Image Processing Techniques applied to Spectroscopy for Nanophotonic Circuit Characterization

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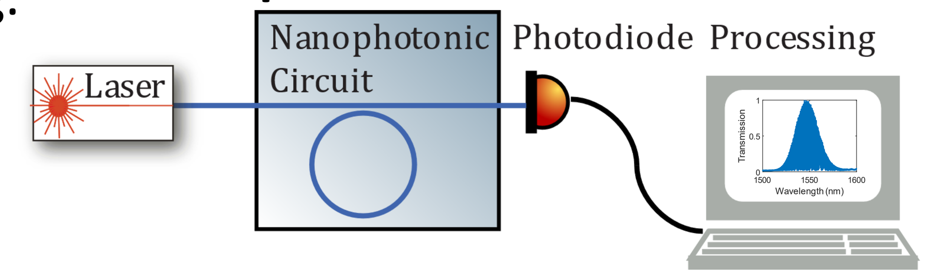
Background: Nanophotonic Circuit Characterization

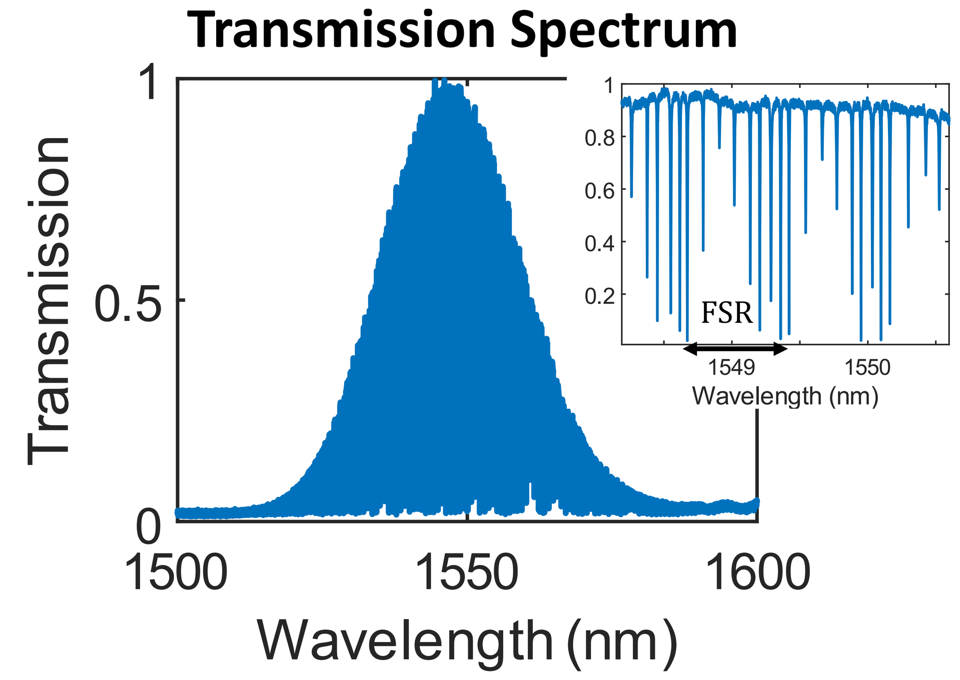
Nanophotonic circuits show promise for low-power sensing and computing.

To characterize: measure transmission as a function of wavelength[1-3].

Nanophotonic Characterization



Transmission Spectrum



Similarities between spectroscopy and imaging:

	Spectroscopy	Imaging
Physics	Light	Light
Dimensions	1	2
Priors	Periodic	Sparse Gradients

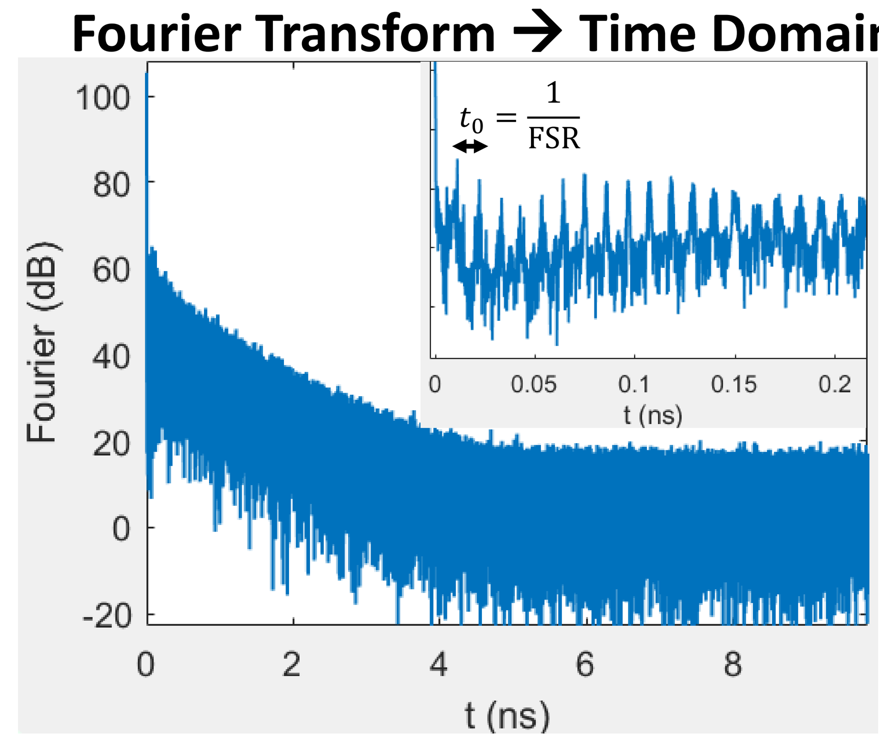
We show that computational imaging algorithms are useful in characterizing nanophotonic circuits.

