NAVAL POSTGRADUATE SCHOOL
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THESIS

ABSOLUTE ELECTROACOUSTIC MEASUREMENT OF TEMPERATURE OSCILLATIONS IN SUPERFLUID HELIUM BY THE RECIPROCITY METHOD

by

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and

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December 1983

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This work is dedicated to our wives, Gwen Montano-Valdivia and Diane Y. Ogg, and to our children James and Trini Valdivia and Todd and Christopher Ogg. This experiment started almost two years ago and throughout this time their faith in our ability to succeeed and their encouragement to persevere, despite some set-backs and mandatory separations, made the completion of this thesis a reality.

I. INTRODUCTION

A. CLASSICAL RECIPROCITY

Before addressing the subject of this thesis, the extension of the acoustical reciprocity technique to thermal (second) sound in superfluid helium, it will be useful to review the development of the classical technique which has been central to the progress of acoustical science over the last forty years. The specific extension of these ideas to the calibration of second sound transducers in superfluid helium will be treated in chapter II.

1. Reciprocity Relations

In applying the Reciprocity Theorem for the absolute calibration of microphones, MacLean [Ref. 1] and independently Cook [Ref. 2], have demonstrated that it is possible to determine the absolute sensitivity of an electroacoustic transducer by making only electrical measurements, without reference to a primary acoustic standard.

To illustrate the technique, consider the linear, passive, four-pole network of Figure 1.1.

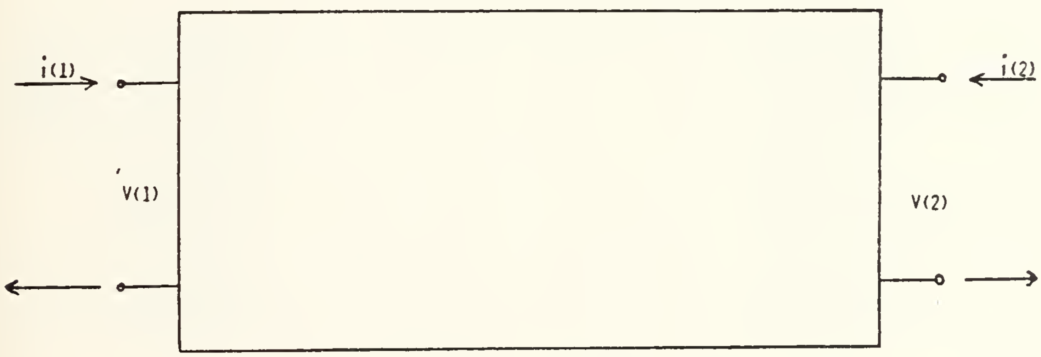

Figure 1.1 A Linear Passive Four-Pole Network.

The system response can be described by the following pair of linear equations,

$$V(1) = a\ i(1) + b\ i(2) \qquad \text{(eqn 1.1)}$$

$$V(2) = c\ i(1) + d\ i(2)\ . \qquad \text{(eqn 1.2)}$$

The above network, whether it serves to model an acoustical, electrical, mechanical, electroacoustical or electromechanical system, will satisfy the Reciprocity Theorem whenever

$$b = \pm c.$$

Capacitive microphones were used in this experiment; therefore, for our purposes, $b = +c$ in equations 1.1 and 1.2 [Ref. 3]. If we let our network model an electroacoustic system consisting of two <u>reversible</u> transducers (Figure 1.2) then,

$$V(1) = a\ i(1) + b\ i(2) \qquad \text{(eqn 1.3)}$$

$$V(2) = b\ i(1) + d\ i(2)\ . \qquad \text{(eqn 1.4)}$$

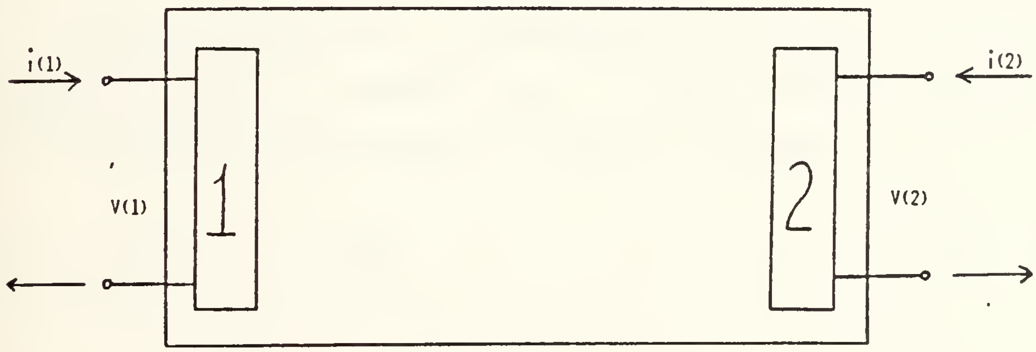

Figure 1.2 Transducers 1 and 2 Coupled by an Acoustic Field.

It should be noted that equation 1.4 represents the receiver, or microphone, side of our network, while equation 1.3 represents the source, or speaker. Also note that c = b must exist since our transducers are electrostatic devices.

For continued compatability with existing literature concerning the Reciprocity Theorem by Rudnick [Ref. 4] and Swift [Ref. 5], the notation of MacLean [Ref. 1] will also be used in this report:

M = Sensitivity as a microphone

S = Strength as a Source

therefore,

$$Mo = \text{open circuit volts/pressure at mic} \qquad \text{(eqn 1.5)}$$

$$Ms = \text{short circuit current/pressure at mic} \qquad \text{(eqn 1.6)}$$

$$So = \text{pressure at mic/current into speaker} \qquad \text{(eqn 1.7)}$$

$$Ss = \text{pressure at mic/volts across speaker .} \qquad \text{(eqn 1.8)}$$

When transducer 1 is used as a <u>speaker</u> driven by a voltage V(1) and a current i(1), and when transducer 2 is short circuited, equations 1.3 and 1.4 become

$$V(1) = a\ i(1) + b\ i(2) \qquad \text{(eqn 1.9)}$$

$$0 = b\ i(1) + d\ i(2) \qquad \text{(eqn 1.10)}$$

which leads to

$$V(1)/i(2) = b - (ad/b) . \qquad \text{(eqn 1.11)}$$

Zero appears at the left side of equation 1.10 because transducer 2's output terminals have been short circuited.

When the same short circuit measurements are again made on our network, but with the roles of the transducers reversed, we find that equations 1.3 and 1.4 now yield

$$0 = a\ i(1) + b\ i(2) \qquad \text{(eqn 1.12)}$$

$$V(2) = b\ i(1) + d\ i(2) \qquad \text{(eqn 1.13)}$$

which leads to

$$V(2)/i(1) = b - (ad/b) . \qquad \text{(eqn 1.14)}$$

From equations 1.11 and 1.14 we see that

$$V(2)/i(1) = V(1)/i(2) , \qquad \text{(eqn 1.15)}$$

which is the Helmholtz/Rayleigh statement of the Reciprocity Theorem [Ref. 6]. By equations 1.6 and 1.8

$$i(2) = P(2)\ Ms(2) \qquad \text{(eqn 1.16)}$$

$$P(2) = V(1)\ Ss(1) \qquad \text{(eqn 1.17)}$$

therefore

$$i(2) = V(1)\ Ss(1)\ Ms(2) \quad \text{(eqn 1.18)}$$

and

$$[V(1)/i(2)] = [Ss(1)\ Ms(2)]^{-1} . \quad \text{(eqn 1.19)}$$

Similarly

$$[V(2)/i(1)] = [Ss(2)\ Ms(1)]^{-1} . \quad \text{(eqn 1.20)}$$

Using equation 1.15 we obtain

$$Ss(2)\ Ms(1) = Ss(1)\ Ms(2) \quad \text{(eqn 1.21)}$$

which finally leads to

$$Ms(2)/Ss(2) = Ms(1)/Ss(1) . \quad \text{(eqn 1.22)}$$

When a similar analysis is performed, using equations 1.5 and 1.7 (microphone output terminals open) we see that [Ref. 1],

$$\begin{aligned} Mo(1)/So(1) &= Mo(2)/So(2) \\ &= Ms(2)/Ss(2) \\ &= Ms(1)/Ss(1) . \end{aligned} \quad \text{(eqn 1.23)}$$

Therefore, the ratio of a transducer's sensitivity as a microphone to it's strength as a source is dependent only on the properties of the space through which the sound must propagate. It should be noted that no mention of resonator geometry has been made, and in fact, the above ratios are independent of the physical aspects of the resonator [Ref. 4], or any other geometric boundary condition.

If we let both transducers be identical and ideal[1] then Mo(1) = Mo(2) and we can define

$$Mo/So = 1/Z \qquad \text{(eqn 1.24)}$$

where "Z" is the quantity which characterizes the acoustic geometry, and has the units of acoustical impedance.

From the open circuit receiver case where i(1) is used to drive side 1 and the output of side 2 is V(2), then equations 1.5 and 1.7 yield

$$V(2)/i(1) = So(1)\ Mo(2)\ . \qquad \text{(eqn 1.25)}$$

Multiplying the right side of equation 1.25 by (Mo(2)/Mo(2)) and using equation 1.24 yields

$$V(2)/i(1) = Z\ (Mo)^2 \qquad \text{(eqn 1.26)}$$

or

$$Mo = [V(2)/(i(1)\ Z)]^{1/2}\ . \qquad \text{(eqn 1.27)}$$

----

[1] The transducer is small compared to a wavelength of sound and is so non-compliant that, as a microphone, it's presence at a point within the sound field will never affect the sound pressure at that point. When used as a speaker it's volume velocity is independent of the acoustical load.

This says that once the acoustical impedance Z is determined, the absolute sensitivity of our identical and ideal transducer can be calculated from equation 1.27.

2. <u>Acoustical Transfer Impedance</u>

To investigate the parameter Z we first drive the ideal transducer of side 1 with voltage V(1) and current i(1). A volume velocity U(1) will appear <u>at the speaker</u> and

$$V(1) = a\ i(1) + B\ U(1) \qquad \text{(eqn 1.28)}$$

$$P(1) = B\ i(1) + D\ U(1) = 0 \qquad \text{(eqn 1.29)}$$

where P(1) is the pressure at the source. Here, P(1) must be equal to zero since no external pressure is being applied to transducer 1 and the ideal source cannot "feel" it's own generated pressure. With transducer 2 as the short circuited <u>microphone</u> we find

$$V(2) = a\ i(2) + B\ U(2) = 0 \qquad \text{(eqn 1.30)}$$

$$P(2) = B\ i(2) + D\ U(2) \qquad \text{(eqn 1.31)}$$

where P(2) and U(2) are the pressure and volume velocity.

From equations 1.28 to 1.31 it is clear that

$$V(1)/U(1) = B - (aD/B) \qquad \text{(eqn 1.32)}$$

$$P(2)/i(2) = B - (aD/B)\ . \qquad \text{(eqn 1.33)}$$

Therefore, we obtain the following ratios

$$P(2)/i(2) = V(1)/U(1) \quad \text{(eqn 1.34)}$$

Utilizing equations 1.6, 1.8 and 1.24 results in

$$Z = P(2)/U(1) = S(1)/M(1) \quad \text{(eqn 1.35)}$$

Therefore, Z represents the acoustical transfer impedance (units = gm/cm^4-sec) relating the acoustic pressure at the microphone to the volume velocity at the speaker.

3. Reciprocity Calibration

With the parameter Z now defined by equation 1.35 it is possible to use equation 1.27 to determine our ideal transducer sensitivities. The parameter Z takes on a variety of forms depending on the geometry of the resonator [Ref. 4]. For the plane-wave resonator of figure 1.3 equation 1.27 becomes

$$Mo = [V(m)/(i(s)\ Z)]^{1/2} \quad \text{(eqn 1.36)}$$

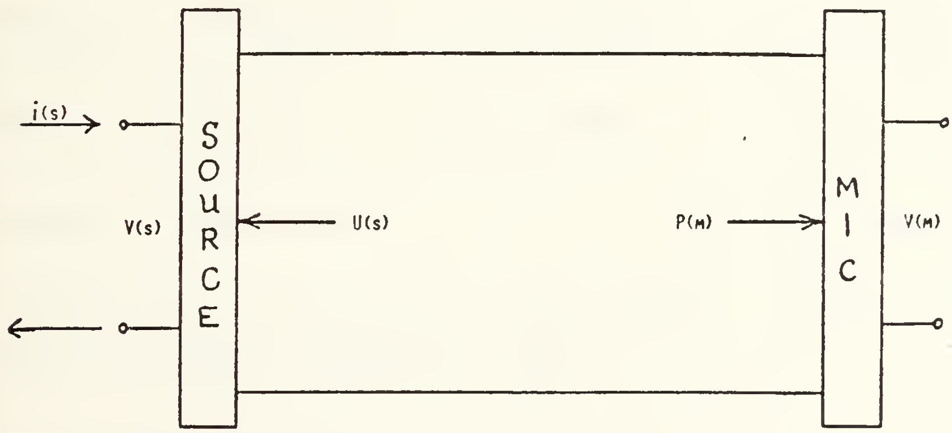

Figure 1.3 Plane-wave Resonator.

TABLE I

Notation for Determining Z

variable	meaning
A	cross-sectional area
C	sound speed
E	energy
f	frequency of n-th mode
ρ	medium density
L	resonator length
n	mode number
P	pressure (rms)
Q	quality factor
V	velocity (rms)

The determination of the acoustical transfer impedance Z for our resonator, using the notation of Table I, is as follows:

$$E(\text{stored}) = \langle KE(\max) \rangle = 1/2\ (\rho A L V^2) \qquad \text{(eqn 1.37)}$$

and since $P = \rho CV$ and $L = nC/2f$ then,

$$E(\text{stored}) = (nAP^2/4\rho Cf) \qquad \text{(eqn 1.38)}$$

and since power radiated is the product of the in-phase pressure and volume velocity, then

$$E(\text{lost/cycle}) = PU/f\ . \qquad \text{(eqn 1.39)}$$

By definition [Ref. 7],

$$Q = 2\pi E(\text{stored})/E(\text{lost per cycle}) \qquad \text{(eqn 1.40)}$$

then we have

$$Q = (P/U)(An\pi/2\rho C) \; . \qquad \text{(eqn 1.41)}$$

Combining equations 1.35 and 1.41 yields [Ref. 4],

$$Z = (2\rho CQ)/(An\pi) \qquad \text{(eqn 1.42)}$$

By direct substitution of equation 1.42 into equation 1.27 we finally obtain a viable method of establishing the absolute sensitivities of our ideal transducers:

$$Mo = 10^{-7/2}[(V(m)'/i(s))(An\pi/2Q\rho C)]^{1/2} \qquad \text{(eqn 1.43)}$$

The factor $10^{-7/2}$ occurs if the electrical parameters are in units of volts and amps and the mechanical parameters are in cgs units.

