FINAL REPORT
NASA CONTRACT NGR-05-018-007
CONTRACT ENDING FEBRUARY 28, 1970

DEVELOPMENT OF A SUPERCONDUCTING BOLOMETER

Submitted By

Darrell L. Judge
Department of Physics
University of Southern California
Los Angeles, California 90007

DEPARTMENT OF PHYSICS
University of Southern California
Los Angeles, California 90007

FINAL REPORT
NASA CONTRACT NGR-05-018-007
CONTRACT ENDING FEBRUARY 28, 1970

DEVELOPMENT OF A SUPERCONDUCTING BOLOMETER

Submitted By

Darrell L. Judge
Department of Physics
University of Southern California
Los Angeles, California 90007

TABLE OF CONTENTS

I. INTRODUCTION

A "superconducting bolometer" having a lead ribbon as a detecting element and operating in the transition region between the normal and the superconducting states, has been developed at the University of Southern California. It has a noise equivalent power (N.E.P.) of 10^{-11} watts/Hz$^{\frac{1}{2}}$ a sensitivity of 70 volts/watt, a primary response time of 8 milliseconds, and a spectral range from 1Å to 0.1 cm.

It was primarily designed to make absolute photon flux measurements in the vacuum ultraviolet. In the past such measurements have been especially difficult below 500Å, where source intensities are generally small. If the radiation is to be dispersed, the intensity is again reduced by the small solid angles subtended at the entrance slit of grazing incidence monochromators. (The low reflectivity of ultraviolet light, in this region prevents the use of normal incident monochromators.)

The superconducting bolometer reported here, however, is in no way limited to work in the ultraviolet, but should be of interest to those also working in the far infrared. Any detector of increased sensitivity is useful; and the advantage of a bolometer is that its sensitivity need not be calibrated as a function of wavelength. Unusual care, however, must be taken when the energy of the incident radiation is great enough to generate photoelectrons. When this occurs some energy is not absorbed by the detector, but is carried away by the electrons. This energy can be regained, however, if the bolometer element is operated at a higher potential than its surroundings. An advantage of the superconducting bolometer in the vacuum ultraviolet region is that due to its very low impedance, the photoelectric current is small compared to the bias current. This is not the case for thermistor and other low temperature bolometers, which can become effectively shorted out by the photoelectrons.

Table I summarizes the characteristics of various detector types. They can be divided into two groups. The first (1-6) being quantum sensitive and the second (7-10) being energy sensitive. In general the first group is the more sensitive, but must rely upon the second for absolute calibration. The superconducting bolometer is only equalled in spectral range by the thermocouple, and only excelled in noise equivalent power by the low temperature high impedance bolometer, reported by Low.[1] The noise equivalent power reported here for the superconducting bolometer is believed to be somewhat dependent on the transition region operating point as reported by Andrews, Milton and DeSorbo [2] and could possibly be improved if the details of this dependence could be determined.

---

[1] F. J. Low, J. Opt. Soc. Am, 51, 1300-1304 (1961).

[2] D. H. Andrews, R. M. Milton, and W. DeSorbo, 36, 518 (1946).

TABLE I

Type of Detector	Wavelength range	Typical NEP (Watts)	Quant. Eff.	Acc. as Abs. Det. (%) Type I[1]	Type II[2]	Limitations to Sensitivity	Limitation to Range, Long λ
1 Photomultiplier/infrared	1μ-.4μ	10^{-15}	0.5-5	20	5	Thermal emission	Work function of photocathode
2. Photomultiplier	.6μ-.16μ	10^{-16}	5-20	20	5	Thermal emission	Work function of photocathode
3. Electron multiplier/Inert photocathode	.15μ-20Å	10^{-17}	5-30	50	20	Statistics (photon noise)	Work function of photocathode
4. Photocell/Inert photo-cathode	.15μ-100Å	10^{-12}	5-30	5	5	Picoammeter noise	Work function of photocathode
5. Rare gas ionization chamber	800Å-400Å	10^{-12}	100%	0.1%	0.1%	Picoammeter noise	Ionization potential
6. Photoconductor	5μ-.4μ	10^{-12}	0.5-2	20	1	Amplifier noise	Band gap
7. Thermistor bolometer	.1cm-.2μ	10^{-10}	100%	0.1%	0.1%	Johnson & current noise	Detector size/λ < 1
8. Thermocouple bolometer	.1cm-1Å	10^{-10}	100%	0.1%	0.1%	Amplifier & Johnson noise	Detector size/λ < 1
9. Low temperature bolometer	.1cm-.2μ	10^{-13}	100%	0.1%	0.1%	Phonon noise	Detector size/λ < 1
10. Superconducting bolometer	.1cm-1Å	10^{-11}	100%	0.1%	0.1%	Transition region noise	Detector size/λ < 1

[1]Type I. Absolute detector requires calibration at one wavelength or less. Therefore, responsivity curve must be the same for "Identical" detectors.

[2]Type II. Absolute detector requires complete calibration curve. Accuracy depends on calibration stability and reproducibility of the same detector over a period of time.

[3]Below 0.2μ, the photoelectric current becomes comparable to the bias current for these high impedance detector. Prior degradation of photon energy has been suggested but not attempted in practice. An estimated order of magnitude decrease in N.E.P. would probably result. In all thermal detectors (7 thru 10), direct energy loss via photoelectrons must be minimized.

(continued)

TABLE I
(continued)

	Limitation to Range, Short λ	Limitation to Accuracy Type I[1]	Limitation to Accuracy Type II[1]	Other Limitations Problems & Tradeoffs
1.	Window Material	Variation of secondary electron emission	Variation of secondary electron emission	Dark current decreases as long cutoff is decreased. Photocathode is too sensitive to contamination for open ended application
2.	" "	" "	" "	
3.	Photo yield of photocathode	" "	" "	Grazing Incidence required for shorter λ
4.	Photo yield of photocathode	Surface contamination	Surface contamination	
5.	Multiple ionization	Collection efficiency	Collection efficiency	Several rare gases required to cover entire range
6.	Transmission	Doping profiles	Structural drifts	
7.	Photoelectric effects[3]	Black body approximation	Black body approximation	Short λ cutoff depends on detector impedance[3] and desired accuracy
8.	Transmission of X-rays	" " "	" "	
9.	Photoelectric effects[3]	" " "	" "	
10.	Transmission of X-rays	" " "	" "	

II. DESCRIPTION OF THE BOLOMETER SYSTEM

A. Electronics

A bolometer, by definition, is a device that responds to radiation by a change in resistance. For this work, the resistance is measured by using a bridge circuit.

The electronics serves two functions. It amplifies the output from the bridge circuit, which is proportional to the radiation incident on the bolometer elements; and it maintains the operating point of the bolometer elements near the center of their superconducting transition region. (See Fig. 1.)

The bridge is driven with a 3 kHz signal, of typically 50 millivolts peak to peak amplitude. The amplitude is set by the signal generator output, voltage divider and buffer amplifier. The buffer prevents loading of the divider by the low impedance bridge.

The bridge is balanced by varying R_1 and C_1. The 3 kHz output signal from the bridge is amplified and synchronously demodulated to give a d.c. output at the demodulator proportional to the bridge unbalance. The radiation incident on the sensing element is chopped by a mechanical shutter at 5 Hz. Thus the d. c. output from this first demodulator changes at 5 Hz, and the change is proportional to the level of chopped radiation.

A second synchronous demodulator, in synchronism with the chopper demodulates the output from the first demodulator to yield a d. c. output proportional to the level of chopped radiation. This signal in turn drives the y axis of an x-y recorder. The abscissa is proportional to the grating angle of the Seya-type monochromator.

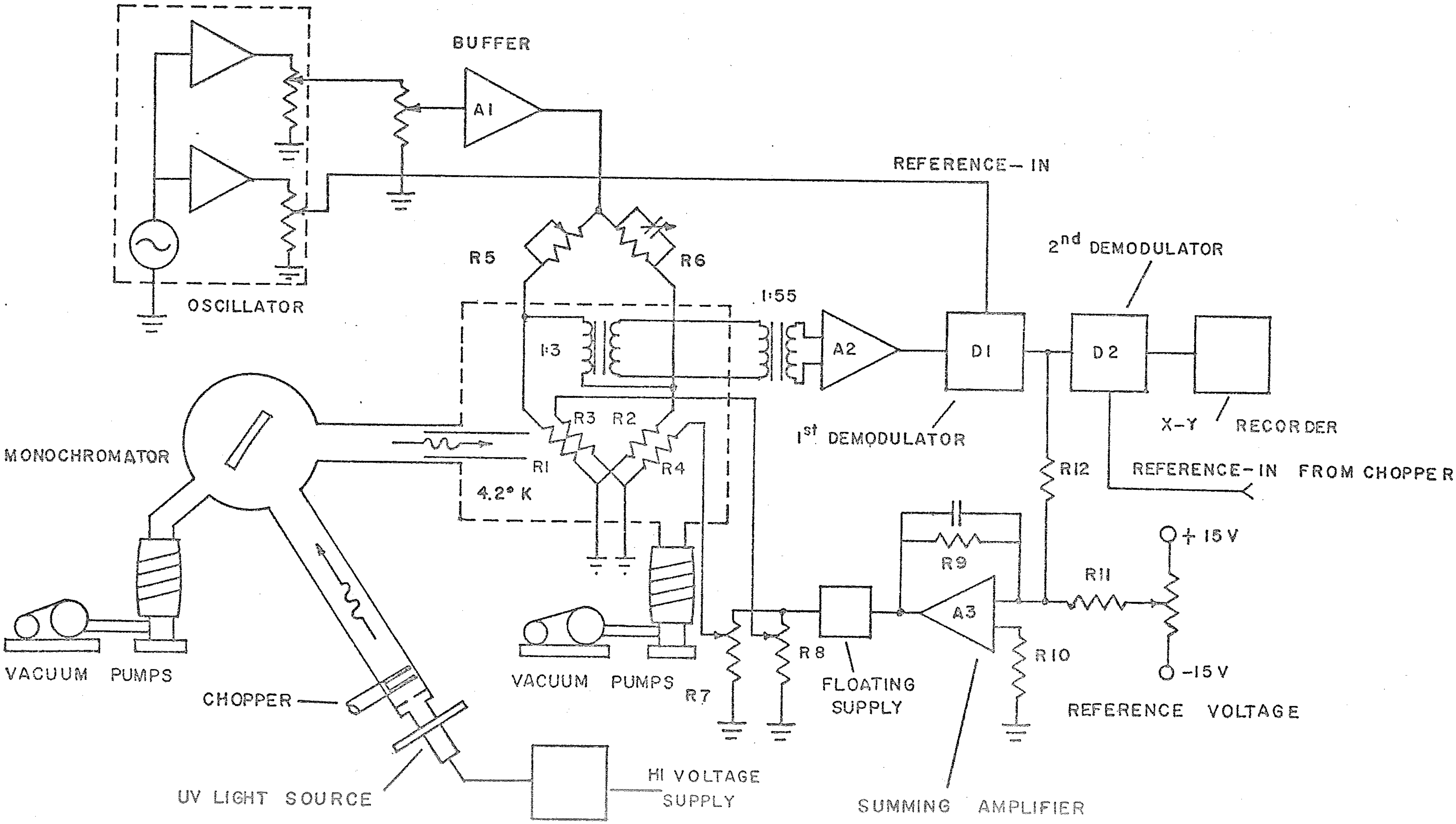


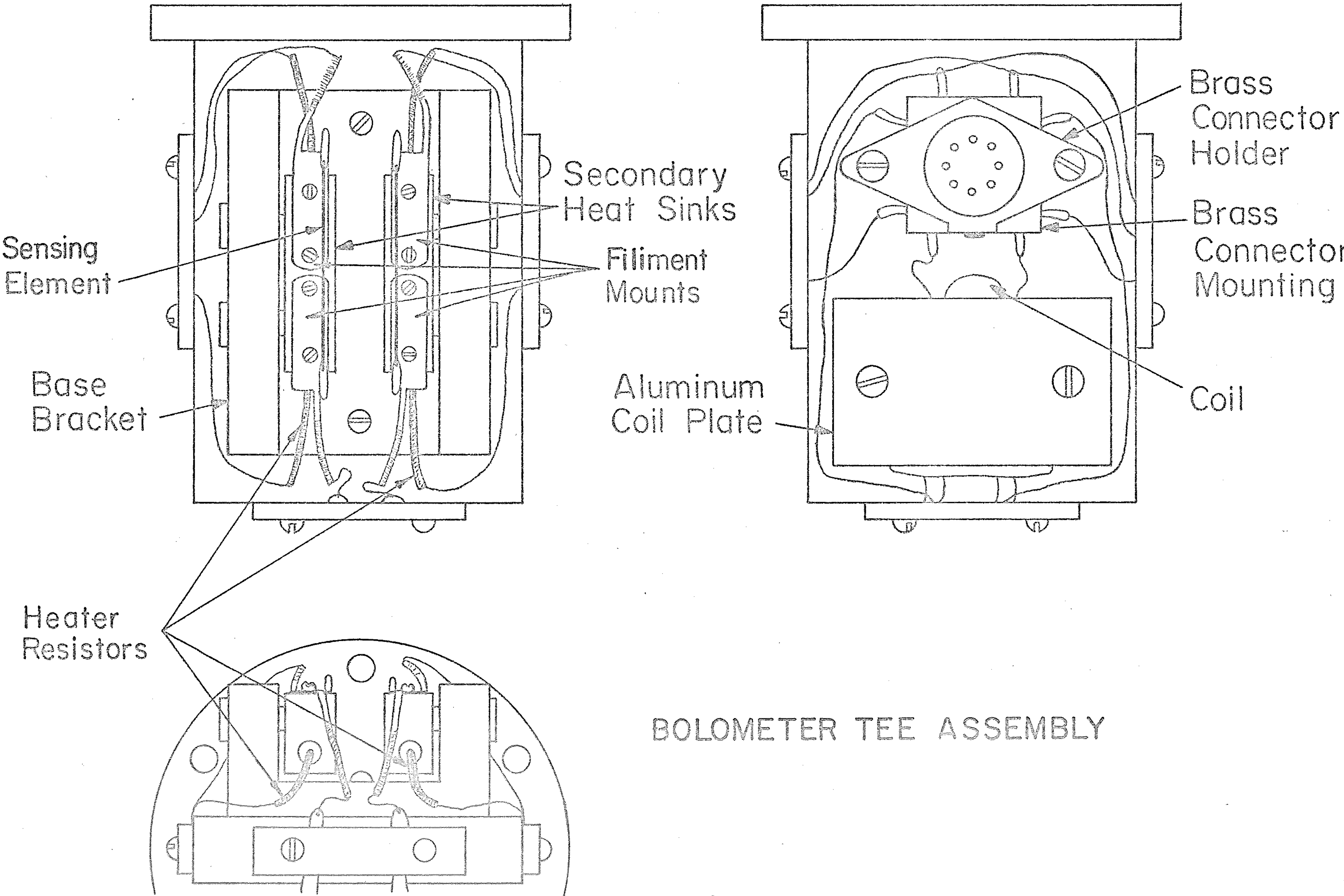
FIGURE 1: BLOCK DIAGRAM OF SUPERCONDUCTING BOLOMETER SYSTEM

Two superconducting lead elements are used in the bridge. R_3 is the sensing element and R_4 is the reference element. It is necessary that R_4 also be a superconducting element to prevent thermal runaway of R_3, and maintain bridge balance for all temperatures.

