Self-Stabilized Silicon Mach-Zehnder Interferometers by Integrated CMOS Controller

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***Abstract*—The first fully-integrated low-power multichannel ASIC for the automatic stabilization of integrated silicon Mach-Zehnder interferometers is presented. Each channel includes all the electronics needed to steer and control the optical power in an interferometer by acting on two thermal actuators and dissipating only around 20mW.**

***Index Terms*—Mach-Zehnder interferometer, CMOS, analog feedback, closed-loop, integrated photonics, system on chip**

I. Introduction

Integrated Mach-Zehnder interferometers (MZIs) are among the main building blocks of photonic circuits. One interesting use of MZIs is in the construction of NxN meshes, where they are used to route N different optical inputs to N different outputs in a reconfigurable way [1]. Diagonal or binary-tree meshes (Fig. 1, up) are a subset of these circuits, which can route all the incoming light to just a single output and can be used either as receivers for telecommunications or as sensors [2]. These applications require an external control system to maximize or minimize the light at the output of each MZI and to stabilize the required working point against changes in the input light or environmental variations. All the control systems proposed in the literature are implemented with discrete electronic components and rely on digital processors, like micro-controllers [3] or FPGAs [4], [5], to perform their control action. Although this approach guarantees maximum flexibility, the area occupation and the power dissipation of the control electronics are much higher than those of the photonic circuit. In this scenario, a better approach would be an integrated controller with a simpler and more specific control strategy, but scalable on a large number of channels and with a reduced power consumption.

II. ASIC-stabilized MZI cells

It has already been demonstrated that large MZI meshes can be controlled by individual control loops acting on single MZIs, without requiring a complex multi-input multi-output optimization [5]. After a significant perturbation, the MZI cells adjust their working point sequentially, starting from the one closer to the input. Around a stable working point, the cells become independent and the control loops work in parallel.

Here, we propose a fully integrated implementation of the dithering-based control architecture first presented in [5]. The dithering technique consists in superimposing a small

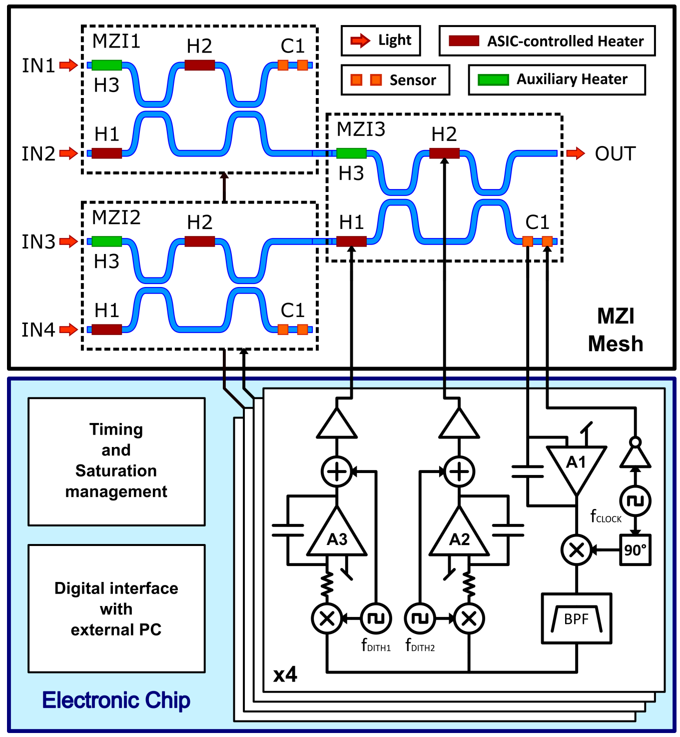

Fig. 1. Schematic representation of the designed 4-channel integrated ASIC controller, together with the schematic representation of the 4-inputs binary tree MZI mesh used to test it. Each MZI in the mesh is controlled separately by a different channel of the ASIC.

perturbation ($1\,\mathrm{mV}$ to $100\,\mathrm{mV}$) to the bias voltage of thermal actuators and in looking at the small perturbation that this causes on the output optical power to deduce the current working point of the photonic device.

We designed a 4-channel ASIC controller (Fig. 1), where every channel is capable of controlling and stabilizing a single MZI device by using a non-invasive CLIPP sensor (C1) and by acting on two different thermal actuators (H1-H2), with the help of two orthogonal dithering signals (f_{DITH1}, f_{DITH2}). Each channel is composed by:

- A low-noise high-resolution readout stage for CLIPP sensors (amplifier A1 and lock-in demodulator at f_{CLOCK}).
- A signal conditioning and filtering chain (BPF), used to extract the small dithering signals.

