Design and Control of a Photonic Neural Network Applied to Low-Latency Classification

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PRINCETON Electrical Engineering

Mode Division Multiplexing

Motivation: MDM Benefits

- **Increases Aggregate Bandwidth:** Allows more information to be carried in a single wave-guide.
- **Increases Network Size**: Allows for more neuron channels in a single sub-network.

MDM Challenges

- **Precise Geometry:** Coupling requires a certain waveguide width and length.
- **Weighting Complexity** to cancel Intermodal Mixing.

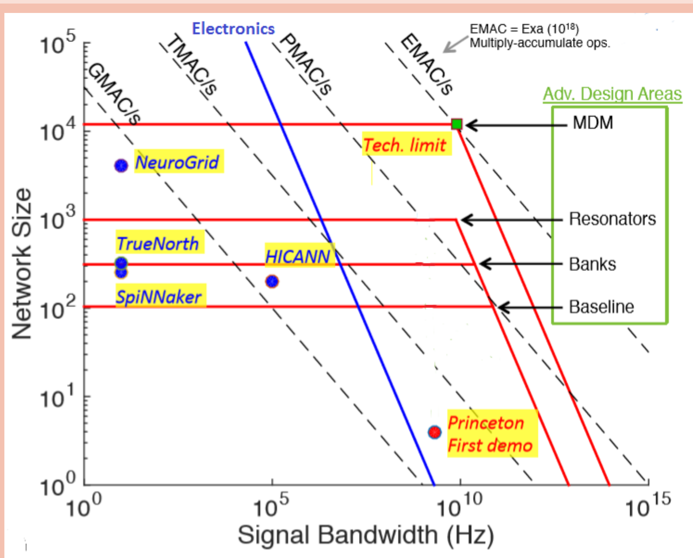


Figure 1: Network Size / Bandwidth Tradeoff for previous neural networks.

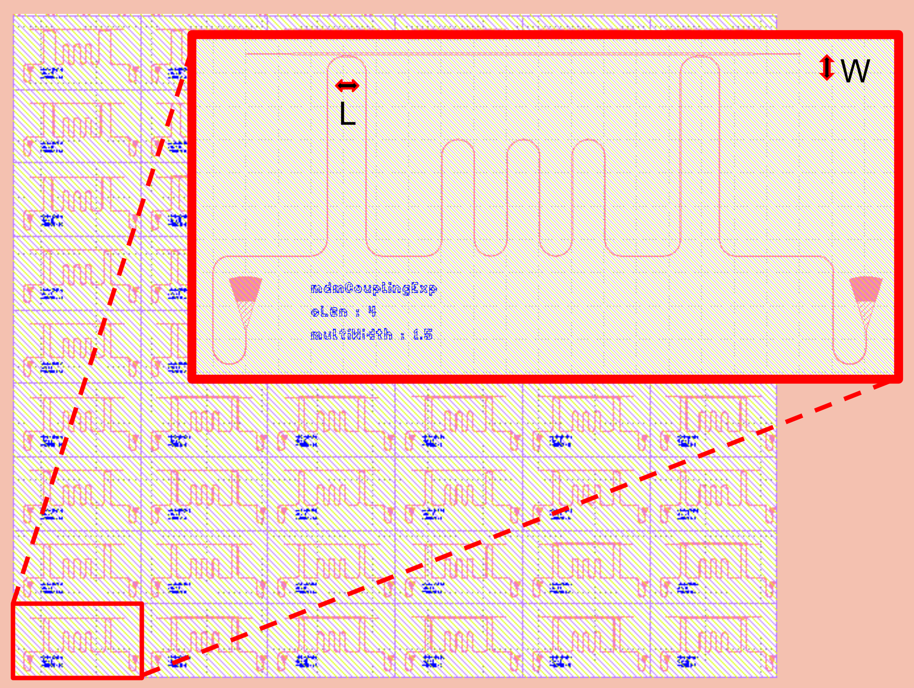
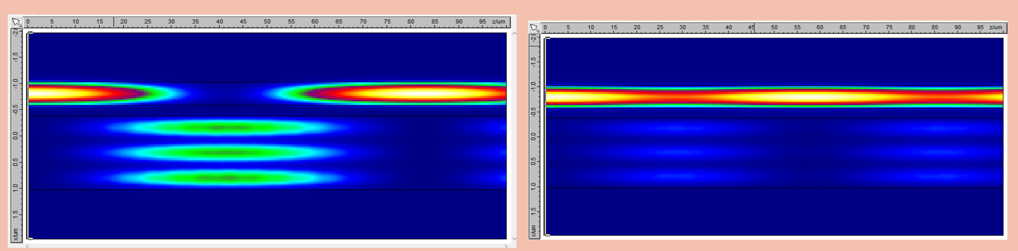


