Abstract: An acousto-optic tunable switch (AOTS) can provide highly selective wavelength switching and wavelength routing in optical DWDM systems. This paper presents the basic concept of AOTS and a simple analysis of the phase mismatch and wavelength deviation in WDM systems using acousto-optic tunable filters (AOTF). Numerical results for phase mismatch and wavelength deviation have also been presented.

Index Terms: Acoustooptic, channel, filter, polarization, tunable, wavelength.

I. INTRODUCTION

The telecommunication networks of today have taken a long journey from an analog switched to a digitally switched network and now in the process of becoming an optically switched network [1]. The Wavelength Division Multiplexing (WDM) and photonics switching technologies used in today’s networks have resulted in very fast optical communication systems. The acousto-optic tunable switch (AOTS) has become the backbone of these high speed DWDM networks. The AOTS can be used as a multi-state WDM switch. For doing so, a single 2 X 2 switching element is placed into the cross state to select an arbitrary subset of WDM channels and in the bar state for other channels. It is important to note that the locations of the WDM channels using AO-switch based WDM routers, are arbitrary. Other important points are that the WDM access node switch should be independent of polarization state, it should provide high extinction digital switching characteristic, and must have switching time in the nano-second range to be suitable for packet switching applications [2],[3], [4], [5]. This paper discusses the basic concept of AOTS in brief, inter-channel interference effects, the analysis of phase mismatch and wavelength deviation in WDM systems with simulation results.

II. BASIC CONCEPT AND BRIEF ANALYSIS OF AOTS

As shown in Fig.1, an acousto-optic tunable switch is a variation of the acoustic-optic tunable filter (AOTF) but is independent of any polarization effects [6]. The narrowband

Fig. 1 (a) AOTF as a TE-TM polarization –conversion filter, resonant with \( \lambda_3 \), (b) Integrated polarization splitter, (c) polarization diversity AOTF in the passive, or bar, state, and (d) in the active, or cross, state.
polarization converter as shown in Fig 1(a) is the main element of AOTS. This element converts the polarization component TE (h) to TM (v) or vice versa of the incoming resonant signal [7]. In a collinear AOTF, the birefringence results in the polarization transformation between TE and TM polarization states. A complete polarization transformation i.e TE to TM or vice versa is obtained for a sufficient interaction length for acoustic and optical signal to create enough signal strength. It means that the selection of the interaction length is very important for complete mode transformation. For coupling it is also necessary that the phase of acoustic waves is close to the phase difference between TE and TM modes [2]. This phase matching condition is necessary as the two polarization states propagate with different velocities. The signal at the input is decomposed into TE and TM modes using a polarization splitter as shown in Fig. 1(b). The other advantage of the polarization splitter is that it provides freedom from polarization effects and spatial switching using a single device. As shown in Fig. 1(c), if the signal corresponding to a particular wavelength is resonant, the recombined output is directed to the cross state while under non-resonant condition the recombined output is directed to the bar state. If the system has polarization symmetry it can be used as reciprocal device. For acousto-optic phase matching, the phase difference between TE and TM modes is related to the acoustic grating period \( \Lambda \) as

\[
|\beta_{TE} - \beta_{TM}| = 2\pi / \Lambda
\]

(1)

The device interaction length \( L = \Lambda \) for proper matching which also requires that \( L = c / \Delta n \), where \( \Delta n \) is the material birefringence.

Finally from the phase matching condition, the acoustic frequency to optical frequency scale factor is obtained as [2]

\[
F_s = \left( \frac{v_s}{c} \right) \Delta n f_0
\]

(2)

where \( F_s \) and \( v_s \) are the frequency and velocity of the acoustic wave, \( f_0 \) and \( c \) are the frequency and velocity of light signal, respectively. As mentioned before, the detailed analysis and experimentation of pass-band shape, transmission function and cross talk of AOTS has been carried out by Smith et al. [2]. These researchers have compared the sinc-squared function detuning from the resonance for cross and bar states in terms of relative power in dB and wavelength detuning in nm for a conventional AOTF and a hybrid AOTF with improvements. Accordingly, in a conventional collinear-optic filter the side lobes are fairly high in magnitude. This poses two serious problems for WDM application: wavelength misalignment tolerance and cross-talk. As suggested by Qin et al. [8] the side lobes can be suppressed upto 33 dB by selecting a low RF drive power (about 20 mW) in a collinear beam interaction acousto-optic tunable filter. In [2] the authors have also defined the desired flat transmission response of AOTS in terms of \textit{rectangularity} function \( \tau \) for a given crosstalk level for cross and the bar states. The minimum channel separation for a given crosstalk level \( c \) is given by [2]

\[
\Delta\lambda_{sep}(c) = \frac{1}{2} \left[ \Delta\lambda_{bar}(c) + \Delta\lambda_{cross}(c) \right]
\]

(3)

where \( \Delta\lambda_{bar}(c) \) and \( \Delta\lambda_{cross}(c) \) are the filter widths for bar and cross states, respectively.

The \textit{rectangularity} \( \tau \) has been defined as the ratio of wavelength misalignment tolerance to the minimum channel separation given as [2]

\[
\tau(c) = \frac{\Delta\lambda_{tol}(c)}{\Delta\lambda_{sep}(c)}
\]

(4)

where \( \Delta\lambda_{tol}(c) \) is wavelength misalignment. It states how close the transmission function is to the desired rectangular function having the ideal value as unity. But in practice it is not possible to get the unity value.

