Liquid Crystal Filled Fabry-Perot Filter

The Fabry-Perot is an optically resonant cavity formed by two partially reflecting mirrors that ideally are non-absorbing and therefore transmit the light that is not reflected. In the simplest case these are extremely flat mirrors that are held almost perfectly parallel. Light of a wavelength that is in resonance with this cavity will be transmitted and light that is not will be reflected. The condition for resonance is that

$$2nd \cos\theta = m\lambda \qquad (1)$$

where

n = index of refraction of the transparent medium in the cavity,
d = the spacing between the mirrors,
θ = angel of the light ray in the cavity relative to the normal to the mirrors,
m = an integer indicating the order of the resonance, and
λ = wavelength.

The transmitted wavelengths of a Fabry-Perot are determined by the cavity resonance and can be tuned by varying the thickness, d, of the cavity. This is mechanically complex, since cavity thicknesses are typically a few microns, and adjustments must be fractions thereof and must be uniform over the diameter of the cavity.

Alternatively, the index of refraction, n, within the cavity can be adjusted to tune a Fabry-Perot to a particular wavelength. This can be achieved by filling the Fabry-Perot cavity with a liquid crystal material. Such Fabry-Perots have an electrically adjustable index of refraction, offering extremely quick bandpass tenability without any mechanical motion of the cavity mirrors. Liquid crystal filled Fabry-Perots are therefore inherently stable devices, and typically require less than 10 volts to tune over more than one free spectral range.

The general equation for transmission of the tunable filter as a function of wavelength and mirror spacing is

$$T(\lambda,d) = \frac{1}{1 + \frac{4R}{(1-R)^2}\sin^2(\delta/2)}, \qquad (2)$$

where

R = mirror reflectivity, and

$$\delta = \frac{4\pi nd}{\lambda}. \qquad (3)$$

Note that equation (2) is on is precisely correct if there is no absorption in the mirrors or in the cavity medium, and if there is no wavelength variation in the phase change on reflection from the mirrors.

A calculated transmission spectrum from a liquid crystal filled Fabry-Perot is shown in Figure 1, and an actual measured spectrum in Figure 2. Note the sharpness of the transmission peaks in each plot. (These plots are not intended to be identical, as different Fabry-Perot cavity parameters were used for each.)

The two figures indicate the periodic nature of Fabry-Perot transmission spectra. The distance in wavelength units between the transmission peaks is defined as the free spectral range (FSR) and can be computed from the equation

$$FSR(\lambda,d) = \frac{\lambda^2}{2nd}. \qquad (4)$$

Another important parameter is the full width at half maximum of the transmission peaks. This can be computed from the following equation:

$$\mathrm{FWHM}(\lambda,d) = \frac{\lambda^2}{2nd\,F}. \qquad (5)$$

F is a parameter called the "finesse," which depends on both the flatness of the mirrors and their reflectivity by the equation

$$\frac{1}{F^2} = \frac{1}{F_R^2} + \frac{1}{F_F^2}\,, \qquad (6)$$

Where F_R and F_F are the reflectivity finesse and the flatness finesse, respectively. The reflectivity finesse is given by

$$F_R = \frac{\pi\sqrt{R}}{(1 - R)} \qquad (7)$$

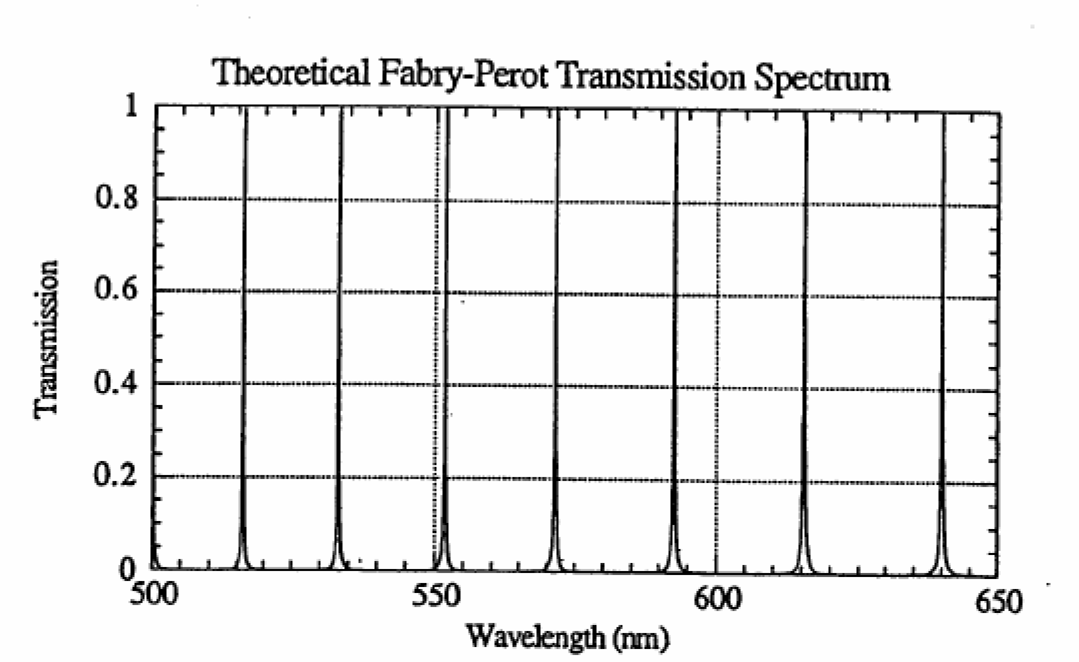

Figure 1: Calculated transmission spectrum for Fabry-Perot with following parameters: R = 96%; n = 1.6; d = 5μm.