So the acoustical transfer function Z can be determined using both measured values of Q and A as well as the a priori quantities ρ and C. Armed with this information, we can now use equation 1.43 to conduct a calibration of our transducers using the Reciprocity Theorem.

The reciprocity calibration requires two sets of measurements to be taken on the acoustical plane-wave resonator of Figure 1.4. The dimensions of the transducers T, S and M and the lateral dimensions of the resonator are small compared to the acoustic wavelength.

The actual resonator of our experiment consisted of a brass body and "slit" electret transducers. More will be said about our experimental resonator in chapter III.

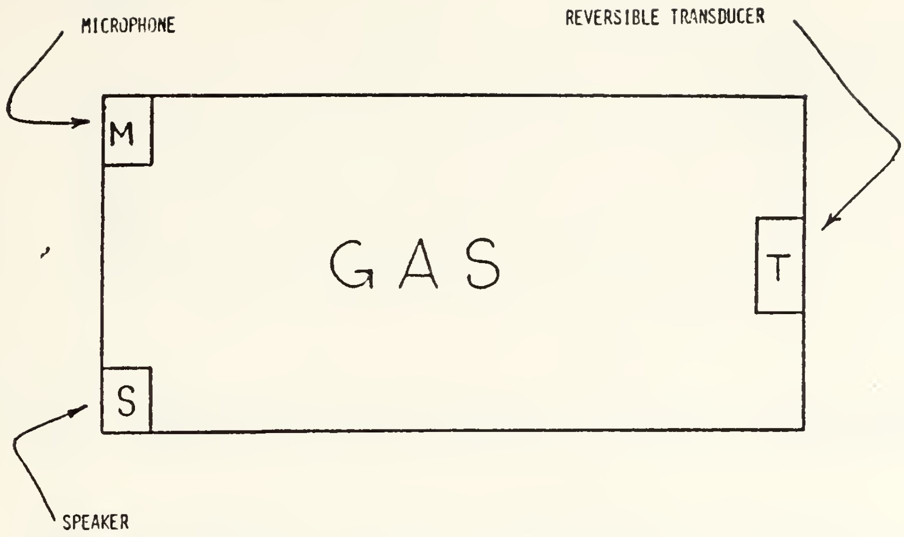

Figure 1.4 Plane-wave Resonator for Reciprocity Calibration.

For the first set of measurements, the reversible transducer T is driven at a resonant frequency of the chamber. The driving voltage V(1) and current I(1) are measured and again, as in equations 1.28 and 1.29, the system response is

$$V(1) = a\ i(1) + B\ U(1)$$

$$0 = B\ i(1) + D\ U(1)\ .$$

The open circuit voltage V(m) at receiver M, used here only as a microphone, is also recorded (refer to Figure 1.5). This voltage corresponds to the pressure P at the ends of the chamber. From equation 1.35 we know

$$P = Z\ U(1)\ . \qquad \text{(eqn 1.44)}$$

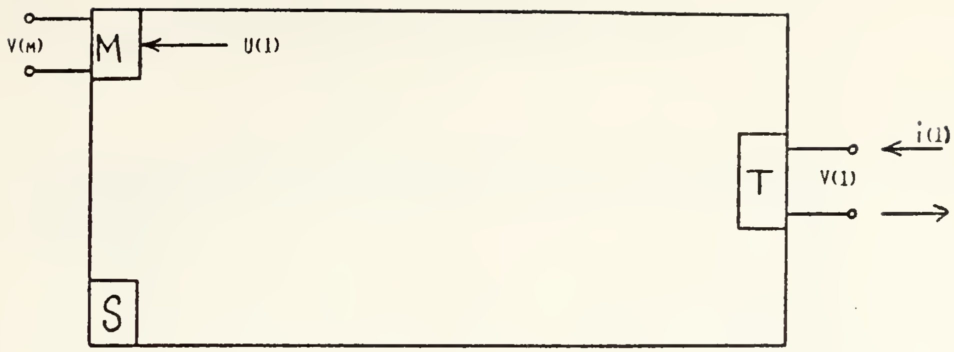

Figure 1.5 Reciprocity Calibration: first measurement set.

For the second set of measurements (refer to Figure 1.6) speaker S is driven with sufficient current i(s) to again produce V(m) at receiver M. This now ensures that the acoustic pressure P has been reproduced within the chamber. The short circuit current i(2) is measured first, giving us equations 1.30 and 1.31

$$0 = a\ i(2) + B\ U(2)$$

$$P = B\ i(2) + D\ U(2)\ .$$

Finally, the open circuit voltage V(2) is measured resulting in,

$$V(2) = B\ U(3) \qquad \text{(eqn 1.45)}$$

$$P = D\ U(3) \qquad \text{(eqn 1.46)}$$

where U(3) is the volume velocity which corresponds to the "open circuit" voltage at the receiver T.

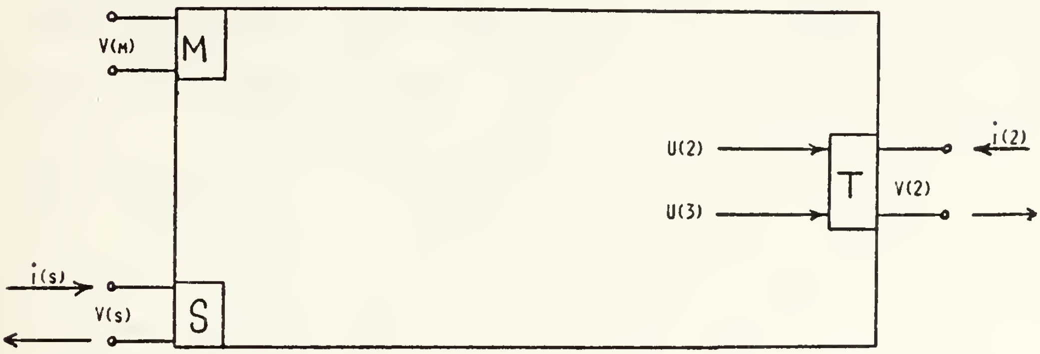

Figure 1.6 Reciprocity Calibration: second measurement set.

The above equations 1.28 to 1.31 and equations 1.44 to 1.46 form a set of seven simultaneous equations in the seven unknown quantities a, B, D, U(1), U(2), U(3), and P. The equations can be combined to yield the following expressions [Ref. 5] for P,

$$P^2 = |V(1)\ i(2)\ Z|$$

$$P^2 = |V(2)\ i(1)\ Z|\ .$$

Therefore, the sensitivities of microphone M and reversible transducer T are given by the following set of equations (Note that the reciprocity calibration has been accomplished without reference to a primary standard <u>and</u> with only easily obtainable electrical and geometric measurements),

$$Sens(M) = V(m)/P$$

$$Sens(T) = V(2)/P\ .$$

B. HISTORY OF SUPERFLUIDITY

Now for a fundamental look at our experimental medium liquid helium. Probably it's strangest characteristic is its apparent ability to remain in a liquid state, under its own vapor pressure, when temperature is reduced, and with an apparent preference to stay that way right on down to absolute zero. To produce the solid phase requires application of a high pressure, 25 atmospheres or more (Figure 1.7).

The reluctance of helium to solidify results from a combination of two factors: (1) the extremely weak van der Waals force between the atoms and (2) their low mass. The forces are weak because of the simplicity and symmetry of the helium atom with its closed shell of two electrons and the absence of dipole moments for its nucleus. The effect of the low mass is to ensure a high value of zero-point velocity. To see this, consider an atom in the liquid as a free particle located in a small "cage" formed by the adjacent atoms.

The total zero-point energy per mole of the lowest state is then [Ref. 8] $(Nh^2/8m)(4\pi/3V)^{2/3}$, where m is the mass of the atom, V is the molar volume of the cage, h is Planck's constant and N is Avogadro's number. At absolute zero the total energy of the liquid is just the sum of the potential and zero-point energies, and London's [Ref. 8] estimate for this zero-point energy (assumed to be the same for both solids and liquids) indicates that it is lowest at a molar volume of approximately $30cm^3$. London then showed that at such a volume liquid helium has a lower energy then it does as a solid; therefore, it is in a stable form as a liquid at absolute zero.

Helium has the lowest boiling point of all known substances. For He^4 it is 4.2 ^oK at STP. Between this temperature and 2.172 ^oK this liquid behaves like an

ordinary fluid. But as the temperature is lowered it transforms into a second fluid phase which exhibits very different dynamical properties.

During early experimentation it was found that a plot of the specific heat of liquid helium versus temperature indicated a sudden discontinuity at a temperature of about $T_\lambda = 2.17\ ^oK$. This temperature is often called the lambda temperature due to the similarity of the shape of the specific heat curve to the Greek letter "lambda". There is an abrupt change in all the properties of liquid helium at the lambda-point. This change is known as the lambda transition. A very important point to be brought out at this time is that the region above the lambda-point is referred to as helium I (He I) and the region below as helium II (He II).

The difference in behavior is visibly apparent when observing a dewar vessel of liquid He^4 which is cooled through the lambda-point by boiling under reduced pressure. In the He I region, the liquid is greatly agitated by bubbles of vapor which form throughout the liquid and eagerly escape the surface. Yet, immediately as the lambda-point is passed, the liquid becomes extremely calm and no more bubbles are formed. Below the transition temperature the liquid <u>refuses</u> to boil. As pointed out earlier, liquid helium has many unusual properties, one of which is a very high thermal conductivity and this is the cause for the absence of boiling below the lambda-point. If a bubble forms below the surface of the liquid, the pressure inside the bubble must be greater than the vapor pressure above the surface by an amount equal to the hydrostatic pressure head plus the surface tension pressure. Vapor at this increased pressure cannot be formed from the liquid unless the temperature of the fluid below the surface is higher than the temperature at the surface.

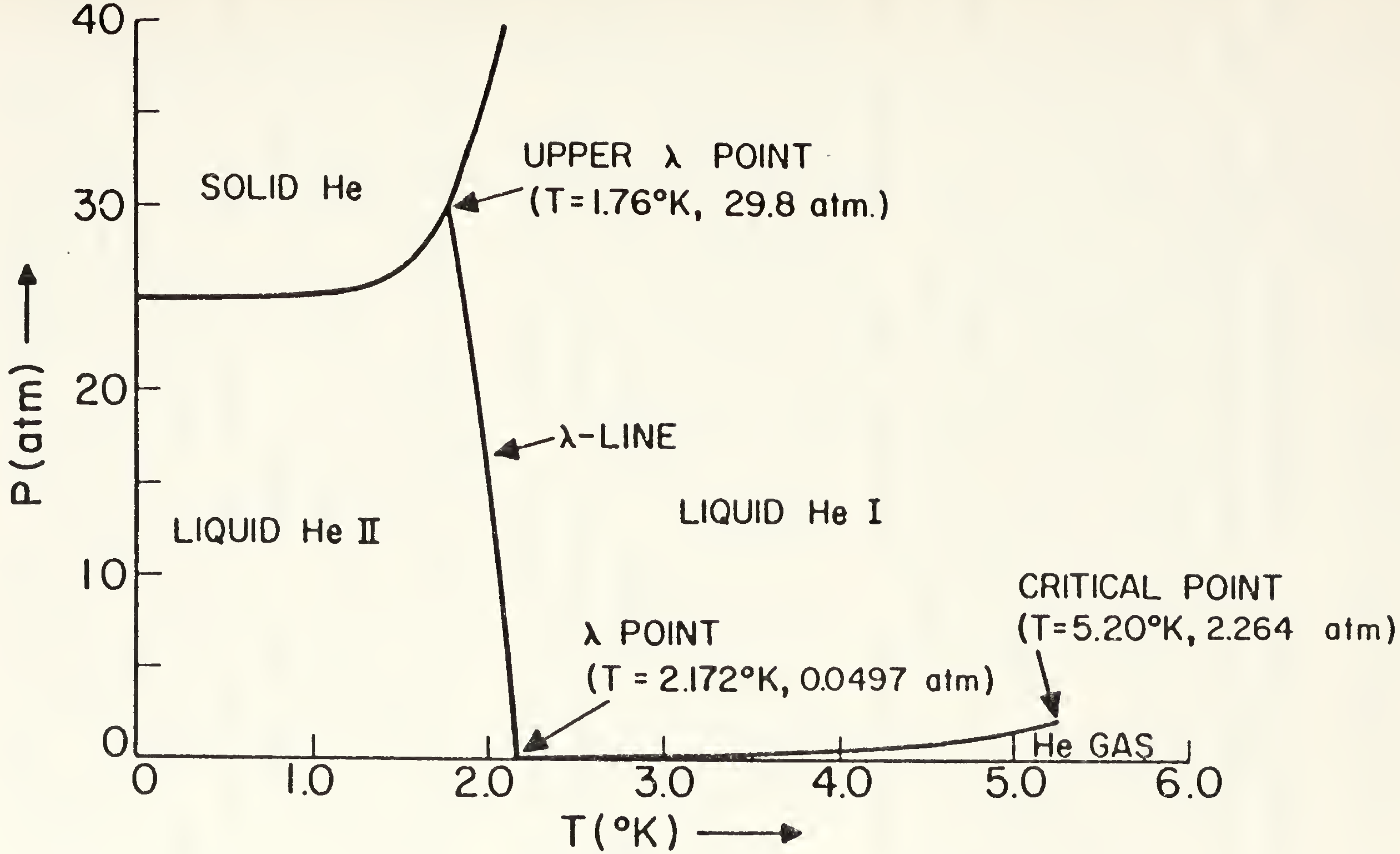

Figure 1.7 Phase Diagram of He^4.

The thermal conductivity of He II is so large that such a temperature gradient cannot be set up, and so the boiling (agitation) is prevented and all of the evaporation takes place at the surface.

That something strange happens to liquid helium below this lambda temperature was also noticed by Kamerlingh Onnes as early as 1911 [Ref. 9]. He found that when the liquid was cooled below this mysterious temperature it starts expanding instead of continuing to contract, thus deviating from the behavior of most substances. Almost 30 years later Allen and Misener [Ref. 10] and Kapitza [Ref. 11] found that at these low temperatures liquid helium could flow through narrow capillaries (about 10^{-4}cm in diameter) with no measureable resistance. This observation led Kapitza to refer to the liquid as a "superfluid".

Superfluid seems an appropriate name for this unique substance since measurements of flow have been made of He II passing through very fine cracks and extremely narrow slits and capillaries, which for normal liquids are, in effect, impassable. Liquid helium can overcome such obstacles freely even without requiring a noticeable pressure difference, and, strangely enough, it seems to leave its entropy behind.

