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# CRYOGENIC EMITTANCE SPECTROMETER

Block Engineering, Inc.



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# CRYOGENIC EMITTANCE SPECTROMETER

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The design and fabrication of a high sensitivity cryogenic emittance Fourier interferometer system for measuring the infrared emission of low absorptance samples is described. The spectrometer, cooled to $LN_2$ temperature has a maximum spectral resolution of 0.5 $cm^{-1}$ in the 2.5 - 14 μm range and a noise equivalent emissivity limit of better than $5 \times 10^{-6}$ at 10 μm.

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In addition to the spectrometer the system includes a data processing system for the reduction and storage of the spectral data. The emissometer system has been tested and meets all specifications. Data obtained during the acceptance test phase of the program is presented in this report.

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## SUMMARY

Under Contract No. F19628-73-C-0265, Block Engineering, Inc., Cambridge, Massachusetts was contracted to design, develop, fabricate and test a cryogenic emittance spectrometer system based on a rapid scanning Michelson interferometer.

The primary objective of the program was to provide a precise measurement system for the determination of very low sample emittance. This information is considered essential in the design and development of high power infrared lasers with the requirement of high reflectivity mirrors and high transmission windows.

The emissometer system to be built for this program was to utilize a rapid scanning, high spectral resolution Michelson interferometer cooled to liquid nitrogen temperature in a specially designed vacuum chamber. The sensor was to have a spectral range of 2.5 - 14 microns, selectable resolution capability to .5 $cm^{-1}$, selectable spectral filtering and a selectable sample viewing area capability. In addition, the system was to include a data processing system for the reduction and storage of the spectra data.

The emissometer system was designed, developed and fabricated at the contractor's facilities in Cambridge, Massachusetts.

## SECTION I

## INTRODUCTION

### 1.0 Program Background

The purpose of this program was to design and fabricate a cryogenic emittance spectrometer, based on a rapid scanning Michelson interferometer operating in the 2.5 - 14 micron region. In this instrument, the interferometer and associated optics are cooled by liquid nitrogen to reduce background radiation, permitting the heated sample to be measured to great precision.

The application of modern rapid scanning Michelson interferometers to obtain spectral distributions of various samples provides a significant increase in sensitivity over contemporary dispersive spectrometers without sacrifice of spectral resolution. This capability is of prime interest to those concerned with the precise measurement of the weak absorptance of high reflectivity mirrors and high transmission windows used with high power infrared lasers. Block has developed an extremely rugged version of the rapid scanning Michelson interferometer in its Model 197 unit that has operated successfully in various configurations from 77$^{O}$K to 327$^{O}$K, in vacuum and under atmospheric conditions of up to 95% relative humidity. This unit formed the basis of the emissometer system.

This report presents a summary of the completed 23 months activity by Block Engineering to construct and successfully test the emissometer system for the Air Force Cambridge Research Laboratories, Bedford, Massachusetts.

## SECTION II

## SYSTEM DESIGN

### 2.0 General

The emissometer system can be divided into two main parts - the spectrometer/cryogenic system and the data system (both hardware and software.) Table Number One is a summary of the performance specifications of the complete system.

### 2.1 Spectrometer Chamber Description

A mechanical view of the spectrometer portion of the system is shown in a sequence of photographs, Figures 1 through 3.

Essentially, the spectrometer unit is housed in a large cylindrical aluminum chamber which acts in much the same manner as a vacuum insulated liquid nitrogen dewar. The chamber shown in Figure 1, provides a long term vacuum environment for the high sensitivity cryogenically cooled system in which all components are cooled to approximately 80$^{O}$K to reduce background radiation in the wavelength region of interest. Sample access to the spectrometer optical system is accomplished via a gate valve/ante-chamber assembly which allows rapid cycling of samples without disturbing the vacuum integrity or temperature stability of the spectrometer chamber. The gate valve is manually operable via a single lever control and serves as a vacuum tight quick release interface between the main chamber and the sample chamber. The sample chamber has been designed for rapid cycling of samples. A quick disconnect "V"-clamp allows removal of the top section of the ante-chamber for insertion of the sample holder, while an independent vacuum line provides pump out capability.

TABLE 1

SYSTEM SPECIFICATIONS

| | |
|---|---|
| **Spectrometer** | |
| Spectral Range | 2.5 to 14 microns |
| Detector | Si:As at $4^{o}K$ |
| Resolution | 0.5, 1, 2, 4 $cm^{-1}$ |
| Emissivity Limits* | Less than 1 x $10^{-6}$ at 10 microns |
| Operating Temperature | $80^{o}K$ |
| Sample Area Limits | 1.0, 0.5, 0.25, 0.125 cm |
| Filter Holder | Four positions, selectable |
| Sample Temperature Range | $80^{o}K$ to $350^{o}K$ |
| Calibration Source Temperature Range | $80^{o}K$ to $500^{o}K$ |
| **Data Processing System** | |
| Processor | NOVA 1200 with 4K of Core |
| Data Input Capability | 16 bit A/D Converter |
| Maximum Transform Size | 16 K |
| Display Devices | CRT Display and Digital Plotter |
| Storage Devices | Digital Magnetic Tape and 128 K Disk |
| Operator Interface | ASR 33 Teletype |

* Measurement Conditions: $300^{o}K$ sample temperature, 0.1 micron resolution, 100 second integration time.

