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Authors	Riza, Nabeel A.;Yaqoob, Zahid
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High-Speed Programmable Optical Attenuator

Nabeel A. Riza* and Zahid Yaqoob

Photonic Information Processing Systems (PIPS) Laboratory
The School of Optics/Center for Research and Education in Optics and Lasers (CREOL)
University of Central Florida, 4000 Central Florida Blvd, Orlando, FL 32816-2700
Tel: 407-823-6829; Fax: 407-823-6880
E-mail: riza@creol.ucf.edu

ABSTRACT

A high-speed programmable optical attenuator (POA) is introduced that can provide high dynamic range and high resolution attenuation control. An acousto-optic Bragg cell has been used to realize the desired attenuator. Various practical architectures have been proposed to prove the concept. A typical acousto-optic deflector (AOD) based design offers a dynamic range of 46.11 dB. The average resolution is 3.08 dB/volt whereas the best resolution achieved is 0.39 dB/volt. The response time of the AO attenuator is in the sub μs regime, and was observed as low as 0.175 μs. The polarization dependent loss (PDL) was about 0.7 dB, whereas the excess losses were about 1.5 dB.

1. INTRODUCTION

Variable optical attenuators play an important role in fiber optic transmission systems. They can be used for power equalization between different channels of a WDM system. Gain flattening of Erbium doped fiber amplifiers is another significant application. An optical attenuator is also an important test and measurement tool. Typical applications are simulating the loss induced by an optical device and bit error rate testing (BERT) which can be a very crucial factor for high speed digital communication links. So far, different types of attenuators have been realized but there are a limited number of practical candidates for continuously variable optical attenuators. Sliding block mechanical attenuators have excellent optical characteristics but they adjust very slowly, in 0.5-1 s. Waveguide thermo-optic attenuators have better response time (e.g., in ms) but they do not offer good dynamic range [1,2]. MEMS reflective optical attenuators offer good dynamic range and better response time [3,4], but they do not match the exceedingly fast switching time offered by acousto-optics. An acousto-optic technique was recently proposed to realize an in-line fiber attenuator [5], but the maximum tuning range achieved was limited to 13 dB. The acousto-optic programmable attenuator presented here [6] is an attractive candidate particularly for very high-speed applications and meets the typical requirements of today's telecommunication networks such as sufficient dynamic range and high resolution [7].

2. AOD-BASED PROGRAMMABLE OPTICAL ATTENUATOR STRUCTURE

The attenuator design is based on an acousto-optic device operating as a beam deflector. An RF signal is fed into the device that launches acoustic waves inside the bulk of the AO device. These acoustic waves perturb the index of refraction of the crystal and hence produce a moving phase grating. A moving phase grating is a well-known problem and can be analyzed by using coupled wave theory [8]. In Bragg regime, we have only two beams inside the AO device – the incident and the diffracted one. As the two beams travel across the device, the grating structure couples more and more power from the incident beam into the diffracted beam as shown in Fig. 1.

The diffraction efficiency of the acousto-optic device, when it is operating in Bragg mode, is then given by [8]

$$\eta = \sin^2\left[\frac{\pi\,\Delta n\, d}{\lambda_o \cos\theta_g}\right], \qquad (1)$$

* Also with Nuonics, Inc., Orlando, FL, Tel: 407-963-3706; nriza@aol.com

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where Δn is the index of modulation, d is thickness of the grating, λ_o is the wavelength associated with the incident beam and θ_g is the Bragg angle inside the device. The index of modulation Δn is determined by the acoustic intensity inside the cell and the figure of merit M of the device. The frequency of the RF signal determines the grating period $L = v_s / f_o$, where f_o is the frequency of the input RF signal and v_s is the velocity of the sound waves inside the AO device.