To insure a constant operating point on the transition region for each element, the heat dissipated in the heating resistors R_5 and R_6 is controlled by a negative feedback loop. The error, or control voltage, is taken as the difference between the output from the first demodulator and the reference voltage. The feedback loop regulates the operating point of the bridge in such a way as to make the error voltage approach zero. Thus, any operating point on the transition curve can be chosen by changing the reference voltage. A_4 is the summing amplifier. Its gain is adjusted to give a nearly critically damped second order system. The floating voltage supply is used to bias the heating resistors near the desired operating points, and also prevents bidirectional operation of the heaters. R_7 and R_8 are voltage dividers used to adjust for differences in heating characteristics between the elements.

B. Bolometer Assembly

The lead elements are supported on the Bolometer "T" Assembly, as shown in Fig. 2. This assembly is connected to a 4.2°K primary heat sink provided by liquid helium. The T assembly and the tail assembly to which it is attached are made of oxygen free high conductivity (O.F.H.C.) copper. The elements are soldered to the filament mounts which make up part of the secondary heat sinks. The base bracket or primary heat sink is isolated from the secondary heat sink



BOLOMETER TEE ASSEMBLY

Figure 2

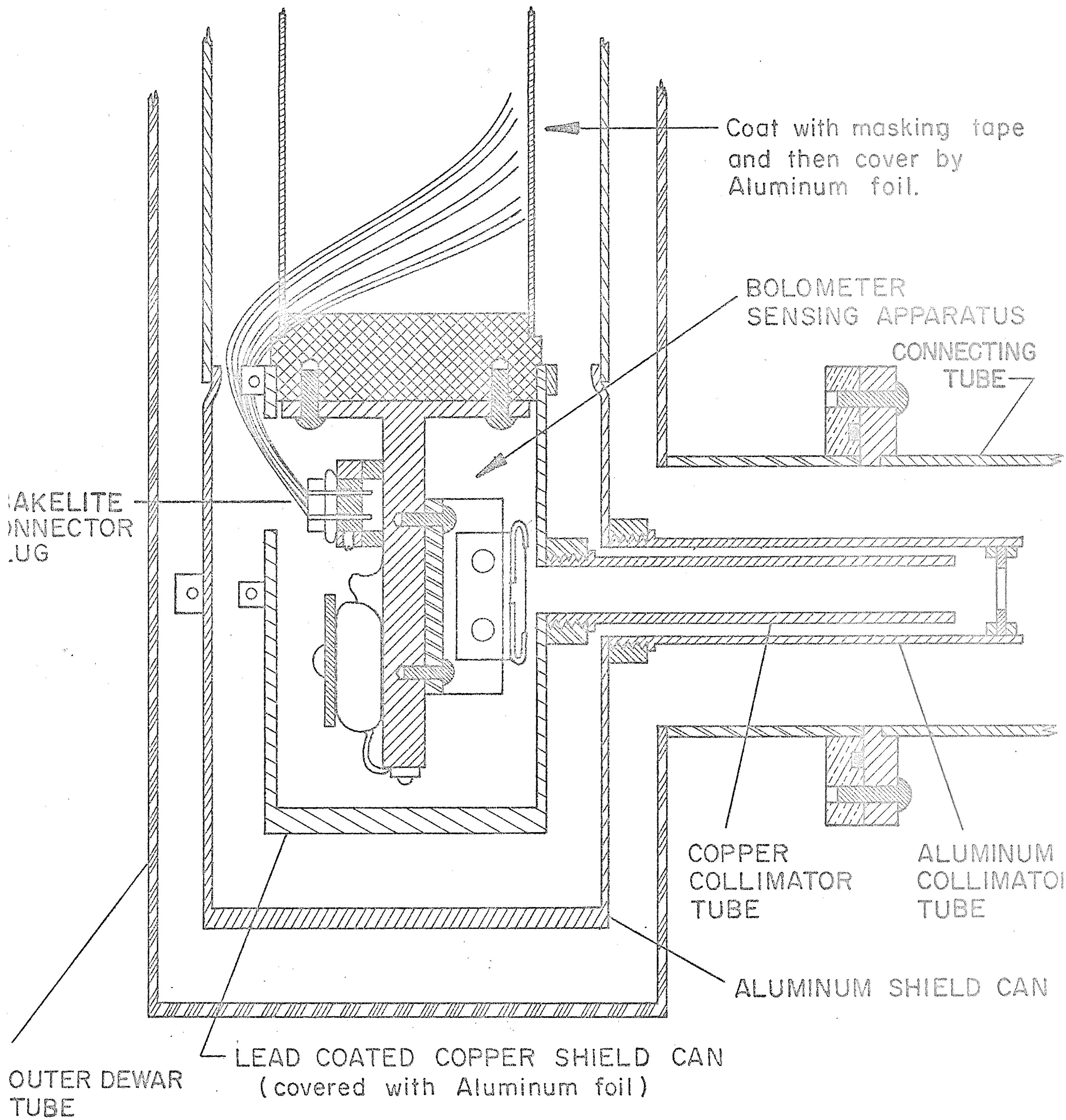
by nylon washers. This isolation, or low heat conductance path, between the elements and the 4.2°K primary heat sink allows the temperature of the elements to be controlled by both the liquid helium and the heater resistors. To prevent a high thermal conductance via the associated connecting wires, the connecting wires are made relatively long and of small cross section. This length is physically compressed by coiling the wires around teflon sleeving attached to the filament mounts. The same technique is used to improve the thermal isolation of the heating resistors. The reverse side of the T assembly provides a connecting socket and mounting area for the transformer which is mounted under the aluminum coil plate.

Fig. 3 shows a side view of the T assembly when it is attached to the tail of the helium dewar. The outer dewar tube is at room temperature (~293°K), the aluminum shield can at liquid nitrogen temperature, 77°K and the bolometer sensing apparatus and inner copper shield at 4.2°K. The inner shield is coated with lead which becomes superconducting during operation, thereby eliminating most magnetic interference.

C. Vacuum System

A vacuum is required both for thermal insulation between the bolometer elements and the laboratory, and because of the absorption by air of the ultraviolet light, whose intensity is to be measured.

The vacuum throughout the sensor area and Seya-Namioka type monochromator is maintained at 10^{-7} Torr by two oil diffusion pumps and the cold dewar surfaces, which act as cryogenic pumps.



LOWER PORTION OF TAIL ASSEMBLY

Figure 3

D. Monochromator

The monochromator is a 1.0 meter Seya-Namioka type using a Bausch and Lomb gold-coated-tripartite grating. It is blazed for 800Å, and has 1200 grooves/mm. It has a ruled area 4 cm x 8 cm. The Seya-Namioka type monochromator is noted for its minimum defocussing of the image as the grating is rotated.

E. Vacuum Ultraviolet Spark Source

The ultraviolet radiation was generated by a spark discharge from a low inductance capacitor, through a water-cooled boron nitride capillary containing argon gas at a pressure of 90μ. The discharge was operated in a relaxation oscillator mode at a 50-Hz. The source operated at 10 kilovolts and 30 milliamperes.

To prevent the high pressure of the light source from affecting the vacuum in the monochromator, differential pumping was provided at the entrance slit.

III. NOISE

The sensitivity of a bolometer is limited in two quite different ways. The simplest of these to understand is the limitation due to the noise components of competing sources of power flow to and from the bolometer element. There is power flow in the form of radiation exchange with the surrounding environment. There is also power flow by thermal conduction between the bolometer element and the heat sink. The noise components of these sources of power are known as photon and phonon noise respectively. These sources can be reduced to arbitrarily low values through control of the temperature of the bolometer, the environment, and conductance between the element and its environment.

Another type of noise limitation is due to thermal effects within the bolometer, such as Johnson noise and transition region noise. Other types of noise are shot and 1/f noise. The influence of these noise sources can be minimized individually, either through control of certain parameters directly affecting their magnitude or jointly, by increasing the detector responsivity. In the case of superconducting bolometers there is an additional source known as the transition region noise. The element operating in this region is in a mixed state made up of superconducting regions and normal regions. Thermal fluctuations in the transition region can cause resistance noise associated with variations of the size and/or distribution of these two regions within the detector.

The noise equivalent power for a superconducting bolometer,which is defined as the radiant power required to produce a signal at the bolometer output equal to the output due to all noise sources per unit bandwidth is given by:

$$\begin{aligned}(\mathrm{N.E.P.})^2 = [\ & 4kT^2G + 8\varepsilon_1\ \sigma kAT^5 + 8\varepsilon_2\sigma hT_b \\ & + (2RI\Delta I)^2 + (I^2\Delta R)^2] \\ & + [\ \frac{4kTR}{S^2} + \frac{(V_i)}{S^2} + \frac{(I\Delta R)^2}{S^2} + \frac{(R\Delta I)^2}{S^2}\ ] \\ & + [\frac{2(I^2\Delta R)\ (I\Delta R)}{S} + 2(2RI\Delta I)\ \frac{(R\Delta I)}{S}\ ]\end{aligned} \qquad (1)$$

where,

S = Responsivity

T = temperature of sensing element

T_b = temperature of background

R = resistance of sensing element

G = thermal conductance between detector and heat sink

I = measuring current

k = Boltzman's constant

ε_1 = emissivity of sensing element

ε_2 = emissivity of background

σ = Stephen-Boltzman constant

h = effective area of background

A = area of detector

ΔR = random resistance fluctuations

ΔI = random current fluctuations

V_i = input voltage noise of amplifier

These noise sources fall into three groups as indicated by the brackets.

The first group consists of terms which describe either the random flow of energy to and from the detector, or the random generation of power within the detector. For convenience, any noise of this type will be called power noise in subsequent discussions. The first three of these terms are independent of the measurement techniques and will be called implicit power noise, while the last two described noise power associated with determining the state of the system, and will be called induced power noise. The second major group of terms describe noise sources which manifest themselves initially as voltages. This voltage noise either arises from implicit fluctuations in the system(or amplifier) as is the case for the first two terms, or is induced by the measurement process as are the latter two terms. These noise sources will be referred to as implicit voltage noise and induced voltage noise respectively. Since all the voltage noise terms contain the reciprocal of S^2, it would appear that they can be arbitrarily reduced by increasing the responsivity. This is true only if the responsivity and voltage noise are suitably independent. An important part of this research has been to determine their degree of independence. The last group of terms arise because of factors affecting the noise phase coherence between the corresponding induced power and induced voltage noise terms. For these cross terms to be important, the corresponding induced noise terms must be of comparable magnitude.

Returning to the power noise sources, the implicit power noise is conceptually easiest to handle, since little choice is available for minimizing these terms. All three are reduced by going to lower temperatures while the first term, the phonon noise, can also be reduced by using a lower thermal conductance between the heat sink and detector. The two photon noise terms involve the emissivity of the detector and of the background, and thus can be controlled to some extent. Unfortunately, the responsivity tends to be proportional to the emissivity of the detector so that it cannot be adjusted arbitrarily. Reduction of the induced power noise is complicated by the fact that the responsivity involves many of the same parameters affecting this noise, so care must be taken that changes aimed at reducing induced power noise do not reduce the responsivity, thus making the voltage noise predominant.

For a superconducting bolometer the most important terms in equation (1) are $(N.E.P.)^2 = 4kT^2G + (I^2\Delta R)^2$, if we (a) assume a large responsivity, and note (b) that $T \to 0$, $R \to 0$; and $T_b \to 0$ for a suitably shielded superconducting detector.

Thus, the noise is determined, for the most part, by phonon noise, that is power conduction between the element and heat sink, and transition region noise which manifests itself in ΔR.

