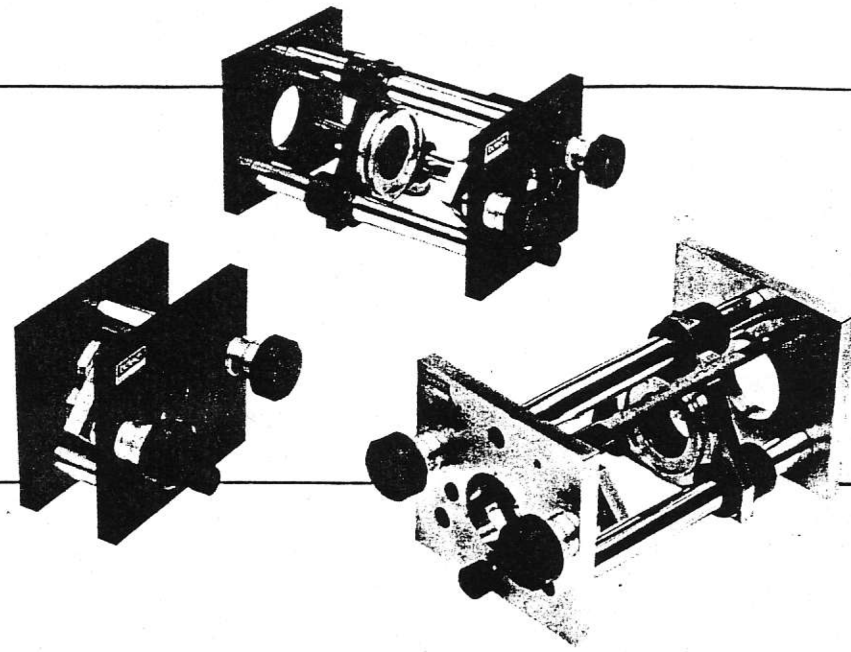

Tech Memo on
Fabry-Perot Interferometry

burleigh

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1. ABSTRACT

This technical memo is written for Fabry-Perot users. For further information on the theory of Fabry-Perot Interferometers several excellent references are listed. This memo briefly describes how a Fabry-Perot works, then summarizes relationships and equations that characterize a Fabry-Perot. Design considerations are reviewed and applications are described. A section outlines how to choose and specify a Fabry-Perot system. A final section describes the different types of interferometers available.

2. GLOSSARY OF TERMS

θ angle of incidence of light to Fabry-Perot
n index of refraction of material between Fabry-Perot plates
λ wavelength
FP Fabry-Perot
d cavity spacing or plate separation
D plate or mirror diameter
r_1 1st surface radius of plates
r_2 2nd surface radius of plates
FSR Free Spectral Range

Plano, general spherical $c/2nd$, $\frac{1}{2}nd$, $\lambda^2/2nd$
Confocal $c/4nd$, $\frac{1}{4}nd$, $\lambda^2/4nd$
Bifocal $c/8nd$

Ω Solid angle from source to Fabry-Perot
a area of aperture of Fabry-Perot
ρ Radius of area
U Etendue = Ωa
F_R Reflectivity Finesse

Plano $\frac{\pi(R)^{1/2}}{1-R}$

Confocal $\frac{\pi R}{(1-R^2)} \cong \frac{\pi}{2(1-R)}$ (for R approaching 100%)

F_F Flatness Finesse M/2 for λ/M plate error
F_I Instrument Finesse

Plano $F_I^{-2} = \sum_i F_i^{-2}$

Confocal $F_I^{-2} = \sum_i F_i^{-2}$

R Reflectivity of coated FP plates
T Transmission of single surface of coated FP plate
A Absorption and scatter loss of single surface of coated FP plate $(R + T + A = 1)$
t FP throughput or transmission

Plano $t_{max} = (1 - \frac{A}{1-R})^2$

Confocal $t_{max} = \frac{1}{2}(1 + \frac{A}{T})^{-2}$

m Order of interference

3. INTRODUCTION

Fabry-Perot Interferometers, Tunable Etalons, Confocal Etalons, Solid Etalons, PZT scanning resonant cavity interferometers, Fixed Air Gap Etalons, pressure tuned Fabry-Perots, these are all names for different versions of one instrument, most properly known as a Fabry-Perot Interferometer (F.P). FP's are capable of extremely high spectral resolution, are extremely efficient (transmission typically ranges from 40% to 99%), and are spectrally tunable. Applications include high resolution spectroscopy, intracavity laser line narrowing, astronomy, line selection or rejection, and many others.

A FP is constructed with two partially transmitting mirrors, which may be flat or radiused, that are parallel to each other. This is said to be the FP cavity. If the cavity is illuminated with a beam of coherent, monochromatic light, it will transmit the beam when the optical path length between the surfaces is an integral number of half, quarter or eighth wavelengths of the incident light. The fractional wavelength varies with the type of cavity used as explained later.

In a solid etalon the two surfaces of one substrate are highly parallel and are coated with partially transmitting coatings. Tuning can be accomplished by tilting the etalon to change the path length or by changing its temperature to change the index of refraction.

In an air spaced etalon two mirrors, or plates as they are often called, are used with partially transmitting coatings on their "first" surfaces and antireflection coatings on their "second" surfaces. Normally the second surface is slightly wedged (10 to 30 min) with respect to the first surface to avoid forming additional cavities. Tuning can be accomplished by moving one mirror with respect to the other. This is often done by using piezoelectric materials, by tilting, by changing the pressure and thus the index of refraction of the air between the plates, or by changing the temperature of the spacer elements used to separate the mirrors. PZT tuning is one of the most convenient methods and allows rapid, repetitive tuning.

FP's typically use 1" to 2" diameter mirrors with flatnesses of $\lambda/100$ to $\lambda/200$, (plates are normally specified for $\lambda = 5461$Å). The parallelism and position of the two mirrors must be maintained to within $\lambda/100$ to $\lambda/200$ or to 25Å for many hours for some applications. Such stability is attained by massive construction, well-constrained symmetrical designs, use of high linearity PZT drives for remote adjustment and tuning, extensive use of low thermal expansion materials, the elimination of compliant materials or interfaces, and extensive testing for quality control. It is estimated that Burleigh has accumulated over 20,000 hours of testing time on FP's at the date of this writing.

With the introduction of Burleigh's DAS Data Acquisition/Stabilization Systems, total automatic control of PZT Fabry-Perots is now possible. These systems continually optimize Fabry-Perot finesse and correct for frequency drift, even in very low light level experiments.

4. THEORY

This section will present and discuss the relevant terms and formulae for the operation of a plano (flat-flat) or general spherical cavity FP. A following section will present the formulae, without discussion, for the special case of a confocal Fabry-Perot (radiused mirrors separated by their radius of curvature). For complete information the reader should consult one of the references listed in the appendix.

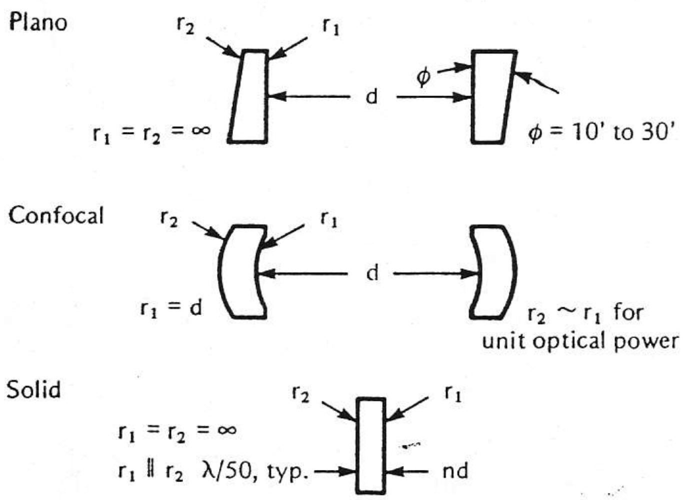


Figure 1
Fabry-Perot Configurations

A. Plano Fabry-Perot

The condition for constructive interference (reinforcement) for a transmitted wavefront is,

$$2nd \cos \theta = m\lambda$$

where:

- n is the refractive index of the medium between the two reflecting surfaces
- d is the mirror spacing
- θ is inclination of the normal of the mirrors to the direction of incoming radiation
- m is the order of interference
- λ is the wavelength

Working through the equation for the shape of the multiple beam interference pattern (Airy formula) and using standard definitions, we find the following set of relationships:

FREE SPECTRAL RANGE (FSR): The spectral display obtained with a FP is repetitive. Consecutive fringes obtained with quasimonochromatic light correspond to consecutive integer values of the order of interference. The range of wavelengths which can be displayed in the same spectral order without falling into adjacent orders is termed the FREE SPECTRAL RANGE (FSR).

Using plano mirrors separated by a distance d, we have:

FREE SPECTRAL RANGE:

$$FSR = \lambda^2/2nd \text{ (wavelength units) } \Delta\lambda_{FSR}$$
$$FSR = 1/2nd \text{ (wavenumbers) } \Delta\sigma_{FSR}$$
$$FSR = c/2nd \text{ (frequency units) } \Delta\nu_{FSR}$$

where c is the speed of light

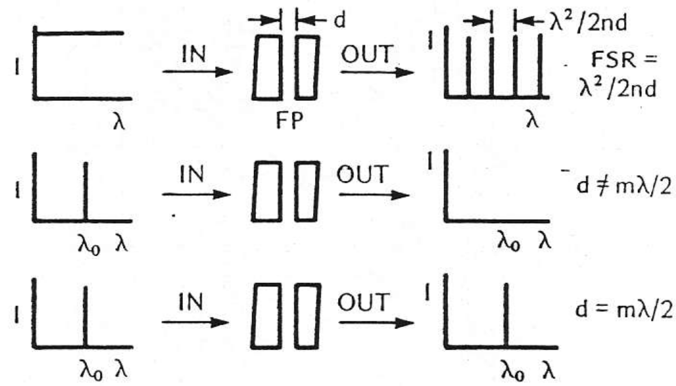


Figure 2
FP output for broadband and monochromatic inputs

MINIMUM RESOLVABLE BANDWIDTH (MRB) OR INSTRUMENTAL FUNCTION: The Instrumental Function is the spectral profile which would be observed with a purely monochromatic source. The minimum resolvable bandwidth is arbitrarily defined as the width (full width at the half-maximum points) of the Instrumental Function. It is given by the following.

