Design of All Pass Filter based All Optical Modulation Format Conversion with Dispersion Compensation

Prakash Poornachari[1*], Arul Prakash Samathuvamani[1], Ganesh Madhan M[1]

[1]*Madras Institute of Technology, Anna University, Chromepet, Chennai-44*

[1]*prakashp79@gmail.com*, [1]*arul2810@gmail.com*, [1]*ganeshmadhan@yahoo.com*

Abstract

A design of All Pass Filter (APF) is proposed to be used as optical delay line to construct all optical multi-level modulation format conversion. The All Pass Filter design principle is utilized to perform modulation conversion from BPSK to QPSK and 16 QAM. Further, Dispersion Compensation properties of All Pass Filter is investigated under both Pre and Post compensation schemes. With APF, 30% improvement is seen for BER when compared with other compensation techniques.

Keywords: Digital Modulation, BPSK, QPSK, 16 QAM, Dispersion, Optical Delay, Dispersion Compensation, All Pass Filter.

1. Introduction

Today's high-speed data transmission is implemented using optical fibers. However, Fiber Optic transmission is affected by dispersion and hence limits the distance of fiber transmission. Dispersion causes pulse broadening due to which transmitted bits get distorted. Hence for high data rate optical transmission, dispersion compensation techniques are employed.

In digital modulation, Phase Shift Keying (PSK) is a process in which the phase is varied in accordance with the data that is being transmitted. Different PSK techniques based on the number of phase variations are commonly used in coherent optical communications. Binary Phase Shift Keying (BPSK) is used to transmit 1-bit digital data and has two phases separated by π. Quadrature Phase Shift Keying (QPSK) contains four phases separated by $\pi/2$. QPSK represents symbol with 2-bits of data. Any number of phase change can be used to construct a PSK signal, but as the number of phase representation increases the Bit Error Rate also become higher. In the case of 16-QAM, 16 phase points are utilized.

These modulation formats are the backbone of modern high-speed digital data transmission as this provides high capacity and spectrum efficiency. The modulation formats are deployed based on channel capacity. All-optical modulation format conversion enables flexibility in the usage of modulation format according to requirements and results in efficient use of fiber network.

Various techniques are available for optical modulation format conversion and dispersion compensation. In this work, a design of All Pass Filter based on delay line to perform all-optical flexible modulation format conversion from BPSK to QPSK and 16 QAM is presented. Further, the same All Pass Filter design is investigated for dispersion compensation in a10 GBPS, 1550nm PSK signal transmission over 50 km single mode optical fiber.

*Corresponding Author

2. Design of All Pass Filter

In electronic circuits, All Pass Filters have been used as phase equalizers. The amplitude response of All Pass Filter is constant over all the frequencies, however the phase varies depending on the frequency.

The normalized group delay of All Pass Filter is given by, [1]

$$\tau(\omega) = \sum_{i=0}^{N-1} \frac{\sinh\chi_i}{\cosh\chi_i - \cos\delta_i} \tag{1}$$

Where $\delta_i=\omega-\theta$ and χ_I is coupling coefficient. As δ varies from $\pm\pi$ to 0, the group delay varies from minimum to maximum.

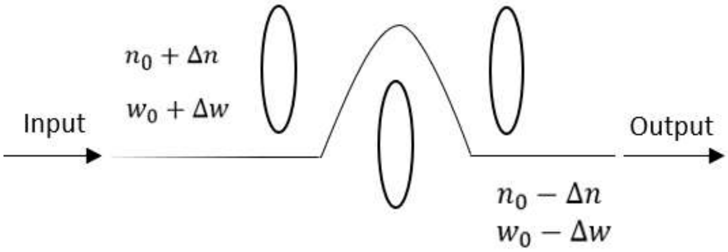

Figure. 1. Balanced SCISSOR three stage All Pass Filter.