IV. RESPONSIVITY OF A SUPERCONDUCTING BOLOMETER

The responsivity S of a resistive bolometer is given by:

$$S = I \frac{\partial R}{\partial T} \frac{\partial T}{\partial P} \tag{2}$$

where $\partial T/\partial P$ is determined by the differential equation:

$$mc \frac{dT}{dt} = P\varepsilon f(t) - G\,(T-T_\circ), \tag{3}$$

where P is the incident power and f(t) is a periodic function which describes the power modulation (e.g. light chopping system). R is the resistance of the element, m its mass, and c its specific heat, while I is the drive current and G the total thermal conductance between the element and the heat sink. For conventional square wave light chopping at a frequency f, which is large compared to the thermal relaxation frequency, this becomes,

$$S = I \frac{\partial R}{\partial T} \frac{\varepsilon}{2\ mcf} \tag{4}$$

This expression contains most of the salient features of the general solution which is rather cumbersome to work with, and need not be written down. It should be noted, however, that in this limit, the mean operating temperature continues to change for periods given by the thermal time constant so that net temperature excursions many times greater than $P\varepsilon/2\ mcf$ will be observed.

From the factors in Eq. 4, various ways of increasing the responsivity of a bolometer are evident. It turns out, however, that many of these approaches simultaneously increase either the voltage noise or the induced power noise, so that careful calculations are required to determine the optimum values of the various factors involved. One relatively safe solution is to maximize the temperature coefficient of resistance, $\partial R/\partial T$. If this can be done without making R itself too large, the noise terms should not be affected. This possibility is of course the major reason superconducting bolometers (which have a very large $\partial R/\partial T$) are so attractive. The major unanswered question is "What is the magnitude of the resistance fluctuations in the voltage noise term, $(I\Delta R)^2/S^2$, and what physical factors affect this fluctuation?". Clearly, if ΔR were proportional to $\partial R/\partial T$, this term would preclude such an approach to lower N.E.P.

A few more examples of the possible adverse net effect associated with increases in responsivity are mentioned below:

1) If the measuring current is increased, a given change of resistance produces a correspondingly greater voltage change. It is well known, however, that the temperature coefficient of resistance in the transition region decreases with increased magnetic field, as well as the specific heat, and in addition, the transition changes from a second to first order phase change with an associated latent heat. Thus, even the response per se may not be increased. Also the induced power noise term, $I^2\Delta R$, is increased and unless the current source is noiseless, the $2IR\Delta I$ term will probably increase. Finally, the induced voltage noise terms $\left(\frac{I\Delta R}{S}\right)^2$ and $\left(\frac{R\Delta I}{S}\right)$ will increase.

2) If the mass of the detecting element is reduced, the smaller total heat capacity means that a given power causes a greater temperature excursion. If, however, the surface area remains the same, the resistance will be correspondingly increased, and probably the resistance

fluctuations will be increased, perhaps at a greater rate. Hence, all the induced noise sources as well as the Johnson noise would be increased. For a superconducting bolometer, the resistivity and consequently the impedance are generally so low that the induced voltage noise sources are negligible. This consideration, however, may be extremely important for other types of bolometers using materials with high resistivity.

3) By changing superconducting materials, the specific heat can perhaps be reduced by $\partial R/\partial T$, ΔR and m will all have new values. Since virtually no data on ΔR, the spontaneous transition region resistance fluctuation, is available and very little on $\partial R/\partial T$, such data must be obtained experimentally and further work is required.

V. AREAS OF PROGRESS MADE THROUGH FEBRUARY 28, 1970

A. Data

The most significant progress is:

1. The ultraviolet spectrum of argon between 500 and 1000Å using a superconducting bolometer has been obtained. (See Fig. 4.)

2. The absolute determination of a N.E.P. = 10^{-11} watt/Hz$^{\frac{1}{2}}$.

The N.E.P. was determined by calibrating the bolometer against a blackbody radiator, and then measuring the noise in the spectrum shown in Fig. 4. The chopper blade was used as the blackbody radiator. The change in emissivity between the open and closed position of the chopper resulted in two radiation levels. These levels were used to make the calibration and the N.E.P. figure was calculated based on the Stefan Boltzman equation for total power radiated by a black body. The fraction of this power falling on the detector was also calculated, making allowance for astigmatism in the monochromator.

For the chopper closed the element looks at a flat black painted surface, and for it open it looks at the brass metal constituting the back side of the entrance slit to the monochromator. The temperature was taken equal to 290°K, the detector emissivity 1.0, the change in chopper emissivity 0.3, the solid angle subtended from chopper to grating, 10^{-3} steradians, and the area of detector and emitter 1.25×10^{-3} in^2 and 1.25×10^{-1} in^2 and 1.25×10^{-1} in^2 respectively.

It was determined that a change in radiated power of 10^{-8} watts fell on the element due to the chopper. This information, along with gain settings was used to calibrate the detector and obtain a N.E.P.

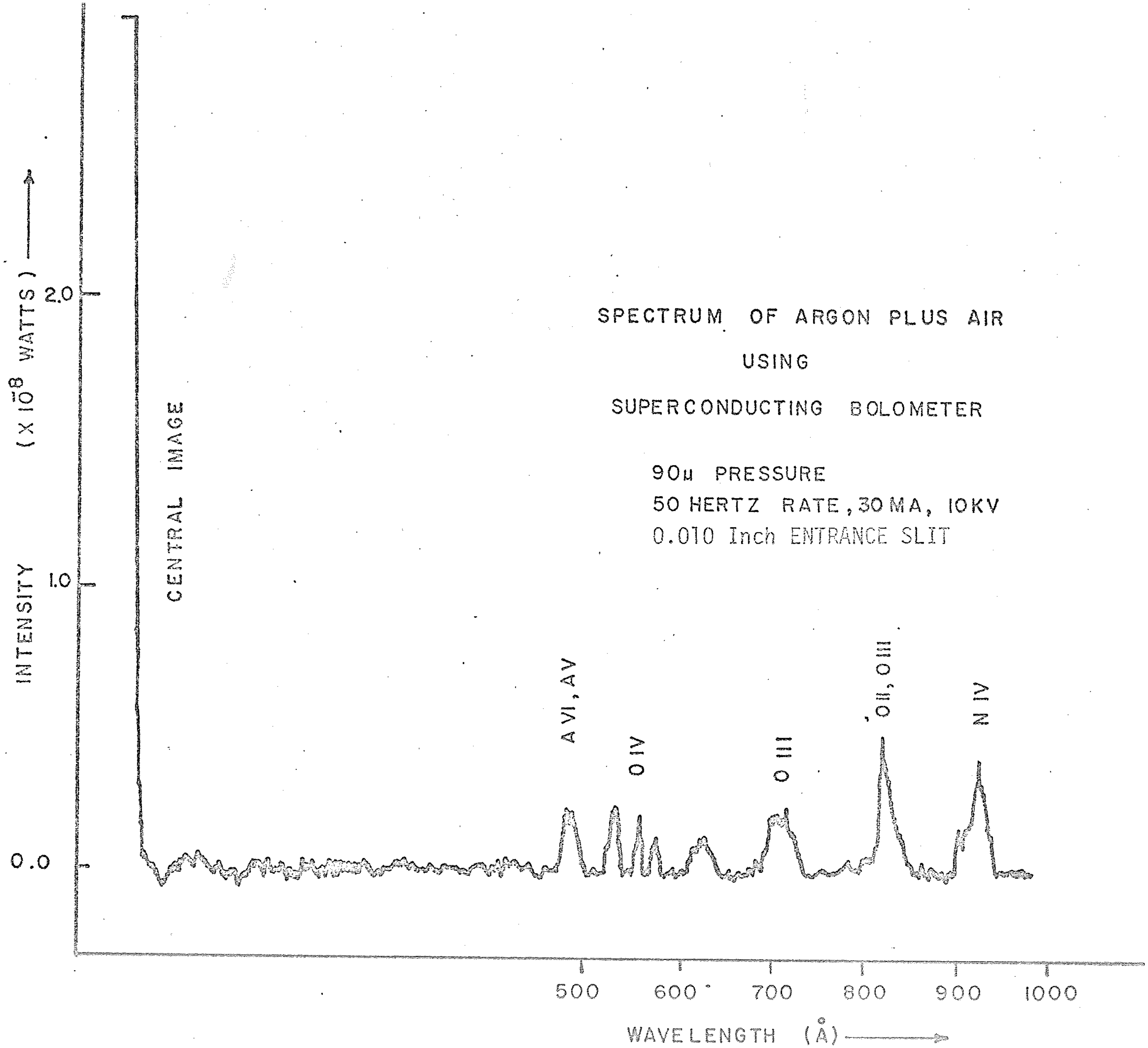

SPECTRUM OF ARGON PLUS AIR
USING
SUPERCONDUCTING BOLOMETER
90μ PRESSURE
50 HERTZ RATE, 30 MA, 10KV
0.010 Inch ENTRANCE SLIT
INTENSITY (X 10⁻⁸ WATTS)
2.0
1.0
0.0
CENTRAL IMAGE
A VI, A V
O IV
O III
O II, O III
N IV
500
600
700
800
900
1000
WAVELENGTH (Å)

FIGURE 4

3. The determination of a primary response time = 8 milliseconds.

Refer to Fig. 5. These pictures were taken at the central image, with the spark source operating at approximately a 50-hertz rate, at 10 kilovolts and 30 milliamperes. The dual trace photographs were taken operating the oscilloscope in the chopped mode. That is,both traces have the same absolute time axis.

Picture 1 shows the output signal from the first demodulator, demodulating at a 3-kilohertz rate. The region of peaked waveforms corresponds to the light chopper open and the spark source firing every 16 milliseconds. The zero signal region corresponds to the chopper being closed.

The upper trace of Picture 2 is similar to Picture 1. The lower trace shows the firing times for the light source.

Picture 3 shows the output from the first demodulator and the corresponding input to the second demodulator.

Picture 4. The upper trace shows the input signal to the first demodulator. The lower trace shows the light source firing times.

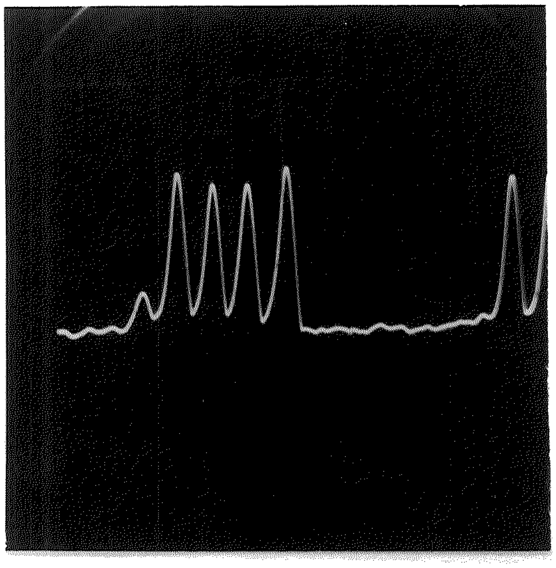
From this latter photograph the recovery time, or time required to conduct heat from the element to the heat sink, was determined to be approximately 8 milliseconds.

B. Thin Lead Films

The thermal mass of the lead elements has been reduced an order of magnitude by going to 0.0002 inch thick elements. These elements are cut from lead sheets 1.5 inches x 1 inch and 0.0002 inch thick, purchased from Goodfellow Metals Ltd., England. The cost for six of these sheets is $40.00.

FIGURE 5

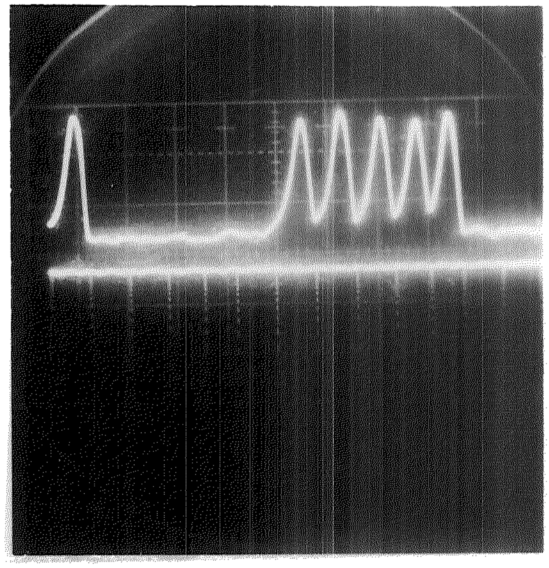
1.



Y=2V /cm X=20msec/cm

CHOPPED LIGHT SOURCE RADIATION

2.

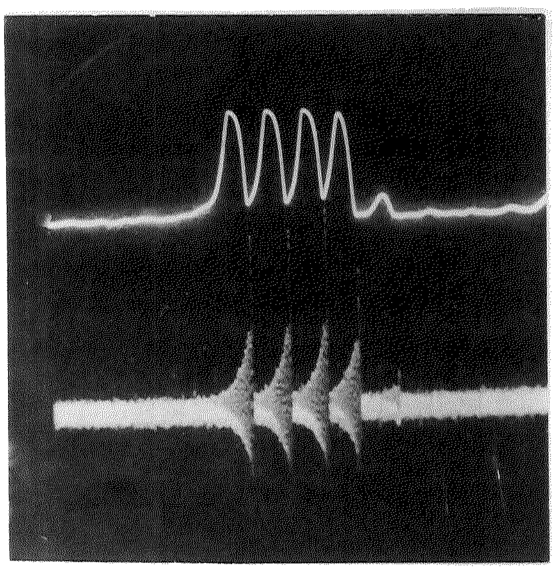


Y=2V/cm X=20msec/cm

CHOPPED LIGHT SOURCE RADIATION

LIGHT SOURCE TIMING PULSE

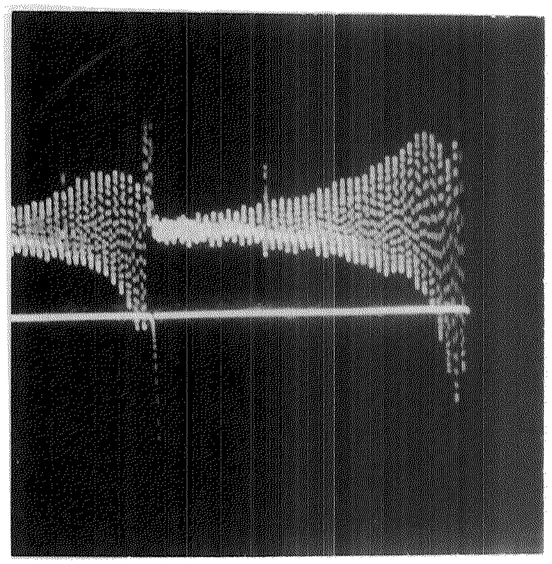
3.



