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## A COMPLETE FOURIER SPECTROSCOPIC SYSTEM FOR THE FAR INFRARED

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**Résumé.** — Les avantages de la spectroscopie de Fourier dans l'infra rouge lointain peuvent être maintenant appliqués à des études de routine. Des interféromètres lamellaires et de Michelson, destinés à se compléter l'un l'autre dans l'infrarouge lointain, plus un calculateur spécialisé donnent un système simple et facile à manier. Nous discutons quelques caractéristiques d'un système commercial et présentons des résultats qui montrent des résolutions comprises entre  $10\text{ cm}^{-1}$  et  $0,25\text{ cm}^{-1}$ .

**Abstract.** - The advantages of Fourier Spectroscopy in the far infrared can now be realised for routine investigation. Michelson and Lamellar grating interferometers designed to complement each other in the far infrared, together with a special purpose computer, give a simple, easily operated system. Some of the design criteria for a commercial system are discussed and results are shown at resolving powers from  $10\text{ cm}^{-1}$  to  $0.25\text{ cm}^{-1}$ .

The far infrared interferometers developed and used by Vanasse [1], Gebbie [2], and Richards [3], are now well known devices. The practical Michelson Interferometer relies upon a thin dielectric beam splitter which is most conveniently used in the region

necessary for optimum performance in these regions. The lamellar grating on the other hand becomes 100 % efficient both as an interference modulator and in terms of energy utilisation between the frequency limits determined by the design. These limits

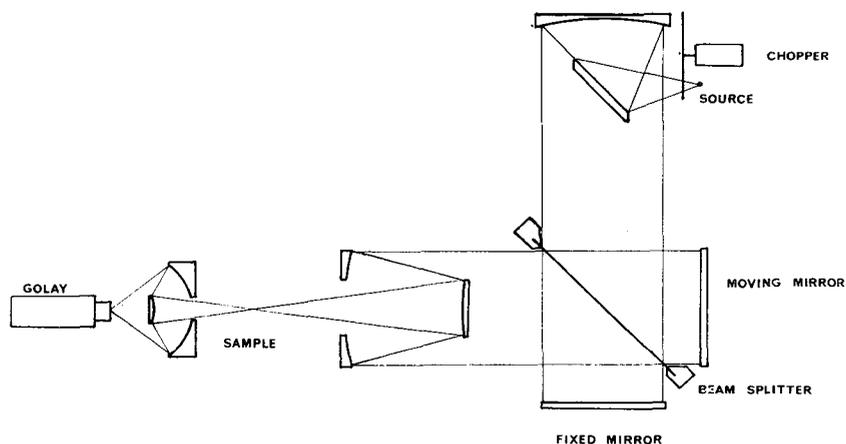


FIG. 1. — Optical layout for the Michelson Interferometer, FS-620.  
The system is based on 3" Cassegrain elements ( $f_2$  entrance aperture).

$500\text{ cm}^{-1}$  to  $10\text{ cm}^{-1}$ . Serious faults are the lack of efficient utilisation of the available energy at longer wavelengths and the many changes of beam splitter

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can cover four octaves, and the device is thus useable over five octaves without any realignment or major modification of the optical system. It is convenient to design a lamellar grating instrument to complement the Michelson in the  $2\text{-}50\text{ cm}^{-1}$  region. Figure 1

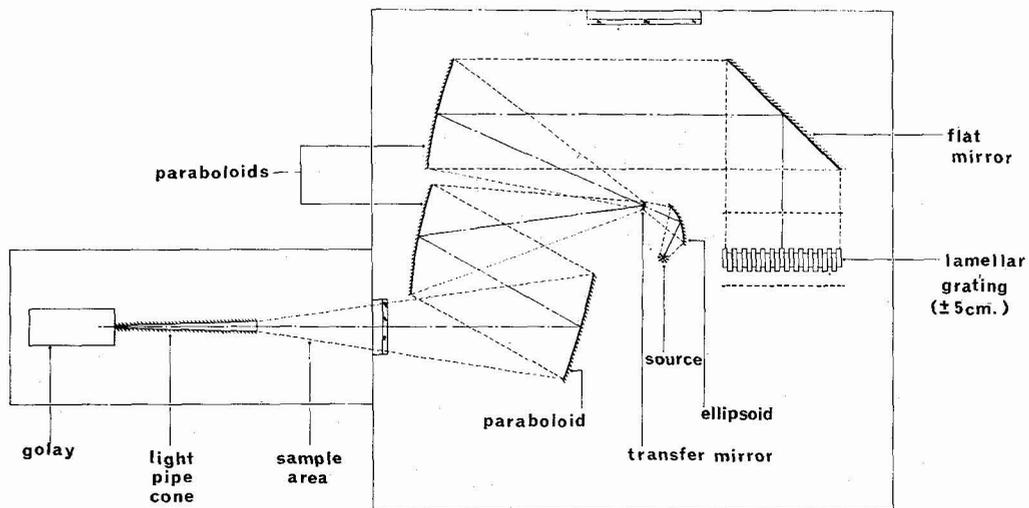


FIG. 2. — The optical layout of the lamellar grating interferometer LG-100.

