Synthesis of the Design of Co-directional Couplers

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INTRODUCTION

Optical directional couplers are one of the basic components of Integrated Optical Circuits. The co-directional and contra-directional couplers are two versions, the former is widely used, while the latter, which requires a grating for phase matching, has not found as many applications. The Mach-Zehnder interferometer has now become the most widely deployed external modulator, replacing the co-directional coupler. However, the additional degrees of freedom available with the coupler results in greater design flexibility, and enables the synthesis of the coupler design to obtain specific response functions. The coupling function of the co-directional coupler may vary along its length, and it is this coupling function that enables the realization of couplers as modulators with linear amplitude response, low switching voltage, and also with particular phase response for dispersion compensation. While the contra-directional coupler grating synthesis has previously been outlined for use as filters by several authors (1, 2, 3), the synthesis of the co-directional coupler design, while originally proposed much earlier (4), has only recently been discussed and implemented (5, 6, 7).

In this paper, the synthesis techniques of the co-directional couplers are outlined, together with their application to specific designs.

SYNTHESIS TECHNIQUES

The two techniques that are used for coupler synthesis are the Gel'fand-Levitan-Marchenko inverse scattering method, and the Inverse Fourier Transform method.

The Gel'fand-Levitan-Marchenko inverse scattering technique, initially proposed for quantum mechanical scattering problems, was modified by Song and Shin(1), and further modified by Winnick (2) for the design of contra-directional couplers as filters. In this method, the response has to be expressed as a rational function, as in traditional electrical filter theory, and then the coupling function between the two coupled guides is obtained. Several approximation response functions have been used, including Butterworth, and Chebyshev polynomial filter functions, and several designs have been obtained. The Butterworth function leads to a maximally flat response, and the Chebyshev, to the usual ripple in the response. The problem here is that the desired response needs to be expressed as a rational functions, and non-traditional response functions are not allowed. While this limitation has been modified by Peral (3) for the contra-directional coupler, it has not been successfully implemented for the co-directional coupler.

The second method is based on the Inverse Fourier Transform proposed by Alferness (4), who suggested that the response function and the coupling function are approximate Fourier transform pairs. This approximation provides an initial guess of the coupling function, and further modifications result in realistic responses, with truncated coupling functions. A linear amplitude response modulator was designed and realized using this Fourier technique (5). Further iterations with the transform coupling function as the first guess have been made to obtain couplers with a specific amplitude function, and also with a specific phase function response to perform dispersion compensation (6).

REALIZATION OF COUPLING FUNCTION

A major issue is the realization of the coupling function obtained from the above synthesis methods. Coupling functions are smoothly varying functions of distance, and also have "zero" coupling points at which the sign changes to yield negative coupling. The smoothly varying coupling function may be implemented by varying the gap between the guides, but this leads to very high V_π values in modulators (5), and therefore the straight section embodiment is preferred, and in this case, the variation of coupling is obtained by the etch depth between the guides. The sign change of the coupling function may be implemented by increasing the path length of one of the arms by $\lambda/2$. The straight guide design with stepped coupling, instead of smoothly varying coupling, has resulted in a small switching voltage modulator, even though the V_π was of the order of 8 V, based on a trapezoidal response function (7). Other techniques include gray scale mask and the corresponding gray scale etching between the guides to provide smooth variation in the coupling function with straight guides with an uniform gap.

SUMMARY

The synthesis of co-directional couplers may be implemented using the Gel'fand-Levitan-Marchenko and the Inverse Fourier Transform techniques. The realization of these designs has also been discussed.

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