$$\Delta\lambda_{BW} = \Delta\lambda_{FSR}/F$$
$$\Delta\sigma_{BW} = \Delta\sigma_{FSR}/F$$
$$\Delta\nu_{BW} = \Delta\nu_{FSR}/F$$

where F is the finesse

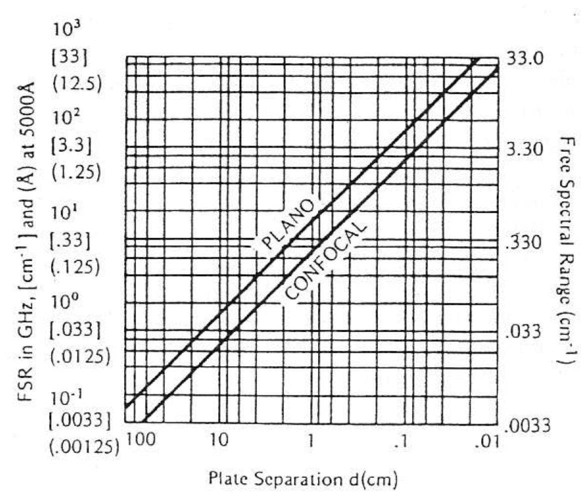


Figure 3
Plate Separation vs Free Spectral Range

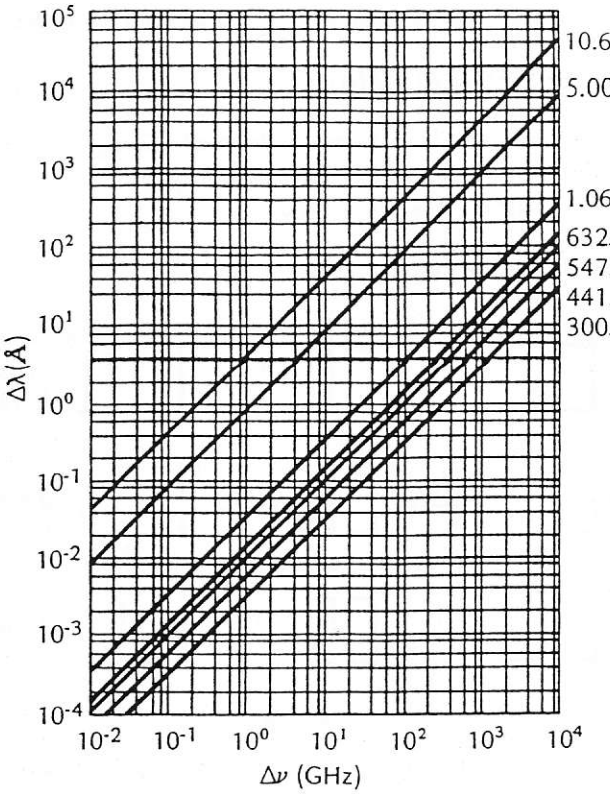


Figure 4
Δν vs Δλ for different wavelengths λ

SPECTRAL RESOLUTION:

$$\frac{\lambda}{\Delta\lambda_{BW}}$$

$$\frac{\sigma}{\Delta\sigma_{BW}}$$

$$\frac{\nu}{\Delta\nu_{BW}}$$

FINESSE (F): As seen from the definition of the minimum resolvable bandwidth, the finesse is the key measure of the interferometer's ability to resolve closely spaced lines. The finesse can be thought of as the effective number of interfering beams involved in forming the FP Multiple-beam interference fringes and is proportional to the time constant or decay time of the FP Interferometer. Each factor which reduces this time constant serves to reduce the finesse. The major factors which limit the net finesse are (1) mirror reflectivity of less than unity; (2) lack of parallelism and/or planeness of the mirrors. Two other factors, the size of the pinhole if present and the diameter of the limiting aperture, are of secondary importance. The net finesse is found by treating the component finesses as if they were parallel impedances.

REFLECTIVE FINESSE (F_R): $F_R = \frac{\pi(R)^{1/2}}{1-R}$

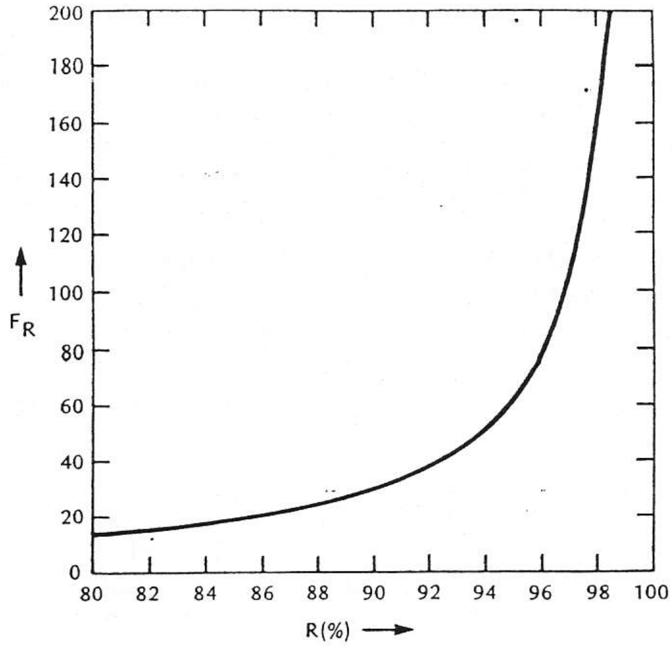


Figure 5 Reflectivity Finesse vs Reflectivity

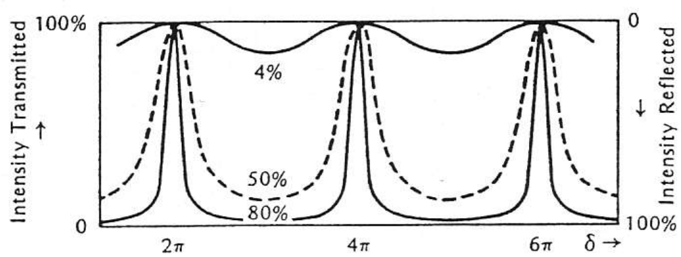


Figure 6
Intensity Contours of Fringes Due to Multiple Reflections as a Function of Reflectivity

FLATNESS OR FIGURE FINESSE: $F_F = M/2$ for λ/M plates

where M is the fractional wavelength deviation from planeness across the mirror aperture, or the measure of the lack of parallelism of the mirrors within the aperture being used (normally specified at λ = 546.1nm)

PINHOLE FINESSE

d	=	plate spacing
f_L	=	focal length of lens L_1
θ	=	$D/2f_1$
D_p	=	pinhole diameter

The maximum path length change $d - d\cos\theta = (1/F_p)(\lambda/2)$

Therefore $\frac{4\lambda L^2}{D_p^2 d} = F_p$

Normally F_p should be two to three times the desired operating finesse, although this will result in some loss of transmission. Note: The pinhole must be exactly on axis or the pinhole finesse will be much reduced due to the non-linear change in fringe radius with angle.

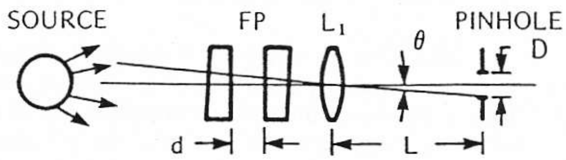


Figure 7
Path Length Change Due to Pinhole Diameter with Extended Source

DIFFRACTIVE FINESSE:

$$F_D = 2D_p^2/\lambda nd \quad \text{(on axis) or}$$

$$D_p/2p\lambda nd \quad \text{(at the p'th fringe off axis)}$$

$$F_D = D_p/2nd\theta p$$

where D_p is the diameter of the limiting aperture.

NOTE: $D_p = D$ if no pinhole is used.

INSTRUMENT FINESSE: $F_I^{-2} = \sum_i F_i^{-2}$

The plots below show theoretical net Instrumental Finesse for λ/100 and λ/200 plates with a spherical error assuming the pinhole finesse is 1.5 x the plate flatness finesse. To simplify the calculation the diffractive finesse is not included.

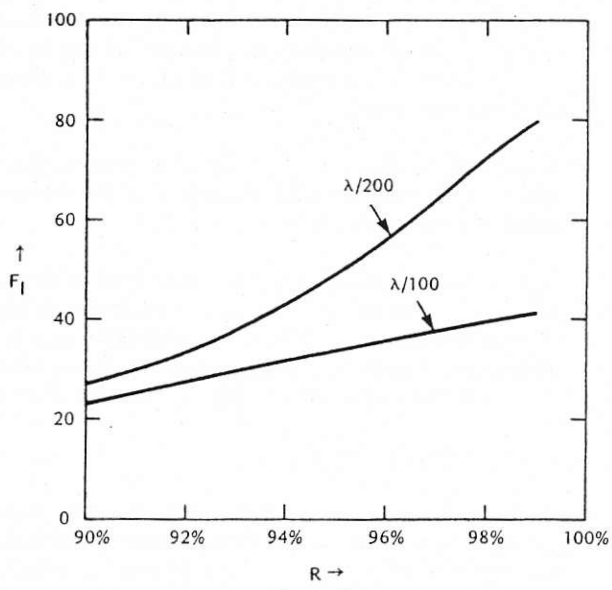


Figure 8
Net Finesse vs Reflectivity as a Function of Plate Flatness Assuming Pinhole Finesse = 1.5x Plate Flatness Finesse

THROUGHPUT: Throughput (t) is defined as the transmission of a FP at resonance. One advantage of a FP is that it is an extremely efficient instrument. For small apertures (or infinitely flat plates) t depends primarily on the losses in the mirrors and the coatings. With modern multilayer dielectric coatings, t can be substantial even with reflectivities of 98 to 99%. t is given by:

$$t = \left(1 - \frac{A}{1-R}\right)^2$$

where A = losses due to scatter and absorption. A is typically $\leqslant$ .2%/surface for modern coatings. Figure 9 is a plot of R vs t assuming A = .1%, .2%, .5% and 1%.

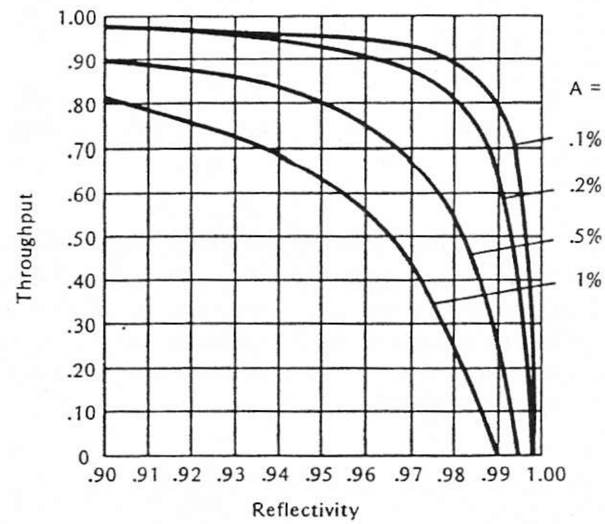


Figure 9
Small Aperture Throughput vs Reflectivity as a Function of Absorption

This definition of throughput assumes perfectly flat plates. If the plates have a surface error, as they always do to some extent, the peak throughput will normally be reduced. In general, the reduction in throughput becomes substantial wher the reflectivity finesse exceeds the flatness finesse.

The relationship for throughput as a function of plate error is highly complex. The graph below plots throughput due to plate flatness error (t_F) assuming only a spherical plate error. In practice, the actual plot would be slightly lower due to gaussian surface errors (imperfect surface finish).

