Acousto-Optic Devices

Reference: see B. E. A. Saleh’s Fundamentals of Photonics

A. Modulator

Acoustic plane wave $$s(x,t) = S_0 \cos(\Omega t - qx)$$

Acoustic intensity $$I_s = \tfrac{1}{2}\varrho v_s^3 S_0^2$$

Analogy to Pockels effect $$\Delta n(x,t) = -\tfrac{1}{2}\mathfrak{p} n^3 s(x,t)$$

Photoelestic constant

$$n(x,t) = n - \Delta n_0 \cos(\Omega t - qx),$$

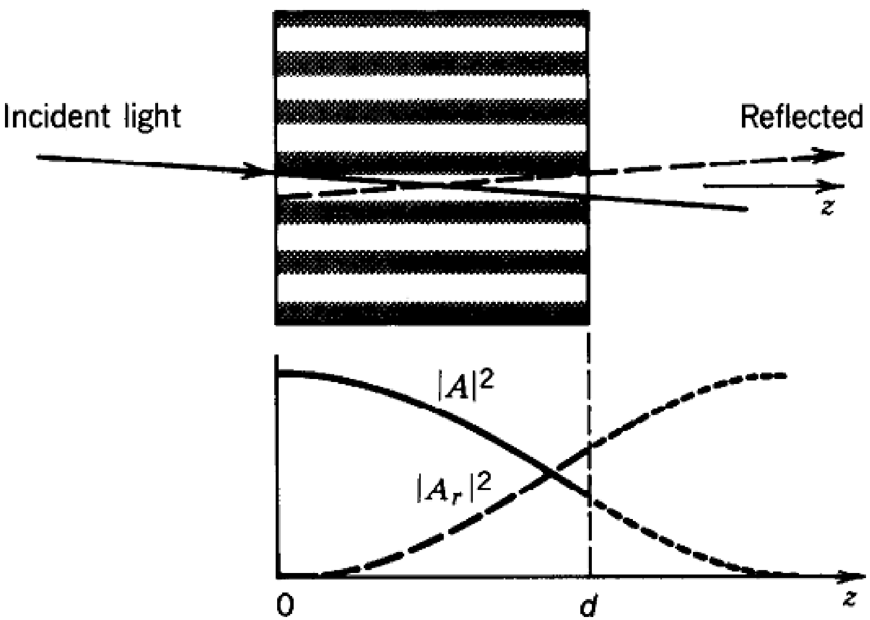
$$\Delta n_0 = \tfrac{1}{2}\mathfrak{p} n^3 S_0$$

$$\Delta n_0 = \left(\tfrac{1}{2}\mathscr{M} I_s\right)^{1/2},$$

$$\mathscr{M} = \frac{\mathfrak{p}^2 n^6}{\varrho v_s^3}$$

$$\frac{dA}{dz} = j\tfrac{1}{2}\gamma A_r$$
$$\frac{dA_r}{dz} = j\tfrac{1}{2}\gamma A,$$

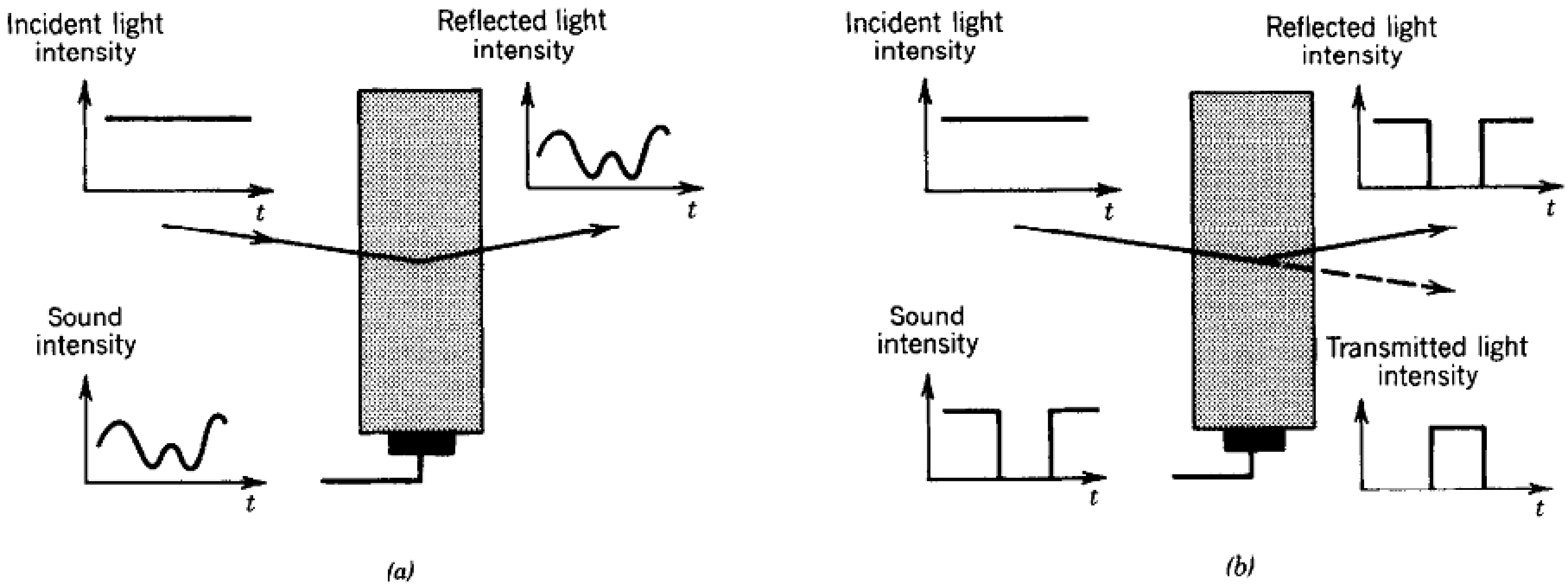
$$A(z) = A(0)\cos\frac{\gamma z}{2}$$
$$A_r(z) = jA(0)\sin\frac{\gamma z}{2}$$