The superfluid flow phenomenon leads one to question the viscosity of He II. Measurements by Keesom and Ende [Ref. 12] of flow through the aforementioned capillaries seem to indicate that the viscosity of He II is 10^6 times less than that of He I; however, measurements of the viscosity by Keeson and MacWood [Ref. 13] using the rotating disk showed that the viscosity of liquid helium <u>below</u> the lambda-point, although it decreased with decreasing temperature quite considerably, nevertheless varies continuously and is certainly not very different from the viscosity of He I. When Allen/Misener and Kapitza reported their

measurements based on the capillary flow method, it showed the viscosity of liquid helium dropping by many orders of magnitude to an immeasureably small value when the temperature was lowered through the lambda-point. The apparent contradiction between Keesom/MacWood and Allen/Misener and Kapitza is really no contradiction. The former was merely observing the effects of the "normal fluid" component of the helium solution while the latter was observing the affects of the "superfluid" component. This two fluid concept will be discussed in the next section.

Although liquid helium has been used in experimental laboratories for many years as a refrigerant, its unique behavior and unusual properties were not realized until the early 1930's.

One of the most unusal features of He II is that variations of temperature propagate through the liquid not according to the usual Fourier equation, but as a true wave motion whose velocity is independent of the frequency. These temperature waves are entirely analogous to ordinary sound waves, except that the thermodynamic variables are temperature and entropy and not pressure and density. Therefore we can excite temperature waves with a heater in a resonance tube, and pickup standing waves using a thermometer as a detector. This very unusual type of heat propagation is known as second sound [Ref. 14].

A very strange phenomenon was discovered in 1938 by Allen and Jones [Ref. 15]. They were interested in helium conductivity measurements and what they observed was truely unexpected. The experiment consisted of a reservoir and a smaller vessel, both filled with liquid helium and connected by a very fine capillary. The set up is shown in Figure 1.8.

When heat was applied to the inner vessel, they observed that the inner helium level rose slightly above that of the reservoir.

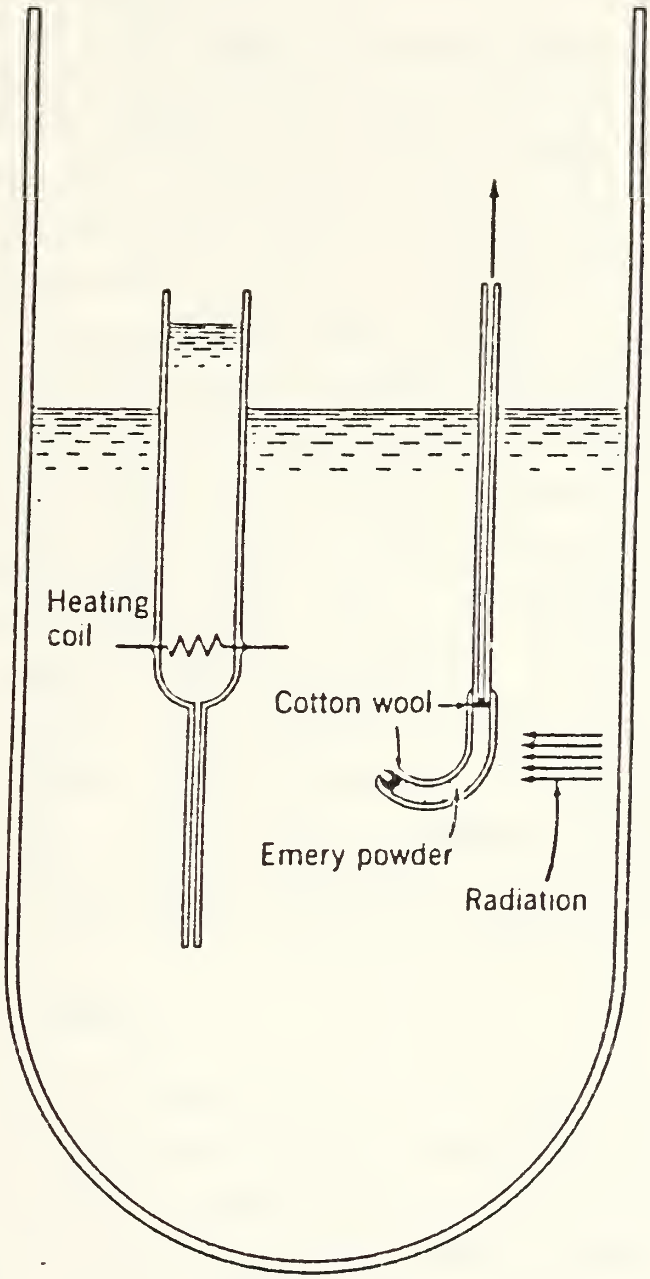

Figure 1.8 Fountain Effect.

In a subsequent experiment, using a narrower inner vessel, they observed a jet of liquid helium rising from the upper end of this narrow vessel to a height of several centimeters. This became known as the "fountain effect", or thermomechanical effect.

What Allen and Jones demonstrated is that you cannot trust intuition to predict the behavior of liquid helium. In the fountain effect, contrary to expectations, the heat current goes in a direction just opposite to the helium current. It would seem that in liquid helium, heat and mass transfer are strongly joined. The inverse of this fountain effect, or the mechanocaloric effect, predicted by Tisza [Ref. 16] and discovered by Daunt and Mendelssohn [Ref. 17], consisted of allowing liquid helium to gravity flow out of its container through a capillary filled with a fine emery powder. As a result, the temperature of the liquid above the capillary rose while the temperature of the liquid helium below the capillary dropped. What this implies is that the liquid which passed through the capillary is different than the bulk liquid in the container from which it came. Again, this alludes to the existance of a two fluid behavior, where one is capable of passage through restricted areas while the other is not, and the thermal properties of these two components are very different.

C. TWO-FLUID MODEL

It should be pointed out at the onset that the phenomenological picture known as the "two-fluid model" is able to correlate the unusual properties of He II with the thermodynamic functions as long as the heat and mass currents are not too large. This requires that we deal with heat fluxes that are linearly proportional to the temperature gradients. Even in this linear region the heat flow is far greater than that observed in other substances.

As mentioned in the previous section, two methods were used to determine the viscosity of He II. One consisted of measuring the viscous resistance to flow (Keesom/Ende) and the other the viscous drag on a body moving in the liquid (Keesom and MacWood). These two methods produced two seemingly different results that would indicate He II is capable of being both viscous and non-viscous at the same time. This apparent contradiction is the basis of the two-fluid model, first suggested by Tisza [Ref. 16]. It is in terms of this model that many of the properties of He II can be explained.

The two-fluid model proposes that helium II behaves as if it were a mixture of two fluids freely intermingling with each other without any viscous interaction. The two parts are referred to as the normal fluid and superfluid components. This does not imply that it is a mixture of two real physical fluids. The liquid is an assembly of He^4 atoms which are all identical, so that it is not possible to regard some atoms as belonging to the normal fluid and the remainder to the superfluid.

The assumptions of the model are very important. Below the lambda-point liquid helium is capable of two different motions at the same time. Each of these has its own 'local' velocity denoted Vn and Vs respectively for the normal fluid and the superfluid. Furthermore, each has its own effective mass density, ρ_n and ρ_s. The total density ρ of the He II is therefore given by

$$\rho = \rho_n + \rho_s \qquad \text{(eqn 1.47)}$$

and the total current density by

$$\bar{J} = \rho_n \bar{V}_n + \rho_s \bar{V}_s \ . \qquad \text{(eqn 1.48)}$$

It is important to note that since the superfluid flow has no viscosity it therefore does not involve dissipation and is truly thermodynamically reversible. The normal fluid flow does have viscosity and undergoes dissipation, but only at a rate proportional to the gradient of its velocity according to Landau and Lifshitz [Ref. 14].

London [Ref. 18] always believed in the macroscopic nature of liquid helium. He drew attention to the fact that the behavior of liquid helium could at least be understood in terms of Bose-Einstein condensation. Simply stated, B-E condensation maintains that at a critical temperature (lambda-point for liquid helium) a macroscopic fraction of an ideal quantum gas's molecules condense into the same single partical quantum state (the ground state). This fraction is 100% at T= absolute zero and vanishes at the lambda- point temperature for liquid helium. London hypothesised that liquid helium could in fact fit the qualitative features of the B-E condensation mechanism, even though it is not an ideal gas, due to its discontinuity of character at the lambda-point. Tisza stated that the B-E condensed particles correspond to the superfluid component while the remaining excited particles correspond to the normal fluid. Furthermore, a single discrete momentum state would mean that there is no continuous reduction of momentum, which would imply zero viscosity. The normal component then carries all of the entropy and is expected to have a viscosity comparable to that of He I. The fraction of the fluid which is in the superfluid state, ρ_s / ρ, is expected to increase as the temperature is decreased.

It should be clear that this model contains an explanation of the viscosity paradox. In the capillary flow experiment only the superfluid is mobile so the liquid exhibits no viscosity. The damping of the rotating disk was due to the drag exerted by the normal component. The observed

decrease in the damping as the temperature decreased is attributed in part to the decrease in the amount of normal fluid available.

D. FIRST AND SECOND SOUND

That in liquid helium a new kind of wave propagation should be possible, was predicted by Tisza [Ref. 16]. He suggested that there should be the pressure wave of ordinary sound where the two components move in phase with each other. Additionally, there should be another wave in which the motion of the two components are 180 degrees out of phase. This second wave would be a compression wave of entropy accompanied by periodic flucuations of the temperature, and the mass density would remain almost constant. This new wave would have to be excited by periodic heating of the fluid and the consequence would be that entropy density and temperature could be the oscillatory parameters in a wave equation.

For ordinary sound the conservation of mass gives us

$$(\partial \rho/\partial t) + \mathrm{div}\ \bar{J} = 0 \qquad \text{(eqn 1.49)}$$

where $\bar{J}$ is the center of mass momentum (equation 1.48), and from the linearize-inviscid Euler equation of hydrodynamics

$$(\partial \bar{J}/\partial t) + \mathrm{grad}\ P = 0 \ . \qquad \text{(eqn 1.50)}$$

Eliminating $\bar{J}$ leads to

$$(\partial^2 \rho/\partial t^2) - \nabla^2 P = 0 \qquad \text{(eqn 1.51)}$$

and for adiabatic processes,

$$(\partial^2 \rho/\partial t^2) - (\partial P/\partial \rho)_s \nabla^2 P = 0 \ .$$

This is the ordinary sound equation, a wave equation for mass density or pressure wave, where

$$U(I)^2 = (dP/d\rho)_S \qquad \text{(eqn 1.52)}$$

is the square of the ordinary sound velocity.

For the development of the wave equation for thermal waves we follow the derivation of Gogate and Pathak [Ref. 19] but still neglect non-linear terms and confine ourselves once again to the reversible process. Starting with the equation for the conservation of entropy

$$(\partial\rho S/\partial t) + \mathrm{div}(\rho S\ \bar{V}_n) = 0 \qquad \text{(eqn 1.53)}$$

which explicitly contains the assumption that the entropy flow follows the normal fluid.

The kinetic energy density of this two-fluid system can be expressed as

$$E = (1/2)(\rho_n \bar{V}_n^2 + \rho_s \bar{V}_s^2) \qquad \text{(eqn 1.54)}$$

$$E = (1/2\rho)(\rho_n \bar{V}_n + \rho_s \bar{V}_s)^2 + E'' \qquad \text{(eqn 1.55)}$$

where $E'' = (\rho_n \rho_s/2\rho)(\bar{V}_s - \bar{V}_n)^2$.

The term E" is called the kinetic energy of internal convection while the first term is considered to be the kinetic energy of the actual mass transfer.

If work is done reversibly by transferring the heat (Q) from temperature T to (T-dT), the second law of thermodynamics requires that work (W) be expressed as

$$W = (QdT)/T .$$

Considering a thin layer of helium of thickness dx in which the temperature varies by dT, the heat current becomes

$$q = \rho S T \bar{V}_n \qquad \text{(eqn 1.56)}$$

and is assumed to propagate perpendicularly through the layer. It carries the heat (qdt) through a square centimeter of the layer in a finite time (dt). As stated earlier, this process must be reversible, therefore the work

$$q(dt)(dT/T) = \rho S \cdot \bar{V}_n \, dT \, (dt)$$

has to be done. Tisza proposed that this work would be required to change the kinetic energy of internal convection (E") per unit area of the layer of thickness dx:

$$dE'' \cdot (dx) = -\rho S \bar{V}_n \, dT \, (dt) \qquad \text{(eqn 1.57)}$$

or

$$dE''/dt = -\rho S (\bar{V}_n \cdot \text{grad } T) \, . \qquad \text{(eqn 1.58)}$$

Due to the fact that the thermal expansion coefficient is so small we can say that for thermal oscillations

$$\bar{J} = \rho_n \bar{V}_n + \rho_s \bar{V}_s = 0 \qquad \text{(eqn 1.59)}$$

and

$$d\rho/dt = 0 \, , \qquad \text{(eqn 1.60)}$$

which yields

$$E'' = (\rho \rho_n / 2\rho_s) \bar{V}_n^2 . \qquad \text{(eqn 1.61)}$$

Substituting equation 1.61 into equation 1.58 we see that

$$(\rho \rho_n/\rho_s)\, \bar{V}_n \cdot (d\bar{V}_n/dt) = -\rho S(\bar{V}_n \cdot \text{grad } T) \qquad \text{(eqn 1.62)}$$

or

$$(d\bar{V}_n/dt) + (\rho_s/\rho_n)\, S \text{ grad } T = 0 . \qquad \text{(eqn 1.63)}$$

We consider terms like $\bar{V}_n$, grad T, grad S, dS/dt, etc., as small of first order, and neglect products of any two of these quantities. This allows us to eliminate $\bar{V}_n$ in equations 1.53 and 1.63 and get

$$(\partial^2 S/\partial t^2) - (\rho_s/\rho_n)\, S^2 \text{ div}(\text{grad } T) = 0 . \qquad \text{(eqn 1.64)}$$

When the process occurs at constant pressure then we are left with a very interesting equation which does have a familiar "form",

$$(Cp/T)(\partial^2 T/\partial t^2) - (\rho_s/\rho_n)\, S^2 \text{ div}(\text{grad } T) = 0. \qquad \text{(eqn 1.65)}$$

This is a wave equation for the temperature. The same equation also holds for the entropy (S). When we compare this equation to that for ordinary sound we are struck by the similarity in format. Therefore, we know that the propagation velocity for these thermal waves can be expressed as

$$U(II)^2 = (\rho_s/\rho_n)[S^2\, T/Cp] . \qquad \text{(eqn 1.66)}$$

E. OUTLINE OF EXPERIMENT

This experiment enables us to obtain the absolute sensitivities of thermal transducers, in situ. A cylindrical plane-wave resonator has been constructed which is closed at either end by capacitive porous diaphragm transducers [Ref. 20]. In addition, one end also has an acoustically transparent "spiral web" electrical heater (thermophone) and the other end has a low mass carbon composition electrical resistance thermometer. A figure of the resonator, and its components, is shown below.