The flatness finesse is

$$F_F = D/2, \qquad (8)$$

where λ/D is the mirror spacing error, or the fractional wavelength error by cavity spacing not being uniform over the clear aperture of the device. Typically the mirror spacing must be uniform to λ/50 or better for the total finesse to be dominated by the reflectivity of the mirrors for liquid crystal filled Fabry-Perots. The finesse is also the ration of free spectral range to the bandpass full width at half maximum.

For an appropriate choice of liquid crystal, a single transmission peak can be electrically tuned in wavelength by more than one free spectral range. Thus, a transmission peak can be located at any wavelength in the spectral range for which the mirror reflectivity is acceptable.

We find we can manufacture liquid crystal tunable Fabry-Perot filters with the following parameters:

R between 85% and 95%
D (cavity thickness) between 4 and 20 μm
Finesse between 15 and 25
Clear aperture less then 2 cm

We use nematic liquid crystals in the Fabry-Perot. These materials are birefringent, which means that they have both an ordinary and an extraordinary index of refraction, n_o and n_e. Because only n_e can be electrically controlled, the incoming light to be filtered must be linearly polarized so the n_e is the index controlling the optical path spacing of the mirrors. This extraordinary index can be electrically varied by about 0.1 or 0.2 around its value of 1.6; this gives tenability of nearly 10% around a specific wavelength. By putting two or more liquid crystal Fabry-Perots in series, one can be used as a blocking filter to eliminate all but one peak of the other. Using a technique known as "mode hopping," the tunable range of the combination can be extended to nearly cover the visible region.

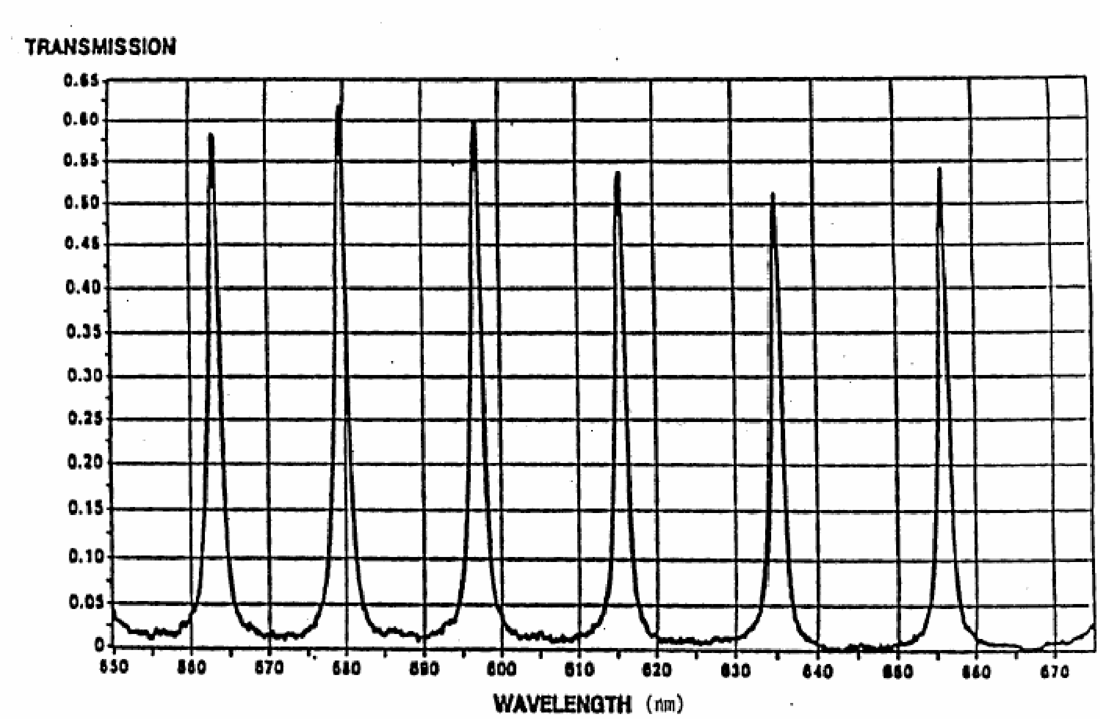

Figure 2: Transmission spectrum of a liquid crystal filled tunable Fabry-Perot manufactured by Meadowlark Optics. Tunability is approximately 15 peak spacings by electrically adjusting the index of refraction within the cavity.

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