Report No. IITRI-A6141-QR3
(Quarterly Status Report)

A HIGH ALTITUDE MEASUREMENT TO DETERMINE
THE RATIO OF DEUTERIUM TO HYDROGEN IN THE
SOLAR ATMOSPHERE

Report No. IITRI-A6141-QR3
(Quarterly Status Report)

A HIGH ALTITUDE MEASUREMENT TO DETERMINE THE RATIO OF

DEUTERIUM TO HYDROGEN IN THE SOLAR ATMOSPHERE

1 December 1965 to 28 February 1966

Contract No. NASr 65(13)/14-003-913
IITRI Project No. A6141

Prepared by
Dr. Gordon Henderson

of

IIT RESEARCH INSTITUTE
Technology Center
Chicago, Illinois 60616

for

National Aeronautics and Space Administration
Office of Space Science and Applications
Washington, D. C. 20546

29 March 1966

IIT RESEARCH INSTITUTE

FOREWORD

This report is the third quarterly status report on Contract No. NASr 65(13)/14-003-913 which is a preliminary phase of an experiment to attempt the detection of deuterium in the solar photosphere by accurately recording the profiles of the H_α and H_β Fraunhofer lines.

The work carried out during this quarter has been the further evaluation of two optical systems each of which is potentially capable of realizing the experimental goals. These goals may be summarized as the realization of a system which can measure a limited spectral region with an accuracy of 1 part in 10^4 and which is compact enough to be flown in a high flying aircraft or balloon.

The staff of IIT Research Institute appreciates the opportunity of conducting this research in the interest of advancing the state of knowledge of the solar system.

Respectfully submitted,
IIT RESEARCH INSTITUTE

Gordon Henderson

Gordon Henderson
Research Physicist
Optics Research

Approved by:

P N Slater

P. N. Slater
Manager
Optics Research

C W Terrell

C. W. Terrell
Director
Physics Research
GH:nj

ABSTRACT

Development of two optical systems is described. These
are,

   (i) A grating monochromator and PRISM Fabry Perot both of
which are scanned synchronously in wavelength.

   (ii) A pair of PRISM Fabry Perot instruments which is
scanned synchronously in wavelength.

   The relative merits of each system are discussed and
also their associated difficulties.

IIT RESEARCH INSTITUTE

I.   INTRODUCTION

This is a Quarterly Status Report covering the period
1 December 1965 to 28 February 1966 on NASA Contract
NASr 65(13)-14-003-913.

The last quarterly report summarized in part the experimental
approach being followed in this work. The reasons underlying
the approach are outlined in the following discussion.

In order to improve on attempts made to date on the problem
of the existence of solar deuterium, two main goals must be
achieved:

(i)   An improvement in the accuracy of the
       measuring system.

(ii)   The removal of the cloaking effect of
       telluric water vapor absorption lines
       in the wings of the H_α profile.

To achieve the first goal the use of photoelectric detectors
is required. The detection system should have a digitized
output and be automatically compensated for variations in
atmospheric transmission. Moreover, the electronic amplification
system should have an accuracy of 1 part in 10^4 and be compensated
for long term drift to the same accuracy. Concomitant with the
accuracy requirement in signal measurement, there exists the
requirement of wavelength specification to the same order of
accuracy as that of the signal measurement, i.e., 1 part in 10^4.
The second goal imposed the constraint on a system design that

IIT RESEARCH INSTITUTE

the instrumentation must be of such weight and dimensions that it can be installed in an aircraft or balloon.

When the present program was undertaken the PRISM instrument (Photoelectrically Recording Interferometer Scanned Magnetostrictively) had attained a level of development which qualified it well for a renewed attempt on the problem of solar deuterium, reference, P. N. Slater, H. T. Betz and G. Henderson, "A New Design of a Scanning Fabry-Perot Interferometer," Jap. J. of Appl. Phys.vol. 4, Suppl. 1, 1965. Proc. of Conf. on Photo. and Spect. Optics, Tokyo, 1964.

To achieve the experimental goals, the following two optical systems involving the PRISM instrument are presently being investigated and compared.

(i) The PRISM Fabry-Perot interferometer preceeded by a Jarrell Ash 1/2 Meter Ebert monochromator operating at low resolution. The interferometer and spectrometer are scanned together synchronously.

(ii) A pair of PRISM Fabry-Perot interferometers in tandem, preceded by a 10A half width interference filter. The two interferometers are scanned synchronously by means of a servo control system.

So far each system has shown the potential ability to perform the experiment according to the requirements already outlined. In the next section of this report a more comprehensive description of each system is given.

IIT RESEARCH INSTITUTE

II. SYSTEMS DESCRIPTION

A. Fabry-Perot Interferometer and Grating Monochromator.

A sketch of the optical arrangement is shown in Fig. 1, and Fig. 2 shows a photograph of a breadboard model of the actual system. Synchronous scanning is achieved by connecting the scanning motor of the monochromator to the ramp generator which controls the scanning rate of the Fabry Perot interferometer. Fig. 3 shows a block diagram of the electronic control system. The scanning motor of the monochromator is connected to the potentiometer by appropriate gearing and the output of the potentiometer is used as the control signal for the interferometer system. The potentiometer output replaces the ramp generated by the scalers in the control system described in Quarterly Status Report No. 1 (No. IIT Research Institute A6141-QR1) of this program.