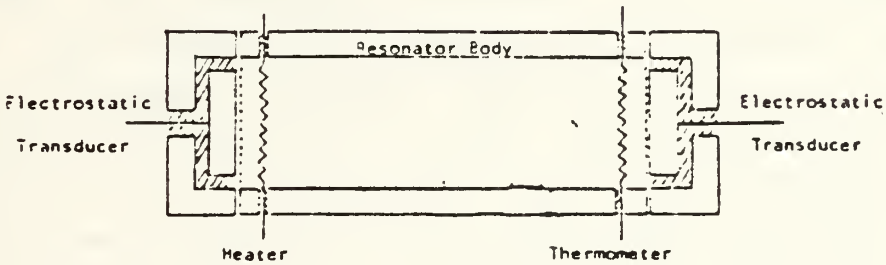

Figure 1.9 Schematic of Experimental Resonator.

At a variety of temperatures the following procedure was used to calibrate one of the three reversible transducers (two electrostatic, one resistive). The transducer to be calibrated (designated R for reversible) will be driven at resonance with current I and used as a speaker. One of the other two reversible transducers will be used as a microphone (M) to determine the resonant frequency f(n) and Q(n) of the n-th plane-wave resonance. Then, while monitoring the output of M, a third transducer will be driven at f(n) until the output of M is again the same value observed when R was being used as the source. In this way the sound field has been recreated. The open circuit voltage of R will then be recorded.

This will be sufficient to determine the sensitivity of R at f(n) from the reciprocity relation and known thermodynamic parameters [Ref. 21]. A comparison of the output voltages of the other two reversible transducers to the now calibrated third transducer will determine their sensitivity. It is then possible to repeat the reciprocity sequence using one of the other reversible transducers and in that way make a "round robin" consistency check. This was done at a variety of temperatures for several plane-wave resonance modes.

To determine whether the reciprocity results are both consistent and absolutely correct, it is necessary to compare the calibrations obtained by the above procedure against a "primary" standard. This is done in two ways:

(1) Knowing the electrical power being generated in the heater and the resonance Q, the theory of superfluidity allows us to calculate the second sound amplitude in the resonator [Ref. 22] if we assume all of the heating (at twice the frequency of the driving current) results in the generation of second sound. Although most of the oscillating energy appears as second sound, a small fraction will leak out along the electrical leads and therefore the sound amplitude obtained in this way will be an upper bound.

(2) The carbon resistor, biased with a constant current source I(b), will generate an oscillating voltage of amplitude

$$\delta V = (dR/dT)\, \delta T \; I(b),$$

where δT is the amplitude of the temperature oscillations generated by the second sound resonance [Ref. 23]. Since (dR/dT) can be determined in a static calibration, the finite frequency effects due to the thermometer heat capacity and thermal conductance and Kapitza resistance will make the sound amplitude measured in this way a lower bound.

The sensitivities of the above transducers are expected to fall within the upper and lower bounds if the reciprocity method is correct. We will show in chapters IV and V that these bounds form a fairly close ceiling and floor limitation on these sensitivities.

II. THEORY

A. INTRODUCTION

The principle of reciprocity was first introduced into acoustics by Rayleigh in 1873 when he derived the reciprocity relation for a system of linear equations and gave "a few examples [to] promote the comprehension of a theorem which, on account of its extreme generality, may appear vague" [Ref. 6]. He cited physical examples in acoustics, optics and electricity and credited Helmholtz with a derivation of the result in a uniform, inviscid fluid in which is immersed any number of rigid, fixed solids, pointing out that the principle "will not be interfered with" even in the presence of damping. The first physical example of the reciprocity theorem given by Rayleigh, and the most relevant for the discussion of the calibration of microphones, is the following:

> Let A and B be two parts of a uniform or variable stretched string. If a periodic transverse force acts at A, the same vibration will be produced at B as would have ensued at A had the force acted at B.

This technique has been central to the developement of acoustical science [Ref. 24]. As previously pointed out in Chapter I(A) the work by Maclean and Cook [Ref. 1] [Ref. 2] has been instrumental in the determination of absolute sensitivities of electroacoustic transducers.

Until fairly recently, the vast majority of the applications of the reciprocity method have been restricted to two standard geometries [Ref. 25] : The far field of a spherically radiating point source, and a pressure coupler whose

dimensions are small compared to the wavelength of the sound involved. In 1978 Rudnick [Ref. 4] demonstrated that the acoustical transfer impedance provided the necessary calibration constant and calculated the reciprocity relation for calibration in plane-wave and Helmholtz resonators. The validity of the expression in a plane-wave resonator has been demonstrated experimentally [Ref. 5] [Ref. 26].

Recall from chapter I(B) that thermal waves, initiated by variations in temperature and entropy, propagate within He II. This was referred to as second sound [Ref. 14].

The purpose of this section is to extend the technique, long recognized as the method of choice for absolute calibration of acoustic transducers, to reversible, linear, second sound transducers, and thereby provide a method for precise, absolute measurement of temperature oscillations in superfluid helium without use of a primary standard.

B. ACOUSTIC TRANSFER IMPEDANCE

Recall from chapter I(A.2), equation 1.35, that

$$Z = S/M = \text{constant.}$$

Also, the absolute sensitivity can be found by equation 1.36

$$Mo = [V(2)/(I(1)\ Z)]^{1/2}$$

It then follows that

$$S = [V(2)\ Z/I(1)]^{1/2} \qquad \text{(eqn 2.1)}$$

In chapter I(A.2) it was stated by equation 1.35 that Z represents the acoustical transfer impedance. Then, referring to Figure 2.1,

$$Z = P(2)/U(1) \qquad \text{(eqn 2.2)}$$

where P(2) is the pressure at the face of transducer 2 caused by the volume velocity, U(1), generated by transducer 1.

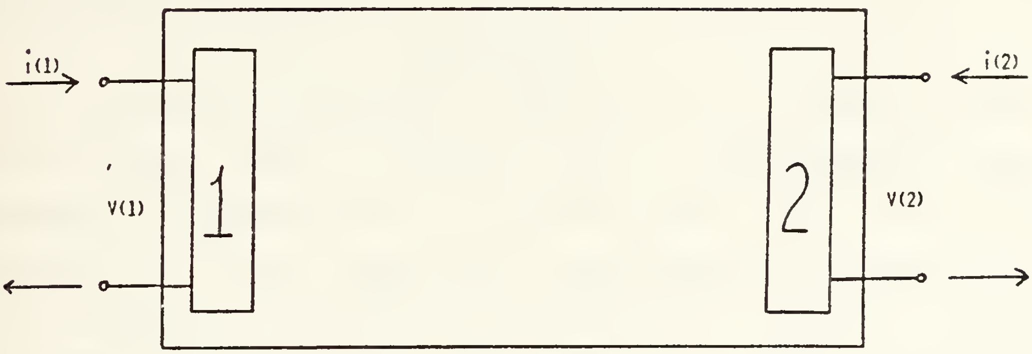

Figure 2.1 Reversible Transducers Coupled by Acoustic Medium.

The volume velocity is simply the mass flux divided by the mass density of the medium coupling the transducers, $\bar{J}/\rho$. This acoustical transfer impedance can, in principle, be calculated for any geometry. It is the ratio of the specific acoustic impedance of the medium, ρc, to a geometrical factor with the units of area. Here, c is the thermodynamic speed of sound in the medium.

For a spherically radiating source in free space [Ref. 1] this geometrical factor is $2r\lambda$, where λ is the wavelength of the sound and r is the separation of the acoustical centers of the source and receiver. For two transducers enclosed in a rigid walled enclosure [Ref. 4], all dimensions of which are much smaller than λ, the geometrical factor is $2\pi V/\lambda$, where V is the enclosure volume. For plane wave propagation in the rigid walled tube

[Ref. 27] of cross-sectional area A, the factor is simply A. Under resonant conditions, the geometrical factor will include the resonant quality factor, Q, and the mode number, n, if there is a spectrum of resonances. For a Helmholtz resonator [Ref. 4] the equivalent area is [$4\pi V/Q\lambda$]; for a plane-wave tube [Ref. 5] of cross-sectional area "A" the geometrical factor is

$$n\pi A/2Q(n).$$

We now know from the calibration procedure given in chapter I(E) that "round robin" measurements can be obtained to determine the sensitivity (M) and source strength (S) of the reversible transducers of Figure 1.9.

It should be noted that equations 1.52 and 1.66 make clear the symmetry which exists between pressure and density for first sound and temperature and entropy for second sound. It is this symmetry which will be exploited in the following section to create the expression which will permit reciprocity calibration of second sound transducers.

C. SECOND SOUND ACOUSTICAL TRANSFER IMPEDANCE

In the previous section (B) of this chapter, it was shown that the acoustical transfer impedance was required to be constant for reciprocity calibrations in classical fluids, and that quantity was the ratio of the pressure to the mass flux. To incorporate different geometries, this constant was written as a specific acoustic impedance divided by a geometric factor with the units of area. To write the expression necessary to perform the same type of absolute calibration of a reversible second sound transducer, one need only write the analogous expressions for sensitivity, M(2), source strength, S(2), and the transfer impedance, Z(2), appropriate to second sound.

As second sound is a temperature-entropy disturbance, the logical definitions for sensitivity and source strength are

M(2) = xducer open ckt volts/ δT at surface

S(2) = δT at mic location / driver current

or their conjugate short circuit current sensitivity and voltage source strength. If heat flux rather than entropy flux is more practical, then S(2) can simply be multiplied by the ambient temperature, T(o).

As before, the Reciprocity Theorem requires that if the transducer is reversible and linear,

$$S(2)/M(2) = Z(2) = T(2)/\rho S\ V\ (1) \qquad \text{(eqn 2.3)}$$

where T(2) is the amplitude of temperature oscilations at the receiver created by an entropy flux (ρ S $V_n(1)$), generated by the transmitter.

The transfer impedance can be evaluated by expressing both the temperature oscillations and the normal fluid velocity in terms of the superfluid velocity. The necessary relations for second sound are given by Landau [Ref. 14]

$$T(2) = -U(II)\ V_s /S$$

$$\bar{V}_n = -(\rho_s/\rho_n)[1-(\beta\rho/\rho_n S)(U(I)^2U(II)^2/(U(I)^2-C(II)^2\}\ \bar{V}_s$$

$$\bar{V}_n = -(\rho_s/\rho_n)[1-\alpha]\ \bar{V}_s$$

where α represents the second term inside the brackets, Cp is the specific heat at constant pressure and β is the isobaric coefficient of thermal expansion. Substituting equation 2.3 yields

$$Z(2) = T(o)/[A\rho U(II)Cp(1-\alpha)]\ . \qquad \text{(eqn 2.4)}$$

For all temperatures between 1.0 °K and 2.17 °K, α is less than one percent. It is worth pointing out that this

result differs from that of other authors due to the choice of entropy flux as the conjugate to temperature. Atkins [Ref. 28] derives an equivalent result which differs by a factor of T(o) in the limit that $\beta = 0$ since he defines the characteristic impedance as the ratio of temperature to heat flux. Pellam [Ref. 29] chooses the less practical but equivalent definition of impedance as the ratio of "osmotic pressure" to counterflow velocity and again treats $\beta = 0$.

Using equation 2.4, we can now write the absolute sensitivity of a reversible and linear second sound transducer as

$$M(2) = M' \left[V(2) / (A\ I(1)) \right]^{1/2}$$

$$M' = \left[U(II)\ Cp(1-\alpha) / T(o) \right]^{1/2}$$

where 'A' is again some effective area which depends upon the acoustic geometry which couples the source and receiver as discussed in section (B) of this chapter. M' is the temperature dependent calibration constant.

It is worth pointing out that a previous attempt to derive this result [Ref. 30] has been shown to be incorrect [Ref. 31] because the resulting expression contained a transducer dependent quantity.

D. SECOND SOUND RECIPROCITY CALIBRATION CONSTANT

The calibration constant, M', has been evaluated using the UCLA second sound speed data [Ref. 32] and the derived hydrodynamics [Ref. 21] in Table II and Figure 2.2 for the saturated vapor pressure. The behavior of this constant in the region from 1.2 °K to 1.9°K has the experimentally convenient feature of being linear in temperature. The points in Figure 2.2 are the data of Table II. The straight line is a least square fit to the points between the temperatures 1.2 °K and 1.9 °K, given by

$$M'(T) = 2.176\ T - 1.775$$

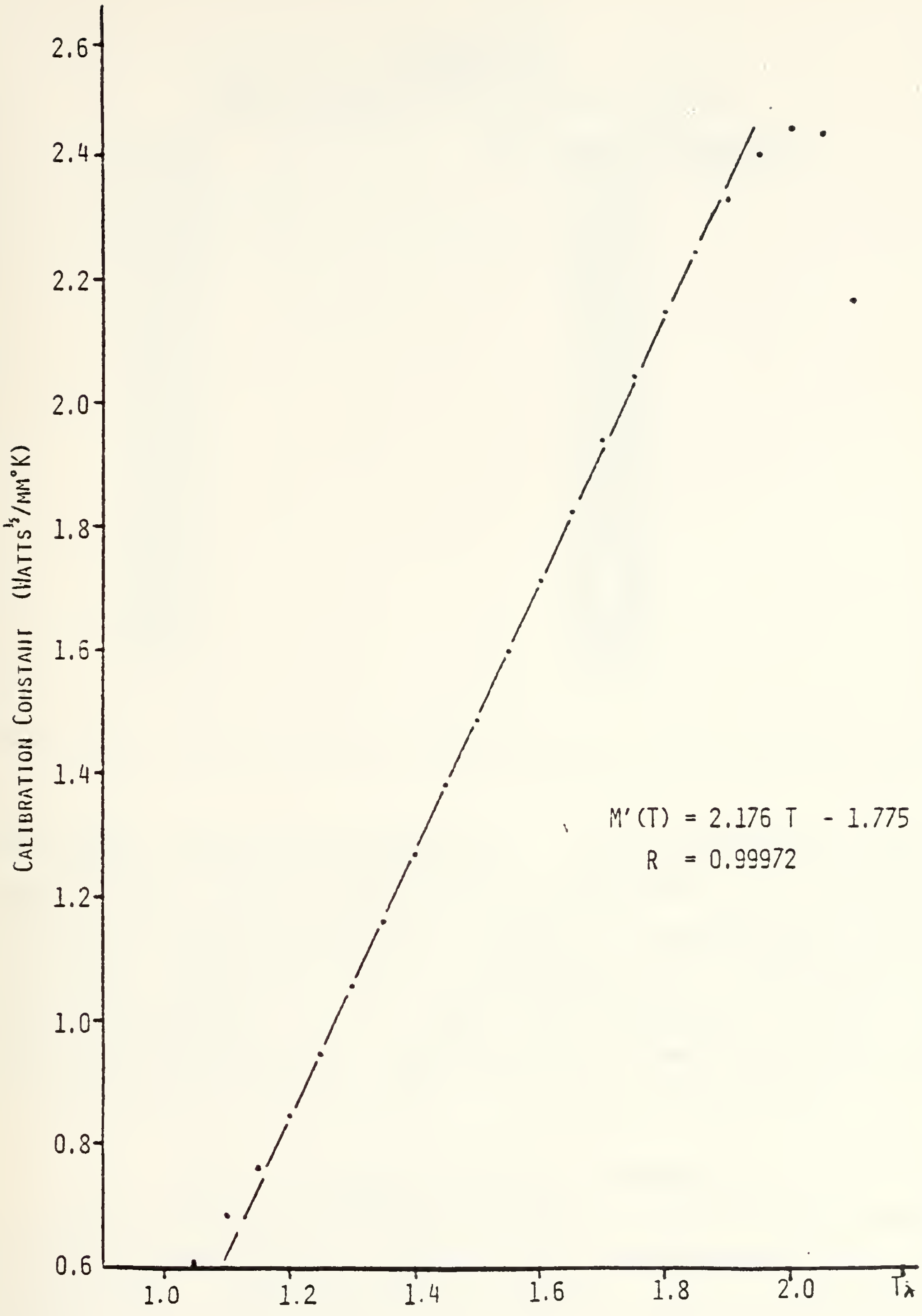

Figure 2.2 Second Sound Reciprocity Constant.

