An Investigation into System-Level Trimming Issues in On-Chip Nanophotonic Networks

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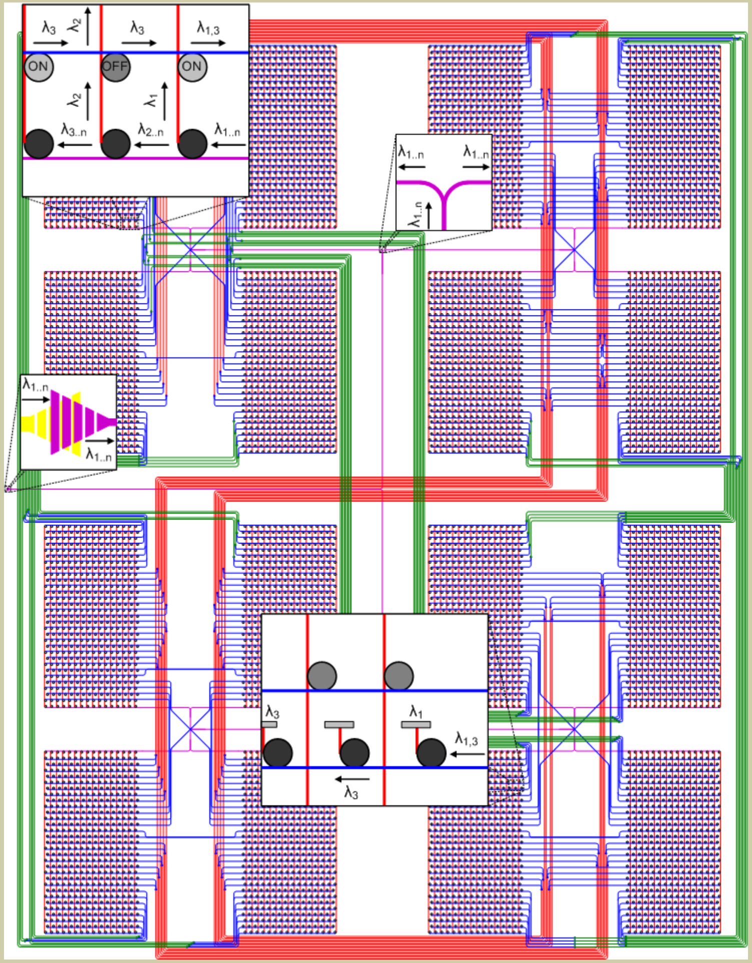
On-Chip Photonic Network

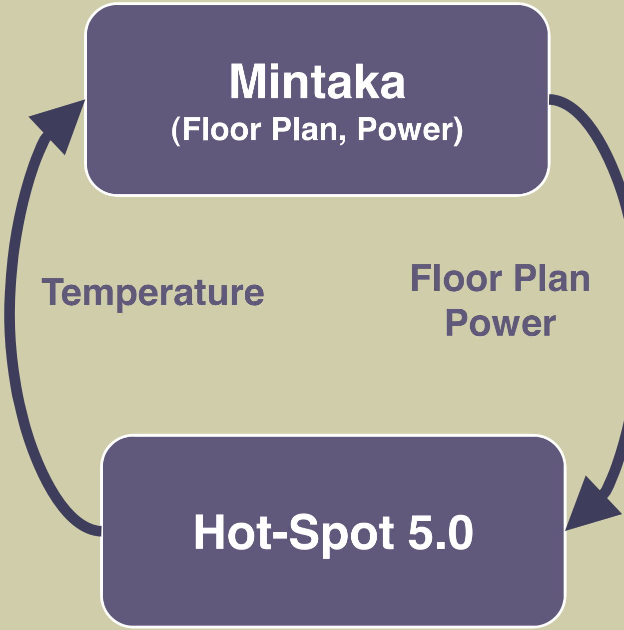


- External Laser
- Microring Resonators
  - Thermally Sensitive
  - Require Trimming
- Microring Trimming
  - Red Shift Use Heating
  - Blue Shift Use Current Injection
  - Literature Assumes Fixed Cost

Overview

- **Trimming Power Analysis**
- Technique to Mitigate Trimming Problem
- Resilience in Photonic Networks
- Conclusions