The optical performance of the system is illustrated in Figs. 4A-4D. Figure 4A shows the intensity distribution from a continuum source such as a tungsten ribbon filament lamp. The tungsten lamp intensity distribution approximates that of a blackbody and, at a temperature of 2000°K, the intensity variation with wavelength of a blackbody is 0.01% per A at λ6500A. Hence, over a 10A interval, the intensity of a tungsten lamp at about 2000°K may be regarded as constant to 0.1%. Fig. 4B shows the distribution of intensity transmitted by the monochromator. To achieve this form of transmission function one of the slits of the scanning monochromator is made wider than the other. Figure 4C
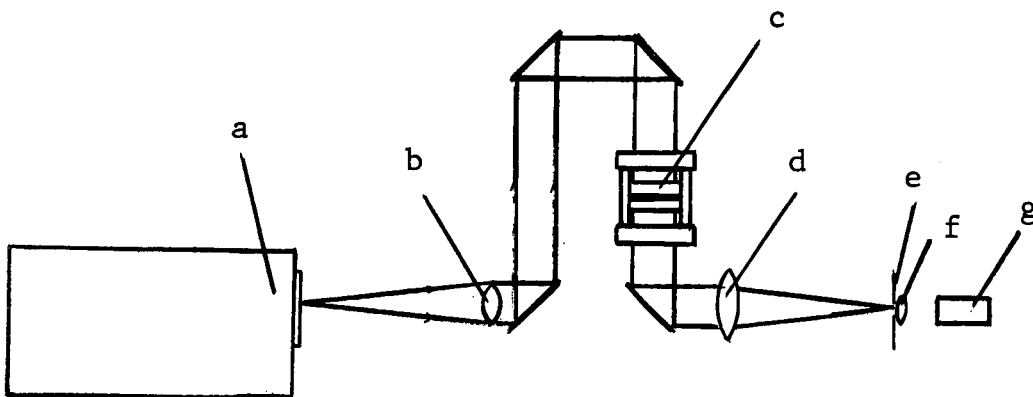
IIT RESEARCH INSTITUTE

Fig. 1. Optical arrangement of synchronous scanning monochromator and Fabry Perot interferometer.

  a) Scanning Monochromator
  b) Collimating Lens
  c) Fabry Perot
  d) Focussing Lens
  e) Aperture Transmitting Central Order
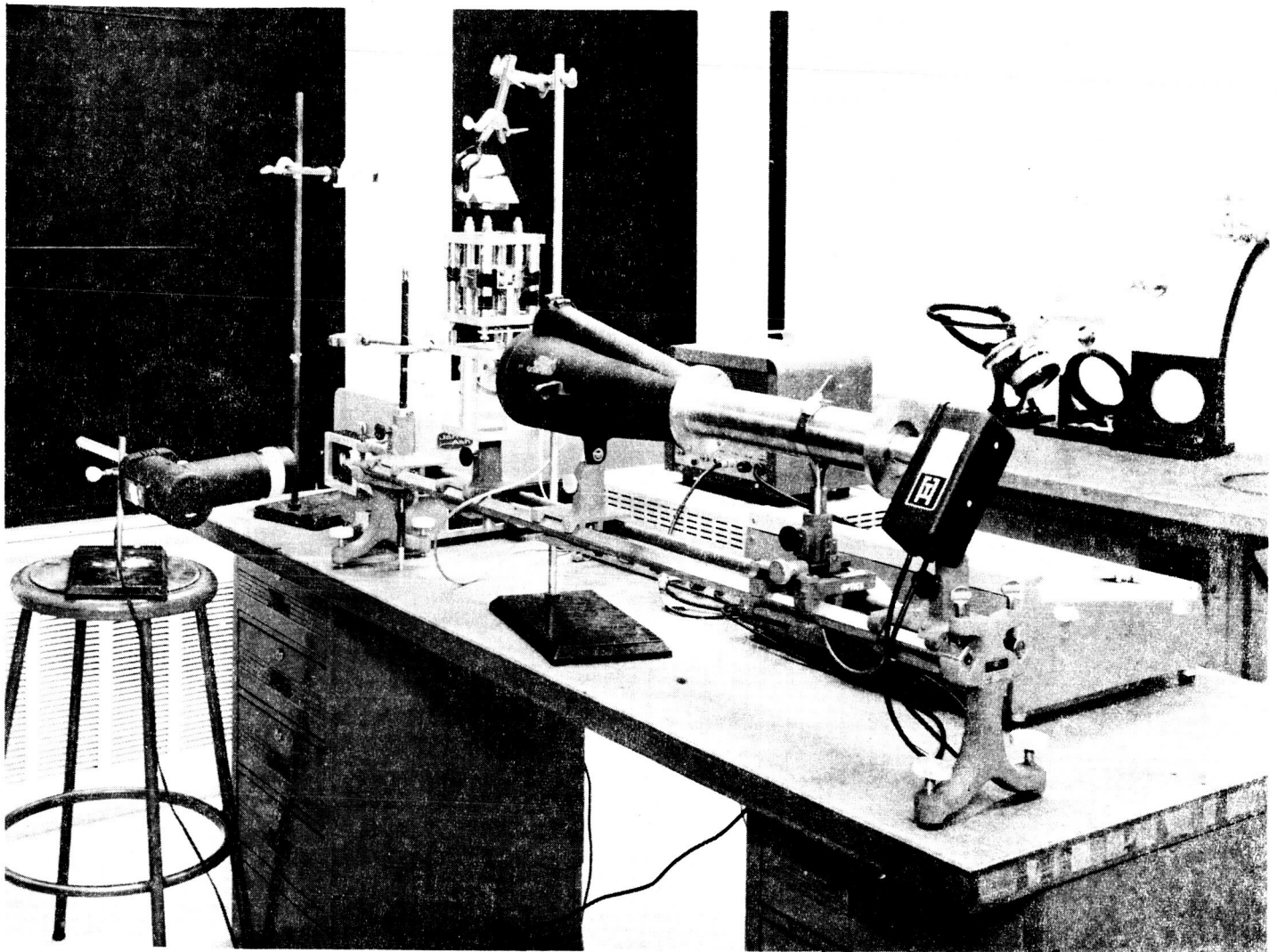 f) Field Lens
  g) Photomultiplier Tube.