TABLE II

Second Sound Reciprocity Constant

T (°K)	M' [watts$^{1/2}$/mm-°K]
1.00	5.31
1.05	6.05
1.10	6.85
1.15	7.60
1.20	8.45
1.25	9.42
1.30	10.44
1.35	11.51
1.40	12.69
1.45	13.73
1.50	14.86
1.55	16.00
1.60	17.14
1.65	18.26
1.70	19.39
1.75	20.46
1.80	21.49
1.85	22.45
1.90	23.30
1.95	24.02
2.00	24.44
2.05	24.74
2.10	24.38
2.15	21.66

with units of [watts$^{1/2}$/(mm-°K)]. The correlation coefficient of the fit is 0.9997 which corresponds to a standard deviation of less than 0.7% over the 15 temperature points. The linear behavior can be understood as a consequence of the thermodynamics of an ideal Bose-Einstein gas and the "Tisza approximation". Neglecting the small correction due to the expression coefficient, $Z(2)^2$ can be written

$$Z(2)^2 = \rho^2(\rho_s/\rho)(\rho S/\rho_n)S \quad [\partial S/\partial T] .$$

For the ideal Bose-Einstein gas $S = 1.284(T/Tc)^{2/3}$ where Tc is the condensation (transition) temperature [Ref. 33], so $S(\partial S/\partial T)$ is proportional to T^2. If the entropy is carried only by the normal component and the entropy of the

normal component is assumed constant, then $S = \rho_n S_n$ and $(S\rho/\rho_n)$ is temperature independent. This is known as the Tisza approximation [Ref. 34], which is found to be correct above 1.2 °K. Although ρ_s/ρ is a strong function of temperature near the lambda-point, the square root of its value rapidly approaches one below 1.8 °K. The total density is very nearly temperature independent.

III. APPARATUS

A. CRYOSTAT

Figure 3.1 is a diagram of the dewar and associated support piping systems. The piping and tubing systems are primarily copper with silver brazed joints, although rubber vacuum tubing is used in small sections.

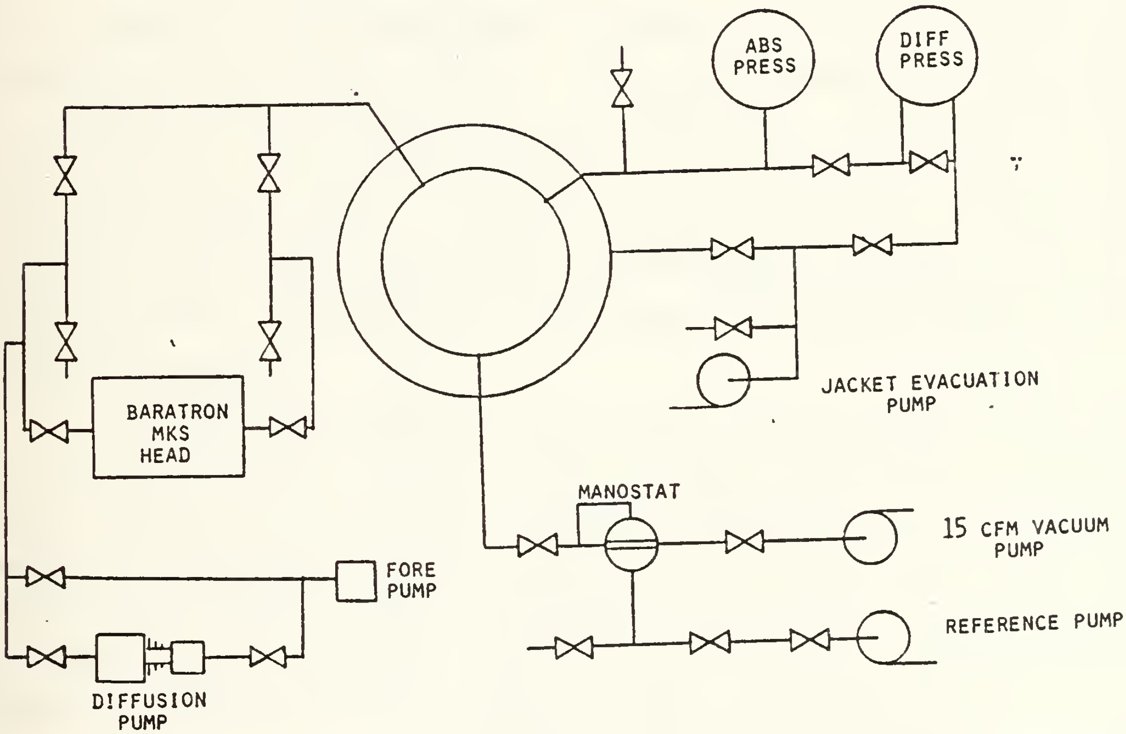

Figure 3.1 Dewar Support Piping Systems.

1. The Probe

The probe pictured in Figure 3.2 provides mechanical support for the experiment inside the dewar, electrical connections between the transducers and the room temperature electronics and a means of introducing liquid helium into the dewar.

The liquid helium fill tube is made in two sections. The first section is the portion that resides outside the dewar area in atmospheric conditions (Helium Recieving Tube). This section is an 8 inch (20.32 cm) long, 15 mil (0.038cm) wall and 0.662 inch (1.68 cm) outside diameter stainless steel tube. The second section is that portion inside the dewar. This section is 58 3/8 inches (148.27 cm) long, 9.8 mil (0.025 cm) wall and 1/2 inch (1.27 cm) out side diameter stainless steel tubing. The two sections are joined inside the top-plate. The difference in tubing size was necessitated in that the atmospheric section must be large enough and strong enough to accept and support the helium transfer tube, while the dewar portion of the fill tube has thin wall size which was choosen to reduce the heat leak (thermal conduction) from the top-plate which is at room temperature.

The dewar portion of the fill tube, which also acted as the main support tube, has 1/8 inch (0.32 cm) diameter holes placed approximately every 8 inches (20 cm) along its length to prevent Taconis oscillations [Ref. 35]. The fill tube has 4 heat shield assemblies that are attached to the central tube to reduce the heating of the helium due to Stefan-boltzman, σT^4, radiation from the top-plate which is at room temperature. At the bottom of the fill tube is a Bakelite plate which supports the experiment.

The top-plate is a 4 11/16 inch (11.9 cm) diameter, 1/8 inch (0.32 cm) thick brass plate.

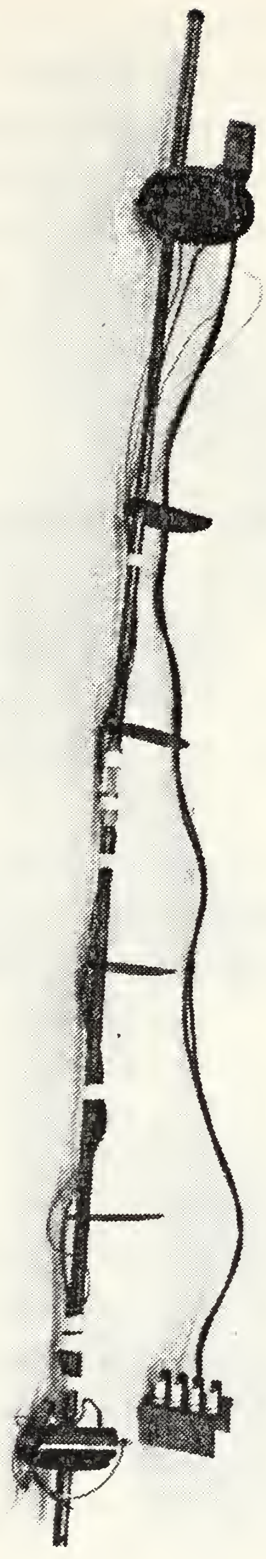

Figure 3.2   The Probe.

The top-plate provides support as well as providing the seal between the low pressure low temperature experimental area inside the dewar and the atmosheric conditions outside the dewar. The top-plate has the following penetrations:

(1) fill tube (helium recieving tube)

(2) hermetically sealed, dual BNC recepticle box which allows two way electronic communication between room temperature electronics and the two capacitive end plates of the resonator

(3) a BNC connection which provides a signal path to the resonator resistor

(4) a 1 inch (2.54 cm) high 9/16 inch (0.46 cm) outside diameter brass tube which contains 4 twisted pairs of wire which is passed through a hermetic seal in the tube.

The 4 twisted pairs are used for a 4 terminal connection to a calibrated resistor used for temperature monitoring during cooldown and the second sound drive heater in the experimental cell (resonator).

The heat conducted to the helium by the thin walled stainless steel tubing supporting the experiment was calculated by using the following information from Goodall [Ref. 36]. For a 10 cm length of stainless steel tubing of 1/2 inch (1.27 cm) O.D. with a wall thickness of 6 mils (0.002 cm), running from 300 °K to 4 °K, will conduct 184 mWatts of heat. As the distance from the helium surface to the top-plate was typically 110 cm, the central tube contributed a heat load of 27.9 mWatts.

The heat calculated for the 4 twisted pairs (8 wires total) of #32 gauge (Brown and Sharp) copper wire (164.5 cm/wire) was performed using the following data from Reference 40. A 10 cm piece of #34 British wire gauge with

a crossectional area of 0.429 X 10^{-3} cm^2, with one end at 300 ^oK and the other end at 4 ^oK, provides a heat leak of 65.2 mWatts. Multiplying by a crossectional area ratio between #34 gauge and #32 gauge wire and the number of wires and then dividing by the length ratio results in the twisted pair heat load of 23.7 mWatts.

The two coax cables, with crossectional area of 0.0065 cm^2 and length of 110.9 cm were modeled as thin walled stainless steel tubes since no heat load information for coax cabling was readily available and the contribution of the teflon insulation is insignificant. Again following Goodall [Ref. 36] the following calculation was made. A 10 cm long piece of 1/2 inch (1.27 cm) O.D. stainless steel tubing with a crossectional area of .0098 cm^2 running from 300 ^oK to 4 ^oK conducts 30 mWatts. Scaling the 30 mWatts by the crossectional area ratio divided by the length ratio times the number of coax cables yielded a heat leak of 3.6 mWatts.

The calculation of heat input (worst case) due to the contributions of the individual elements discussed above is summarized as follows:

THIN WALL TUBE	27.9 mWatts
TWISTED PAIRS	23.7 mWatts
COAX CABLE	3.6 mWatts

TOTAL	55.2 mWatts

A run was conducted on 27 October 1982 to determine an actual system heat leak. A plot of Helium Height (cm) verses Time (minutes) over a period of 400 minutes resulted in a slope of -11.6 X 10^{-3} cm/min with a correlation coefficient of 0.997. This slope was converted into a boil-off rate and multiplied by the latent heat of vaporization of

helium at 1.65 °K (L=3.27 Joules/cc) [Ref. 37] to yield experimentally calculated heat leak. For this case the leak is 51 mWatts, which is in excellent agreement with the previous analysis. This heat leak rate permitted 82.2 hours of run time and a minimum temperature of 1.4 °K using the 15 CFM pump assuming no energy input to the system. The fact that our worse case calculations exceeded the observed depletion rate, hence power input, indicates no significant unknown heat leaks exist within the dewar.

2. Dewar System

All experiments were performed in a glass double dewar system. The inner dewar is 4 inches (10.16 cm) inside diameter. The temperature of the helium bath is reduced by pumping away its vapor with a Kinney vacuum pump, Model KC-15. The connection between the pump and the dewar is by means of a 2 1/4 inch (5.7 cm) outside diameter pipe which tapers to a 1 1/2 inch (3.8 cm) outside diameter pipe. The 1 1/2 inch O.D. line has an isolation valve which isolates the pump from the dewar.

The helium bath temperature is determined by measuring the vapor pressure of the helium and converting it to temperature by Cubic Spline interpolation [Ref. 38] using tables based on the 1958 He temperature scale [Ref. 39]. The pressure is measured by a MKS Baratron, head type 370 H, with a 0-1000 mmHg range. An analog voltage output which is proportional to the pressure is sent to the computer controlled data aquisition system. The reference side of the differential head is backed by a diffusion pump so the pressure reading can be regarded as absolute.

A vacuum drop test of the dewar, covering a three day period resulted in the following:

(1) first 24 hour period leak rate was 0.154 mmHg/hr

(2) three day period leak rate was 0.120 mmHg/hr .

Since the volume of the inner dewar space is 12.15 liters this corresponds to a leak rate of 0.0048 standard cc/sec. This rate is sufficiently small to allow operation of the experiment for periods in excess of 50 hours. No icing of the inner dewar space was visible at any time.

3. Temperature Control (Pressure Control)

Temperature was controlled by controlling dewar pressure and thereby controlling the vapor pressure of the helium contained within. The pressure is controlled by the use of a manostat [Ref. 35]. The manostat is located in the dewar vacuum system between the 1 1/2 inch (3.8 cm) O.D. isolation valve and the dewar itself (see Fig 3.1).