Two basic design approaches for delay line based on coupled resonators are reported in the literature. They include Coupled Resonator Optical Waveguides (CROWs) and Side-Coupled Integrated Spaced Sequence of Resonators (SCISSORs). CROW's based on coupling of optical resonators consists of sequence of coupled high-Q resonators [2].SCISSOR's comprises of a sequence of waveguide coupled resonators. The resonators in SCISSOR are close to waveguides in order to achieve evanescent coupling but at the same time they are far enough from one another such that direct resonator to resonator coupling is negligible [3].CROW structures have been implemented in many devices, but much longer delay is possible by using SCISSOR structure. The spread of resonator parameters due to fabrication in CROW devices causes reduction in performance due to localization. Figure.1 shows the structure of "Balanced SCISSOR", where as in normal SCISSOR structure, the resonant frequency of the rings is shifted up by a factor of $\Delta\omega$. Long tunable delays of wide bandwidth can be achieved through "Balanced SCISSOR". In this structure, one half of the rings have their resonant frequency shifted up by a factor of $\Delta\omega$ and resonant frequency of other is down shifted by the same factor. By changing the refractive index of the rings, the delay of the system is altered. The spectra of upper ring and lower ring are given by $T_d(\omega+\Delta\omega)$ and $T_d(\omega-\Delta\omega)$ respectively. The resultant delay is given by $T_d = (T_d(\omega-\Delta\omega))/2 + (T_d(\omega+\Delta\omega))/2$ [4].

The waveguide is created on a z-cut wafer of Lithium Niobate with surrounding cladding material as air, which is oriented along y-optical axis of wafer. Thickness of the substrate and cladding are 10µm and 2µm respectively. The wafer is crystal cut at z-direction and the signal propagation is along y-direction. The three stage All Pass Filter consists of linear wave guide and s-bend waveguide, where the rings are arranged in zig zag manner.

The group delay of three stage cascaded All-Pass Filter is given by, [5]

$$\tau(\omega) = \sum_{i=0}^{3} T_i \frac{\sinh\chi_i}{\cosh\chi_i - \cos(\omega T_i + \theta_i)} \tag{2}$$

Where T is round trip delay in the cavity of the filter.

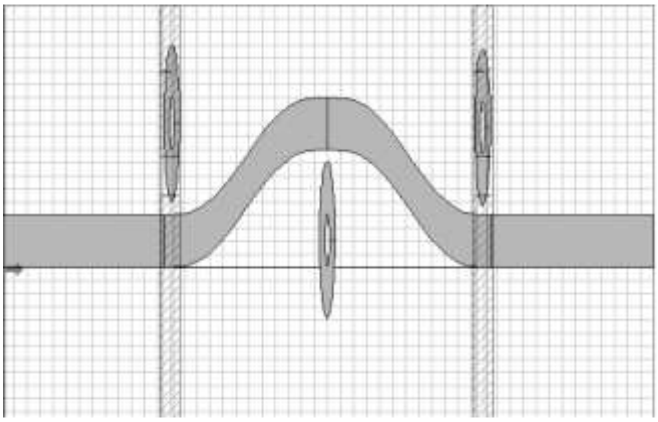

Figure. 2. Waveguide design of three stage APF using OptiBPM.

3. Modulation Format Conversion using All Pass Filter

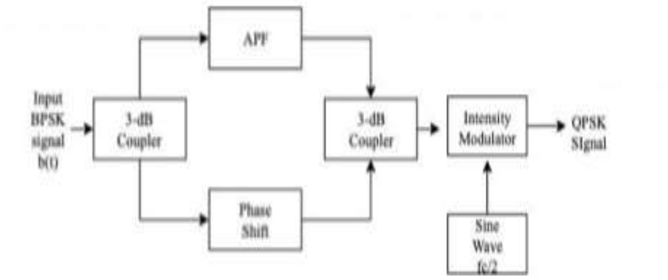

Figure. 3. Structure of BPSK to QPSK converter using APF whose delay is ∆T.

Various authors have reported on all optical modulation format conversion [6,7]. Figure 3. shows the basic schematic diagram of modulation format conversion from BPSK to QPSK using All Pass Filter. The All Pass Filter provides the optical delay necessary to perform modulation format conversion. The binary input is converted into NRZ pulse ‘V’ of frequency ‘f’, which is then converted into optical signals with help of MZ modulator by using CW laser as input source. The optical signal is given by $\sum_i V_i e^{j\emptyset_k}$,

Where, $e^{j\emptyset_k}$ is the phase difference introduced between two arms of the MZ modulator. The output from two arms of 3-dB coupler is given by, $\frac{1}{\sqrt{2}}V_i e^{j\emptyset_k}$ and $\frac{-j}{\sqrt{2}}V_i e^{j\emptyset_k}$ respectively. The upper arm provides a delay of ∆T where T is inverse of frequency of message signal. The signal in lower arm provides phase shift of$\frac{\pi}{2}$. The signals are then combined using 3-dB coupler and the output is given by,

$$\frac{1}{\sqrt{2}}V_i e^{j\emptyset_{k-1}} + \frac{1}{\sqrt{2}}V_i e^{j\emptyset_k + \frac{\pi}{2}} \quad (3)$$

