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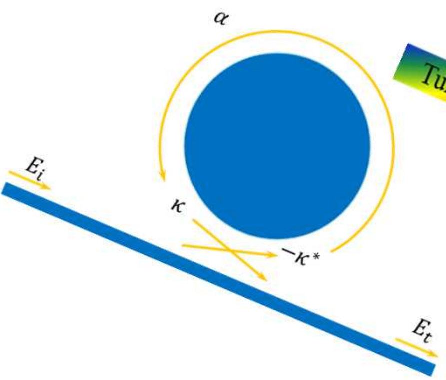

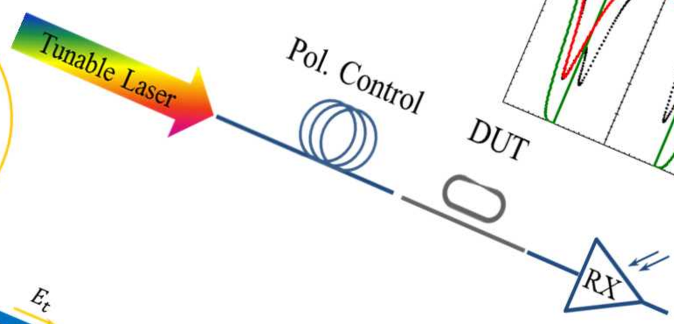

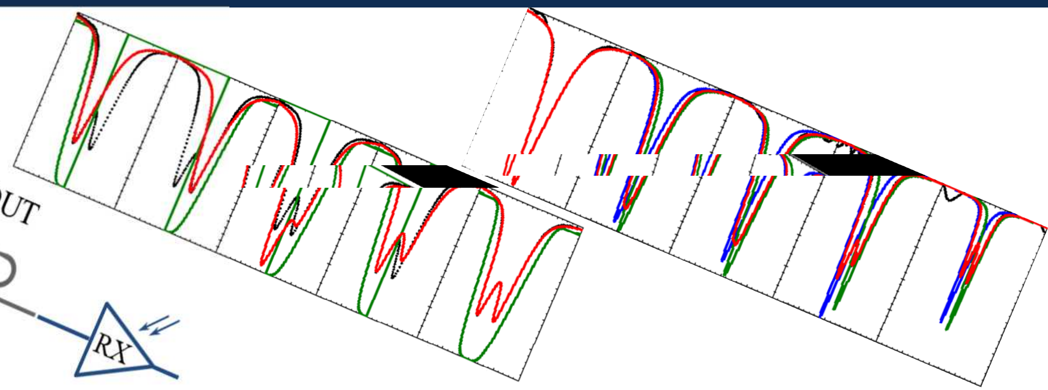

Efficient Coefficient Extraction from Doublet Resonances in Microphotonic Resontator Transmission Functions

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Outline

- Introduction – resonators, splitting, importance of fitting, 6 parameters, degeneracy, correlation and heteroskedasticity in noise
- Microphotonic Resonators – importance of resonators, resonance formation, transmission function equation
- Resonance Splitting – mechanisms, modification to equations
- Intro to Fitting – GLS, OLS, WLS, SMA, EMA
- Distillation of the Transmission Function – envelope function, noise behavior
- Coefficient Extraction – Prior Art (SA, GA)
- Coefficient Extraction – proposed perturbative approach
- Experimental Method – device geometry, MESA callout, scan type, resolution
- Results – Summary of devices applied to and error in result

