OPTICAL SWITCHES

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October 3,1999

The Acousto-Optic Modulator

The Acousto-Optic Modulator is based on the elasto-optic effect, in which a material strain causes a change in the refraction index of the material. When the strain is generated by an acoustic compression or rarefaction, an AOM is formed. Because the acoustic signal is sinusoidal, a moving refractive index grating is formed in the device. Like a permanent grating, the various wavelengths are spatially diffracted and separated from each other. With an output coupler placed at the appropriate diffraction order location, tunable filtering and switching can be achieved.

The '*IntraAction Corp.*' develops one such Acousto-Optic Modulator 'ADM-40'. Research has demonstrated that the ADM-40 can provide multiple wavelengths filtering in a single device. In addition, multiple RF signals can be generated, enabling access to a number of optical wavelengths, a unique capability among filter designs.

Applying this technology to current WDM regenerator sites will enable an optical ADM function to be performed, whereby individual or multiple wavelengths can be selected and interfaced with other terminal equipment. *(Fig 3)*

PRINCIPLE

The acousto-optic effect occurs when a light beam passes through a transparent material, such as glass, in which traveling acoustic waves are also present, as depicted in *Fig. 1*. Acoustic waves are generated in the glass by a piezoelectric transducer that is driven by a RF signal source. The spatially periodic density variations in the glass corresponding to compressions and rarefactions of the traveling acoustic wave are accompanied by corresponding changes in the index of refraction for propagation of light in the medium. These traveling waves of index of refraction variation diffract the incident light much as the atomic planes of a crystal diffract x-rays in Bragg scattering.[2] For acoustic waves of sufficiently high power, most of the light incident on the acousto-optic modulator can be diffracted and therefore deflected from its incident direction.

For acoustic waves of frequency f traveling at the speed of sound in a medium, v_s, the wavelength of the acoustic waves, Λ, and therefore the spacing between the planes of index of refraction variation, is given by the usual wave relation $v_s = \Lambda f$. A light beam passing through the acoustically driven medium will be diffracted to angles θ given by

$$\sin\theta = \left(m\lambda / 2\Lambda \right) \qquad (1)$$

where m = 0, ±1, ±2, ... is called the diffraction order[2]. (Similar to Bragg diffraction equation of x-rays by atomic planes)

From *Fig. 1*, the angle α between a diffracted beam and the undiffracted beam is given by

$$\begin{aligned} \sin(\alpha/2) &= \left(m\lambda / 2\Lambda \right) \\ &= \left(m\lambda f / 2v_s \right) \qquad (2) \end{aligned}$$

At this point it is helpful to consider numerical estimates for these quantities for the IntraAction ADM-40, flint glass, acousto-optic modulator/deflectors used in this experiment. The "40" in the model number signifies that these acousto-optic modulators have been optimized for operation at an acoustic frequency f = 40 MHz, but the manufacturer guarantees good performance over the range 30-50 MHz. Although v_s for the flint glass material used in the ADM-40 is not given by the manufacturer, an estimate can be made using the speed of sound in clear lead glass, v_s = 3800 m/s, from Ref. 4. The acoustic wavelength Λ will therefore be $\Lambda = v_s/f$ = 9.5 µm. For deflection of a HeNe laser beam, the deflection angle α for the first order (m = 1) diffracted beam is less than a degree, so that the usual small angle approximation can be made in Eq.(2) to give

$$\begin{aligned}\alpha &= (\lambda f/v_s)\\ &= ((6328 \times 10^{-10}\ \text{m})(40 \times 10^{6}\ \text{s}^{-1})/3800\ \text{m/s})\\ &= 6.7 \times 10^{-3}\ \text{rad} = 0.38^{0} \qquad (3)\end{aligned}$$

a very small, but useful deflection.

Three common operating modes of the acousto-optic modulator will be described in detail.

Deflection

Under optimal conditions, the ADM-40 can diffract nearly 85-90% of the incident light into the first order-diffracted beam. By simply turning the acoustic energy source on and off, the acousto-optic modulator can act as a rapid light deflector. The switching of the incident light beam to the first order diffracted beam can occur in a very short period of time (< 5 µs) depending only on how rapidly the acoustic wave field can be turned on and off in the volume of the flint glass traversed by the laser beam. From Eq. (3) it can be seen that an acousto-optic modulator can deflect a laser beam to different angles α by simply varying the acousto-optic modulator frequency f. The diffracted beam emerging from the ADM-40 can be swept through an angular range of 3.3 mrad when the acoustic driver frequency is swept from 30 to 50 MHz. This property can be used to move a laser beam rapidly in space - without moving parts - in such applications as the laser printer and direct laser display devices.

From Eq. (3) it can be seen that the deflection angle α depends on the wavelength λ of the incident light beam. The acousto-optic modulator can therefore be used to deflect beams of polychromatic light into component colors or wavelengths, in a manner reminiscent of the dispersive prism.

