# Design Proposal: Mach–Zehnder Interferometer

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## I. Introduction

The Mach–Zehnder interferometer (MZI) is a fundamental building block for integrated photonic systems, enabling filtering, switching, and phase modulation. This work investigates the design of unbalanced MZIs using compact waveguide models suitable for circuit-level simulation.

## II. Theory

### A. Transfer Function of an MZI

An MZI operates by splitting an input optical field into two paths of different lengths and recombining them at the output. Assuming lossless waveguides and identical splitting ratios, the output intensity is

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

where $I_i$ is the input intensity, $\beta = \frac{2\pi n_{\text{eff}}}{\lambda}$ is the propagation constant, $n_{\text{eff}}$ is the effective index, $\lambda$ is the wavelength, and $\Delta L$ is the path-length difference.

### B. Free Spectral Range

The free spectral range (FSR) is defined as the wavelength spacing between adjacent transmission maxima:

$$\text{FSR} = \frac{\lambda^2}{\Delta L\, n_g}, \tag{2}$$

where the group index $n_g$ is

$$n_g = n_{\text{eff}} - \lambda \frac{dn_{\text{eff}}}{d\lambda}. \tag{3}$$

where parameters $n_1, n_2$, and $n_3$ are are found to be $2.43361, -1.13284$, and $-0.394493$ respectively.

## III. Modelling and Simulation

Waveguide modes are characterized using an eigenmode solver. The effective index is fitted using a second-order Taylor expansion around a reference wavelength $\lambda_0$:

$$n_{\text{eff}}(\lambda) = n_1 + n_2(\lambda - \lambda_0) + n_3(\lambda - \lambda_0)^2. \tag{4}$$

## References

[1] L. Chrostowski and M. Hochberg, *Silicon Photonics Design*. Cambridge University Press, 2015.

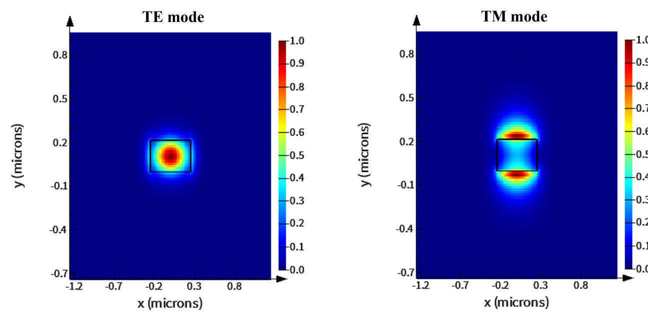


Fig. 1. Simulated mode profile.

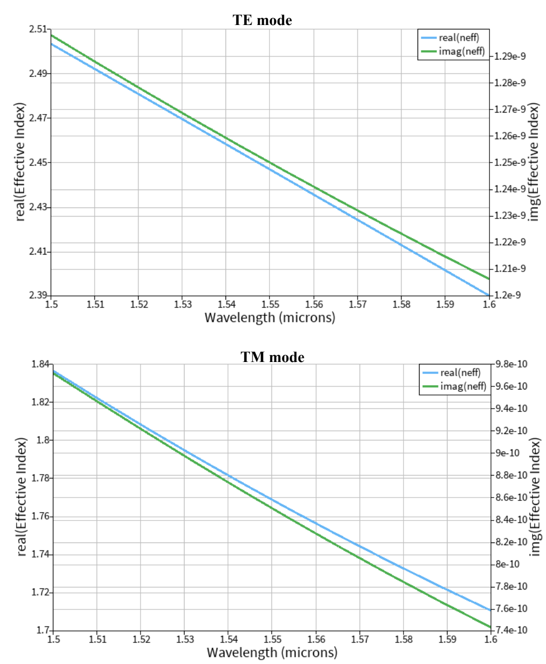


Fig. 2. Simulated fundamental modes effective index.