Introduction

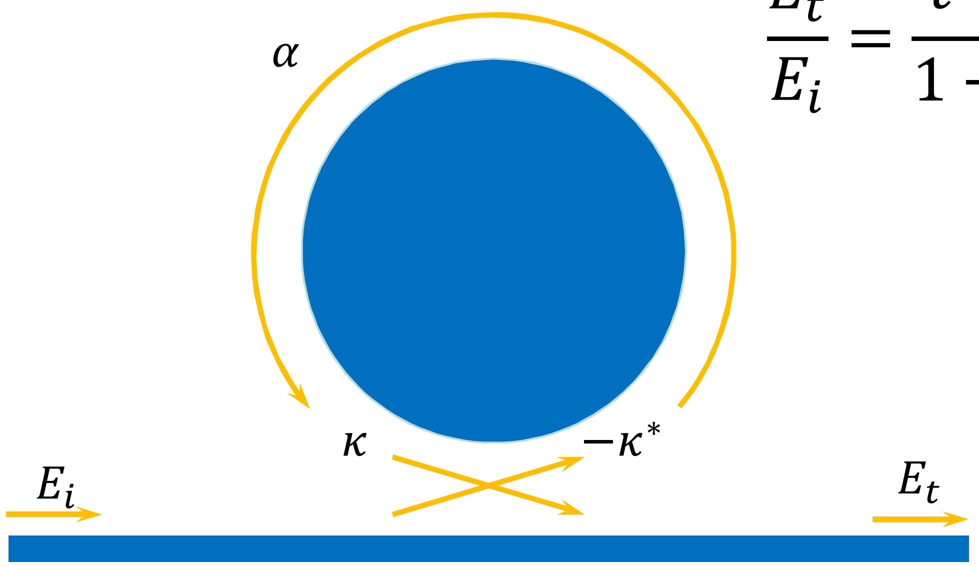
- The Microphotonic Resonator
  - Transmission function of a microphotonic resonator uniquely dependent on intracavity loss and coupling mechanisms
  - Used to create tunable and passive filters, sources, modulators, cross-bar switches, and nonlinear cavities to name a few.
  - Used to estimate propagation loss in low loss waveguides and insertion loss of efficient passive components when in a modified racetrack resonator configuration.
  - Detailed knowledge of the intracavity loss and external coupling magnitudes required to design a device with the desired lineshape.
- The Trouble with Reflections
  - Intracavity reflection mechanisms cause resonance splitting.
  - This doubles the number of coefficients that must be estimated.
  - These coefficients often exhibit nearly degenerate impact on the transmission function.

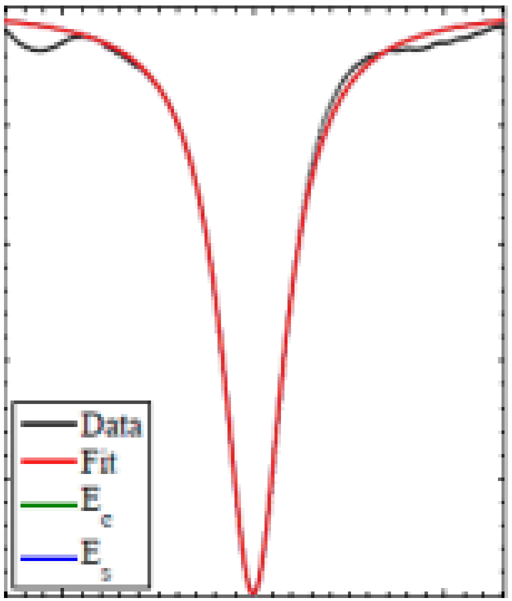
Here, we present a perturbative approach to the 6D problem of fitting split resonances. This algorithm deftly avoids local minima while maintaining the ability to converge to a the globally optimum solution.

Example Resonator: Passive Filter

- We wish to design a two port disk resonator with maximum extinction ratio and a known 3dB bandwidth.
- Assume the round trip propagation loss, field coupling coefficient, and round trip accumulated phase are given by α, κ, φ, respectively.
- Sans reflection, the transmission function can be determined by coupled mode theory.

$$\frac{E_t}{E_i} = \frac{t - \alpha e^{-i\varphi}}{1 - \alpha t e^{-i\varphi}}$$

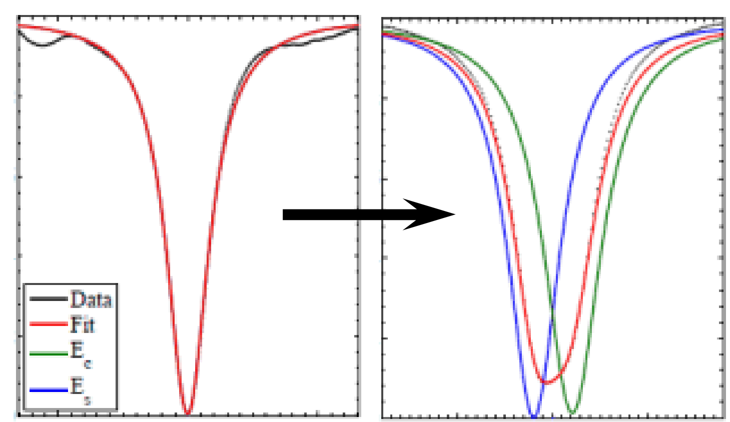




Resonance Splitting

- Intracavity reflections cause splitting of the transmission function.
  - Increases bandwidth and drops extinction ratio.
- Transmission function is now a linear combination of singlet resonance transmission functions corresponding to high and low frequency standing wave modes formed within the cavity.

