NASA-CR-92009

SINGLE CHANNEL AIRBORNE INFRARED RADIOMETER

FINAL REPORT

Prepared by:

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4 January 1968

Prepared Under Contract NAS 9-6817

Submitted to:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS 77058

Submitted to:

BLOCK ENGINEERING, INC.

19 Blackstone Street

Cambridge, Massachusetts 02139

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INTRODUCTION

The subject contract was initiated by the Manned Spacecraft Center of NASA as part of its airborne effort in the Earth Resources Program. The radiometer resulting from this contract will be flown over land and water in conjunction with a spectro radiometer and a visual mapper and ultimately with other instruments such as microwave equipment.

The required hardware consists of the radiometer proper and a blackbody, which is used as a calibration standard for the radiometer.

NOTE: No flight data is presented in this report, as the instrument has not been airborne yet at the time of writing of this report.

HdW/eac 1/2/68

REQUIREMENTS

Calibration Blackbody

The blackbody, serving as the calibration standard for the radiometer, was required to be an accurate, precise and stable source from which the emitted energy would follow Planck's radiation law as closely as possible, i.e. an ideal blackbody radiator. The contractual requirement was for a blackbody with a controlable thermal range between 0 and +71°C to a precision of ±0.2°C.

Radiometer

A precision radiometer was required measuring the intensity of energy in a wavelength region between 9.9 and 12.5 microns in a 24 arc-minutes field of view. The range of energy levels to be measured was between -40 and +70°C blackbody radiation to an accuracy of 0.5°C blackbody radiation and a precision of 0.1°C.

DESIGN

Calibration Blackbody

The configuration of the cavity is a simple cone. The material is electro deposited copper and the outside is machined to a cone with an apex which is slightly larger than that of the cavity, such that the heat transfer function from the outside of the copper cone to the cavity wall is constant over the length of the cavity. The outside of the copper cone is heated uniformly with respect to the area over its entire surface. A calibrated precision platinum resistor is installed close to the surface of the cavity. This surface is painted with 3M velvet black. The heater-cavity unit is supported solely by rigid foam, so that minimum heatflow - minimum power consumption - and absence of local heat drain areas are achieved.

The temperature sensing resistor - as well as the temperature controlling resistor - are each one leg of a bridge which is part of a zero error first order servo system. When a difference in resistance values exists between the sensor and the controller, representing a difference in temperature setting and cone temperature, an error voltage is generated. This error voltage is amplified by a low drift operational amplifier and an integrated circuit amplifier. The gain of both amplifiers is determined by external passive components. The amplified error voltage is now applied to the heater drive amplifier so that the power dissipated in the heater is proportional to the temperature error.

The calibration blackbody is also provided with a variable speed chopper wheel, the configuration of which is such that a one inch diameter beam is chopped sinusoidally. The frequency is variable between 0 and 120 Hz.

<u>Radiometer</u>

The radiometer consists of two units: an optical head and a power, control and display unit.

<u>Optical System</u>

The radiometer collecting optical element is a f/2 germanium lens one inch in diameter. The target energy, after passing a chopper wheel and spectral filter, is focussed by this lens on to a Ge·Hg detector, which is cooled to LHe temperature. The detector being in the focal plane of the lens the field of view is equal to

$$\frac{\text{detector size}}{\text{f.l.}} = \frac{.0138''}{2''} = 6.9 \text{ mradian} = 24'$$

The lens also focusses energy from a reference source onto the detector. This occurs via reflection off the chopper wheel when it is in a position where the target energy beam is being blinded (see figure 1). The reference source is built identical to the calibration blackbody. The detector then views the target and the reference source alternately, a feature which is utilized in the signal processing design of the electronic system.

Instrument Sensitivity

The available energy from a 237°K blackbody is computed according to

$$N_{\lambda_{1-2}} = \frac{W \times E}{\pi}\left(\frac{W_{\lambda_o-\lambda_2}}{W_{tot}} - \frac{W_{\lambda_o-\lambda_1}}{W_{tot}}\right)$$

which yield, utilizing the Thornton radiation sliderule

$$N_{\lambda} = \frac{1.66 \times 10^{-2} \times 1}{\pi} (2.25 \times 10^{-1} - 1.25 \times 10^{-1})$$

$$= 5.3 \times 10^{-4} \text{ w/cm}^2\text{/ster}$$

The change in emitted blackbody energy due to a temperature change of 0.1°C is 0.15%, so that:

$$\Delta N_{\lambda_{1-2}} = 7.9 \times 10^{-7} \text{ w/cm}^2\text{/ster}$$

The NEI of the system follows from

$$NEI = \frac{(A_d \times f)^{\frac{1}{2}}}{D^* \times A_c \times \Omega \times \eta} = \frac{\{\frac{\pi}{4} \times (3.5 \times 10^{-2})^2 \times 250\}^{\frac{1}{2}}}{5 \times 10 \times 4.65 \times 3.85 \times 10^{-5} \times 7 \times 10^{-1}}$$

$$= 7.8 \times 10^{-8} \text{ w/cm}^2\text{/ster}$$

The signal to noise ratio of the system resulting from a 0.1°C target temperature change is then

$$S/N = \frac{7.9 \times 10^{-7}}{7.8 \times 10^{-8}} = 10$$

This S/N indicates that the system will be able to distinguish between blackbody targets which are at less than 0.1°C difference in temperature.

