Proposal of Mach-Zehnder-Interferometer

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***Abstract*—The Mach-Zehnder interferometer or MZI is a measurement device to determine the relative phase shift between two light beams derived from a single light source. Further usecases for a Mach-Zehnder interferometer are high speed switching applications, electro-optical modulators, optical filters or as well as sensing applications.**

***Index Terms*—waveguide geometry, mode profile, effective and group index, compact model, transfer function, parameter variation, transmission spectra, free spectral range**

I. INTRODUCTION

THIS proposal gives a brief overview about the theoretical background of the MZI and simulation results of crucial parameters to determine for the waveguide group index for instance.

II. COMPACT MODEL OF THE WAVEGUIDE

From reasons of simplicity in this proposal a standard waveguide size is used. That means the height is set to 220 nm and the width is set to 500 nm. The used central wavelength in the models is 1550 nm of wavelength.

In order to get the compact model (polynomial expression) of the waveguide used in the MZI model it is needed to use a Finite Difference Eigenmode Solver (FDE). The equation of this model is stated below.

$$n_{eff}(\lambda) = n_1 + n_2(\lambda - \lambda_0) + n_3(\lambda - \lambda_0)^2 \quad (1)$$

In Fig. 1 one will find the energy density plot of the fundamental TE mode provided by the waveguide. A subsequent frequency analysis of the waveguide leads to a determination of the effective index and group index versus wavelength as shown in Fig. 2.

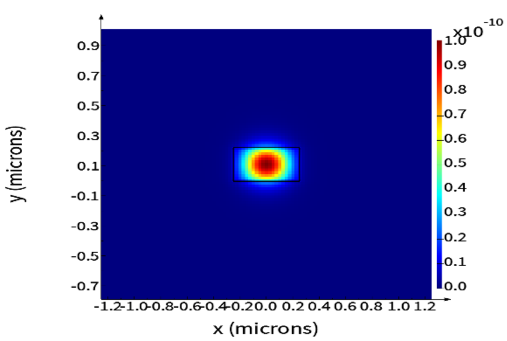

Fig. 1. Fundamental TE mode (energy density) provided by the stated waveguide in Section II

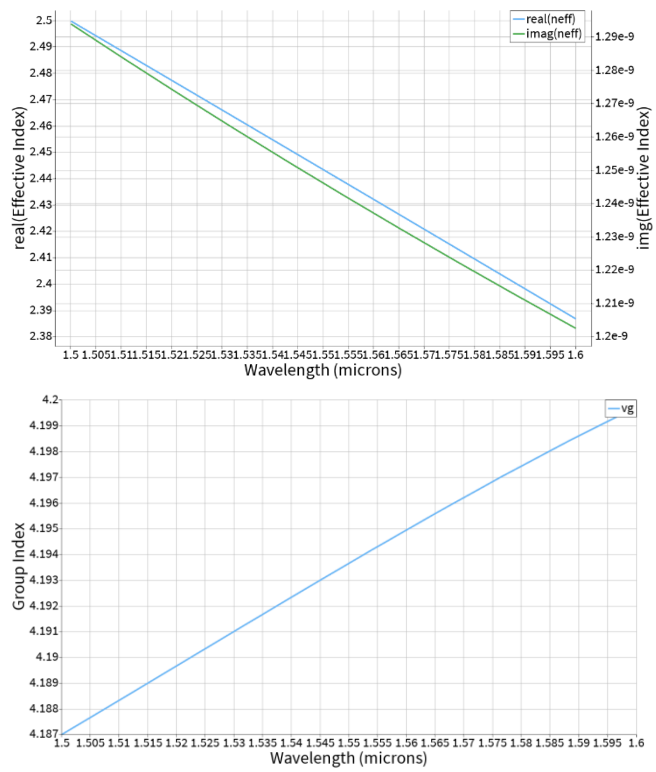

Fig. 2. Effective index versus wavelength (top) and group index versus wavelength (bottom)

LUMERICAL MODE provides a Script Prompt which is used to determine the polynomial coefficients of the compact model (see Table 1). The script for a polynomial model fit was provided by the lecture.

TABLE I
PARAMETERS OF THE COMPACT MODEL

Parameter	Value
λ_0	1550 nm
n_1	2.44
n_2	-1.13
n_3	-0.04

III. MACH-ZEHNDER INTERFEROMETER

For the simple case of an imbalanced Mach-Zehnder interferometer for identical waveguides the course lecture gives the following expression as optical transfer function:

$$I_o = \frac{I_i}{2}[1 + \cos(\beta \Delta L)]$$

Hereby ΔL is the path length difference between the two arms of the Mach-Zehnder interferometer, I_i is the incident light power, I_o the output power and β is the waveguide propagation constant.
In the lecture the derivation of the free spectral range for the given interferometer type was shown. The conclusion is described in the formula below.

$$FSR = \Delta\lambda = \frac{\lambda^2}{\Delta L\left(n - \frac{\lambda dn}{d\lambda}\right)} = \frac{\lambda^2}{\Delta L(n_g)}$$

In Table II the planned design variations are shown. In Fig. 3 the photonic circuit and the gain (transmission) spectra are shown of design 1 and 7. SPAR_3 and SPAR_4 are the TE grating couplers (S parameters provided by lecture). SPAR_1 and SPAR_2 are the Y-branches. WGD_1 and WGD_2 are the waveguide models derived from previous LUMERICAL frequency analysis and ONA_1 the optical network analyzer.

