Multiobjective Optimization for Electrooptic Modulators

Ademar Muraro Jr.[1], Airam J. Preto[2], Stephan Stephany[2], Angelo Passaro[1], Nancy M. Abe[1]

[1] Virtual Engineering Laboratory - Applied Physics Division, Institute for Advanced Studies (IEAv/CTA) - 12228-001 - São José dos Campos - SP - Brazil

[2] Laboratory for Computing and Applied Mathematics, National Institute for Space Research, (LAC/INPE) - 12227-010 - São José dos Campos - SP - Brazil

`{ademarm,angelo,nancy}@ieav.cta.br, {airam,stephan}@lac.inpe.br`

Abstract. *This work presents preliminary results of the optimization of Mach-Zehnder type lithium niobate modulators. Some design parameters were optimized using a multiobjective approach that uses a genetic algorithm to iteratively refine candidate sets of parameters. The characterization of the modulators for each solution is performed by the finite element method. Test cases include optimization of conventional and floating-electrodes Mach-Zehnder modulators.*

1. Introduction

In fiber optics communication systems, the external modulation is an alternative to eliminate the frequency chirping caused by the direct modulation of semiconductor lasers which limits the transmission bandwidth. Mach-Zehnder type modulators are important devices used to achieve this task. This kind of devices, made of titanium diffused lithium niobate (Ti:LN) substrate with traveling-wave electrodes, allows zero or adjustable frequency chirp, low bias drift and large electrooptic coefficients. Moreover, recent technological advances has resulted in a supply of high-quality LN modulator components for use in many commercial and military applications.

Materials and geometric configurations affect the electromagnetic characteristics of electrooptic modulators and, in general, their effect can not be evaluated analytically. The use of computational models and software tools based on numerical methods allow analyzing the performance of the device with different materials and geometric design.

This work, presentes a computational analysis of electrooptic modulators (Figure 1) by using a stochastic optimization technique, in order to explore the effect of some geometric parameters of the coplanar waveguide on the performance of the modulator. A genetic algorithm (GA) is used for the design optimization of the electrooptic modulator and the finite element method (FEM) is applied on each candidate solution generated by GA.

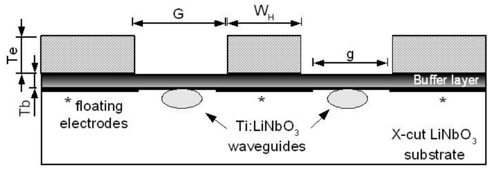

Fig. 1. The cross section of a Mach-Zehnder modulator with CPW: *Tb* is the thickness of the buffer layer, *Te* is the electrode thickness, *G* is the gap between the hot electrode and the ground electrode, W_H is the width of the hot electrode and *g* is the gap between the floating electrodes.

Test cases include optimization of a conventional Mach-Zehnder modulator and a variation of this kind of device using additional floating electrodes. The set of characteristics include parameters such as characteristic impedance (Z_c), effective index of the microwave (N_m) and half-wave voltage (V_π).

2. Multiobjective Approach

The modulation in lithium niobate modulators is produced by a voltage-induced change in the refractive index. A useful figure of merit for modulation is the product of the half-wave voltage and the electrode length. Other electrical parameters of the modulator, which are determined from the microwave propagation characteristics of its electrodes, are the characteristic impedance and the effective index of the microwave.

The design optimization processes are composed by two mechanisms: the analysis engine, performed by FEM, and the search algorithm, performed by GA.

To calculate the electrical parameters of the modulator, it was used a two-dimensional FEM in the quasi-static approximation (TEM modes) to numerically compute the microwave properties generated by each different geometry of the modulator [Muraro, 2006], [Rahman, 2002].

GA [Haupt, 2004] have been applied as search algorithm in the multiobjective optimization approach, in order to build a set of Pareto-optimal solutions [Deb, 2002]. To find these solutions, the weighted sum method has been adopted, mathematically described as follows:

$$\text{Min} \quad F(\boldsymbol{x})=\sum_{i=1}^{n} w_i\, f_i(\boldsymbol{x}) \ , \quad \text{and} \quad \sum_{i=1}^{n} w_i=1 \ .$$

Almost all optimization processing time is spent by the analysis engine computing the electromagnetic fields for each solutions. In order to minimize this time, the optimization process utilizes a parallel GA implementation that follows a master-slave scheme, executed in a distributed memory parallel environment. The master processor executes the GA and sends the solutions to the slave processors for parallel evaluations. The parallelization of the software employed the Message Passing Interface communication library (MPI) [MPICH, 2006].

3. Results

Results for the optimization of pairs of characteristics: Z_c with V_π and Z_c with N_m, are shown in Figures (2) and (3), respectively. These results were obtained for a Mach-Zehnder modulator using floating electrodes.

Figure (2) shows the results considering the characteristics: Z_c with V_π. The minimization of these two characteristics provide a clear Pareto-optimal front for this problem. The set of optimal solutions converge to the Pareto-optimal front and a sparsely spaced distribution was obtained, which ensures a good set of trade-off solutions that provide a compromise between the different objectives. These results were better than the ones obtained for the conventional structure, as expected [Franco, 1999].

In a second study, both the Z_c and the N_m characteristics were optimized at a time (Figure 3). All solutions in the front are feasible but a lack of solutions can be observed in the range $0.1 \leq \mathbf{F}_{Zc} \leq 0.4$, suggesting a nonconvex region.

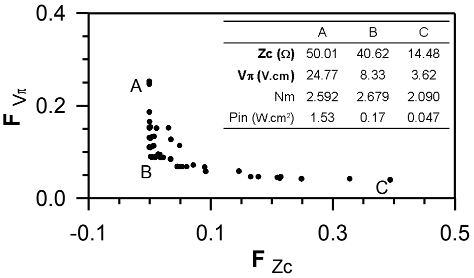

Fig. 2. Pareto-optimal solutions for Z_c and V_π for floating electrodes modulators.

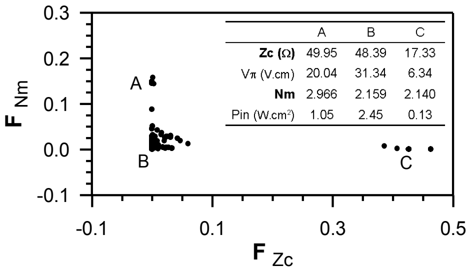

Fig. 3. Pareto-optimal solutions for Z_c and N_m for floating electrodes modulators.

4. Conclusion

A multiobjective design optimization method was proposed for Mach-Zehnder type modulators. A Genetic Algorithm performs the optimization and the Pareto-optimal solutions were obtained by the weighted sum method. Numerical results have shown that the proposed method was able to obtain the Pareto-optimal front for the modulator characteristics Z_c and V_π. Additional efforts are required to improve the method in order to build the Pareto-optimal front when it presents nonconvex regions.

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