

Active wavelength control of silicon microphotonic resonant modulators

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Abstract: We present simulations and preliminary experimental results of a new method to stabilize the resonant wavelength of an optical resonant modulator using bit error rate measurements from a local receiver to drive an integrated microheater.

Optical interconnections have the potential to significantly reduce the power dissipation and greatly increase the aggregate connection bandwidth in high performance multiprocessor digital computers, intra-satellite communications, and data centers. Silicon photonic micro-ring and micro-disk modulators for the transmit side of the links are an active area of research, because of they are compatible with silicon electronics processing and have been demonstrated at data rates above 10 Gb/s and at sub 100fJ/bit switching energies [1-3]. However, a key problem that remains to be solved for these devices is control of their optical wavelength that varies as a function of fabrication tolerances (thicknesses and dimensions) and temperature. In [4], a heater and sensor were integrated with a modulator to stabilize its wavelength, but the method demonstrated suffers the potential drawbacks of aging of the sensor over time and the potential need to pre-calibrate every sensor/modulator. Here, we present a new method of tuning the resonant wavelength of the device to match the incident light's wavelength using independent logic one and logic zero bit errors from a local receiver and simple logic circuitry to drive an integrated micro-heater to adjust the temperature of the device. Simulations of the control loop show it to be robust to the choice of gain, receiver decision threshold, and starting point temperature. Preliminary experimental results using an integrated microresonant heater modulator device [5] operating at 3.125 Gb/s with an FPGA and external receiver driving the control loop show a tuning range of 25C–32C (> 2 nm shift). No dithering or calibration is required; the technique is not susceptible to sensor aging, and it can compensate for long-term drift in the characteristics of the modulator.

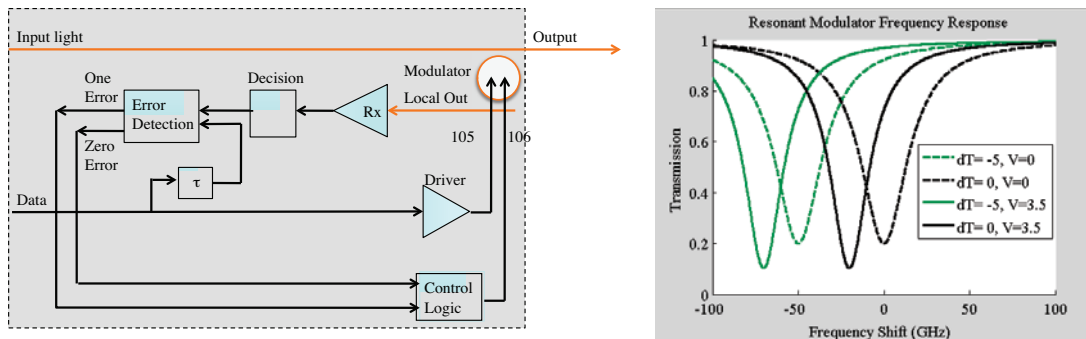


Fig 1. (a) Block diagram of the control technique. The truth table in the upper left shows the decision logic. (b) Illustration of the performance of the modulator as a function of temperature and bias voltage. The black solid (3.5V) and dashed (0V) curves are modulation at the desired wavelength of operation and the green solid (3.5V) and dashed (0V) curves are operation and the initial temperature 5 deg C below the optimum.

Figure 1 shows the transmitter side of the link including the local receiver used to monitor the bit errors generated because of misalignment of the resonant wavelength of the modulator with the incoming wavelength. The output optical signal is also routed to the ‘link’ receiver not shown to complete the interconnection. Importantly, the local receiver is must have higher noise characteristics than the link receiver, so that it is generating errors that are used by the control loop while the link receiver is error free. The electrical data is routed to the modulator and to the logic gates that detect the bit errors. A CW laser source is connected to the optical input of the modulator. The signal from the either the drop port or an output tap is routed to an integrated photo-receiver. The output from the local receiver is routed to a circuit that performs a threshold (comparator) operation that determines whether the received bit is a logic zero or one. The circuit must be sampled with the clock signal to generate the digital signals, but does not need a “clock recovery” circuit, because the clock is local to the circuit. After the decision (thresholding) circuit, the signal is routed to an error detector that compares the received data against the data that was transmitted and determines when errors are made. The circuits that detect logic one and zero errors are simple AND gates with an inverter on one of the inputs. The modulator output is of course also routed to the interconnect receiver with better noise characteristics, ensuring that the interconnection link will be error free when the algorithm is functioning.

Figure 1b illustrates the operation of the modulator as a function of both wavelength and temperature. The black solid and dashed curves represent the states of the modulator under modulation, the solid curve representing a logic zero and the dashed curve a logic one at the wavelength indicated by the arrow λ_0 at a nominal temperature T_0 .

