The aim of recent interferometric studies (ARMSTRONG 1969) of the airglow and aurora has been that of temperature determination from measurements of the fringe profiles. Experimentally the problem reduces to a determination of the fringe half width in terms of order separation of successive fringes. For a line of wavelength $\lambda$ influenced solely by thermal broadening the half intensity width $h$ is related to the absolute temperature $T$ and atomic weight $M$ of the emitting atoms by the simple relation

$$ h = 7.16 \times 10^{-7} \times \lambda \times \sqrt{\frac{T}{M}} \quad \ldots \quad (2) $$

due to BUSSIDON AND FABRY (1912). Rapid progress in multilayer coating techniques since 1949 and improvements in the sensitivity of the photomultiplier tubes during 1950s have made interferometric photoelectric instrumentation quite handy. In recent years Fabry-Perot interferometers have gained wider application in studied of the profiles of spectral lines emitted by excited atoms in various regions of the earth's ionosphere. (HERNANDEZ AND TURTLE 1965; HILLIARD AND SHEPHERD 1966; JARRETT AND HOEY 1966; BIONDI AND FEIBELMAN 1968; ARMSTRONG 1968; HAYS ET AL, 1969).
2.1 BASIC CONSIDERATIONS

Obtaining temperatures from the measurements of line profiles required highly accurate measurement of line width, because of the fact that the width is proportional to square root of temperature. Secondly the airglow is faint with the emission rate in the visible region varying from a few Rayleighs (R) to a kilo Rayleigh (KR) or little more. The Rayleigh is a unit (HUNSEN ET AL., 1956) giving the number of photons emitted per second from a column of 1 cm$^2$ in diameter extending along the line of sight through the emitting region, and corresponds to an emission rate $E$, of $10^6$ photons per second from this column. The surface brightness of a uniform layer of emission rate $E$ is simply,

$$B = \frac{10^6 E}{4\pi} \text{ photons cm}^{-1} \text{ s}^{-1} \text{ sterad}^{-1}$$

Hence with the airglow we are concerned with $B$ from $10^5$ to $10^8$ photons cm$^{-2}$ s$^{-1}$ sterad$^{-1}$ which demands spectrometers of large angular acceptance. The spectrometer device to be used for the measurements of the Doppler width from airglow emissions must therefore satisfy the following requirements.

1. Should have adequately high resolution. Instrumental halfwidth should be preferably somewhat less than the halfwidth to be measured. For $\lambda 6300$ Å night airglow emission line the width is typically 0.035 Å.
(ii) Instrumental function must be accurately known. This is because the instrument width cannot be made arbitrarily small (or else the flux collecting power becomes too low). So, in general the true airglow line width has to be obtained by deconvoluting the observed line width with the known instrument function.

(iii) The spectrometer must have a large flux gathering power. Flux gathering power can be increased by

i) using large aperture dispersing element and

ii) choosing a spectrometer system with large throughput (luminosity resolving power product) (MEABURN 1976).

2.2 SPECTROSCOPIC DEVICES

Consider a spectrometer that accepts flux to be analysed from an extended source of surface brightness $B$ (measured in terms of photons cm$^{-2}$ s$^{-1}$ sterad$^{-1}$). If the device has an entrance aperture $A$ and accepts flux over a solid angle $\Omega$ the flux received will be

$$F = \tau \times A \times \Omega \times B \text{ photon/sec}$$

where $\tau$ being system transmissivity. '$\Omega$' depends, however, inversely upon the resolving power of the spectrometer and
the product $\lambda x R$ becomes a constant as shown by
JAQUINOT (1954). Different spectrometer systems such as
prism, grating, Fabry-Perot and Michelson differ with respect
to their value of $\lambda R$. JAQUINOT (1954, 1960) further
compared the different systems in this respect and showed
that interference spectrometers like Fabry-Perot and
Michelson have a large advantage over the grating
spectrometers and even larger over prism spectrometers. This
advantage is essentially by virtue of the circular symmetry
of dispersion in interferometers. Further in case of
interferometers the value of $\lambda R$ can be increased further
by a large factor by adopting special design (field
widening). Field widening is achieved in Fabry-Perot systems
by using spherical plates (CONNES 1958) or in Michelson
interferometer by introducing a dispersive element in the
path of the one of the interfering beams (HILLIARD AND
SHEPHERD 1966). Spherical Fabry-Perot interferometer has
been used by BLAMONT AND LUTON (1972) in GO6 satellite for
measuring Doppler temperatures of $\lambda 6300$ airglow line.