Modulation

The amount of laser light diffracted to the first order beam depends on the amplitude of the acoustic waves that diffract the incident laser beam, and therefore, by modulating the power level of the acoustic wave source, the intensity of the diffracted light beam can be modulated. By this means an electrical signal containing voice, music, or television can modulate the intensity of a light beam as part of an optical communications system.

Frequency shifting

This is one of the most useful properties of the acousto-optic modulator. The ability of the acousto-optic modulator to shift the frequency of a laser light beam by a precise and stable amount is crucial to production of a beat note from two light beams in this experiment. The similarity of Eq. (1) for the acousto-optic effect to Eq. (2) for Bragg diffraction of x-rays belies an important difference between the two diffraction situations. Bragg diffraction of x-rays occurs for atomic planes that are at rest in the laboratory, while acousto-optic diffraction occurs from acoustic wave planes that travel at the relatively high-speed v_s with respect to the laboratory. The fact that the diffracting acoustic planes moves, leads to a Doppler shift of the frequency of the diffracted beams. The frequency of the first order-diffracted beam is shifted by an amount exactly equal to the acousto-optic modulator frequency f. If ν_0 is the frequency of the light incident on the acousto-optic modulator, the frequency of the first order beam will be up shifted to ν_0+f in the case that the acoustic planes have a component of motion toward the incident light beam, and downshifted to ν_0-f when the acoustic planes have a component of motion away from the incident light beam.

The frequency shift produced by an acousto-optic modulator can be used to transform a fixed frequency laser like the HeNe laser, into a tunable laser, although only over the small range of frequencies (20 MHz for the ADM-40) over which the acousto-optic modulator can be operated.

SPECIFICATIONS

Spectral Range	440 to 700 nm
Center Frequency	40 MHz
Beam Separation at 40 MHz	6.5 mrad (633 nm)
Deflection RF Bandwidth	20 MHz (See Fig.1)
Angular Deflection	3.2 mrad (633 nm)
Diffraction Efficiency	85 percent
Nominal Drive Power	2 watts (633 nm) 1 watt (442 nm)
Nominal Impedance	50 ohms
Active Optical Aperture	2 x 20 (mm)
Time Bandwidth Product	100
Intensity Modulation Bandwidth	2.9 MHz (1.0 mm dia.) 4.5 MHz (.65 mm dia.)
Optical Rise Time	170 nsec (1.0 mm dia.) 110 nsec (.65 mm dia.)
Extinction Ratio at DC	>1000 to 1 (1st order)
Optical Frequency Shift Range	± (30 to 50) MHz
Static Optical Insertion Loss	2 percent (633 nm)
Optical Polarization	Any
Weight	225 gm

More Information can be found from the following:

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COMPARISON WITH COMERCIAL OPTO-MECHANICAL SWITCHES

The following specifications are form the ***TECOS Optical Switches***

Electro-Optical Characteristics:

PARAMETER	1 X 1	1 X 2
Wavelength Range (nm)	1280 - 1650	1280 – 1650
Insertion Loss (dB), typ.	-0.6	-0.6
Insertion Loss (dB), max.	-1	-1
PDL (dB), typ.	0.03	0.03
Return Loss (dB), typ.	65	65
Cross-Talk (dB), min.	-80	-80
Switching Speed (ms), typ.	2	2
Repeatability (dB)	<± 0.01 (>10^7 cycles)	<± 0.01 (>10^7 cycles)

Electrical Characteristics:

PARAMETER	1 X 1	1 X 2
Coil Resistance (W)	45	45
Operation Current (mA), typ.	66.7	66.7
Operation Voltage (V), typ	3	3
Operation Voltage (V), max.	4.5	4.5
Power Consumption (mW), typ.	200	200

Mechanical & Environmental:

PARAMETER	1 X 1	1 X 2
Operation Temperature (°C)	-10 to +75	-10 to +75
Humidity	5 to 85% RH	5 to 85% RH
Insertion Loss Variation (dB)[2]	± 0.6 dB	± 0.6 dB
Durability (cycles), min	>10^8	>10^8
Fiber Pigtail[3]	Æ 0.9 mm (SM,10/125)	Æ 0.9 mm (SM,10/125)
Dimension (L x H x W) (mm)	30.5 x 8 x 11	30.5 x 8 x 11

2. Measured over the entire operating temperature range
3. Other options are available

More information can be found from the following:

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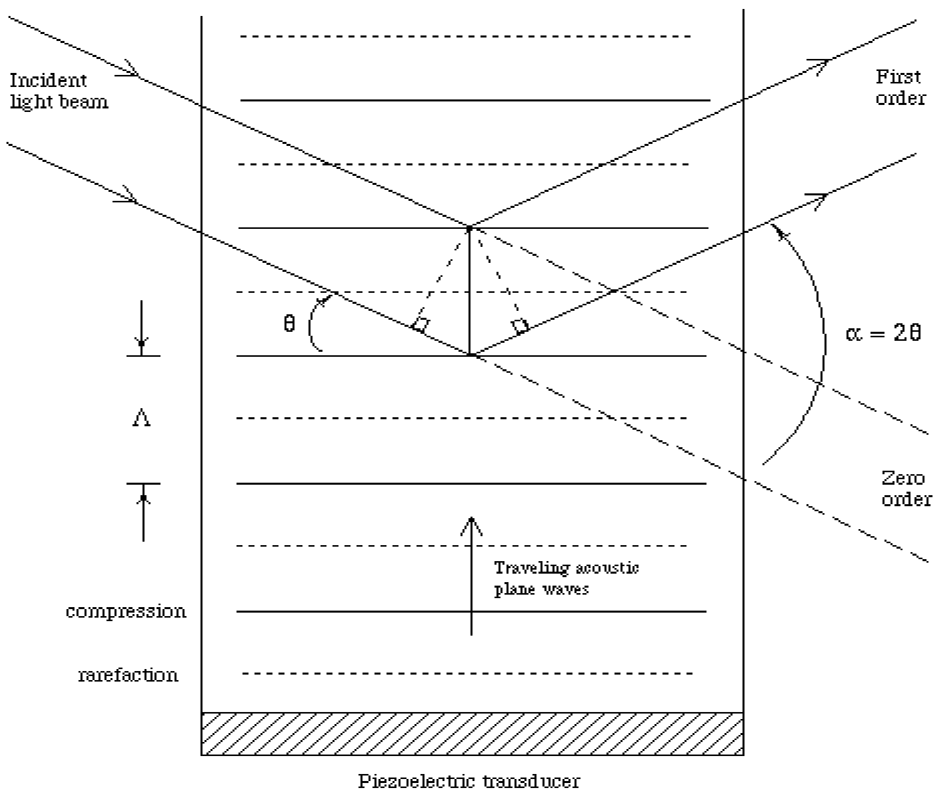
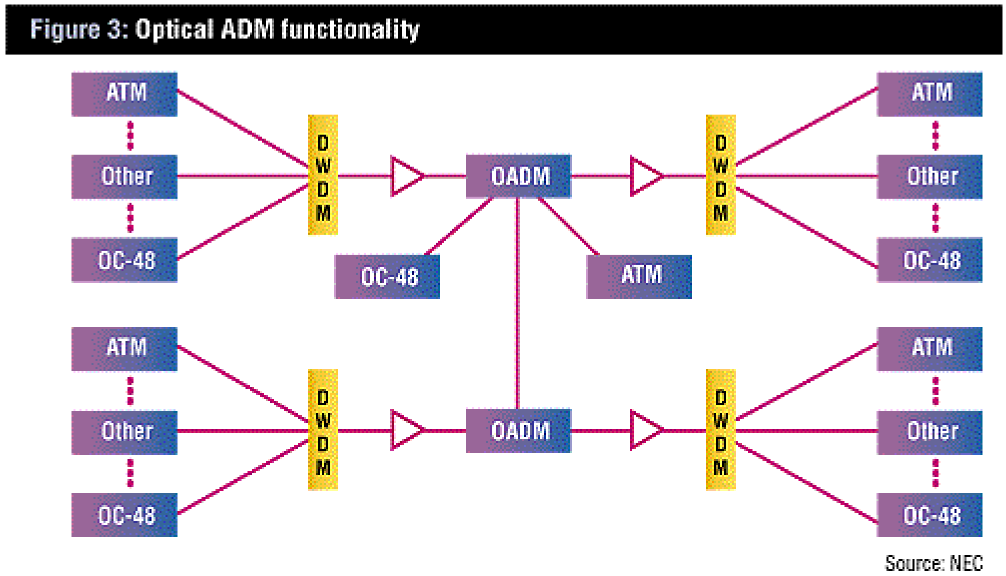


FIG. 1. Diffraction of a light beam by traveling acoustic plane waves in an acousto-optic modulator.
The refraction of light at the air-glass boundaries is not shown.



CONCLUSION:

Optical switches are integral part of WDM systems. There is variety of optical switches commercially available in the industry using different switching techniques. Once such switch is the acoustic-optical switch. This paper presents the working of Acousto-Optical switch manufactured by the IntraAction Corp. The complete specification of this switch is shown in comparison with an Opto-Mechanical Switch manufactured by the TECOS (Germany).

REFERENCES:

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2. IntraAction Corp.http://www.intraaction.com
3. TECOS Opto-Mechanical Switches http://www.tecos.de
4. Fiber Optics Online http://www2.fiberopticsonline.com