$$\frac{E_t}{E_i} = \frac{t_c - \alpha_c e^{-i\varphi_c}}{1 - \alpha_c t_c e^{-i\varphi_c}} + \frac{t_s - \alpha_s e^{-i\varphi_s}}{1 - \alpha_s t_s e^{-i\varphi_s}}$$

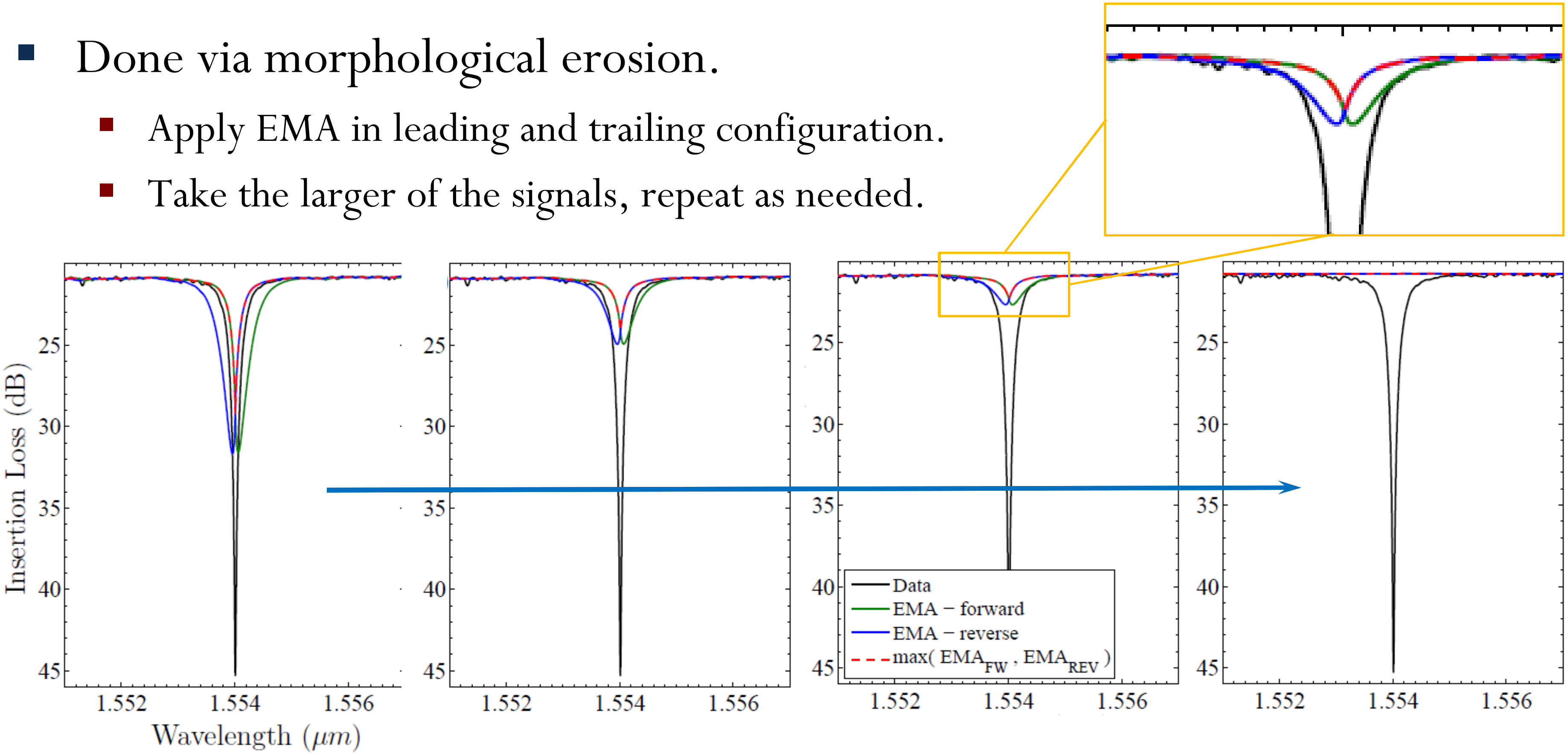


Intro to Curve Fitting

- Intracavity reflections cause splitting of the transmission function.
