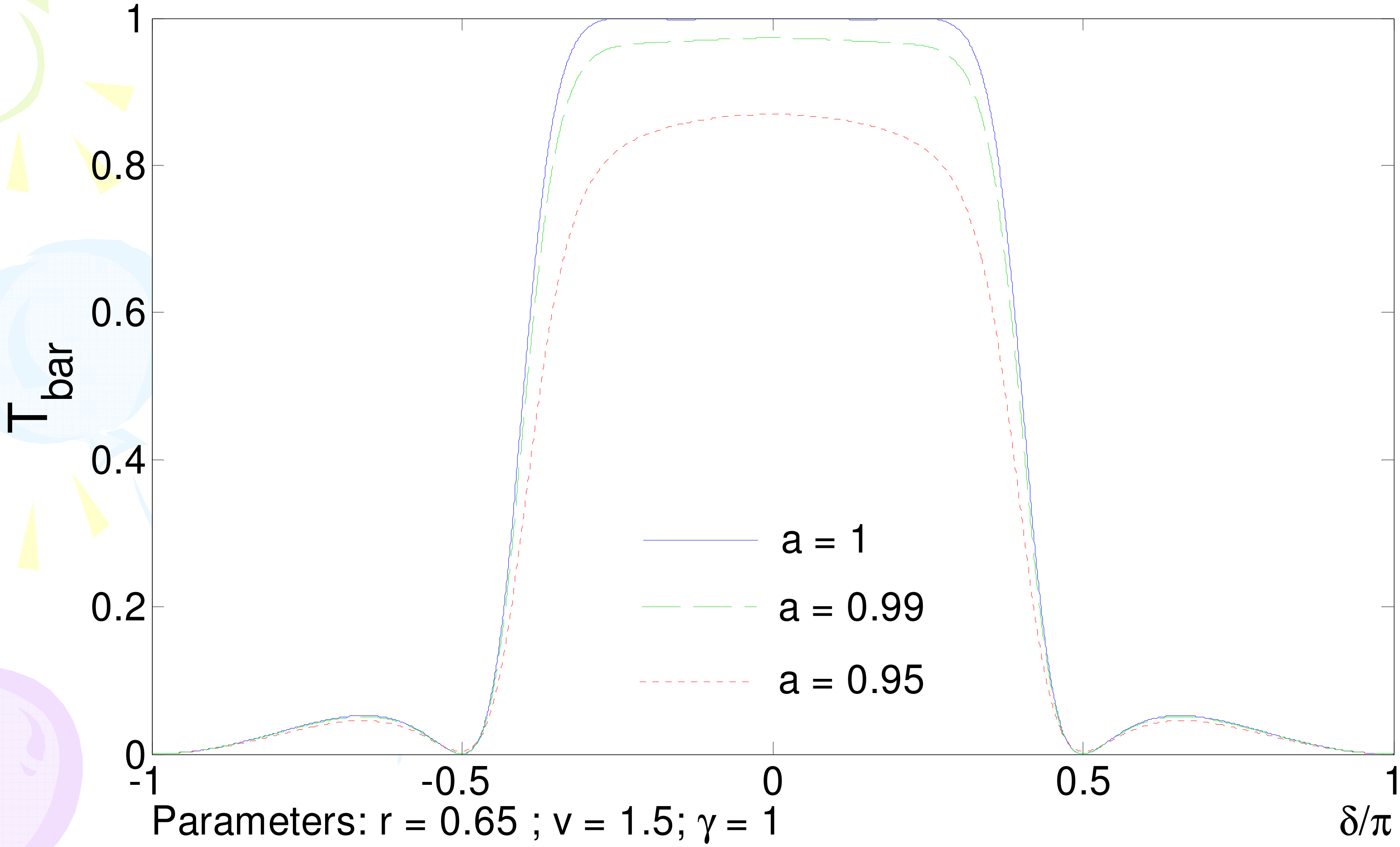


Cascaded NRMZI: Suppress sidelobes

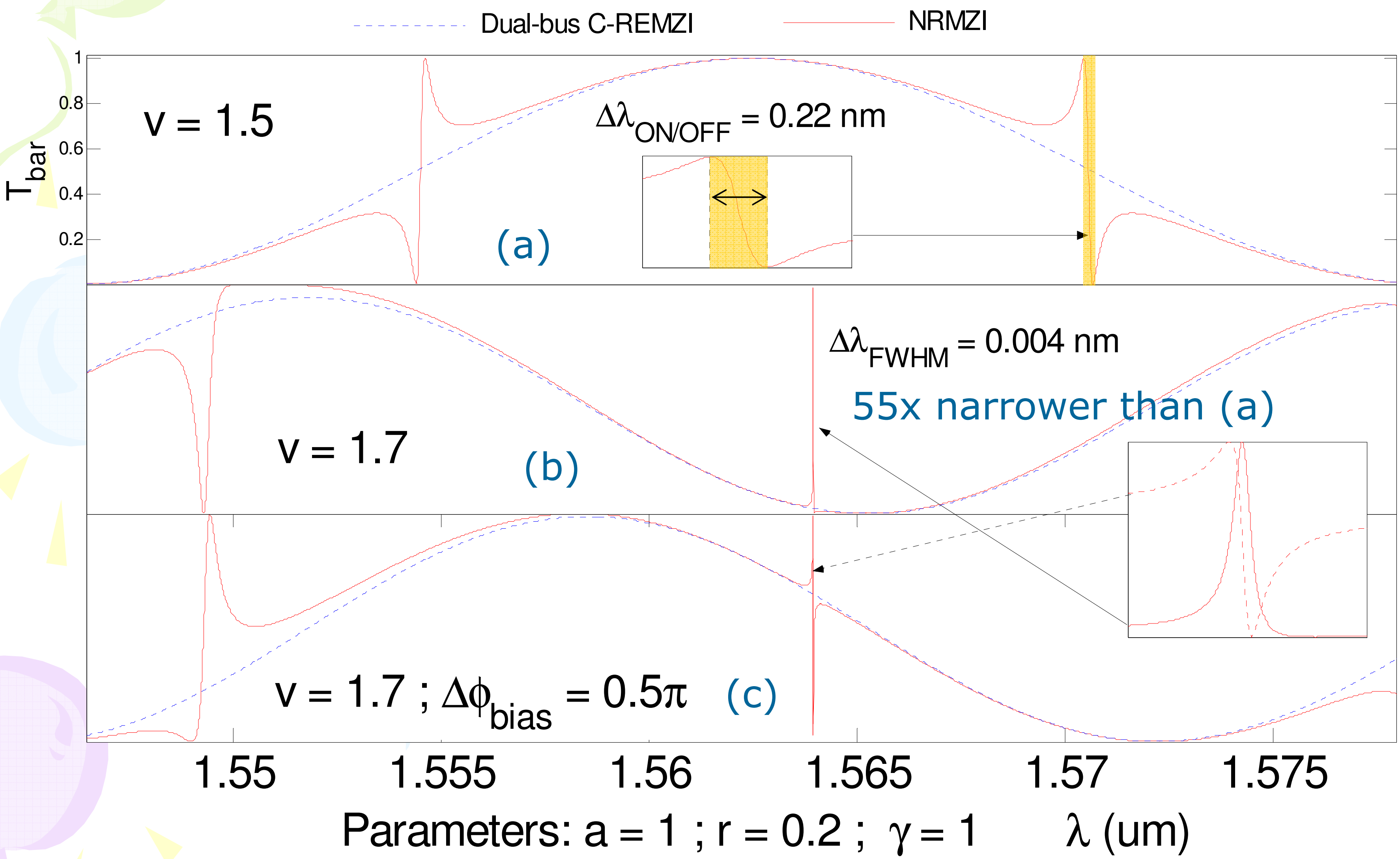


Parameters: a = 1 ; r = 0.67 ; v = 1.5 ; γ = 1 ; n_{eff} = 1.5 ; L_c = 50μm

The effect of loss on box-like output



Engineering ultra-sharp Fano-resonance



Conclusion

- We have proposed for the first time, a NRMZI which is capable of producing a *box-like spectral* response and an *ultra-sharp resonance*.

- The NRMZI may be treated as *an integrated-optic analog of the grating.* The box-like output is possible mainly due to the *double Fano-resonances* which is caused by the multiple interference within the nested-ring.

- The sharpness of these Fano resonances depends on the length of the feedback loop ($L_v^{(1)} = vL_c$) as well as the reflectivity (r) of the coupler.

- The device can be potentially used as *a filter, low powered switch/ modulator ,* and *ultra-sensitive sensor*, at the appropriate operating wavelength.

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