TABLE II
DESIGN VARIATIONS (PRELIMINARY)

Design #	Polarization	ΔL /µm	Circuit type	Splitter type	WG width / nm
1	TE	50	Mach-Zehnder	Y-branch	500
2	TE	100	Mach-Zehnder	Y-branch	500
3	TE	100	Mach-Zehnder	Y-branch	500
4	TM	100	Mach-Zehnder	Y-branch	500
5	TE	150	Mach-Zehnder	Y-branch	500
6	TE	200	Mach-Zehnder	Y-branch	500
7	TE	250	Mach-Zehnder	Y-branch	500
8	TE	100	Mach-Zehnder	Broadband	500
9	TE	100	Michelson	Broadband	500
10	TE	----	Loss estimate (GC)	----	500
11	TE	----	Y-branch test	Y-branch	500

TABLE III
FSR SIMULATIONS FOR DIFFERENT DESIGN

Design #	Simulated FSR / nm
1	11.1
2	5.47
3	5.47
4	~6.4
5	~3.8
6	~2.8
7	~2.3
8	~5.9
9	~5.8
10	---

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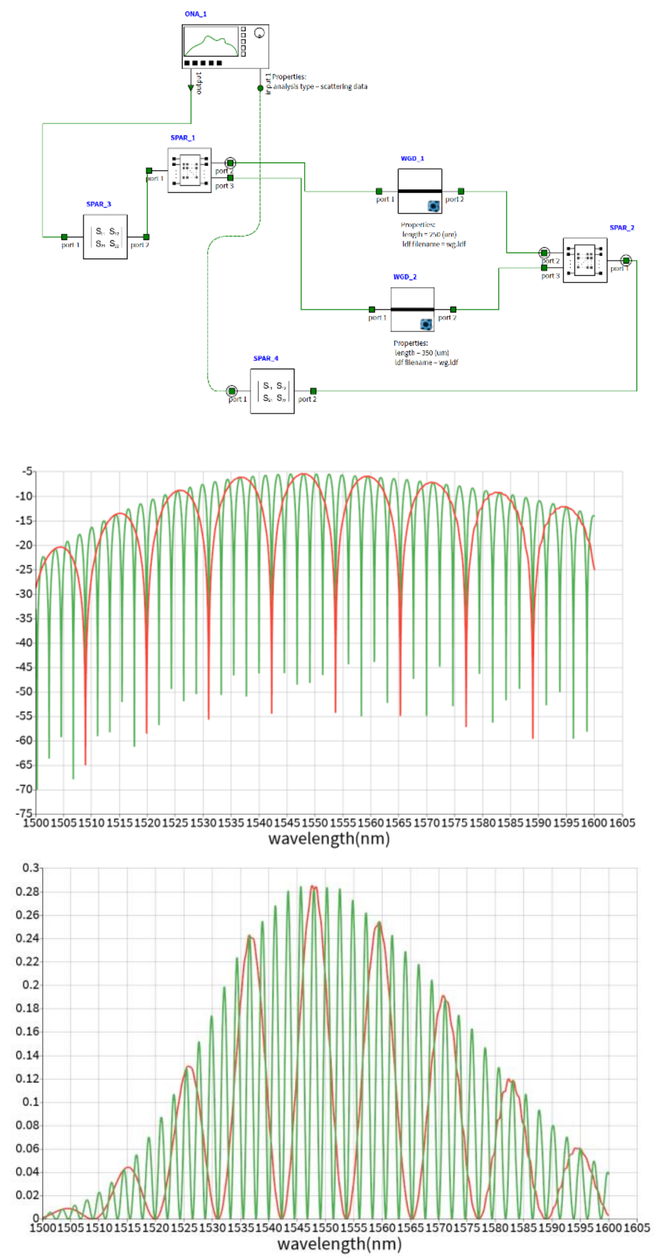

Fig. 3 Gain spectrum in dB (center) and transmission spectrum (bottom) of the MZI circuit (top) versus wavelength. The green curve is related to design 7 and the red curve to design 1 respectively.

The group index can be derived by rearrangement of the equation of the FSR for an unbalanced interferometer (see above). To obtain the FSR from the measurement data, one could perform a data fit, extract the peak points from the fit, and then calculate the FSR values from these.