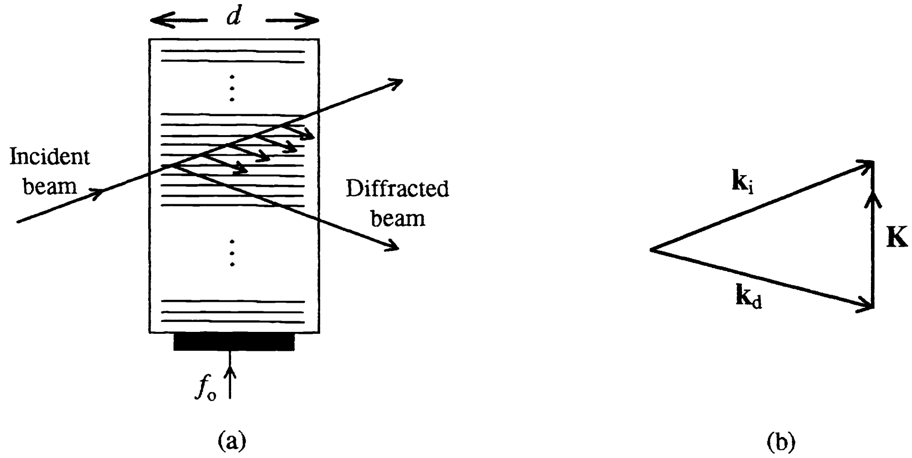


Fig.1 (a) Small-Bragg-angle diffraction of light beam from sound waves; (b) Conservation of momentum: $\mathbf{k}_i$ and $\mathbf{k}_d$ are the propagation vectors corresponding to the transmitted and diffracted beams respectively; $\mathbf{K}$ is the grating vector.

The basic structure of our attenuator is shown in Fig. 2. Collimated beam of light from the input fiber GRIN lens is incident on the AO device at Bragg angle. RF signal from a variable source is fed into the AO cell. The acoustic signal as discussed before produces a phase grating inside the device that makes a portion of the light to diffract at certain angle – hence two beams are coming out the AO cell. The output fiber GRIN lens is placed in front of the DC beam that goes straight undeviated. Since the amplitude of the RF signal determines the acoustic power fed into the device, we can control the index of modulation and hence the power in the DC beam. When the frequency of the RF signal is changed off the center frequency, the Bragg condition is violated which results in loss of diffraction efficiency. Hence, varying the frequency of the RF signal can also change the intensity of the DC beam. This design gives comparatively lower dynamic range and therefore can be use for tweeking purposes.

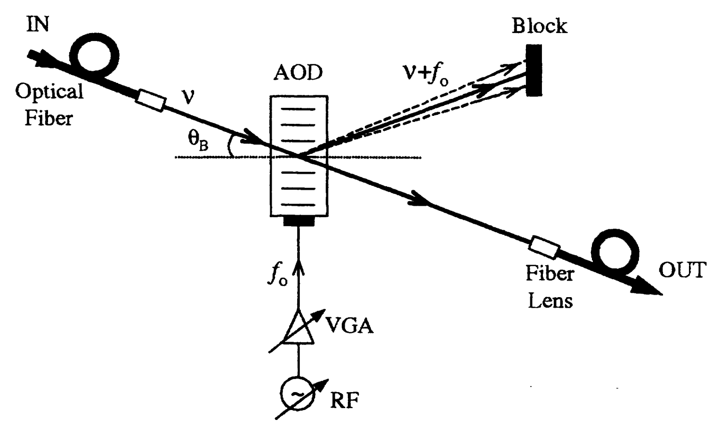


Fig.2 Tweeker: Un-deflected DC beam used as an output beam to get the attenuated signal. v: Optical Frequency, θ_B: Bragg Angle, f_o: RF frequency, AOD: Acousto-Optic Device, VGA: Variable Gain Amplifier.

We can also use the deflected beam as the output beam. Fig. 3 Shows another design for the POA where the output fiber GRIN has been placed in front of the deflected (+1 order) beam. Again, we can control the attenuation in the output beam by varying the amplitude or the frequency of the RF signal. Varying the frequency f_o affects the light reaching the output fiber in a dual fashion. First, it results in the variation of diffraction efficiency as discussed before. Secondly, it causes the output-diffracted beam to move across the output fiber GRIN lens. As a result, we observe an offset as well as a tilt in the beam entering the GRIN lens, which provides extra loss [7]. The advantage of this design is that it provides a high dynamic range.