Methods: Discrete Fourier Transform

An alternative visualization of the data is the “time” domain[4].

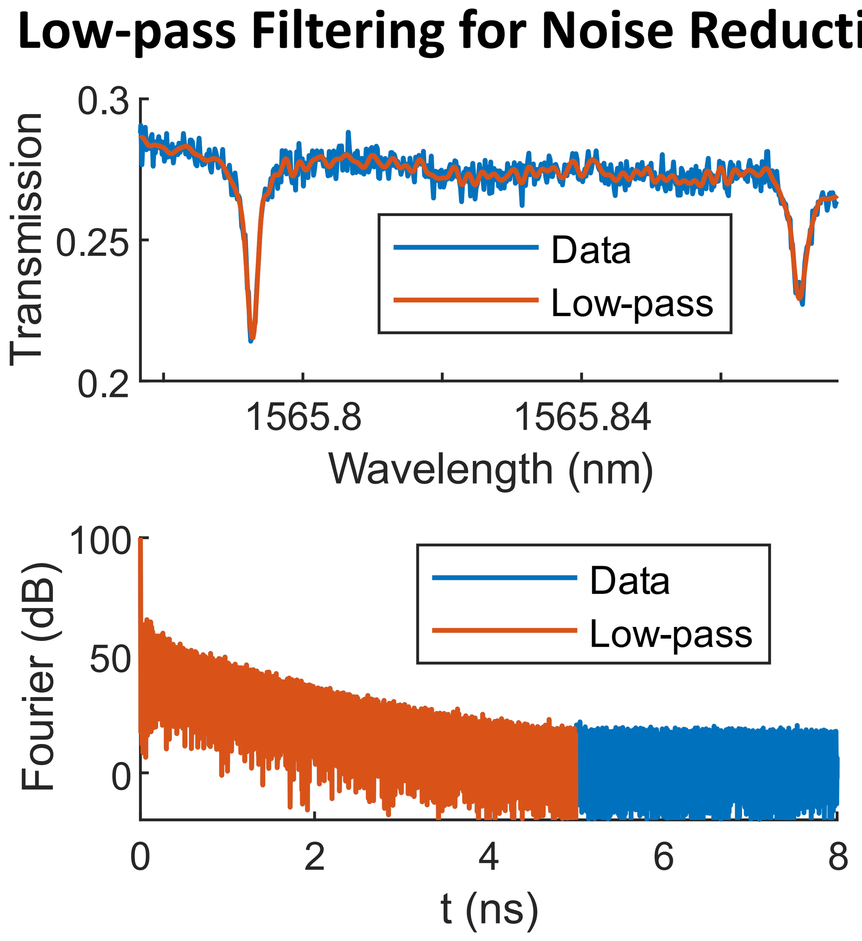
Time domain is useful for
- Denoising
- Feature extraction
- Convolution for data processing