Figure 2 (above): Asymmetric Mach-Zehnder Interferometer Design. Width (W) and Coupling Length (L) need to be optimized for maximum coupling.
Figure 3 (below): Simulated coupling results for ideal (left) and non-ideal (right) waveguide width.



Experimental Design

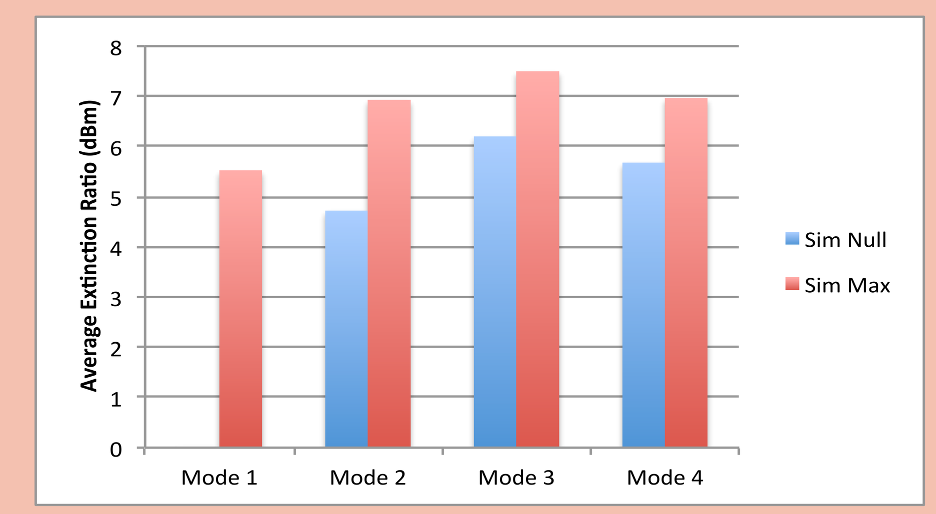
- **Goal:** Determine optimal coupling width and length for each mode.
- **Principle**: Asymmetric Mach-Zehnder Interferometer (**r = coupling percentage)**
- $T = r^2 + (1-r)^2 + 2r(1-r)\cos(\lambda \Delta L)$
- Extinction Ratio: **2*r*(1-r)**,
- r=0 when W is not optimal: 0% Coupling
- **Adjust W to maximize extinction ratio: r=0.5**
- **Adjust L to minimize extinction ratio: r=1**

Simulated Results

Since a null extinction ratio could actually correspond with 100% or 0% coupling, we can use simulation data to determine which is more likely.

(All µm)	TE_0	TE_1	TE_2	TE_3
W	0.5	0.95	1.4	1.9
L	25	35	41	47

Figure 4: Experimental results. **Above** shows maximum extinction ratio near optimal width. **Below** shows lower extinction ratio near optimal coupling length. No data = no extinction ratio above noise floor.



Results and Next Steps

- **Successfully showed good coupling near simulated results.**
- **Parameter space was too coarse:** Steep drop-off in extinction ratio by 4μm off optimal width.
- **Next Step:** Good enough to begin test on full MDM Weight Banks on-chip.
- **Next Step:** Re-run experiment with finer parameter space.