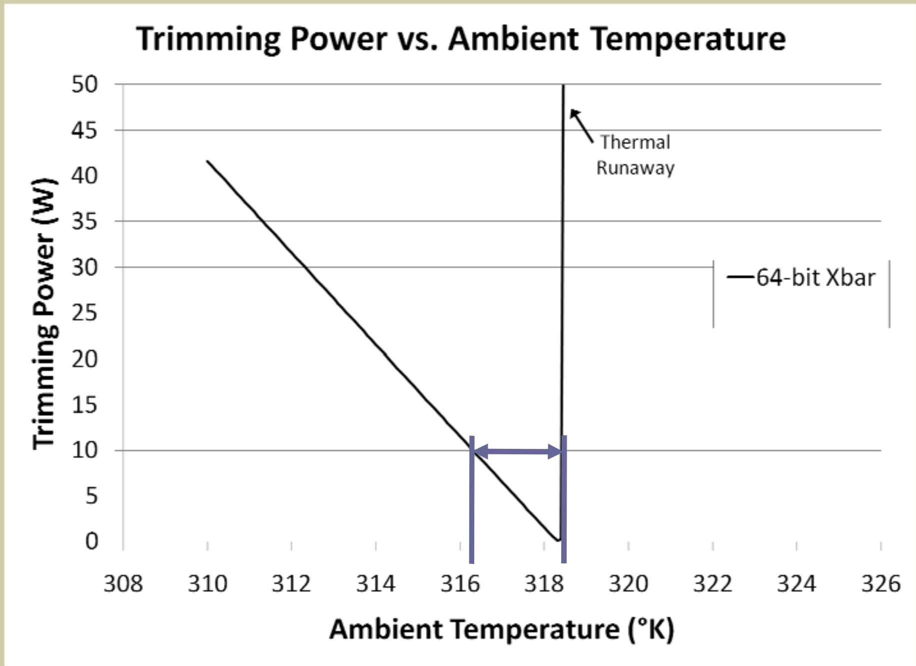
Methodology



- Developed Simulator (Mintaka)
- Used Hot-Spot 5.0 to Determine Temperature
  - 90 W/m°K Conductance[1]
  - 1.63e6 J/m^3°K Spec Heat[1]
  - Steady State Solver
- Closed Loop to Solve for Trimming Power
- Varied Ambient Temperature

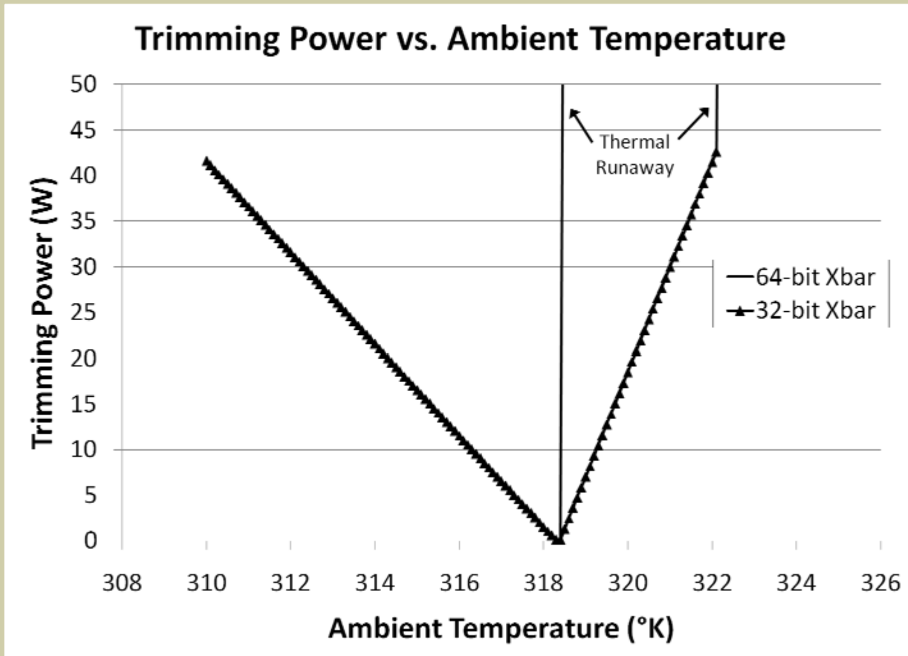
[1] Aubain, M., et al., "In-Plane Thermal Conductivity Determination in Silicon on Insulator (SOI) structures through Thermoreflectance measurements," Materials Research Society Symposium Proceedings Volume 1267, 2010.