Fourier Transform → Time Domain



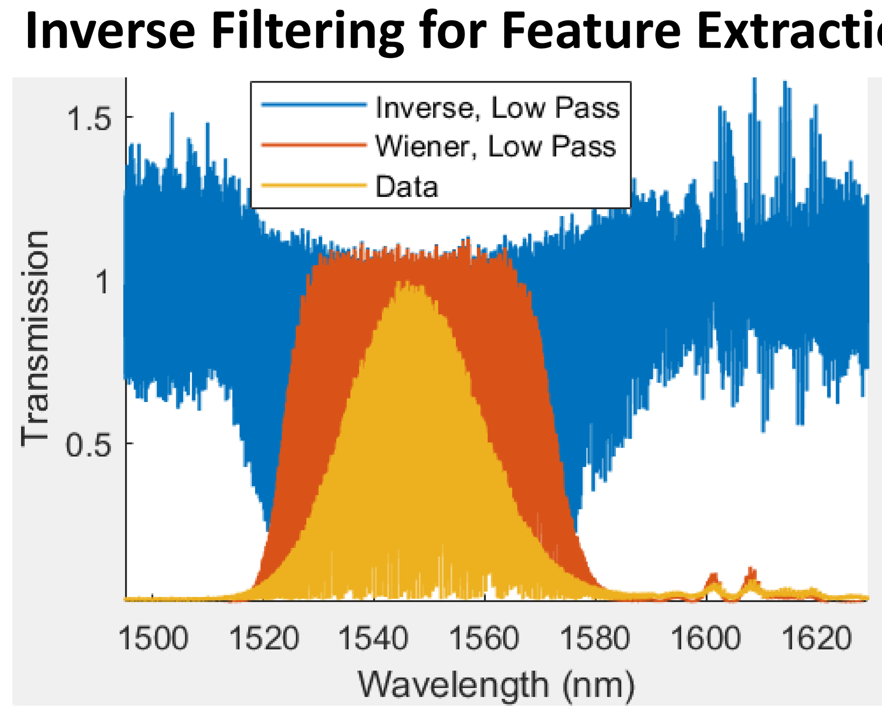
Results: Denoising, Feature Extraction

Low-pass Filtering for Noise Reduction



Remove noise without affecting signal

Inverse Filtering for Feature Extraction



$$T(\lambda) = T_{background}(\lambda) * T_{resonator}(\lambda)$$

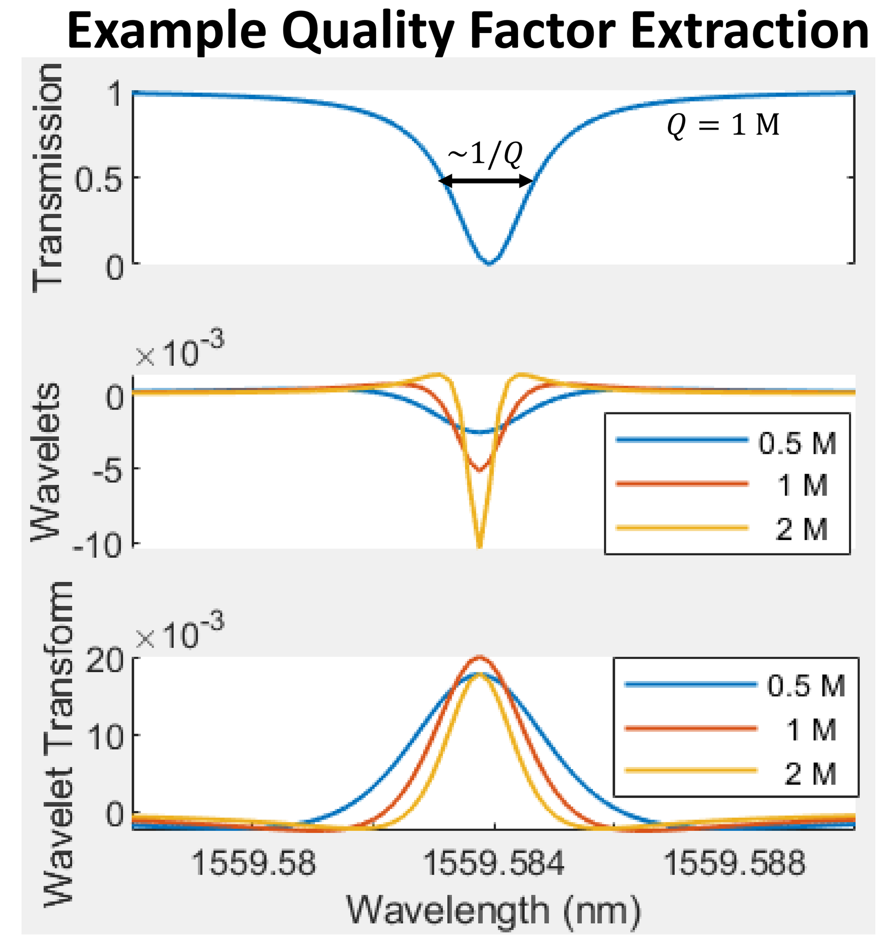
Cascaded nanophotonic circuits → multiply optical transfer functions
Isolate $T_{resonator}(\lambda)$ with inverse filtering or Wiener deconvolution.

Results: Quality Factor Extraction without Fitting

Important parameter in data: resonance quality factor (Q).

We use a series of convolutions (wavelet transform[5-6]) to estimate the Q of all resonances, without performing any fits.