The crosstalk in WDM arises from the fact that the signal from a particular channel filters in the neighboring channels which is highly undesirable. For this reason it is very important that the side lobes be as small as possible.

This also puts the limitation on the channel bandwidth. The cross talk in this device can be divided as acoustic crosstalk, inter-channel cross talk and coherent crosstalk. Out of these three, the coherent cross talk is the most severe one as it falls in the same wavelength channel as the desired signal, and thus cannot be removed as discussed in [9], [10]. Therefore the pass band should be as flat
as possible which is possible only when the side-lobe level is very low. Jackel et al. have suggested a very effective technique for pass band flattening [11]. The technique to reduce crosstalk among various channels is known as wavelength dilation which has been discussed in detail in [2], [12], [13], [14].

III. POLARIZATION MISMATCH

As mentioned in section 2, complete phase matching in collinear acousto-optic filter is obtained when the polarization beat length, \( L_b = \lambda / \Delta n \), is equal to the acoustic grating period \( \Lambda = v_s / f_s \) with \( v_s \) and \( f_s \) as the acoustic signal velocity and frequency, respectively. As the polarization beat length is dependent on \( \Delta n \), i.e. the waveguide index birefringence, the waveguide shape, diffusion history and metallization are important considerations to obtain complete phase matching condition. Based on these factors, the phase mismatch per unit length is given by [2]

\[
\Delta \phi = 2\pi \left( \frac{\Delta n}{\lambda} - \frac{f_s}{v_s} \right)
\]

(5)

It can further be given in terms of the reference wavelength \( \lambda_0 \) and a mean acoustic velocity \( V_s \) as [2]

\[
\Delta \phi = -2\pi \left( \frac{\Delta \lambda}{L_b \lambda_0} - \frac{\Delta V}{\Lambda \lambda_0 V_s} \right)
\]

(6)

The phase mismatch per unit length for 1500 – 1600 nm range is plotted in Fig. 2. Here \( V_s \) has been considered to be 3.7 km/s, \( L_{bo} = 20 \mu m \) and \( f_s \) is taken to be 175 MHz i.e. similar to [2].

From Fig.2 we observe that as the channel wavelength increases the phase mismatch decreases. Also the phase mismatch has a linear relationship with the wavelength.

IV. NORMALIZED CHANNEL SEPARATION AND WAVELENGTH DEVIATION

The important parameters to be considered for the analysis and determination of transmission characteristics of AOTS are channel separation and bandwidth of the acousto optic mode converter used in the device. The normalized channel separation is given by [15]

\[
NS = \frac{\lambda_2 - \lambda_1}{FWHM_{\lambda}} = \frac{\Delta \lambda}{FWHM_{\Omega}}.
\]

(7)

where \( \lambda_1 \) and \( \lambda_2 \) are the center wavelengths of the two consecutive channels and the corresponding SAW frequencies for obtaining phase matched condition are \( \Omega_1 \) and \( \Omega_2 \), respectively, FWHM\( \lambda \) is the full width at half maximum of the transmission bandwidth \( \Delta \lambda \) if operated only with one acoustic wave at a fixed frequency. At the same time FWHM\( \Omega \) is the full width at half maximum for acoustic frequencies. Now the normalized wavelength deviation can be obtained as [15]

\[
ND = \frac{\delta \lambda}{FWHM_{\lambda}} = \frac{\delta \Omega}{FWHM_{\Omega}}.
\]

(8)

where \( \delta \lambda \) is the deviation of the wavelength from the wavelength at which complete phase matching condition is obtained for the acousto optic interaction with the SAW at \( \Omega_1 \) and \( \delta \Omega \) is the corresponding frequency deviation of the SAW frequency from \( \Omega_1 \). The full width half maximum is given by [7].
\[ \Delta \lambda_{\text{FWHM}} = \frac{0.80 \lambda_0^2}{\Delta n L_{b0}}. \]  \hspace{1cm} (9)

where \( L_{b0} \) is the interaction length of AOTF.

The plot between the wavelength and the normalized wavelength deviation is shown in Fig. 3 for a wavelength variation from 1.550 \( \mu \text{m} \) to 1.560 \( \mu \text{m} \). It is observed that it is a linear relationship and the wavelength deviation is increased with the wavelength while lower value of phase mismatch is obtained at higher wavelength. This requires a trade off between these two characteristics of AOTS. Further the bit error rate (BER) of AOTS can be given by [15]

\[ BER = \frac{1}{2} \text{erfc} \left( \frac{P_d - P_{\text{cross}}}{P_{\text{noise}}} \right). \]  \hspace{1cm} (10)

with \( P_d \) and \( P_{\text{cross}} \) are the transmitted power of the desired and cross talk signals, respectively.

V. CONCLUSION

A simple AOTF for WDM switching in the form of AOTS has been discussed in brief. The necessary requirements for complete phase matching condition and minimum wavelength variation have been presented. The importance of flat response with minimum value of the side lobes has been discussed. Some numerical results for phase mismatch and wavelength variation have also been presented.

REFERENCES