Figure 4 (SHEPHERD 1971) compares the offaxis angles
at different spectral widths for Diffraction Grating
Spectrometer (DGS) Fabry-Perot Spectrometer (FPS) and Wide
Angle Michelson Interferometer (WAMI). For the spectral
FIG 4 Dispersion curves for various spectroscopic devices. The off-axis angle or slit width is plotted against the associated spectral width for a diffraction grating spectrometer, Fabry-Perot spectrometer, and wide-angle Michelson interferometer. For a given spectral width, off-axis angle increases rapidly for those devices in just that order. Note that a separate degrees scale is required for each device.
widths needed (<0.035A) large advantage of WAMI AND FPS over DGS is quite apparent. WAMI however, has one disadvantage that the line width is to be recovered indirectly from the fringe visibility. (which is a parameter expermentally observed). FPS on the other hand directly observes the fringe profile and hence much better control on experiment is possible and interfering effects if any present, during a particular observation set, can readily be seen. Also now the airglow features have been well identified and their characteristics known, attention has turned to the dynamical behaviour of specific emissions as a function of the many variables that characterize geophysical phenomena. Hence for many problems only a limited spectral range is required, limited often to a single band or line. Hence the conditions of well seperated emission spectra and narrow spectral ranges, together with demands of large angular acceptance with high resolving power make Fabry-Perot Spectrometers well suited for this type of experiment.

2.3 FABRY-PEROT SPECTROMETER

Even after the large throughput advantage of Fabry-Perot Spectrometer over Grating spectrometers was realized, it took sometime before Fabry-Perot spectrometers became
wide accepted spectroscopic devices in Atmospheric and Astronomical Studies. A major factor that contributed to the wide acceptance of EPS systems was the development of low light loss multilayer dielectric coatings having high reflectivity, (BANNING 1947). The transmittance of Fabry-Perot Spectrometer at the fringe peak is given by

\[ T = \left[ \frac{R}{1 - R} \right]^2 = \left[ 1 - \frac{A}{1 - R} \right]^2 \]

where

- \( T \) = Transmissivity of each FP plate
- \( R \) = Reflectivity of each FP plate
- \( A = 1 - (R + T) \) = Absorption of each FP plate

At high values of \( R \) needed in Fabry-Perot etalons (\( R \geq 75\% \)) metallic coatings like aluminium and silver show significant absorption which results in drastic reduction of \( T \). Multilayer dielectric coatings can on the other hand give very high values of '\( R \)' with 'A' remaining practically zero. Hence etalons with dielectric high reflection coatings can have \( T = 1 \). Effect of \( A \) on \( T \) is shown in figure 5 (TITLE 1970). Typically for fresh silver at \( R = 85\% \) \( A = 5\% \). Hence \( T_A = 43\% \) This clearly shows the necessity of using multilayer dielectric coatings for etalons intended for use in Airglow spectroscopy.
Fig. 5 The maximum transmission, $A_{\text{max}}$, versus reflectivity $R_e$ for several values of mirror light loss $L_i$. (after Title, 1970).
2.4 BASIC DESIGN OF FPS FOR AIRGLOW LINE WIDTH STUDIES

Air pressure scanned (KARANDIKAR 1968) IPS systems are most widely used in airglow spectroscopy, although piezo electrically scanned devices (BLAMONT AND LUTON 1972, HERNANDEZ 1970) have also been used at times. For basic design of air pressure scanned Fabry-Perot spectrometer One may refer to MEABURN (1976). Essentially one has a pressure tight chamber housing of Fabry-Perot etalon, collimating lens, analysing diaphragm and photomultiplier detector. Line to be analysed is scanned by varying the air pressure in the chamber by some device. Schematic representation of the system is given in Fig. 6.

2.5 PARAMETERS OF FPS AND THEIR OPTIMIZATION

If the separation between the Fabry-Perot plates is \( t \) then the free spectral range is

\[
\Delta \lambda = \frac{\lambda^2}{2 \mu t^2}
\]

\( \mu \) being the refractive index of the medium between the plates (usually air). If we analyze an ideally monochromatic incident flux, using Fabry-Perot Spectrometer with an analysing diaphragm of infinitely narrow angular size, the output function will be what is called the etalon.
Fig. 6 Pressure scanning Fabry-Perot interferometer. Basic design.
function $E$. If the width of the etalon function $E$ is "e" (in wavelength units) then the ratio $\Delta \lambda / e$ is the effective finesse of the Fabry-Perot spectrometer. The basic parameters of the Fabry-Perot spectrometer are:

(i) Form of the instrument function

(ii) Overall transmission of the FFS.