Figure 4. Shows the schematic diagram of modulation format conversion from QPSK to 16 QAM using All Pass Filter. The QPSK signal is split into two equal halves by a 3-dB coupler. The upper arm of the signal is delayed by a factor of ∆T by All Pass Filter where T is inverse of frequency. The signal from the lower arm is attenuated to half of its

original value and is also phase shifted. The signals from both the arms are combined and is then passed through intensity modulator, driven by a sine wave of frequency half the value of carrier frequency.

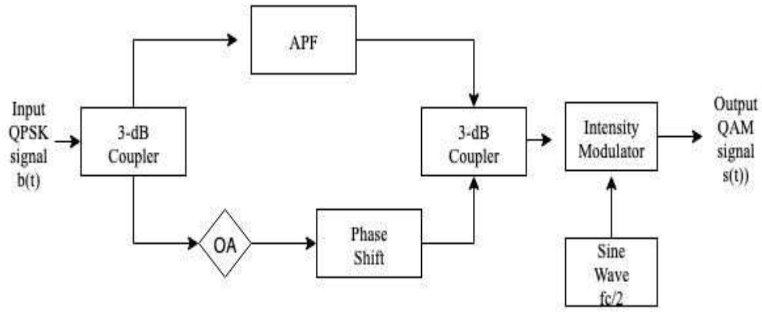

Figure. 4. Schematic diagram of modulation format conversion from QPSK to 16-QAM

All optical conversion from BPSK to QPSK and 16-QAM, using All Pass Filter is performed. Various authors have reported schemes based on optical delay techniques [8]. In this work we simplify the system by using All Pass Filter for both format conversion and dispersion compensation in a 1550nm SMF link.

Different techniques are available for dispersion compensation. Among them pre and post transmission compensation techniques are investigated. However, post compensation method has been found efficient in compensating dispersion [9]. Quadratic dispersion is the reason for ISI and pulse broadening. The derivative of group delay with respect to frequency is defined by quadratic dispersion. For a single stage APF, quadratic dispersion will lead to maximum delay. Dispersion is related directly to the number of stages of APF and inversely with FSR and distance of poles and zeros from unit circle. In post compensation, All Pass Filter is placed next to fiber link, as it has positive compensation.

4. Dispersion Compensation Using APF

Ring response of a multi-stage All Pass Filter is given by, [10]

$$H(z) = e^{j\phi}\frac{\tau e^{-j\phi} - z^{-1}}{1-\tau e^{j\phi} z^{-1}} \quad (4)$$

Where, $\tau=\sqrt{(1-k)}$ and k is coupling coefficient. The free spectral range for ring based All Pass Filter is given by, FSR= c / ($n_e 2\pi R$) where R is radius of the ring and n_e is effective refractive index. N is the number of rings and ρis the round trip delay. The group delay of the SCISSOR structure can be given by,

$$T_d(\omega) = T_{d_0} - N\,\beta_3(\omega-\omega_r)^2 + N\,\beta_5(\omega-\omega_r)^4 + .. \quad (5)$$

At resonance, the delay is given by, T_{d0}, which is given by,

Nρ(1+t)/(1-t). $\beta_3 = \rho^3 t(1+t)/(1-t)^3$ and $\beta_5 = \rho^5 t(1+t)(1+10t+t^2)/12(1-t)^5$, are for higher GDD per ring. On a balanced SCISSOR structure, delay of 10ns is obtained by using ρ = 0.2 ns with coupling co-efficient of k = 0.25. The filter co-efficient all pass filter is given by,$H(z)=0.866 + 0.75z^{-1} + 0.649z^{-2}+0.5624z^{-3}+0.48706z^{-4}$

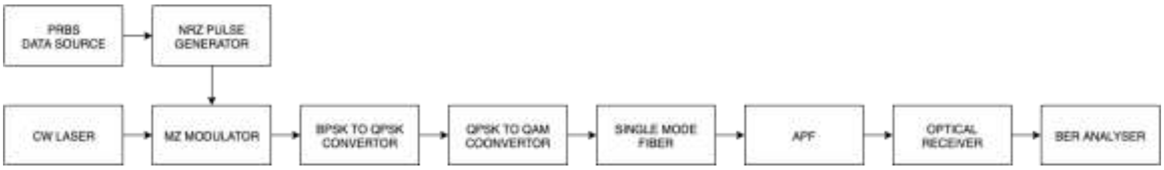

Figure. 5. Schematic diagram for modulation conversion along with dispersion compensation.