Example Quality Factor Extraction

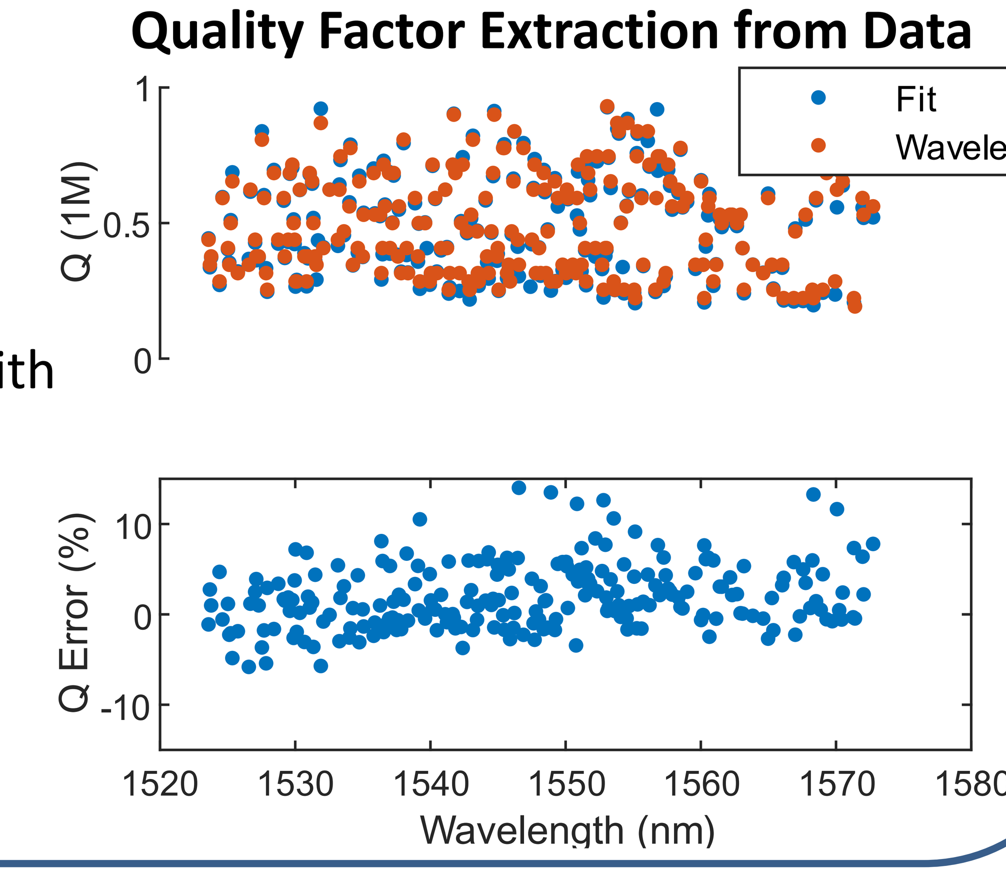


Resonance: narrow dip with linewidth $\sim 1/Q$

Wavelets with different widths are convolved with the data.

Peaks occur wherever wavelet width matches resonance width, indicating Q.

Quality Factor Extraction from Data



Quality factor by convolution agrees with direct fitting.

Conclusion

We demonstrated that computational imaging techniques such as denoising, deconvolution, and convolution are useful to characterize nanophotonic circuits.

Parallels between computational imaging and spectroscopy suggest that many more computational techniques can be applied.

References

1. M. Zhang, C. Wang, R. Cheng, A. Shams-Ansari, and M. Lonˇcar, “Monolithic ultra-high-q lithium niobate microring resonator,” Optica 4, 1536–1537 (2017).
2. T. Herr, V. Brasch, J. D. Jost, I. Mirgorodskiy, G. Lihachev, M. L. Gorodetsky, and T. J. Kippenberg, “Mode Spectrum And Temporal Soliton Formation In Optical Microresonators”, Phys. Rev. Lett. 113, 123901 (2014).
3. Yang He, Hanxiao Liang, Rui Luo, Mingxiao Li, and Qiang Lin, "Dispersion engineered high quality lithium niobate microring resonators," Opt. Express 26, 16315-16322 (2018)
4. Brian J. Soller, Dawn K. Gifford, Matthew S. Wolfe, and Mark E. Froggatt, "High resolution optical frequency domain reflectometry for characterization of components and assemblies," Opt. Express 13, 666-674 (2005)
5. Torrence, C., and G. P. Compo, 1998: A Practical Guide to Wavelet Analysis. Bull. Amer. Meteor. Soc., 79, 61–78.
6. Taubman, David; Marcellin, Michael (2012). JPEG2000 Image Compression Fundamentals, Standards and Practice: Image Compression Fundamentals, Standards and Practice. Springer Science & Business Media. ISBN 9781461507994.

Data provided by Luke Qi.