TECH NOTE 002

THE FABRY-PEROT ETALON FILTER

The Fabry-Perot etalon consists of two, semi-reflective surfaces, separated by a gap. This can be facing surfaces of two substrates separated by air or vacuum or the two sides of a solid substrate. Given sufficiently high optical tolerances, this structure has the unusual property of reflecting all wavelengths except those which are an integral number of half waves of the gap between the surfaces. These wavelengths it transmits fully. As such it can be used, very effectively, as a filter.

In order to look at the properties of the etalon as a filter, it is convenient to examine the general equation that defines the interference,- viz:

$$\mathbf{T_e = T^2 / (1 - R)^2 \{1 + [4R/(1 - R)^2]\sin^2\delta\}} \quad \text{...................................(1)}$$

in which: $\mathbf{T_e}$ is the total transmission of the etalon.
$\mathbf{T}$ is the transmittance of the coating on either surface.
$\mathbf{R}$ is the reflectance of the coating on either surface.
δ is the angle of incidence of the light within the etalon cavity.

This can be simplified because of the following relationships:

It can be assumed that, with good coatings, $\mathbf{T = 1 - R}$
and, further, let: $\mathbf{F = 4R/(1 - R)^2}$

Then, (1) becomes:

$$\mathbf{T_e = 1 / 1 + F\sin^2\delta} \text{...(2)}$$

Now, $\mathbf{T_e}$ is a maximum for $\delta = \mathbf{m\pi}$
where **m** is the order of intereference and is: **0, +/-1, +/-2,** etc.

Also, the Finesse (***F***) of the etalon is defined as: $\boldsymbol{F} = \mathbf{FSR / HBW}$

Where **FSR** is the Free Spectral Range of the etalon;- i.e. the distance between adjacent peaks of transmission and **HBW** is the bandwidth of the etalon at 50% of the peak transmission; i.e.:

$$\mathbf{HBW = 0.5T_e}$$

Therefore, from (2):

$$\mathbf{0.5 = 1 / 1 + F\sin^2\delta}$$

For a narrowband filter $\mathbf{\sin\delta} = \delta$

Therefore,

$$\mathbf{0.5 = 1 / 1 + F\delta^2}$$

i.e.: $\delta = 1 / F^{0.5}$ (= ½ Fringe, or filter, width)

The separation between fringes is π, therefore,

$$\textbf{Finesse } (\mathcal{F}) = \pi F^{0.5} / 2$$

Or, $\mathcal{F} = \pi R^{0.5} / (1 - R)$ ……………………………….(3)

This is a very significant result as it indicates that the Finesse of an etalon is totally dependent on the reflectance of the surfaces only. However, hidden in this calculation is the presumption that the etalon plates, or surfaces, are perfectly flat and parallel,- a condition that would not exist in practice.

To ascertain how non-perfection in these parameters affects the performance of the filter, an error will be added to the design to see how this affects the actual Finesse.

Let the error in the etalon be $\Delta \mathbf{d}$
And let this be $</= \delta$

Then: $\Delta\lambda / \lambda = \Delta d / d = </= 0.5 \Delta\lambda_h / \lambda$

Where: $\Delta\lambda$ is error in wavelength, and
$\Delta\lambda_h$ is half the bandwidth

Now, since the resolving power of the filter is defined as:

$$\lambda / \Delta\lambda = m\mathcal{F}$$

Then, $\mathcal{F} </= 0.25\lambda / \Delta d$ ………………………………(4)

This is a most important equation in the construction of an etalon filter as it defines the optical quality of the substrates in order to achieve a particular Finesse. The Finesse is very important to the overall design of a system as it connects the bandwidth with the Free Spectral Range. The longer the FSR, the easier it becomes to use other filters to block unwanted orders and wavelengths. However, a longer FSR implies a wider bandwidth for a given Finesse. It can be seen from (4) that for a Finesse of 25, which is typically required to construct a complete system, the required optical tolerance is **0.01λ**. This is a total allowable tolerance between the flatness of the surfaces and the parallelism of the surfaces. Therefore, statistically, each of these has to be **$</= 0.003\lambda$**, or 1/300 wave. In reality, flatness and parallelism of **~1/200 wave** is usually sufficient due to some compensation.

However, it is very important to note that the beginning of this calculation made the assumption that $\Delta \mathbf{d} </= \delta$ which is half the bandwidth. Therefore, even the tolerances referred to above imply a broadening of the bandwidth by approximately 15% over the ideal.