Electronic Circuitry

The current from the Ge·Hg detector (see figure 2) is first amplified (the transresistance of the preamplifier is 10 megohms) to make the signal immune to noise pickup while it is conducted to the control unit. A highpass filter then eliminates the target fluctuations after which the signal is amplified 30 times. The chopper frequency is then translated back to zero in the synchronous demodulator. The chopping function is generated by a lightbeam and a detector at the optical axis of the target beam and perpendicular to the chopper wheel. A lowpass filter then removes all spurious frequencies above 250 Hz and finally the output amplifier generates the offset voltage, so that both negative and positive data information is displayed as a positive voltage (between 0 and 5 volts). The data information is given in the form of an analog DC voltage which represents the absolute summation of the detector signals due to alternately the target and reference radiances.

The temperature control of the reference source is identical to that of the calibration blackbody.

The functional thermal dynamic range of the instrument is -40 to +70°C. However, the irradiance is not displayed as an analog voltage. The irradiance level is compared with the reference source energy level and the difference of the two is given as an analog voltage. The reference source radiance level is variable according to the variation in temperature of the blackbody 0 to +60°C. The maximum target/reference differential temperature range is set by the following limits: target -40/reference +60°C -- $\Delta T = +100°C$, target +70/reference 0°C -- $\Delta T = -70°C$; maximum operational thermal dynamic range: 170°C. Selecting this range would impose a severe strain on data recording, the resolution would have to be $\frac{5000 \text{ mvolt}}{2 \times 1700} = 1.4$ mv average (1.0 mv @ lowest target temperature). For reasons of convenience in data recording the smallest possible operational thermal dynamic range has been selected: $\Delta T_r = 50°C$; the limits are: target -40/reference 0°C -- $\Delta T = +40°C$ (the + sign denotes that the reference temperature is higher than the target temperature) and target +70/reference +60°C -- $\Delta T = -10°C$. The data now must be resolvable to $\frac{5000}{2 \times 500} = 5$ mv. As the voltage output is not allowed to be negative, zero ΔT energy level is analog to an offset voltage of +0.970 v, while a positive ΔT will yield an output voltage between +0.970 and +5 v, and a negative ΔT will yield an output voltage between 0 and +0.970 v. Larger ΔT extremes will yield output voltages above 5 v and negative values respectively.

The temperature of the reference source is also given as an analog voltage between 0 and Δ5 v, so that the irradiance channel output voltage can be interpreted. Both these channels are also displayed in a course manner on meters while the reference source temperature is displayed to a fine scale as well (utilizing a nulling meter and a potentiometer with digital readout).

FABRICATION

Calibration Blackbody

The fabrication of the calibration blackbody was uneventful, and the unit was delivered and accepted at three and one half months in the program

Radiometer

The properties of the Ge·Hg detector are given in table 1, the transmittances of the optical filter and lens are given in figure 3 and 4. The lens was provided with an antireflection coating, peaking at 10.5 micron (note that figure 4 represents the relative transmittance).

The optical processing subassembly was suspended in a support structure by means of eight multiplane vibration isolators. The resonance frequency was 11 Hz, and the coupling factor was such that the subassembly was subjected to no more than 2 g's at any point of the specified vibration spectrum (after delivery to NASA the suspension system was modified such that the optical processing subassembly is rigidly fastened to the support structure).

Some difficulties were experienced with the LHe dewar: at receipt by Block the spider suspension system was loose and the window coating was damaged. The spider was tightened and the window was replaced by Santa Barbara Research. However, a little later in the program, the window coating on the outside peeled off almost over the entire surface. It was decided to accept the dewar with a window that was coated for antireflection on the inside only; this configuration even showed a slight gain in D*. The optical head was constructed such that its cover above the mounting flange is sealed against gas conductance. The boiling off helium gas will thus drive out and keep out any environmental air, preventing water condensation inside the optical head. This was borne out during all of the temperature and pressure/temperature environmental tests. It is to be noted that the optical head is not designed to operate properly when its inside is exposed to water condensate, a condition which will occur during certain environmental combinations when the "helium flush" system is not functioning.

The fabrication of the electronic system proceeded entirely smoothly. During system integration noise problems due to cross-talk were encountered, but these were all eliminated.

During a preliminary checkout of the system, with the rotor of the chopper motor and chopper wheel not yet dynamically balanced, a large noise level was generated in the detector wiring due to microphonics. This phenomenum was completely absent after the chopper components had been dynamically balanced.

The instrument was subjected to the environmental test program as dictated in the contract. Initially the equipment did not meet the RFI test: at certain frequencies, both conducted and radiated interference, the levels were above the specified levels. The conducted excess interference was corrected by modifying the filter network immediately behind the power input connector, while the radiated excess interference was traced to a faulty connector of the interconnecting cable. After these corrections, the instrument passed all tests in one run.