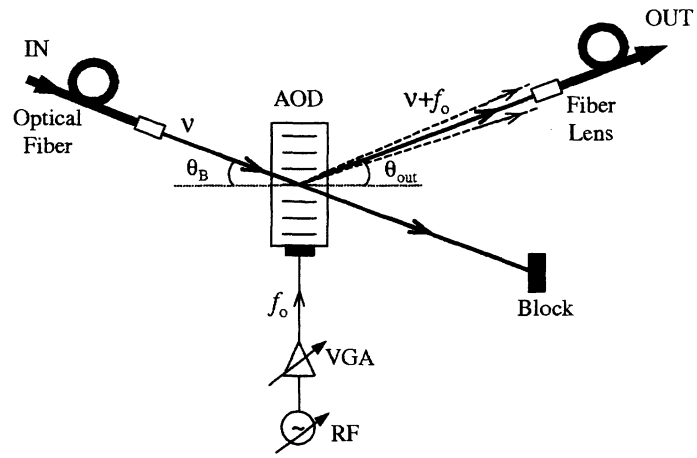


Fig.3 Deflected (+1 order) beam used as an output beam to get the attenuated signal. ν: Optical Frequency, θ_B: Bragg Angle, θ_{out}: Diffraction Angle, f_o: RF frequency, AOD: Acousto-Optic Device, VGA: Variable Gain Amplifier

While using the attenuator design shown in Fig. 3, an important consideration is the Doppler shift in the output light frequency. The output light beam frequency is Doppler shifted by an amount equal to the acoustic frequency. This might be an unwanted feature when it comes to communication systems equipped with such attenuators. Another design shown in Fig. 4, which involves two AO Bragg cells can counter this problem of frequency shift. The +1 order beam coming out of the 1st Bragg cell enters the 2nd Bragg cell, and out comes +1,-1 order beam – hence no Doppler shift.

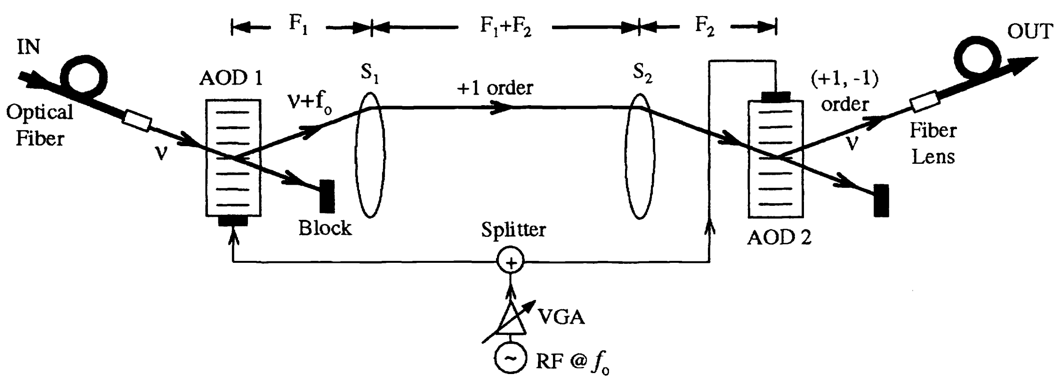
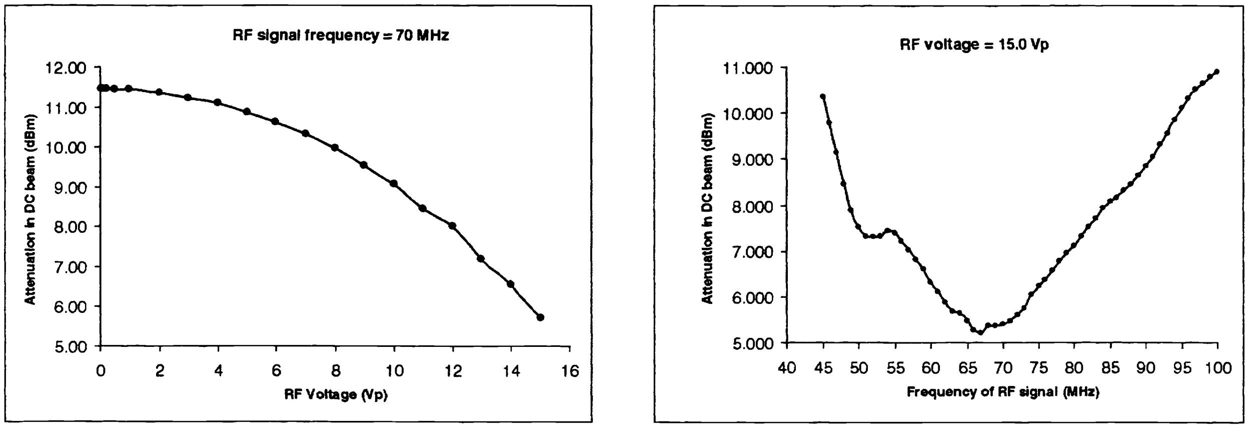


