Liquid Crystal Fabry-Perot Tunable Filter

Boulder Nonlinear Systems
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There are many compelling reasons to consider a Liquid Crystal Fabry-Perot filter. Tuning of the filter by means of a low voltage is attractive when compared with mechanically switched filters. LC Fabry-Perots are conducive to imaging applications, an advantage over dispersive filtering techniques. This paper describes the design considerations surrounding the use of Liquid Crystal Fabry-Perot Filters.

Introduction

A Fabry-Perot filter is simply an optical resonator, consisting of two planar partial reflectors spaced by a fixed distance. Light incident on the device must satisfy a resonance condition, representing a standing wave in the cavity, in order to be efficiently transmitted. Thus, the ideal transmission spectrum is a periodic function consisting of narrow resonant bands that efficiently transmit, separated by broad bands with strong rejection. The rejected non-resonant light is back reflected by the structure.

Free Spectral Range

Management of this light by the optical system is key to achieving high performance. The periodicity of the spectrum, or free spectral range (FSR), depends only upon the separation of the mirrors, with period increasing as the mirrors are moved together. The width of the spectral band satisfying the resonance condition specified by the full-width-half-maximum (FWHM), narrows as the mirror reflectivity is increased. Likewise, the degree of blocking (or rejection) increases with reflectivity.

The transmission function for the ideal lossless Fabry-Perot filter is determined by the round-trip phase of the cavity, ϕ, and the mirror reflectivity, R.

$$T = \frac{1}{1 + \frac{4R}{(1-R)^2}\sin^2\phi}$$

where

$$\phi = \frac{2\pi\bar{n}l\cos(\theta_i)}{\lambda},$$

and where $\bar{n}$ is the refractive index of the liquid crystal, l is the cavity length, and θ_i is the angle of incidence.

The periodicity of the spectrum, or free-spectral-range (FSR), is inversely proportional to the separation of the mirrors and is independent of the mirror reflectivity,

$$FSR = \frac{\lambda^2}{2\bar{n}l}.$$

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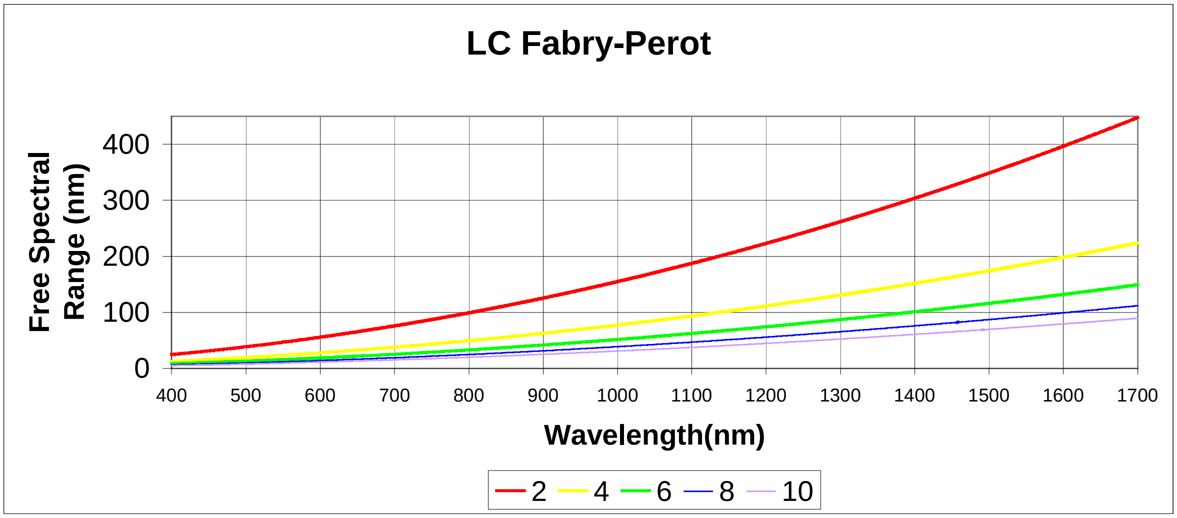
The plot below shows how the FSR varies with wavelength for various cavity thicknesses (2 μm, 4μm, etc.).



The resolution of the spectral band satisfying the resonance condition, often specified by the full-width-at-half-maximum (FWHM), is proportional to the FSR and a factor that depends solely on reflectivity of the mirrors:

$$FWHM = \frac{(1-R)}{\pi\sqrt{R}} FSR\,.$$

The coefficient of the above equation is the inverse of the filter finesse, or number of wavelength channels in a spectral period. The above assumes ideal performance, termed the "reflective finesse" condition of the filter, and is a situation highly sought in fabrication The plot below shows the relationship between FSR and resolution at various reflectivities.

In actuality, defects and the ever-present cavity losses, however small in a single pass, determine the upper limit of performance. It is therefore extremely important that the optical losses be minimized when implementing high finesse filters. Mirror flatness, parallelism and RMS roughness must all be taken into consideration when attempting to achieve reflective finesse over the desired clear aperture.

The Liquid Crystal tunable Fabry-Perot filter is a hybrid device that combines the F-P structure with LC technology. The LC tunable F-P filter is a electro-optical device. The transmission mode can be tuned by changing the optical path length of an intra-cavity material. This is ideally accomplished using a material with a voltage dependent refractive index, allowing rapid electronic wavelength selection. In this case, tunability is accomplished using a specific LC alignment, which induces the anisotropic molecules to "stand-up" in the presence of an applied AC field.