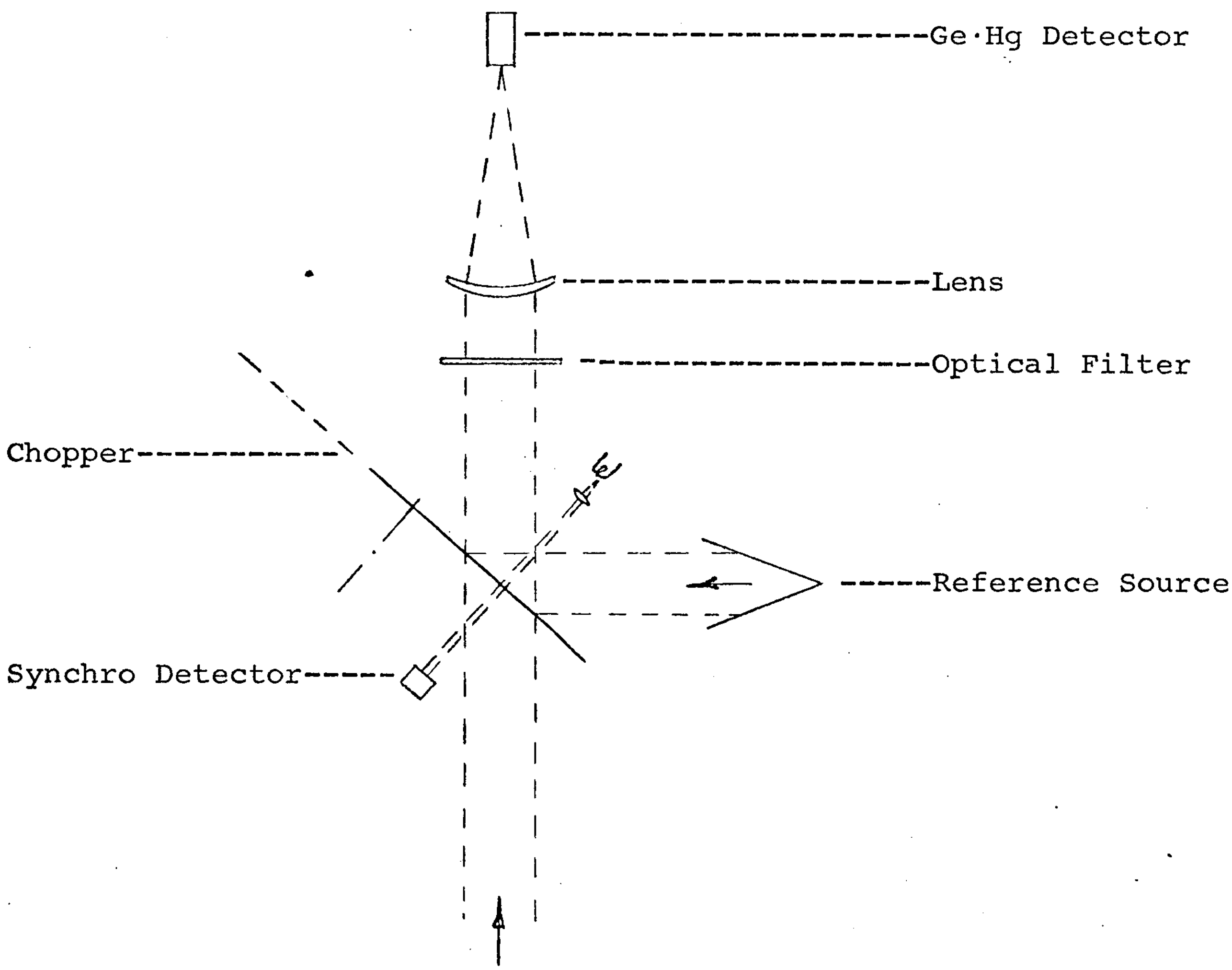
RESULTS

Calibration Blackbody

The precision of the calibration blackbody proved to be 0.02°C for temperatures within 15°C of environment temperature and 0.08°C at the highest temperature (71°C). An investigation of the radiative properties of the blackbody was performed by the Eppley Laboratory, Inc. As stated in the calibration report (appendix A) the "greyness" of the blackbody is excellent and it was also found that the level of emission is between 0.4% and 0.7% of the theoretical values. In addition then to the very good radiative properties of the cavity, the temperature control and display of the cavity is highly accurate. It is felt that a reliable standard for the radiometer has been obtained.

Radiometer

The thermal dynamic range (-40 to +70°C) of the instrument was demonstrated as well as its thermal resolution of 0.1°C over the entire range. When the reference source temperature is within 10°C of the target temperature, the thermal resolution is in fact 0.03°C. This is apparently possible due to the higher than strictly necessary S/N of 10 (for ΔT = 0.1°C) and a higher instrument efficiency as was initially estimated. The field of view was measured to be 24.5 to 27 arc-minutes. The accuracy, as referenced to the calibration blackbody, was found to be between 0.1 and 0.4°C.



