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Automatic Tuning of a Ring Resonator-Based Optical Delay Line for Optical Beamforming

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Abstract

We investigate two automatic tuning methods for continuously tunable optical delay lines that use the measured group delay response in a feedback loop. The methods are validated experimentally on an optical delay line consisting of three optical ring resonators.

1 Introduction

Optical beamformers can provide the accurate phase shifts or time delays required for high-speed beam steering in phased array antennas. Compared to electrical beamformers they are lighter, smaller, have a higher bandwidth and reduced loss. A type of optical beamformer based on individually heatable optical ring resonators (ORRs), organized in a binary tree topology, has been shown capable of continuously tuning the true-time delay optical delay lines [1]. To achieve a desired flat group delay response, the heater voltages need to be tuned accordingly. For larger bandwidths and delays, however, the required number of ORRs increases. With a more complex system manual tuning quickly becomes futile, and automatic methods as in [2, 3] have to be employed. These automatic tuning methods have successfully been applied to optical beamforming, but only in simulations. We now wish to investigate the performance on a real system.

2 Experiments

In this work, an automatic tuning method based on the DONE algorithm proposed in [3] is validated experimentally for an optical delay line with three ORRs. As a baseline, the DONE algorithm is compared with a simple hill climbing algorithm. This is an algorithm that tunes one heater at a time until no improvement is possible, after which it turns to the next heater. This cycle is repeated after all heaters have been tuned. Both algorithms require an objective that is to be minimized. We chose the root mean square error (RMSE) between the desired group delay response and the measured group delay in the frequency range of interest. Minimizing this objective should result in a group delay response of the system that is close to the desired response. The desired group delay response is flat and its value has been set to 278.18 ps. With no specific application in mind, all values were chosen in such a way that the algorithms would be challenged to find a good solution, as the exact desired group delay response is not attainable in reality with these values. The frequency range of interest was chosen between 73 and 78 GHz, giving a bandwidth of 5 GHz. All frequencies are relative to the optical carrier frequency of 193.2 THz and are only an approximation due to the nonlinear relation between laser drive current and frequency. The feedback loop is as follows: first, the ORR heater voltages are set to the initial value

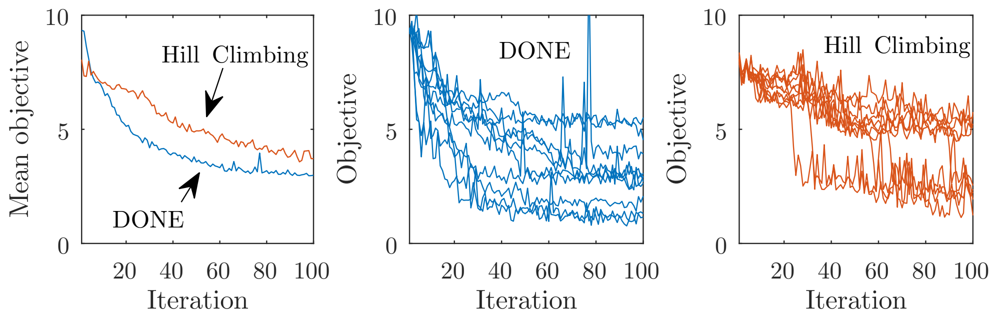

Figure 1: The value of the objective function to be minimized plotted against the iteration number of the algorithms. Results are averaged over 10 runs in the first plot. The second and third plots show the results of individual runs.

$[2.0, 2.0, 1.55, 2.0, 1.85, 2.0]$, making sure that the resonance frequencies of the ORRs are in the frequency range of interest. Then the group delay response is measured using a similar set-up as in [4], and the value of the objective is calculated. This value is given to the automatic tuning algorithm, which in turn provides a set of suggested heater voltages. The heaters are set correspondingly, and the cycle is repeated.

Figure 1 shows how the RMSE decreases while the algorithms are running, with the DONE algorithm giving better results. The average over 10 runs of the algorithms is shown, as well as the individual runs. Figure 2 shows the final group delay response of the most successful runs for both algorithms, over three periods of the ORRs. It can be seen that both algorithms successfully tuned the ORRs in such a way that they provide a group delay around the target value. The performance is similar to the end result of manual tuning. One iteration of the DONE algorithm took about 3 seconds, and half of that for hill climbing. These times include the calls to the external beamformer interface software. The algorithms were implemented in Python such that the beamformer interface was easy to access. In previous work, we have shown that an optimized C++ implementation of the DONE algorithm requires only a few milliseconds per iteration in a similar setup [3]. The delay ripple can be decreased by decreasing the bandwidth or the desired group delay, or by increasing the number of ORRs.

3 Conclusion

The feasibility of tuning optical delay lines automatically has been demonstrated experimentally for the first time on the optical beamformer under consideration. Future work will indicate whether these results can be extended to tune multiple delay lines at the same time.

Acknowledgments

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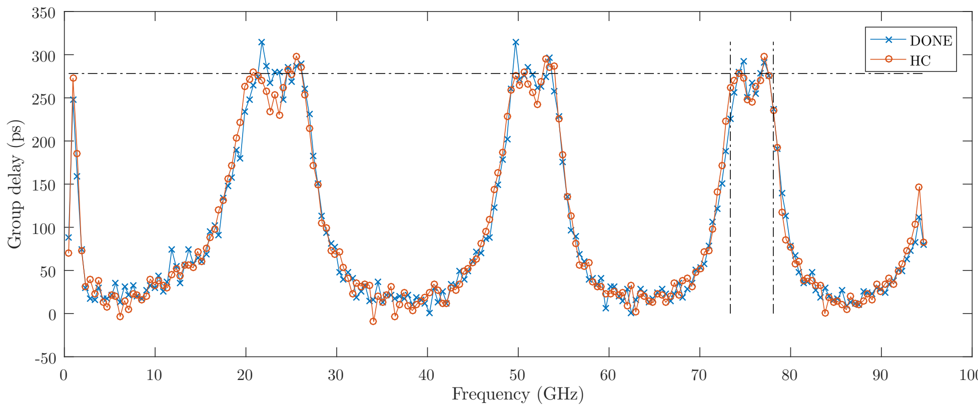

Figure 2: Group delay response of a 3-ring tunable delay line after automatic tuning with the DONE algorithm and the hill climbing algorithm. Only the results of the best runs are shown. The dotted lines indicate the desired group delay (287.18 ps) and the frequency range of interest (73-78 GHz) relative to the optical carrier frequency.

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