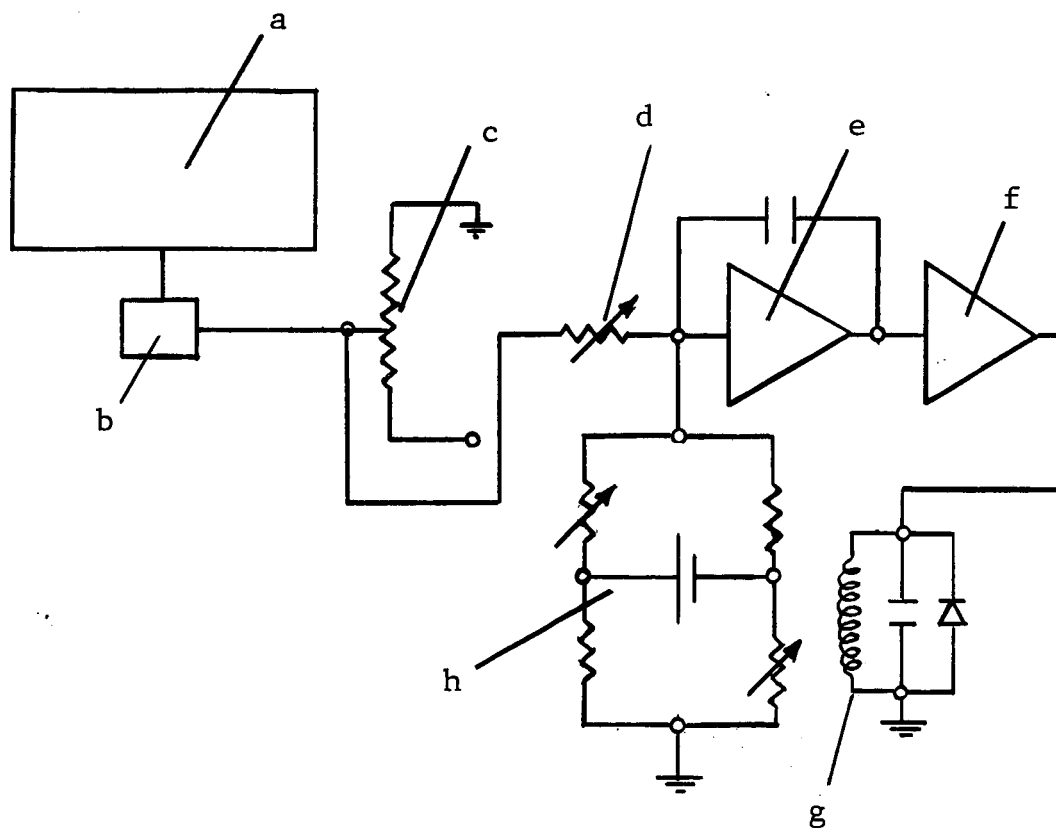FIG. 2   PHOTOGRAPH OF BREA BOARD MODEL OF PRISM FABRY PEROT AND
MONOCHROMATOR

Fig.3. Block diagram of monochromator and interferometer
scanning system.

a) Monochromator   g) Interferometer coils

b) Gear Train   h) Strain gage bridge

c) 10 turn Potentiometer

d) Operational amplifier

e) Operational amplifier

f) Power amplifier

represents the multiple transmission function of the Fabry

Perot interferometer alone. Figure 4D shows the transmission

function of the scanning monochromator-interferometer combina-

tion. As the monochromator and interferometer are scanned

together the passbands keep in step on the wavelength scale so

that, effectively, the spectrum is scanned by an instrument with

a single narrow instrumental function as represented by Fig. 4D.