  - Increases bandwidth and drops extinction ratio.
- Transmission function is now a linear combination of singlet resonance transmission functions corresponding to high and low frequency standing wave modes formed within the cavity.

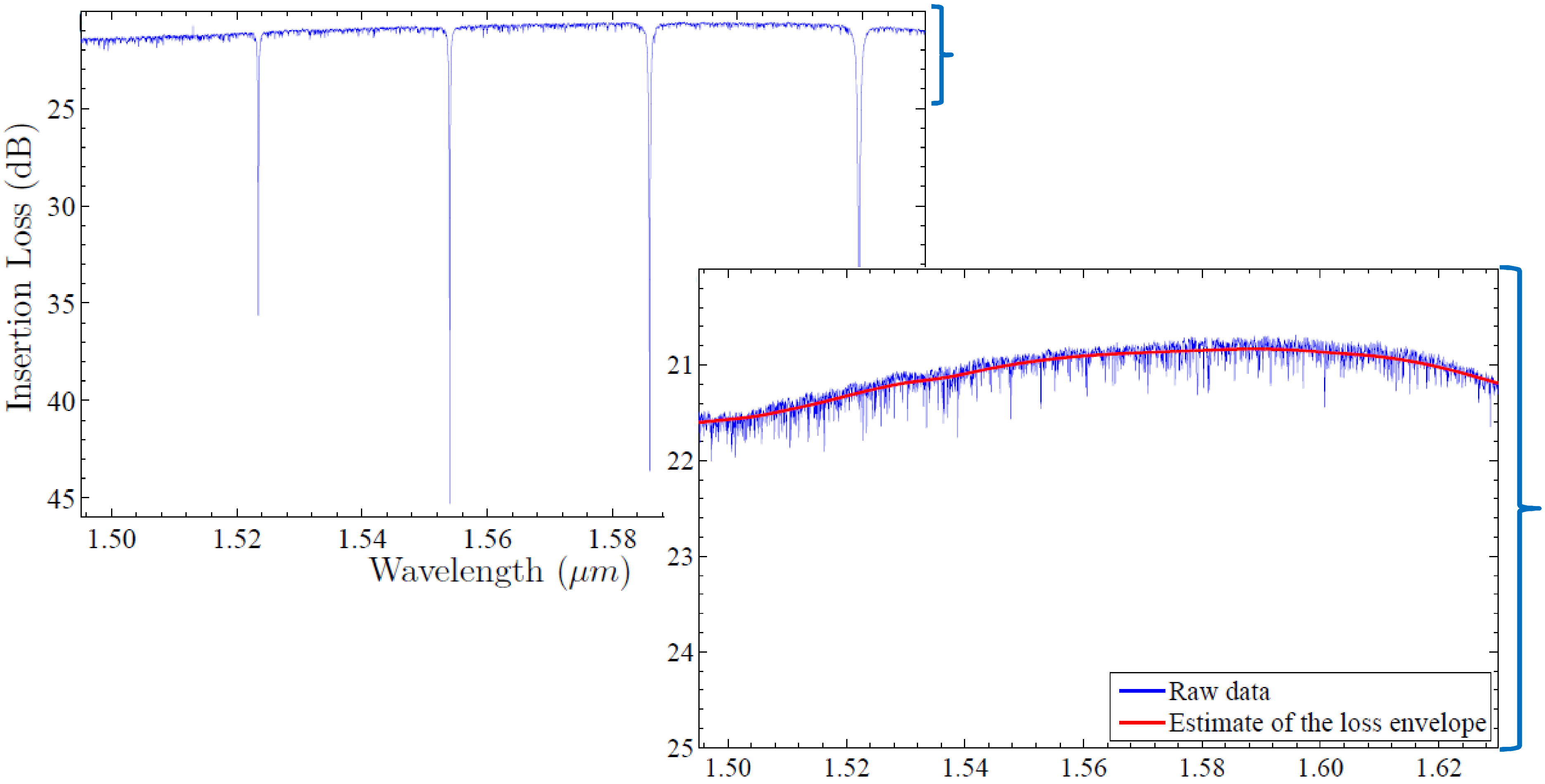
Distillation of the Transmission Function