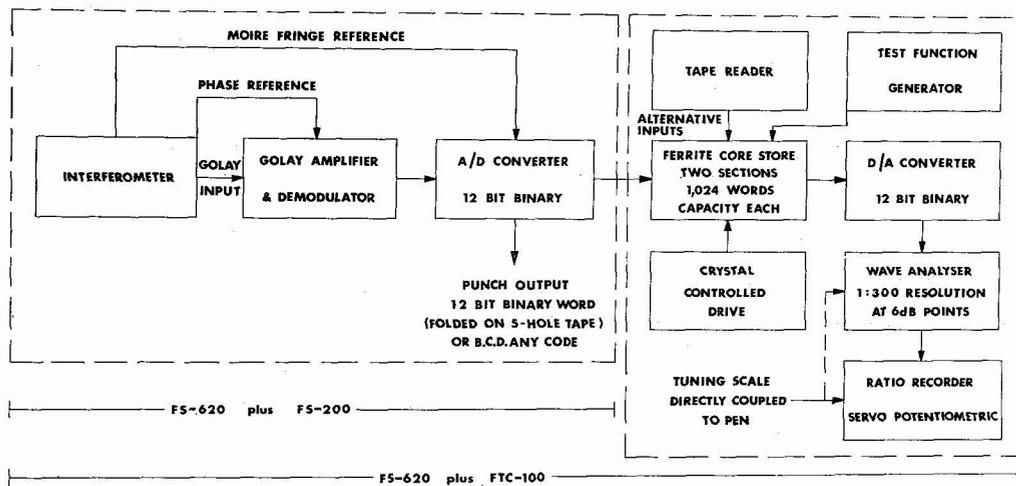


FIG. 3. — The complete system block schematic diagram.

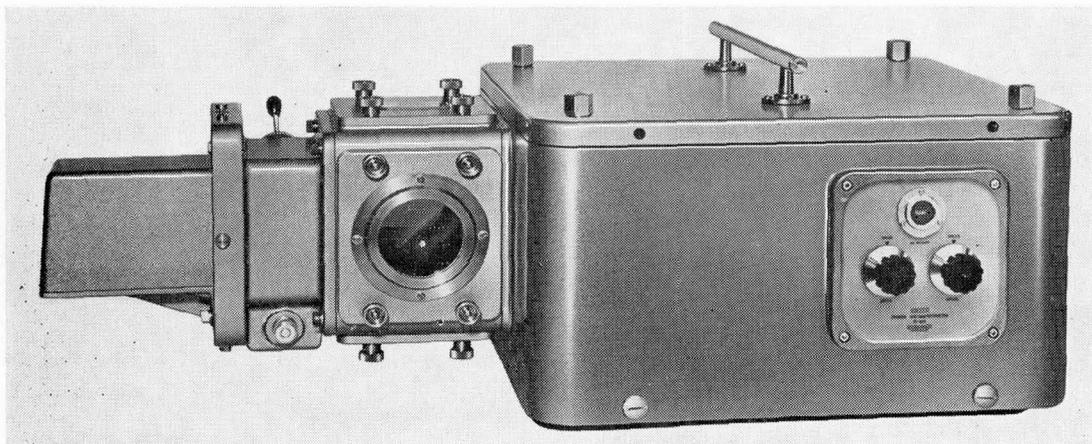


FIG. 4. — Photograph of the Michelson Interferometer, FS-620.

shows the optical layout of the Michelson interferometer FS-620, and figure 2 the lamellar grating interferometer LG-100. The luminosity disadvantage of the lamellar grating over the Michelson is not important at these frequencies with an acceptable size of optics, and in practice one gains several factors in detectable energy.