Figures 5A and 5B show various actual traces obtained using the

breadboard model, a Keithley Model 417 picoammeter and Moseley

XY recorder. Figure 5A is a trace of the cadmium $\lambda6438A$

emission line obtained from an Osram lamp. The discharge was

focussed on the entrance slit of the monochromator and the Fabry

Perot scanned the line while the monochromator was kept fixed

at the wavelength of the cadmium source, i.e., $\lambda6438A$. The trace

obtained was effectively the transmission function or instru-

mental profile of the Fabry Perot since the line width of the

cadmium emission line was negligible compared to the instrumental

profile. From Fig. 5A it can be seen that the finesse of the

Fabry Perot was 21 and, since the free spectral range was 5A,

the instrumental function was therefore 0.24A. Figure 5B shows

a trace of the transmission function of a Jarrell-Ash Scanning

Spectrometer, used as a monochromator illuminated by a tungsten

ribbon filament lamp and set at $\lambda6438A$. The dispersion of the

instrument was 64A/mm and matched entrance and exit slits of

25μ were used. The transmission function of the monochromator

was then explored using the Fabry Perot by holding the

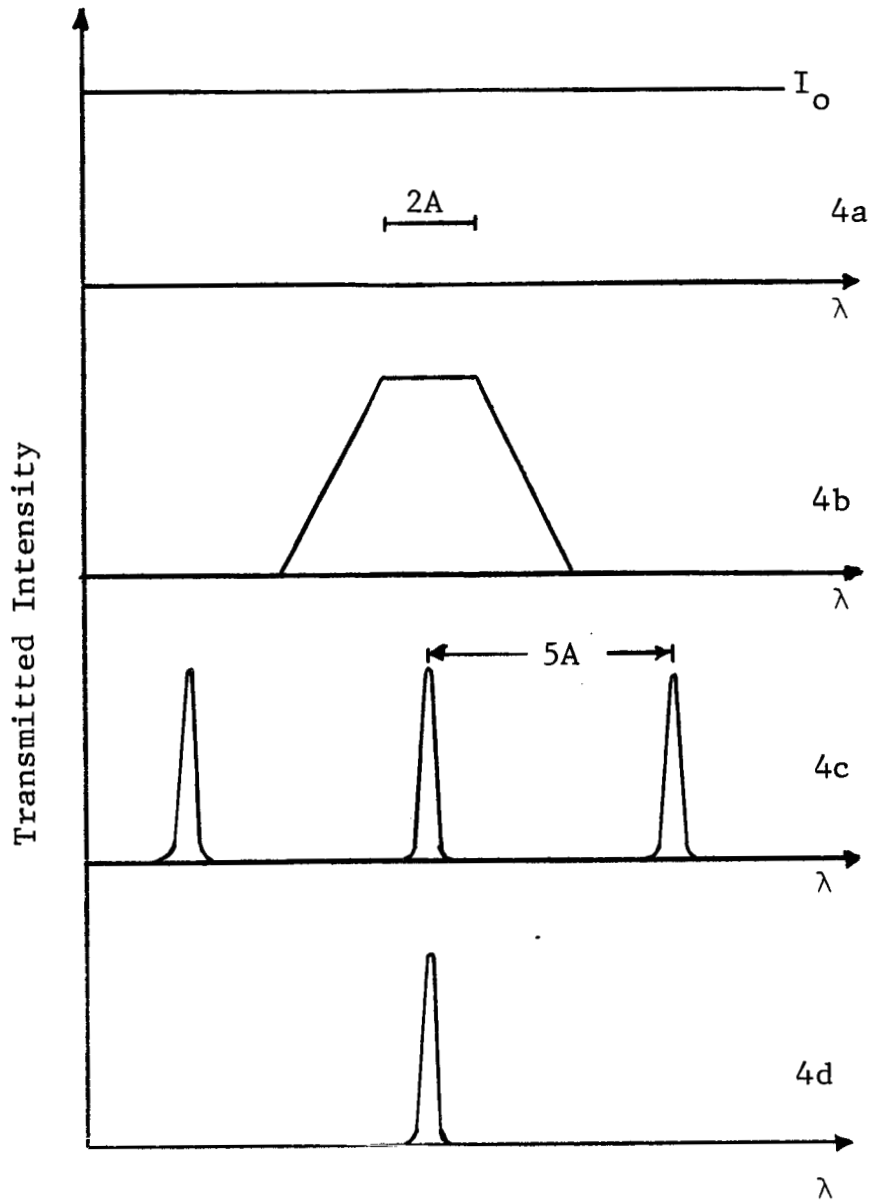IIT RESEARCH INSTITUTE

Figure 4a   Intensity distribution of tungsten ribbon filament
             lamp over short wavelength interval.
Figure 4b   Passband of monochromator operating at low resolution
             with mismatched entrance and exit slits.
Figure 4c   Passbands of Fabry Perot interferometer
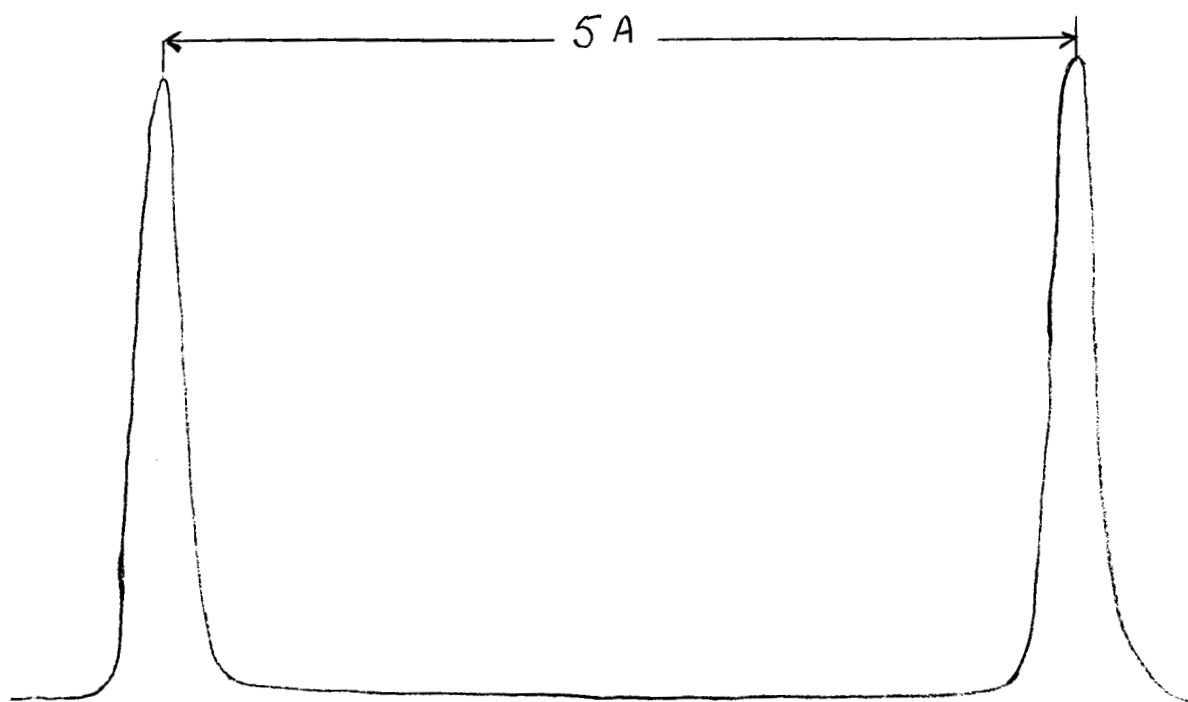Figure 4d   Passband of monochromator and interferometer together.

