EE 367 Term Project Proposal
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Project Proposal Writeup

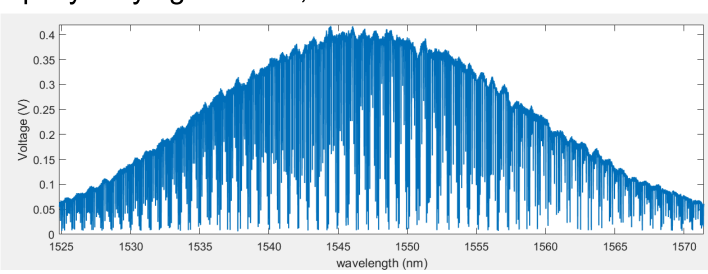
Motivation

Images and videos are an essential part of modern day life. In 2020 alone roughly six billion CMOS image sensors were manufactured (source). Computational Imaging describes the algorithms and techniques used to process the often 2-dimensional images taken by these and other imagers. Many algorithms are routinely applied for tasks such as denoising, deconvolution, and data reduction.

We will show that many of these algorithms are useful in a different area of optical sensing - spectroscopy. Whereas imaging captures the spatial profile of light emanating from a 2D scene, spectroscopy captures the spectral profile of light emanating from a point.
Spectroscopy is useful in characterizing nanophotonic waveguides. Nanophotonics is a rapidly growing field that broadly refers to wavelength scale optical devices. Here we will show that computational imaging algorithms are useful in characterizing fabricated waveguide circuits

Introduction (to waveguide characterization)

To characterize fabricated waveguide devices, one typically shines a laser on one end of the waveguide and collects all light output from the other end of the waveguide with a single pixel photodetector. The photodetector voltage is measured as a function of laser wavelength - providing the spectrum of the waveguide device. A typical spectrum contains both slow and rapidly varying features, as shown below.



Although photon noise, quantization noise, and electronic noise all contribute to the overall noise in spectroscopic measurements, electronic noise becomes the dominant noise source at low optical powers (where the SNR is lowest). We can model the electronic noise as Gaussian distributed zero mean voltage noise on the photodiode signal. We can directly measure the variance of the voltage noise (without any incident optical power), and therefore calculate the SNR as a function of power.

When multiple waveguide components are cascaded, their transfer functions become multiplied. This is nothing but the convolution theorem, except we are directly measuring and working within the frequency domain. Therefore, to isolate the transfer function of a resonator, we need to divide by the transfer function of the other components on the chip.

Fourier analysis

An alternative, though not to our knowledge ever before used, visualization of the data is in the "time" domain by taking the discrete fourier transform of the data. In the time domain the background spectrum appears near zero time, while the periodic features appear at peaks corresponding to multiples of one divided by their repetition rate, up until the Nyquist time. We will apply computational imaging techniques to this time domain representation of the data to aid in nanophotonic device characterization.

First, we apply noise reduction without compromising the signal by low-pass filtering the noisy data in the time domain.
Second, we (Wiener) deconvolve the spectrum in the frequency domain to isolate the transfer function of a resonator from the transfer function of the rest of the measurement scheme.
Third, we extract basic resonator information from the time domain representation of data. Time domain peaks indicate the presence and free spectral range (FSR) of resonances.
Fourth, we attempt to extract dispersion, or a change in FSR with wavelength, from a single peak in the time domain. If successful, solving this inverse problem will greatly simplify and improve dispersion analysis, an essential tool for wavelength calibration and device characterization.
Lastly, we briefly mention other possible applications of computational imaging techniques to spectroscopy. These include high dynamic range data collection and model fitting.

Intermediate goals

- noise reduction without compromising the signal by low-pass filtering
- Wiener deconvolve to isolate the transfer function of a resonator
- Extract basic resonator information
- extract dispersion from a single peak in the time domain.
- briefly mention other possible parallels with computational imaging techniques

Timeline

- 2/26 - 2/28 writeup parallels with computational imaging techniques
- 3/1 - 3/4 Noise reduction, Wiener deconvolution, extract basic info
- 3/4 - 3/7 extract dispersion
- 3/10 work on presentation, writeup
- 3/13 Presentation
- 3/15 Report due

References

Dispersion engineered high quality lithium niobate microring resonators Qiang Lin 2018
Mode-locked dark pulse Kerr combs in normal-dispersion microresonators Weiner 2015
Mode Spectrum and Temporal Soliton Formation in Optical Microresonators Kippenberg 2014