OPTICAL SCHEMATIC

Figure 1

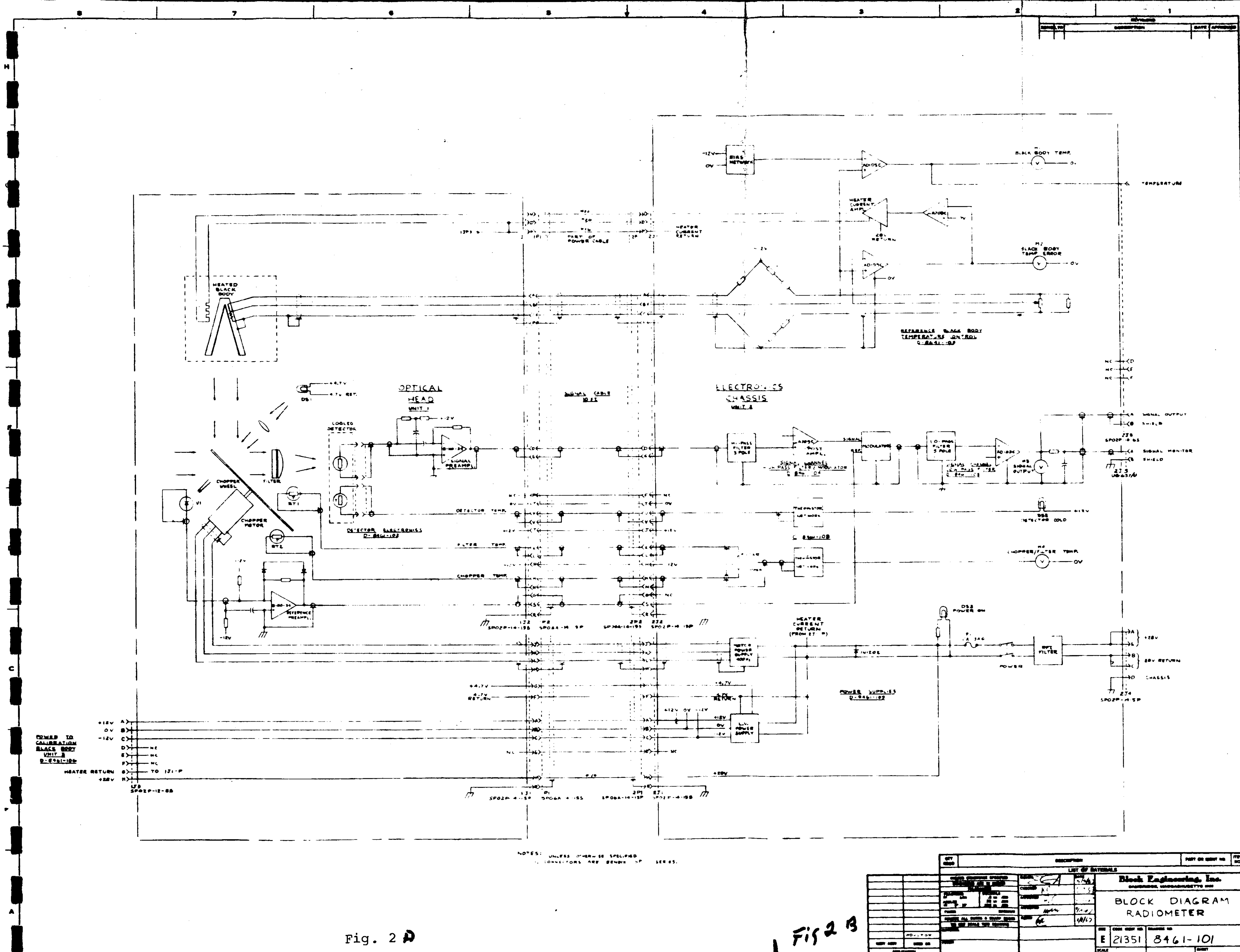
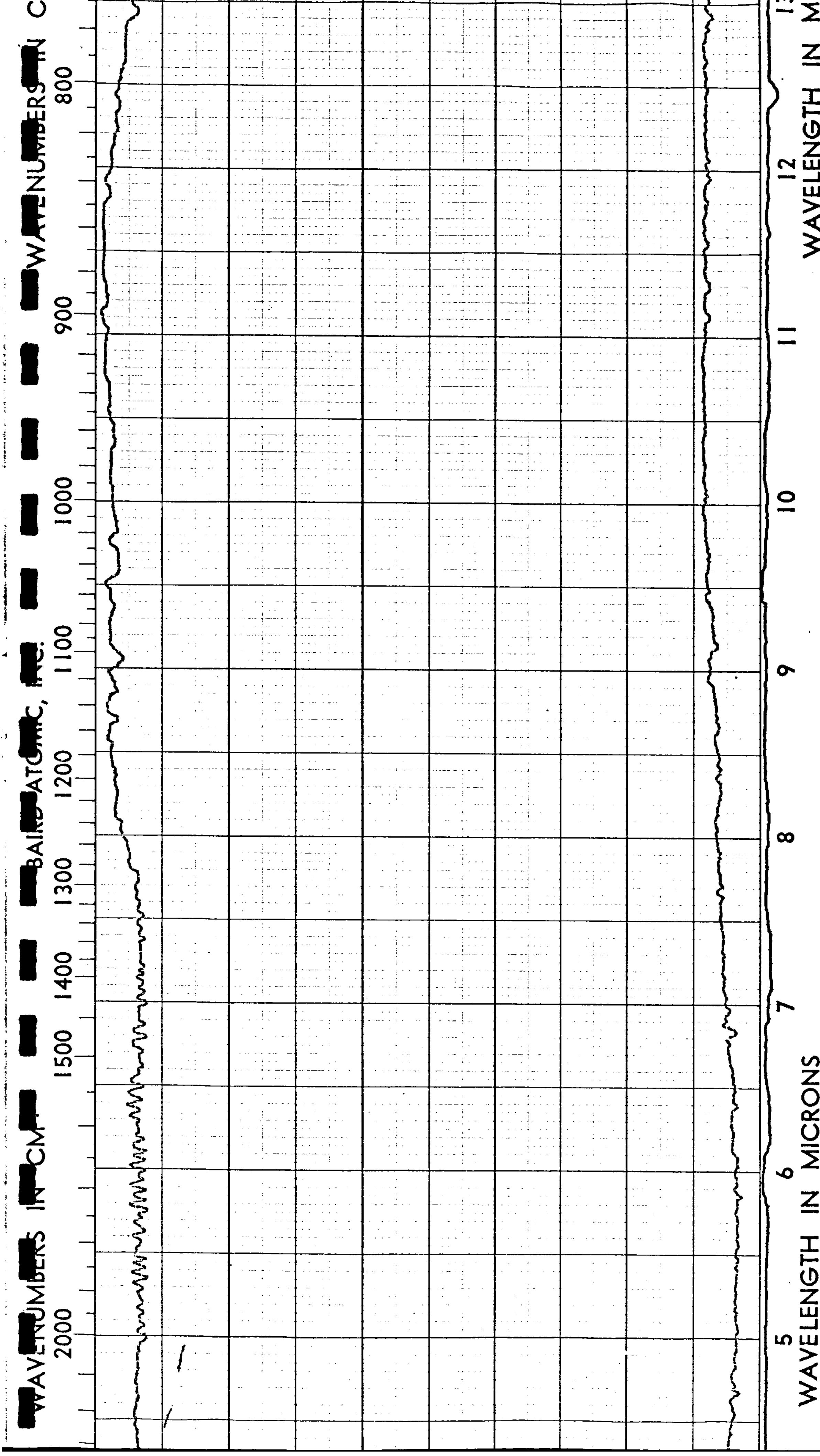