Property of FFS in this respect and conditions for its best use have been studied in great detail by CHABBAL (1958). Here only the essential results are summarized.

The form of the instrument function is jointly determined by:

(i) plate reflectivity and

(ii) plate figure

Plate reflectivity contribution is expressed in terms of well known Airy function. (BORN AND WOLF 1959; CANDLER 1951; WILLIAMS 1950). Ratio of the width of free spectral range to that of Airy function is termed as the "Reflective Finesse $N_A". 

$$N_A = \frac{\pi \int R}{(1 - R)}$$

where $R$ = Reflectivity of FP plates. The etalon function $E$ is also broadened by imperfections of the flatness.
of FP plates (and also due to misalignment and lack of perfect parallelism between the plates). Plate imperfection may be

(i) microtopographical errors, essentially randomly distributed

(ii) plate curvature

Analytical forms of the broadening functions associated with plate figure imperfections have been discussed by DUFOUR AND PICA (1945) and HILL (1963). We only note here the following important points.

Microtopographical errors are expressed in terms of the root mean square fluctuations from an ideal plane. Let this (expressed as a fraction of wavelength - normally Hg 5461Å) be \( \lambda/n \). The broadening due to this type of plate figure imperfection is Gaussian in its analytical form and has a width given by \( 1/N_D \) where \( N_D = n/4.7 \).

So typically if the plates are qualified as say \( \lambda/50 \), limiting finesse due to plate figure will be \( N_D = 50/4.7 \approx 10.6 \).

Other major type of plate figure error is its curvature. Here the Sagitta \([1 - \cos \theta]y\) is expressed as \( Jx = \lambda/n \). The broadening function can now shown to be rectangular in shape with full width in terms of
fraction of free spectral range, given by $2/n$; so that the associated coefficient of finesse is $n/2$ overall performance of the etalon will now be described by a broadening function $E$ which itself is a convolution of three independent broadening functions viz.

(i) Airy function ($A$)

(ii) Broadening due to microtopographical errors ($D_Q$)

(iii) Broadening due to plate curvature errors ($D_R$)

The two latter functions convolved together are usually written as $D = D_Q * D_R$. Form of $D$ can vary from Gaussian to rectangular in extreme cases. Overall etalon function is $E = A * D$ and width of $E$ will be larger than individual widths of $D_Q$, $D_R$ and $A$. As a guideline one can always recall when two Gaussian functions $G_1$ and $G_2$ are convolved, the resulting function $G$ is also a Gaussian and if $g_1$, $g_2$ and $g$ are the respective widths then

$$g = \sqrt{g_1^2 + g_2^2}$$

Finally there is broadening associated with scanning aperture, scanning aperture being of finite radius, allows a finite wavelength interval to fall on the detector. Let us restrict the consideration to situation where aperture is
placed exactly on the axis of Fabry-Perot Spectrometer. (is concentric with the fringe system). Off axis aperture will in general cause asymmetric scanning function and is therefore undesirable. The value of wavelength interval \( \delta \lambda \) passed by the scanning aperture is readily obtained using the basic Fabry-Perot etalon equation

\[
\frac{\lambda}{t} = n \Delta \lambda
\]

where \( t \) = Separation of FP plates
\( n \) = order of interference and
\( \lambda \) = wavelength of light

Let \( r \) be the radius of the aperture and \( f \) be the focal length of the collimating lens. Semiangle made by the aperture at the lens is \( \phi = \frac{r}{f} \). Hence since all the wavelengths within \( \delta \lambda \) are transmitted with equal efficiency ( \( \approx 1 \)), form of broadening function associated with the scanning aperture is also rectangular of width

\[
\delta \lambda = \frac{\lambda^2}{2t^2}.
\]

One can associate coefficient of finness with this given by

\[
(N_F)^{-1} = \frac{\delta \lambda}{\Delta \lambda}
\]
Δλ being the free spectral range. Unless the source brightness is very large, Δλ cannot be made very small.