The detector and source are of course serious limitations, but with the energy advantages inherent in interferometric multiplex spectroscopy, the Golay pneumatic detector is useful up to the long wavelength limits set by the window diameter. Cryogenic solid-state detectors can give an order of magnitude better performance in signal to noise ratio, but the convenience of the Golay detector has much to recommend it. No better source has yet been found than the mercury arc discharge lamp. The plasma radiation contribution is small above  $60\text{ cm}^{-1}$  due to the fused silica envelope, but the envelope black body radiation gives a smooth transition and covers the remainder of the region up to  $500\text{ cm}^{-1}$  extremely adequately. When a slow detector such as the Golay is used, and the source energy is modulated by a mechanical chopper, the drive of necessity is of a single traverse type or «aperiodic». The signal to noise ratio is maintained in such a system by accurate digitising rather than by coherent addition of several successive interferograms.

Several drive mechanisms have been proposed, but for the far infrared region stated, the simple piston and cylinder has many advantages, not the least being a freedom from vibration sensitivity due to mechanical resistive damping in the mirror movement direction. Few investigations require better resolution capability than  $0.1\text{ cm}^{-1}$ , and a path difference necessary for such a performance, with a few seconds of arc mirror deviation, is relatively easy to achieve.

The accuracy of sampling the detector output should be at least equal to the resolving power and preferably several times greater than this if weak structure is not to be missed or quantisation noise is not to become excessive. For a commercially available system the cost versus performance has to be optimised, and for the system described, a 1:4 000 accuracy is used. Noise levels achieved are extremely low at 1:1 000 resolving power, the order of 1% at the energy maximum being a typical figure. An accuracy of this order cannot be easily obtained by analogue recording, and analogue to digital conversion is necessary, irrespective of the means of computation. The sampling interval should ideally be derived from

reference fringes if periodic errors are to be avoided. In the far infrared Moire fringes are most conveniently used, and an interval of 4 microns on the gratings gives an upper frequency limit, without aliasing, of  $625\text{ cm}^{-1}$ .

The digitised output can be processed by a high speed general purpose computer, but the delays



FIG. 5. — Photograph of the Fourier Transform computer system FTC-100.

which occur can be a nuisance if an immediate check on the spectrum quality is required. The hybrid, special purpose Fourier Transform Computer FTC-100 is a simple means of overcoming this disadvantage for resolving powers of 1:200 of the bandwidth sampled. Figure 3 shows the complete system in block schematic and photographs of the interferometer and computer's external appearance are shown in figures 4 and 5. The digitised output is stored serially in a ferrite core memory and the final interferogram waveform is wave analysed by cycling the memory and passing the re-analogue information through a tunable narrow band filter coupled to the spectrum plotting pen. The time compression available by this

method enables the equivalent spectral frequencies to fall in the audio bandwidth, and computing times are thus reasonable, about 10 minutes for 200 resolution widths. Apodisation is achieved by the natural shape of the filter bandwidth and the apodisation function is thus exponential. The information can only be fully utilised if a delay is introduced between each cycle, to allow the filter to cease ringing. This is also true for periodic interferometers where the detector output is fed directly into a filter. An improvement in the «stray light» caused by a finite gain outside the filter bandwidth can be improved by two filters in series, which is equivalent to a double monochromator in an optical spectrometer. The

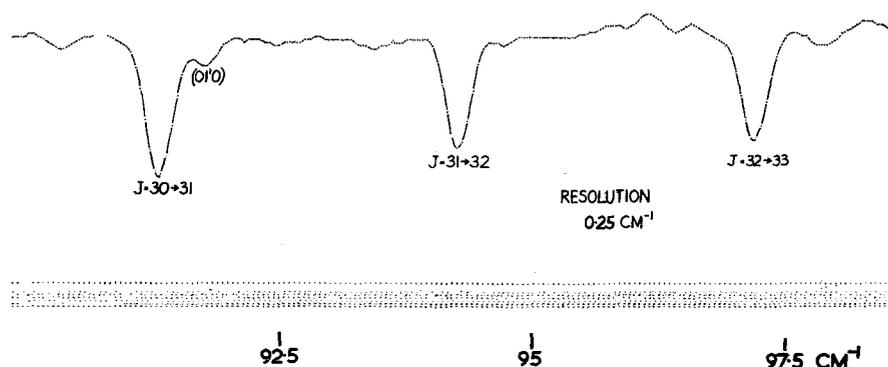


FIG. 6. — Part of a high resolution spectrum obtained with a digital computer. The actual computer output is shown unretouched. The optical bandwidth was 200 cm<sup>-1</sup> (G. Wilkinson, King's College, London).