Y=2V/cm X=20msec/cm

CHOPPED LIGHT SOURCE RADIATION
(output 1st demodulator)
CHOPPED LIGHT SOURCE RADIATION
(input 1st demodulator)

4.



Y=50mv/cm X=2.0msec/cm

CHOPPED LIGHT SOURCE RADIATION
(input 1st demodulator)
LIGHT SOURCE TIMING PULSE

C. Insulation Between Primary and Secondary Heat Sinks

The primary and secondary heat sinks are thermally insulated from each other by nylon washers. However, in the past as the T assembly was cooled to liquid helium temperatures, the metal screws which go through the nylon washers very often came in contact with the primary heat sink. This caused a thermal short between the primary and secondary heat sinks resulting in the lead elements always being too cold. To prevent this, a thin sheet of kapton is used to center each of the four supporting secondary heat sink screws.

D. Vacuum Ultraviolet Light Source

To take the spectrum shown in Fig. 4, a new, low noise, spark source, described earlier, was added to the system in place of the glow source. The advantage of the spark source is that it produces a more intense spectrum. Because of the complete coaxial symmetry of this source very little electromagnetic noise was produced. This made it possible for the first time to utilize the full sensitivity of the bolometer electronics with this type of source.

E. Tripartite Grating

The previous 600ℓ/mm, aluminum coated grating in the monochromator was replaced with a Bausch and Lomb 1200ℓ/mm, gold coated, tripartite grating. This replacement greatly increased transmission through the monochromator and substantially reduced interferring scattered light near the central image.

VI. SUMMARY AND CONCLUSIONS

A fully operational superconducting bolometer has been developed. It operates in the transition region between the superconducting and normal states of lead. It has a N.E.P. = 10^{-11} watts, a sensitivity of 70μ volts/μ watt, and a primary response time of 8 milliseconds. The wide spectral range, high-sensitivity and low noise make this a valuable absolute detector for many applications, particularly in the vacuum ultraviolet.

The N.E.P. and sensitivity for the present bolometer do not, however, represent a fundamental limit for such detectors. Indeed, more sensitive detectors have been constructed in this laboratory but their reliability was uncertain and hence not useful in a laboratory instrument. In order to improve the reliability and sensitivity of this type of bolometer it will be necessary to learn much more about transition region noise in superconductors.

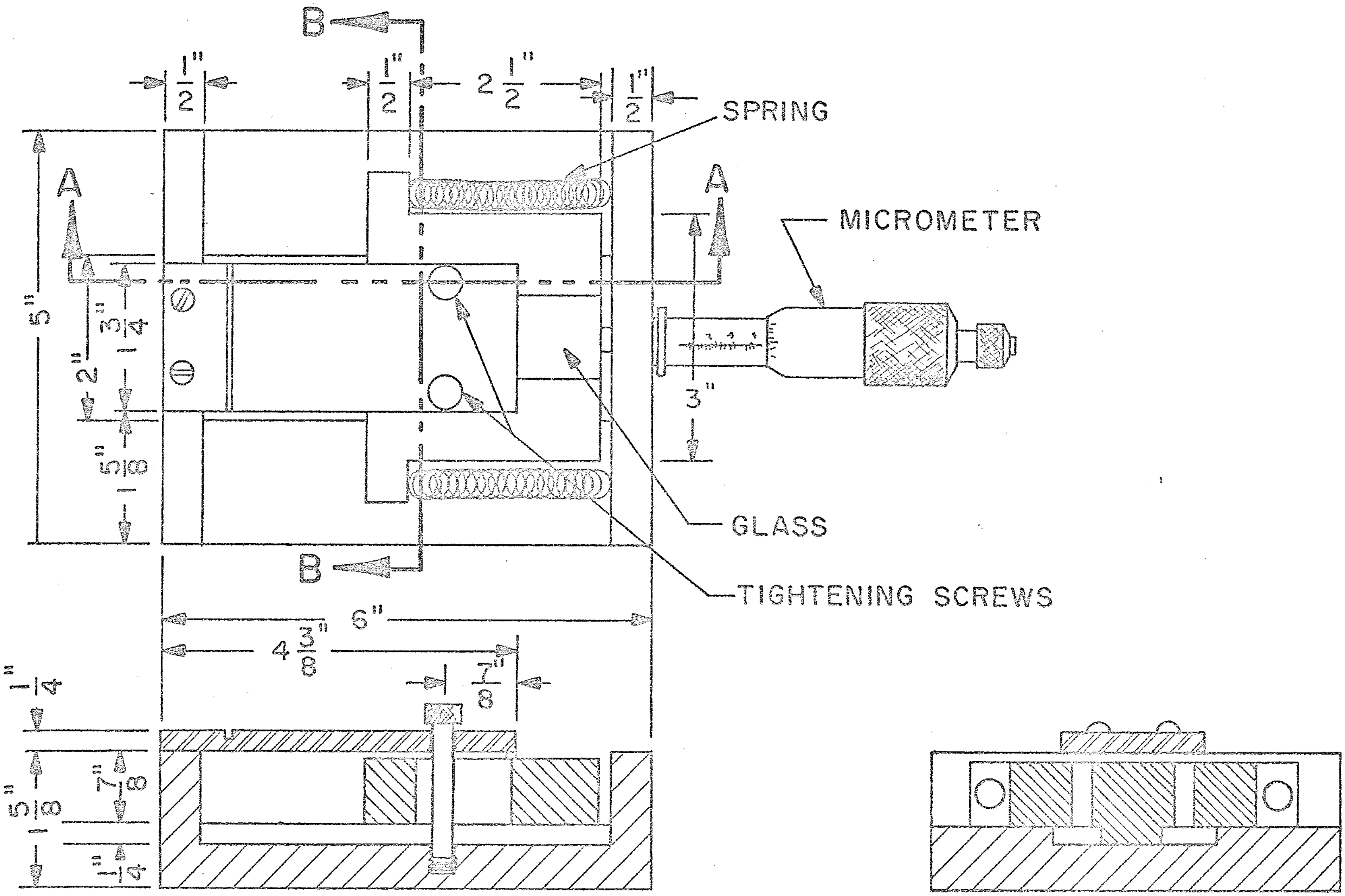
APPENDIX I

Construction of the Bolometer

A. Instructions for Assembly of Sensor Unit ("T" Assembly)

The heater resistors are inserted into the secondary heat sinks and the secondary heat sinks are mounted on the base bracket with bolts (see Figs.2, 3 and 6-11). Two nylon washers are used on each bolt, one to insulate the head of the bolt from the base bracket and the other to insulate the base bracket from the secondary heat sink. The electrical connector is mounted in the brass connector holder and brass connector mounting (see Figs. 2, 12a and 12b). One wire from each resistor is connected to the heater pins #3 and #6; the other lead from each resistor is soldered to the heater return pin, #1 (see Fig. 10). In connecting the leads, first the end which is connected to the heating resistor is soldered as close to the main body as possible, leaving room for a piece of small diameter teflon sleeving to be inserted up to the point where the lead is soldered (see Fig. 7a). The wire is then coiled about the tube twenty or thirty times before going on to its other connection, thus giving the required high thermal isolation. The leads are then soldered to thin strips of copper foil which go to the connector via brass connector thermal decoupler mounting.

The filament mounts are made by cutting 1 mil copper as shown in Fig. 7b. They are mounted to the secondary heat sink with nylon bolts, and are insulated from the secondary heat sink with nylon bolts, and are insulated from the secondary heat sink by 1 mil mylar insulators cut as shown in Fig. 4b (see Fig. 2). Leads



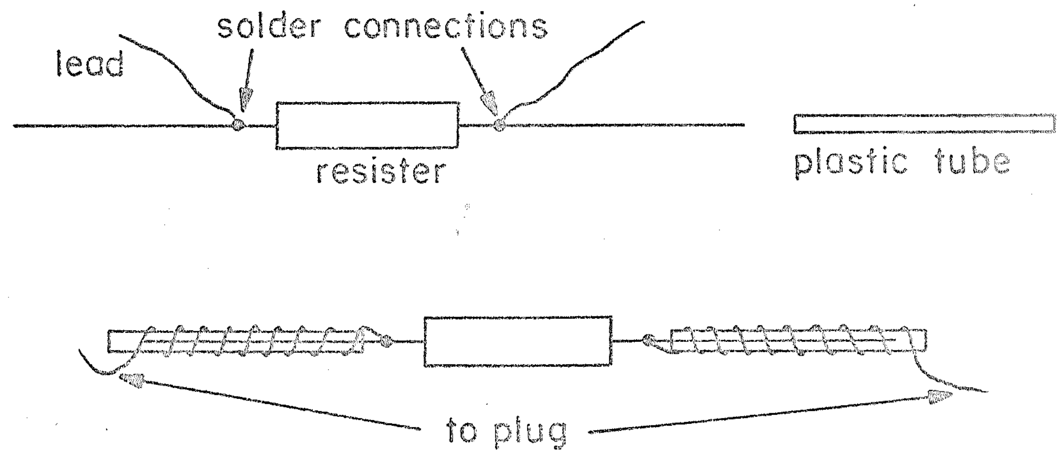
Section A-A

Section B-B

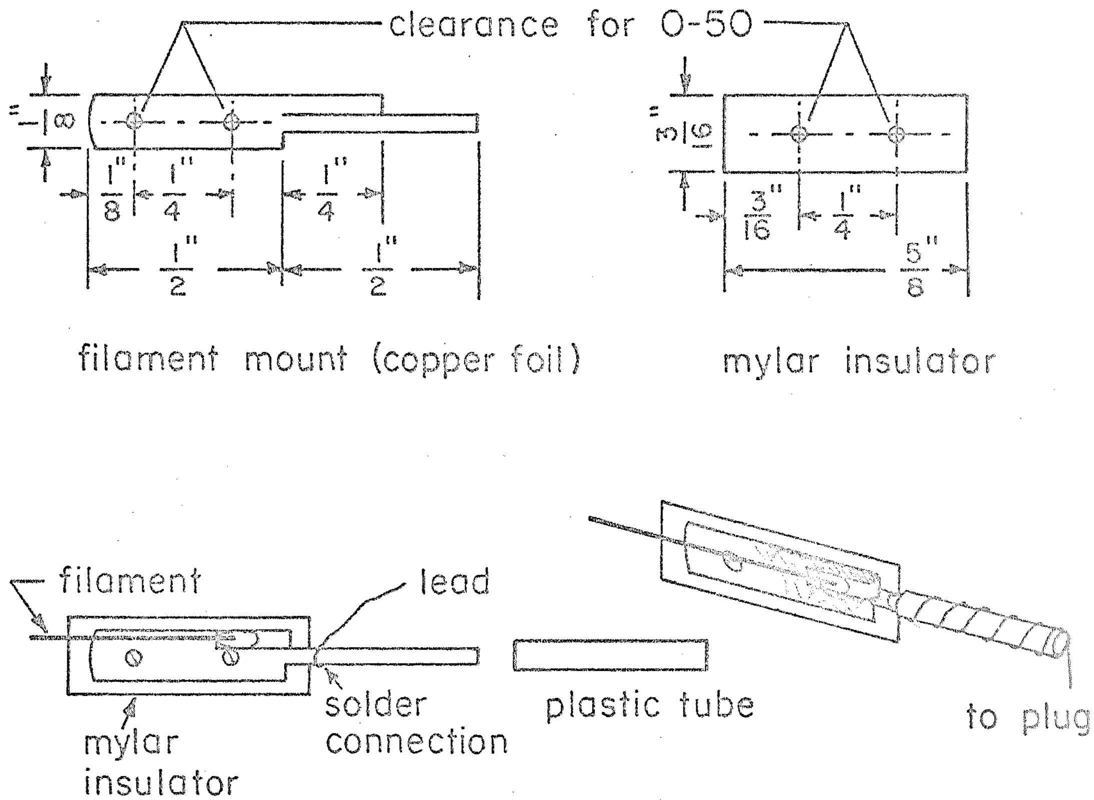
FILIMENT CUTTING PLATFORM

Figure 6

RESISTER LEAD CONNECTION METHOD (a)