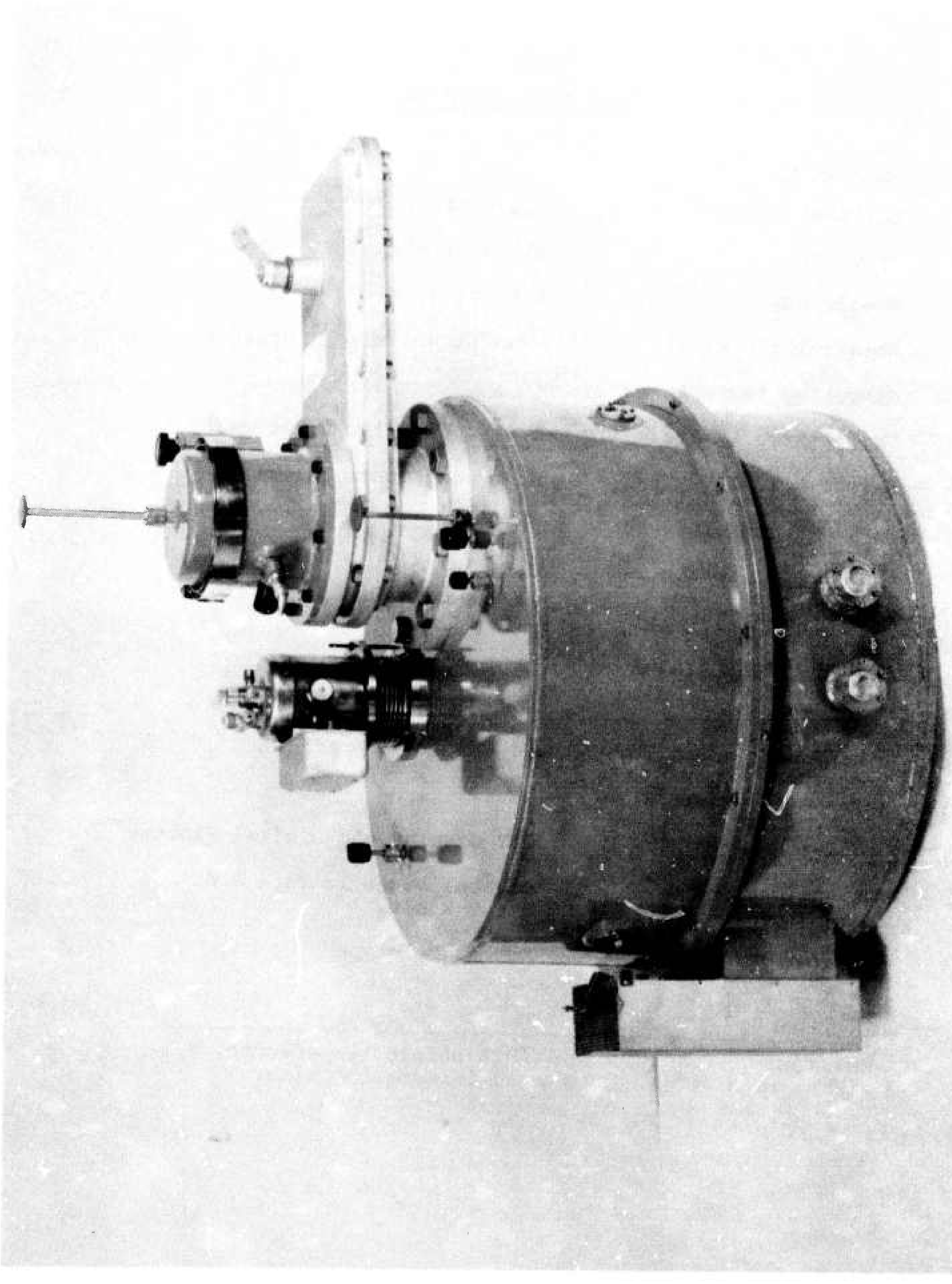


Figure 1. Assembled System

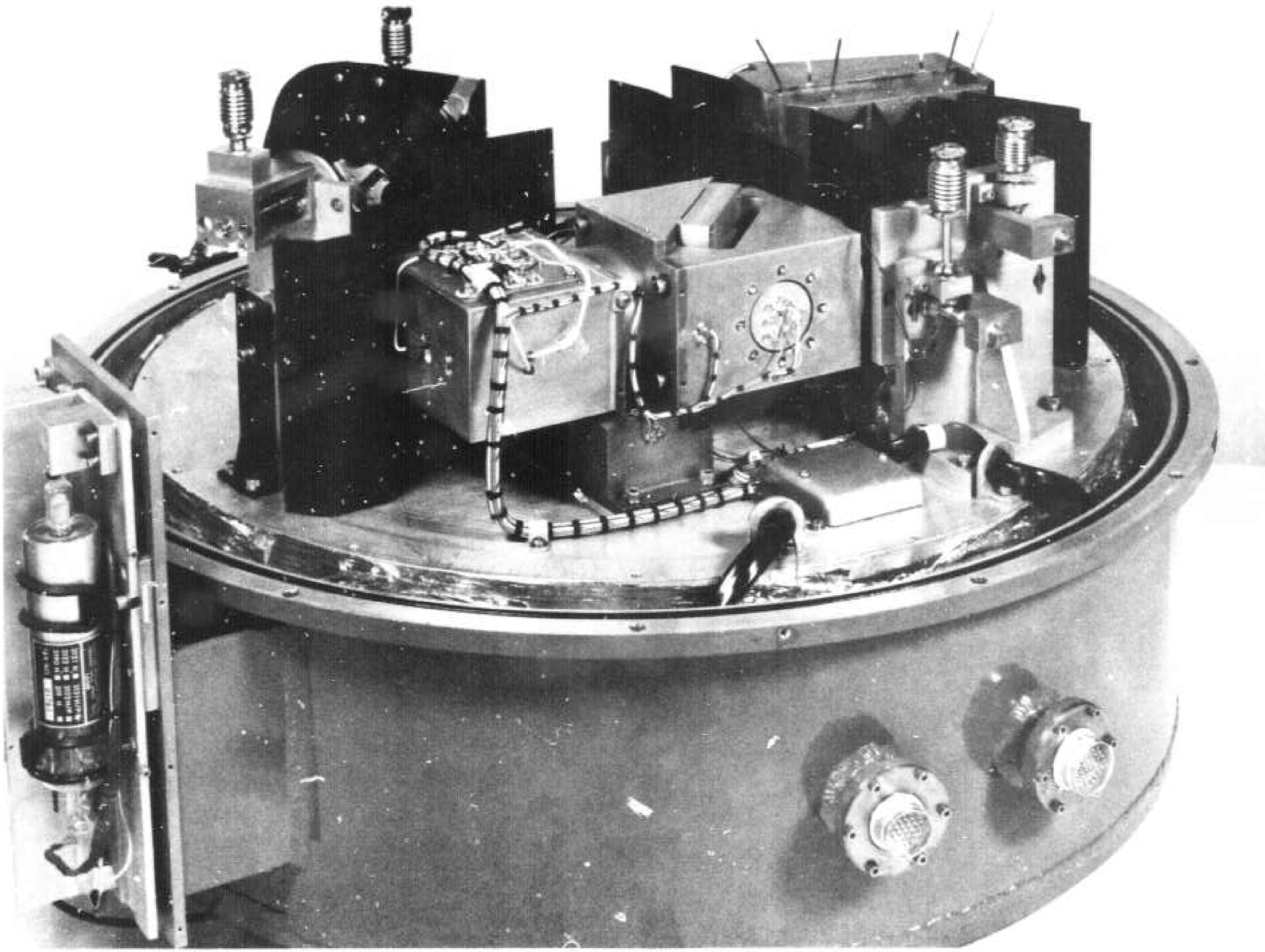


Figure 2. Chamber Top Section Removed

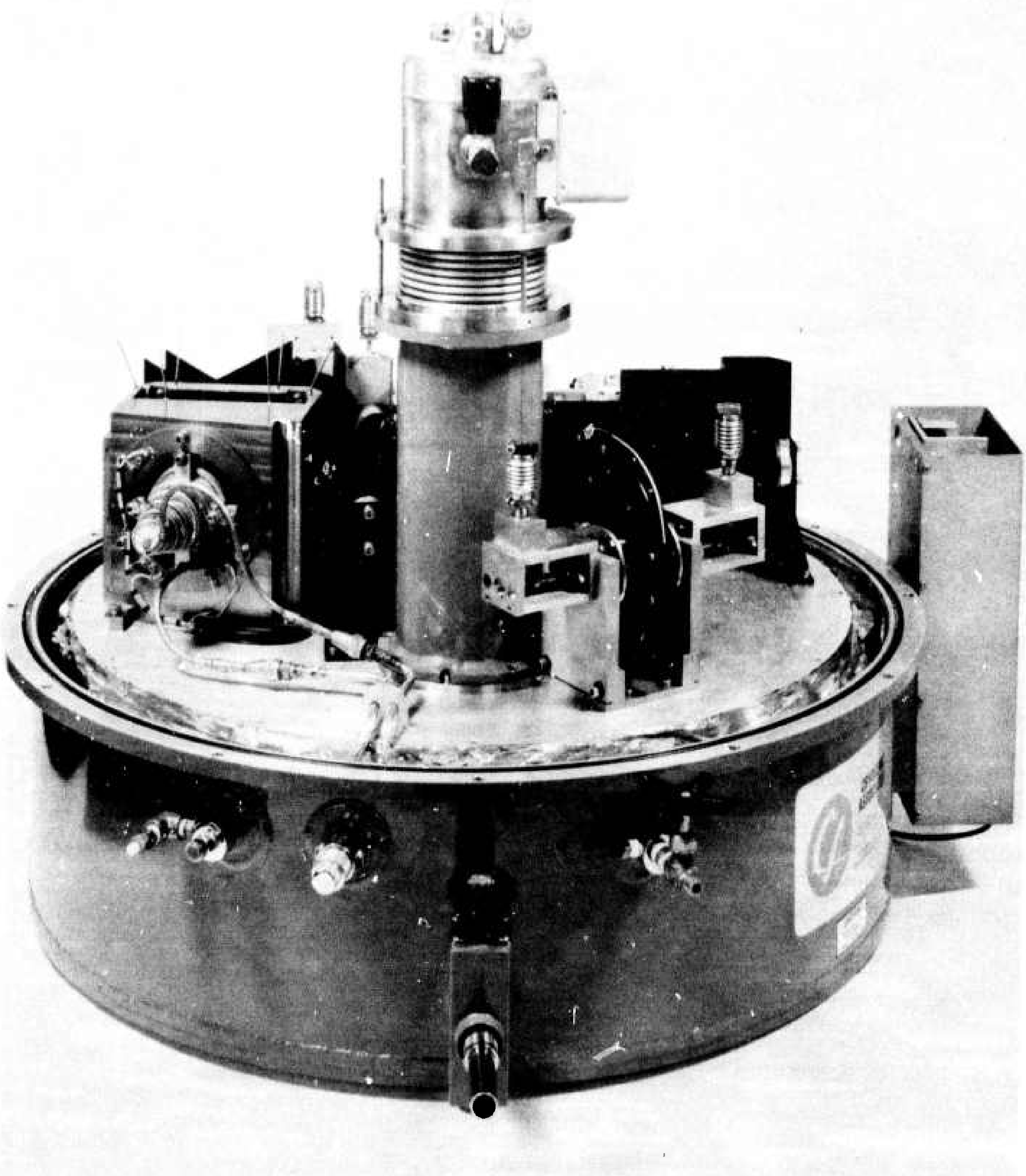


Figure 3. Warm Operating Mode

Access to the spectrometer and optics for routine maintenance and alignment purposes is provided through the removable top section of the instrument housing which, when removed, exposes an aluminum cold shield which encloses the entire internal system. This removable cold shield, which is maintained at approximately $80^{\circ}K$, provides total isolation from the $300^{\circ}K$ warm outer housing, minimizing radiative loading on the optical assembly as well as minimizing stray background radiation on the detector. The cold shield also improves the system performance from a reliability point-of-view by eliminating any need for low temperature vacuum seals, since all pressure interfaces are located on the room temperature outer housing.

Removal of the top section of this instrument housing and the cold shield, see Figure 2, reveals that the spectrometer and optics are mounted on a 1 inch thick optical mounting plate which forms the ceiling of the internal liquid nitrogen reservoir. This mounting plate is designed to maintain flatness to .005" T.I.R. over the temperature range $300^{\circ}K$ to $77^{\circ}K$. The $LN_2$ reservoir area utilizes the lower half of the assembled chamber, and under normal operating conditions can maintain the optical components at cryogenic temperatures in excess of 60 hrs. of unattended operation.

Alignment of the instrument is facilitated by having the optical mounting plate the top most surface with the outer housing and cold shield removed. Provision has also been made allowing operation of the liquid helium ($4^{\circ}K$) cooled infrared signal detector in this ambient temperature/pressure mode of operation via an auxiliary warm detector dewar housing, see Figure 3. Under normal operating conditions, the detector dewar utilizes the vacuum that exists within the instrument chamber for thermal isolation. In the warm mode, however, it is necessary to evacuate only the warm auxiliary housing to maintain the proper thermal isolation. The hold time of the liquid helium dewar in either arrangement is enhanced by a liquid nitrogen outer jacket surrounding the helium reservoir which enables a design hold time of 1 hour. Access to both the liquid nitrogen and the liquid helium reservoir is through the top section of the detector dewar. Detector alignment is preserved in either mode of operation by a stanchion located on the optical mounting plate which serves as a reference surface in the vertical axis.

Manual control of various assemblies, including the two axis sample scanning mirror, the field stop wheel and the filter wheel are accomplished through low thermal conductivity stainless steel connecting rods attached to the particular assembly via stainless steel bellows couplings which accommodate the dimensional shift due to the low temperatures. Dynamic seals at the warm outer housing allow complete rotational freedom of the control rods without loss of vacuum integrity.

Due to the critical temperature dependence of glass envelope lasers, the HeNe laser, which provides the necessary reference signal for proper operation of the interferometer, is mounted on the outside of the chamber with a small optical access window in the chamber wall for the beam passage, see Figure 1.

In addition to the reference interferometer laser window, a sample access path, including window, has also been provided, allowing localized heating or irradiation of the sample from an external source.

