On-Chip Photonic Frequency Combs

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Background

The rationale for this work is that photonic frequency combs are inherently a very powerful technology to convert a bright, nearly monochromatic source like a laser into a fully-tunable optical source that spans a broad (yet adjustable) range of wavelengths. In principal, these sources have all the capabilities that one might desire, such as adjustable bandwidth, intensity, coherence, cross-correlation, and modularability. The discovery of this unique technology led to a Nobel Prize awarded in 2005 to John L. Hall and Theodor W. Hänsch "for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique."

In spite of their promising possibilities, challenges remain with optical combs. Significantly, high-performance optical combs now available commercially are large, bulky, and expensive, which generally constrains widespread deployment outside the laboratory. Incorporating these structures into on-chip micro-resonators adds two key *features: small size / portability, as well as compatibility with CMOS processes and circuits.*

What were the goals?

The goal of our project was to create a compact model for on-chip photonic frequency combs. The objective to facilitate the process of integrating optical combs with CMOS-compatible manufacturing and circuits by creating a MAPP-compatible compact model.

What was accomplished?

This project has led to the development of a compact model for the operation of a microring resonator, which was validated against finite-difference time-domain simulations, and shown to run 720 times faster [1]. Excellent agreement was observed in both the frequency and the time domain, as shown in Figure 1, below. Features matching well include the beat frequencies and associated range of generated wavelengths. The primary mismatch occurs at short times during the transient pulse, when the greatest nonlinearities are present. These errors can be systematically by including additional coupling terms for self- and cross-phase modulation in the compact model, at the expense of slightly longer computational times.

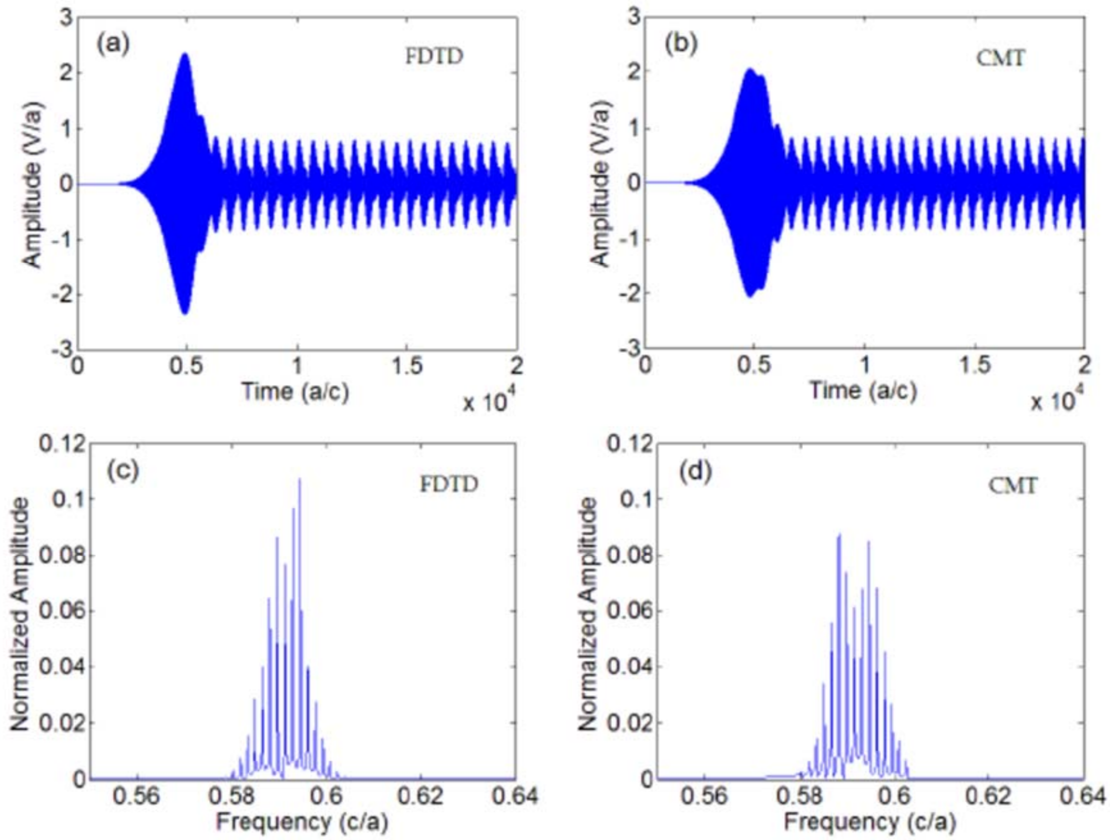

Figure 1: Comparison of FDTD and CMT results for the normal dispersion case: (a) FDTD in the time domain (b) CMT in the time domain; (c) FDTD in the frequency domain; and (d) CMT in the frequency domain.

This compact model was then subsequently released as an open-source tool with a graphical user interface [2]. By combining the recently developed pilot MAPP-opto module with the nonlinearities embedded in the developed model, it is possible to complete our work this year by designing a programmable optical timing circuit, with possible applications in highly accurate time-keeping and optical metrology (e.g., detection of trace impurities) in small devices.

Why was it important?

The main impact of this work to date is to demonstrate that fairly complex systems such as photonic frequency combs can be treated in a computationally tractable way through compact modeling, which can pave the road toward integration into other systems. MAPP provides a specific platform to accelerate this integration through a step-by-step process of rapid prototyping of MATLAB-based compact models, before the development of Verilog-A models. This facility's rapid transition into Verilog-A models and thus commercially-relevant SPICE models for further development by individual companies. The foundational pieces of the compact modeling platform and nonlinear optical models have now been released, and the transition of this specific technology into specific applications is already under way. Multiple companies, specifically including Toptica Photonics and Menlo Systems GmbH, have expressed a great deal of interest in this strategy, which is underscored by their recent financial investments in licensing this technology.

References (* denotes work supported or partially supported by NEEDS)

[1] R. Shugayev and P. Bermel, "Time-domain simulations of nonlinear interaction in microring resonators using finite-difference and coupled mode techniques" Optics Express 22, 19204-19218 (2014).

[2] Y. Guo, P. Bermel, and R. Shugayev "Generation Model with Coupled Mode Theory" (2015). URL: https://nanohub.org/resources/cmtcomb3. DOI: 10.4231/D38911R9Q.