- Transmission data includes intracavity *and* extracavity losses.
- Removal of the extracavity losses requires estimation of these losses.
- Need data without the transmission functions to do so.
- Done via morphological erosion.
  - Apply EMA in leading and trailing configuration.
  - Take the larger of the signals, repeat as needed.



Distillation of the Transmission Function

- Example data from a 6μm diameter ring resonator.



Coefficient Extraction – Prior Art

	Avoids Local Minima	Converges
Simulated Annealing (SA)	✓	✗
Genetic Algorithm (GA)	✓	✗
Gradient Descent (GD)	✗	✓
Proposed Perturbative Approach	✓	✓

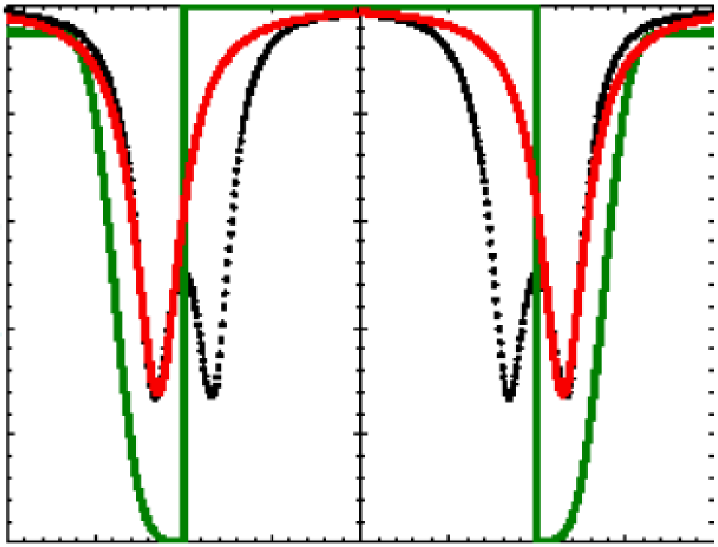
- SA & GA rely on pseudo-randomly selected candidates to avoid local minima; this prevents guaranteed convergence to the global optimum.
- GD is designed to converge rapidly, but is unable to avoid local minima.
- The proposed algorithm decomposes the 6D problem into a set of two 3D problems that are iteratively solved to produce the correct result.

Proposed Algorithm - Background

- Normalized transmission T given by equation (1) with six parameters to fit ($\beta_c = [\alpha_c, t_c, \varphi_c]$ and $\beta_s = [\alpha_s, t_s, \varphi_s]$).