Fig.4 Two AO based attenuator design to cater the problem of Doppler shift caused by the acoustic waves. ν: Optical Frequency, f_o: RF frequency, Si: Spherical Lens, F_i :Focal Length of i^{th} Lens, AOD: Acousto-Optic Device, VGA: Variable Gain Amplifier

3. EXPERIMENTAL RESULTS

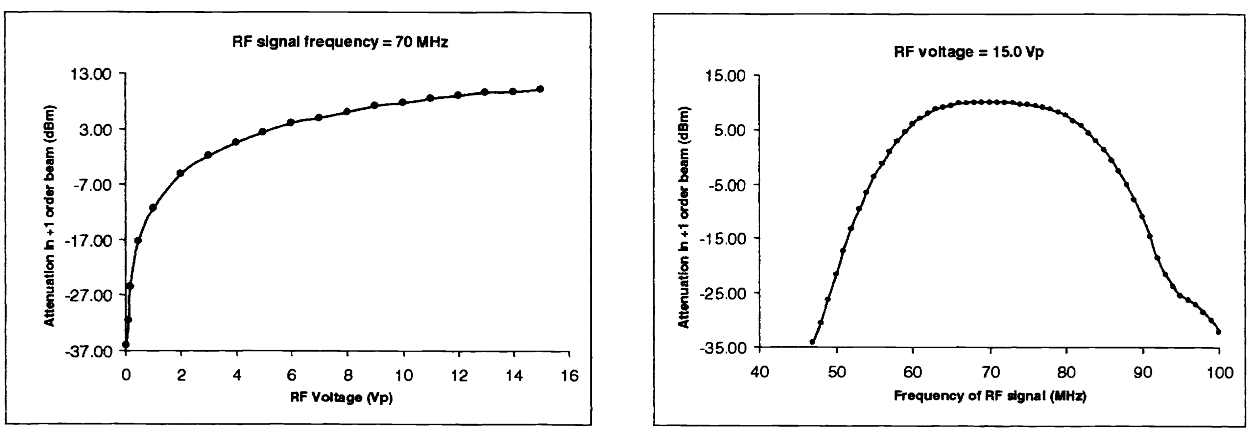
The experimental setup of our AOD based programmable optical attenuator (POA) is similar to that shown in Fig. 2, except that fiber coupled GRIN lenses have not been used. Instead, we have simulated GRIN lenses by deploying circular apertures of diameter 1.8 mm in our setup. A 632.8 nm (HeNe) laser has been used as a light source. We have used AOD-70 acoustic device manufactured by IntraAction Corporation Inc. This device has been designed for $\lambda = 632.8$ nm and has a center frequency of 70 MHz. The variable RF source used is 0.1–160 MHz ultrafast switching frequency synthesizer manufactured by WAVETEK. Optical power meter manufactured by Newport Corp. was used for light intensity measurements. Both amplitude and frequency of the input RF signal were changed to observe the attenuation in the output beam. Fig. 5 shows the plots for the attenuation in the output DC beam. The attenuator offers a dynamic range of 5.74 dB when the amplitude of the RF signal is varied. The average resolution is 0.38 dB/volt whereas the best resolution is 0.05 dB/volt. The excess loss is defined as $10\log(P_o/P_i)$ when no attenuation is desired, where P_i and P_o are the input and output beam powers, respectively. For the output DC beam, the excess loss is 0.13 dB.



(a) (b)

Fig.5 Plots for attenuation in the DC beam against (a) RF voltage, (b) RF frequency.

However if the frequency of the RF signal is varied, a dynamic range of 5.67 dB is attained. In this case, the average resolution achieved is 0.17 dB/MHz whereas the best resolution is 0.11 dB/MHz. The excess loss comes out to be 1.22 dB. The excess loss can be reduced and hence the dynamic range can be increased if we do not restrict the RF signal frequency to 100 MHz. The polarization dependent loss in the output DC beam under minimum attenuation conditions (RF signal – 50 mV peak value and 70 MHz) is 0.38 dB. The low dynamic range accounts for the fact that power in the DC beam cannot be reduced to zero since the AO device offers a maximum diffraction efficiency of ~70% as observed in the laboratory. The attenuator design, however, can be used for tweeking purposes where large dynamic range is not desired.



(a) (b)

Fig.6 Plots for attenuation in the +1 order beam against (a) RF voltage, (b) RF frequency.