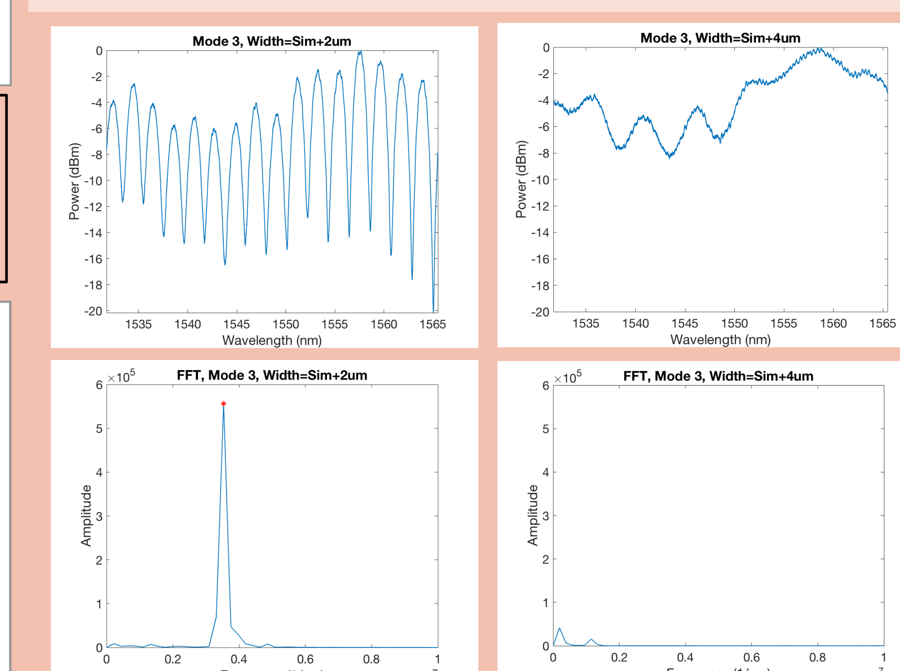


Figure 5: Results with high (left) and low (right) extinction ratio..