The manostat shown in figure 3.3 is a 6 inch (15.24 cm) inside diameter 3 inch (7.62 cm) deep cylindrical aluminum vessel. The top is constructed out of 1/4 inch (0.635 cm) thick clear polyethylene. The manostat has four piping penetrations. Two are 1 1/8 inch (2.86 cm) O.D. which are used to place the manostat in the vacuum system between the vacuum isolation valve and the dewar. The penetrations protrude 1 1/2 inches (3.8 cm) into the vessel radially from opposite directions leaving a 3 inch (7.62 cm) gap between them. A condom (Shiek Reservoir End Sensi-Creme Lubricated) with the end cut off was placed over the ends of the two protrusions and is held on each end by an O-ring. This flexible membrane acts as an extremely sensitive control valve. The other two penetrations are 3/8 inch (0.95 cm) outside diameter. One connects to a reference flask and the other connects through an isolation valve to the dewar side vacuum line to sense dewar pressure.

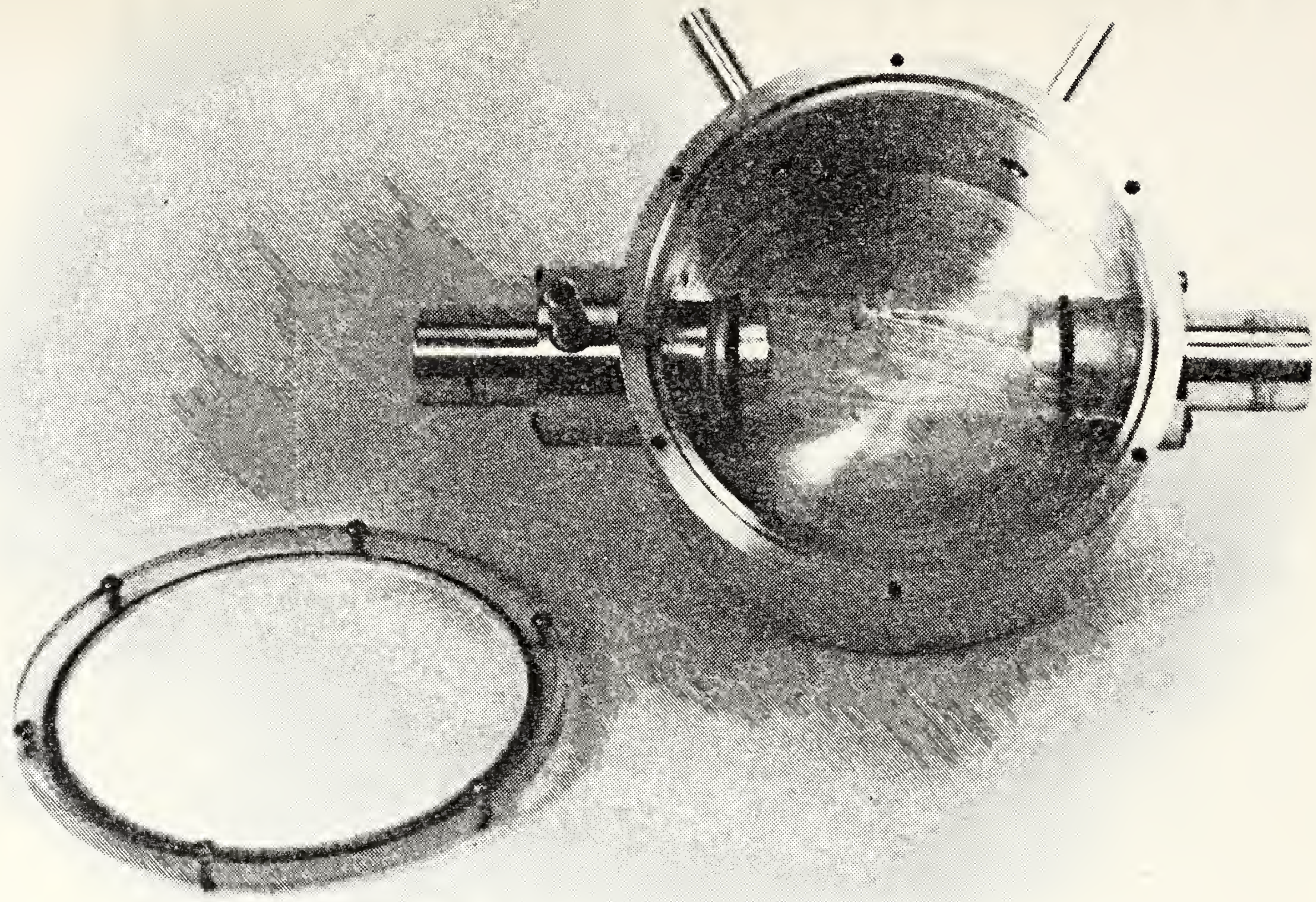

Figure 3.3 The Manostat.

With the isolation valve in the open position, the pressure inside and outside the membrane are equal, allowing the membrane to remain in an uncollapsed state. This permits the vacuum pump to continue to evacuate the dewar. When the desired pressure is reached (2.5-30.0 mmHg) the isolation valve is shut. The pressure in the dewar at the time the isolation valve is shut is the pressure felt and maintained on the outside of the membrane. The inside of the membrane is sensing present dewar pressure. If the dewar pressure drops below the desired pressure, the pressure inside the membrane drops below that maintained on the outside of the membrane causing it to collapse and thereby isolating the vacuum pump from the dewar. As the liquid helium evaporates and vapor pressure increase the pressure inside the membrane also increases. When the dewar pressure exceeds the pressure maintained on the outside of the membrane the condom begins to expand and once again opens a path between the vacumn pump and the dewar to allow the pressure to be decreased and thereby decrease the system temperature.

This manostat was found to be quite reliable and was able to maintain a constant pressure to within 0.025 mmHg over a one hour period. This relates to an approximate 0.004 degree Kelvin temperature change over the same time period in our temperature range of concern.

The choice of condom was found to be suprisingly important. Several different types and brands were used but the Shiek Sensi-Creme Lubricated was found to be most pressure sensitive and capable membrane for maintaining a desired pressure.

B. TRANSDUCTION

1. The Resonator

A cylindrical plane-wave resonator geometry was determined to be the best choice for testing second sound reciprocity calibration. The slow speed of second sound U(II) is less than 20 m/s and the consequent shortness of wavelengths limits the frequency range of a coupler to inconvenient dimensions. While restricting our experiment to a limited number of operating frequencies, at a given temperature, the plane-wave resonator guarantees a well defined geometry, plane wavefronts below cut-off for higher order modes [Ref. 40], and simplicity of design.

A schematic diagram of our resonator, previously illustrated in chapter I(E), is repeated here in Figure 3.4. A picture of the actual experimental resonator is shown in Figure 3.5.

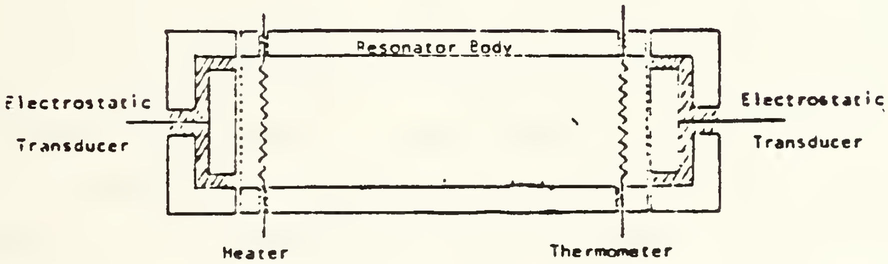

Figure 3.4 Schematic of Experimental Resonator.

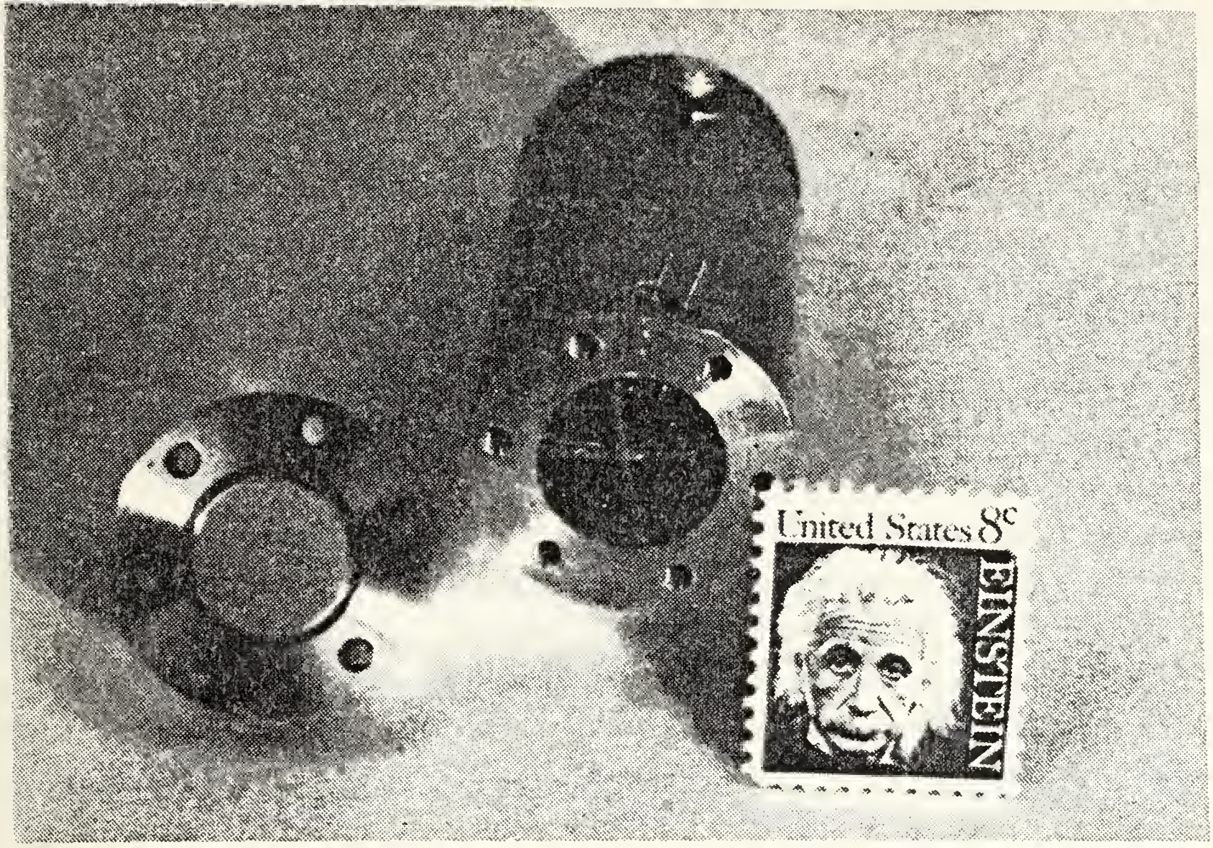

Figure 3.5 Experimental Resonator.

The resonator is made of brass (5.0 cm in length and 2.54 cm OD) and has been longitudinally bored (1.43 cm ID). The two cylindrical endcaps contain epoxy (slanted lines) insulated metal "buttons". When combined with transduction elements which incorporate electret technology [Ref. 41], they form two reversible, mechanical and electrostatic second sound transducers. Micro-dot connectors on each end provide an electrical interface to make positive electrical connection to the grounded endcaps and the electrically "hot" buttons. The button faces have been lightly sand-blasted to improve their sensitivity when they are used as the hot electrode in an electret microphone consisting of the button as a backplate and the electret as the pressure sensitive diaphragm. The endcaps contain a very narrow and shallow trough on their face which mates with the resonator body, thus providing a free flooding port for liquid helium to completely fill the experimental chamber.

The heater has been constructed from insulated #41 manganin wire. The wire (0.0057 cm diameter) was found to offer 51.66 Ω/ft using an HP-3456A multimeter with null. The wire was fashioned into an acoustically transparent "web". It is used to generate thermal waves (second sound). A picture of the heater is provided in Figure 3.5.

The thermometer has been fabricated from an Allen-Bradley carbon composition resistor (1/10 watt) which has been sanded to form a thin slab. This type resistor was chosen due to its high differential resistivity [d(ln R)/dT] in the 1-2 °K range. It can be calibrated against the vapor pressure curve [Ref. 39] and then used as a detector (microphone) of second sound. In a later section (Transducers: Thermometers) we discuss our attempt to improve on the Allen-Bradley thermometer and our motivation for improvement. A picture of our resistive thermometer is provided in Figure 3.6.

2. Transducers

a. Electret-type

In our resonator the pressure disturbances, as well as the counterflow of the super and normal components, are detected using the electret microphone [Ref. 42] which consists of an aluminized sheet of 1/2 mil (12.7 μm) thick FEP teflon laid on the endcaps with the aluminized surface away from the button. A large quasi-permanent charge density, σ, of the order of 10^{-7} coulomb/cm^2 [Ref. 43] is deposited in the aluminized teflon by placing it in an electric field. The membrane is polarized by placing it, aluminized side up, on a sheet of ordinary window glass and applying 12-18 KVDC across the aluminized surface and a conducting plate under the glass. The electric field is maintained for approximately 1-3 hours. Then the electret

Figure 3.6 Resistive Thermometer.

is removed from the glass and placed over the sandblasted electrode (button) to which it adheres due to electrostatic forces. Holes for the fastening screws, which tightly sandwich the endcap to the resonator body, and random slits, for passage of He II, are cut in the electret with a scalpel. This can be seen in the following figures which show pictures that were taken of our slit-electrets using an electron microscope. Figure 3.7 gives an overview of a typical electret showing the random number of arbitrarily placed slits. In Figure 3.8 it is possible to see the detail of the slits, especially noticeable is the jaggedness of the slits and the areas of apparent arcing that has occurred during testing. From such slit-electret resonators we were still able to consistantly obtain spectral diagrams which clearly showed multiple resonances, as illustrated in figure 3.9.