## 2.2 Spectrometer Description

The rapid scanning Fourier spectrometer used in this system, see Figure 4, is of the conventional Michelson design, utilizing the phenomenon of interference to produce a spectrally encoded signature of the input energy referred to as an interferogram. The recovery of the spectral information is obtained

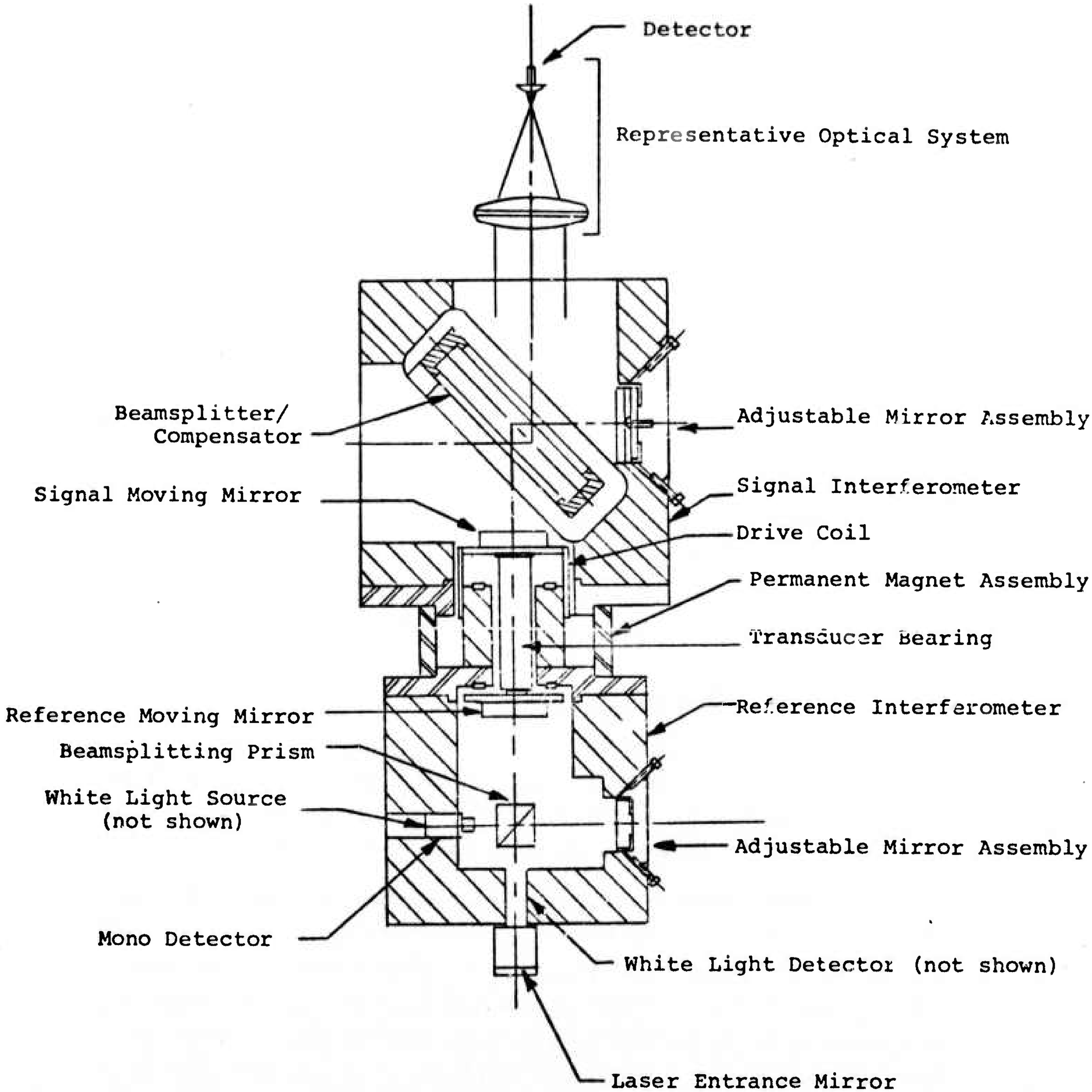



Figure 4.

Signal and Reference Interferometer

by performing a Fourier transform on the resulting signal which may be thought of as a simple harmonic analysis of the interferogram.

The resolution $\Delta\nu(cm^{-1})$ of a Fourier spectrometer is inversely proportional to the difference in optical path length (retardation) of the two interfering beams and is constant in wavenumbers throughout the spectrum. Spectrally encoded signals in the audio frequency range are produced by continuously varying this path difference in the form of a scanning mirror smoothly driven at a uniform speed. The instrument is designed to scan at a retardation rate of 2.5 cm/sec yielding output signal frequencies in the 1.7 to 8.3 kHz region. Four selectable retardations, .25, .5, 1, and 2 cm, are available corresponding to a nominal resolution of 4, 2, 1, 0.5 $cm^{-1}$ respectively.

There are actually three main areas comprising the spectrometer assembly; namely, the signal or main interferometer, the moving mirror transducer assembly, and a second "reference" interferometer assembly which provides accurate information concerning the position and velocity of the moving mirror.

### 2.2.1 Signal Interferometer

The signal interferometer consists of the beamsplitter assembly and the adjustable fixed mirror which can be aligned in two orthogonal axes via piezoelectric elements. As a unit, this assembly is attached to the transducer assembly.

The spectrometer beamsplitter/compensator substrates are of solid germanium. By multilayer coating applied to one side of the beamsplitter substrate and to both sides of the compensator, undesirable reflections and energy losses are reduced. The beamsplitting is accomplished by the Fresnel reflection from the uncoated beamsplitter surface. This high index material (n = 4) is a nearly perfect beamsplitter over the required spectral region.

### 2.2.2 Transducer Assembly

The bearing and transducer assembly which supports the moving mirror in the signal interferometer also supports the moving optical element in the reference interferometer as well. This transducer assembly consists of the two moving mirrors, a coil, and a spring loaded inner bearing. The coil is placed within the field generated by a permanent magnet. Scanning is thus accomplished by applying the proper voltage waveform to the coil, causing the assembly to move in a manner similar to the voice coil moving in a loudspeaker assembly. The moving assembly is supported by a cylindrical outer bearing manufactured to extremely close tolerances such that the tilt and wobble characteristics of the bearing are held within predetermined specifications commensurate with the wavelength coverage of the instrument.

### 2.2.3 Reference Interferometer

The most complex of the three major subassemblies within the spectrometer is the reference assembly. The reference interferometer generates electrical signals from both a monochromatic source (HeNe laser at .6328 μm) and a tungsten lamp source to provide position as well as velocity information to the mirror drive servo loop.

The reference interferometer for this particular instrument utilizes a double pass approach with corner cube retroreflectors inserted in place of plane mirrors as in a standard interferometer. The advantage of using retroreflectors in this situation is their insensitivity to tilt or wobble. This stability is of prime concern due to the low temperature operation of the system.

## 2.3 Optical Description

The optical layout for the emissometer system is shown in Figure 5. Table 2 tabulates the pertinent system design numbers and dimensional relationships. Figure 5 reveals that

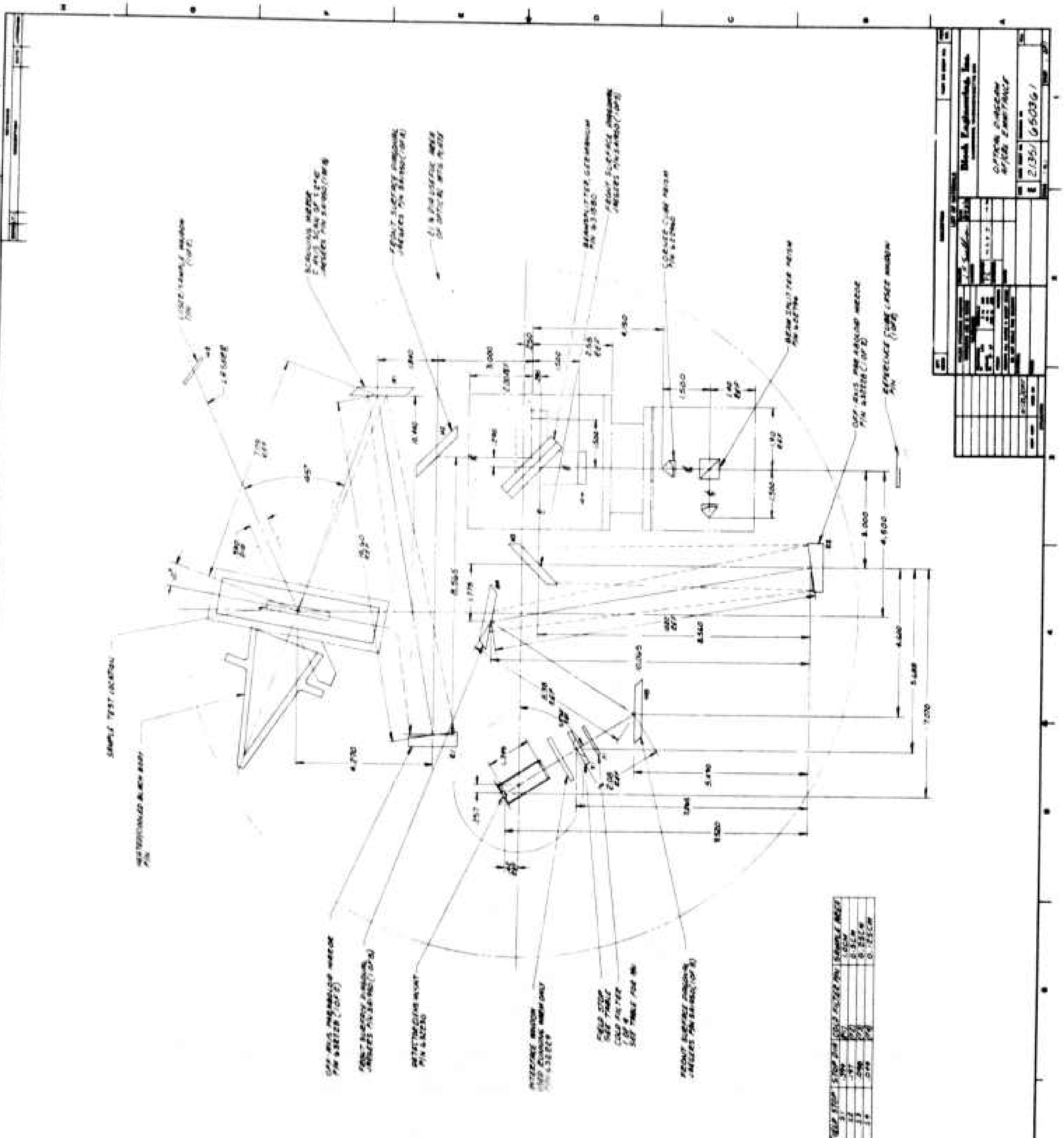


Figure 5

System Optical Diagram

## TABLE 2

## OPTICAL SYSTEM PARAMETERS

(dimensions in inches)

