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Configuration and Optimization of a Programmable Coupled-Ring Loaded Mach-Zehnder Filter

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***Abstract*—We propose a novel filter circuit that incorporates a balanced Mach-Zehnder interferometer (MZI) loaded with a double coupled ring resonator. A global optimization method is applied to optimize the proposed auto-regression/moving average (ARMA) filter to a specific target function.**

***Index Terms*—Filter Circuit, Ring-loaded MZI.**

I. INTRODUCTION

The auto-regression/moving average (ARMA) filters consist of feed-forward delays such as MZI combined with ring resonators. A typical example is a ring loaded MZI filter, which has demonstrated its capability to realize high-quality bandpass filters, and can theoretically fit certain exact bandpass profiles. Recent programmable designs [1] composed of nested ring or SCOW resonators demonstrated the reconfigurability of such filter circuits, but fail to demonstrate that such designs can exactly fit the proposed bandpass filters. In this work we present a filter circuit which incorporates an MZI where both arms are coupled to the opposite inputs of the same double coupled ring resonator. A hypercube sampling method is applied to generate near-random sampling of the parameter values to analyze pole-zero diagrams of the proposed design and compare it to a traditional ring-loaded MZI. Simulation results show that the two designs are equivalent in spectrum response, thus proving that our proposed design could also exactly realize bandpass filters. The circuit, fabricated in IMEC's silicon photonics platform, is also equipped with a broadband tunable coupler [**?**] at the input and output, which improves the dispersion on the output channels.

We applied a global optimization algorithm to fit the filter parameters, where the optimization target function is carefully tailored to the problem. This optimization routine for the double-stage filter is both in simulation and real experiments, since the electrical and thermal cross talk severely downgrades the performance without optimization. To our best knowledge, it is the first time that a global optimization strategy is directly used in an ARMA filter synthesis and optimization without any additional requirement.

II. OPTIMIZATION ALGORITHM

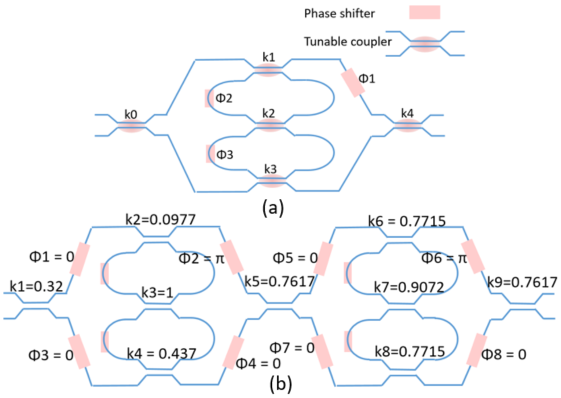

Fig. 1. (a) Schematic drawing of the filter circuit , the phase shifter is shown as a pink box. (b) Schematic drawing of a two stage filter.

To control both the finite and infinite impulse response of the filter, we choose a circuit that incorporates both ring resonators and a Mach-Zehnder interferometer. The schematic drawing of it is presented in Fig. 1(a). Higher-order filters can be constructed by cascading first- and second-order filters. As an example, a fourth-order elliptical low-pass filter with normalized edge frequencies of 0.5π rad/s, 2dB pass band ripple and 40dB attenuation is synthesized. Figure 1(b) shows the schematic drawing of the synthesized two-stage filter and the fitted coupling values and phase shifts. Once the filter coefficients have been synthesized, a second optimization step is needed, for two reasons. Firstly, the calculated coupling coefficients correspond to the lossless case, and the actual waveguides and couplers introduce an additional loss factor. This we solve by treating the loss as a perturbation in our simulations. Secondly, in experiments we find that fabrication variation, dispersion, thermal and electronic cross-talk reinforce the need for this additional optimization step. The choice of the target function for the optimization is quite critical. Traditionally, a box shape on a dB scale can only capture some of the critical characteristics of the filter spectrum response, while a linear box shape emphasises other properties. Therefore, we try to minimize the following error function:

$$T = w_1 \cdot x_{lin} + w_2 \cdot x_{dB} \tag{1}$$

where the error between the optimization result and the desired filter response is denoted as x_{lin}, and the same error

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on a dB scale is denoted as x_{dB}. The coefficients w_1 and w_2 can be tuned depending on the problem.

As the wavelength filters are phase-sensitive interference-based circuits, the optimization space has many local optima. In this section, we will focus two classes of algorithms and we show that these are sufficiently robust to solve our problem in simulation and eventually can be incorporated to optimize and tune the experimental filter circuits in real time.