Cascaded Weight Bank Control

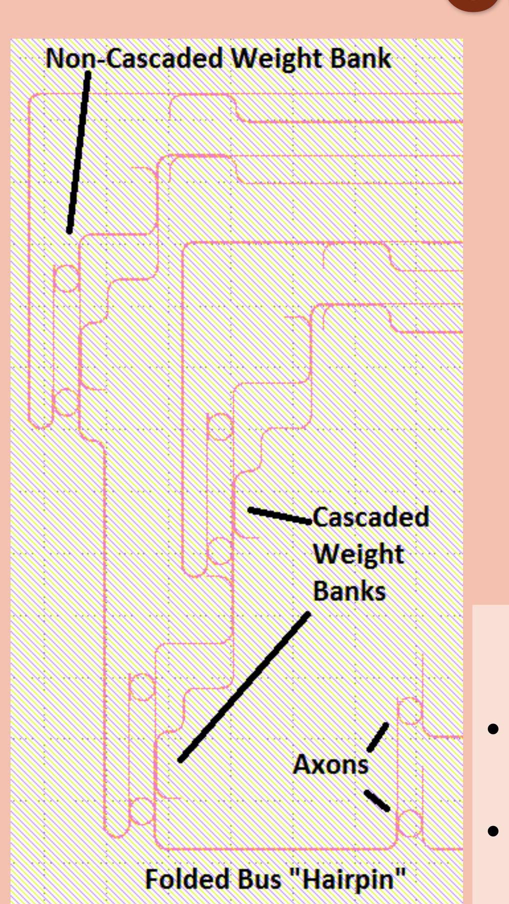
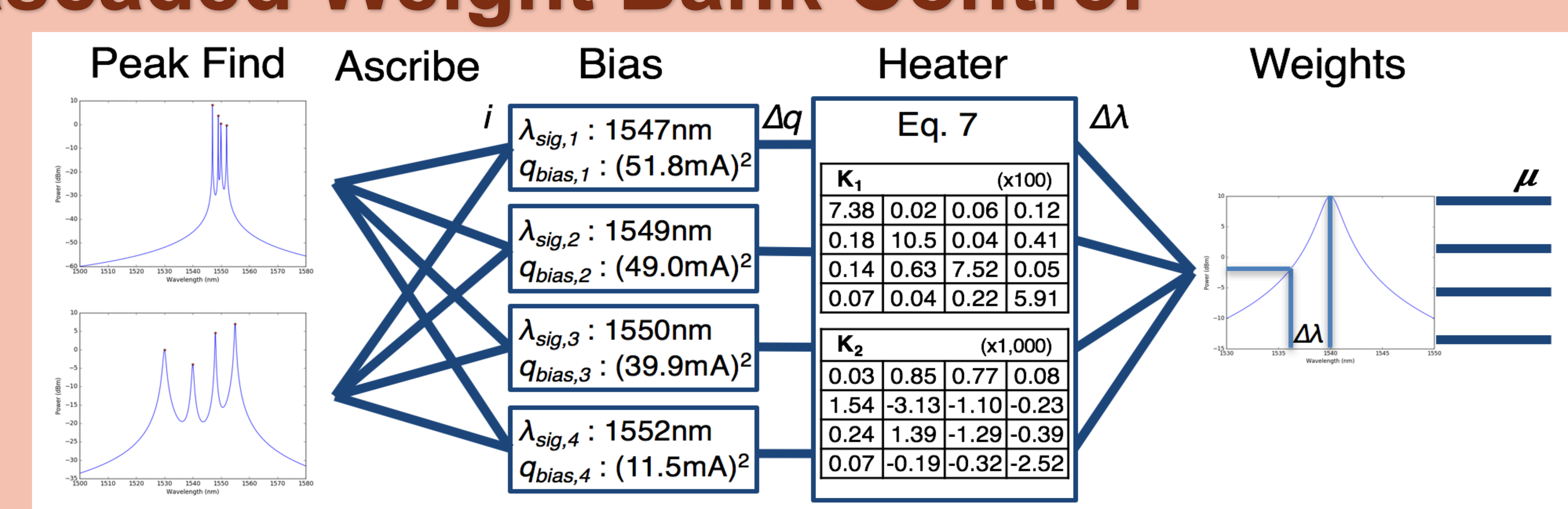


Figure 6: Two MDM neurons in a hairpin topology.



Motivation: Network Topology

- **Folded Bus "Hairpin" Topology:** Space-efficient layout of MDM networks.
- **Cascaded Bank:** Allows each neuron to pull a percentage of power off the bus.
- **Challenge:** How to adjust weights in network given cross-talk and indirect sensing.

Control Process

- **Peak Detection:** Detect inputs and the Lorentzian Peak of each micro-ring.
- **Ascription:** Assign each micro-ring to an input.
- **Bias** each input to micro-ring peak using PI Loop.
- **Heater:** Measure thermal cross-talk between rings.
- **Weights:** Use peak shape to convert to weight vector.

