Automatic look up table generation technique for photonic integrated circuits

(Student Paper)

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ABSTRACT

In this work we presented a technique which can be adopted to create automatically and efficiently lookup tables for arbitrary photonic integrated circuits compensating for external perturbations like thermal crosstalk. Its performance is experimentally examined in coupled microring resonators implemented in silicon photonics. These lookup tables can dynamically update themselves to new conditions of the chip upon the need.

Keywords: Automatic tuning algorithm, lookup table, thermal crosstalk

1. INTRODUCTION

Most Photonic Integrated Circuits (PICs) are kept under control and led to work in the desired condition using values for their key parameters pre-calculated or pre-determined and stored in a memory of the electronic circuit that drive and control the PIC. The generation of these values is usually very time consuming and obtained with specific measurements strongly dependent on the circuit architecture, the typical random initial state of the circuit and other uncertainties.

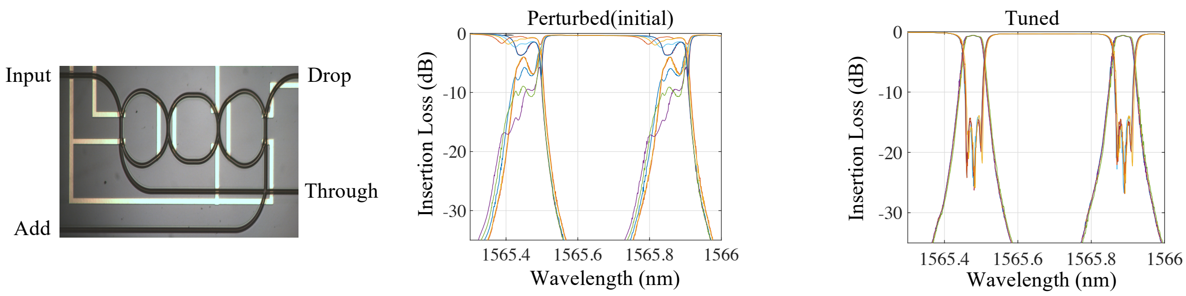
Creating a lookup table requires the tuning of the device, the extractions of the control parameters and the storage in a typically multidimensional matrix named generally lookup table. The generation of the table in a fast, efficient, precise and robust way is a challenging task that has a significant impact in the production, testing and qualification process of most PICs.

Here we propose the automatic generation of the lookup table exploiting a tuning technique robust against external perturbations and thermal crosstalk, which is one of the main reasons for slow or even failure convergence in the tuning and alignment of the circuits. Conventional tuning methods exploiting sequential tuning of individual point of the function through sweeping solutions to find the optimum status [1]. This technique can operate on filters with 5 degrees of freedom even in presence of thermal crosstalk in the time scale of a second.

2. Thermal cross-talk free tuning technique

In this section we present a novel technique, named *Thermal Eigenmode Decomposition* (TED) [2], which can be adopted in generic control algorithms to cancel out the effects of thermal crosstalk in arbitrary PICs including heat sources such as heaters, lasers or electronic drivers. In other words, the TED concept is neither circuit-specific, nor algorithm specific. This allows us to use TED in the required tuning algorithm based on the need, for example to generate lookup tables to align filters, tune lasers to the WDM grid or configure switch fabrics.

TED technique requires all the actuators to be controlled simultaneously according to appropriate weights, which are based on eigensolution of the thermally coupled system. Mathematically this implies a deterministic coordinate transformation. Here we evaluate experimentally the performance of the TED based tuning algorithm on a 3rd order coupled MRR filter. Fig. 1(a) shows a top view microphotograph of the device, which was fabricated in a



(a) (b) (c)

Figure 1: Experimental validation of automatic tuning based on TED method. (a) Top view photograph of a 3rd order coupled MRR filter fabricated in SiON technology. Measured transmission of the Through and Drop port of the filter (b) for five randomly perturbed configuration (+/- 100 pm) induced by using thermal phase shifters and (c) after automated tuning performed by using TED based method.

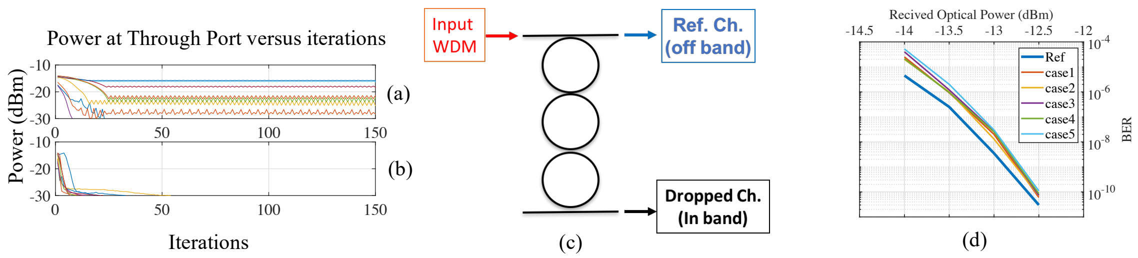


Figure 2: (a) Convergence rate of TED based tuning (with adaptive step size scheme) for 10 random cases versus (b) individually tuning of the MRRs starting from the same random perturbations. (c) schematic of the setup for bit error rate (BER) measurements. As a reference, BER was measured at Through port (in blue) while the filter was detuned from the signal then measurements were done for 5 locked filters observing the signal at drop port (in black)). (d) BER measurements comparing reference path with 5 different tuned filters. Blue curve is the reference obtained at Through port when the filter is detuned from signal. 5 other curves present BER of dropped channel showing less than half a dB power penalty in all the cases.