The design shown in Fig. 3 was also setup in the laboratory, where the output beam is the +1 order diffracted beam. Fig. 6(a) shows the plot for the attenuation in the output +1 order beam, against the RF voltage. This architecture offers a dynamic range of 46.11 dB. The average resolution is 3.08 dB/volt whereas the best resolution is 0.39 dB/volt. The excess loss in this case is 1.51 dB. Fig. 6(b) shows the plot for the attenuation in the +1 order output beam against the frequency of the RF signal. In this case, we get a dynamic range of 44.02 dB. The average resolution is 1.4 dB/MHz whereas the best resolution is

0.14 dB/MHz. The measured excess loss is 1.56 dB. The polarization dependent loss observed in the output +1 order beam under minimum attenuation conditions (RF signal – 15 V peak value and 70 MHz) is 0.66 dB.

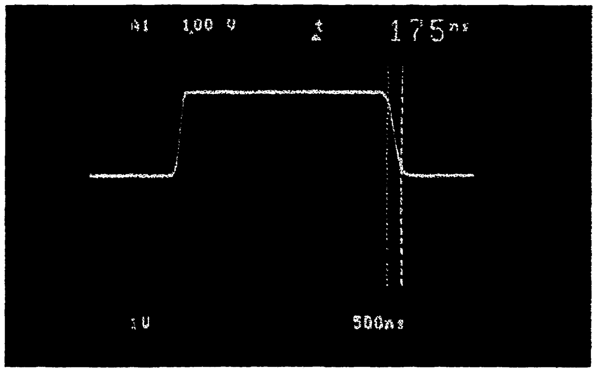


Fig.7 Oscilloscope trace of an AOD-70 switching time: 0.175 μs (from 90% to 10%) fall time.

The switching speed of the programmable optical attenuator depends upon the access time of the deflector used, which is defined as the time taken by the sound waves to cross the Gaussian optical beam spot. The response time of the AO attenuator, as shown in Fig. 7, was observed as low as 0.175 μs.

5. CONCLUSION

We have proposed a high-speed programmable optical attenuator (POA) based on acousto-optic Bragg cells. The beam deflection characteristic of AO devices has been exploited to realize the desired attenuator. The attenuation in the output beam can be achieved by either changing the amplitude or the frequency of the RF signal. The proposed POA can provide high dynamic range and high-resolution attenuation control. Two architectures based on the definition of the output beam (DC or +1 order) were discussed. A typical acousto-optic deflector (AOD) based design offers a dynamic range of 46.11 dB. The average resolution is 3.08 dB/volt whereas the best resolution achieved is 0.39 dB/volt. The response time of the AO attenuator is in the sub μs regime, and was observed as low as 0.175 μs. The polarization dependent loss (PDL) was about 0.7 dB, whereas the excess losses were about 1.5 dB.

REFERENCES

1. T. V. Clapp, S. Day, S. Ojha and R. G. Peall, "Broadband variable optical attenuator in silica waveguide technology," *ECOC* '98, pp. 301-302, September 1998.
2. S. -S. Lee, Y.-S. Jin, Y.-S. Son, and T.-K. Yoo, "Polymeric tunable optical attenuator with an optical monitoring tap for WDM transmission network," *IEEE Photon. Technol. Lett.* **11**, pp. 590-592, 1999.
3. C. R. Giles, V. Aksyuk, B. Barber, R. Ruel, L. Stulz, and D. Bishop, "A silicon MEMS optical switch attenuator and its use in lightwave subsystems," *IEEE J. Select. Top. Quant.Elect.* **5**, pp. 18-25, 1999.
4. N. A. Riza and S. Sumriddetchkajorn, "Digitally controlled fault-tolerant multiwavelength programmable fiber-optic attenuator using a two dimensional digital micromirror device," *Opt. Lett.* **24**, pp. 282-284, March 1, 1999
5. K. Jedrzejewski, M. Franczyk, and A. Leszczynski, "Acousto-optically tuned single-mode in-line fiber attenuator," *Proc. SPIE* **3731**, pp. 103-106, 1999.
6. Patent pending.
7. GR-910-CORE, *Generic Requirements for Fiber Optic Attenuators*, Issue 2, Bellcore, December 1998.
8. Yariv and P. Yeh, *Optical Waves in Crystals: Propagation and Control of Laser Radiation*, John Wiley & Sons, Inc., 1984.
9. S. Yuan and N. A. Riza, "General formula for coupling-loss characterization of single-mode fiber collimators by use of gradient-index rod lenses," *Appl. Opt.* **38**, pp. 3214-3222, May 1999.