Fig. 5a. Trace obtained from cadmium lamp at λ6438A through monochromator and Fabry Perot interferometer.
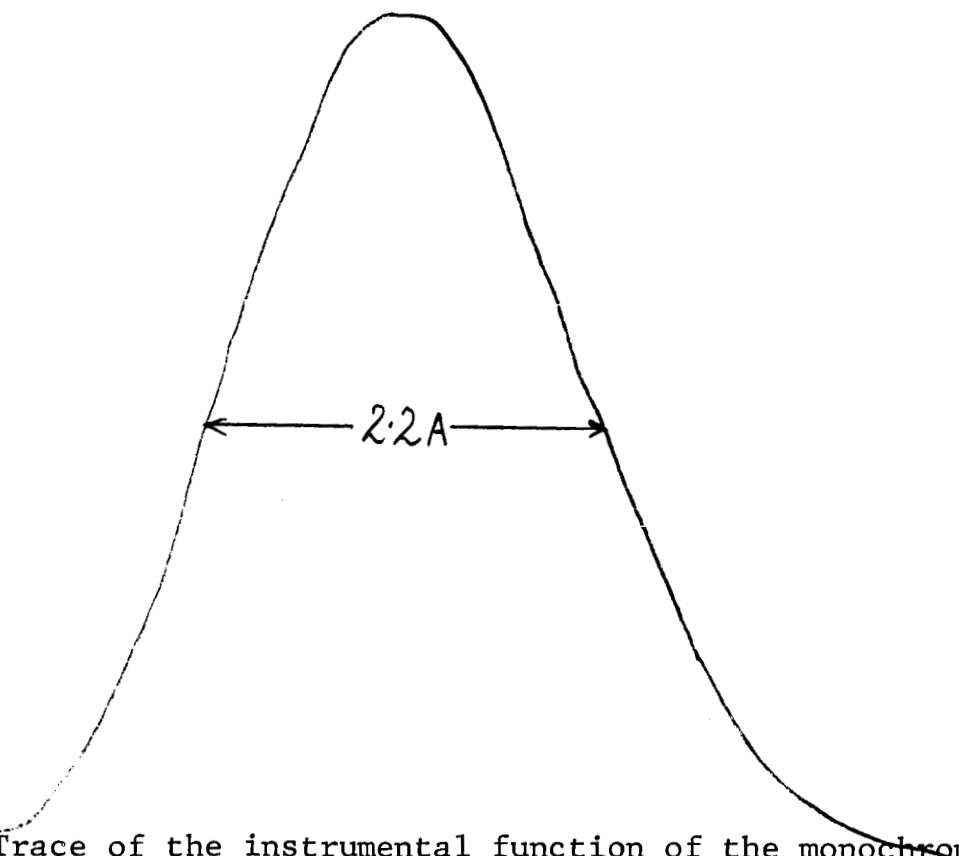

Fig. 5b. Trace of the instrumental function of the monochromator using the Fabry Perot interferometer.

A6141-QR3

monochromator fixed at $\lambda6438A$ and scanning the Fabry Perot. Unfortunately, with the monochromator available, it was not possible to mismatch the entrance and exit slits in order to provide a flat-topped profile. The desirability of flattening the top of the profile of the monochromator is to relax the tolerance requirement on the synchronous scanning. This preliminary investigation was simply intended to test the feasibility of the system and so the lack of the flat-topped profile was not a hindrance at this stage. Work is continuing in development of the gear train and electronic control system to scan the monochromator and Fabry Perot together.

B. Double Fabry Perot System.

As previously described, the control of the Fabry Perot spacing is achieved by the use of strain gages placed across the air gap and attached to the interferometer plates. Figure 6 shows a photograph of one interferometer with a gage in position. The adjacent gage is one of the temperature compensating gages.