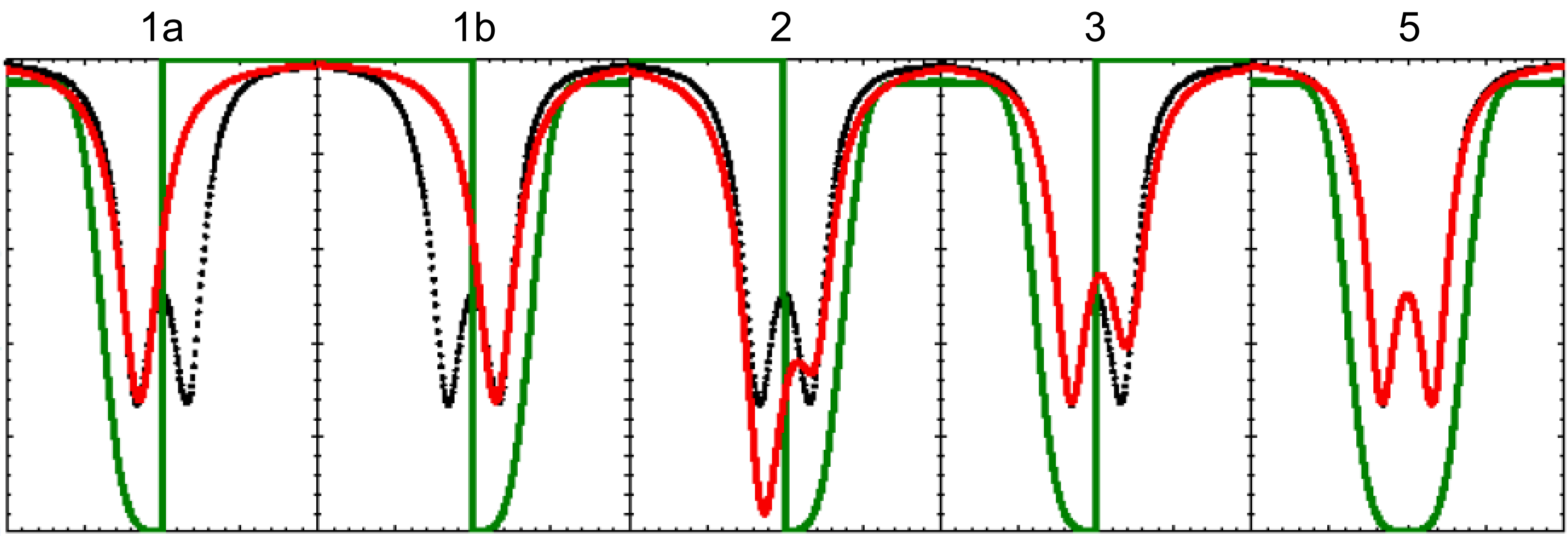
$$T = \left| \frac{t_c - \alpha_c e^{-i\varphi_c}}{1 - \alpha_c t_c e^{-i\varphi_c}} + \frac{t_s - \alpha_s e^{-i\varphi_s}}{1 - \alpha_s t_s e^{-i\varphi_s}} \right|^2 = |E_c + E_s|^2$$

- Multiplicative noise yields lowest noise in the center of the signal.
- WLS improves performance in the presence of noise.
- Weighting half of the resonance allows for 1st order estimation of each singlet resonance.



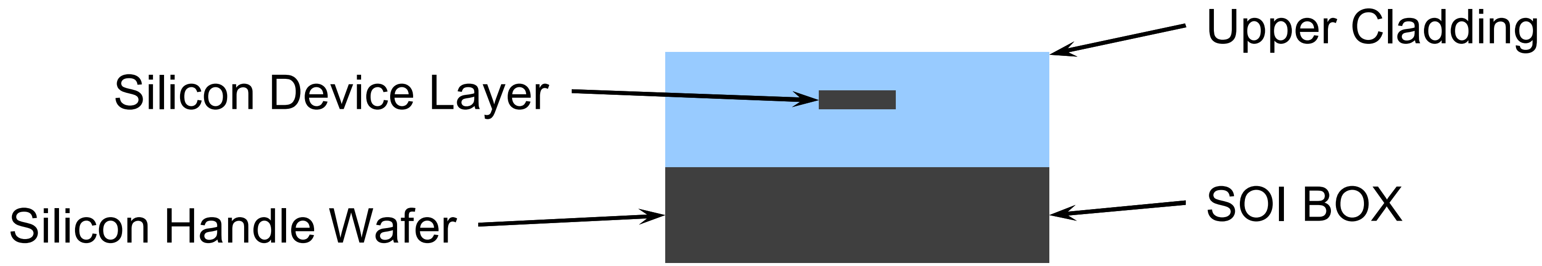
Proposed Algorithm - Method

1. Fit each half of the data with a singlet resonance using WLS.
2. Choose the best fit and keep the estimated parameter set (e.g. $\hat{\beta}_c$).
3. Fit the transmission function varying the alternate parameter set (e.g. $\hat{\beta}_s$).
4. Iterate (3) alternating the fixed and variable parameter sets.
5. Algorithm terminates when fit quality converges.