The grey solid and dashed curves represent the modulator states at a new temperature, T_n , shifting the wavelength to λ_n . The shift in wavelength is approximately 10 GHz/C.

The operation of the control algorithm can be better understood by sweeping temperature using the curves from figure 1b and calculating the number of ones errors in blue and zeros errors in red that are generated as illustrated in figure 2a. If the temperature is colder than optimum, all the errors are logic ones. However, if the temperature is hotter than optimum, there is a mix of logic zeros and logic ones. If it is much too hot, then it again has only logic one errors.

If the temperature is initially less than the desired temperature, the control loop will apply an increasingly positive signal to the heater and heat the device up. When the number of errors is about equal, just to the right of the resonance, the positive and negative stimulus to the control loop will cause the device to settle near its optimum wavelength. Extra weighting on the logic zero errors keeps the operating point from climbing up the curve to the right of the resonance where the ones and zeros errors are comparable, but rapidly increasing.

The temperature of the Matlab Simulink™ simulation is shown in figure 2b stabilizing at a temperature 30 degrees above the initial turn on voltage. In the simulation, the frequency response of the modulator was approximately 10 GHz, the frequency response of the heater was chosen as 1 MHz, and the local receiver BER was approximately 10^{-4} . The tuning range in this case was 30 deg. C, limited by the current V/R through the heater.

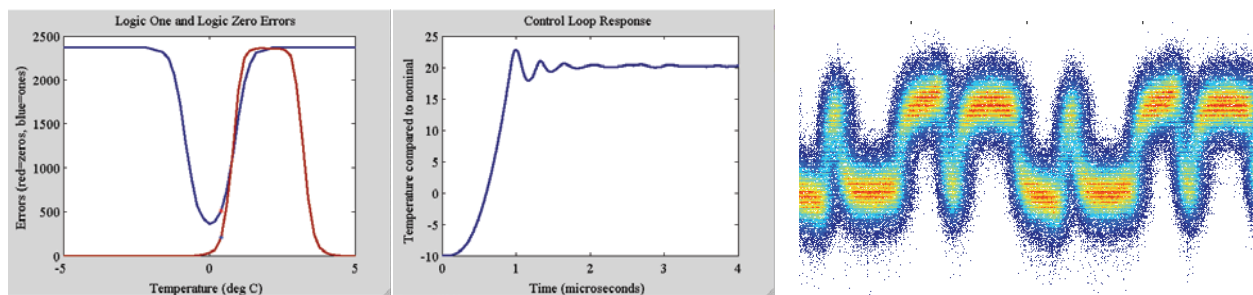


Fig 2: (a) Simulated logic one (blue) and logic zero (red) errors as a function of the temperature on the device with the control loop inactive. (b) Simulation of the heater voltage and temperature of the device as a function of time showing the control loop converging. (c) Experimental bit stream after locking of the control loop at a bit rate of 3.125 Gb/s.

The circuit was tested using an integrated silicon heater/modulator resonant microphotonic modulator [5] mounted on a thermoelectric cooler (TEC). The local receiver was a Nortel transimpedance amplifier (TIA) with a transimpedance of ~ 500 ohms and a 3 dB bandwidth of ~ 12.5 GHz. The output from the receiver was routed to the 3.125 GHz transceiver input of a Xilinx FPGA prototype board that implemented the logic. The pattern implemented so far was a fixed 16-bit pattern, although the matlab/simulink simulations were performed with a 2^7-1 pseudorandom pattern. The heater drive signal was generated using variable numbers of ones and zeros in a long pattern, implementing pulse width modulation. This signal was low-pass filtered and amplified externally to drive the heater. The optimum wavelength of the device at room temperature was 1550 nm.

The external laser was initially set to 1552nm, 2 nm from the optimum. Before the control loop was enabled, no visible pattern was observed from the output of the device. When the control loop was enabled, the device was heated and the correct bit stream was observed on the data output as shown in figure 2c. The excess noise on the trace was present even when the control loop was disabled (with the wavelength optimally tuned), so we are confident the control loop was not adding that excess noise. The laser was tuned in 10pm steps from 1551 to 1553 nm and the device resonance tracked the wavelength shift of the input laser by tuning the device temperature about 25C. In a second experiment, the device temperature was varied, using the TEC, ~ 16 degrees hotter and colder from the initial starting point in a timeframe of about two seconds in each direction, and the device maintained lock within that range. In these experiments, the energy to stabilize the device was obviously quite high, because of all the discrete components. When integrated, we believe that the dominant energy component will be the micro-heater. We will present detailed simulations verifying this assumption.

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