Classification Applications

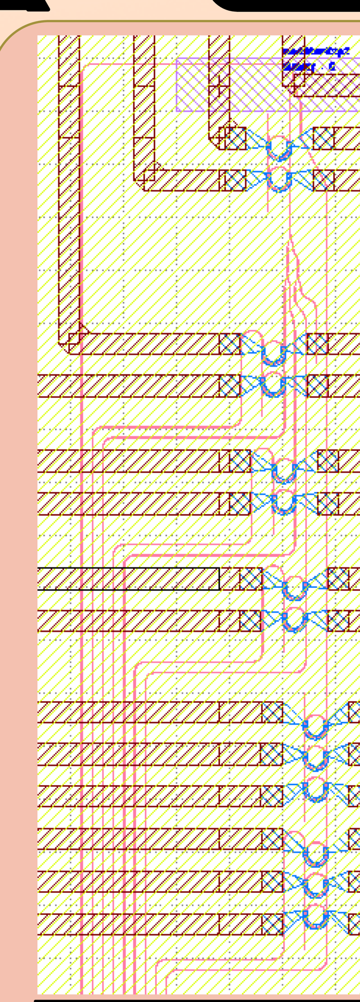


Figure 7: 2-3-1 Layer Feed Forward Neural Network

Negative Result: Quantum Bit Classification

- **Question:** Could a recurrent neural network, such as a Long Short-Term Memory (LSTM) network, increase the fidelity of quantum bit read-outs compared to current thresholding techniques?
- **No, because the read-out trajectories are completely linearly separable.** (Fig. 8)
- Transient effects are drowned out by high levels of white noise.
- With these problems combined, averaging and thresholding is close to optimal.

Possible Next Steps

- **RF Modulation Scheme Classification:** Track non-linearly separable trajectories through I-Q space.
  Challenge: LSTM networks are non-trivial to implement in our network architecture.
- **Low-Latency RF Demodulation:** Can be done with a Feed-Forward Network (Fig. 7).

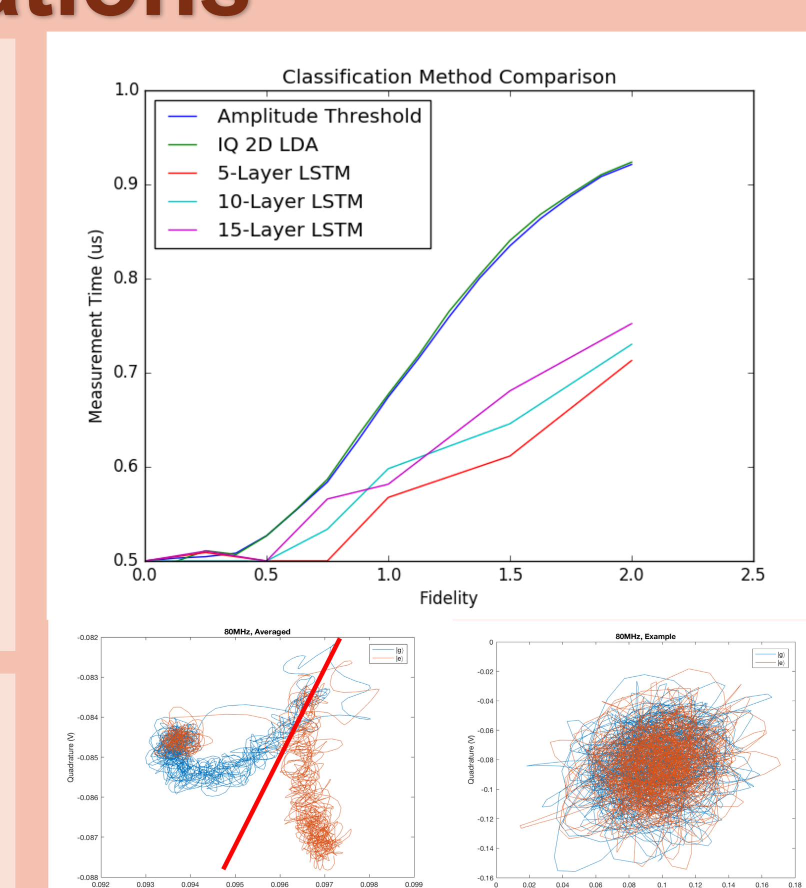


Figure 8: (top) Linear Thresholding vs. Neural Network Classification. **(left)** Averaged Qubit Data, showing linear separation. **(right)** Example of single trajectory, showing low SNR.

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