2.6 TRANSMITTANCE OF ETALON

It was seen earlier that the transmission of ideal F.P. etalon is

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

A being the absorption coefficient of FP plates. For properly made dielectric high reflection coatings, A ≈ 0 and T = 1. For non ideal FP etalon (with plate imperfections, finite scanning aperture) there is further reduction in transmission. Let

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

Depending upon the relative widths of functions A (Airy), D and F (the function associated with scanning aperture) there is further loss of transmittance which will be described now. Here a brief summary of results which find immediate application is presented. For details reference should be made to CHABBAL (1958, 1953).
Quite often the primary constraint on the experimenter will be the quality of available Fabry-Perot plates, which means that one starts with a predetermined value of $N_D$. Values of $N_A$ and $N_F$ have now to be optimized with respect to resolution and transmittance.

Figure 7b gives the variation of transmittance with the ratio $N_A / N_D$ for the two cases where $D$ could either be $D_Q$ (plate figure limited by microtopographical errors) or $D_P$ (curvature of plates). It is seen that substantial reduction in $C_E$ could happen particularly if $D$ is $D_Q$, when $N_A / N_D \geq 1$.

On the other hand choice of two low a value of $N_A$ could cause large reduction in effective overall finesse, and hence the resolution without corresponding gain in transmittance. When resolution and transmittance are equally important as in the case of night airglow line width study, $N_A = N_D$ is a good choice.

It is also necessary to match the size of the scanning aperture with the etalon finesse as determined by the width of the function

$$E = A \ast D$$
Fig. 7a. Above set shows effect on Transmission $T_E$ of the width due to scanning aperture to that of the etalon function (i.e. ratio $N_E/N_F$; in fig. 1/x).
Etalon function could be: rectangular $F$
  Gaussian $G$
  or Airy $A$

Fig. 7b. Above set shows effect of the ratio of width of plate function to the width of Airy function on the transmission (i.e. $N_A/N_D$; in fig. 1/x).
D could be rectangular $F$
  Gaussian $G$
  or Triangular $T$
This is seen from the curves given in Fig. 73 which shows the dependence of $\tau_F$ on the ratio of width of etalon function to that of scanning function. Scanning function is always rectangular, defined by finesse $N_F$. Etalon function could have any form extreme cases being Airy, Gaussian or rectangular. Hence $\tau_F$ is shown as a function of $N_E / N_F$ when $E$ could be either R, G or F. Here again it is observed that to have a combined optimization for transmittance and resolution

$$N_E \simeq N_F$$

seems to be a good choice. Overall Fabry-Perot Spectrometer transmission is then given by

$$\tau = \tau_A \times \tau_B \times \tau_F$$

2.7 CHOICE OF PARAMETERS IN PRESENT EXPERIMENT

The Fabry-Perot plates used in the present experiment were 70 mm aperture and $\lambda/30$ flatness; plate figure being basically curvature limited. Since 70 mm is not quite large enough aperture for night airglow observations, it was necessary to have $\tau$ as large as possible without unduly sacrificing resolution. In accordance with the thumb rule

$$N_A = N_D$$
Plates were coated with alternate layers of Zns and MgF₂ (5 layers) to give a reflectivity of 75% and $N_A = 10.9$. Because parallelism was not servocontrolled, some misalignment was expected which would further reduce $N_D$. Preliminary tests indicated that $N_D > 10$ was not likely to be achieved. With $N_A$ and $N_D$ both about 10, $N_B$ was expected to be around 7. With collimating lens of focal length 500 mm, scanning aperture of diameter 2.7 mm was used which gives

$$\frac{\delta \lambda}{\lambda} = 3.6 \times 10^{-6} \quad \text{or} \quad \delta \lambda = 2.27 \times 10^{-2} \text{Å}$$

Etalon spacer chosen was approximately 1.5 cm which gives a free spectral range of 0.13Å. This choice was based on the requirement that maximum resolution be attained without order overlap occurring. About three times the line width expected (0.04 Å) was considered a good choice. $N_E$ was therefore

$$\frac{0.13}{2.27} \times 10^2 \approx 6$$

overall spectrometer finesse expected was approximately

$$\left[ \left( \frac{1}{6} \right)^2 + \left( \frac{1}{7} \right)^2 \right] \approx 4.5$$
Laser calibrations showed in general an average finesse of little less than 3 (≈ 2.9). Significantly lower value of observed finesse is mostly due to contribution of misalignment. Optically contacted Fabry-Perot etalons which have now become available in recent years permit working with very high degree of parallelism and would of course be now a better choice. Other alternative, which is active or dynamic stability has been obtained by means of servocontrol using white light fringes (RAMSAY 1966; 1962), a reference wedge etalon etc. In the dynamic case a feedback stabilisation method described by HERNANDEZ AND MILLS (1973) in which creating correction signals proportional to the displacement of the fringe maxima of three auxiliary spectral sources with respect to a fixed reference point and feeding these signals back to the interferometer piezoelectric drive so that the correcting signals become time invariant, and the interferometer is stabilised in parallelism up to $\lambda/1000$, is remarkable.