$$\mathscr{R}_e = \sin^2(\gamma d/2)$$

$$\gamma = k\frac{\Delta n_0}{n}$$

The intensity of the reflected light in a Bragg cell is proportional to the intensity of sound, if the sound intensity is sufficiently weak. Using an electrically controlled acoustic transducer, the intensity of the reflected light can be varied proportionally. The device can be used as a linear analog modulator of light.

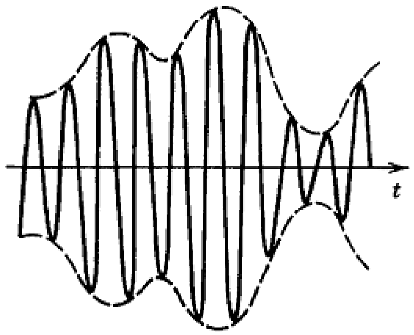


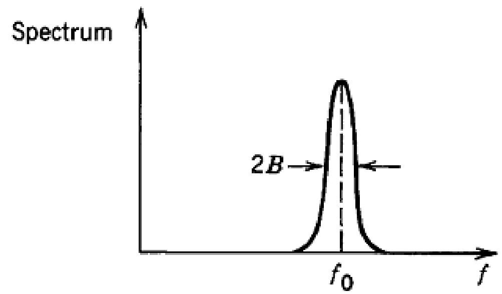
(a) An AOM. The intensity of the reflected light is propotional to the intensity of sound. (b) An acousto-optic switch.

Modulation Bandwidth

The bandwidth of the modulator is the maximum frequency at which it can efficiently modulate.

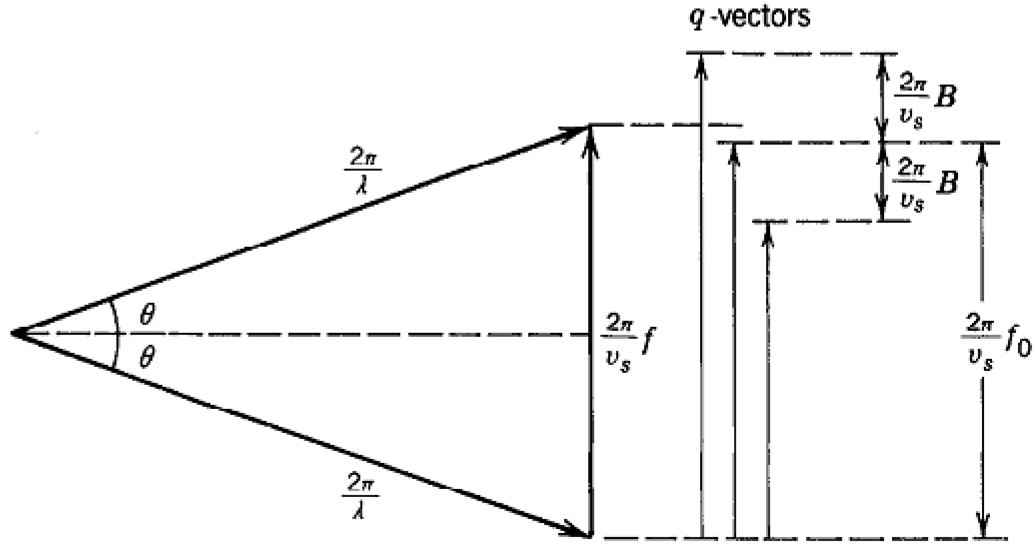
When the amplitude of an acoustic wave of frequency f_0, is varied as a function of time by amplitude modulation with a signal of bandwidth B, the acoustic wave is no longer a single-frequency harmonic function; it has frequency components within a band $f_0 \pm B$ centered about the frequency f_0.