| Element | Surface Number | Radius of Curvature | Clear Aperture Diameter | Distance Next Surface | Material | Appropriate BEI Dwg. |
|---|---|---|---|---|---|---|
| Calibration Blackbody | 1 | - | 2.00 | 1.00 | Cast Aluminum | 632262 |
| Sample | 2<br>3 | - | - | -<br>7.09 | -<br>- | -<br>- |
| Wobble Mirror | 4 | Infinite | 1.25 x 1.75 | 10.60 | Pyrex | Jaegers 5A1950 |
| Entrance Off-Axis Paraboloid | 5 | 8.85 | 1.40 | 8.565 | Fused Silica | 632228A |
| Diagonal Mirror | 6 | Infinite | 1.25 x 1.75 | 3.000 | Pyrex | Jaegers 5A1950 |
| Beamsplitter/ Compensator | 7 | Infinite | 2.000 | 1.500 | Germanium | 631580 |
| Fixed/moving Mirror | 8 | Infinite | 1.000 | 1.500 | Quartz | 62259A |
| Beamsplitter/ Compensator | 9 | Infinite | 2.000 | 3.000 | Germanium | 631580 |
| Diagonal Mirror | 10 | Infinite | 1.25 x 1.75 | 5.38 | Pyrex | Jaegers 5A1950 |
| Exit off-axis Paraboloid | 11 | 8.85 | 1.40 | 10.065 | Fused Silica | 632228A |
| Diagonal Mirror | 12 | Infinite | 1.25 x 1.75 | 5.38 | Pyrex | Jaegers 5A1950 |
| Diagonal Mirror | 13 | Infinite | 1.25 x 1.75 | 1.50 | Pyrex | Jaegers 5A1950 |
| Cold Filter | 14<br>15 | Infinite | 0.88 | 0.085<br>0.500 | - | - |
| Exit Field Stop | 16 | Infinite | 0.394<br>0.197<br>0.098<br>0.049 | 0.500 | Aluminum<br>-<br>-<br>- | 623472-1<br>623472-2<br>623472-3<br>623472-4 |
| Interface Window (Warm Operation Only) | 17<br>18 | Infinite | 1.00 | 0.120<br>0.500 | Zinc Selenide | 632229 |
| Field Lens | 19<br>20 | 1.366<br>3.150 | 0.50 | 0.134<br>1.229 | Cadmium Telluride | 8001238 |
| Detector | 21 | Infinite | 0.08 | - | Arsenic-doped Silicon | 8001236A |
| Optical Access Window | -<br>- | Infinite | 1.10 | 0.08<br>8.065 | Zinc Selenide | 623466 |
| Reference Cube Laser Window | -<br>- | Infinite | 1.10 | 0.120<br>5.56 | BK-7 Glass | 623488 |

reflective optics are used as much as possible in this instrument to minimize losses over the spectral range of interest. In addition, off-axis parabolas with relatively long focal lengths are employed to minimize the effect of the dimensional shift in cooling from 300°K to 80°K. Angular shifts of the parabolic elements with temperature are minimized, since the entire optical system is attached to a relatively massive structure designed for minimum warp at low temperature.

In a typical optical sample or responsivity measurement, the radiation from the optical specimen or the blackbody proceeds to the entrance parabola (R1) by means of the diagonal mirror (M1), which can be manually rotated ±2°10' or ±1 cm in two axes, to provide sample scanning capability. The energy collimated by paraboloid (R1) enters the spectrometer through diagonal mirror (M2). After passing through the spectrometer, the energy is directed to the exit paraboloid (R2) by the diagonal mirror (M3) where it is refocussed throught diagonals M4 and M5 on the exit field stop (S). This stop is manually selectable, providing the following sample viewing area capability:

| Field Stop | Stop Diameter (cm) | Sample Area (cm) |
|---|---|---|
| S1 | 0.394 | 1.0 |
| S2 | 0.197 | 0.5 |
| S3 | 0.098 | 0.25 |
| S4 | 0.049 | 0.125 |

A filter wheel (F), which is also manually selectable, is included in the system, allowing various spectral bands to be utilized as desired. Finally, the cadmium telluride field lens (L1) images the interferometer mirror on the detector (D). With this system then, the detector serves as an exit pupil, with the entrance pupil located at the sample position. The interferometer mirrors in this arrangement act as intermediate pupils.

In addition to the optical system described above, in the warm mode of operation, a zinc selenide interface window mounted on the detector dewar warm housing is inserted in the optical system. During normal operation, this window is not necessary.

Optical access to the sample in the standard mode of operation is provided through a zinc selenide window mounted on the warm outer housing of the system. A small cavity at the end of the optical access path allows maximum dissipation of 100 watts to the internal structure without adversely affecting the temperature stability of the optical components.

Stray radiation entering the field of this system is minimized through use of liquid nitrogen cooled baffles on the optical mounting plate, as well as the system cold shield described earlier, to effectively isolate the optical beam.

A single multipurpose blackbody source is provided with this system. The source, which can be force cooled to cryogenic temperatures ($80^{o}K$) directly from the internal $LN_2$ reservoir, is located behind the sample position, thermally isolated from the optical mounting plate. The source in its cooled state provides controlled background radiation during sample measurement. For calibration of the spectrometer, the sample is removed from the system and the blackbody is raised in temperature to provide the calibration signal. The overall temperature range of the source is $80^{o}K$ to $500^{o}K$.

The design of the optical system incorporates an arsenic doped silicon (SiAs) photoconductive infrared detector cooled to liquid helium temperature, $4^{o}K$, to achieve photon noise limited performance down to very low background levels. The sensitivity of the detector is enhanced by use of a liquid helium cooled filter combination of zinc sulfide and barium fluoride, which serves to limit the response of the system to 14 microns while increasing the overall sensitivity in the 2.5 - 14 micron region. The detector filter assembly along with the field lens are mounted in the side looking liquid helium dewar.

The preamplifier designed to complement the low noise signal detector consists of a liquid nitrogen cooled FET input stage coupled to a standard operational amplifier circuit whose gain has been optimized for this particular detector. The noise contribution of the preamplifier, less than 2 nanovolts per root cycle input noise voltage, is such that the photon generated noise of the detector is the limiting noise in determining the sensitivity of the instrument and results in a significant increase in performance over a similar room temperature system.

## 2.4 Sample Holder

A mechanical view of the sample holder is shown in Figure 6. The unit consists of a split ring sample mount designed to accomodate 1.5 inch diameter samples. The split ring approach provides a uniform thermally conductive edge contact on the sample which can be heated to $350^{o}K$. The heater element consists of a single 51 inch electric heating cable wrapped around the perimeter of the split ring sample mount in a spool arrangement. The cable has a sheath diameter of 0.04 inches and a resistance of 70 ohms. Temperature control of the sample is accomplished through a calibrated thermistor attached directly to the sample surface. Variations in the sample temperature are monitored by the operator via a digital temperature readout and controlled via a variac heater supply.

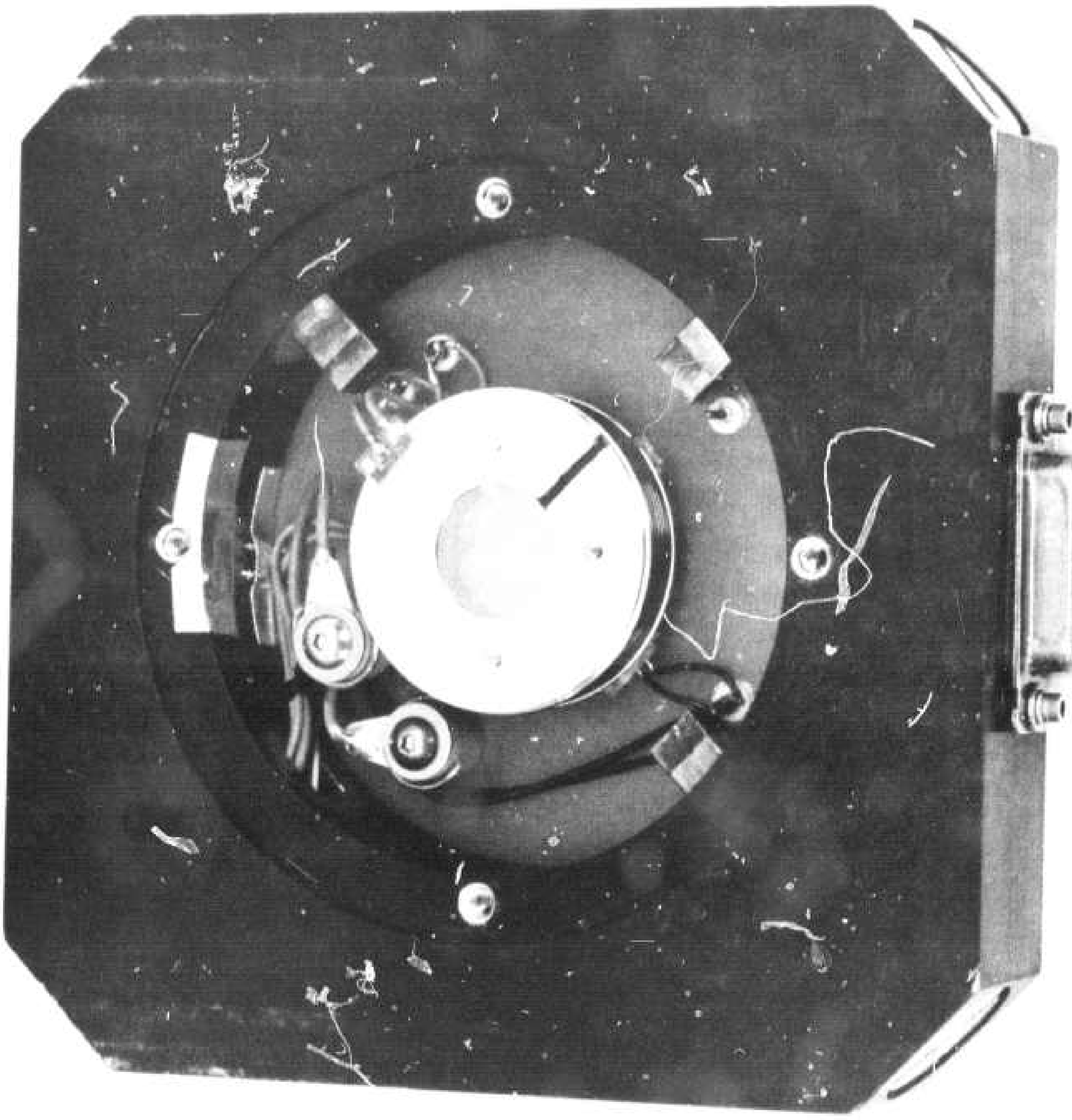


Figure 6. Sample Holder

### 2.5 Cryogen System

Two cryogenic fluids are used in the emissometer system, both liquid nitrogen and liquid helium. The $LN_2$ is used as the coolant for the optics while the LHe is used as the coolant for the Si:As detector. The fabrication of the system is simply a single nitrogen reservoir, the top surface of which is used to carry the optical system and spectrometer which are thereby cooled by conduction. The optical system is surrounded by a radiation shield conductively cooled by thermal contact with the nitrogen reservoir. This entire assembly is then wrapped in blankets of super insulation and the assembly is placed inside a room temperature outer jacket which is subsequently evacuated. (The liquid nitrogen reservoir is vented to ambient pressure and is not pumped.) The detector dewar is inserted into the system through a hold in the warm shell and a port in the radiation shield. Access is provided for insertion and removal of the samples by means of a gate valve in the warm shround and a simple shutter in the radiation shield. The system (less detector) will remain cold for up to 60 hours of unattended operation.