OPTICAL HEAD
UNIT 1
ELECTRONICS CHASSIS
UNIT 2
SIGNAL CABLE
HEATED BLACK BODY
CHOPPER WHEEL
CHOPPER MOTOR
FILTER
COOLED DETECTOR
SIGNAL PREAMPL.
REFERENCE PREAMPL.
DETECTOR ELECTRONICS
D-8461-103
BIAS NETWORK
HEATER CURRENT AMPL.
BLACK BODY TEMP.
TEMPERATURE
BLACK BODY TEMP ERROR
REFERENCE BLACK BODY TEMPERATURE CONTROL
D-8461-102
MODULATOR
SIGNAL OUTPUT
SHIELD
SIGNAL MONITOR
DETECTOR COLD
CHOPPER/FILTER TEMP.
DETECTOR TEMP.
FILTER TEMP.
CHOPPER TEMP.
POWER ON
POWER
RFI FILTER
+28V
28V RETURN
CHASSIS
HEATER CURRENT RETURN
POWER SUPPLIES
D-8461-105
L.V. POWER SUPPLY
POWER TO CALIBRATION BLACK BODY
UNIT 3
D-8461-106
HEATER RETURN
NOTES: UNLESS OTHERWISE SPECIFIED
1. CONNECTORS ARE BENDIX SP SERIES.
Block Engineering, Inc.
BLOCK DIAGRAM
RADIOMETER
E 21351 8461-101

