Optical Filters Based on Casacaded Point-Symmetric Mach-Zehnder Interferometers

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Abstract — **A design method for cascaded point symmetrical MZI based WDM filters is reported. An MZI-WDM filter design is simulated and optimized to achieve < –1.5dB insertion loss and –20 dB crosstalk. Characterization results for the proposed MZI WDM ONU filter are discussed.**

Keywords: Mach-Zehnder Interferometer, WDM filter, point-symmetrical configuration.

I. Introduction

Wavelength-Division-Multiplexing (WDM) filters are essential components in Optical Network Units (ONU) for Fibre-To-The-Home (FTTH) networks. There is a variety of optical structures that can be used to realize WDM filters, such as wavelength add/drop filters, multimode interferometers, directional couplers and Y-branch splitters [1-3]. However for the FTTH application, the WDM filter is used to separate the upstream (1260nm-1360nm band) and downstream (1480nm-1500nm band) signals as described by the ITU-T standards [4]. The Broadband PON and Ethernet PON standards require filter channel insertion loss < 1.5 dB, unidirectional crosstalk < –10 dB and bidirectional crosstalk < –40 dB. Therefore an optical filter based on point-to-point symmetrically connected MZIs is particularly attractive due to the super-broad optical bandwidth and low crosstalk for both up- and down- stream directions. In this paper, the principle of point symmetrical connected MZIs is illustrated and an optimized novel WDM filter design based on cascaded MZIs is proposed.

II. Principle of Point-Symmetrical Connected MZIs

Figure 1 shows the configuration of a WDM filter composed of two point symmetrically connected MZIs. The transmittances of first MZI sub-circuit, the connecting waveguide sections and the second (identical) MZI sub-circuit are T_A, T_B, and T_C respectively. The overall transmittance of the full point-to-point symmetrically connected MZIs WDM filter is T expressed in Equation 1.

$$T=T_A\times T_B\times T_C \qquad \text{Equation 1}$$

where,

$$T_A=\begin{pmatrix} x & -y^* \\ y & x^* \end{pmatrix}, T_B=\begin{pmatrix} e^{-j\frac{\Delta\varphi_M}{2}} & 0 \\ 0 & e^{j\frac{\Delta\varphi_M}{2}} \end{pmatrix}, T_C=\begin{pmatrix} x^* & -y^* \\ y & x \end{pmatrix},$$

and x and y are the wavelength dependent complex transfer functions at the through and cross ports of the MZI sub-circuit respectively.

The coupling ratio of the complete filter photonic circuit, μ, is

$$\mu=4\eta(1-\eta)\cos^2\left(\frac{\Delta\Psi_M}{2}\right) \qquad \text{Equation 2}$$

where $\Delta\Psi_M=2\pi n\Delta L_M/\lambda$, λ is wavelength, η is the coupling ratio of the basic MZI and η = $|y|^2$ [5], which is expressed as

$$\eta=4\alpha(1-\alpha)\cos^2\left(\frac{\Delta\Psi}{2}\right) \qquad \text{Equation 3}$$

where $\Delta\Psi=2\pi n\Delta L/\lambda$, α is the coupling ratio of the directional coupler used in the MZI sub-circuit, ΔΨ is the phase shift resulting from the length difference of two arm waveguides (ΔL) in the MZI sub-circuit.

If the length difference of the waveguide arms connecting the two MZI sub-circuits is zero, i.e. ΔL_M=0 μm (i.e. $\Delta\Psi_M$=0), the transmittance matrix T of the full circuit reduces to:

$$T=\begin{pmatrix} |x|^2-|y|^2 & -2x^*y^* \\ 2xy & |x|^2-|y|^2 \end{pmatrix} \qquad \text{Equation 4}$$

It is clear that the phase components of x and y do not appear in the full circuit transmittance T. This gives the advantage of simplicity when designing point symmetrical MZI WDM filters.

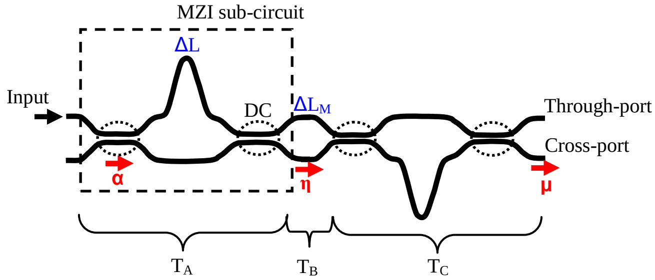

Figure 1. Configuration of WDM filter based on point-symmetrical connected MZIs.

III. Design of an Point-Symmetrical MZI WDM Filter

We have used this approach to design a WDM filter to demultiplex the 1310 nm wavelength band to the through-port and the 1490 nm band to the cross-port of a filter design similar to that in Figure 1. The waveguides are designed with refractive index difference Δn = 0.003 at 1490 nm wavelength, equivalent to the index step of a commercially available polymer system, and a core size of 9 μm × 9 μm. The design process was as follows:

1. In order to obtain $\mu=0$ at $\lambda_{th}=1310$ nm (i.e. at the through-port), η could be set to either 0 or 1 according to Equation 2. Here we use $\eta=0$ as an example. To set $\eta=0$ in Equation 3, ΔL is set so that $\Delta\Psi/2=\pi, 3\pi, 5\pi, 7\pi$...