high-index-contrast silicon oxynitride (SiON) photonic platform (details in [3]). The round trip phase of each MRR of the filter can be individually controlled by means of metallic heater deposited on top of the waveguide uppercladding. The optical power is measured via an external photodiode and transmitted to a PC where a control algorithm determines the control signals to be applied to the heaters. Phase perturbations were intentionally introduced in every MRR of the SiON filter by applying random errors in the voltages driving the heaters around their optimum tuning point. Figure 1(b) shows the measured Through and Drop port transmission of the perturbed filter when the induced frequency spread of the MRR resonances is as large as 100 pm (12.5 GHz versus 6.5 GHz BW of the filter). A 5 Gbit/s OOK modulated signal (with carrier wavelength of 1565.470 nm) was used and the TED based tuning algorithm was targeted to minimize the output power at the Through port. Transfer function of converged filter for Through and Drop port is presented in Fig.1(c) demonstrating a fined tune frequency response obtained through this technique. To illustrate the improvement in tuning performance, TED based method was then compared to the individual tuning in terms of convergence ratio and speed. For a fair comparison, we assumed the same perturbed configurations of Fig.1(b) as the initial state of the filter and we applied both schemes with the same phase step-size for the heaters. Figure.2(a), shows that in many cases sequential tuning of individual resonators did not converge to the target filter shape and a poor Through port isolation with deep oscillations in the steady state was obtained. In contrast, the TED-based tuning did converge for all the considered initial cases in less than 40 iterations (see Fig. 2(b)). To demonstrate that these tuned frequency responses of the filters (Fig.1(c)) are optimum for the transmitted channel, using the setup in Fig.2(c) we measured the BER of dropped channel for 5 converged cases and compared it with the reference BER obtained at through port when the filter was detuned. We can see all converged cases, even if they started from different initial perturbations share the same BER performance which is less than a half dB power penalty.

3. Automatic lookup table creation

A tuning algorithm based on the TED technique is adopted in a software which can control the tuneable laser source (TLS) to automatically create a lookup table for a 3^{rd} order coupled MRR add/drop filter based on silicon photonics. The silicon channel waveguide is 490 nm wide and is buried in a silica cladding. The filter design is optimized to have 1 THz (8 nm) FSR, 40 GHz 3dB bandwidth, and 20 dB in-band isolation. Deeply etched thermo optical actuators offers improved performance. The schematic of complete 4 port filter along the control loops is presented in Fig.3(a). A channel labeller is integrated on chip by using a thermally tuneable Mach Zehnder (MZ) modulator allowing to distinguish the operating channel at the monitor CLIPP in presence of other WDM channels. This is done by applying a shallow modulation to the channel inserted in the Add port which can be extracted from the readout signal of the CLIPP. The FPGA reads the CLIPP measurements while controlling the MZ and heaters alongside the TLS. For each row of the lookup table, it moves the TLS to the relevant wavelength and execute the tuning algorithm to find the tuned parameters of the filter for that channel. This is done till the table is completely filled up based on the performance requirements of the filter along the frequency band. Microscopic picture of the fabricated chip including the labelling MZ is presented in Fig.3(b). In the first trial, starting from natural frequency response of the filter (blue curves in Fig.3(c)), tuning algorithm is examined with a 10 Gbit/s OOK modulated channel at 1561.83 nm being launched at the Add port. This channel is labelled through the integrated MZ and the optical power is measured at the Drop port through the implemented CLIPP. Label amplitude is extracted from the CLIPP reading and minimized to find the fine-tuned filter response as presented in Fig.3(c) with green curves.