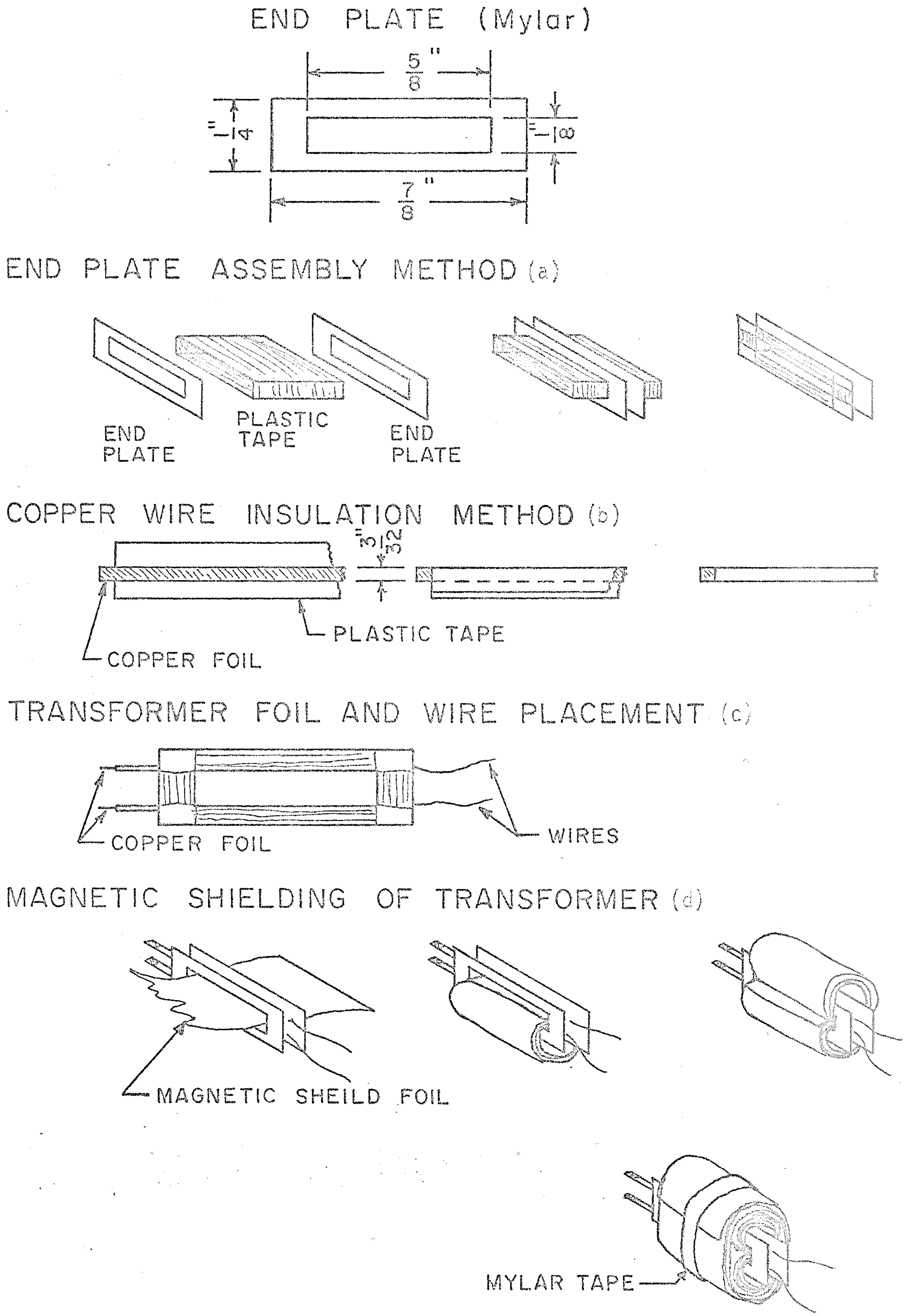


FILAMENT MOUNT LEAD CONNECTION METHOD (b)



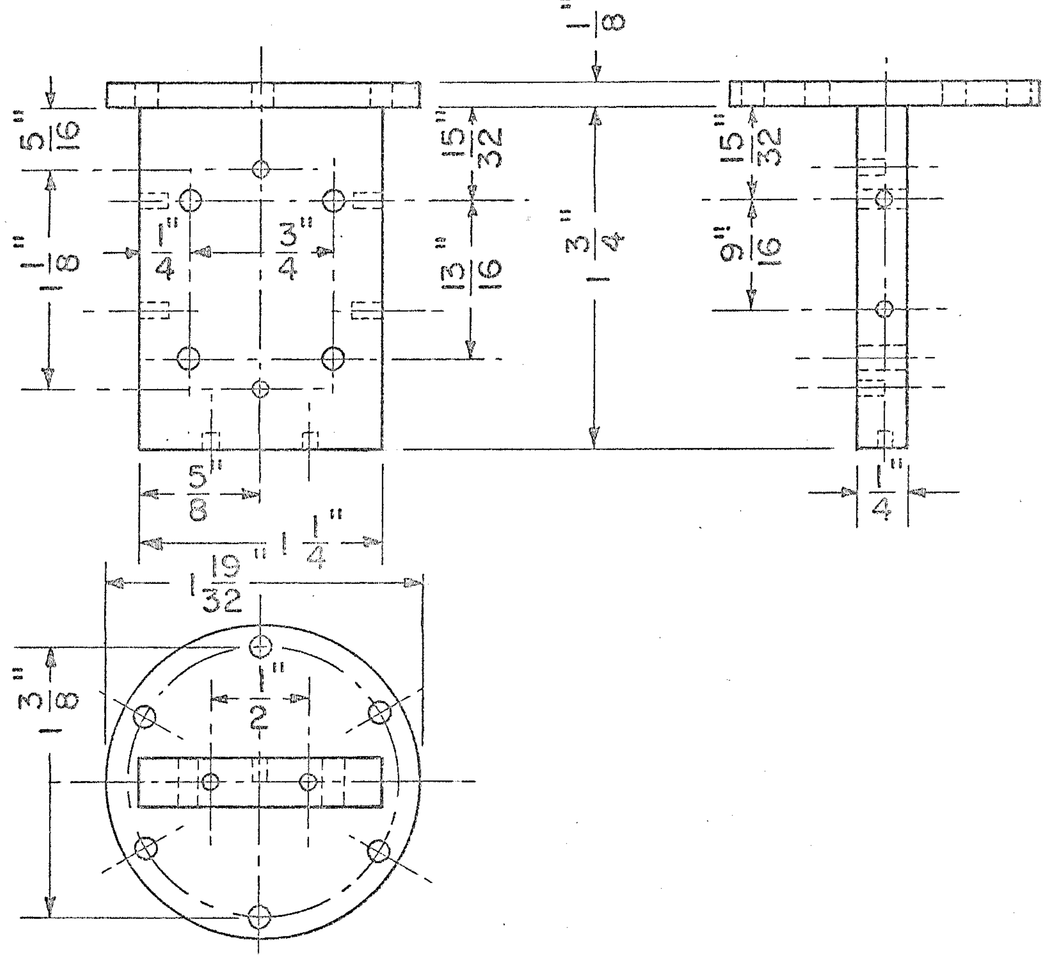
TEE ASSEMBLY

Figure 7

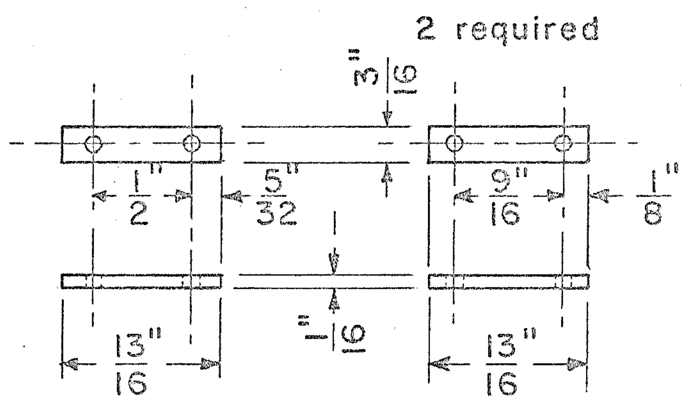


TRANSFORMER ASSEMBLY

Figure 8



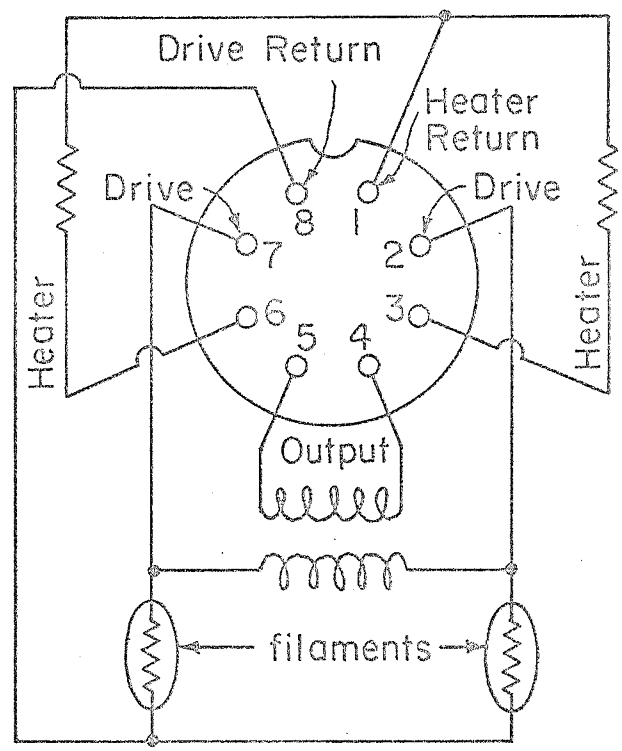
TEE HEAT SINK - OFHC COPPER (a)



WIRE CLAMPS (b)

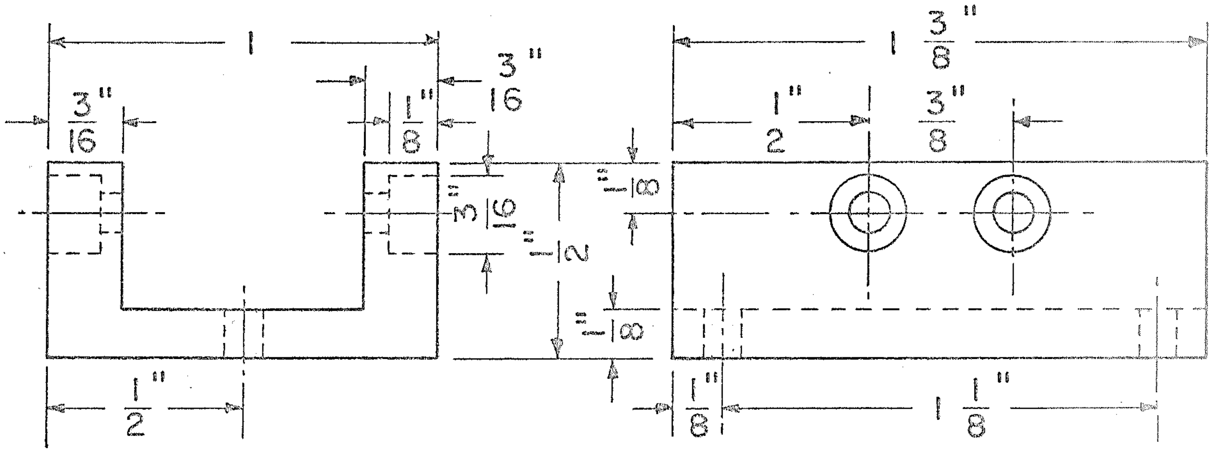
(Bolometer Sensing Apparatus)

Figure 9

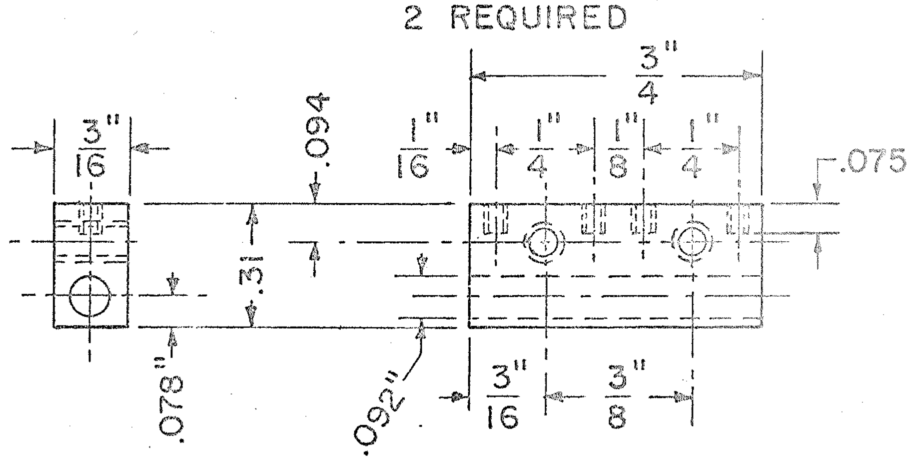


PLUG CIRCUIT

Figure 10



BASE BRACKET FOR TEE – OFHC COPPER (a)

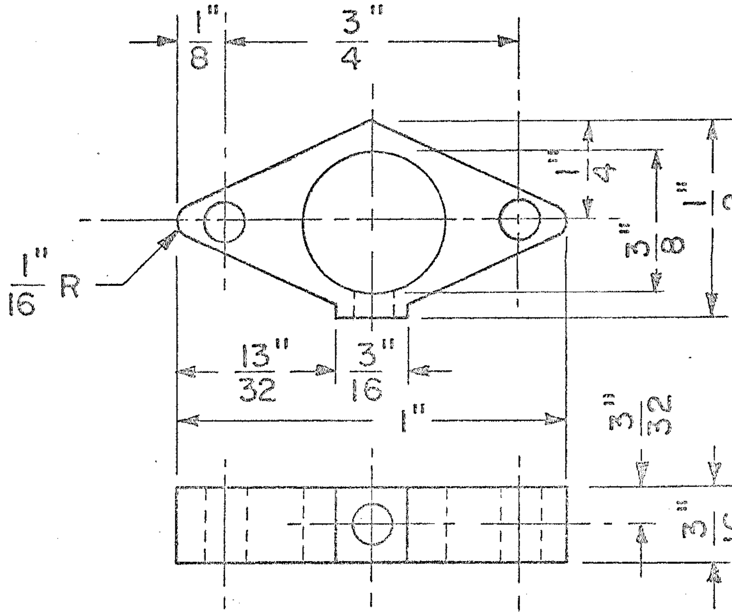


SECONDARY HEAT SINK FOR TEE
OFHC COPPER (b)