### 2.6 Data Processing System

The data processing is a commercial system based on a NOVA 1200 mini-computer with 4K of core. The system is outlined in Figure Number 7. In addition to the NOVA there is a Digilab generalized input/output device which interfaces the spectrometer with the data system, contains the analog-to-digital converter, the hardware multiply-divide, and the interfaces for the CRT display and the hard copy digital plotter. In addition to these items the system is provided with a 128K fixed head disk for storage of the system software and working spectral files as well as digital magnetic tape for archival storage

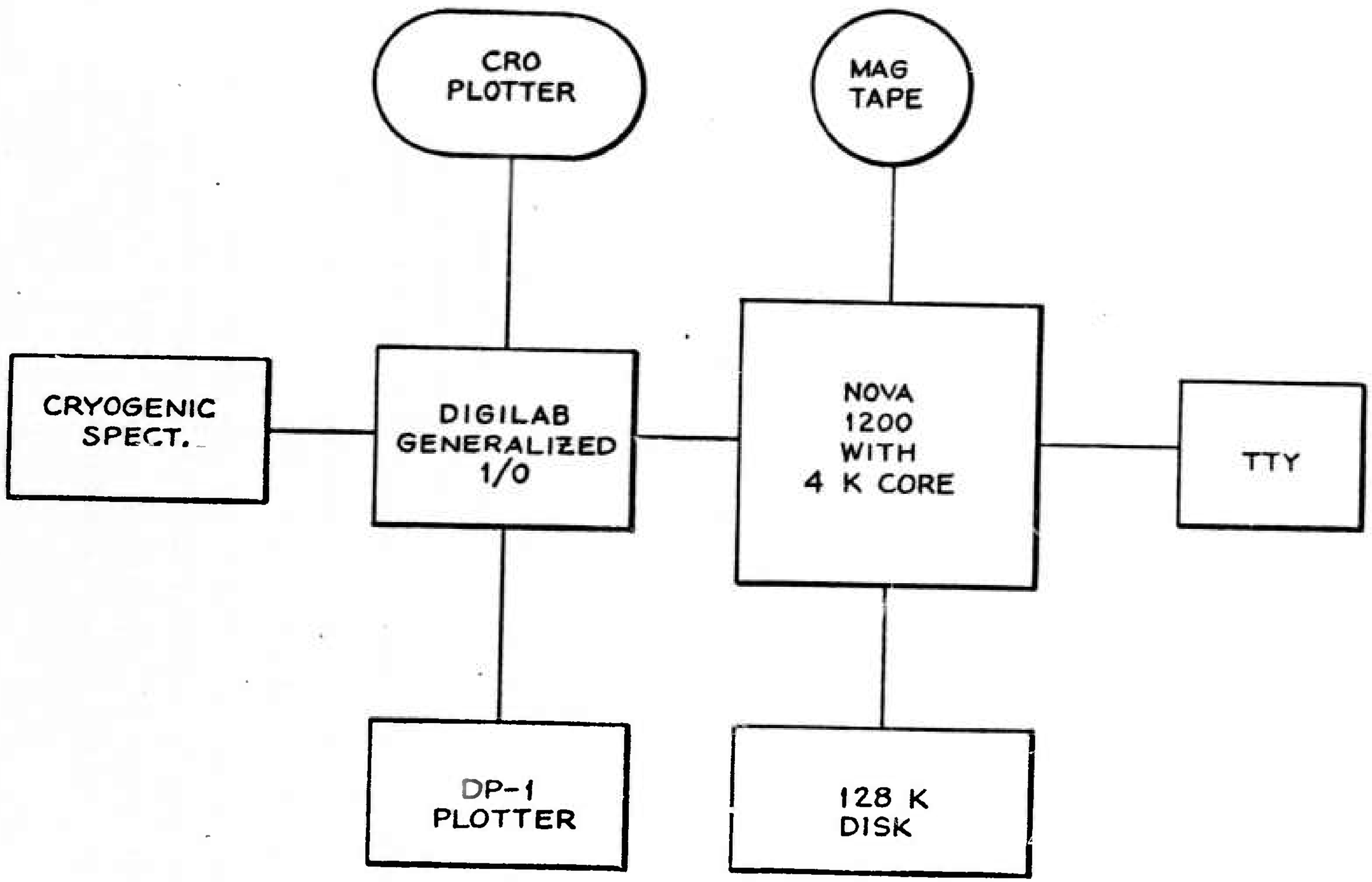



Figure 7. Data Processing System

of the system programs and spectral data files. Operator interaction with the data processing system is by means of the teletype.

### 2.6.1 Software Description

The system has been programmed with a custom set of software specifically designed to perform all processing of the data that is collected in order to calculate the emissivity of a sample. To this end the software allows the operator to

- collect and transform the interferograms from the calibration blackbody and the sample and to normalize this collected data for the instrument gain and the number of scans;
- perform the necessary operations on the calibration spectra (such as subtraction of background and calculation of the theoretical blackbody functions) to produce and store for future use an instrument response function;
- correct the sample spectrum with the instrument response function resulting in a sample radiance spectra which is then divided by the theoretical blackbody to obtain the emissivity of the sample;
- plot the resultant spectra along with any of the intermediate results in publishable form.

To assist in the performance of the above functions the system is also able to perform addition, subtraction, multiplication or division of any two spectral files in addition to computing of the blackbody functions.

## SECTION III

## ACCEPTANCE TESTING

### 3.0 General

This section presents the results and conclusions of a series of tests and demonstrations performed by the contractor for the purpose of verifying conformance with certain performance requirements.

### 3.1 Spectral Resolution

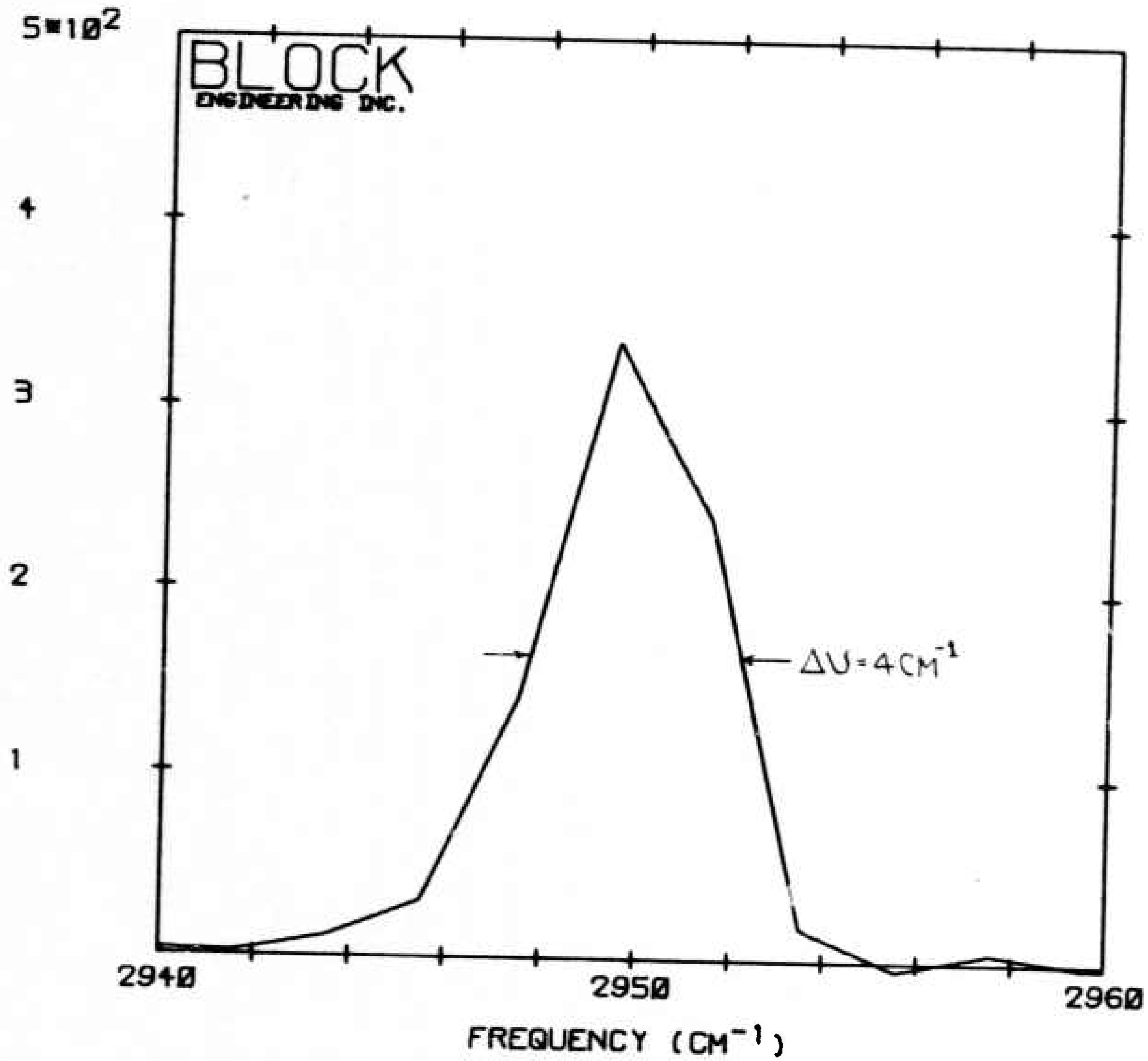
The spectral resolution of the emissometer system in the 4 $cm^{-1}$ mode of operation was verified via the evaluation of computer processed spectra of a 3.39 μm HeNe laser illuminating a diffusely scattering sample. Figure 8 reveals the unapodized instrument resolution indicating a half height line width of 4 $cm^{-1}$ which agrees with the design constraint.