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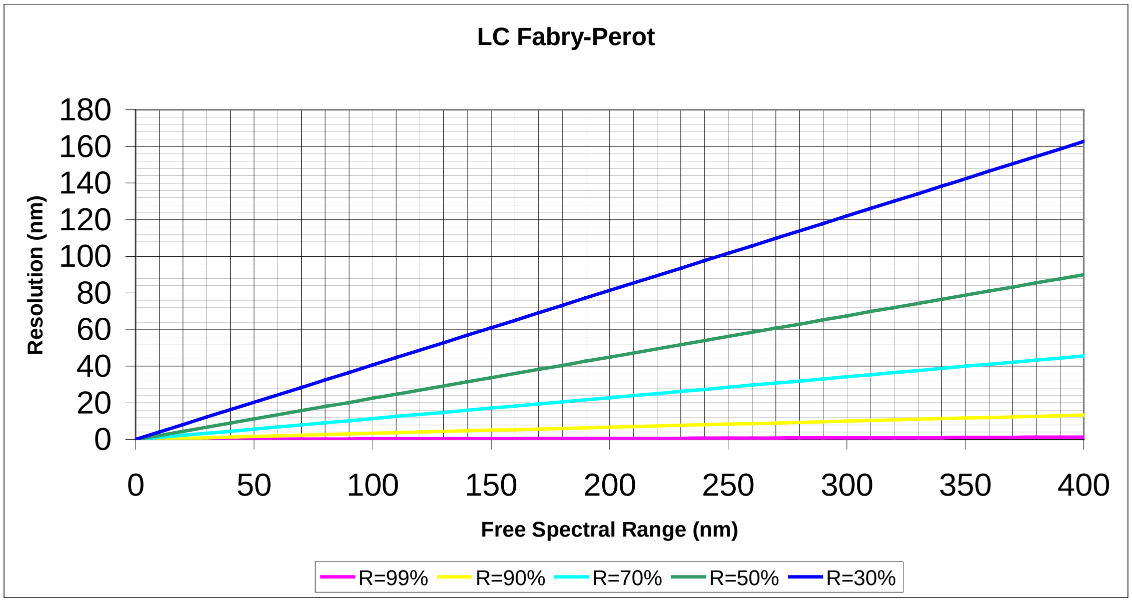
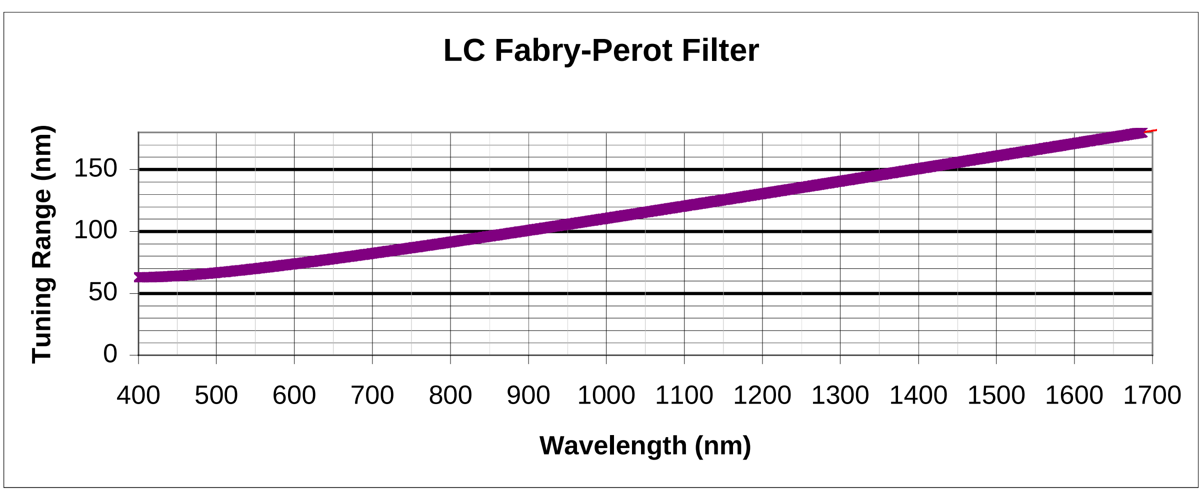


In order to shift the resonance wavelength through an entire period, (full FSR of tunability), a single-pass optical path length change of λ/2 is required. In other words, full-tunability requires an analog optical phase shifter with a 180° phase modulation within the cavity. In light of the large FSR required, one might assume that a decrease in cavity width would increase the tuning range. However, the tuning range of the filter is given by

$$\Delta\lambda \approx \frac{\lambda}{\bar{n}}\Delta n\,.$$

The important thing to note here is that the tuning range is independent of the cavity width, simply requiring a large percentage change in refractive index of the nematic LC.



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Tunable liquid crystal based Fabry-Perot filters are suitable for applications requiring reasonable passband widths (> 3nm). These solid-state devices are attractive alternatives to mechanically rotating filter wheels. The tuning range of these devices can be 60-80 nm in the visible or 120-160 nm at telecom wavelengths. Their analog tuning capabilities and large clear aperture make these filters especially suitable for spectroscopic imaging applications

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