F_R = Reflectivity finesse
F_F = Plate flatness error finesse = M/2

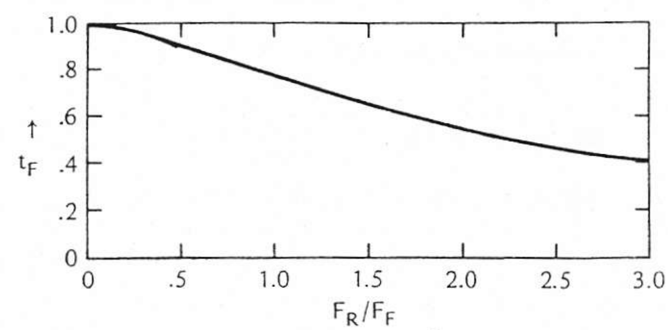


Figure 10
Plate Flatness Throughput vs Reflectivity as a Function of Plate Flatness

Combining Figures 9 and 10 a set of net transmission to plots can be derived. See Figure 11.

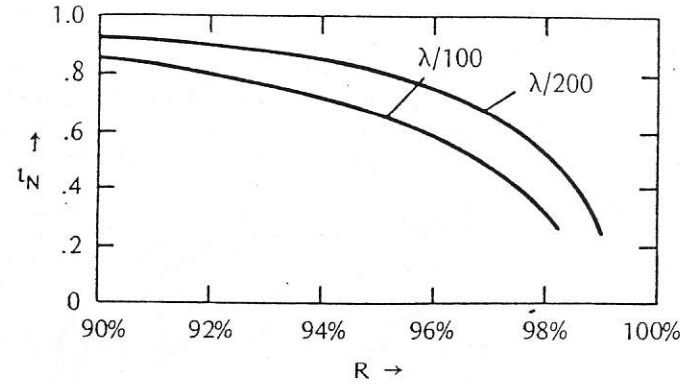


Figure 11
Net Throughput vs Reflectivity as a Function of Plate Flatness for 0.2% Absorption

ETENDUE U: The light gathering power of a FP is characterized by etendue U. All the radiation from a source within a solid angle Ω subtended at an aperture of area a can be transmitted at a bandpass $\Delta\nu$

$$U = \Omega a = \frac{(\pi D_p^2 \lambda)}{4dF_I}$$

B. Confocal Fabry-Perot

d = mirror spacing
r = mirror radii
R = Reflectivity

Maximum Transmission: $t_{max} = ½ (1 + A/T)^{-2}$

Free Spectral Range: $FSR = c/4nd$

Minimum Resolvable Bandwidth: $MRB = \Delta\lambda_{BW} = \frac{C(1-R^2)}{4\pi rR}$

Reflectivity Finesse: $F_R = \frac{\pi R}{(1-R^2)} \cong \frac{\pi}{2(1-R)}$

Figure Finesse: $F_F = M/2$ for λ/M figure errors (alignment does not affect the finesse of a confocal FP)

Instrument Finesse: $F_I^{-2} = \sum_i F_i^{-2}$

Etendue $U = \Omega a$

Approximate optimum etendue $U = \pi^2 r\lambda/F_I$

5. DESIGN CONSIDERATIONS

The parameters to consider in Fabry-Perot designs include mechanical stability regarding both vibrational stability and mechanical creep; thermal stability; linearity of mirror tuning which would often be piezoelectric; ease of adjustments for plate spacing and alignment; mirror mounting without distortion and ease of changing mirrors; and of course, cost.

Application determines final design. On a lab table a large instrument is permissible so versatility and ease of operation can dictate the size and configuration. Inside a laser cavity or telescope, size governs the design to a large degree. Burleigh's Fixed Air Gap etalons are the ultimate in terms of simplicity mechanical stability, but lack versatility. Burleigh's RC series FP Interferometers offer maximum versatility and are very stable, but would rarely fit into a laser cavity.

A. Mechanical Stability

The two requirements for mechanical stability are sensitivity to vibration and mechanical creep. The Fabry-Perot plates can not move any more than about 10Å (for λ/200 plates) in response to normal vibrations such as footsteps or bumping a lab table, and they must return to their original position to within about 10Å. Otherwise the finesse or axial position can change enough to degrade the performance.

All mechanical devices tend to creep after being perturbed. Oil or grease films flow and metal flows when stresses change. But the FP must settle to a stability of about 20Å after an initial period for stabilization. This period can be as long as several hours after a gross adjustment, even in a carefully designed instrument.

Using PZT elements is a great aid in this regard, as the alignment can be finalized electronically after the instrument has stabilized mechanically.

In general, mechanical stability can be insured by maintaining a high degree of design symmetry, using heavy spring loads against adjustment threads, incorporating hardened, polished adjustment interfaces, constraining all elements except for desired motion, and using highly rigid construction materials.

B. Thermal Stability

Coefficients of expansion, thermal inertia, and mechanical configuration are the controlling parameters for thermal stability. Different materials have different thermal conduction rates. Ceramic, for instance, changes temperature much more slowly than aluminum, and therefore has a higher thermal inertia. If ceramic and aluminum parts are arranged to compensate for each other's expansion, the aluminum will change dimensions much more quickly than the ceramic when the temperature varies, and the FP alignment and axial position will wander until a new thermal equilibrium is reached. Controlling the thermal mass of components helps minimize thermal cycling.

Using low coefficient materials will also minimize thermal inertial effects as well as insure low thermal drift. Burleigh makes extensive use of Invar and specially made Super-Invar, low expansion ceramic insulators, epoxies and PZT materials in Fabry-Perots and etalons.

C. PZT Drive

Three independent PZT elements can be used for alignment by adjusting the voltage to each element separately, and for tuning by adjusting the voltage to all three simultaneously. Electronically controlled alignment and tuning allows hands-off adjustments and makes automatic control possible.

It is important for a FP to use high linearity, low thermal expansion PZT materials. These materials are more difficult to work, are less sensitive than other commonly used PZT materials, and consequently are more expensive. PZT linearities of better than 1% inter-order spacing are possible. The linearity of the PZT driven mirror motion can be further improved approximately 10 times by utilizing the programmable ramp feature on all Burleigh Ramp Generators.

D. Mirror Mounting

Two of the most difficult tasks in building a FP are holding the plates so they are not warped, and holding them such that their position is precisely defined both thermally and mechanically. Considering that distortions or drifts of 10 to 20Å will degrade the performance of a $\lambda/200$ plate, the problem is easily understood.

One classic technique is to support the plate on the front surface at three points, and to hold it in place with three adjustable point contacts on the rear surface. To a first order this eliminates warping, although it introduces local distortions in the vicinity of the front surface contacts and makes narrow plate spacings virtually impossible. With proper choice of materials the plate position can be well defined thermally and mechanically. See Figure 12.

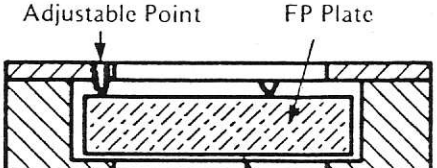


Figure 12
Three Point Mounting of FP Plates

Another technique which can be used with some success is cementing plates into a holder on their edges. Narrow plate spacing is an advantage. This system is somewhat less precise thermally but quite acceptable if carefully done. It can be very good mechanically if effects of creep in the cement are eliminated. Choice of cement is very important, as shrinkage during cure can badly stress and warp the plates. This technique is not recommended for $\lambda/200$ plates. Burleigh uses a variation of this technique in the TL series Tunable Etalon.

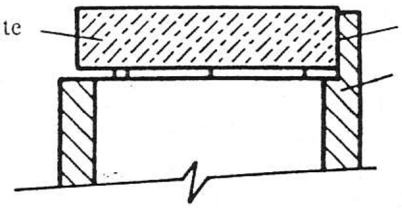


Figure 13
Edge Mounting of FP Plates

A technique which meets all criteria was independently developed by both Ramsay and by Burleigh, and has since been much refined by Burleigh. The technique eliminates essentially all distortions, allows narrow plate spacing, is mechanically rigid, and is well defined thermally with proper choice of materials.

Three tabs, preferably of Invar, are cemented to the OD of a plate. These tabs have solid glass spheres pressed or epoxied into through holes bored in the tabs. The plate with tabs is placed in a holder, with the glass spheres resting on hardened pads. The spheres are then pressed onto the pads with a spring loaded retainer. Thus, the plate can not distort since no forces can be present on the plate, its position is well defined thermally by choice of material, it is rigidly held, and narrow spacings are possible.

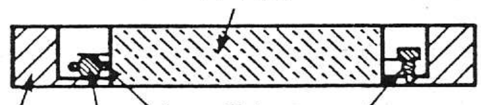


Figure 14
Burleigh FP Plate Mounting Technique
(See Figure 43)

6. APPLICATIONS

A. Optical Systems

In optical system applications, the FP is used as a wavelength filter. As discussed earlier, the Free Spectral Range (FSR) limitations of the FP necessitates simultaneous use with other FP's or narrow band interference filters to isolate the pass band or wavelength of interest assuming the source bandwidth exceeds the Fabry-Perot FSR. This requirement varies with the application.

For an extended source (a source of finite size) the wavelength response of the optical system including the FP will depend on the angular distribution of all the rays from all object points on the source through the FP. It is possible from the Airy formula to obtain the transmission for one ray. Integration over all rays from each object point yields total system transmission. In most optical systems the angular distribution of rays through the interferometer differs for each object and is therefore a complicated calculation. Three optical systems will be discussed. The first is a special case, the second two describe common systems for imaging a source through a FP.

The special case is illuminating the FP with essentially perfectly collimated light, as is possible with laser sources and good quality beam expanding optics. This is equivalent to having a true point source at the focal point of an imaging lens so that there is only one object point to be imaged through the FP. In this case the instrumental bandwidth of the FP is not broadened, since all rays through the FP are parallel to each other.

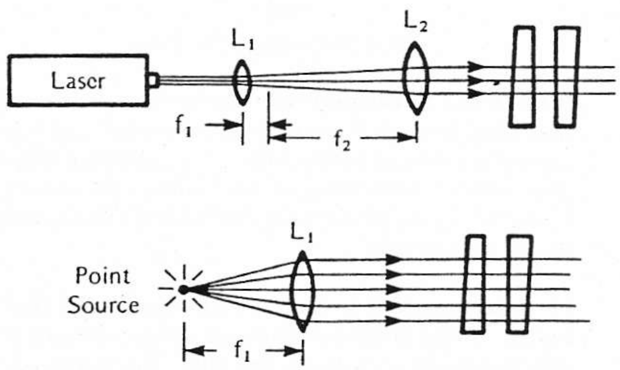


Figure 15

FP Illuminated with Perfectly Collimated Source

An alternative method of producing an effective point source is to employ a pinhole with a detector that is small compared to (or nearly equal to) the spot size of a lens that focuses the FP fringe pattern onto the detector. For example, one computes the pinhole size in conjunction with the focusing lens that will produce an angular spread of the beam at the FP which causes a wavelength shift that is smaller than the instrumental bandwidth of the FP due to reflectivity or flatness considerations.