Baseline



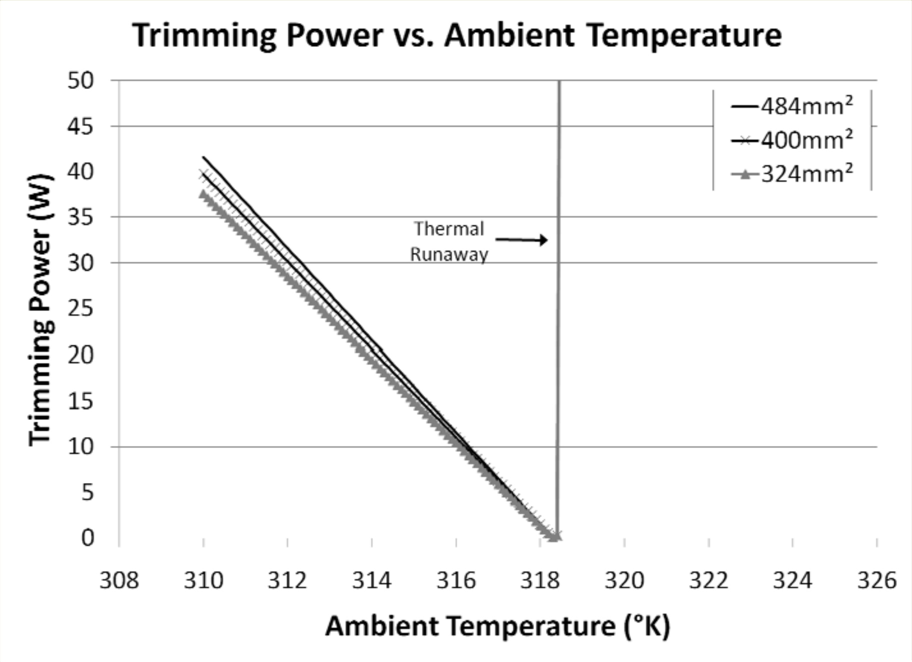
- Optical Crossbar
  - 64 node, 64 wavelengths
  - ~524K Microrings
  - $484mm^2$ Area
- Heating
  - ~5.1W/°K
- Current Injection
  - Thermal Runaway <1°K
- Temperature Control Window (TCW)

Fewer Microrings



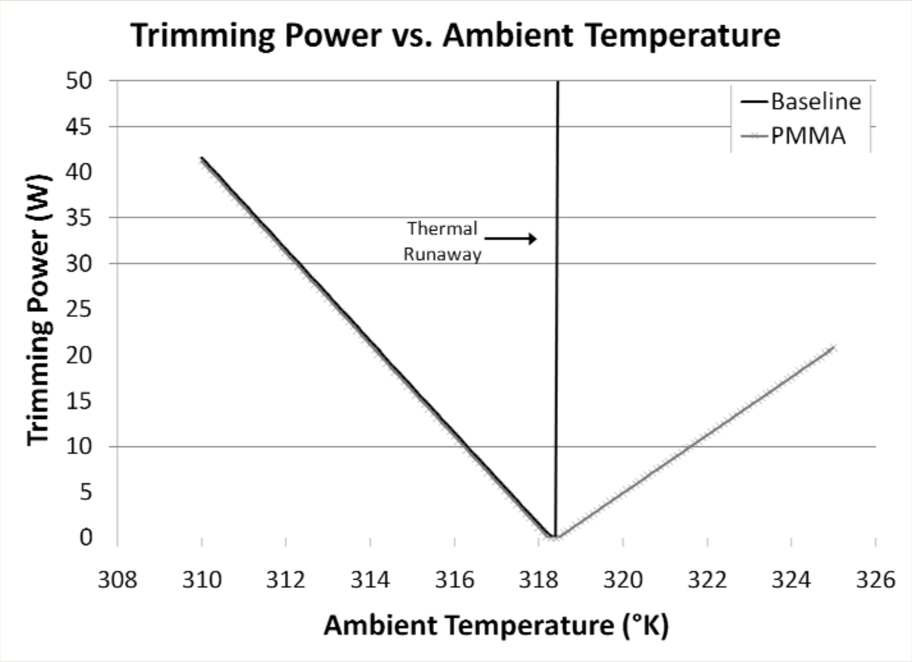
- Optical Crossbar
  - 64 node, 32 wavelengths
  - ~270K Microrings
  - 484mm^2 Area
- Heating
  - ~5.1W/°K
- Current Injection
  - Thermal Runaway <4°K