Tuning of filter in presence of DWDM channels requires the it to be optically disconnected from the bus (during the tuning process) to prevent impairing other channels. This operation is known as hitless channel tuning. In our device, this operation is achieved by switching MZ tuneable coupler connecting the filter to the bus WG between In/Out ports. This enables reaching high degrees of isolation during the tuning and realized by introduction of π

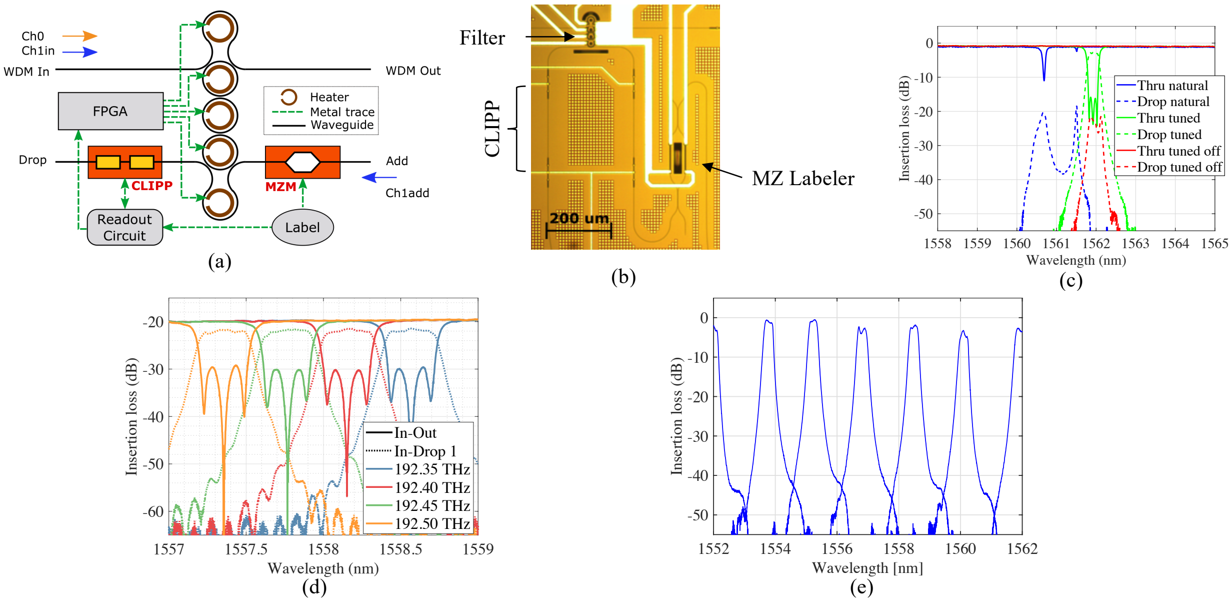


Figure 3: (a) Functional block diagram of the reconfigurable hitless filter along the relevant control elements adopted to demonstrate fine tuning and automatic look up table creation b) Filtering unit including monitoring CLIPP and on-chip labeler to mark the add signal (c) tuning of filter for one channel starting from its natural response (in blue) tuned filter response in green and tuned for disconnected case (hitless scheme) in red. (d) Through and Drop port detailed transfer function of filters for automatically created lookup table on 4 channels 50 GHz apart. (e) Drop port transfer function of filter from automatically created lookup table for 7 channels on a 10 nm span. Frequency response of filter is tailored to match the requirements of the channel without any penalty on the WDM comb.

phase shift through the implemented heater in the MZ. Unfortunately, this process introduces thermal perturbations to the filter which is needed to be considered. Brilliant point of the TED based algorithms is that, this is taken care of automatically. To demonstrate, using the fine-tuned filter (green curve in Fig.3(c)) bias of the MZ heater is modified to disconnect the filter from the bus. Since TED based algorithm was running, it automatically compensated the thermal perturbations due to this shift and maintained the filter at its channel. Red curves in Fig.3(c) presents disconnected Drop port frequency response without any wavelength drifts and centred at the channel.

Adopting this technique in a software which can shift the TLS wavelength and tune the filter for each channel, we tried to create a look up table for four different channels with 100Gbit/s DP-QPSK signal spaced at 50 GHz. Transfer functions of the filter using this automatically created lookup table for connected case is shown in Fig.3(d). Measuring the performance of these filters, we observed in all the cases required performance is satisfied. To examine this concept on a wider frequency band, using a 10 Gbit/s OOK modulated channels starting from 1552 nm, we tried to automatically create lookup table for 10 nm of channels spaced 200GHz apart. Drop port transfer function of this lookup table is presented in Fig.3(e). Frequency response of filter is automatically reshaped to match the BW of the channel without any consequence on the comb. This concept can be extended to multiple filters implemented in the same chip. Thermal perturbations from the neighbouring filters (along their tuning process) can be accounted while tuning the filters to automatically find their fined tuned conditions and create the relevant look up table. Upon the need, these lookup tables can adapt themselves to new conditions of the chip automatically. These new conditions could be large changes in working points of a neighbouring function or even failures in controlling the overall temperature of the chip through thermos optic controllers. This technique can be used to create automatically lookup tables for arbitrary photonic integrated functions with different requirements for example different routing path of a mesh, or different configuration of a tuneable bandwidth filter.

4. CONCLUSION

We presented a robust concept to automatically create lookup table for photonic integrated functions in presence of thermal cross talk in dense circuits. Through experimental trials in coupled microring resonators we demonstrate a thermal cross talk free tuning technique and its application in creating an algorithm to automatically create and update lookup tables in presence of external perturbations.

This work was supported in part by the EU H2020 Program under Grant STREAMS (no. 688172)

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