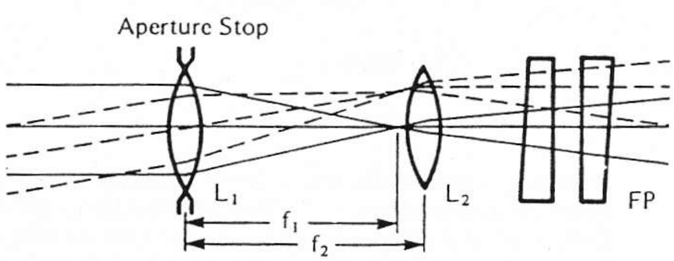


Figure 16

Telecentric Optical System

Another optical system is the telecentric system. In this system the FP is located at a position in the optical system where all the chief rays are collimated or parallel to the optical axis. Such a location is produced by taking a lens and locating it one focal length away from the aperture stop (the stop that limits the beam diameter). Hence the center of the pass band for each object point is identical to any other. The instrumental width is broadened due to the f-number of the optical system and is identical for each object point on the source.

In another type system, the FP is located in the collimated section of the optical system. Here all rays from the same object point on the source are parallel through the Fabry-Perot and hence have the same pass band. However, for each different object point the parallel bundle of rays intersects the FP at a different angle relative to the optical axis. Therefore, each bundle will have a different pass band relative to some other bundle of rays.

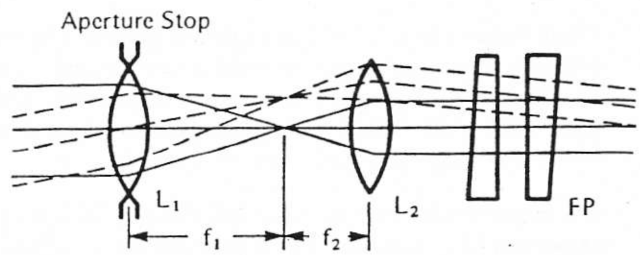


Figure 17

Collimated Optical System

Figures 16 and 17 illustrate these two types of systems which are commonly used in astronomy. Note carefully that the location of the FP relative to the image plane determines how much of the beam diameter the FP "sees". This factor can effect the transmission characteristics of FP due to non-flatness of the mirrors. Uniform transmission occurs when the beams from all object points overlap completely. However, trade-offs are necessary due to the fact that the smaller the aperture used the better the flatness finesse and hence throughput and resolution characteristics of the FP.

Of course, besides the above consideration, size of the FP and the imaging consideration of the optical system also play a part in the decision making process as to where to place the FP.

The use of FP's has been limited in the past because of a lack of reliable commercial instrumentation. A number of common applications will be briefly discussed and diagrammed.

B. Light Scattering

From gases, liquids or solids, Raman, Brillouin or Rayleigh scattering are often studied with FP's. Measurements are made of line shifts and line shapes. Burleigh's RC series Fabry-Perot Interferometers are particularly appropriate for this application. Photon counting and correlation techniques are often applied with this work. "Laser Light Scattering" by Chu, published 1974, Academic Press is recommended for those entering the field. See Figure 18.

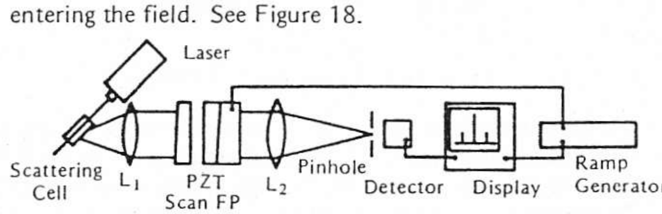


Figure 18

Typical FP Light Scattering System

The choice of pinhole size and placement of the collimator is often an important question in scattering systems. In general, the pinhole should be as small as possible to maximize finesse but there are a number of trade offs.

If all samples investigated in Brillouin spectroscopy were ideal and if noise were not a problem, no focusing lenses or pinholes would be required. Since we must deal with samples with imperfections, and we do not have infinite signal to noise ratios, it is necessary to use a lens to maximize the light collected and an aperture to reject spurious scattering due to "real world" samples that are imperfect. Because various samples differ in the degree to which they scatter the incident laser light, they pose different problems to the Brillouin spectroscopist. The choice of lens and aperture system is thus a reflection of the quality, size, etc. of the sample. Depending on the state and homogeneity of the sample one may choose an experimental set up with a pinhole either fore or aft of the Fabry-Perot Interferometer. The following discussion compares the features and applications of the two systems.

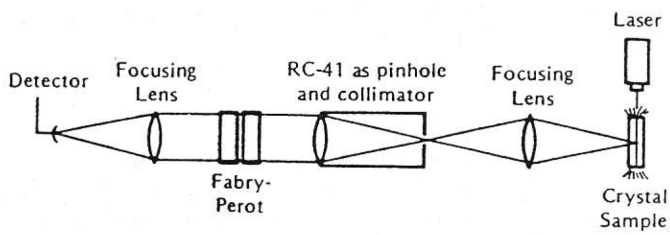


Figure 19

Fore Pinhole System

B.1. Fore Pinhole System

The polished ends and defects in inhomogenious materials can cause problems if the intensity of the scattered light from these points is great compared with the light scattered from the point of interest and this parasitic light enters the interferometer. In such cases, a spatial filter at the front end of the Fabry-Perot is required to reject this spurious scattered light. This is especially true for small or multi-domain crystals. See Figure 19.

One would want to reject:

1) High intensity, scattered light from surface of the crystal sample.
2) Parasitic light from beam scattering due to flaws or cleavage planes in the crystal.
3) Multiple scattering inside the crystal.

It is desirable to have the pinhole small enough to block unwanted scattered light but large enough to collect as much light as possible. There is always a trade-off between pinhole finesse and beam intensity. For homogeneous extended sources, open the pinhole until there is a degrading of instrument finesse due to a decrease in pinhole finesse. Fore system pinholing is recommended to obtain the cleanest signal if intensity is not a problem. See Figure 20.

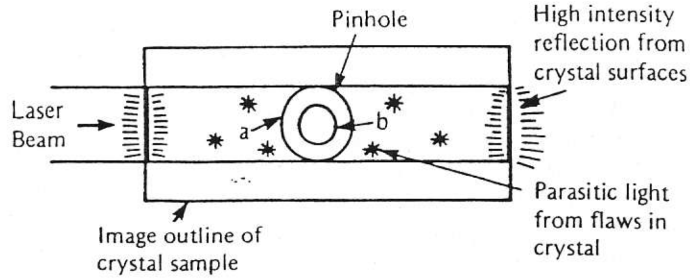


Figure 20

Image of Laser Beam through Crystals at Pinhole Plane

Pinhole of radius a:

- optimum for light collection
- collects all (full width) of exciting laser beam; no beam intensity is lost due to pinhole cut-off

Pinhole of radius b:

- needed if there is a great number of flaws in the crystal and that is the largest aperture attainable to collect "pure" scattered light from the sample
- collection of available scattered light is reduced

For inhomogeneous extended sources, guidelines for pinhole of radius b apply. A fore pinhole system introduces extra cost, possible aberration, and transmission loss due to the extra focusing lens.

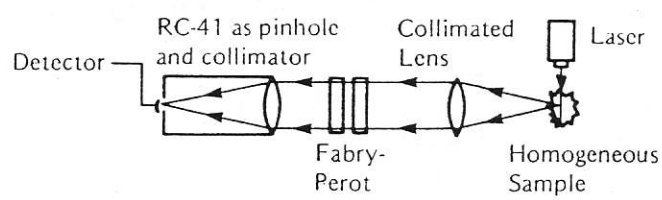


Figure 21
Aft Pinhole System

B.2. Aft Pinhole System

With homogeneous liquid or gas samples, there is little or no parasitic light scattered from flaws, irregularaities or surfaces of the sample. Therefore, there is no need to prevent light entering the interferometer from certain portions of that sample. The focusing of the lens is such as to image light from one point of the sample onto the pinhole of the RC-41 Collimator. Any additional light collected from other points of the sample will not be imaged onto the pinhole. The pinhole at the aft end therefore acts to eliminate detection of the light scattered from points in the sample at unwanted angles.

Since this system incorporates one less lens, it is less costly and simplier to align. There is, however, a potential for collecting some unwanted scattered light, but if the sample is homogeneous this light is minimal.

C. Intra-Cavity Insertion

An etalon, or Fabry-Perot, can be inserted in the cavity of a cw or pulsed multi-mode laser for single mode operation, or into the cavity of a modeless laser to narrow the linewidth. Burleigh has several etalons for this application. If PZT tuning is desired, the TL Series Tunable Etalons are recommended. The VS Series Variable Spaced Etalons are suggested for tuning by tilting or pressure. The spacing is easily varied with this model from 0 to 10mm. Burleigh can also supply Fixed Air Gap (FAG) or Solid Etalons (SE). Ask for our special Tech Memo on Intracavity Etalons for further information.

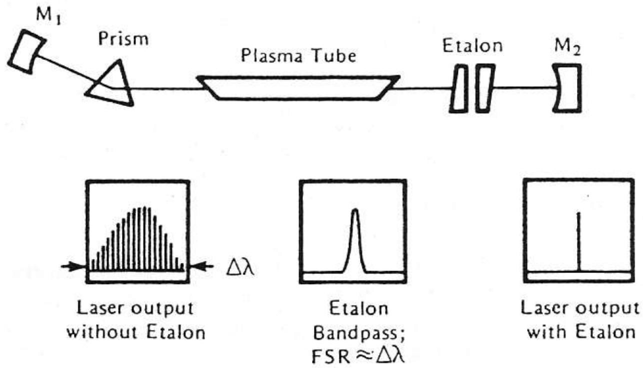


Figure 22

Effect of Intracavity Etalon on Argon Laser

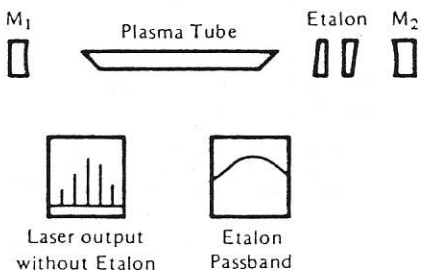


Figure 23

Effect of Intracavity Etalon on HeNe Laser

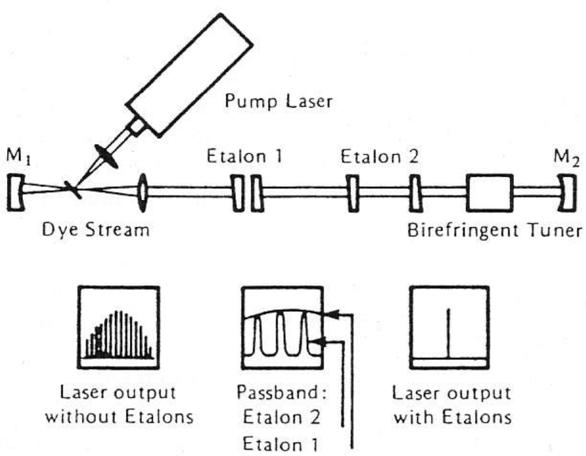
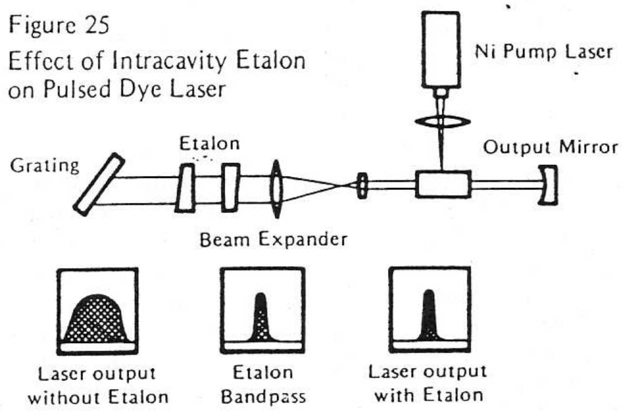


Figure 24

Effect of Intracavity Etalon on CW Dye Laser

Figure 25
Effect of Intracavity Etalon on Pulsed Dye Laser



D. Laser Mode Analysis

A PZT scanning FP is suggested for laser mode analysis. A plano FP such as Burleigh's RC Series is most versatile. Burleigh's Super-Invar CFT Series Confocal Etalons are easiest to use and offer the highest resolution.

