Electro-Optics:

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Yoonchan Jeong
School of Electrical Engineering, Seoul National University
Tel: +82 (0)2 880 1623, Fax: +82 (0)2 873 9953
Email: yoonchan@snu.ac.kr

Electro-Optic Modulation

Electro-optic effect in KH_2PO_4 (KDP):

$$n_{x'} = n_o - \frac{1}{2} n_o^3 r_{63} E_z, \quad n_{y'} = n_o + \frac{1}{2} n_o^3 r_{63} E_z, \quad n_z = n_e$$

$$\rightarrow \ n_{y'} - n_{x'} = n_o^3 r_{63} E_z$$

$$\rightarrow \ \Gamma = \frac{\omega}{c}(n_{y'} - n_{x'})d = \frac{2\pi}{\lambda} n_o^3 r_{63} V$$

Rotation of the polarization state:

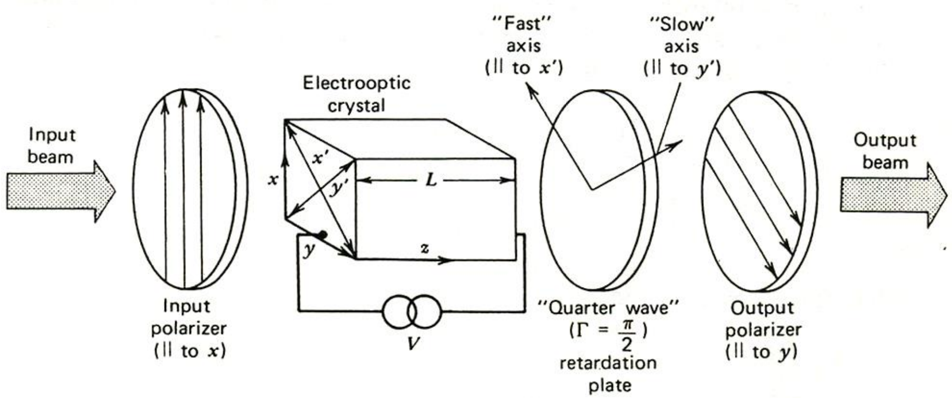
Input: $\rightarrow \frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ 1 \end{pmatrix}$ Output: $\rightarrow \frac{1}{\sqrt{2}}\begin{pmatrix} e^{i\Gamma/2} \\ e^{-i\Gamma/2} \end{pmatrix}$

Half-wave voltage:

$$\rightarrow \ V_\pi = \frac{\lambda}{2 n_o^3 r_{63}}$$

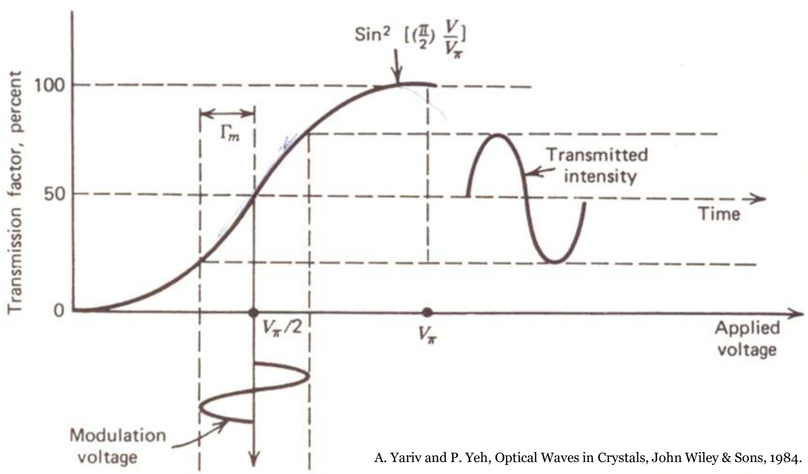
Amplitude Modulation

Electro-optic amplitude modulator:



A. Yariv and P. Yeh, Optical Waves in Crystals, John Wiley & Sons, 1984.

Transmission:



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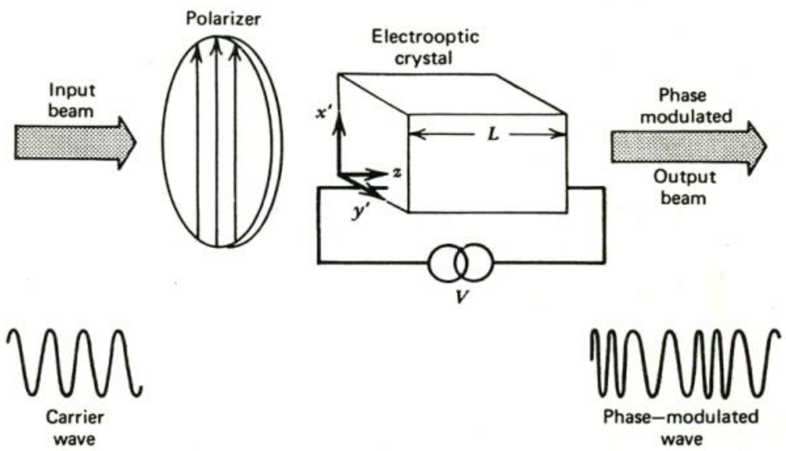
$$\rightarrow T = \sin^2 \frac{\Gamma}{2} = \sin^2 \left(\frac{\pi}{2} \frac{V}{V_\pi} \right)$$

$$\rightarrow \Gamma = \frac{\pi}{2} + \Gamma_m \sin \omega_m t$$

Phase Modulation

Electro-optic phase modulator:



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Phase change:

$$\rightarrow \Delta\phi_{x'} = -\frac{\omega d}{c}\Delta n_{x'} = -\frac{\omega n_o^3 r_{63}}{2c}E_z d \quad \rightarrow E_z = E_m \sin\omega_m t$$

$$\rightarrow E_{out} = A\cos\left[\omega t - \frac{\omega}{c}\left(n_o - \frac{n_o^3}{2}r_{63}E_m \sin\omega_{mt} t\right)d\right]$$

$$\rightarrow E_{out} = A\cos[\omega t + \delta\sin\omega_m t]$$

$$\leftarrow \delta = \frac{\omega n_o^3 r_{63}E_m d}{2c} = \frac{\pi n_o^3 r_{63}E_m d}{\lambda}$$

Quadratic Electro-Optic Effect

$$\rightarrow s_{ij} = \begin{pmatrix} s_{11} & s_{12} & s_{13} & s_{14} & s_{15} & s_{16} \\ s_{21} & s_{22} & s_{23} & s_{24} & s_{25} & s_{26} \\ s_{31} & s_{22} & s_{33} & s_{34} & s_{35} & s_{36} \\ s_{41} & s_{22} & s_{43} & s_{44} & s_{45} & s_{46} \\ s_{51} & s_{22} & s_{53} & s_{54} & s_{55} & s_{56} \\ s_{61} & s_{22} & s_{53} & s_{64} & s_{65} & s_{66} \end{pmatrix}$$

Permutation symmetries:

$$\rightarrow s_{ijkl} = s_{jikl}$$

$$\rightarrow s_{ijkl} = s_{ijlk} \qquad \rightarrow 1 = (11),\ 2 = (22),\ 3 = (33),$$

$$4 = (23) = (32),\ 5 = (13) = (31),\ 6 = (12) = (21)$$

Index ellipsoid: $\rightarrow \eta_{ij}(\mathbf{E}) x_i x_j = 1$

$$\rightarrow x^2\left(\frac{1}{n_x^2} + s_{11}E_x^2 + s_{12}E_y^2 + s_{13}E_z^2 + 2s_{14}E_yE_z + 2s_{15}E_zE_x + 2s_{16}E_xE_y\right)$$

$$+ y^2\left(\frac{1}{n_y^2} + s_{21}E_x^2 + s_{22}E_y^2 + s_{23}E_z^2 + 2s_{24}E_yE_z + 2s_{25}E_zE_x + 2s_{26}E_xE_y\right)$$

$$+ z^2\left(\frac{1}{n_z^2} + s_{31}E_x^2 + s_{32}E_y^2 + s_{33}E_z^2 + 2s_{34}E_yE_z + 2s_{35}E_zE_x + 2s_{36}E_xE_y\right)$$

$$+ 2yz\left(s_{41}E_x^2 + s_{42}E_y^2 + s_{43}E_z^2 + 2s_{44}E_yE_z + 2s_{45}E_zE_x + 2s_{46}E_xE_y\right)$$

$$+ 2zx\left(s_{51}E_x^2 + s_{52}E_y^2 + s_{53}E_z^2 + 2s_{54}E_yE_z + 2s_{55}E_zE_x + 2s_{56}E_xE_y\right)$$

$$+ 2xy\left(s_{61}E_x^2 + s_{62}E_y^2 + s_{63}E_z^2 + 2s_{64}E_yE_z + 2s_{65}E_zE_x + 2s_{66}E_xE_y\right) = 1$$