### 3.2 Field-of-View Verification

The instrument field-of-view directly corresponds to a fixed viewing area at the sample site and can be measured by scanning the field across a small aperture placed in front of the heated calibration source. The scanning was accomplished using the two axis adjustable mirror which scans the instrument field at the sample site, .91 cm per control rod revolution The results of this test are tabulated below:

| F.S. | Measured Sample Area (cm) | Design Specification (cm) |
|---|---|---|
| 1 | 0.120 | 0.125 |
| 2 | 0.26 | 0.25 |
| 3 | 0.58 | 0.50 |
| 4 | not measured due to mechanical failure on test apparatus | 1.0 |

In each case the measured field was in good agreement with the expected result. As an illustration of the field definition at the sample site, see Figure 9.

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3.39 MICRON HELIUM-NEON LASER

Figure 8.

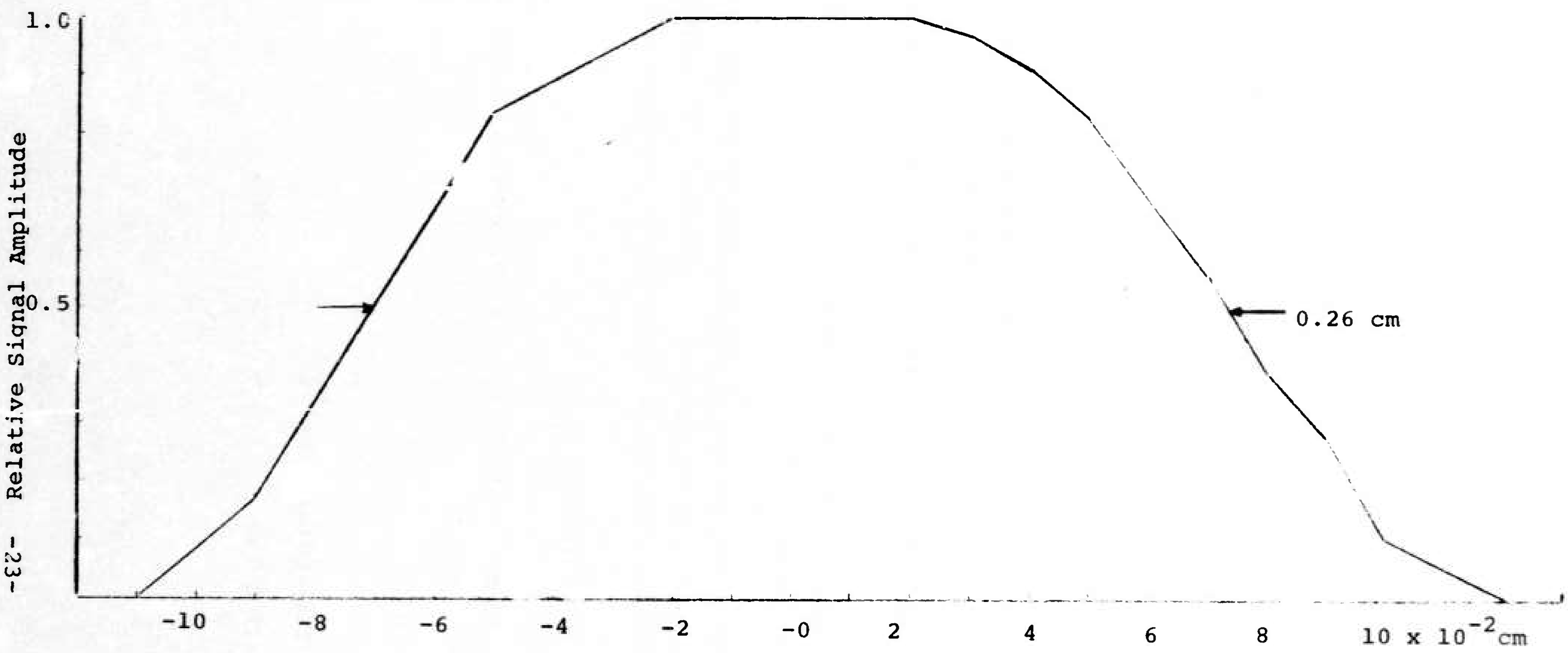



Figure 9. Spectrometer Field of View at the Sample Site - Field Stop 2

3.3 Sensitivity Verification - NESR

Numerically, the noise equivalent spectral radiance is equal to the ratio of the radiance to the rms signal to noise in the spectrum and is calculated by first computing the system net response at a particular temperature and wavelength expressed as

$$R_\lambda = \frac{A(\text{source}) - A(\text{bkgd})}{N(\text{source}) - N(\text{bkgd})}$$

where

$R_\lambda$ = spectral responsivity at a wavelength $\lambda$ (microns) in: arbitrary units/watts/$cm^2$-ster-$cm^{-1}$,

$A(x)$ = amplitude of the spectra (arbitrary units) at the specified $\lambda$,

$N(x)$ = radiance of the blackbodies at the specified temperature and $\lambda$.

Once $R_\lambda$ has been determined, a measurement of the rms noise level at the specified wavelength is obtained and substituted into the following expression to determine the system NESR

$$\text{NESR} = R_\lambda^{-1} \cdot (\text{Noise}_{rms}).$$

The sensitivity measurement for the emissometer system was conducted under the following conditions:

| | |
|---|---|
| Resolution: | 4 $cm^{-1}$ |
| Throughput: | 2 x $10^{-3}$ $cm^2$-ster |
| Source Temperature: | $169^\circ K$ |
| Integration Time: | 3.2 sec (32 scans). |

It should be noted that the measurement was performed with the emissometer in a fully operational mode, that is under vacuum and at low temperature.

A plot of the source spectrum at the elevated temperature of $169^{\circ}K$ is shown in Figure 10. A(source) is determined from this plot to be $1.5 \times 10^{1}$ arbitrary units at 1000 $cm^{-1}$ (10 μm). In a similar manner, A(bkgd) can be determined from Figure 11 to be essentially zero arbitrary units due to the cold background, $90^{\circ}K$. This result is consistent with the theoretical estimates on the radiance levels involved with blackbodies at $169^{\circ}K$ and $90^{\circ}K$ at 10 μm in which $\left[N(\text{source}) - N(\text{bkgd})\right] \sim N(\text{source}) = 2.4 \times 10^{-7}$ $w/cm^2\text{-ster-}cm^{-1}$. The remaining number to be determined for the sensitivity calculation is the spectrum noise which can readily be obtained from Figure 11 as

$$\text{Noise}_{rms} = 1.1 \times 10^{-2} \text{ arbitrary units}$$

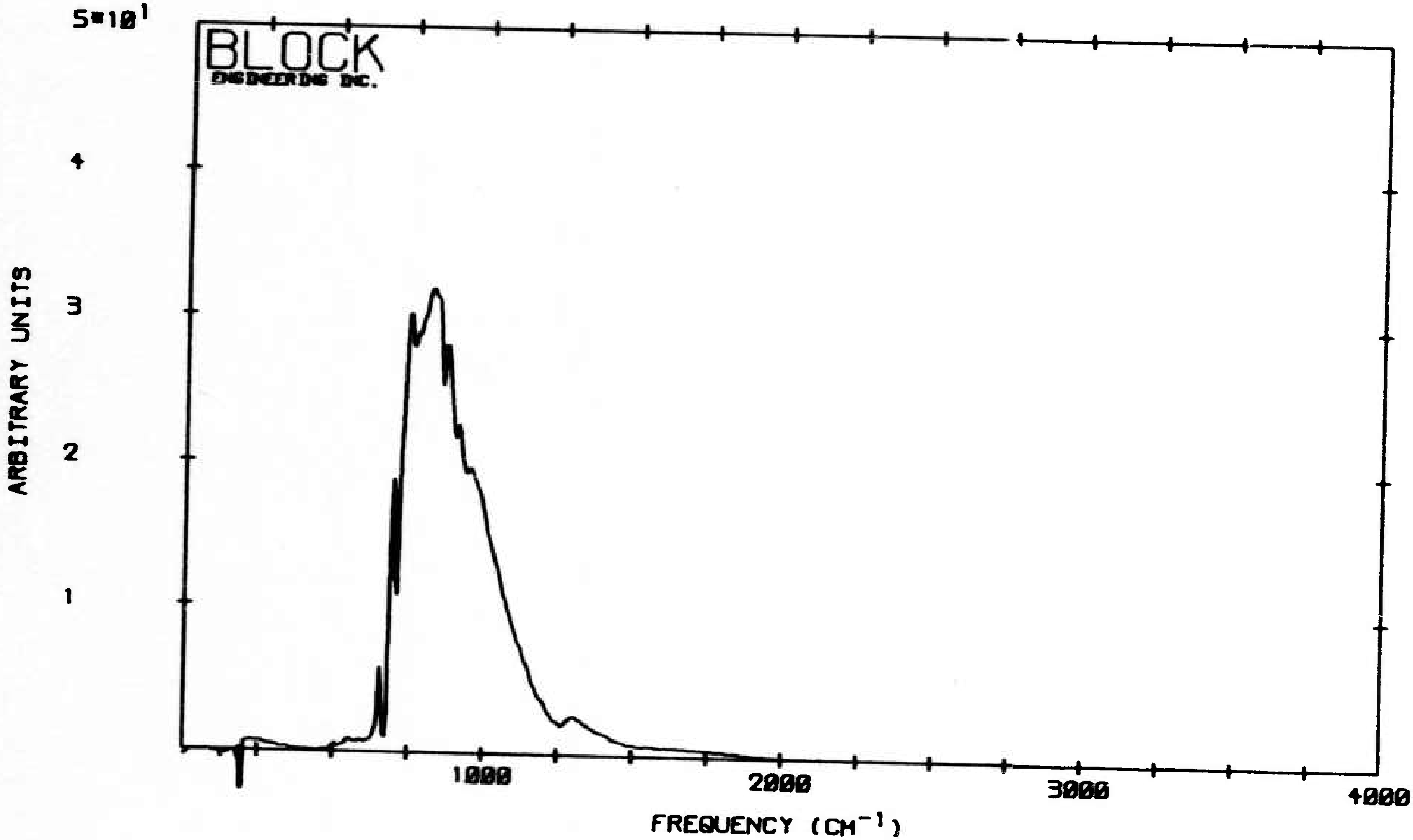
therefore

$$\text{NESR} = \frac{(2.4 \times 10^{-7} w/cm^2\text{-ster-}cm^{-1}) \cdot (1.1 \times 10^{-2} \text{ Arb units})}{(1.4 \times 10^{1} \text{ Arb units})}$$