E. Astronomy

Numerous applications in astronomy are possible, such as an Hα filter for observing the sun's activity or for high resolution spectroscopic measurements of stars. Many others are also possible.

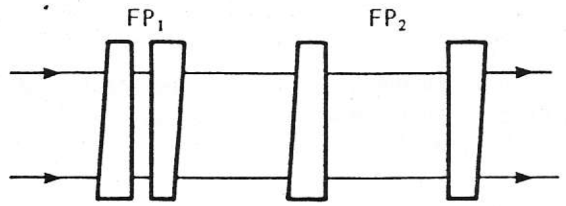
Use of a Coude mount is recommended in tracking applications to minimize misalignment effects due to tilting the etalon. With a solid or fixed etalon, this is less of a problem. Automatic alignment and cavity length control eliminate this problem entirely. Choice of a collimated or telecentric optical system will depend on the application.

F. Multipass Fabry-Perot

Multipass interferometry refers to passing the wavefront to be analyzed through the cavity a predetermined number of times (passes). By passing a beam through a FP n times, the contrast is greatly increased, from C, for single pass, to C^n for n passes. A triple pass system using corner cube retroreflectors to return the beam through the cavity is easy to use and allows constrasts of 10^8 to 10^9. A 5-pass system offers contrasts exceeding 10^{12}. Please refer to the Burleigh Multipass Tech Memo/Instruction Manual for complete details on multipassing.

G. Tandem Fabry-Perots

By using two or more Fabry-Perots in series, a wide spectral range with very high resolution can be attained. The first FP has a large FSR. The second FP has a FSR just a little larger than the bandpass of the first FP. The effective system finesse can be $F = F_1 \times F_2$. A more convenient system involves setting the spacings of the cavities at a precisely defined ratio to sort the orders. The triple FP described by Mack, McNutt, Roesler and Chabbal (Applied Optics 2: 873, 1963) uses this technique.



$FSR_1 = c/2d_1$ $\quad$ $FSR_2 = c/2d_2 \approx 1/F_1 \times c/2d_1$

Finesse = F_1 $\quad$ Finesse = F_2

Overall Finesse = $F_1 \times F_2$

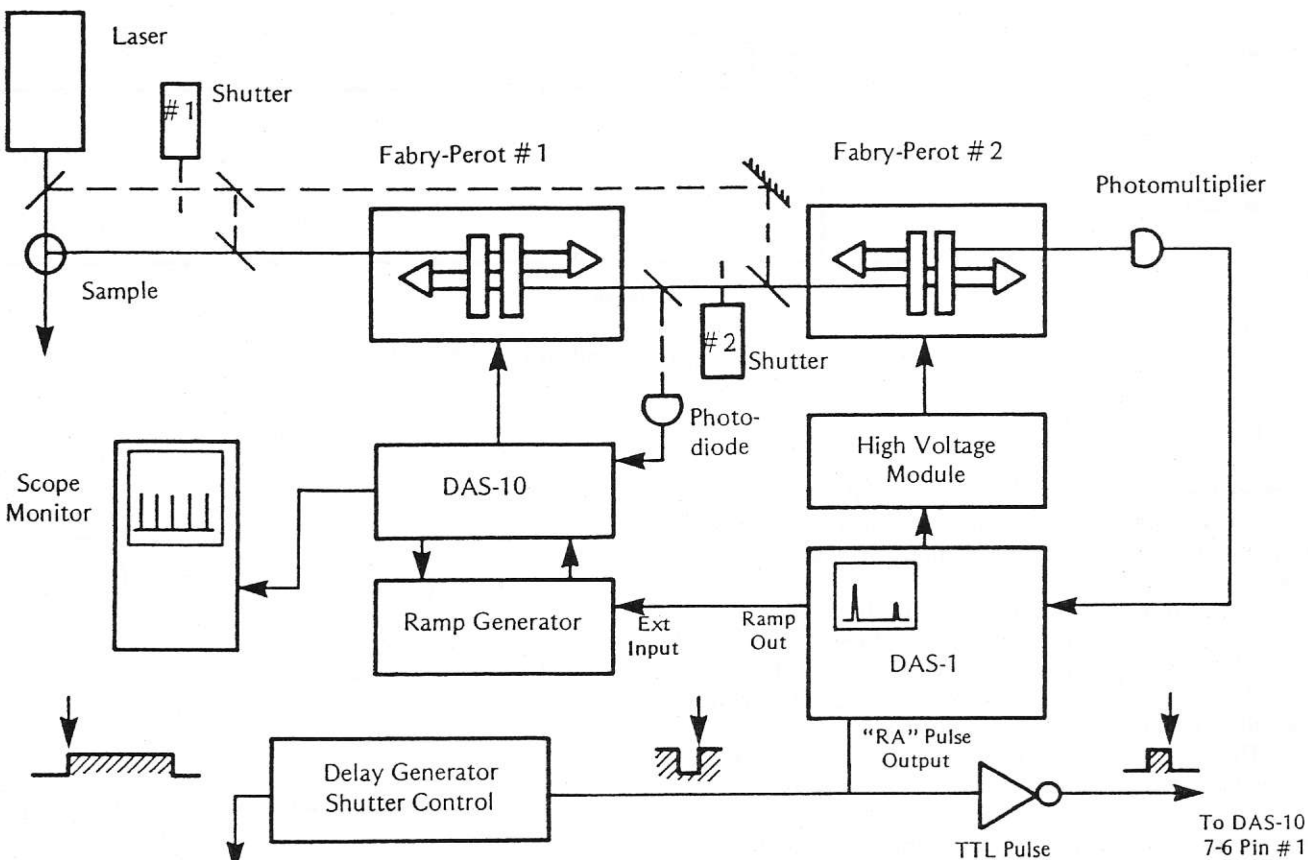
Figure 26

Tandem Fabry-Perot System

Active stabilization of Fabry-Perot Interferometers makes it possible to operate two interferometers in tandem. One experimental arrangement that demonstrated this is described by J. G. Dil and co-workers (Applied Optics Vol. 20, p. 1374 (1981)). Both a Burleigh DAS-10 and DAS-1 were used to separately stabilize two triple-passed Fabry-Perot interferometers to the same reference laser frequency. A similar set-up is shown in Figure 27.

Part of the laser light is directed through each Fabry-Perot and detected as the stabilization peak. Shutters # 1 and # 2 are used to block this reference beam for the remainder of each scan so that light from the sample region can be anlayzed by passage through both Fabry-Perots to the photomultiplier and DAS-1 data accumulation. Shutter control is derived through simple timing circuitry initiated by the DAS-1 "RA" signal on the rear panel CONTROL connector.

If the two Fabry-Perot interferometers are set up with slightly different mirror spacings (for example in the ratio 4:5) and scanned with ramp amplitudes proportional to the mirror spacings, both will sweep out the same wavelength range but transmit at different wavelengths except where their individual transmission spectra overlap as shown in Figure 28. With such a scheme, a second spectral line (shown dashed in Figure 28) will only be transmitted at its correct spectral location relative to the increased free spectral range of the system.



	Shutter # 1	Shutter # 2
Stab. Peak	Open	Closed
Spectrum	Closed	Open

Figure 27

Active Stabilization for Tandem Multipass System

Synchronization of the ramp voltages and adjustment for common sweep rate is simplified by using the DAS-1 RAMP OUTPUT to drive the first Fabry-Perot controlled by the DAS-10 system. For synchronization a special BLANKING pulse derived from the DAS-1 "RA" output must be introduced to the DAS-10 through a small circuit modification specified in Figure 27. The RAMP AMPLITUDE control on the Ramp Generator can be used to set the DAS-10 ramp in the correct proportion to that of the DAS-1 H.V. Module.

Another unique high performance system has been described by Lindsay, Anderson and Sandercock in Rev. of Sci. Instr. 52 (10) 1478 (1981).

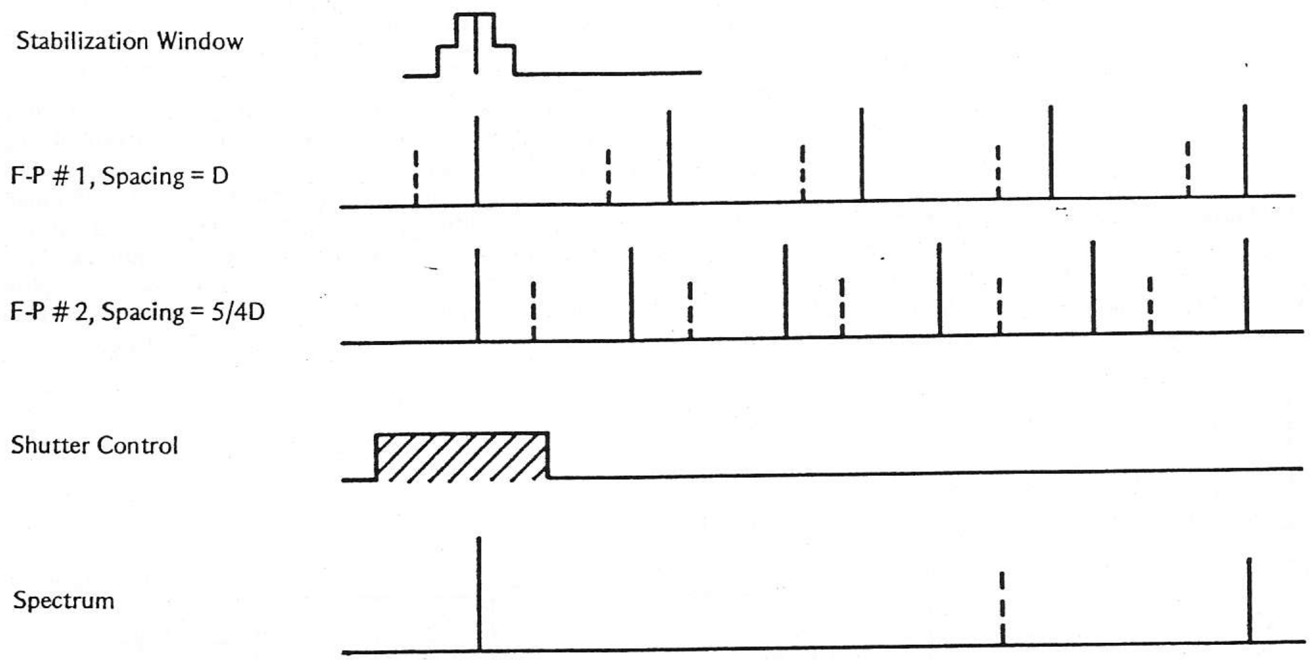


Figure 28

Transmission Spectra for Tandem Fabry-Perot System

H. How to Align a Fabry-Perot

There are two requirements for aligning a FP. First, the FP must be aligned relative to the incoming radiation. In most cases, the FP will be normal to the input. The degree of angular alignment required is not great. Reflecting a gas laser reference beam, which is coincident with the optical axis, back on itself as well as can be determined visually will normally be adequate. The input radiation should be centered on the FP aperture. Burleigh RC-24 and RC-25 Mounting Bases allow angular and vertical adjustment for RC series FP's. The TL Tunable Etalons and VS Variable Space Etalons will mount directly in Burleigh Star Gimbal Mounts.