How does monochromatic light interact with this multifrequency acoustic wave and what is the maximum value of B that can be handled by the acousto-optic modulator?

$$\theta = \sin^{-1}\frac{\lambda}{2\Lambda} = \sin^{-1}\frac{f\lambda}{2v_s} \approx \frac{\lambda}{2v_s}f$$

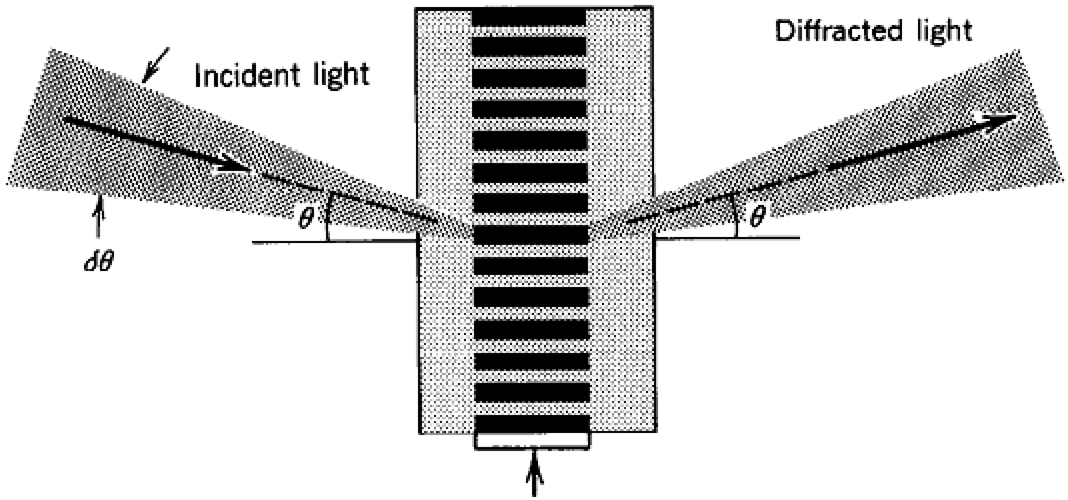


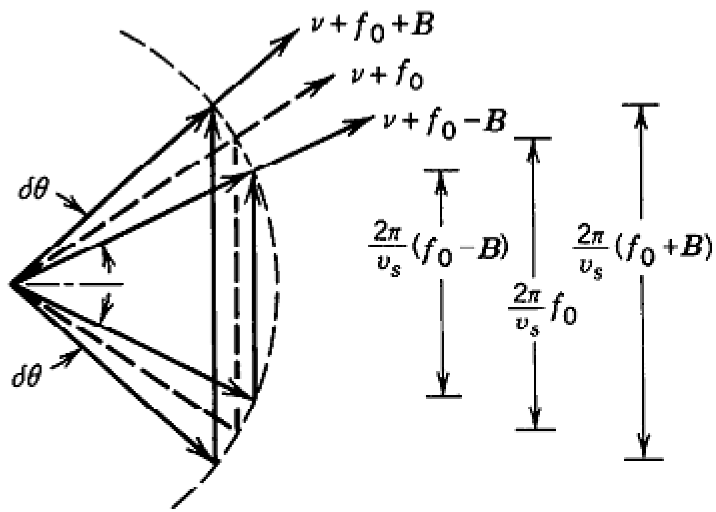
More tolerant situation is therefore necessary.

Suppose that the incident light is a beam of width D and angular divergence $\delta\theta = \lambda/D$ and assume that the modulated sound wave is planar. Each frequency component of sound interacts with the optical plane wave that has the matching Bragg angle. The frequency band $f_0 \pm B$ is matched by an optical beam of angular divergence

$$\delta\theta \approx \frac{(2\pi/v_s)B}{2\pi/\lambda} = \frac{\lambda}{v_s}B \qquad B = v_s\frac{\delta\theta}{\lambda} = \frac{v_s}{D}$$