$$= 1.76 \times 10^{-10} \; w/cm^2\text{-ster-}cm^{-1}.$$

On a 1 minute integration basis, this corresponds to

$$\text{NESR } (10 \; \mu m, 1 \text{ min}, 4 \; cm^{-1}) = 4.06 \times 10^{-11} w/cm^2\text{-ster-}cm^{-1}$$

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169 DEG K BB/-15V BIAS/32 SCANS

Figure 10.

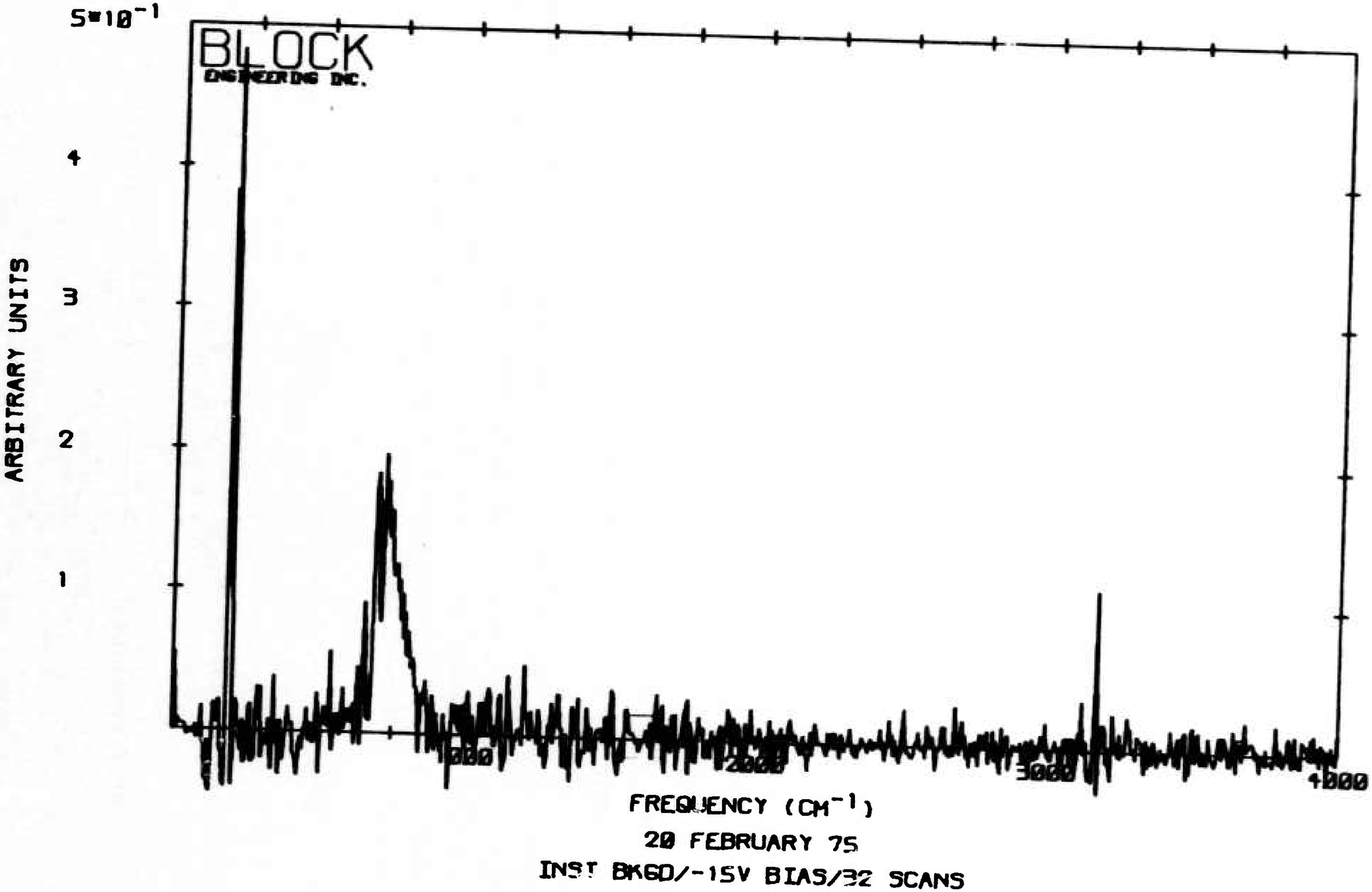

5*10^-1
4
3
2
1
ARBITRARY UNITS
BLOCK
ENGINEERING INC.
1000
2000
3000
4000
FREQUENCY (CM^-1)
20 FEBRUARY 75
INST BKGD/-15V BIAS/32 SCANS

Figure 11.

The predicted NESR for the sensor can be determined from the relation

$$NESR = \frac{\sqrt{A_D} \cdot \sqrt{\Delta_f}}{D^* \cdot \Theta \cdot \eta \cdot \Delta\nu}$$

where

$A_D$ = Area of detector, $3.24 \times 10^{-2}$ cm$^2$,

$\Delta_f$ = 1/T, where T is the integration time, 1 minute,

$D^*$ = detector figure of merit, $1.8 \times 10^{12}$ cm.Hz$^{1/2}$/watt (measured),

$\Theta$ = throughput $2 \times 10^{-3}$ cm$^2$-ster,

$\eta$ = optical efficiency, $5 \times 10^{-1}$,

$\Delta\nu$ = resolution, 4 cm$^{-1}$

so that the predicted

NESR = $3.2 \times 10^{-11}$ w/cm$^2$-ster-cm$^{-1}$.

These figures can be converted to NER (noise equivalent radiance) for a 0.1 micron band at the specified wavelength which in turn can be manipulated to determine the minimum detectable emissivities (NE$\Delta\varepsilon$) in a 1 minute observation time for a typical 300$^\circ$K sample measurement according to

$$NE\Delta\varepsilon = \frac{NER}{N(300^\circ K,\ 10\ \mu m,\ \Delta\lambda = .1\ \mu m)}$$

$$NE\Delta\varepsilon\,(\text{measured}) = \frac{4.06 \times 10^{-10} \text{w/cm}^2\text{-ster}}{9.9 \times 10^{-5} \text{w/cm}^2\text{-ster}} = 4.1 \times 10^{-6}$$

$$NE\Delta\varepsilon\,(\text{predicted}) = \frac{3.2 \times 10^{-10} \text{w/cm}^2\text{-ster}}{9.9 \times 10^{-5} \text{w/cm}^2\text{-ster}} = 3.2 \times 10^{-6}.$$

These numbers are in good agreement considering the number of parameters experimentally determined.

## 3.4 Typical Response Function

Figure Number 12 represents a typical response function from the emissometer showing a useable response from 700 $cm^{-1}$ (14.5 microns) to beyond 2000 $cm^{-1}$ (5 microns). Low background measurements at ten microns have demonstrated that the system has a noise equivalent emissivity limit (under typical 1 minute observation times) of better than $5 \times 10^{-6}$. By examining the response function one concludes that the noise equivalent emissivity is better than $2 \times 10^{-5}$ over the spectral range of 5 to 14.5 microns.

## 3.5 Emissivity Measurement

Figures 13 and 14 are spectral plots of the emissivity of a ZnSe sample measured on the emissometer system in a fully operational mode, 1 minute observation time, 4 $cm^{-1}$ resolution. The spectra are fully calibrated and background corrected and clearly indicate the capability of the system.