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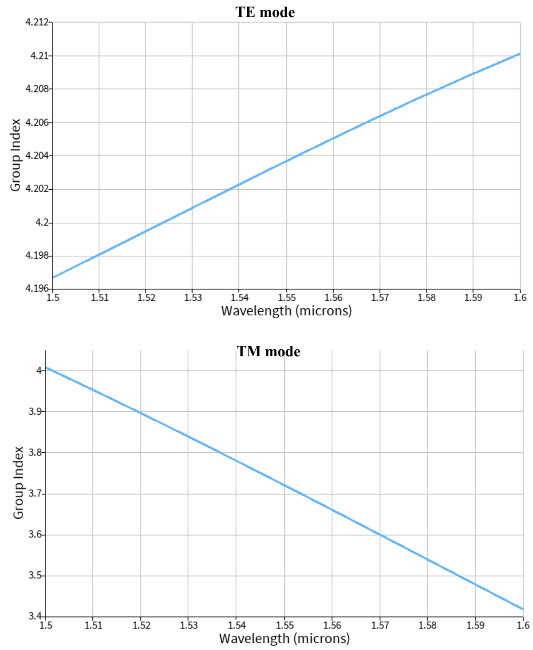


Fig. 3. Simulated fundamental modes group index.

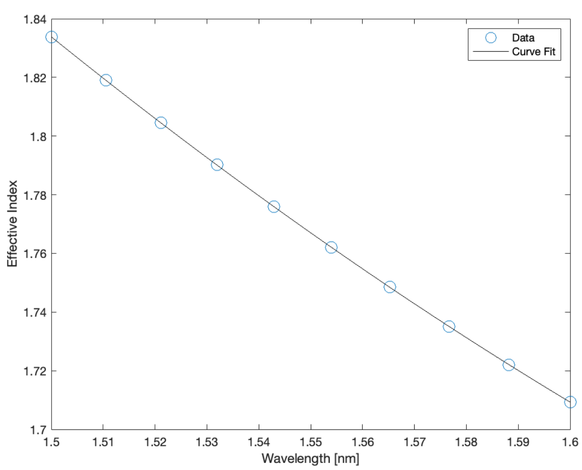


Fig. 4. Simulated compact model fitted effective index

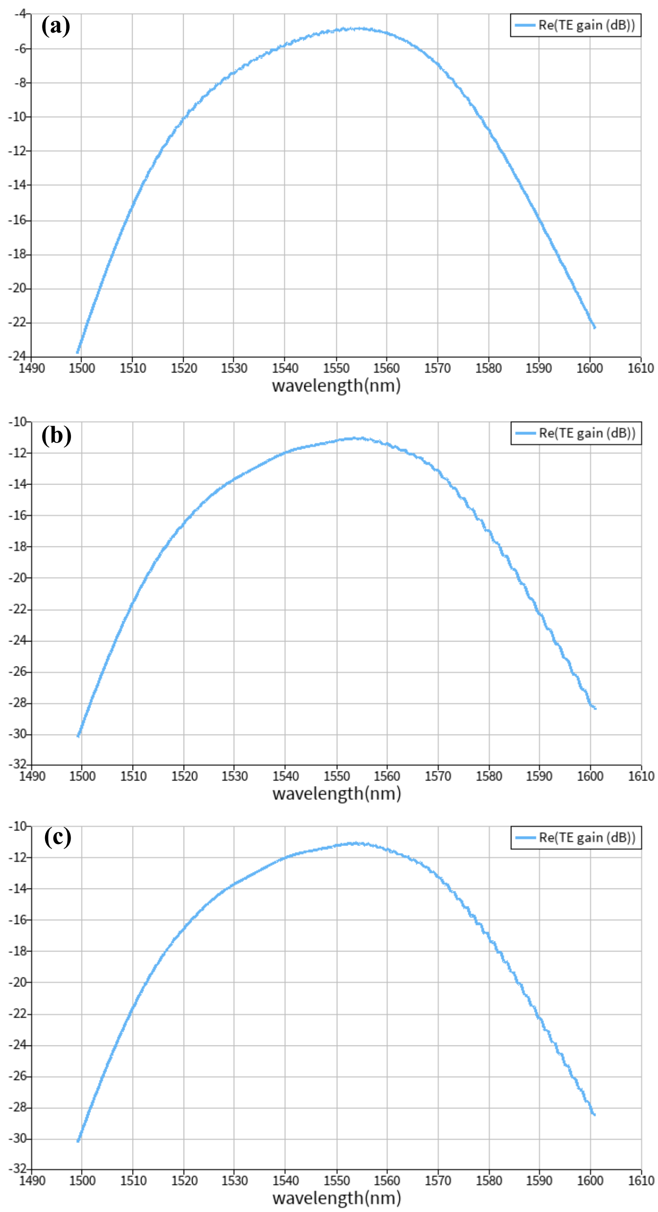


Fig. 5. Insertion loss reference spectrum of (a): grating coupler, (b),(c): y-branch splitter.