Change Die Area



- Baseline
  - 484mm^2 Area (22mm sq)
  - ~5.1W/°K Heating
- Medium
  - 400mm^2 Area (20mm sq)
  - ~4.9W/°K Heating
- Small
  - 324mm^2 Area (18mm sq)
  - ~4.6W/°K Heating

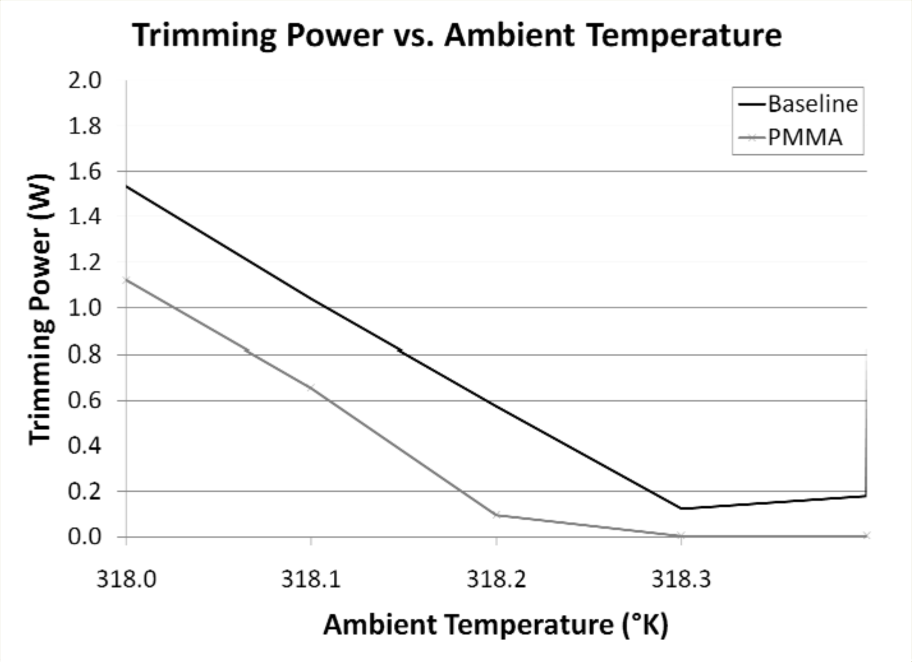
Partial Athermalization



- Baseline
  - ~524K Microrings (64-bit)
  - 0.09nm/°K Drift
  - ~5.1W/°K Heating
  - Thermal Runaway <1°K
- PMMA[2]
  - 0.027nm /°K Drift
  - ~5.1W/°K Heating
  - ~3.0W/°K Current Injection

[2] L. Zhou et al., "Athermalizing and trimming of slotted silicon microring resonators with uv-sensitive pmma upper-cladding," Photonics Technology Letters, IEEE, vol. 21, no. 17, pp. 1175–1177, Sept.1, 2009.

Partial Athermalization



- Baseline vs. PMMA
  - Both ~5.1W/°K Heating
  - 0.415W Delta Heating
  - 0.08°K Lower Minimum Temperature for PMMA

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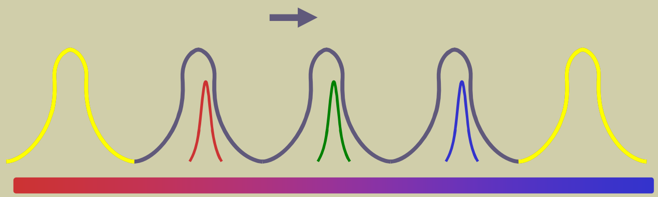
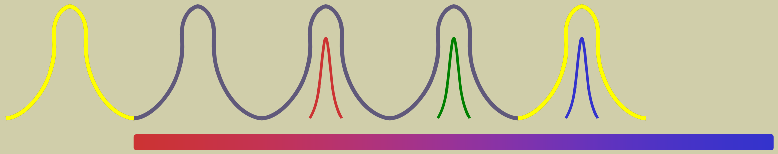
Sliding Ring Window