Fig. 2 D

Fig 2 B



800
900
1000
1100
1200
1300
1400
1500
2000
WAVELENGTH IN MICRONS
5
6
7
8
9
10
11
12

Figure 3

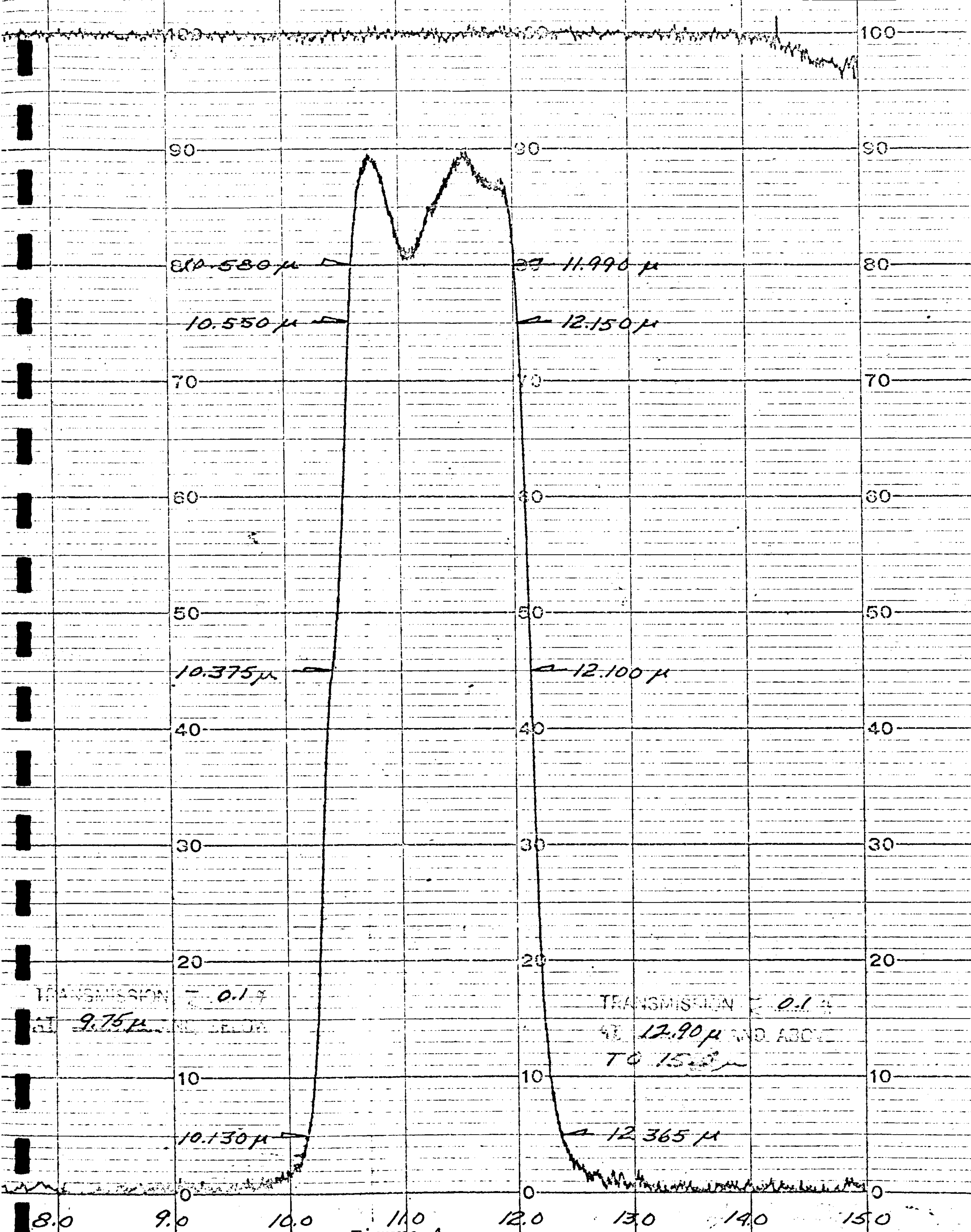

10.580 μ
11.990 μ
10.550 μ
12.150 μ
10.375 μ
12.100 μ
10.130 μ
12.365 μ
TRANSMISSION 0.1 %
AT 9.75 μ AND BELOW
TRANSMISSION 0.1 %
AT 12.90 μ AND ABOVE
TO 15
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0