A. *Nelder-Mead and Powell method*

Nelder-Mead and *Powell* are two free-derivative optimization methods. Both methods work well for local optimization starting from a good initial estimate. The *Nelder-Mead* is slow and has a convergence order of 1, which means that large termination errors may occur due to limited iteration steps. It has been tested that the *Powell* method converges much faster than *Nelder-Mead* method in our experiments. The *Nelder-Mead* is often used when the number of optimizable parameters is very large. The spectrum response of the synthesized elliptical filter in Fig 1(b) obtained from the circuit simulator Caphe has an initial extinction ratio of around 34 dB since the waveguide loss is considered in the simulation. The Nelder-Mead method is used to further optimize the spectrum response, where we optimize on the dB scale. The circuit simulation in Caphe of initial 34 dB extinction ratio is optimized to the desired 40 dB elliptical filter response and the result is shown in in Fig. 2(a).

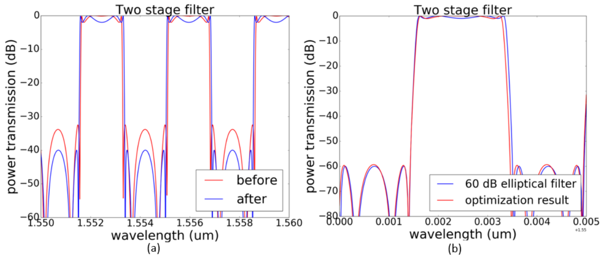
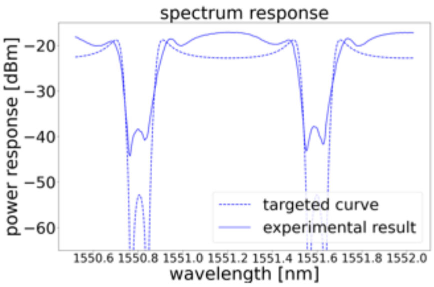


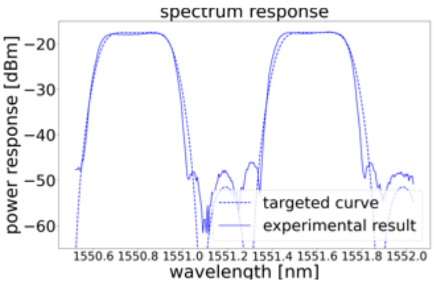
Fig. 2. (a) Spectrum response of an optimized elliptical filter targeting 40 dB extinction ratio. (b) Spectrum response of the optimized elliptical filter pass band starting from a random filter configuration.

B. *Basin-Hopping method*

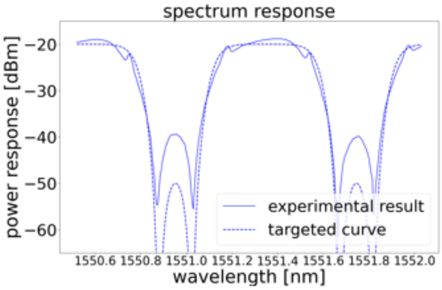
In this section, we focus on a global optimization algorithm - *Basin-hopping*. The *Basin-hopping* is a two-phase method that combines a global stepping algorithm with local minimization. For this second step, we could use the *Nelder-Mead* or *Powell* method. The number of basin-hopping interactions is set according to the difficulty of the problem. Our first experiment starts from a random filter configuration and optimizes the circuit to a elliptical filter. For each optimization, 100 Nelder-Mead evaluations and 10 basin-hopping iterations are applied. If we start from a good initial guess the optimization goes very smoothly. However, if we do not set any constraint on the initial coupling values, more optimization steps are needed and even the target function has to be adjusted in order to get a suitable optimization result.The final optimized result is shown in Fig. 2(b).



(a): ellip(2,2,17,0.8,'low') ; a = [1, 1.28,0.62] ; b = [0.59, 1.13, 0.59]



(b): ellip(2,0.03,17,0.21,'low') ; a = [1, -0.212,0.239] ; b = [0.3,0.4,0.3]



(c): cheby2(2, 15, 0.75, 'low'); a = [1, 0.44,0.25] ; b = [0.46, 0.77, 0.46]

Fig. 3. Experimental results for programmable filter design.

III. EXPERIMENTAL RESULTS

We applied this optimization schemes to experimentally configure this filter circuit fabricated in IMEC's iSiPP50G process.As the measurement data is noisy and the initial guess might be not accurate due to crosstalk, the *Powell* is chosen since it converges faster than the *Nelder-Mead Method* in experiments. The final optimization result is shown in Fig. 3 for three filter specifications.

IV. CONCLUSIONS

We have proposed an MZI filter circuit loaded with a coupled double ring resonator to realize a configurable second-order auto regressive-moving-average (ARMA) filter, and demonstrated optimization of the tuning coefficients both in simulation and in experiments.

REFERENCES

[1] W.Bogaerts et al.,"Programmable photonic circuits", Nature, vol.586,no.4,pp.1476-4687,2020
[2] M.Wang et al.,"Tolerant broadband tunable 2×2 coupler circuit",Optics express, vol.28,no.4,pp.5555-5556,2020