The arrangement of a pair of Fabry Perot interferometers is shown in Fig. 7 and a photograph of the system is shown in Fig. 8. In the last two Quarterly Status Reports a description of the electronic control system was given. This system has been partially evaluated and modified in order to try to attain the desired experimental accuracy. Modifications have included a change in the type of strain gages used from 150Ω gage resistance to 350Ω in order to provide a higher voltage for a given current
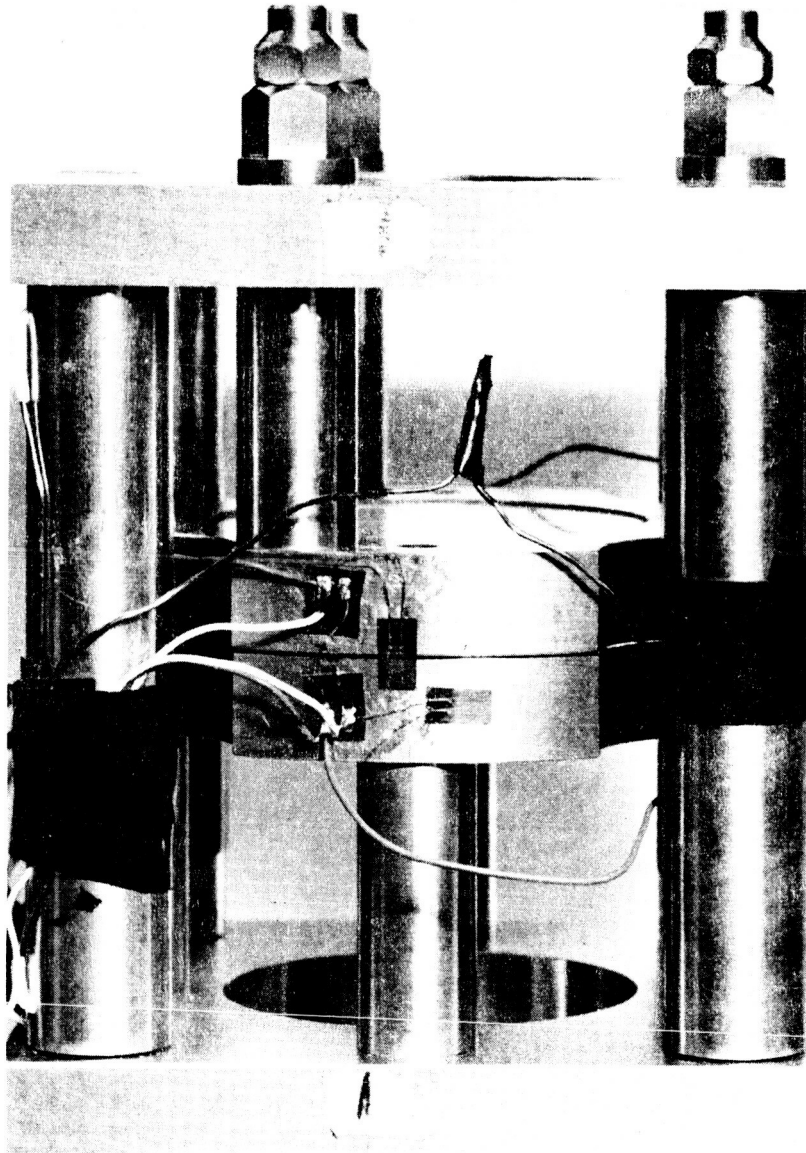
FIG. 6   PHOTOGRAPH OF STRAIN GAGES FOR CONTROLLING SCAN OF PRISM
         INSTRUMENT.