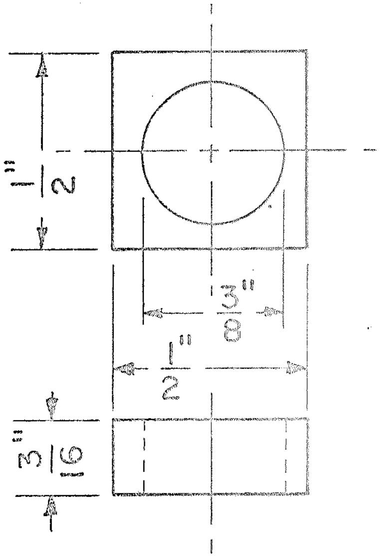
(Bolometer Sensing Apparatus)

Figure 11

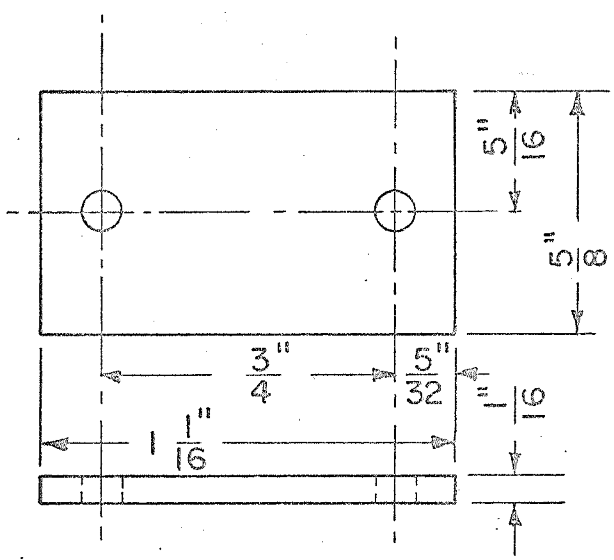
Figure 12



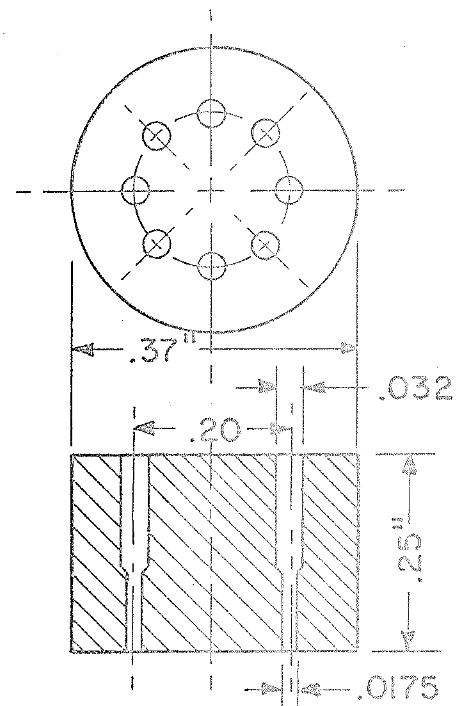
BRASS CONNECTOR HOLDER (a)



BRASS CONNECTOR MOUNTING (b)



ALUMINUM COIL PLATE (c)



BAKELITE CONNECTOR PLUG (d)

(Bolometer Sensing Apparatus)

to the filament mounts are soldered as the resistor leads were (see Fig. 7b). The leads from one end of the secondary heat sink are soldered to the drive pins, #2 and #7 (see Fig. 10) and the leads at the other end are soldered to the drive return pin (see Fig. 10).

The wire clamps are then mounted on the tee heat sink. These clamps both thermally decouple and secure wires connecting the filament mounts, the primary of the coil (on the bottom), and the heater resistors, and filament mounts (on the sides). All of these wires are going from the connector to the various components attached to the secondary heat sink. (See Figs. 2 and 9b).

B. Filaments

The filaments for the bolometer are made from lead foil, 0.0002" thick, purchased from Goodfellow Metals Ltd., Rusdex Towers, Claygate-Esher, Surrey, England. The foil is cut on the filament cutting platform (see Fig. 6), and is placed on the glass with the tightening screws loose. The micrometer is turned until the glass is as much under the clamp as possible. The foil is placed such that it is extended about 0.005" to 0.040" under the clamp. The screws are then tightened and an exacto-knife with a curved blade is used to cut the foil. The edge of the blade closest to the handle is placed on the glass next to the clamp on the edge of the foil and rocked forward cutting the foil. Typical film sizes were 0.005" wide and 3/4" long. The filaments are soldered to the filament mounts (see Fig. 7) and coated with Kodak black. The kodak black is applied with the edge of a small piece of tissue paper while viewed with a wide field binocular microscope in order to avoid damaging the filaments.

C. Construction of Transformer

In constructing the transformer, a metal bar 1/8" by 5/8" by 1" is wrapped with 1 mil mylar tape four or five times (see Fig. 8b). Next, two end plates are cut by making a 1/8" x 5/8" hole through 5 mil thick mylar which is then slipped over the tape on the bar until they are 3/32" from each other and are evenly spaced from the ends of the tape (see Figs. 8a and b). The tape is removed from the bar and slots are cut in the tape outside the end plates so that the tape can be folded flush with the mylar (see Fig. 8b). Copper wire, EW 9313 magnet wire K-9721-RR1, #63, is wound 100 times around the resulting bobbin leaving an inch free at both ends of the wire. One mil copper foil is cut into a strip 6" long by 3/32" wide and is placed in the middle of a strip of nylon tape which is folded around it, the excess nylon tape being trimmed away (see Fig. 8c). The insulated copper is now wound seven times around the bobbin on top of the previous 100 turn winding. The ends should have 1/2" freedom and should face in the opposite direction to the two wire ends (see Fig. 8d). A 5/8" strip of magnetic shield foil, AA-Co-Netic foil annealed, is wound four times about the core and one side, four times about the core and the other side and four times about the entire transformer, then taped with mylar tape (see Fig. 8c).

The transformer is mounted on the tee heat sink with the coil plate and two bolts (see Figs. 2, 3, 9a, and 12c). The primary coil (seven turns) is connected to the filament mounts which are connected to pins two and seven of the connector, and the secondary is connected to pins four and five (see Figs. 12 and 10).

D. Wiring of the Dewar

A Janis liquid helium research dewar, Model #8 D.T., was used for cooling the bolometer elements. Eight wires are run from an eight pin feed-thru on the outer wall of the dewar. The wires are divided into three groups. One group consists of the left and right heater wires and the heater return. The second group consists of the left and right drive wire and the drive return. The third group consists of the two output wires. The individual groups are tightly twisted and put within separate teflon sleeves. The groups are then wound around the dewar tail and taped down with masking tape leaving the ends free for attachment to the bolometer connector (see Fig. 3).

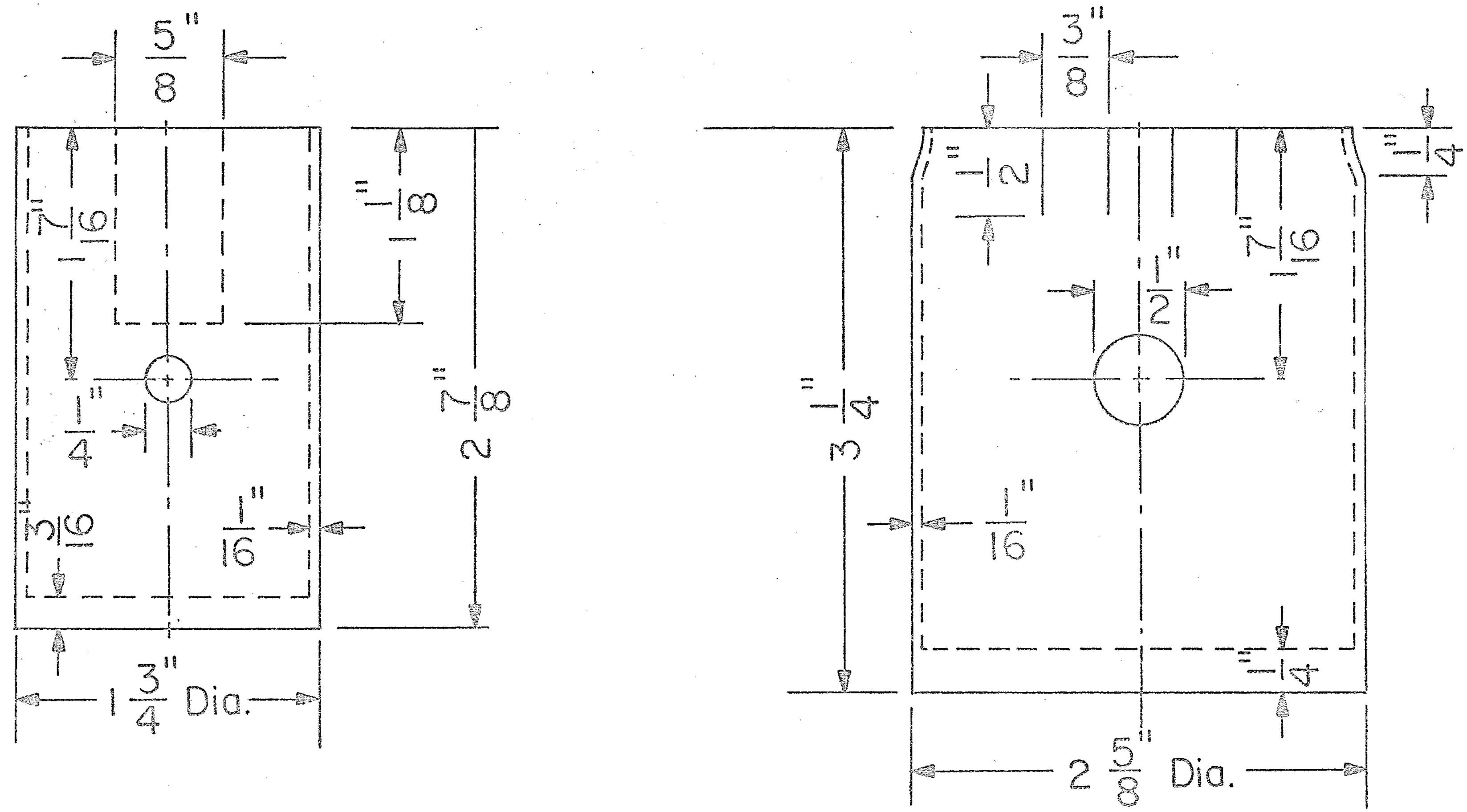
To make the bolometer connector, (see Fig. 12d), eight metal pins, 0.017" in diameter are inserted into a bakelite plug so that they extend from the plug 1/4". The pins are wound with three or four turns of #36 heavy formvar magnet wire, the varnish being first removed from the ends by use of a flame and sandpaper, and soldered. Three or four inches of wire per pin should be used. When the pins are inserted the ends with the wire, face away from the connector plus as the pin is inserted through the wider side of the holes. This side is now coated with epoxy to seal the pins in.

The wires from the plug are connected to those leading down the dewar tail. First a piece of teflon sleeving just large enough to fit loosely over the wire is slid over each wire from the dewar tail. This tubing should allow 1/2" of wire uncovered at the end for connections. The varnish from the wires from the dewar tail and the connector plug is removed. One pair of needle-nosed pliers holds one wire against the other 1/4" from the end of the other wire. The second wire is wound about the first and soldered with as little solder as possible and the teflon sleeving is slid over the solder joint for insulation. All sets of wires are likewise joined. The wires are of course connected so that the connector plug pins match those in the tee assembly connector (see Fig. 10).

E. Shielding and General Assembly

The top surface of the bolometer tee assembly is coated with type N apiezon vacuum grease and bolted to the bottom of the dewar tail as shown in Fig. 3.

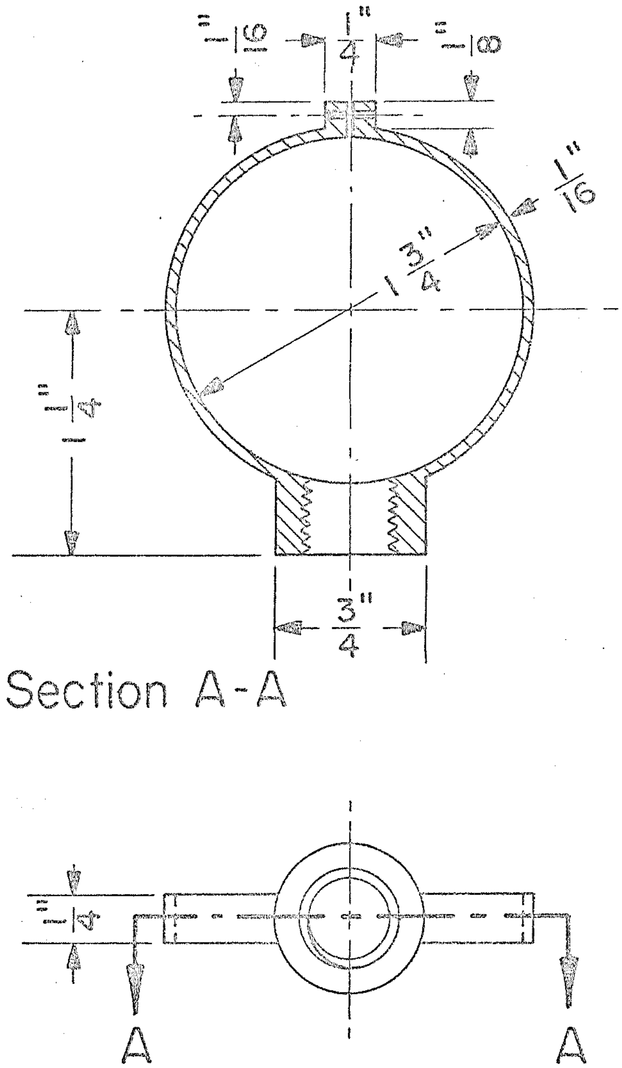
The lead coated copper shield can has collar for the copper collimator tube adjusted such that the hole of the collar lines up with the hole in the can (see Figs. 13 and 14). The can is then covered on the sides and bottom with aluminum foil which is held in place with aluminized mylar tape. The hole and notch are kept free of foil. The can is coated on the inside at the top with the vacuum grease. The brass shield clamp is coated on the inside surface with vacuum grease and put loosely over the can at the top so that the extending portion of the clamp fits the can's notch (see Fig. 15). The can is placed over the tee assembly so the hole is centered over one filament (see Fig. 3). The filament, when