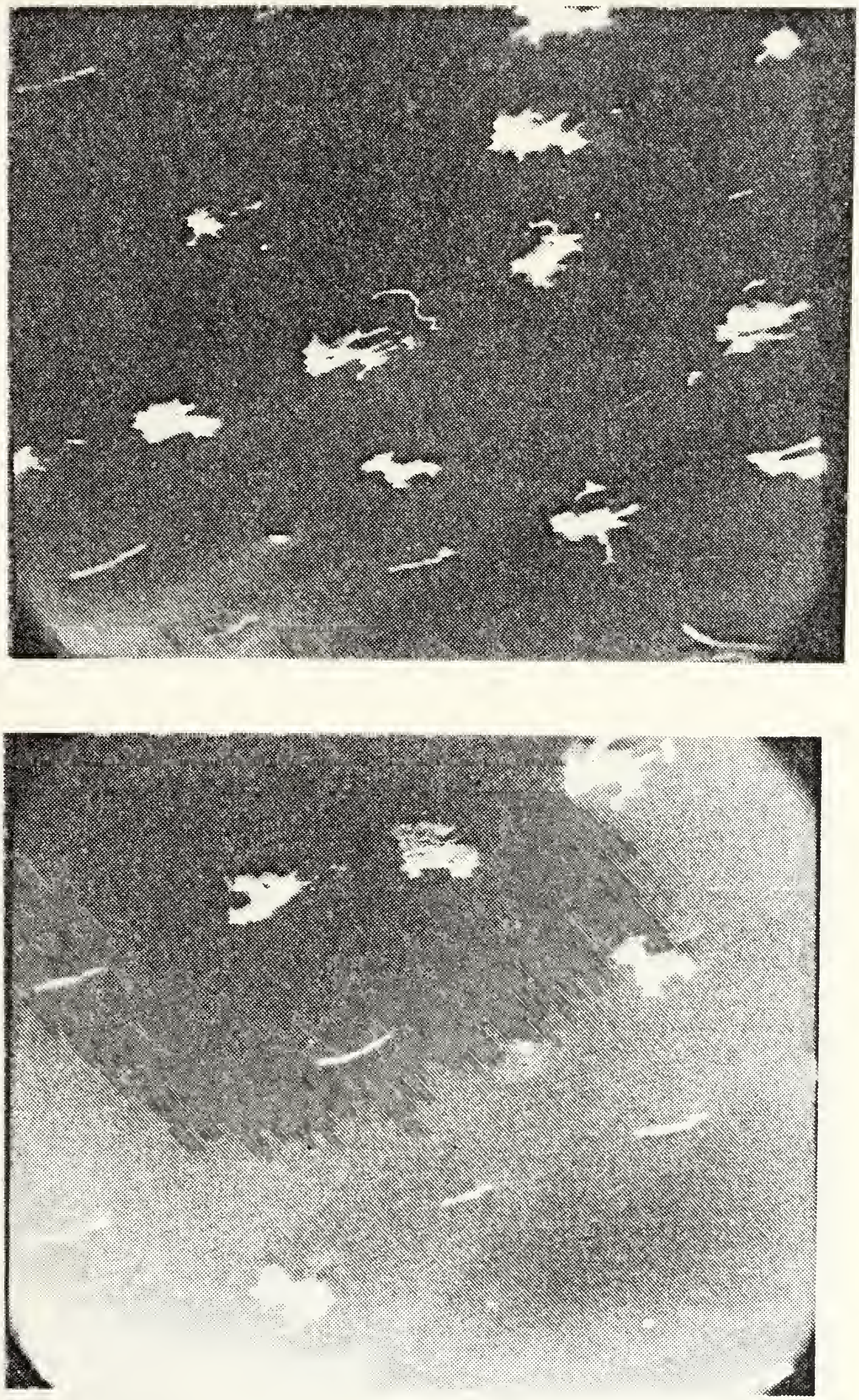

Figure 3.7   Overall View of Electrets (x20).

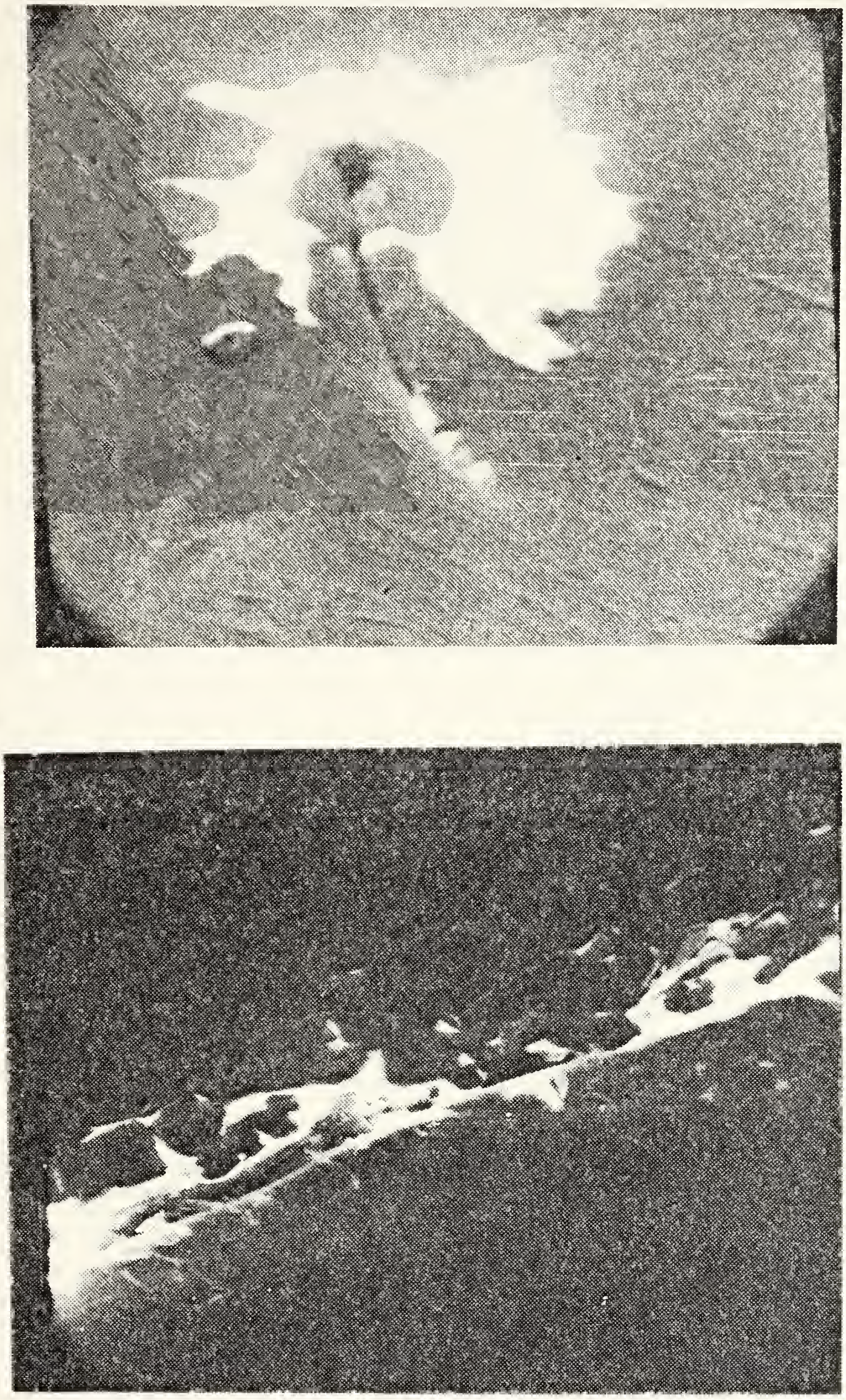

Figure 3.8 Close-up On Electret (x120) and Slit (x600).

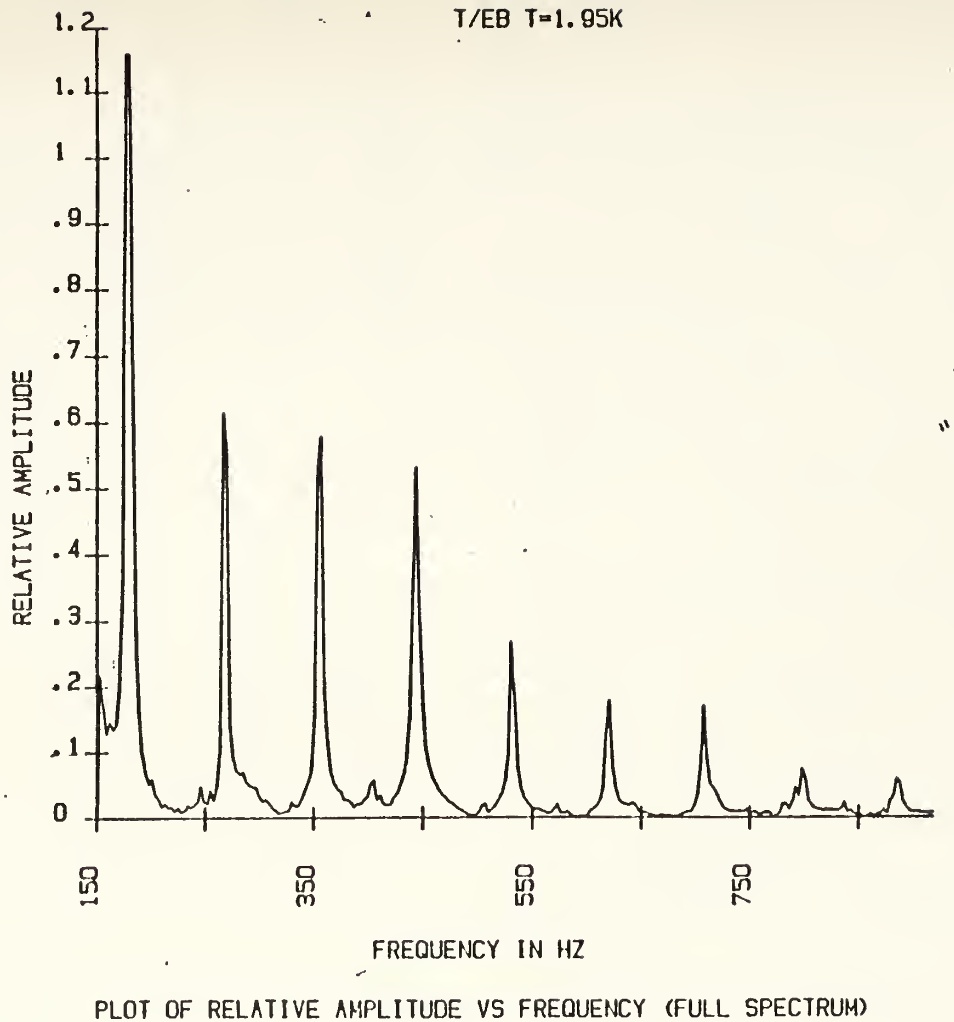

Figure 3.9 Typical Display of Multiple Resonant Modes.

When an oscillating voltage of frequency ω is applied between the electret and the button, the driver acts like an electrostatic speaker coupled directly into the resonator. Since the electret has a stored charge which has been found to have an equivalent bias voltage ranging from 150-210 volts [Ref. 44] the sound generated by the driver will also be at ω without an external biasing voltage.

Within the resonator, pressure and super/normal fluid component counterflow are detected using the electret device as a microphone. Therefore, a voltage is generated between ground (resonator body) and the button whenever there is an oscillation of the membrane. This causes the membrane to deviate from its equilibrium position and thereby changes the capacitance between the electrode and the aluminized surface. The charge on the electret is fixed and $Q = CV$, where $Q = \sigma A$ and A is the surface area of the button (almost 0.25 cm^2), C and V are the capacitance and equivalent voltage across the aluminized surface and the backplate. When the membrane is displaced by a small amount we can let

$$C = C(o) + \delta C(t) \qquad \text{(eqn 3.1)}$$

and

$$V = V(o) + \delta V(t) \qquad \text{(eqn 3.2)}$$

and

$$[\delta C(t)/C(o)] = [-\delta V(t)/V(o)] \qquad \text{(eqn 3.3)}$$

where V(t) is the time varying voltage generated by the membrane displacement and V(o) is the equivalent bias voltage across the transducer due to the stored charge density in the electret. As stated before, this equivalent bias voltage is approximately 150-210 volts for our typical electrets. This value was determined utilizing the circuit of figure 3.10.

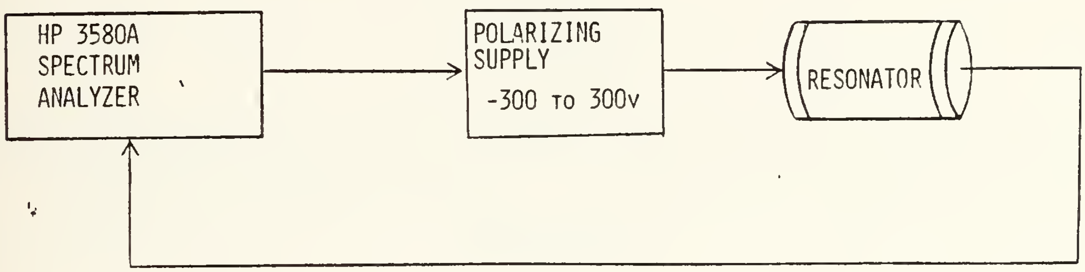

Figure 3.10 Determination of Electret Equivalent Bias Voltage.

While driving the electret of side A with the d.c.-bias voltage, the relative microphone (side B) response is monitored. After plotting the relative response as a function of the increased bias voltage, a linear extrapolation of the relative response to a "zero volt" condition yields, experimentally, the equivalent bias voltage, V(o), of the electret microphone (side B). Figure 3.11 shows some typical data taken at 293 °K. It is worth pointing out that this technique of measuring bias voltage worked equally well in helium or at room temperature.

During the experiment it was necessary to determine, to as high a degree of accuracy as possible, the capacitance of these electrostatic transducers. In addition

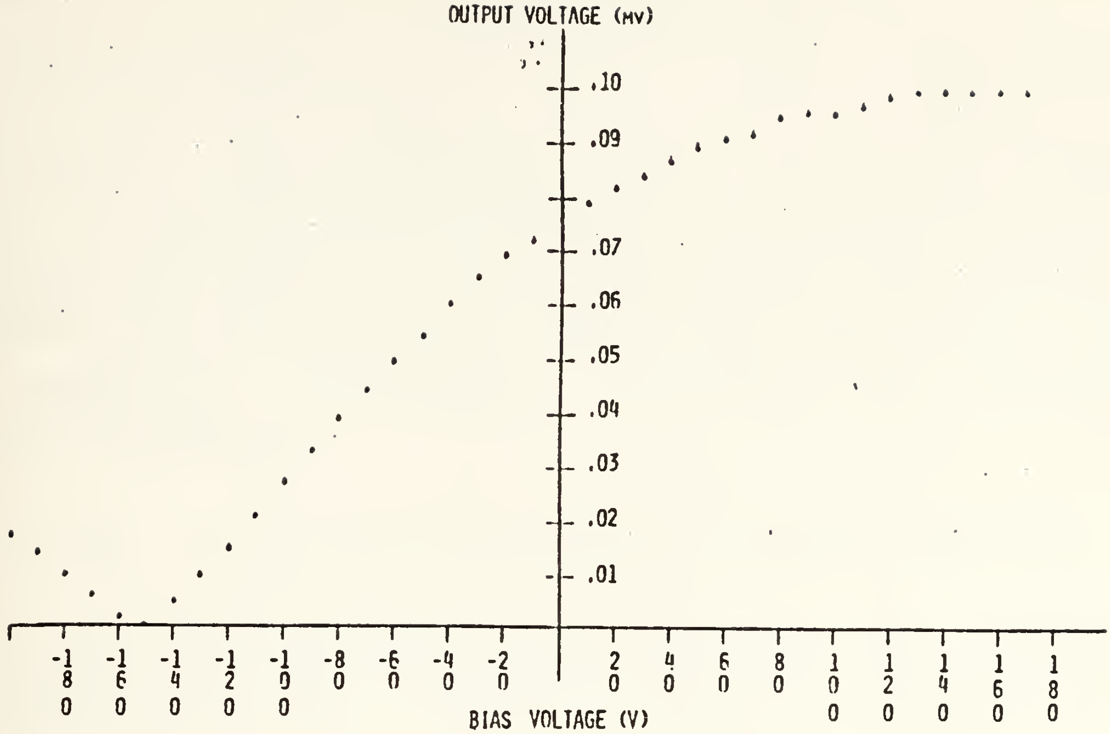

Figure 3.11 Back-bias Volts vs. Received Acoustic Signal.

to correcting for the inherent capacitances of peripheral equipment and leads, covered in a later section, it was also necessary to account for the dead capacitance of the endcap-button ensemble. This dead capacitance is the transducer's capacitance without the electret in place. For our electrets the average value of dead capacitance was found to be 12.7 $\pm$ 1.4 pf.