$$\boxed{B = \frac{1}{T}, \qquad T = \frac{D}{v_s},}$$



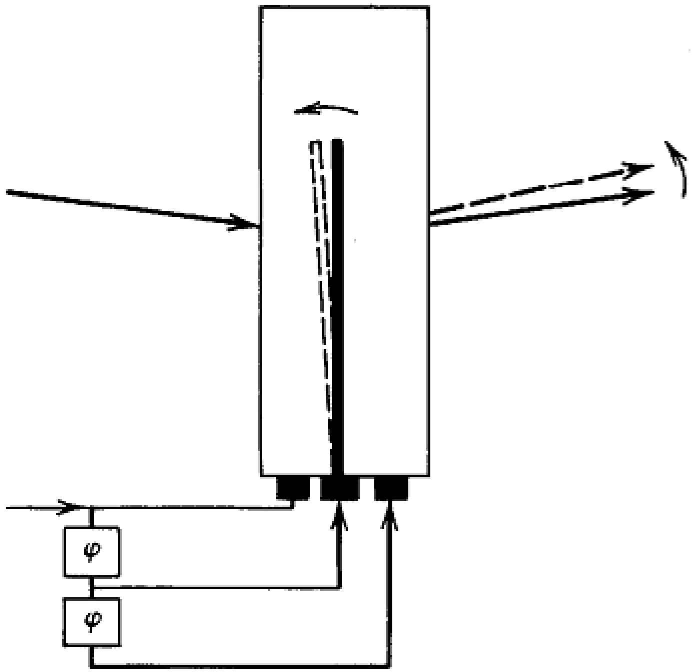


How to increase the bandwidth of the modulator ??

B. Scanners

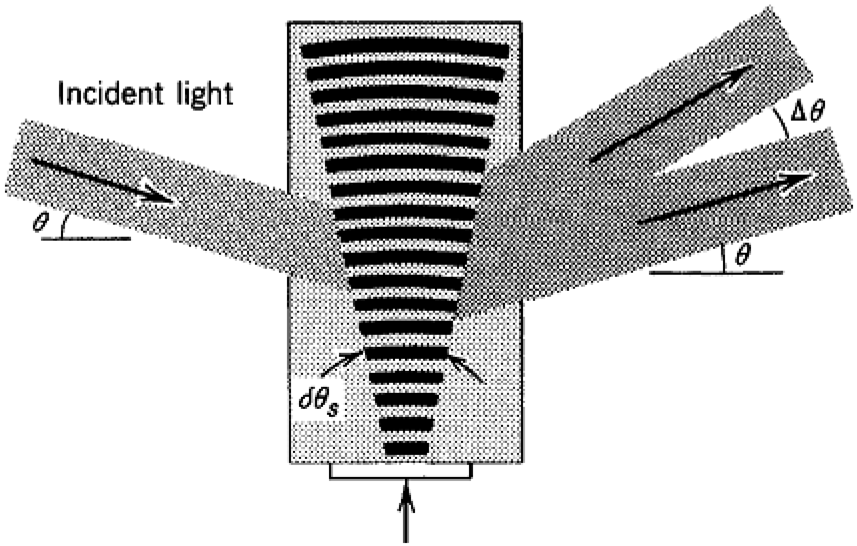
$$2\theta \approx \frac{\lambda}{v_s} f$$

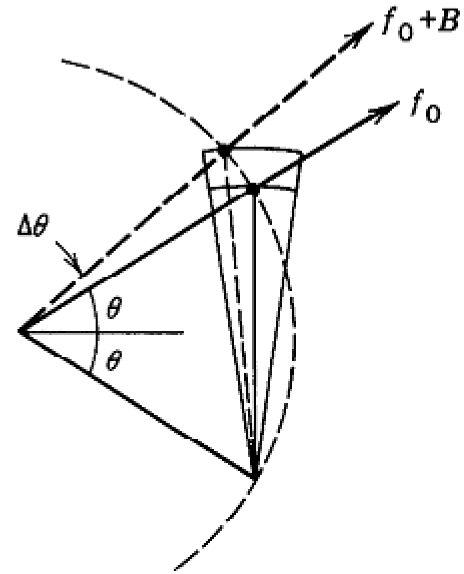
<u>One difficulty:</u> θ represents both the angle of reflection and the angle of incidence. To change the angle of reflection, both the angle of incidence and the sound frequency must be changed simultaneously.



Scan Angle

$$\Delta\theta = \frac{\lambda}{v_s} B.$$





Scanning an optical wave by varying the frequency of a sound beam of angular divergence $\delta\theta_s$ over the frequency range $f_0 \leq f \leq f_0 + B$.

This, of course, assumes that the sound beam has an equal or greater angular width $\delta\theta_s = \Lambda / D_s \geq \Delta\theta$. Since the scan angle is inversely proportional to the speed of sound, larger scan angles are obtained by use of materials for which the sound velocity v_s is small.

Number of Resolvable Spots

$$N = \frac{\Delta\theta}{\delta\theta} = \frac{(\lambda/v_s)B}{\lambda/D} = \frac{D}{v_s}B$$

$$\boxed{N = TB,}$$

B is the bandwidth of the FM modulator used to generate the sound, and $T=D/\nu_s$, is the transit time of sound through the light beam