photomultiplier

aperture

focussing lens

Fabry Perot

quarter wave plate
and polarizer

Fabry Perot

filter

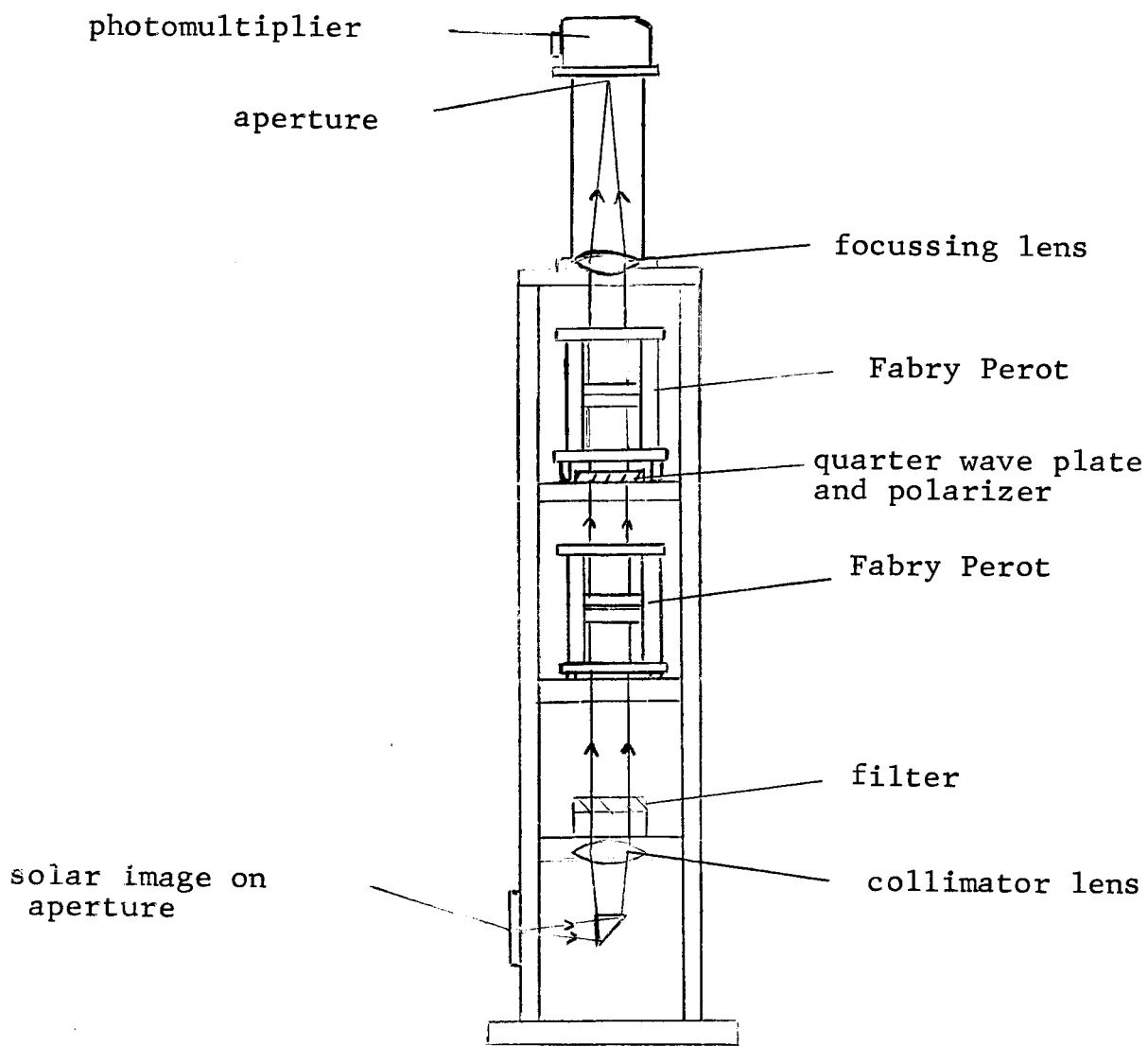solar image on
aperture

collimator lens

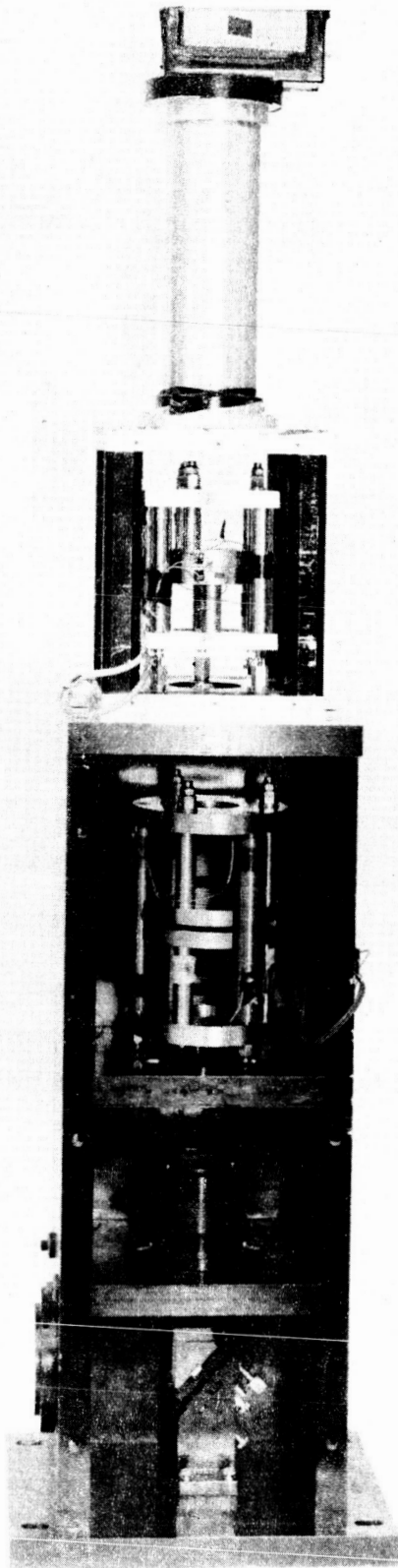Fig. 7.   Showing arrangement of a pair of Fabry Perot
interferometers.

FIG. 8   PHOTOGRAPH OF BREADBOARD MODEL OF DOUBLE FABRY PEROT SYSTEM.

13

through the bridge circuit. A difficulty experienced with this control system has been the amount of thermal drift which the system undergoes. The design of the strain gage bridge attempted to compensate for thermal effects by placing a thermal compensating gage adjacent to each active gage, the compensating gages making up the complete bridge circuit together with the active gages. This arrangement has not succeeded in eliminating thermal drift and further work is required before this system can be evaluated. Two approaches to the problem are being undertaken. These are, (i) To help equalize the heat sinking of the gages, the thermal compensating gages will be placed across the air gap of the interferometer in the same way as the active gages, but will be attached rigidly to only one of the plates. (ii) It is possible that differential thermal effects between the two active gages on each interferometer are the cause of the drift. To test this a thermally controlled bridge composed of four gages independent of the interferometer is being tested.

It has been verified that thermal effects are the cause of the drift problem for the drift is reduced as the voltage across the bridge circuit is reduced.

III   SUMMARY, FUTURE WORK AND DISCUSSION

The work of the last quarter has been directed to the evaluation of two alternative optical systems, namely, (i) A PRISM Fabry Perot interferometer preceeded by a grating mono-

IIT RESEARCH INSTITUTE

14   A6141-QR3

chromator, both instruments being scanned synchronously over the spectral region of interest. (ii) A pair of synchronously scanned PRISM Fabry Perot interferometers in tandem, preceeded by a narrow band interference filter.