BPSK to QPSK conversion is explained in Figure.3 and QPSK to 16-QAM conversion is indicated in Figure.4. The All Pass Filter design has been designed using OptiBPM as discussed in Figure.2.

5. Result and Discussions

A 10 Gbps Pseudo Random Binary Source (PRBS) is coded into NRZ pulse, which is then converted into BPSK signal by modulating with a carrier sine wave of frequency f_c. The BPSK signal is converted into QPSK signal followed by QPSK to 16-QAM conversion. The signal is then passed through single mode fiber of length 50 km to analyze dispersion compensation properties of All Pass Filter. Q-Factor is analyzed under both post and pre compensation schemes. Further BER calculation also made of a 50Km SMF link, under 16 QAM transmission. Figure.5 shows APF used in post compensation. Figure. 6. shows BPSK spectrum before format conversion and Figure. 7. shows QPSK and 16-QAM spectrum. Format conversion has been employed with variety of techniques. However, most of them use non-linear methods. By employing linear approach using optical super-position by delaying the signal using APF, received power is improved by 30dbm and BER is comparable to other format conversion techniques. By employing APF, the need for a separate component for dispersion compensation can be also mitigated. The dispersion compensation properties of APF is discussed below.

The dispersion of the single mode fiber is fixed as 16.75ps/nm/km with differential delay of 0.2ps/km, for simulation purposes. Q-Factor of the signal is calculated from BER in order to analyze the quality of the received signal. Q-Factor of the signal using 4 port coupler-based dispersion compensation is 5.4 [11]. Q-Factor of the signal without using APF at receiver end is 5.4 which is comparable to 4 port coupler based pre compensation. By using APF at receiver end to perform post compensation, the Q-Factor of signal is improved to 6.7 with eye height of 2.38 $e^{(-005)}$.Moreover, the Q-factor obtained using other post dispersion compensation techniques is found to be around 4.7. 30% improvement is seen when All Pass Filter is used for dispersion compensation. Table.1 shows dispersion compensation performance when using APF for modulation format conversion with Pre and Post compensation techniques. In Pre compensation technique, the All Pass filter for format conversion is also used for dispersion compensation. In post compensation, the signal from the fiber is sent into an All Pass Filter before detector. This is compared with All Optical modulation format conversion without the use of All Pass Filter [12].

Table.1 Comparison of Dispersion Compensation

Scheme	Min. BER
APF with Pre Compensation	10^{-08}
APF with Post Compensation	10^{-12}
Without using APF	10^{-05}

Table.1. Shows dispersion compensation properties when performing all optical modulation format conversion. The results show that All Pass Filter can be used to perform dispersion compensation with results better than other dispersion compensation techniques with only limitation being optical loss.

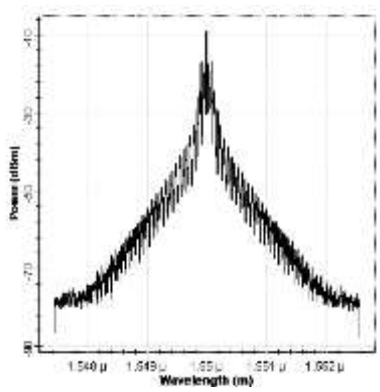

Figure. 6. BPSK spectrum

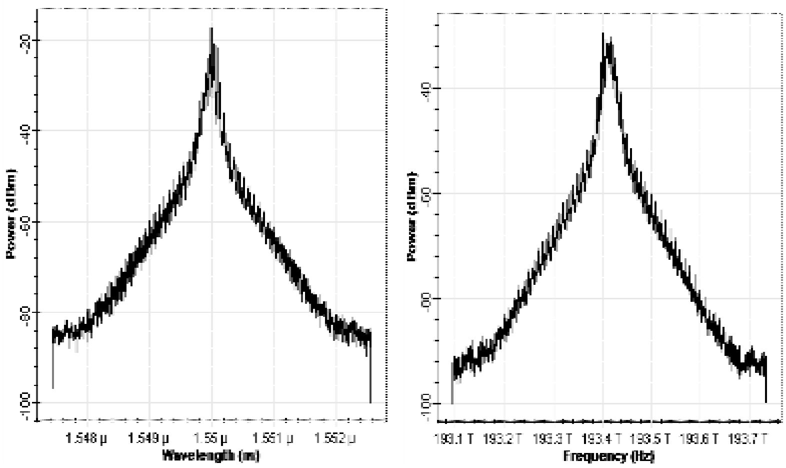

Figure. 7. Spectrum of QPSK and 16-QAM after modulation format conversion using APF.