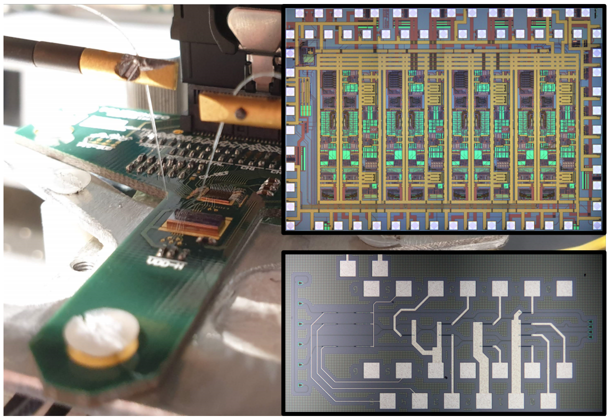

Fig. 2. Experimental setup: the PIC and the controlling ASIC are glued on the same PCB and are connected together with chip-to-chip wire bonds to optimize noise performances.

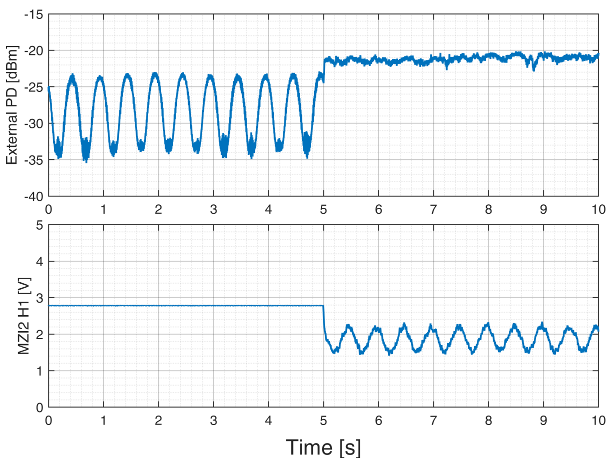

Fig. 3. Disturb rejection results: a sinusoidal phase disturb at $2\,\mathrm{Hz}$ was injected in the system through Heater3 of MZI2. While the control system is off ($t < 5\,\mathrm{s}$), the disturb causes the power at the output of the PIC to oscillate. After the control system is activated ($t >= 5\,\mathrm{s}$), the controlled heater voltage starts tracking the disturbance and the power at the output remains constant.

- Two analog integrators (A2-A3) working in parallel, each used to integrate one of the two dithering signals and to extract the correct bias voltage for one of the two heaters.
- Two driving stages ($0\,\mathrm{V}$ to $5\,\mathrm{V}$) for the two thermal actuators, each taking the output of one of the integrators and superimposing the small dithering signal to it.

III. Experimental results

The proposed ASIC controller was designed and fabricated using AMS CMOS $0.35\,\mu\mathrm{m}$ technology. Tests on the controller were performed with a 4-inputs binary tree MZI mesh designed using AMF AMFSiP technology. The electronic and the photonic chips were designed to allow direct bonds between them for optimal performances. Fig. 2 shows the test setup with the two circuits mounted on a custom-designed holder PCB and connected together.

To test the capabilities of the control system, we used additional heaters present in each MZI of the test mesh (H3 in Fig. 1) to inject phase disturbs between the optical inputs of the mesh. Fig. 3 shows the results of a disturb-rejection test: light was injected on inputs IN3 and IN4 of the mesh and a sinusoidal phase disturb at $2\,\mathrm{Hz}$ was injected through H3 of MZI2. The signal applied to the heater had an amplitude of $400\,\mathrm{mV}$. With the control system disabled, a $10\,\mathrm{dB}$ disturb was present at the optical output. When the system was turned on, the voltage of the controlled heater started moving to compensate for the disturbance and the output optical power was correctly stabilized at its maximum value, with residual oscillations of less than $1\,\mathrm{dB}$ given by noise and by fluctuations of the input power.

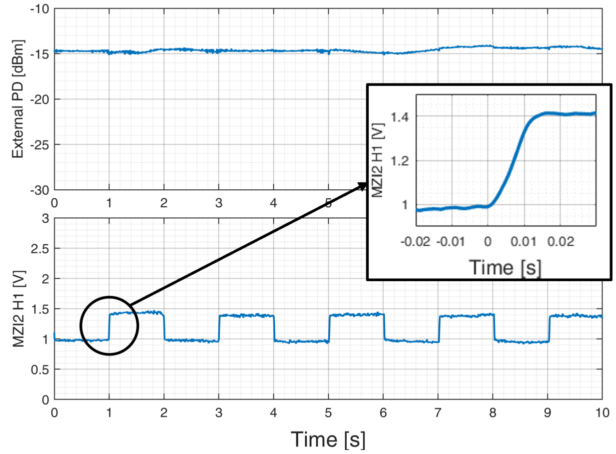

Fig. 4. System bandwidth measurement: a square wave phase disturb at $0.5\,\mathrm{Hz}$ was injected in the system through Heater3 of MZI2. The control system reacts by changing the voltage on Heater1 of MZI2 to compensate for the disturb and to keep the output power constant. The transient response of the controlled heater has a time constant of $\tau \approx 3\,\mathrm{ms}$.

The bandwidth of the proposed control system was assessed by introducing a small square wave perturbation and by measuring the duration of the transient response of the system. Results are shown in Fig. 4. The measured time constant of the system is around $3\,\mathrm{ms}$, indicating a bandwidth of $50\,\mathrm{Hz}$ with the selected settings of the system, which were chosen to optimize noise performances in the readout of the CLIPP.

Acknowledgment

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