A Reflectance Display: Supplemental Appendix

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C Liquid Crystal SLMs

To better understand the operation of our SLM we review some basic properties of nematic LC cells. A full description of LC technology is out of the scope of this manuscript, for more details we refer the reader to [Lazarev et al. 2012]. Note that other LC types such as twisted-nematic cells operate in a different manner.

The effect of an LC cell on a fully polarized, monochromatic light wave can be described using the formalism of *Jones matrices* [Goodman 1968].

Let

$$\vec{U} = \begin{pmatrix} U_x \\ U_y \end{pmatrix} = \begin{pmatrix} U_{0x}e^{i\phi_x} \\ U_{0y}e^{i\phi_y} \end{pmatrix} \tag{1}$$

be the polarization vector, or *Jones vector*, describing the complex amplitudes of a monochromatic fully polarized light wave. The Jones vector is essentially expressing the projection of the polarization vector on some predefined x, y basis. The action of a polarizing element such as a LC cell is described using a 2×2 Jones matrix L. The resulting state of polarization $\vec{U}'$ is given by

$$\vec{U}' = L\vec{U} \tag{2}$$

As explained in [Hermerschmidt et al. 2007; Lazarev et al. 2012] the Jones matrix which describes the action of the LC cell of the PLUTO SLM is given by

$$L = \exp\{i\phi\} \begin{pmatrix} \exp\{-i\beta\} & 0 \\ 0 & \exp\{i\beta\} \end{pmatrix} \tag{3}$$

where the birefringence β and the phase offset ϕ are given by

$$\beta = (n_{eo} - n_o)\frac{\pi d}{\lambda} \tag{4}$$

$$\phi = (n_{eo} + n_o)\frac{\pi d}{\lambda}. \tag{5}$$

Here n_o and n_{eo} are the ordinary and extraordinary indices of refraction of the LC material, respectively, d is the thickness of the cell, and λ is the wavelength. By applying voltage we can change the birefringence β. If the incident light is linearly polarized parallel to the extraordinary axis of the LC molecules, its Jones vector have the form $U = (0, U_y)$. Thus, it is retarded by the voltage-dependent extraordinary index of refraction, in effect, allowing controlled phase modulation.

Amplitude Modulation LCs are also commonly used to implement amplitude modulation, this can be achieved by placing two perpendicular linear polarizers one before and one after the LC. The jones matrix for a $\pm 45^\circ$ linear polarizer is given by

$$L_{\pm 45} = \frac{1}{2}\begin{pmatrix} 1 & \pm 1 \\ \pm 1 & 1 \end{pmatrix}. \tag{6}$$

This is a rank 1 matrix projecting the $\vec{U}$ vector at the $\pm 45^\circ$, zeroing the orthogonal component. The LC of Eq. (3) acts as a wave retarder. Up to scalar multiplication, Eq. (3) reduces to the following Jones matrix

$$L_r(\Delta) = \begin{pmatrix} 1 & 0 \\ 0 & e^{-i\Delta} \end{pmatrix}. \tag{7}$$

Where Δ is controlled by the birefringence β.

The combined effect is given by

$$L = L_{+45}L_r(\Delta)L_{-45} = \alpha \begin{pmatrix} 1 & -1 \\ 1 & -1 \end{pmatrix} \tag{8}$$

where $\alpha = \frac{1}{4}(1 - e^{-i\Delta})$. The intensity of the light that passes through this system is then given by

$$U^\dagger L^\dagger LU = -\frac{1}{4}(cos(\Delta) - 1)|U_x - U_y|^2 = \tag{9}$$

$$-\frac{1}{4}(cos(\Delta) - 1)(|U_x|^2 + |U_y|^2). \tag{10}$$

The last equality holds for randomly polarized natural light for which $< U_x^* U_y >_t = 0$. Thus, by varying Δ we can control the intensity of the reflected light.

References

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