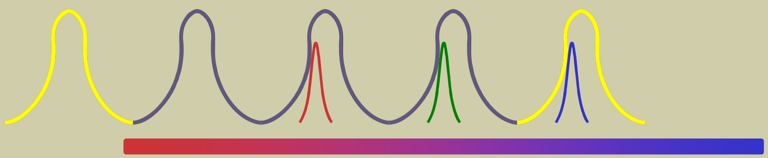
- Additional Rings on Both Sides of Spectrum
- Rings Heat
  - Increase Current to Hold

Sliding Ring Window



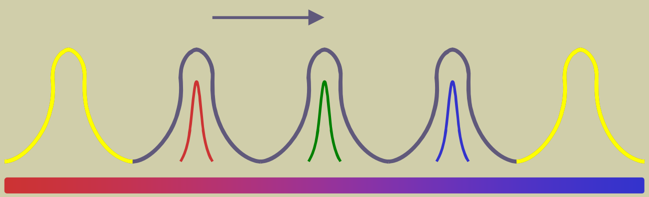
- Additional Rings on Both Sides of Spectrum
- Rings Heat
  - Increase Current to Hold
  - Reduce Current Once Heated for Full Shift

Sliding Ring Window



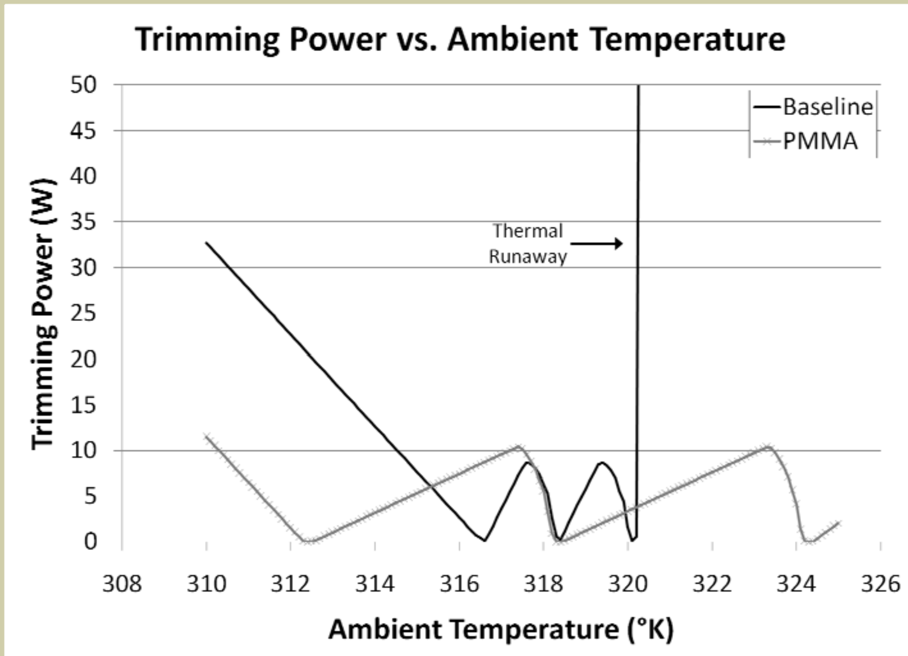
- Additional Rings on Both Sides of Spectrum
- Rings Heat
  - Increase Current to Hold
  - Reduce Current Once Heated for Full Shift
- Rings Cool
  - Allow Drift Initially

Sliding Ring Window



- Additional Rings on Both Sides of Spectrum
- Rings Heat
  - Increase Current to Hold
  - Reduce Current Once Heated for Full Shift
- Rings Cool
  - Allow Drift Initially
  - Increase Current to Force Full Shift

Sliding Ring Window Results



- Baseline SRW
  - 2 Additional Rings per Group
  - ~540K Microrings
  - 5.1°K TCW with 10W Budget
  - Increase TCW from 2.2°K
- PMMA SRW
  - ~20°K TCW with 12W Budget
  - Increase TCW from 6.4°K

Overview

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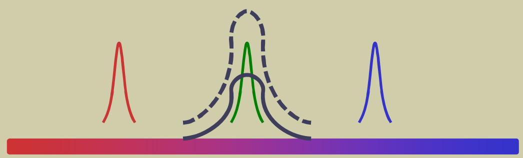
Resilient Photonic Networks