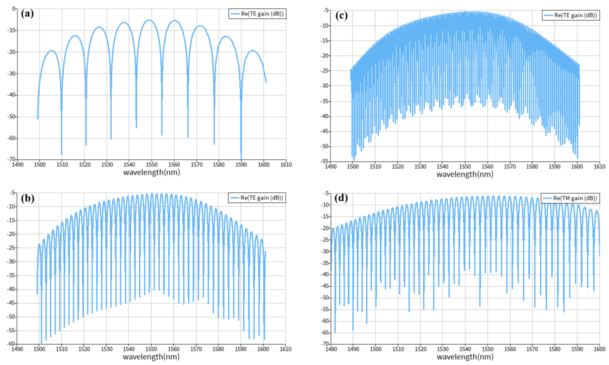


Fig. 6. (a),(b),(c): Y-branch splitter/combiner based MZI transmission for variable path length difference.

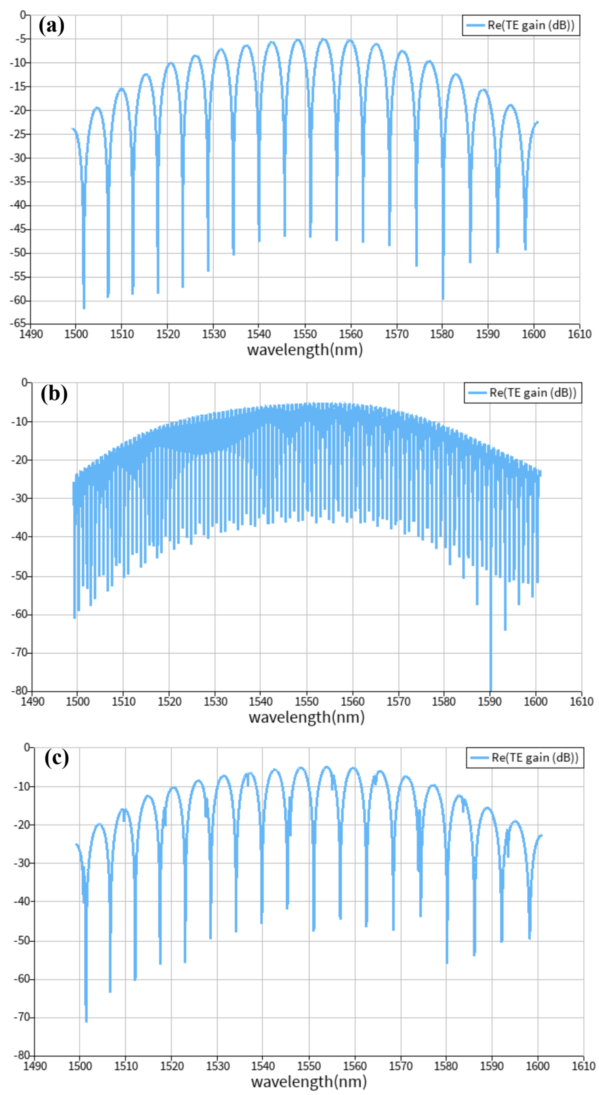


Fig. 7. (a),(b),(c): Y-splitter, broadband directional coupler, and ring resonator based MZI transmission.