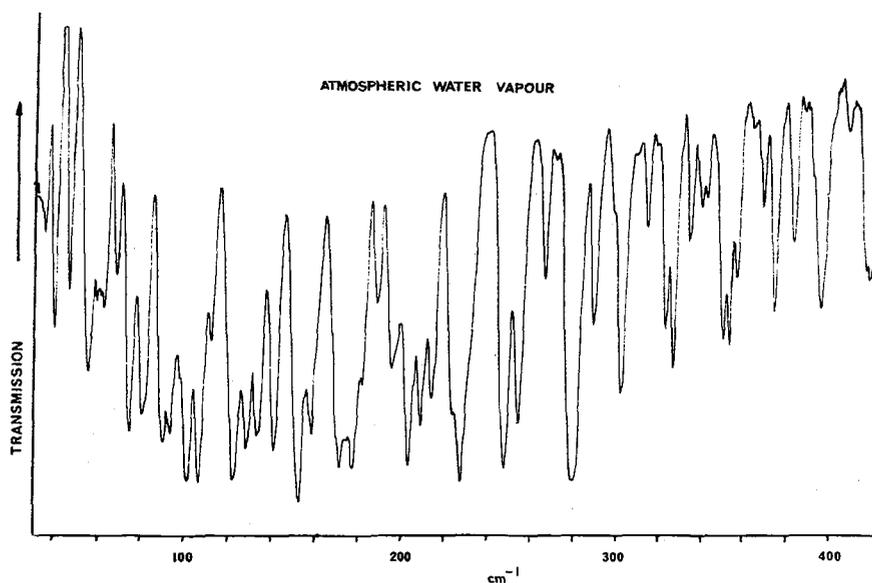


FIG. 7. — 3 cm<sup>-1</sup> resolution spectrum computed by the analogue computer, ratio recorded with the instrument background.

wave analyser consists therefore of two ganged continuously tunable filters in series, followed by a linear rectifier system.

It is common practice to display double beam spectra, that is, the background divided into the sample spectrum. The hybrid computer described has the facility of simultaneous computation of two interferograms and ratioing of the two outputs. The display is thus equivalent to a true double beam spectrophotometer output, although the interferograms were not obtained simultaneously. The stability of the background in an evacuated instrument is entirely adequate for this to be valid.

Figures 6 and 7 are results of the Michelson interferometer when used with a digital computer for high resolution studies and when used with the integral analogue computer at a resolution width satisfactory for the majority of chemical investigations. Both spectra are ratioed with the background. Figure 8

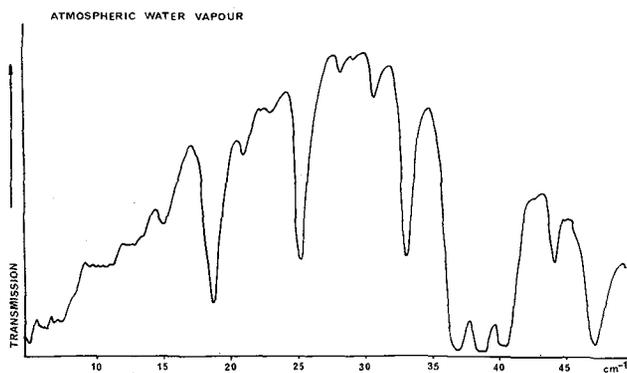


FIG. 8. — Analogue computed spectrum from the lamellar grating interferometer operated at  $1\text{ cm}^{-1}$  resolution, and high information rate conditions (6-minute double sided interferogram scan followed by 6-minute computation).

shows a single beam medium resolution spectrum of atmospheric water vapour from the lamellar grating

instrument coupled to the analogue computer. The interferogram was recorded in six minutes followed by a six-minute computation, showing the information rate possible with the system.

## INTERVENTIONS

E. BELL. — The « Jacquinot advantage », the large « étendue », or the large « throughput » of the Michelson interferometer in the far infrared region as compared to the conventional spectrometer are misleading. The small size of most far infrared detectors (the Golay cell, for example) has made it possible to fill the detector area with the full solid angle of acceptance in the spectrometer. Under this situation there is nothing to be gained by the « étendue » of the Michelson interferometer. The signal to noise gain by the « Fellgett advantage » is the important result which can be obtained from the Michelson interferogram.

J. RING. — Because the faith which chemists will place in these instruments, the manufacturers have a great responsibility to acquaint them with the intensity errors and asymmetries which may result from the sort of effects J. Connes has been describing. Perhaps the best way to proceed in future would be to display spectra as suggested by P. Connes, when describing commercial instruments.

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