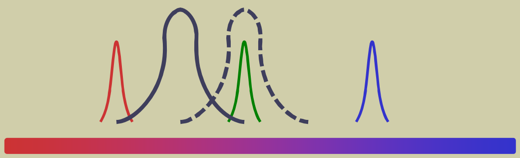
- Tradeoff Surplus Bandwidth for Resilience
- Communication Power Mostly Prepaid
  - External Laser Static Overhead
  - Trimming Static Overhead
- Fault Model Necessary
  - Must Incorporate Unique Features of Photonics

Fault Model



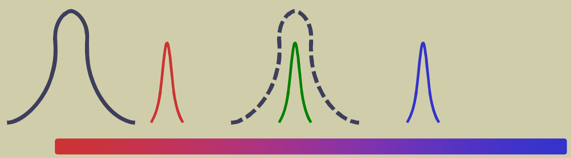
- Microring Faults
  - Attenuation

Fault Model



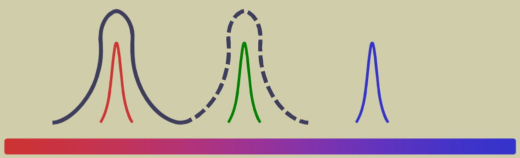
- Microring Faults
  - Attenuation
  - Off Resonance

Fault Model



- Microring Faults
  - Attenuation
  - Off Resonance
- Off Resonance Rings
  - Non-Interfering

Fault Model



- Microring Faults
  - Attenuation
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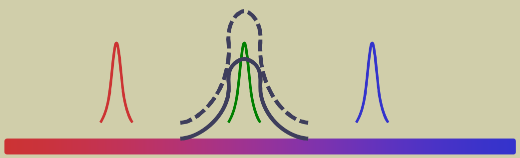
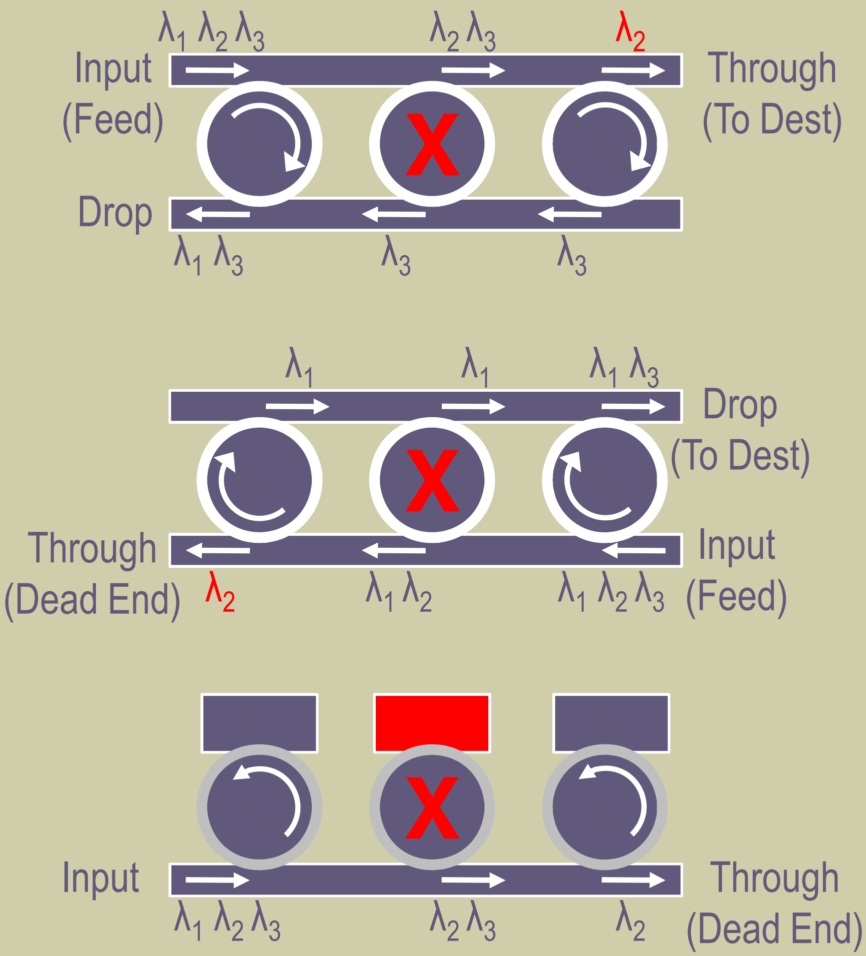
Fault Model