Second, the FP plates must be aligned relative to each other. Initial alignment with visible or UV plates is easiest with a narrow collimated beam from a small cw laser; the wavelength is not important since even 20 or 30% reflectivity is adequate for this step. Illuminating the FP with the laser and looking at the output on a white card, a train of dots will be observed, resulting from reflections of the misaligned plates. The coarse adjust mechanism should be used to collapse the dots to a single spot. Now the plates will be sufficiently well aligned to see fringes.

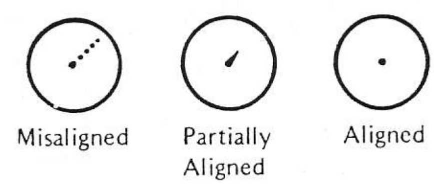
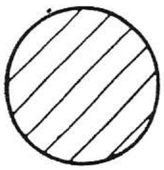


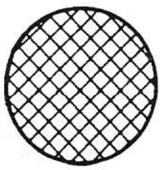
Figure 29

FP Alignment with Small Visible Laser Beam

If the FP is illuminated with a large, collimated monochromatic beam at a wavelength within the spectral range of the plates (assuming operation in the visible), a few straight line fringes will be observed in transmission on a white card. The fine adjust mechanism should be used to adjust for zero fringes, and for even transmission across the aperture when the FP is tuned to the input wavelength.



Misaligned by 3 fringes over aperture



Perfect alignment indicated by even transmission over aperture with FP tuned to input wavelength

Figure 30

FP Alignment with Large Collimated Beam

In the IR (3 to 16μm region) the substrates are generally not transparent to the visible, thus making alignment more difficult. If a laser source is available, however, alignment can be accomplished without undue difficulty.

First, by measuring the actual plate positions relative to each other, the plates should be aligned to about 0.001" to 0.002". Now, if the Fabry-Perot was to be illuminated with a large, collimated beam, and if the output could be viewed, ten or fewer straight-line fringes would be observed (at $\lambda = 10.6\mu$m). This fringe pattern can be effectively determined by illuminating the Fabry-Perot with a small laser beam, traversing the beam across the plates in X and Y, or traversing the Fabry-Perot itself, collecting the throughput with a lens and plotting the detector output. Thus the effective fringe pattern, and therefore plate alignment, can be determined. By changing the alignment and repeating the process, the Fabry-Perot alignment can be improved until the transmission is symmetric over the plates when tuned to the source wavelength.

Burleigh recommends using ZnSe Fabry-Perot plates for wavelengths $\geqslant 3.5\mu$m. ZnSe is transparent in the visible down to 600nm and facilitates this alignment. Finesse at 632.8nm, for example, is generally around 2 for a 90% reflecting coating. This is adequate to provide simple alignment of the Fabry-Perot cavity.

In the case of a confocal FP, there are only two adjustments. The first is setting the mirrors to a spacing coinciding exactly to their radii. This adjustment is easily determined by observing the intracavity fringe pattern or optimizing the finesse of a scanned laser spectrum. When properly set at the confocal spacing the FSR is c/4nd.

The other adjustment required is angular positioning of the confocal etalon to make the etalon axis coincident with the input beam. A two axis gimbaled mount is convenient for this requirement except for very long etalons.

7. HOW TO SPECIFY A FABRY-PEROT SYSTEM

The two primary considerations in specifying a system are choice of model and choice of optics. Secondary considerations are choice of electronics, if applicable, and accessories.

A. How to Choose a Model

1) If large apertures, versatility, and ease of use are important, and size is not, a research type of FP is most suitable. Light scattering is commonly done with this type of instrument. Burleigh's RC series Fabry-Perots are three-rod, open frame instruments with PZT scanning. Plates of up to 70mm diameter are easily installed or changed, plate spacing is continuously variable from 0 to 15cm with the RC-110 and RC-140, 0 to 13cm with the RC-170 and from 0 to 5.5cm by a combination of discrete and continuous adjustments in the RC-150. Coarse and fine adjustments are provided for initial plate alignment and spacing, scales on the RC-110, RC-140 and RC-170 read the spacing to 0.1mm and individual PZT elements are used for final alignment and tuning or scanning.

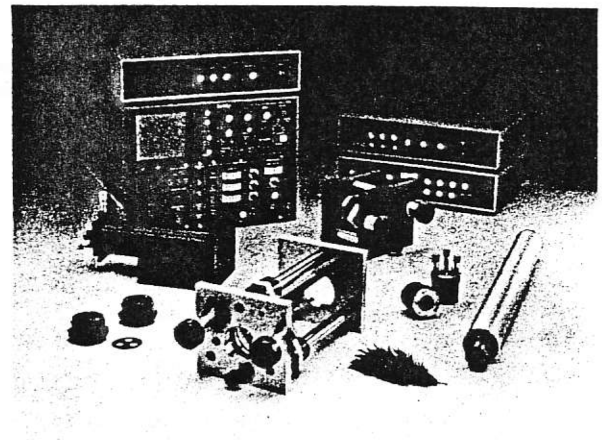


Figure 31

Burleigh Fabry-Perots and Accessories

2) For applications where space is at a premium and PZT alignment and tuning are required, a more compact instrument is called for. Such applications might include intracavity etalons for tuning and line narrowing or line selection, astronomy or coupling with a grating instrument or other type of spectrometer.

Burleigh TL Series Tunable Etalons are designed for these applications. Apertures of 12mm or 32mm are provided in two models with OD's of 1.5" and 2.5". Plate spacing is discretely variable from 0 to 10mm, coarse and fine mechanical adjustments are provided, and PZT final alignment and tuning are standard.

3) There are many applications for non-PZT scanning etalons, such as intracavity line selection or narrowing of special importance. These etalons are tuned by tilting or by changing the pressure for air-spaced etalons and have the advantage that no electronics are required. Solid etalons and fixed air-spaced etalons provide extremely good mechanical stability. Furthermore, fixed air-spaced etalons can be extremely stable thermally. Solid etalons frequently suffer in thermal stability due to the

change in index of refraction with temperature. Burleigh offers a wide range of high-flatness solid and fixed air-spaced etalons. Apertures to 3" are available.

The thickness of a Solid Etalon or the spacing of a Fixed Air Gap Etalon can be determined as follows:

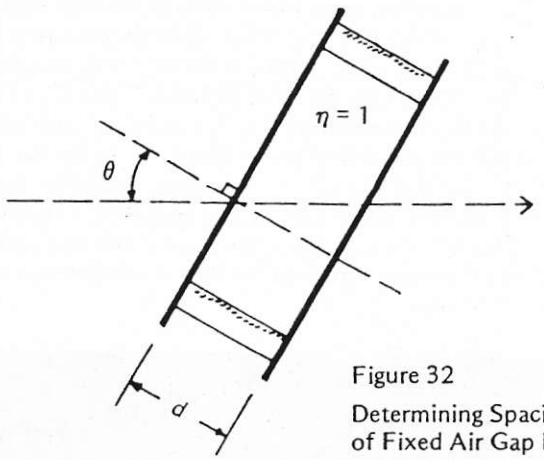


Figure 32

Determining Spacing of Fixed Air Gap Etalon

Fixed Air Gap Etalons

The interference equation is

$$m\lambda = 2nd\cos\theta$$

θ_1 = angle of first transmission

and therefore

$$m\lambda = 2nd\cos\theta_1$$

θ_2 = angle of second transmission

and it follows

$$(m-1)\lambda = 2nd\cos\theta_2$$

Subtracting the second from the first gives

$$\lambda = 2nd\,(\cos\theta_1 - \cos\theta_2)$$

$$d = \lambda/(2n(\cos\theta_1 - \cos\theta_2))$$

where n = 1 for Fixed Air Gap Etalons

To determine d measure θ_1 and θ_2.

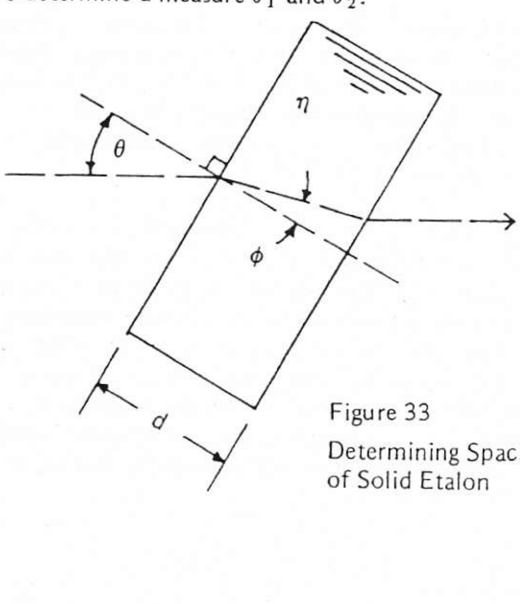


Figure 33

Determining Spacing of Solid Etalon

Solid Etalons

In this case the transmission angle depends on the internal angle of refraction ϕ, where

$$n\sin\phi = \sin\theta$$

$$\phi = \sin^{-1}(\sin\theta/n)$$

Since $m\lambda = 2nd\cos\phi$

$$m\lambda = 2nd\cos\left[\sin^{-1}\left(\frac{\sin\theta}{n}\right)\right.$$

As before:

$d = \lambda/B$

where $B = 2n[\cos[\sin^{-1}(\frac{\sin\theta_1}{n})] - \cos[\sin^{-1}(\frac{\sin\theta_2}{n})]]$

As before, to determine d measure θ_1 and θ_2.

4) One disadvantage of solid and fixed etalons is that the spacing can not be adjusted. Burleigh's VS Series Etalons solve this problem. These all-Invar, air-spaced non-PZT scanned etalons have plate spacing continuously variable from 0 to 10mm. Three sets of 80-pitch Invar screws are used for setting the spacing, coarse alignment locking the assembly and final alignment. Apertures of 1" are offered.

5) For very high resolution applications where low light levels are not a problem, Burleigh's CFT Series Confocal Etalon Systems are recommended. Other uses include laser mode analysis and line narrowing. The Confocal Etalon's chief advantage is insensitivity to alignment. Because of this, it is practical to use very high reflectivity mirrors for high finesse. Throughput is less than for a plano FP, and the thermal sensitivity is higher since only a $\lambda/4$ scan is required for one order. The all Super-Invar construction and the actively controlled thermal housing insure extremely good mechanical thermal stability.