Figure 4

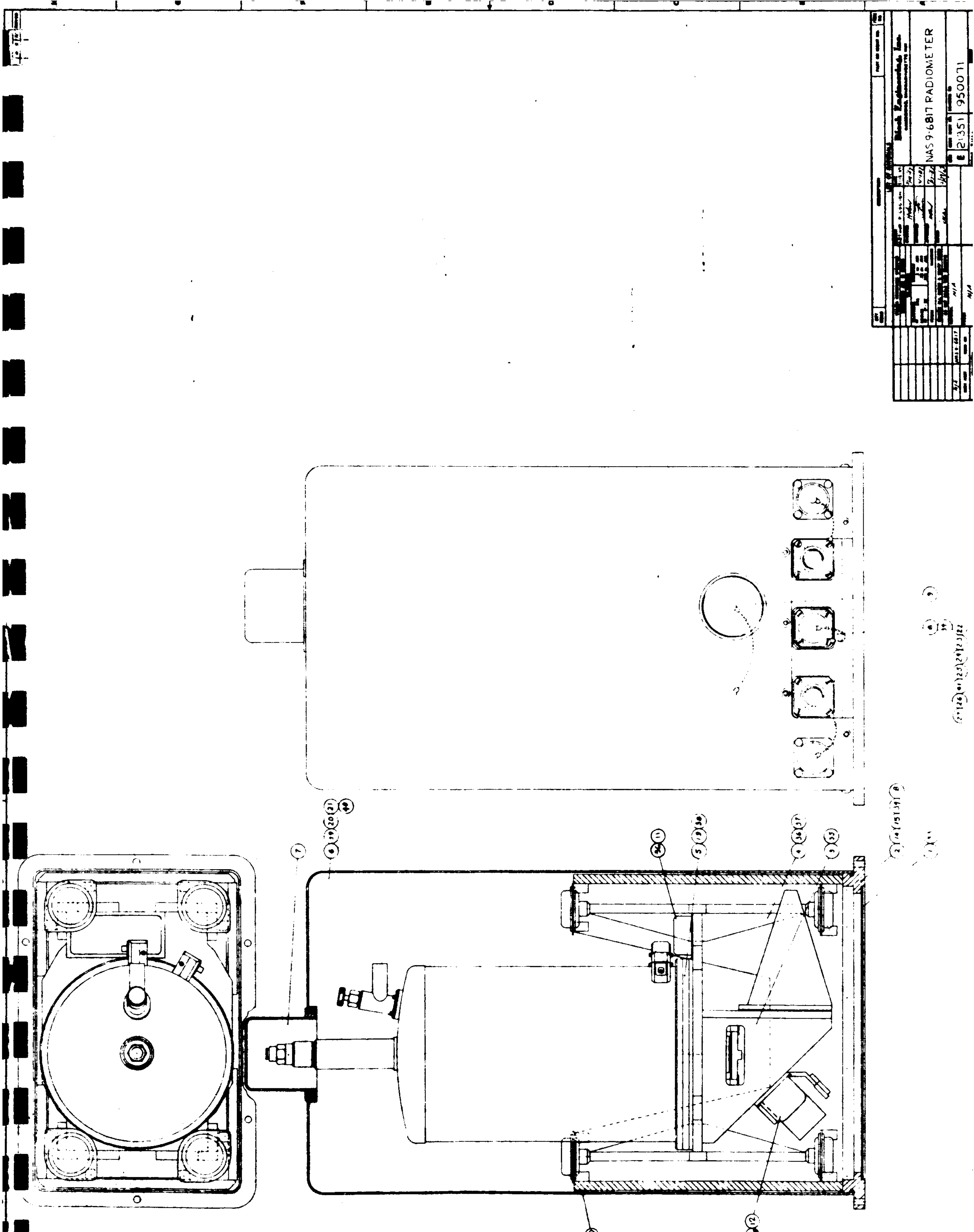


Fig. 5a

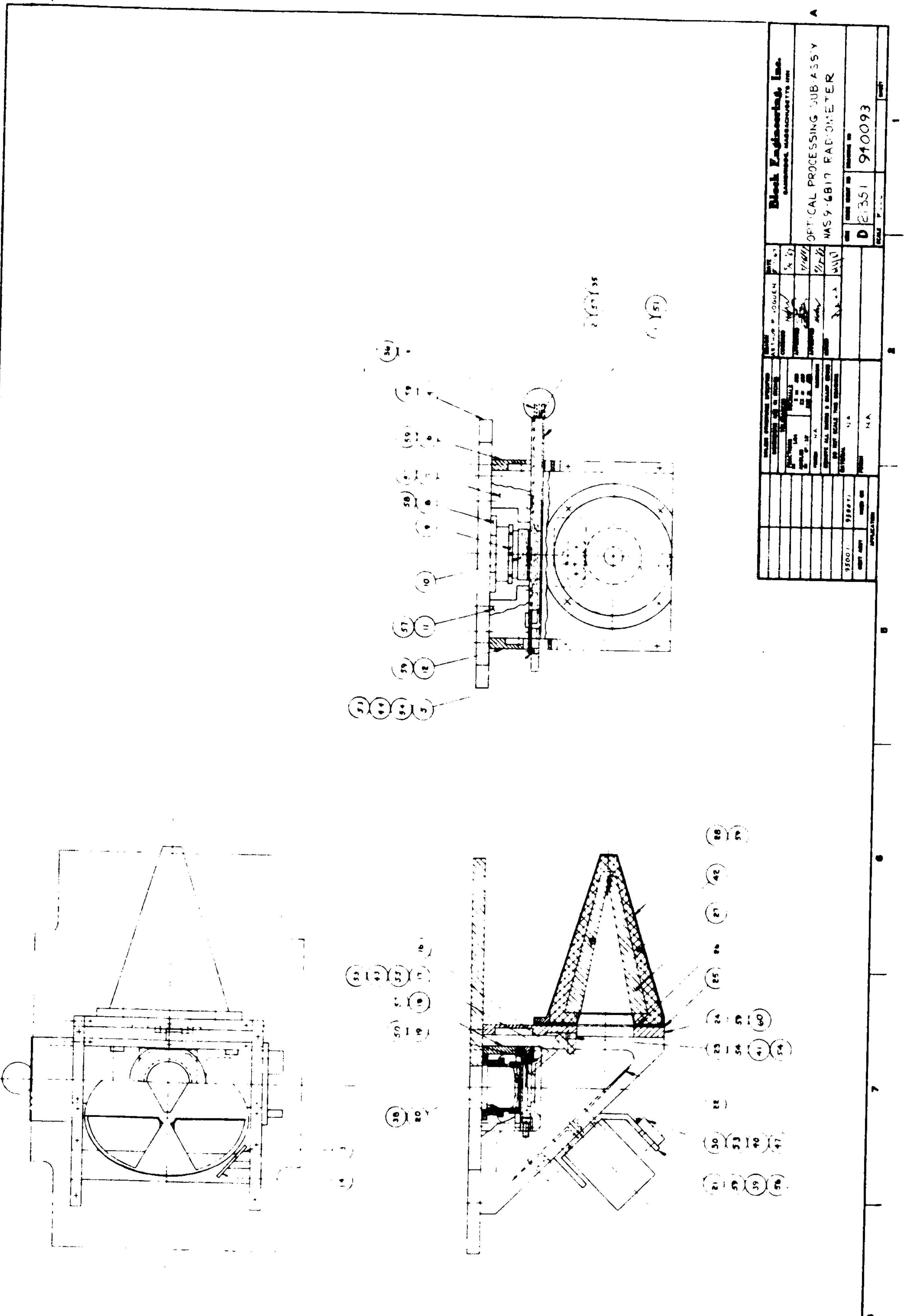

Block Engineering, Inc.
OPTICAL PROCESSING SUB-ASS'Y
NAS 9-6817 RADIOMETER
D
21351
940093

Fig. 5b

PHONE (401) 847-1020

APPENDIX A

EPLAB

THE EPPLEY LABORATORY, INC.
SCIENTIFIC INSTRUMENTS
NEWPORT, R.I. 02840 U.S.A.

CALIBRATION OF BLACKBODY
P.N. 950068

Calibration of the blackbody, submitted by Block Engineering, Inc. under P.O. 74955-8462, was achieved by measuring the source irradiance at three fixed distances and at three dial (temperature) settings. The purpose of the calibration was to determine the accuracy of the dial settings in terms of radiative output and assign radiance values to the source at three temperatures. From the dial calibration chart temperatures of 40°C, 55°C and 70°C were selected.

The radiation detector employed in the measurements was a thermopile-type working standard, No. 3317, manufactured by the Eppley Laboratory. Its calibration is traceable to the National Bureau of Standards through calibration against NBS standard lamp C-900. A sensitivity value of 0.121 $\mu v/\mu w\ cm^{-2}$ has been assigned to this detector. The absolute accuracy of the thermopile calibration has an uncertainty in terms of a blackbody radiator of 2 to 3%.

Table 1 gives the observed thermopile values at three dial settings and three distances between the thermopile receiver and the base of the conical blackbody.

TABLE 1.

R	D	t	EMF
17.9 cm	575	40°C	12.9μv
	784	55°	25.9
	989	70°	41.2
22.6	575	40°	8.1
	784	55°	16.0
	989	70°	25.1
27.6	784	55°	10.3
	989	70°	16.5

R - distance between thermopile receiver and source
D - dial setting of controller