General schematic arrangement of the entire system is shown in Fig. 8. The Fabry-Perot plates are accommodated on a step in a brass chamber and rests on the full area and not on three ball supports as described by NILSON AND SHEPHERD (1961). The plates were fabricated by the author at the optical workshop of Hhabha Atomic Research Centre.
Fig. 8. Experimental set-up of the Fabry-Perot interferometer (Pressure variation section is not shown).

- W - Window
- C - Pressure chamber
- FP - Fabry Perot plates
- L - Collimating lens
- m - Viewing mirror
- B - Mirror for admitting airglow radiation to spectrometer
- F - Interference filter
- S - Blanking shutter
- PMT - Photomultiplier
- J - Jacket (cooling) for PMT
Bombay, India. There is a mirror 'm' which can be introduced from a side window to view the fringes for checking the alignment with a spectral lamp (cd) and is taken out during observations. Below the scanning aperture 'a' is an interference filter 'F' and a photomultiplier P.M.T. The interference filter has a halfwidth of 2.5Å with a central pass band wavelength of 6301Å and a transmission of about 40%. The temperature of the filter is maintained at 15°C by a servocontrolled circuit and the filter is tuned to 6300Å exact. The accuracy of this temperature control is ± 0.3°C. A plane mirror is kept over the front window W of the spectrometer set up which can be moved in azimuth and elevation to direct radiation into the spectrometer from any portion of the sky.

2.8 DETECTION COUNTING AND PRINTING SYSTEMS

The detector was a 4 stage PHILIPS photomultiplier, type TVP 56 with a trialkali S20 cathode having a quantum efficiency of 0.1. The photomultiplier housing is a double walled brass chamber where cooled glycol is circulated by means of a water pump thus keeping the photomultiplier around -10°C. The glycol is cooled by means of an immersion type cooler refrigeration system made in Physical Research Laboratory. The photomultiplier was operated at 2500V.
The output of the photomultiplier is operated in a pulse counting mode. Its output passing through a discriminator and pulse shaping circuit. This type of pulse counting was employed by many workers (FEIBELMAN ET AL, 1972, HAYS ET AL, 1969). The single electron pulses were discriminated at a suitable voltage level and monoshot pulses were generated for counter using Fairchild IC 710 (MILLER 1968). Detailed circuit diagram is shown in Fig. 9. These pulses were displayed in a frequency counter and simultaneously printed in a digital printer.

2.9 SCANNING SYSTEM

As it was shown earlier that the Fabry-Perot plates are contained in a pressure tight housing and the concentric ring interference pattern is imaged by a lens on a plate containing a small aperture centered on the pattern. Thus a portion of the radiation constituting the central spot of the pattern passes through the aperture to the detecting photomultiplier. The wavelength corresponding to constructive interference at the central spot is made to change with time or in other words the fringe system is scanned with time by pressurising the medium, thereby producing a consequent change in the refractive index of the medium in the chamber. This type of index of refraction...
Fig. 10 Schematic diagram of scanning piston device.
scanning was described by CHANTREL (1958), KUAN ET AL, (1968) and COCK (1960). This refractive index variation is effected by means of a Cam and Piston arrangement. The piston system is shown in fig. 10. It contains a cylindrical Cam with the piston connected to a screw and gear system to the main shaft of a continuous Ac motor of 1/10 HP. The continuous motion of motor is converted to step motion by using a geneva gear system. Steppings are repeated at \( \approx 3 \) seconds interval. As the motor operates the screw advances and pushes the piston forward. Total travel of the piston is 26 mms which is effected in 217 equal steps by means of a geneva gear drive. Since it is a reversible motor and hence the direction of travel of the piston can be reversed and scanning is effected during forward as well as in the reverse motion of the piston. Since the volume that is changed in equal steps the pressure, steppings \( (\Delta P) \) are nonlinear. Since the exact value of pressure at each step is known, fringe profile is plotted after linearizing pressure values.