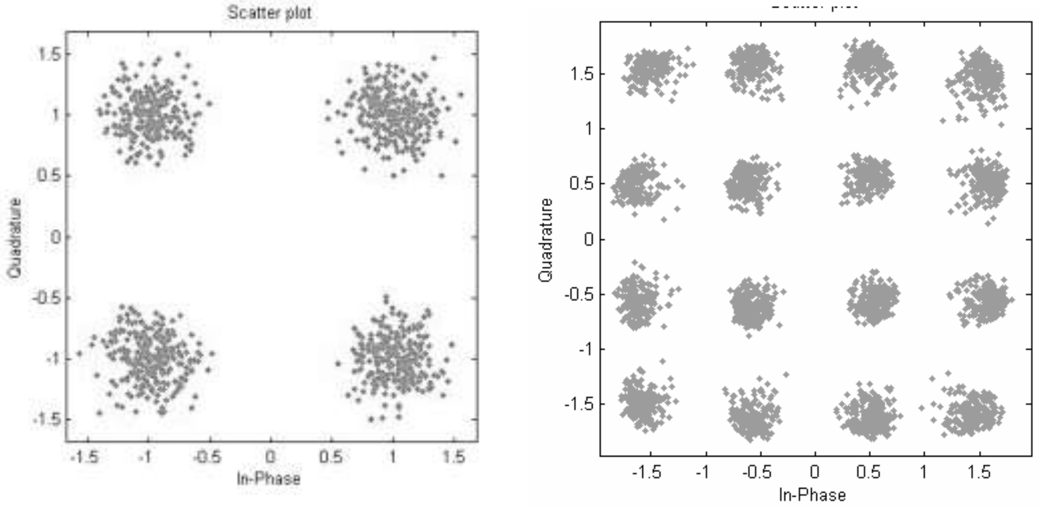

Figure.8. Constellation diagram of QPSK and 16-QAM signals after modulation format conversion using APF

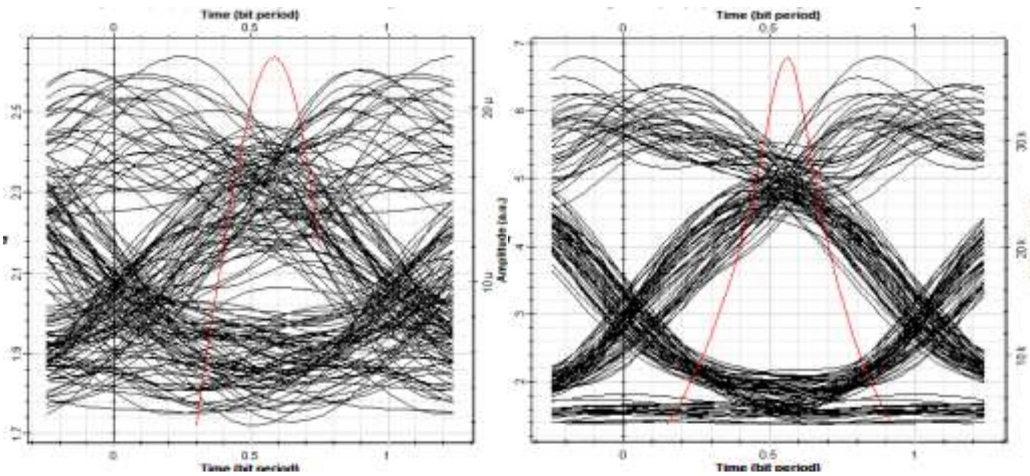

Figure. 9. Eye diagram without dispersion compensation and after dispersion compensation.

5.Conclusion

In this work, an All Pass Filter design is presented to perform optical delay for modulation format conversion. Dispersion compensation properties of All Pass Filter is also analyzed. Such systems open a new world of flexibility to designers. By employing APF for modulation format conversion, received power is improved and BER is comparable with other conversion techniques. Further APF can be employed for pre dispersion compensation and thus reduce the number of components. The minimum BER during pre-composition and post compensation is improved by 30%.

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