2. To obtain $\mu=1$ at $\lambda_{cr}=1490$ nm (i.e. at the cross-port), η is required to be as close to 0.5 as possible. We find the DC coupling ratio α at $\lambda_{cr}=1490$ nm, by using the ΔL obtained from condition 1.

3. By trial and error, we find that when $\Delta\Psi/2=7\pi$ at $\lambda_{th}=1310$ nm, the physical length difference ΔL is 3.06 μm, which results in the coupling ratio of the MZI sub-circuit being $\eta=0$ regardless of the DC coupling ratio α at $\lambda_{th}=1310$ nm. Consequently $\mu=0$ at $\lambda_{th}=1310$ nm at the through-port is obtained. Meanwhile, at $\lambda_{cr}=1490$ nm, for the length difference $\Delta L=3.06$um in the basic MZI circuit and $\eta=0.5$, the DC coupling ratio is approximately 0.8. This results in $\mu=1$ at $\lambda_{cr}=1490$ nm at the cross-port.

4. By using the FIMMWAVE software package to obtain the parameters of the simulated directional couplers and MZIs, the optimized deign of the point symmetrically connected MZI WDM filter is shown in Table 1.

DC gap	DC coupling length	Length difference ΔL	Length difference ΔL_M
7 μm	5000 μm	3.06 μm	0 μm

Table 1. Summary of the optimized point symmetrical MZI WDM filter design.

IV. Simulation Results for the Optimised Point-Symmetric MZI WDM Filter

The simulation work is carried out by utilizing a 3D mode solver, based on the film mode matching method within the FIMMWAVE software package, to find all modes in the waveguide and then FIMMPROP is employed to simulate the 3D optical propagation in the MZI device based on the beam propagation method.

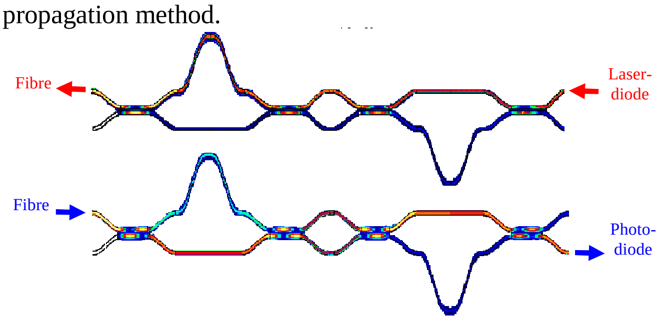

Figure 2. Optical light field intensity plots at $\lambda_{th}=1310$ nm (upper) and $\lambda_{cr}=1490$ nm (lower) of the proposed MZI WDM filter.

It can be seen from the light intensity plots in Figure 2 that the optimized WDM filter based on point symmetric MZIs proposed in Table 1 passes the upstream 1.31 μm wavelength at the through-port and the 1.49 μm downstream signal at the cross-port.

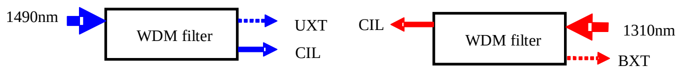

Figure 3. Illustration of unidirectional crosstalk (UXT) and bidirectional crosstalk (BXT) in optical filter.

The channel insertion loss (CIL), unidirectional crosstalk (UXT) and bidirectional crosstalk (BXT) are defined in figure 3. The wavelength dependent transmission of the optimized point symmetrical MZI WDM filter is shown in Figure 4. The shadowed areas show the 1260 – 1360 nm and the 1480 – 1500 nm wavelength windows defined in the ITU standard. The channel insertion loss within both wavelength ranges is less than –1.5 dB, and the unidirectional crosstalk is as low as –20 dB. The bidirectional crosstalk is lower than –40 dB.

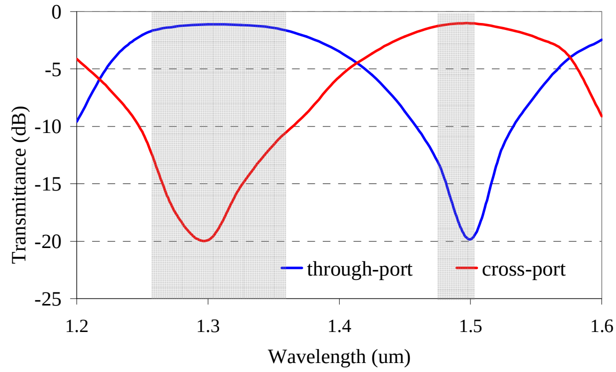

Figure 4. Optical spectrum of the proposed MZI WDM filter with point symmetrical configuration. The shadowed areas show the ITU specified 1310nm upstream window and 1490nm down stream window.

V. Conclusion

The method of cascaded MZIs WDM filter with point symmetrical configuration is demonstrated. Furthermore, the proposed WDM filter design shows less than –1.5 dB insertion loss and –20 dB crosstalk across the broad up-/down-stream wavelength windows. The performance meets the requirements of the ITU-T standards for ONUs.

Acknowledgment

The authors would like to acknowledge the support of Dow Corning Corporation, for the STOIC research project, and of the Engineering and Physical Sciences Research Council (EPSRC).

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