Towards structural optimization of planar integrated lightwave circuits

M. M. SPÜHLER AND D. ERNI
Laboratory for Electromagnetic Fields and Microwave Electronics, Swiss Federal Institute of Technology, 8092 Zurich, Switzerland

Abstract. In this paper we present a simulation and optimization approach which is based on a sophisticated representation scheme. Three levels of representation (geometry, functional description, and netlist) in combination with a scattering matrix approach allow a very fast and accurate simulation of geometrically defined lightwave circuits. A semantic analysis makes the transition between the geometry and the functional description by detecting and extracting elements like, e.g., different shapes of directional couplers. Based on this representation scheme an evolutionary optimization strategy is proposed, which allows the optimization of a given topology using a number of different mutation operators, and with which in future it should be possible to find new topologies. An outlook in this direction is given.

Key words: evolutionary algorithms, integrated optics, topological optimization

1. Introduction

When designing integrated optical filters there are two main criteria. First, the filter characteristics have to be fulfilled. And second, the design and fabrication costs should be held low. While the filter characteristics have to be met without compromises, the factor of cost is always wanted to be minimized.

The overall cost of a product is a combination of the design costs and fabrication costs. Depending on the production volume, the weighting of the two factors varies in a wide range. The following text presents a new approach for a design and optimization platform which can potentially reduce both cost contributions. The design costs are reduced because the system is able to operate autonomously with minimal user interaction, and potentially find solutions that are as cost-effective as possible. Especially in this context a tool that is able to take into account the different optimization criteria would be a big advantage.

In the past, several integrated optical devices have been optimized with evolutionary algorithms. These are short spot-size converters (Spühler et al. 1998a, b), coupled-cavity semiconductor laser diodes (Erni et al. 1998), and apodized grating filters (Wiesmann et al. 1999). In this paper it is described, how a transition can be done from the device level to the circuit level. Topological optimization of integrated lightwave circuits results in a very demanding inverse problem. Besides a smart optimization scheme, a very
sophisticated forward solver, which allows the inclusion of *a priori* knowledge concerning the problem, is mandatory.

Several implementations of optical filters with well known design methods (Oppenhein and Schafer 1989; Jingui 1996) exist, depending on the specifications. Three of the most convenient structures are waveguide grating filters (Dragone 1989), resonant coupler (cascaded Mach-Zehnder) filters (Kuznetsov 1994), and cascaded ring-resonators (Orta et al. 1995). The problem of all these structures is the large chip space they require. To obtain a desired filter characteristic is easier when using more structural elements or more stages. With a correct topology, however, the required chip space may be reduced.

Beside gratings, approaches using ring resonators (Barbarossa et al. 1995a, b), are also suited for compact designs (see examples in Fig. 1). However, their drawback is, that only very narrow passbands are obtained. Such structures have no general design method available. For every new topology, the calculation method has to be developed almost from scratch.

A system, where the user can just enter the required filter characteristics and then the system would design the most compact filter that meets the given requirements would be very powerful. Such a system would solve the inverse problem for the optical filter circuit and has to be composed of a forward solver as well as an optimizer to solve the inverse problem. Both topics will be addressed in the following sections. First, the forward solver is described and then the optimizer strategy will be explained.

2. The concept of the forward solver

As depicted in Fig. 2 the forward solver relies on several design representation schemes. There are three representation formats: (1) the geometry description, (2) the semantic or functional description and (3) the netlist.

Fig. 1. Two examples of filters composed of ring resonators which are more compact than standard designs using waveguides and directional couplers. The couplers are encircled. (a) Triple-coupler ring-based waveguide resonator (Barbarossa et al. 1995a), (b) compound triple-coupler ring resonator (Barbarossa et al. 1995b).