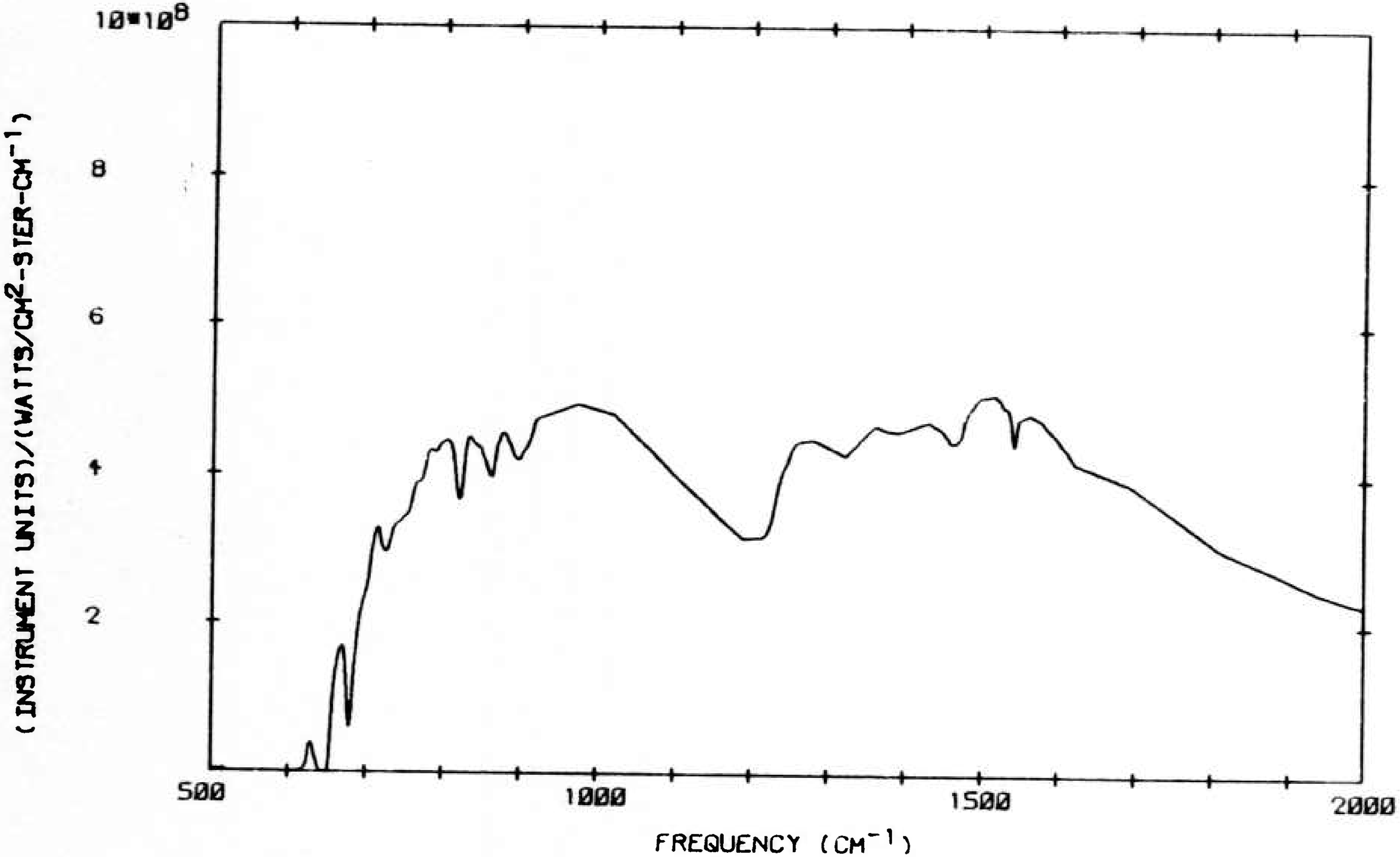
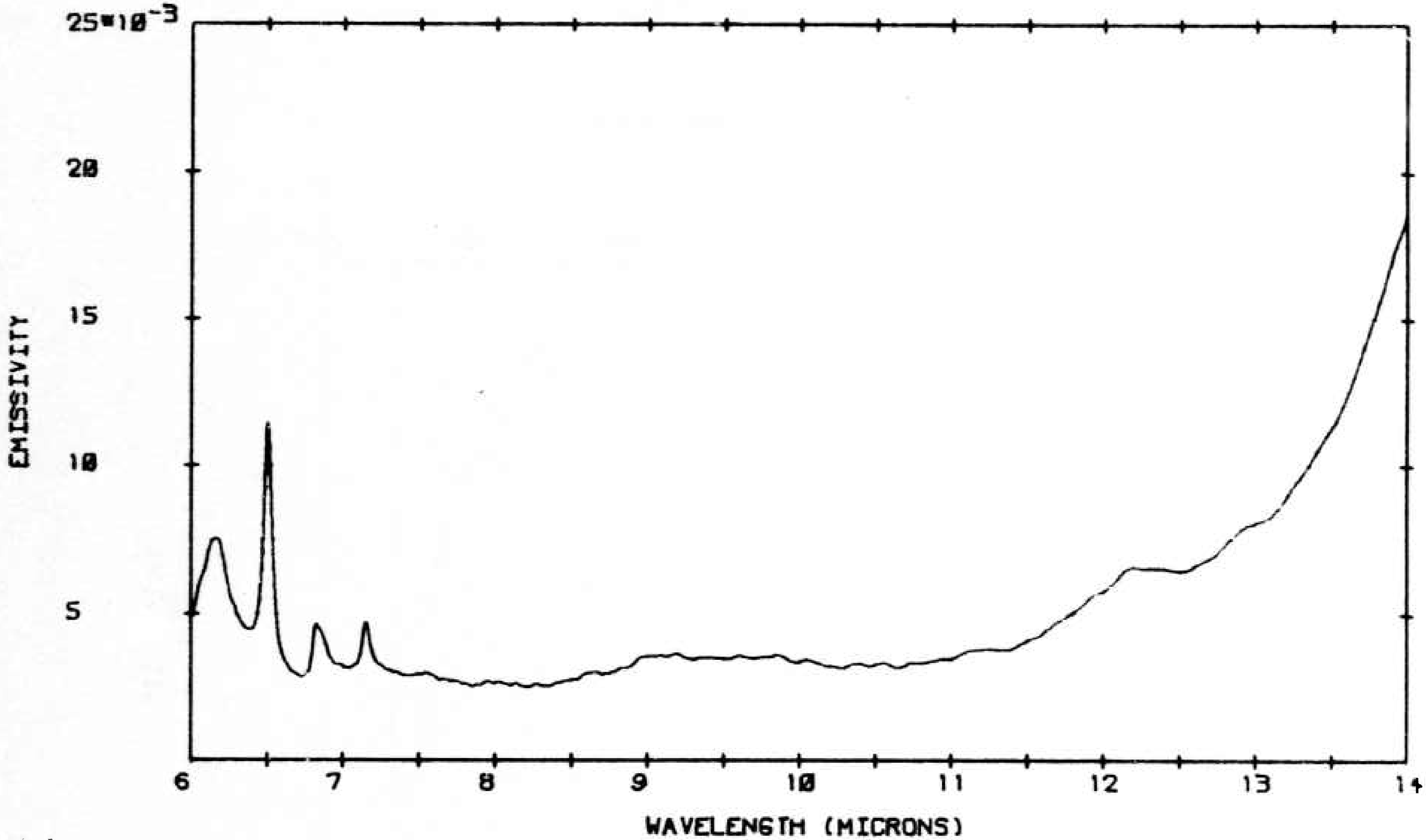
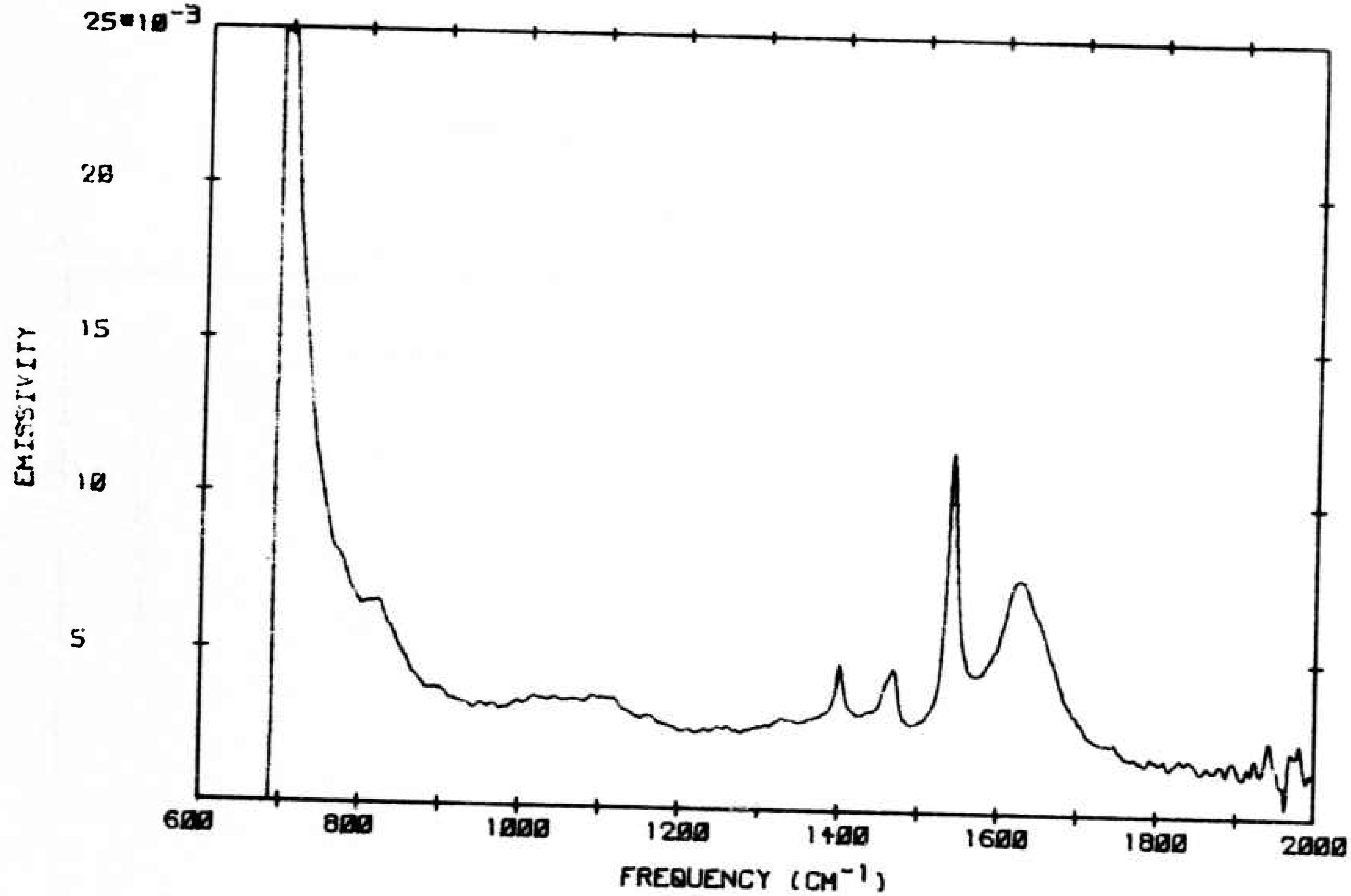



Figure 12. Fudged Radiance Response




ZNSE SAMPLE AT 320 DEGREES KELVIN

Figure 13




ZNSE SAMPLE AT 320 DEGREES KELVIN

Figure 14.

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## of
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