The results of the comparison of the two systems, as far as this has been done, indicate that the system (i) has less practical difficulties associated with it than system (ii) has.

Further evaluation of both systems is planned in an extension to the present program. It may be noted that no known system similar to (i) has yet been developed for any kind of scanning Fabry Perot interferometer with the exception of one using mechanical scanning devised by M. D. Laplaze and A. M. Vergnoux (J. Phys. (France), Vol. 26, No. 4, 167-70, (April 1965)). These authors were performing measurements at a wavelength of 5.5μ to 8.5μ and, hence, the tolerance maintenance of parallelism between the plates of the interferometer was an order of magnitude less than that required when operating in the visible region of the spectrum.

The advantages to be gained by system (i) over, for instance, a simple grating spectrometer, may best be described in terms of the luminosity resolution product, $A\Omega R$, where A is the effective aperture, Ω is the solid angle of acceptance of system and R is the resolution of the instrument. Consider the half meter Ebert spectrometer used in the present program. The effective aperture A is the area of the grating and the solid angle of acceptance Ω is given by S/f^2 where S is

the area of the entrance slit and f is the focal length of the collimating mirror. To obtain a given resolution with the spectrometer operating alone, a specific slit width is required and, hence, S is fixed. For example, the dispersion of the instrument, using a 300 grooves/mm grating, is 64A/mm in the first order, and an instrumental function of 0.2A requires a slit width of about 3μ. The value of 0.2A used is, in fact, below the limit of resolution of the Jarrell-Ash instrument with this grating but, for the purpose of this comparison, this may be ignored. If now system (i) is used to obtain the same instrumental function we can calculate the gain in luminosity over that given by the spectrometer alone. In system (i), the spectrometer operates at low resolution (i.e., larger slit width) as a monochromator and we may use the result obtained in Section II, Fig. 6B, which shows the instrumental profile of the monochromator for a slit width of 25μ, obtained with a resolution of slightly greater than 0.2A. Since the area S and the luminosity are directly proportional to the slit width, system (i) represents a gain of slightly greater than 8 times in the luminosity for the same resolving power. The transmittance of the Fabry Perot will probably reduce this value to about 7. It may be noted that the realization of this gain requires matching the Fabry Perot optics to those of the monochromator in order to use all the light transmitted by the monochromator, i.e., the Fabry Perot system will operate at f/9. We have therefore a significant increase in the luminosity resolution product using the Fabry

Perot together with the monochromator.

Extending the above discussion to determine the gain of system (ii) over (i), consider the optical system shown in Fig. 7. The effective aperture A for this system is given by the useful aperture of the Fabry Perot interferometer plates which is about 1/2 that of the grating in system (i).

The transmittance of the second interferometer will reduce the luminosity of system (ii) by about 20% relative to (i).

The optimum solid angle subtended by the central order aperture of the scanning Fabry Perot has been given by R. Chabbal (J. de Recherches du C.N.R.S. No. 24, 1953) and J. Jacquinot (Rep. Prog. Phys. p. 267, 1960) as $2\pi/R_o$ where R_o is the resolving power of the instrument.

$$R_o = \lambda/\delta\lambda = \frac{6563}{0.2} = 32815.$$

Hence

$$2\pi/R_o = \frac{2\pi}{32815} = 1.91 \times 10^{-4} \text{ ster.}$$

Due to the limb darkening of the sun it will be necessary to view only an area of the solar image limited to the central 10% of the solar diameter. Using a telescope of 178 cm focal length, an aperture of approximately 0.25 cm diameter is required to select the central 10% of the disc diameter. If the collimator in Fig. 8 has a focal length of 50 cm, then the solid angle subtended by the aperture is

$$\Omega = \frac{S}{f^2} = \frac{\pi(0.25)^2}{4 \times 50^2} = 1.94 \times 10^{-5} \text{ ster.}$$

The relevant solid angle for system (ii) is the smaller of the two calculated, viz. 1.94×10^{-5} ster. System (i) has a solid angle of acceptance, Ω, given by the area of the slit in use. The slit width is 25μ and the height is

$$\Omega = \frac{WxH}{f^2} = \frac{0.0025 \times 0.25}{50^2} = 2.5 \times 10^{-7} \text{ ster}$$

limited to the central 10% of the solar image diameter, i.e., 0.25 cm. We can now compare the luminosities of systems (i) and (ii) thus:

$$\frac{(A\Omega)_{(ii)}}{(A\Omega)_{(i)}} = \frac{0.8}{1} \times \frac{1}{2} \times \frac{1.94 \times 10^{-5}}{2.5 \times 10^{-7}} = 31$$

The factor of 0.8 accounts for the additional transmission factor contributed by the second Fabry Perot in (ii). Hence system (ii) has a luminosity gain over (i) by a factor of about 30 times for a similar resolution.

The foregoing discussion shows the relative gains of the system considered. It can be seen that the optimum system is (ii), however its realization is likely to be more difficult.

A6141-QR3

DISTRIBUTION LIST

No. of Copies	Recipient
25	Miss Winnie M. Morgan Technical Reports Officer Office of Grants and Research Contracts Office of Space Science and Applications National Aeronautics and Space Admimistration Washington, D. C. 20546
3	IIT Research Institute Optics Files via P. N. Slater
1	IIT Research Institute J. J. Brophy
1	IIT Research Institute C. W. Terrell
1	IIT Research Institute B. A. Murray/Main Files