B. How to Specify Optics

Performance of FP plates is usually measured in terms of finesse and throughput, which are determined by the coated plates. In specifying a system, a compromise is often made between the two. The plate parameters to specify are diameter, surface flatness, coating reflectivity and spectral coverage. The plano FP will be discussed first.

Performance is degraded by errors in flatness of the plates or the coating, non-parallelism of alignment, absorption and scatter in the coating and variation in reflectivity with wavelength if broad spectral coverage is needed. A general rule of thumb is not to specify a higher finesse than is required. Alignment sensitivity increases and therefore long term stability may decrease as finesse increases and throughput decreases. To review the relevant formulae:

Reflectivity finesse = $F_R = \frac{\pi(R)^{1/2}}{1-R}$

where R = reflectivity

Flatness finesse = $F_F = M/2$ for λ/M plates

Pinhole Finesse = $4\lambda L^2/D_p^2 d$

Throughput = $t_{max} = (1 - \frac{A}{1-R})^2$

where A = losses from absorption and scatter

Instrumental finesse = F_I

where

$$F_I^{-2} = F_I^{-2} + F_R^{-2} + F_p^{-2}$$

1. Substrates

Fabrication of $\lambda/100$ and $\lambda/200$ FP plates is more an art than a science, and only a few establishments in the world are capable of producing consistent quality plates. Burleigh's in-house capability yields the finest plates available. Plate error is normally specified as the error over 80% of the aperture at $\lambda = 5461$Å.

Plate errors with the Burleigh production technique, are consistently spherical. A 2" diameter, $\lambda/200$ plate for example, will be bowed in cross section with an error of 5461Å ÷ 200 = 27Å over 80% x 2" = 1.6". Therefore, for a given aperture, the larger the plates, the smaller the error over that aperture. The second surface is normally wedged at 10' to 30' with respect to the first surface to avoid forming second and third cavities, and to displace secondary fringe patterns angularly with respect to the main pattern. These secondary patterns occur due to reflections of the second surfaces, and can not be eliminated since even the best "V" AR coatings have 0.1 to 0.2% reflectivity. However, a pinhole at the detector will normally block the second set of fringes.

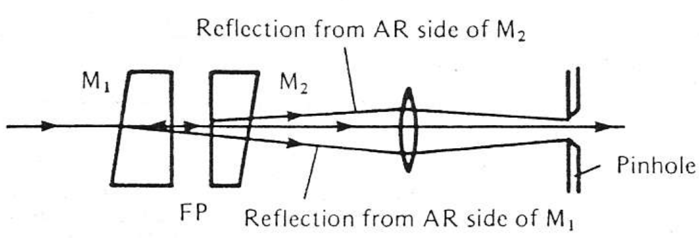


Figure 34

Elimination of Secondary Fabry-Perot Fringes Produced by Second Surface Reflections

2. Coatings

High quality, low loss multi-layer dielectric coatings are readily available today, although there are a number of problems associated with application in FP's.

Hard coatings, which must be applied hot, are not recommended unless necessary for power resistance. The heat can stress relieve the plates causing warping. In addition, these coatings must be stripped and the substrates repolished. This is an expensive and time consuming process and may cause some degradation in plate performance. The best damage resistant coatings also have very limited spectral coverage.

With so called "soft" coatings, a proper coating design with a limited number of layers will give good spectral coverage (at least 100nm in the visible) with minimal flatness error and losses of less than 0.2%. Such coatings are available from about 350nm to 16μm. Broadband coatings are available from Burleigh, although these coatings have additional layers and subsequently higher flatness error and higher absorption losses. Further research is in progress to improve upon present coatings, although Burleigh's present coating designs are state of the art and offer excellent performance.

3. Throughput

For many applications high throughput is very important. Considering a monochromatic input, the limiting factor for throughput in most cases is plate error. The small aperture throughput formula $t = [1-A/(1-R)]^2$, assumes infinitely flat plates. If the plates have an error, the spacing varies slightly across the area of the plates, and there will be only certain areas of the plates at the optimum spacing for maximum transmission.

It is important to keep in mind when specifying the reflectivity on coatings that reflectivity finesse and flatness finesse are properly matched. For example, if one is coating $\lambda/100$ plates (i.e. flatness finesse = 50), there would be significantly more reduction in throughput than would be gained in instrument finesse if the reflectivity exceeded around 93-94% (assuming full aperture illumination).

Plate flatness = $\lambda/100$

for R = 93%, $F_I \approx 30$
$t_i \approx 77\%$

for R = 98%, $F_I \approx 40$
$t_i \approx 32\%$

Of course, if one is using a small aperture beam ($\leqslant$ 4mm), the plates are flatter over the smaller area and the finesse and throughput become a function of the reflectivity only.

For high resolution spectroscopy, where high finesse is most important, some throughput loss is acceptable. Typically, 97.5%, $\lambda/200$ plates will have a finesse of $\geqslant 65$ with a throughput of 30 to 50% over 75 to 80% of the aperture.

For some intracavity or astronomical applications throughput must be maximized while still providing good finesse. If 93%, λ/100 plates are specified, the throughput will usually be over 90%, with a finesse of 30 to 35.

4. Confocal FP

Confocal FP's are used when high resolution is required and efficiency is not necessary. With no alignment requirement, the confocal FP is easy to use. Some limitations are that the aperture used is restricted for high finesse and a separate mirror set is required for each cavity spacing. For very large spacings, however, the efficiency of a confocal FP can exceed that of a plano FP since the etendue increases with plate spacing.

The transmission function for a confocal FP is about half that of a plano FP. In addition it is more sensitive to absorption losses in the coating. For a confocal FP the reflectivity finesse function yields about half the finesse as for a plano FP for a given reflectivity. It is clear then that very high reflectivity is required for high finesse with a confocal FP. However, transmission losses due to absorption in the coating become significant as reflectivity is increased. See Figures 9-11 for information on a plano FP; remember that transmission in a confocal etalon is one half that of plano FP. Burleigh's Confocal Etalons use 99.3% reflectivity coatings as a compromise between high finesse and high transmission.

Table 1 shows typical coating ranges, recommended optics and Burleigh codes for various situations.

COATINGS

1. To order coatings, specify the wavelength and reflectivity from the Coating Code Table by adding the two digit code to the model number (e.g. RC-670-B4).
2. All mirrors are AR coated on second surface.
3. Coatings for visible and UV wavelength ranges are soft coatings. Hard, high power coatings are also available. Flatness finesse not guaranteed with high power coatings. These coatings are more spectrally narrow.
4. Coating examples:
   a) RC-670-B4 Mirror Set
      1 pair 50.8mm dia. plates, λ/200 flatness with reflectivity of 93% from 450 to 550nm mounted in Invar holders.
   b) RC-620-V9 Mirror Set, 88% at 1.06μm
      1 pair 25.4mm dia. plates, λ/100 flatness with reflectivity of 88% centered at 1.06μm (range 1.01 - 1.11μm), mounted in Invar Holders.
5. Fused silica has a fundamental water absorption band at 2.7 microns and a harmonic band at 1.35 microns. We suggest the use of water free fused silica if work is planned in this region. Contact Burleigh for a special quotation.

WAVELENGTH

Code	λ Range	Δ λ	Comment
B	450 - 550nm*	100nm	—
C	550 - 650nm	100nm	—
U	240 - 450nm	10% λ	Specify λ
DL	800 - 900nm	100nm	—
V	.45 - 1.3μm	10% λ	Specify λ
NR	1.3 - 1.5μm	.2μm	—
FL	2.2 - 3.3μm	1.1μm	Finesse 25
IR	1.5 - 9.6μm	10% λ	Specify λ
CD	9.6 - 10.8μm	1.2μm	—
FR	10.8 - 16μm	10% λ	Specify λ

REFLECTIVITY

Code	R	Comment
1	99.3 ± .5%	Confocal Etalons, High Resolution
2.3	97.5 +1/-2%	High Resolution
4	93.0 ± 2%	Multipass, Moderate Resolution
5	80 ± 7%	Intracavity, High Throughput, Moderate Resolution
6	85 ± 7%	Solid and Fixed Air Gap Etalons
9	Special	Specify R

* Center of coating may shift ± 10nm, which can cause reflectivity to be slightly out of specification at one end of the band.

Table 1 Coating Code Table

High damage resistant coatings are also available. The spectral range is 5% of the center wavelength. Several broadband coatings have been field tested and are now available on a best efforts basis. These coatings include:

77 ± 5%	410nm - 680nm
92 ± 2%	500nm - 1000nm
94 ± 2%	400nm - 800nm

The center of these broadband coatings may shift ± 10nm which can cause the reflectivity to be slightly out of specification at one end of the band.

8. MODELS AVAILABLE

A. RC-110 Fabry-Perot Interferometer

This is the top of the line research type Fabry-Perot. The RC-110 uses all Super-Invar construction. Super-Invar, a special blend of Invar has a coefficient of thermal expansion of less than $0.4 \times 10^{-6}/^{o}C$, compared to 1.6×10^{-6} for regular Invar, 15.1×10^{-6} for steel, and 23.4×10^{-6} for aluminum.

The RC-110 uses mirrors to 2" in diameter mounted with Burleigh's unique tab system. All mirrors are easily interchanged. PZT scanning and alignment is included for wavelengths up to 16μm. Plate spacing is adjustable from 0 to 15cm. Super-Invar screws with 250μm/turn pitch, massive Delrin knobs, scales and dials simplify alignment and final setting of the spacing. A cavity length scale reads to 0.1mm over 15cm.

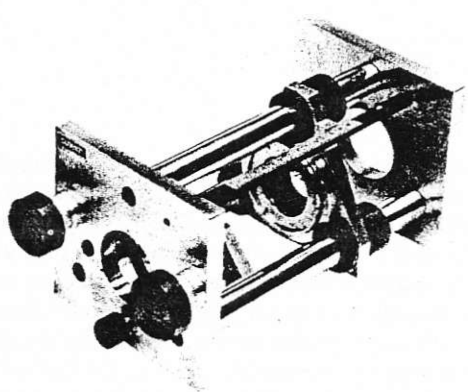


Figure 35
All Super-Invar Fabry-Perot (RC-110)

B. RC-170 Fabry-Perot Interferometer

The RC-170 is identical to the RC-110 except that it accepts 70mm diameter optics and the plate spacing is adjustable from 0 to 13cm. Outside dimensions are the same and all other Fabry-Perot options are available for the RC-170.

C. RC-140 Fabry-Perot Interferometer

The RC-140 is also identical in design to the RC-110 except that all temperature sensitive components other than the rods, are made of regular Invar instead of Super-Invar. Components which are primarily for support and which do not contribute to thermal performance are aluminum. Aluminum is used to permit rapid thermal equilibrium and also to reduce material and machining costs. These components have only a second order effect on thermal stability.

D. RC-150 Fabry-Perot Interferometer

The RC-150 has plate spacing adjustable from 0 to 5.5cm in a series of 0.5cm steps, plus continuous adjustment of up to 1.0cm with the Invar screws. Other than this difference in cavity adjustment the construction of the RC-150 is identical to the RC-140.