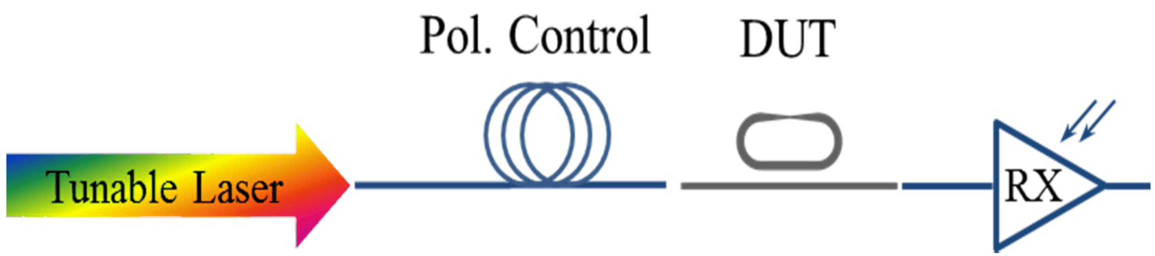


Experimental Method

- SOI waveguides with a 230nm thick device layer and 3μm BOX.
- Devices fabricated at Sandia National Laboratories' MESA facility.
- Optical loss reduced via two thermal oxidation and oxide strip cycles.
- Upper cladding (3μm) deposited via HDP.

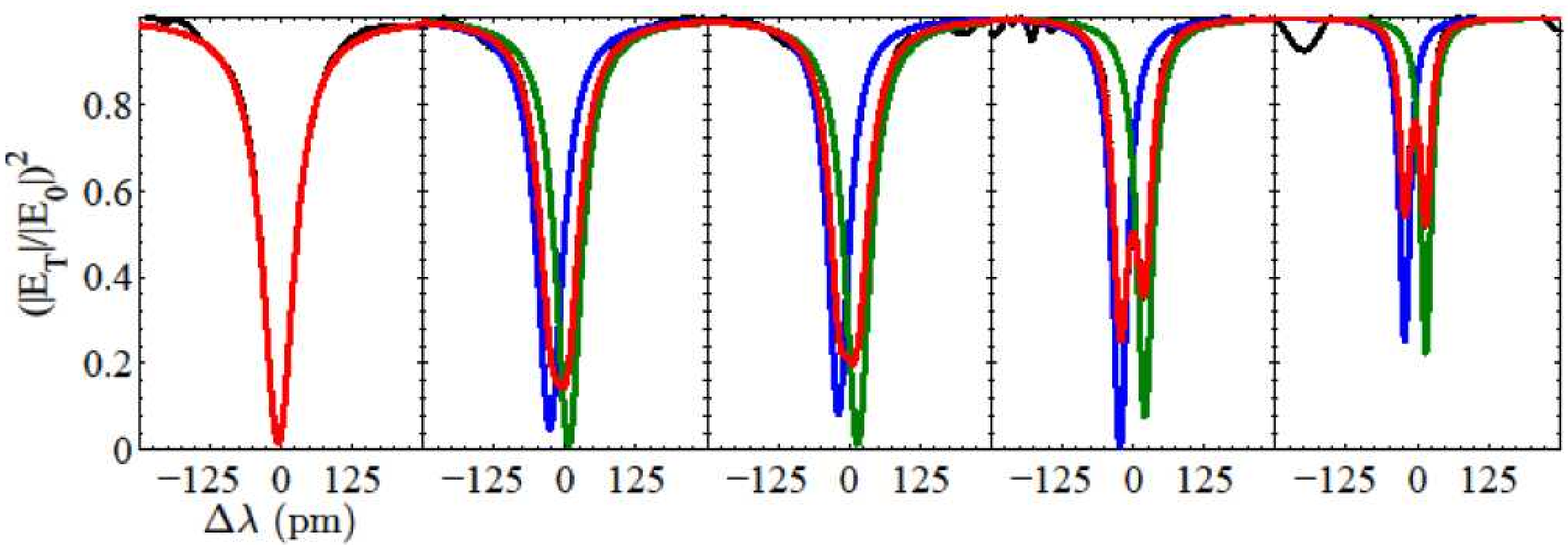


- Transmission data taken using an Agilent 81600B tunable laser source and 81635A power sensor with TE polarized input over a wavelength range of 1500 to 1630nm with a 1.1pm step size.



Results

- Two port ring resonators with 400nm ring width and 50μm diameter.
- Eleven devices totaling 418 resonances analyzed.
- Residuals taken from fit of each coefficient as a function of wavelength to a second order polynomial.
- RMS deviation calculated for all parameters was $7.29X10^{-4}$
- Algorithm proved robust for singlets, apparent singlets, clearly separated doublets and doublets with clear asymmetry.



Questions?