High Throughput Bandwidth Characterization of Silicon Photonic Modulators using Offset Frequency Combs

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Abstract: We develop a low complexity, high-throughput testing technique for concurrently characterizing the bandwidths of multiple in-series modulators with independent frequency combs. The approach is demonstrated on two serial modulators at 9.2 GHz and 15.5 GHz.

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1. Introduction

Photonic integrated circuits can contain thousands of photonic elements [1]. As the complexity of these circuits continues to grow, the increasing scale of photonic integrated circuits pushes testing and characterization to be integral components of photonic manufacturing. For testing to keep pace with design complexity, high throughput testing strategies must be developed.

The demand for high data rate interconnects pushes transceivers to combine wavelength division multiplexing (WDM) with high speed devices, increasing the number of photonic elements in transceivers [2,3]. For WDM transmitters, it is necessary to determine the bandwidth of all the modulators, as the slowest modulator will establish the system bandwidth. Approaches that measure the frequency response of optical modulators include calibrated vector network analyzers [4], optical spectrum analysis of sidebands [5], sweeping frequency measurements [6], and self-calibrating two-tone modulation [7], all measuring the modulation bandwidth of one device at a time. We develop a high throughput testing strategy for WDM transmitter frequency responses by measuring multiple modulators simultaneously, which decreases measurement time and simplifies the testing setup. We demonstrate two experimental setups using two different receiver methods. The first approach uses a photodiode and electrical spectrum analyzer, and the second approach uses an optical spectrum analyzer. This high throughput testing method allows device characterization to keep pace with photonic design complexity.

2. Electrical Receiver Experimental Setup

We measure the frequency response of multiple devices simultaneously by generating multiple electronic frequency combs. Each frequency comb has the same tone spacing, with the combs offset so there is no overlap between them. The frequency combs are applied to different microring modulators. At the output, the individual device bandwidths are discernable with minimal processing because the frequency combs are staggered. The device is a silicon photonic eight-channel microring based modulator for WDM modulation. PN depletion phase shifters drive the RF...
microring modulation, and thermal tuners are used to adjust the resonances of the ring modulators. Light is coupled into and out of the chip with grating couplers. Thermal and RF control is achieved through electrical probes.

For this experiment, only two microring modulators are used (Fig 1). A tunable laser was set to 1546 nm, and the microring modulators were tuned with both ring resonances overlapping so that the laser was located on one side of the resonance. Ring one was driven with a 29-tone frequency comb from 1.0 GHz to 22.0 GHz with 0.75 GHz spacings. Ring two was driven with a 29-tone comb from 1.3 GHz to 22.3 GHz with 0.75 GHz spacings. Both frequency combs were generated by independent outputs from an arbitrary waveform generator with 65 GSa/s. The output from the device was amplified with an EDFA before being received by a photodiode and sent to an electrical spectrum analyzer. The frequency combs were calibrated for the cables and connectors along the signal path to provide equal tone power to the microring modulators and compensate for the attenuation of higher frequencies. While the calibration did not account for the photodiode or the contact probes, they were selected because their bandwidths are 70 GHz (photodiode) and 40 GHz (contact probes) to mitigate effects on the signal path.

3. Electrical Receiver Results

All frequency combs are visible at the electrical spectrum analyzer. Since the tone locations of the frequency combs are known, we separate the spectrum analyzer’s signal into the separate frequency combs, so the device bandwidths can then be determined (Fig. 2). For this particular example, ring one’s 3 dB bandwidth was at 9.2 GHz and ring two’s 3 dB bandwidth was at 15.5 GHz. By measuring the bandwidth of the two rings together, the overall measurement time takes half as long. This approach can also be applied to more than two modulators by increasing the number of frequency combs which will further increase the overall measurement speed.

4. Optical Receiver Experimental Setup

Introducing a modern, high resolution optical spectrum analyzer (OSA) allows for the measurement process to be simplified. With an electrical receiver, the resonance of the WDM modulators must to be determined prior to making a bandwidth measurement, and requires an equipment switch. With the OSA, a laser can be swept to determine the modulator’s resonance and the tones of the separate electrical frequency combs can be measured with one piece of equipment. The setup for the optical receiver is similar to the electrical receiver case but there is no longer a need for a photodiode or DC block as the optical signal is inputted directly into the OSA. Since the OSA has a limited dynamic range and cannot filter the carrier away, the tone strength of the modulation combs needs to be larger compared to the electrical receiver case, which introduces the need for RF line amplifiers. The frequency combs are again calibrated to account for the frequency dependent attenuation of the electrical path. For ring one, there were 20 tones spaced from 1.0 GHz to 20.0 GHz and for ring two there were 20 tones spaced from 0.5 GHz to 19.5 GHz. Our OSA measurement approach offers several advantages compared to the electrical spectrum analyzer approach. First, it requires less equipment, so the setup is less complex, potentially less expensive and faster because there is no need to switch equipment. Second, the frequency comb calibration needs to account for fewer elements because there is no electrical path on the receive side, which has the potential to produce higher precision measurements. Finally, the OSA approach future-proofs the system for increasing device modulation bandwidths. Electrical spectrum analyzers have a maximum frequency, but with the OSA approach increased modulation frequencies result in modulation sidebands further away from the laser frequency.
5. Optical Receiver Results

Figure 3 shows the measurement steps taken in the OSA to determine the WDM modulator bandwidths. Images (a) through (c) show the tuning of the microrings with overlapping resonances. Image (d) shows the optical spectrum with the laser set at 1546.0 nm and both frequency combs turned on, with the modulation sidebands generated by the frequency combs clearly visible. Similar to the electrical receiver, the received frequency tones are separated into the two separate combs, which are then used to generate the bandwidth responses of the modulators. The bandwidth curves from this approach are not as clean as the electrical receiver setup, which could be due to the OSA resolution of 150 MHz. OSAs with higher resolutions exist and would improve the results. Additionally, there is a noticeable asymmetry in image (d) which is a result of differences in DC power due to the laser positioned on one edge of the superimposed modulator resonances. From image (f), we determine the 3 dB bandwidth for ring one to be approximately 10 GHz and for ring two to be approximately 14 GHz. It should be noted that the rings used in the electrical and optical experiments are not the same modulators.

![Optical Spectrum](image1.png)

![Optical Spectrum](image2.png)

![Optical Spectrum](image3.png)

![Optical Spectrum](image4.png)

![Optical Spectrum](image5.png)

![Optical Spectrum](image6.png)

![Optical Spectrum](image7.png)

![Optical Spectrum](image8.png)

Fig 3: a) The initial optical spectrum. b) Ring 1 tuned. c) Ring 1 and 2 tuned. d) The spectrum with the laser on and frequency combs applied. e) The separated frequency combs. f) The resulting frequency responses of the rings.

6. Conclusions

We develop a testing strategy to enable faster bandwidth characterization of serial WDM modulators by applying calibrated offset frequency combs to separate modulators, allowing simultaneous measurement of multiple modulators. Additionally, we expand the idea to an all optical receiver setup that simplifies the measurement process by removing the need to switch between optical and electrical receivers. The testing strategy was demonstrated on a WDM microring modulator chip, and 3 dB modulation bandwidths were determined to be 9.2 GHz and 15.5 GHz. As silicon photonics device testing strategies continue to grow in importance, this characterization approach will simplify measurements and reduce measurement time.

7. References