Table 2 shows the ratio of emf values at two distances and two dial settings.

TABLE 2

R	D_1	EMF_1	D_2	EMF_2	EMF_2/EMF_1
17.9 cm	575	12.9μv	784	25.9μv	2.01
22.6	575	8.1	784	16.0	1.97
17.9	784	25.9	989	41.2	1.59
22.6	784	16.0	989	25.1	1.57
27.6	784	10.3	989	16.5	1.60

In evaluating the radiant flux from a source operating at the above temperatures, a correction for the shutter temperature (T_0) must be applied. Using a shutter temperature of 295°K (22°C), Table 3 gives the $EMF/T^4-T_o^4$ ratios.

TABLE 3

R	D	T	T_o	$T^4-T_o^4$	EMF	$EMF/T^4-T_o^4$
17.9 cm	575	313	295	2.0×10^9	12.9 μv	6.45×15^9
	784	328		4.0	25.9	6.47
	989	343		6.2	41.2	6.64
22.6	575	313	295	2.0	8.1	4.05
	784	328		4.0	16.0	4.00
	989	343		6.2	25.1	4.05
27.6	784	328	295	4.0	10.3	2.58
	989	343		6.2	16.5	2.66

T - temperature (°K) from dial setting calibration chart

T_0 - shutter temperature (°K)

The results in Tables 2 and 3 indicate the source is operating as an excellent gray body. As the calculated emissivity of the radiating cone is better than 0.99, the source is essentially a blackbody radiator within the few per cent uncertainty of the experiment.

Assigning a radiance value to the blackbody required the determination of a geometry factor. This was derived from the areas of the radiating surfaces (thermopile receiver and source), and when applied to the thermopile emf measurements, gave values close to those calculated from the blackbody equation $W = \sigma T^4$.

For the operating temperatures employed

D	t	W
575	40°C	5.4×10^{-2} watts/cm^2
784	55°	6.5
989	70°	7.7

Alton R. Karoli

Alton R. Karoli
Senior Scientist

September 15, 1967

RECEIVED
SEP 18 1967
ACCOUNTING