Lead Coated
COPPER SHIELD CAN (a)
(Bolometer Sensing Apparatus)

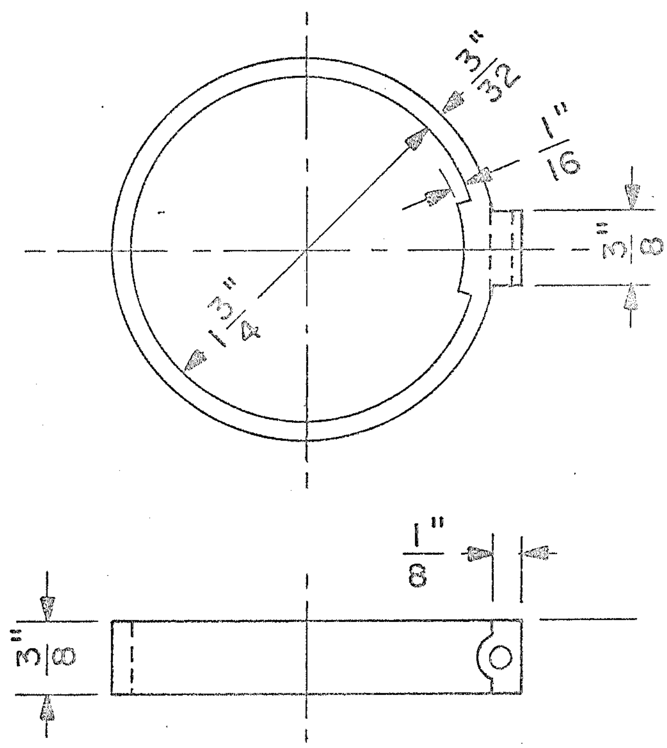
ALUMINUM SHIELD CAN (b)
(Bolometer Sensing Apparatus)

Figure 13



COPPER COLLAR
for Collimating Tube
(BOLOMETER SENSING APPARATUS)

Figure 14



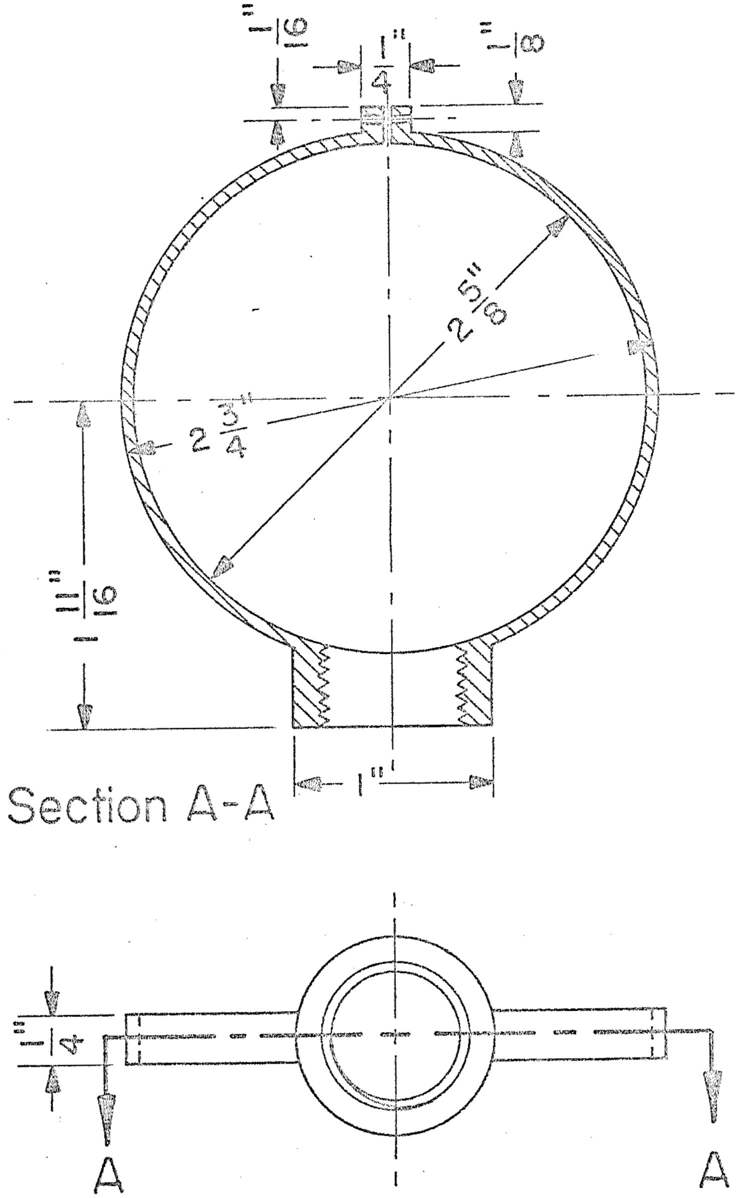
BRASS SHIELD CLAMP
(Bolometer Sensing Apparatus)

Figure 15

looking through the hole on the left, is generally used. An alignment light source is turned on, and the light is centered in the collimator tube by turning the copper can (see Figs. 3 and 17b). The connector plug is plugged in and all excess wires to the plug are taped to the dewar tail with aluminized mylar tape and the collimator is removed.

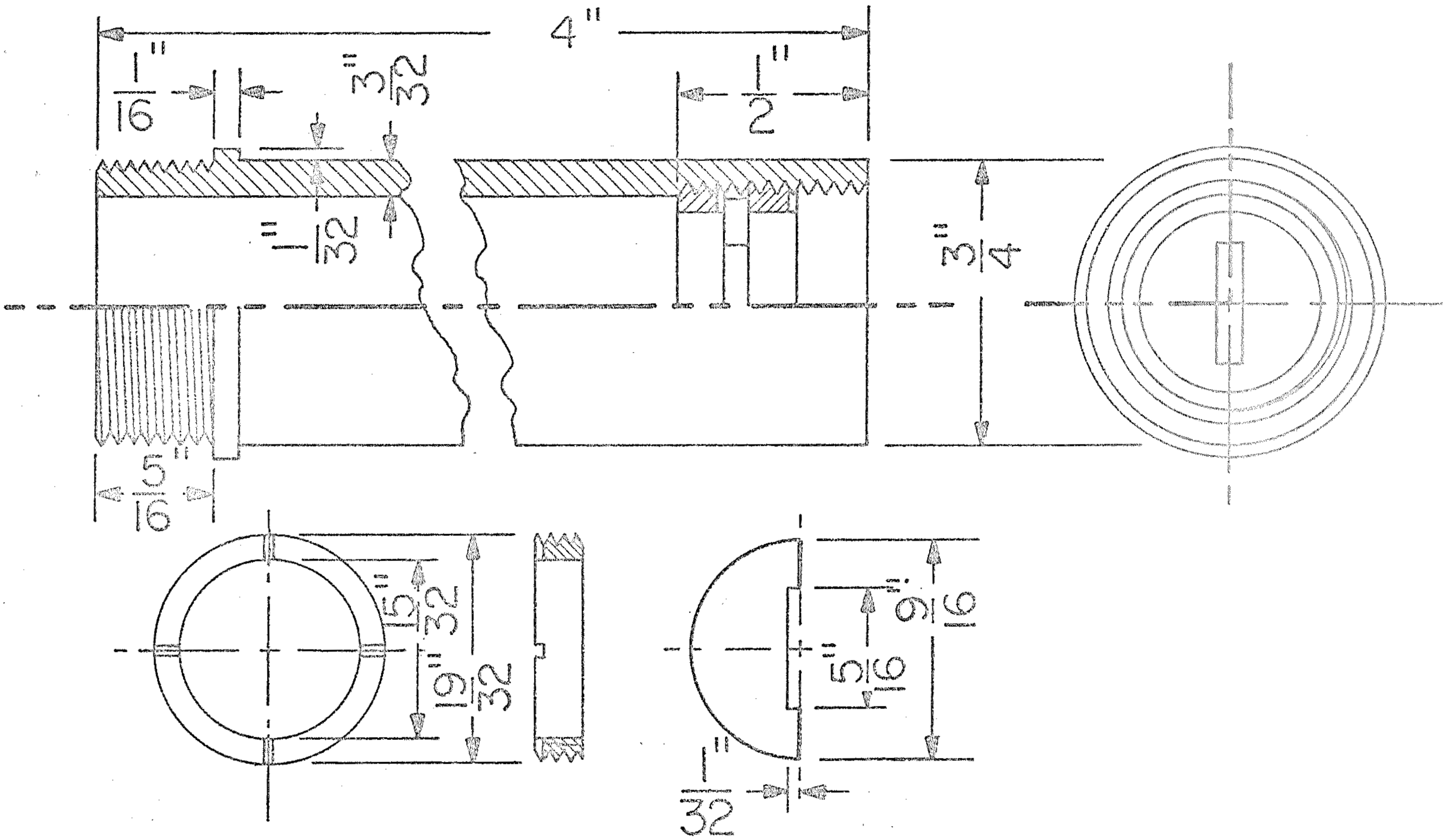
Now the tail of the dewar is covered with a piece of aluminum foil cut as wide as the height of the tail and 6" long, and is taped with masking tape at the top, middle, and bottom of the tail. It is then wound around the tail and taped tightly with aluminized mylar tape. A notch is cut where the groups of wires just begin to wind about the dewar tail so that the wires only touch the aluminum while they are heat sunk to the dewar tail (see Fig. 3).

The aluminum shield is then bolted onto the base of the dewar. Using a mirror and a light, the dewar tail inside the aluminum shield is checked to make sure that there is nothing touching the shield, such as wires, tape or foil. The aluminum shield can is snapped into the aluminum shield (see Figs. 3 and 13b). The aluminum collimator holder is mounted on the aluminum "can" and is centered over its aperature (see Figs. 13b and 16). The aperature in both the aluminum and copper radiation shields must be aligned. Both collimators are screwed in, the copper first and the slit in the aluminum tube is set verticle (see Figs. 3 and 17). The light source is turned on again to center the aluminum tube. A light is used to look through the slit in the aluminum tube to be sure there is no contact between the aluminum collimator and copper collimator. If they are touching, the aluminum tube is moved until it is free and

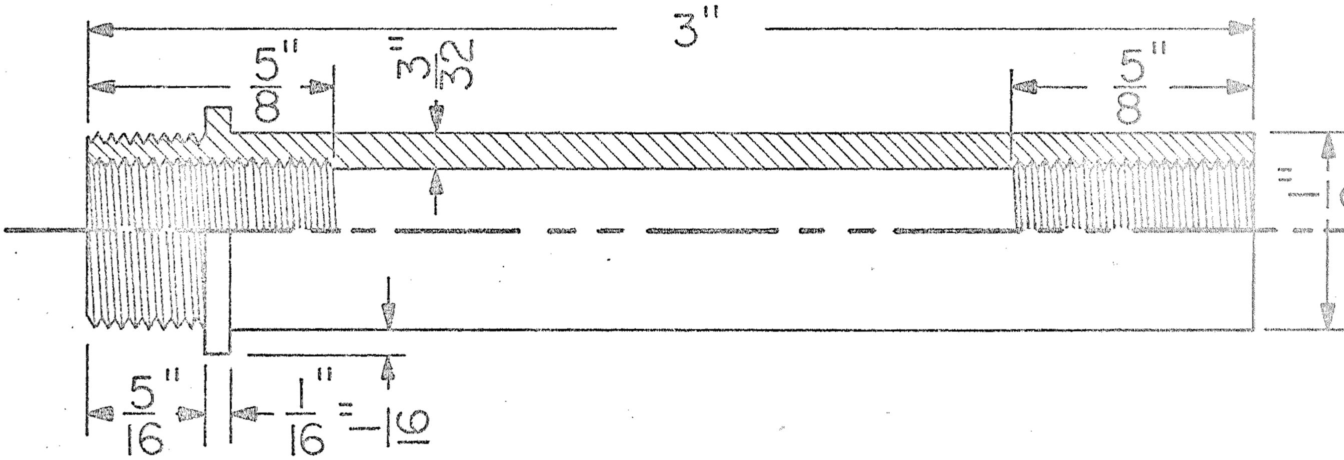


ALUMINUM COLLAR
for Collimator Tube
(BOLOMETER SENSING APPARATUS)

Figure 16



ALUMINUM COLLIMATOR TUBE (a)
(BOLOMETER SENSING APPARATUS)



COPPER COLLIMATOR TUBE (b)
(BOLOMETER SENSING APPARATUS)

Figure 17

then the bolt on the aluminum collimator holder is tightened. The tubes are now removed. The outer dewar tube is bolted on as shown in Fig. 2 and the collimators are screwed in as before. Connecting tubes are bolted on to connect the outer dewar tube to the monochromator.

APPENDIX II

Cooling and Operation of the Superconducting Bolometer

A. Pumping

After the bolometer is completely assembled and all possible connections are tested the pumping can begin. When the pressure falls below 50μ the diffusion pumps are turned on.