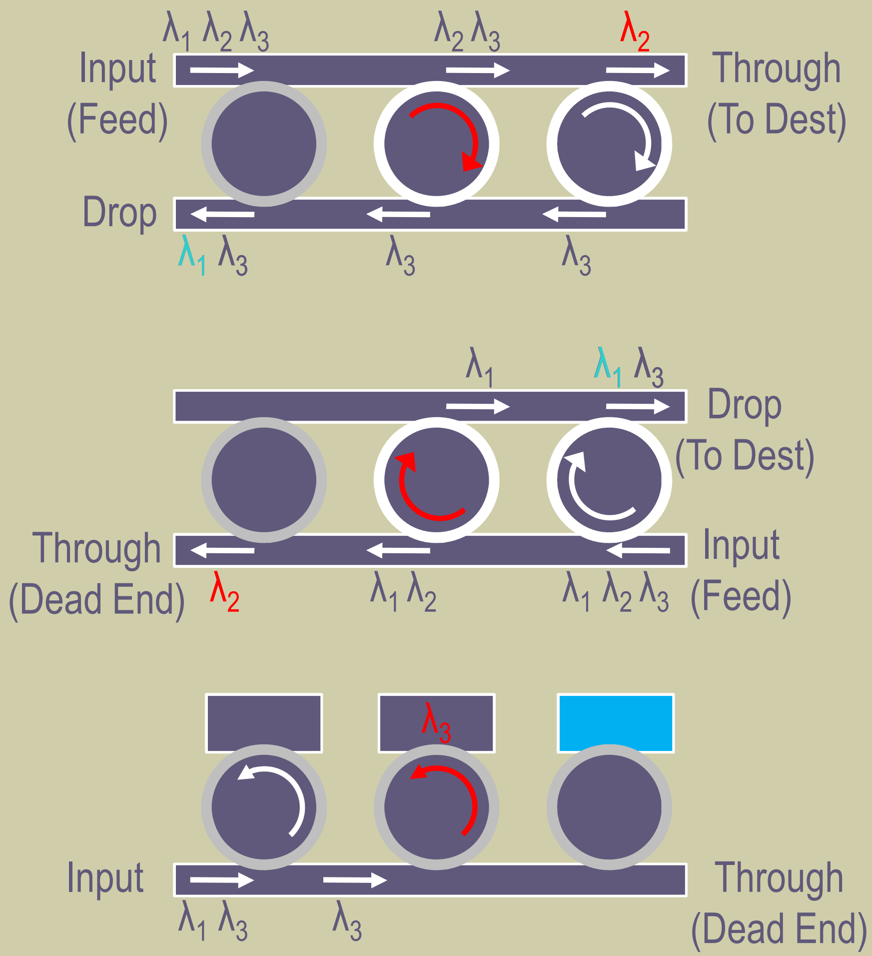
- Microring Faults
  - Attenuation
  - Off Resonance
- Off Resonance Rings
  - Non-Interfering
  - Interfering
- Waveguide Faults
  - Increased Attenuation

Bit Errors



- Non-Interfering Faults
  - Modulation Zeros
    - Stuck at One Faults
    - $0 \longrightarrow 1$ Bit Errors
  - Modulation Ones
    - Stuck at Zero Faults
    - $1 \longrightarrow 0$ Bit Errors
  - Receivers
    - Stuck at Zero Faults
    - $1 \longrightarrow 0$ Bit Errors

Bit Errors



- Interfering Faults
  - Modulation Zeros
    - Interfered Logical And
    - Interfering Stuck at One
  - Modulation Ones
    - Interfered Logical Or
    - Interfering Stuck at Zero
  - Receivers
    - Interfered Stuck at Zero
    - Interfering RX Interfered Bit

Asymmetric Errors

- Eliminate Interfering Faults
- Structures with Same Bit Errors
  - Waveguides ($1 \longrightarrow 0$)
  - Receivers ($1 \longrightarrow 0$)
  - Modulating Ones ($1 \longrightarrow 0$)
- Asymmetric Errors Much Easier to Detect/Correct

Conclusions

- Trimming is Tricky Issue
  - Heating has Non-linear Relationship with Ring Count
  - Current Injection May Be Thermally Unstable
- Sliding Ring Window
  - Increases TCW
  - May Not Be Complete Solution
- Resilience in Photonic Networks

Thank You

- Questions?