

# Electro-Optics:

## Electro-Optics (2)

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# Electro-Optic Modulation

Electro-optic effect in  $\text{KH}_2\text{PO}_4$  (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:

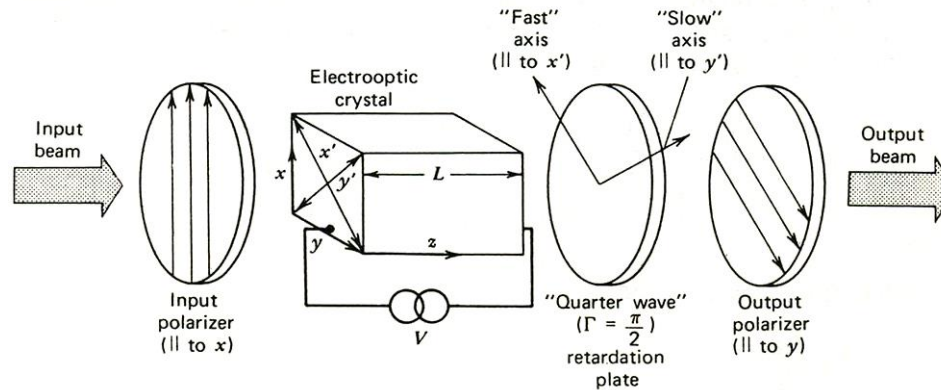
$$\text{Input: } \rightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix} \quad \text{Output: } \rightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} e^{i\Gamma/2} \\ e^{-i\Gamma/2} \end{pmatrix}$$

Half-wave voltage:

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

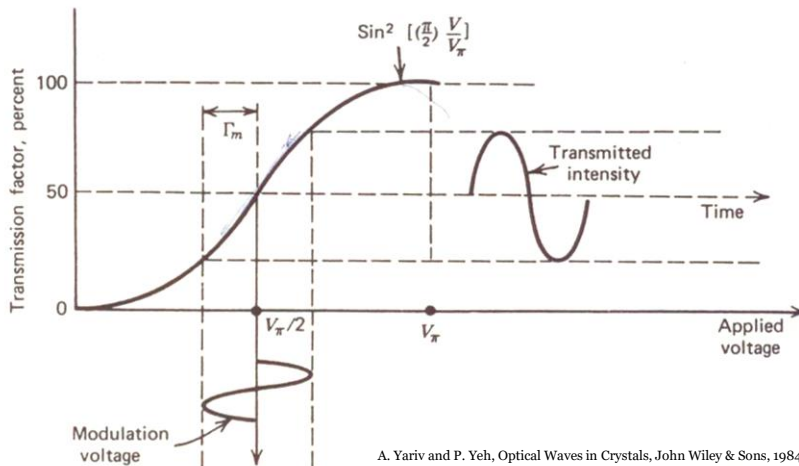
# Amplitude Modulation

## Electro-optic amplitude modulator:



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

## Transmission:



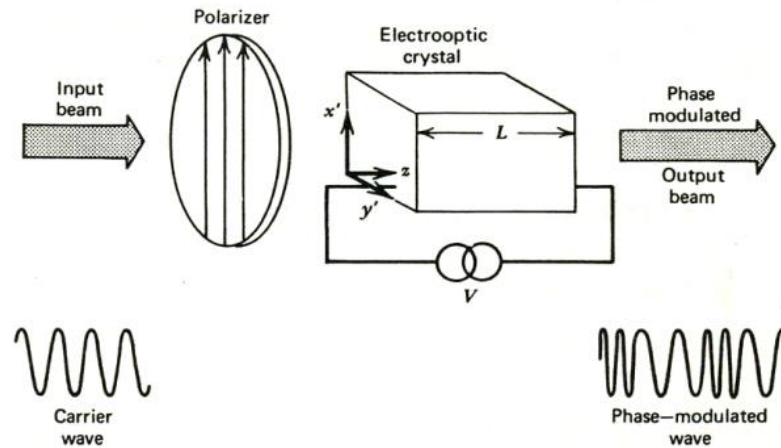
A. Yariv and P. Yeh, Optical Waves in Crystals, John Wiley & Sons, 1984.

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

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

# Phase Modulation

Electro-optic phase modulator:



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

Phase change:

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

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

$$\rightarrow E_{out} = A \cos \left[ \omega t + \delta \sin \omega_m t \right] \quad \leftarrow \delta = \frac{\omega n_o^3 r_{63} E_m d}{2c} = \frac{\pi n_o^3 r_{63} E_m d}{\lambda}$$

# Quadratic Electro-Optic Effect

Permutation symmetries:

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

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

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

$$\rightarrow s_{ij} = \begin{pmatrix} s_{11} & s_{12} & s_{13} & s_{14} & s_{15} & s_{16} \\ s_{21} & s_{22} & s_{23} & s_{24} & s_{25} & s_{26} \\ s_{31} & s_{32} & s_{33} & s_{34} & s_{35} & s_{36} \\ s_{41} & s_{42} & s_{43} & s_{44} & s_{45} & s_{46} \\ s_{51} & s_{52} & s_{53} & s_{54} & s_{55} & s_{56} \\ s_{61} & s_{62} & s_{63} & s_{64} & s_{65} & s_{66} \end{pmatrix}$$

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

$$\begin{aligned} \rightarrow & x^2 \left( \frac{1}{n_x^2} + s_{11}E_x^2 + s_{12}E_y^2 + s_{13}E_z^2 + 2s_{14}E_yE_z + 2s_{15}E_zE_x + 2s_{16}E_xE_y \right) \\ & + y^2 \left( \frac{1}{n_y^2} + s_{21}E_x^2 + s_{22}E_y^2 + s_{23}E_z^2 + 2s_{24}E_yE_z + 2s_{25}E_zE_x + 2s_{26}E_xE_y \right) \\ & + z^2 \left( \frac{1}{n_z^2} + s_{31}E_x^2 + s_{32}E_y^2 + s_{33}E_z^2 + 2s_{34}E_yE_z + 2s_{35}E_zE_x + 2s_{36}E_xE_y \right) \\ & + 2yz(s_{41}E_x^2 + s_{42}E_y^2 + s_{43}E_z^2 + 2s_{44}E_yE_z + 2s_{45}E_zE_x + 2s_{46}E_xE_y) \\ & + 2zx(s_{51}E_x^2 + s_{52}E_y^2 + s_{53}E_z^2 + 2s_{54}E_yE_z + 2s_{55}E_zE_x + 2s_{56}E_xE_y) \\ & + 2xy(s_{61}E_x^2 + s_{62}E_y^2 + s_{63}E_z^2 + 2s_{64}E_yE_z + 2s_{65}E_zE_x + 2s_{66}E_xE_y) \end{aligned}$$