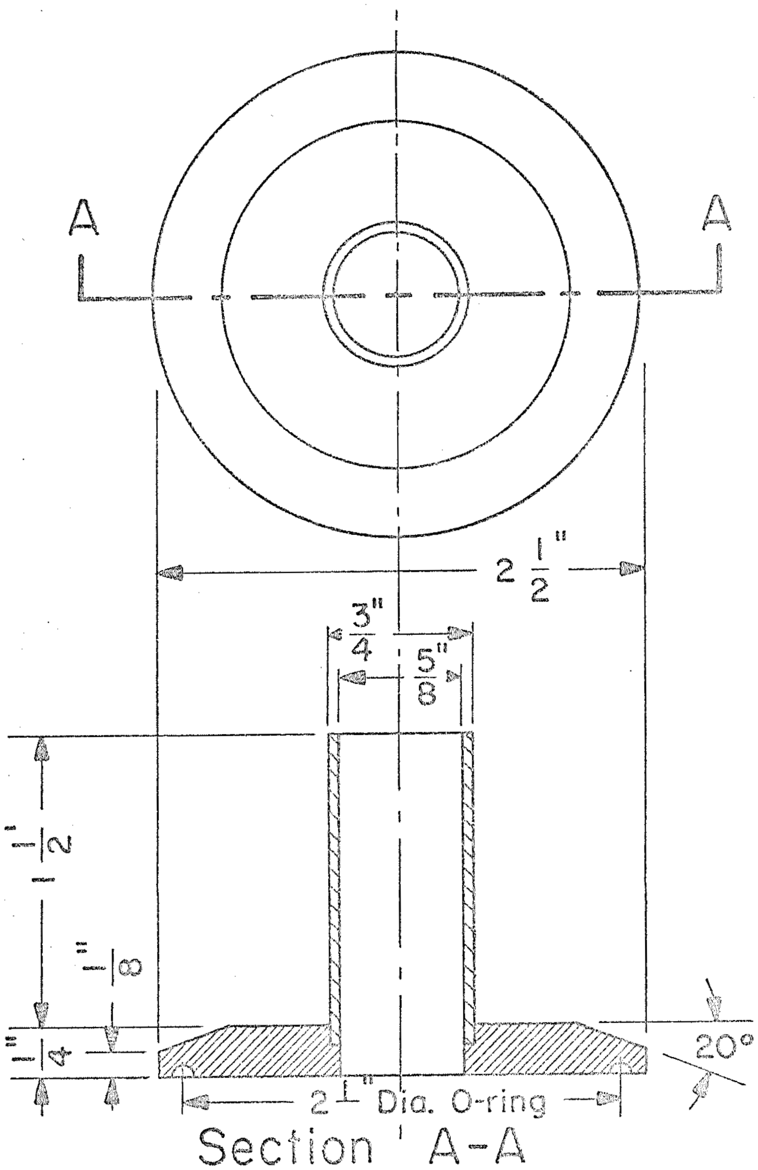
B. Cooling

The inner dewar is wiped with a cloth to remove moisture. Now cooling can begin. Liquid nitrogen is put into the Janis dewar's outer jacket. When the liquid level reaches the top, a piece of insulating plastic is set on top of the dewar and the bolometer is then left for about an hour to cool. The inner dewar is then slowly filled with liquid nitrogen until the level is two to three inches above the inner dewar's tail and bolometer is left for another 1/2 hour to cool before proceeding.

If the inner dewar is cooled too quickly its indium O-ring seal may leak. The system should then be allowed to warm up with the pump on. Upon warming, the dewar is brought up to atmospheric pressure by opening the bleed valve. The bleed valve is then closed and the pumping process repeated to reseal the O-ring. If the pressure goes down to $5 \times 10^{-2}\mu$ the cooling process is repeated. If there is no rise in pressure upon adding liquid nitrogen to the inner dewar the leak is sealed. If the pressure rises or never goes below $5 \times 10^{-2}\mu$ or does not lower upon cooling, then the O-ring must be replaced (see operating instructions for detachable tail research dewars by Janis).

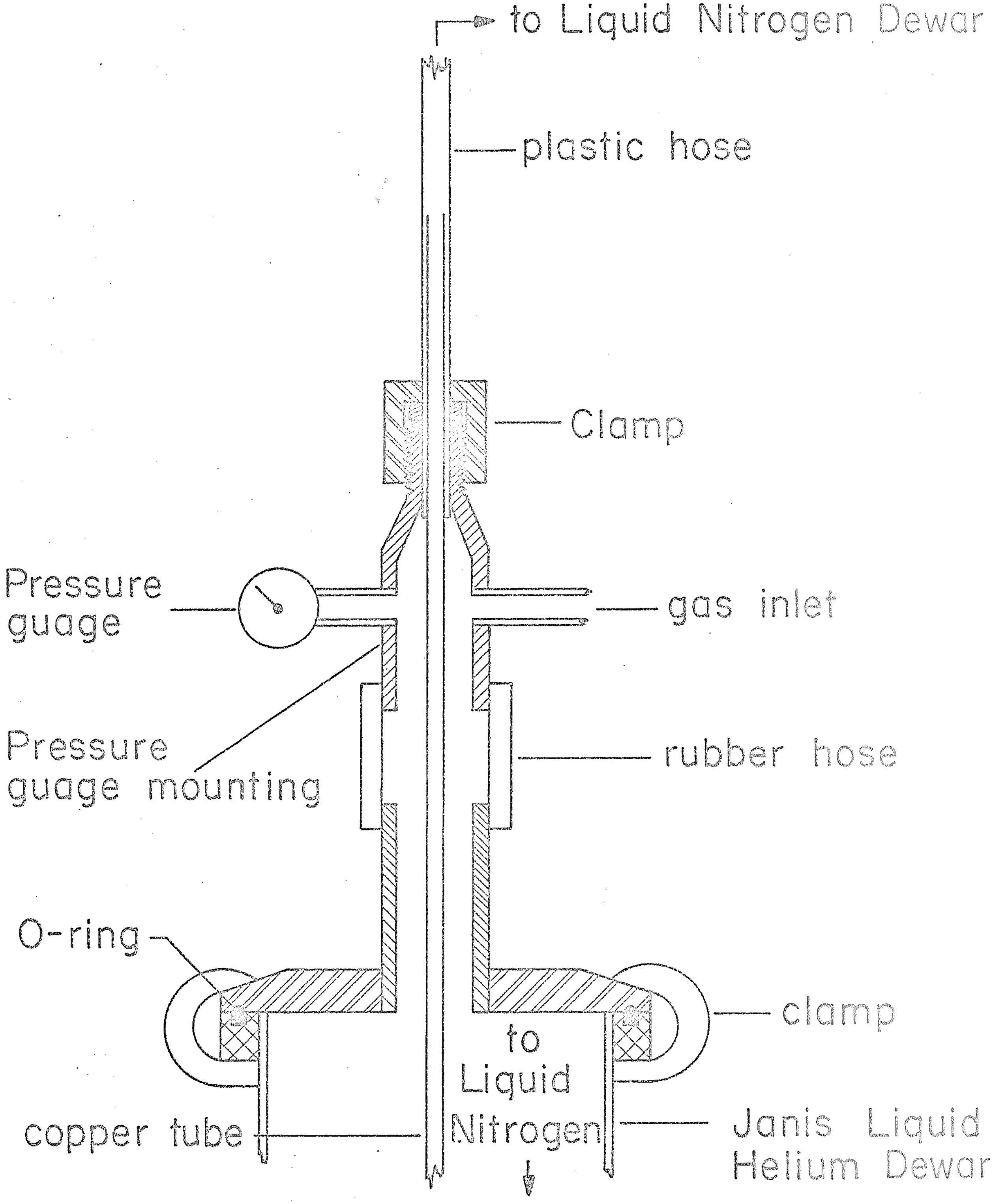
Next, the liquid nitrogen is removed from the inner dewar. A brass stopper is clamped to the top of the inner dewar (see Figs. 18 and 19) and a piece of thick rubber vacuum tubing is attached to it which is in turn attached to a pressure gauge. The gas inlet of the gauge is connected to a rubber tube running to a cylinder of helium gas. A copper tube, reaching to the bottom of the dewar and extending three inches above the pressure gauge is covered for eight inches at one end with plastic hose, the hose extends a foot from the end of the tube. The tube is inserted into the gauge until it reaches the bottom of the dewar and the clamp is tightened on it (see Fig. 10). The hose is put into the liquid nitrogen in the outer dewar. The vent holes of the inner dewar are sealed by attaching a piece of hose so one end is tightly placed over each hole. Helium gas at a pressure of about 20 oz. is used to force the liquid nitrogen out. A slow decrease of pressure, if the gas inflow is stopped, indicates nitrogen is being transferred. A rapid drop in pressure will be observed when the liquid nitrogen has been transferred. The liquid nitrogen removal apparatus may then be removed and the covers replaced until liquid helium is transferred.

When the liquid helium is to be transferred, the caps are removed from the inner dewar. The liquid helium storage dewar is then fitted with a Janis transfer tube, (Model FHT flexible tube) and the dewar is pressurized to about "8 oz." with helium gas. If a dense white plume can be seen rising from the inner dewar, the pressure should be lowered since this indicates liquid helium is being blown out. Periodic checks should be made to determine the level of helium in the bolometer dewar. To measure the level, a rod four feet long of 1/8" I.D. thin walled stainless steel tubing is



BRASS STOPPER
(Liquid Nitrogen Removal Apparatus)

Figure 18

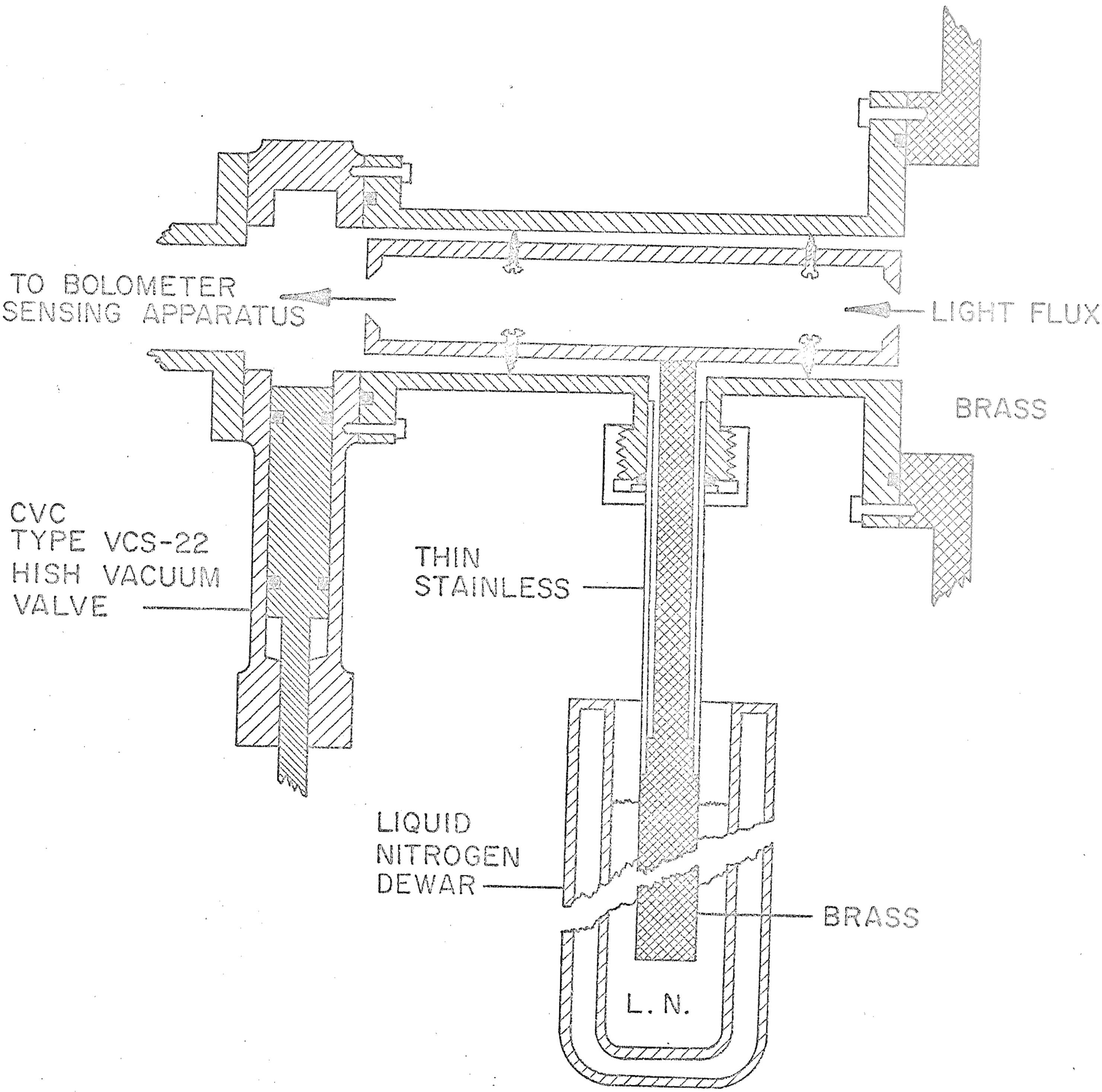


Liquid Nitrogen Removal Apparatus Assembly

Figure 19

used. On one end a cap is mounted on which one's finger is placed. On lowering the other end into the dewar vibrations are felt and reaching the liquid level the frequency sharply decreases. When the level in the bolometer dewar is sixteen inches from the bottom transferring should be stopped. This corresponds to roughly 6 liters. The covers and insulation should now be replaced on top of the inner dewar.

The low temperature exit arm collimator baffle, shown in Fig. 20, can now be cooled with liquid nitrogen. By reducing the temperature in this region of the monochromator exit arm the background radiation reaching the detector can be reduced. This affords a lower N.E.P. since the noise associated with this radiation will be reduced and, in addition, thermal drift of the detector due to temperature changes of the monochromator envelope is minimized.



LOW TEMPERATURE EXIT ARM COLLIMATING BAFFLE

Figure 20