E. TL Series Tunable Etalons

These PZT tunable and alignable Fabry-Perots are designed for use in applications where size is important. The TL-15 has a 12mm aperture in a 1.5" diameter by 2.5" long package, and the TL-38 has a 32mm aperture in a 2.5" diameter by 2.5" long package. Plate spacing is incrementally adjustable from 0 to 10mm.

Invar, PZT ceramic and a specially selected steel determine the thermal performance of the TL Etalons. The dimensions and choice of materials are designed for zero thermal expansion with the reentrant cavity design.

Mechanical adjustments allow preliminary alignment and serve to lock the entire assembly into an integral mechanical package. After mechanical alignment, only PZT adjustments in the steel flexure spring loaded assembly can move the mirrors.

Figure 36
TL Etalons (TL-15, -38)

F. VS Series Variable Space Etalons.

Burleigh's all-Invar, non-PZT scanning VS Etalons are recommended for use as an alternative to solid and fixed space etalons. They offer the advantages of continuously adjusting the cavity spacing from 0 to 10mm, and being able to interchange plates. These VS Etalons can be tuned by tilting or by pressure.

A series of 80TPI Invar screws in a push-pull configuration are used for setting the spacing, initial alignment, locking and assembly and final alignment with a differential flexure technique.

25.4mm diameter substrates are used with their full aperture available at normal incidence.

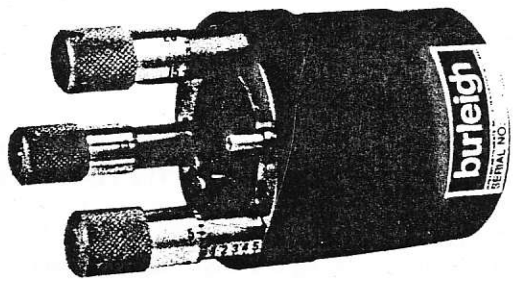


Figure 37
VS Etalon (VS-25M)

G. CFT Series Confocal Etalons

For high resolution spectral analysis or filtering, the all Super-Invar Confocal Etalons have mirrors with radii and therefore spacings of 2.5, 10 and 50cm. These etalons are available with thermally controlled, hermetically sealed housings. PZT scanning is normally used but systems can be constructed for pressure tuning. The modular construction allows easy interchange of mirrors, PZT drives and spacers. A focusing lens is also included with visible models. The usable aperture is 10mm although smaller working apertures are recommended.

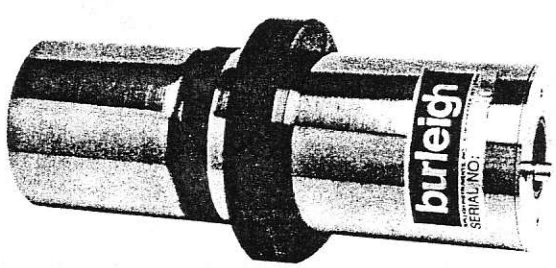


Figure 38
CF Etalon (CF-25)

H. Fixed Space and Solid Etalons

Burleigh offers optically contacted fixed air spaced etalons with apertures to 3". For mechanical and thermal stability, these etalons are excellent. Solid etalons provide even greater mechanical stability. However, thermal stability may suffer since the index of refraction is sensitive to temperature.

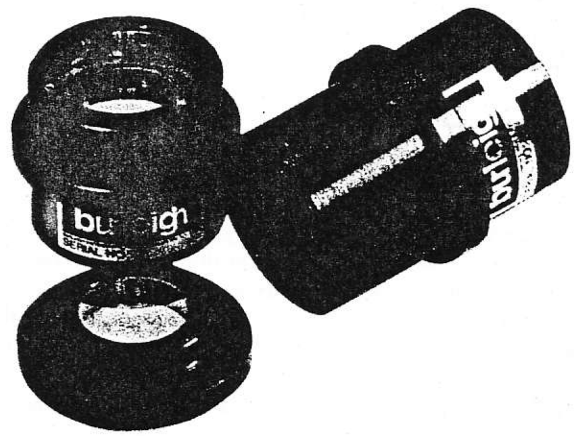


Figure 39
Fixed Air Gap and Solid Etalon

For more complete details on the above consult the Burleigh Instruments Fabry-Perot Interferometer and Etalon catalog.

9. ACCESSORIES

A. THERMAL BOXES

Handsom, insulated, wood boxes are available to provide thermal isolation of RC-110, 170, 140, 150 Fabry-Perots. The Thermal Boxes are constructed of 3/8" thick walnut stained birch and 1" thick urethane foam. The tops of the boxes are removable from the base and are attached with four clips. The tops include ports for window holders to completely seal the instrument. Cut-outs for electrical cables are provided. The Thermal Boxes are designed to accept the Fabry-Perot Mounting Bases, so that the instruments can be mounted on these bases within the box. The RC-34 Thermal Box is designed for the RC-110 and RC-140, the RC-37 Thermal Box is for the RC-170 and the RC-35 Thermal Box is designed for the RC-150.

B. THERMATROL ENCLOSURE

Burleigh's RC-75 or RC-77 Thermatrol is available for active control of the Fabry-Perot in the enclosure to an accuracy of $\leqslant 0.05^{\circ}C$ for $6^{\circ}C$ room temperature change. The enclosures are identical in size to the passive Thermal Boxes. Temperature settings of $29^{\circ}C$ and $33^{\circ}C$ are provided. For alternative temperature settings, contact the factory.

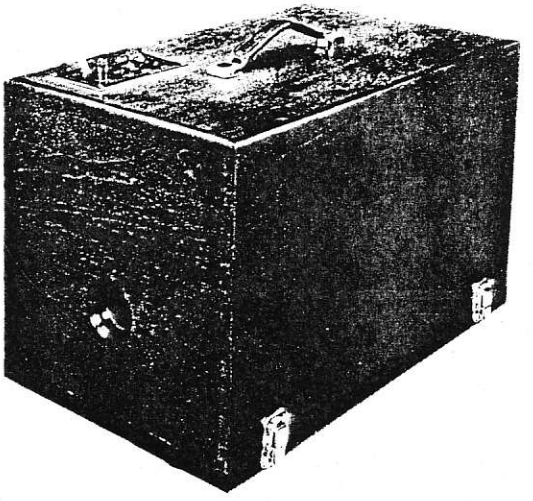


Figure 40

Thermatrol Enclosure (RC-75)

C. KINEMATIC MOUNTING BASE

Kinematic Mounting Bases are available for the Fabry-Perots which permit several degrees of θ and ϕ adjustment, as well as approximately ½" of vertical adjust. These adjustments are very useful for properly aligning the entire Fabry-Perot with respect to the incoming radiation. Also, the Mounting Base is Super-Invar stabilized to insure no distortion of the Fabry-Perot due to differential thermal effects of the base. The RC-24 Mounting Base accepts the RC-110, RC-170, RC-140, while the RC-25 Mounting Base accepts the RC-150.

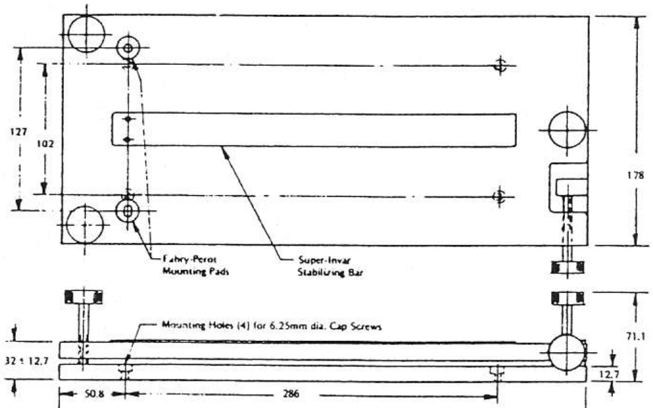


Figure 41 All dimensions in mm

Kinematic Mounting Base (RC-25)

D. MULTIPASS OPTION

The RC-22 Multipass Option includes two corner cube retro-reflectors mounted in special holders for attachment to any of the Fabry-Perots. The Multipass Option permits 3 or 5 passes when the Fabry-Perot is equipped with 2" diameter plates. The corner cube retroreflectors are AR coated to minimize stray reflections. Internal and external masks are also provided to further reduce stray light which may be introduced by the corner cubes or other optical elements. The RC-27 is identical to the RC-22 but used with the RC-170.

Figure 42

Multipass Option (RC-22)

E. IRIS DIAPHRAGM

The RC-39 is a variable Iris Diaphragm mounted in a special holder for attachment to the RC-110, 140 or 150. The diaphragm is variable from 1mm to 38mm and is very useful for limiting the input radiation diameter.

F. COLLIMATORS

Collimators are available to collect the output of the Fabry-Perots onto a pinhole. A 60mm diameter lens with a 254mm focal length is mounted in a cylindrical housing and an X-Y slide is used to position the pinhole at the focal length of the lens. A set of pinholes and eyepiece screw into this X-Y slide. Pinholes are 50, 100, 200 and 500μm in diameter. The collimators are designed to be mounted free standing with the RC-41-1 Collimator Mounting Base. A larger size collimator is available for the RC-170.

G. MIRROR SETS

A wide range of mirror sets are available for the RC Series Fabry-Perots, the TL Series Tunable Etalons, the VS Series VS Etalons and for the CF Series Confocal Etalons. Mirrors of 15mm to 70mm diameter, and larger, are available in flatnesses of $\lambda/100$ and $\lambda/200$. A wide range of reflectivities may be specified. ZnSe is used in the infrared. Mirror sets for the various product lines are available with special holders which minimize distortion, provide optimum thermal and mechanical stability and are designed for proper interfacing to the various instruments. Relevant data sheets and the comprehensive price list should be consulted for further information.

Figure 43

Mirrors, Mirror Holders, Shipping Box

H. DAS AUTOMATIC CONTROL SYSTEM

Burleigh's Data Acquisition and Stabilization Systems allow totally automatic control of Fabry-Perots to correct for any thermal or mechanical drift. The DAS-1 accumulates spectral data into it's 1024 channel memory with large screen CRT display and will continuously optimize Fabry-Perot finesse and correct for frequency drift. The DAS-10 includes only the finesse optimization and frequency stabilization electronics. Both systems are entirely digital and normally operate with an analog or photon counting detection system. With a DAS system a Fabry-Perot can be operated at optimum efficiency, unattended, for extended periods of time.

For more information on any of the above consult the Burleigh Fabry-Perot Interferometer and Etalon Catalog.

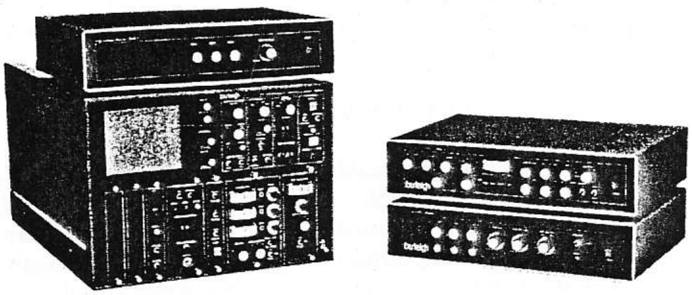


Figure 44
DAS-1 and DAS-10 with RC-43

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