The process of driving an electret source (A) and picking up on an electret microphone (B) is denoted EA/EB. This process was used in the experiment to determine the <u>product</u> of sensitivities [M(A) M(B)] by the Reciprocity Theorem

$$M(A)\ M(B) = [V(m)/(i(s)\ Z)]$$

where

$$i(s) = V(s)(2\pi fC), \quad \text{(eqn 3.4)}$$

"f" being the resonant frequency and C the driver capacitance. The parameter Z, as previously mentioned, depends on the measured values of Q and A [area] as well as some thermodynamic quantities [specific heat, second sound speed, He II density and temperature]. Therefore, the resulting equation appears as

$$M(A)M(B) = [d^2\pi U(II)C_p\rho/16][V(m)n/(V(s)QfCT)] \quad \text{(eqn 3.5)}$$

where d is the experimental chamber diameter, and the other parameters have been previously defined. The units of equation 3.5 are (volts/ $^oK)^2$, as expected.

In order to obtain the absolute sensitivity of our individual electret transducers we need to conclude the reciprocity procedure. We will choose to drive thermally (heater) and pick up on electret. This is denoted T/EA or T/EB, depending on which electreted side is to play the role of the microphone. The results of this approach will be the ratio of the sensitivities.

We now take great care to drive the heater with a voltage V(i) that is necessary to produce an equivalent response from side B as obtained when electreted side A was being driven[2] (the choice of A or B is arbitrary).

After the input and output voltages are recorded, the output response of side A is recorded, while the heater drive remains the same.

---

[2]We have found that this is an unnecessary restriction since for typical drive voltages of interest to us, and within the power limitations of the heater, the transducers respond linearly.

This then gives us

$$M(A)/M(B) = [T/EA]/[T/EB] \qquad \text{(eqn 3.6)}$$

where for the values obtained from T/EA we get

$$T/EA = V(o)/V(i)^2. \qquad \text{(eqn 3.7)}$$

For the different set of values obtained for T/EB we get

$$T/EB = V(o)/V(i)^2. \qquad \text{(eqn 3.8)}$$

Therefore by equation 3.6,

$$M(A) = M(B)\,[T/EA]/[T/EB]\,. \qquad \text{(eqn 3.9)}$$

After substituting equation 3.9 into equation 3.5 we find that

$$M(A) = (\text{constant})[\text{available data}]^{1/2} \qquad \text{(eqn 3.10)}$$

and now M(B) can be determined from equation 3.9. As will be pointed out later, there is sufficient data to determine M(B) using equation 3.10 and M(A) can be measured by comparison (equation 3.6). This provided a self-consistancy check of our procedure.

b. Thermophone

The heater element is made from a 1.2 ft length of insulated manganin wire which has been folded in half and twisted. As previously stated this wire offers 51.6Ω/ft. The twisted wire was spirally-threaded through holes located in a mylar crossbar arrangement whose arms are only slightly shorter than the diameter of the resonator chamber. This is

to ensure a snug fit when the spiral heater is epoxied into place just within the chamber (recessed less than 2 mm) and literally cut of touch with the aluminized side of the electret transducer. Figure 3.6 shows the heater.

The heater is driven by a sinusoidally time-vaying voltage at half the frequency of the desired second sound. Since the heating is proportional to the square of the applied voltage the generated second sound is at twice the frequency of the applied voltage according to Pellam [Ref. 22]. That this is true can be seen from the trigoncmetric identity,

$$\cos^2(\omega t) = (1/2)[1 + \cos(2\omega t)], \qquad \text{(eqn 3.11)}$$

which shows that only half of the electrical signal delivered to the heater gces into creating second sound (at 2ω) and the other half goes into d.c. heating of the fluid.

In the previous discussion on electrets we were able to use the Reciprocity Theorem to calculate the absolute sensitivities of our transducers without the use of a primary standard and with only easily obtainable parameters. But how good are these sensitivities?

In order to determine whether these values are absolutely correct we must at least compare our calibrations against some standard. The thermophone principle can be used to set an upper limit for our calibration if we make the fcllowing assuption. Although only half of the signal delivered to the heater is instrumental in generating second sound, we calculate the temperature swing that would occur if **all of this power** that is available (at 2ω) goes into the production of seccnd sound. Pellam has shown us hcw to calculate the second sound amplitude; however, we know that there is always energy leakage at least along the electrical leads, and so calculations derived from this assumption are

surely upper limits for expected temperature swings necessary to produce a given output.

The derivation of the necessary equation to determine this temperature swing for the thermophone follows from previously stated relationships which will not be restated here. The electrical power that is available for the production of second sound will be equal to I^2R where I is the rms current supplied to our heater of resistance R. A reinforcement factor of $(2Q/n\pi)$, used for classical resonator systems (and used by Pellam for n=1), will be used to enhance the temperature oscillation amplitude due to resonance. If we define

$$\text{power/Area} = \rho S V_n T(o) \qquad \text{(eqn 3.12)}$$

$$V_n = -\rho_s V_s / \rho_n \qquad \text{(eqn 3.13)}$$

$$\text{Power/Area} = -\rho S\, T(o)\, \rho_s V_s / \rho_n \qquad \text{(eqn 3.14)}$$

therefore,

$$V_s = -(\text{Power})\, \rho_n / (\rho_s\, \rho\, S\, T(o)\, \text{Area}). \qquad \text{(eqn 3.15)}$$

From chapter II and according to Landau [Ref. 14],

$$\delta T = -U(II)\, V_s / S \qquad \text{(eqn 3.16)}$$

$$\delta T = U(II)\, [\, (\text{Power})\, \rho_n / (\text{Area}\, \rho_s\, \rho\, T(o)\, S^2)\,] \qquad \text{(eqn 3.17)}$$

the re-enforcement factor must also be included, therefore,

$$\delta T = [U(II)\ 2Q\ (\text{Power})\ (\rho_n/\rho_s)]/[\text{Area}\ S^2\ n\rho\pi T(o)]$$

but since the specific heat at constant pressure is

$$Cp = (\rho_s/\rho_n)\ T(o)\ S^2 / U(II)^2\ , \qquad \text{(eqn 3.18)}$$

then,

$$\delta T = 8Q\ V(i)^2/[R\rho\ \pi^2\ n\ d^2\ Cp\ U(II)\ sqr(2)] \qquad \text{(eqn 3.19)}$$

where V(i) is the rms voltage into the heater of resistance R, n is the modal number, and d is the chamber diameter. Therefore, with readily available data we are able to calculate, and thereby set, an upper bound for our reciprocity calculations made earlier.

c. Thermometry

Thermometry, like the thermophone, is a principle that will be used to again test our reciprocity calibration of thermal transducers within a quantum fluid. However, this time we will use our resistance thermometer to set a lower bound for a temperature swing producing a particular output.

The second sound generation (heater) and pick up by the carbon resistance thermometer is referred to as thermal-thermal and is denoted T/T. The thermometer was fabricated from an Allen-Bradley 1/10 watt resistor. It was sanded down until approximately 1mm thick in order to minimize its thermal inertia. The thermometer has been electrically interfaced with peripheral equipment by a micro-dot connector, thus making it modular, and fully shielded.

The principle employed in the resistance thermometer, for the detection of second sound, is that the resistance (R) is a function of temperature and if a constant current, I, passes through the resistor, then the changes in resistance with temperature, dR/dT, appear as an oscillating voltage, $\delta V(t)$, which is proportional to the temperature swings, δT, in the following way:

$$\delta V = I\ (dR/dT)\ \delta T \qquad \text{(eqn 3.20)}$$

therefore the temperature swing can be determined by:

$$\delta T = \delta V/[I\ dR/dT]. \qquad \text{(eqn 3.21)}$$

Typically, our bias current, I, was set at 2.7 to 3.0 μA.

The factor of dR/dT was determined by static calibration. The calibration data is obtained while the temperature of the helium bath is being reduced. The vapor pressure and resistance are recorded each time the pressure changed by 0.1 mmHg. The temperature corresponding to a given pressure was found using the Cubic Spline method [Ref. 38]. The differential resistivity was calculated by making a least square best fit to an exponential in the temperature range of interest for each particular helium run. Figure 3.12 gives a sample of the data. The exponential resistance was motivated by the semiconductivity energy gap activation model; and the exponential form,

$$R(T) = R(o)\ \exp[-\alpha T]$$

was convenient for the expression of differential resistivity

$$\alpha = [1/R(o)][\partial R/\partial T].$$

Table III shows the thermometer calibration constant, α, for specific temperatures used during our experiment.

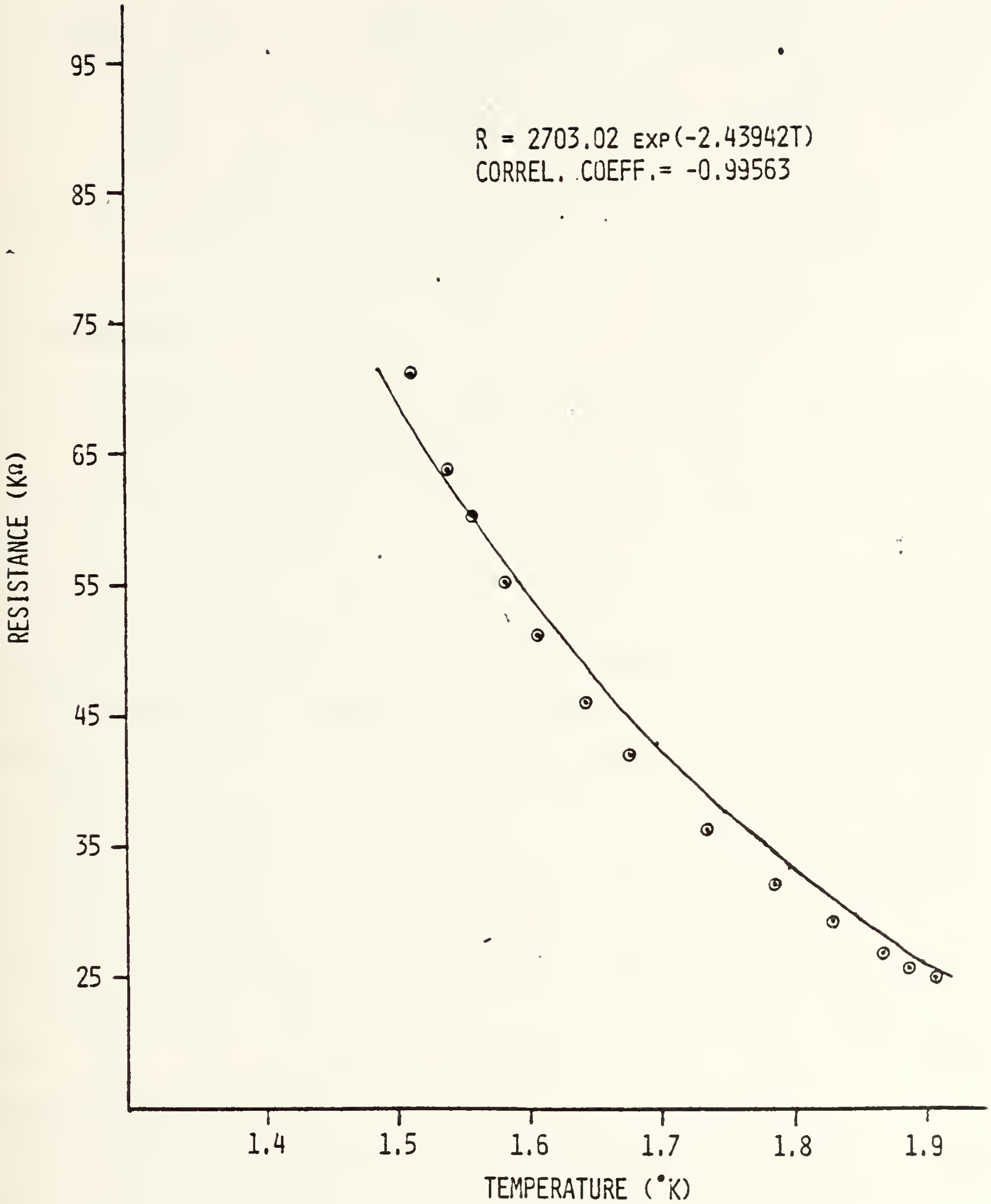

Figure 3.12 Thermometer Calibration Curve.

TABLE III
Thermometer Calibration Constant

Temp. (^oK)	Resist. ($K\Omega$)	α (^oK)$^{-1}$
1.47	81.44	-3.175
1.53	66.62	-3.387
1.65	46.11	-2.735
1.83	29.59	-2.205
1.95	23.11	-1.859

C. ELECTRONICS

Three different methods were employed to generate and detect second sound standing waves. First one electret transducer was driven and the resulting second sound was detected by the remaining electret transducer. In the remainder of this report this will be designated as Electret/Electret or E/E. The second method was to drive the heater and detect the generated sound using one of the electret transducers (Thermal/Electret; T/E). Both electret transducers were used in data gathering. After sufficient data had been obtained using one electret transducer as a reciever the output was shifted to the remaining electret transducer and the data was obtained using that combination. The third method again drove the heater, but this time the thermally generated second sound was detected by its associated temperature oscillations using a carbon resistor, biased by a constant current, as the receiver (Thermal/Thermal; T/T).

All three methods used a sinusoidal drive signal. Due to the size and symmetry of the electret transducers and the heater that generated second sound waves, all wave forms were assumed to be planar, and the harmonicity of the detected modes varified that assumption.

In the following sections on transducer electronics, Electret/Electret, Thermal/Electret, and Thermal/Thermal the HP-3325A Synthesizer/Function Generator and the EG&G Princeton Applied Reasearch (PAR) Model-5204 Lock-in Anyalyser are the output and input respectively of the data acquisition system which is discussed briefly in the RESULTS chapter.

1. Electret/Electret

Figure 3.13 is a block diagram of the electronic set up for the electret drive, electret pick up mode of generating and detecting second sound.

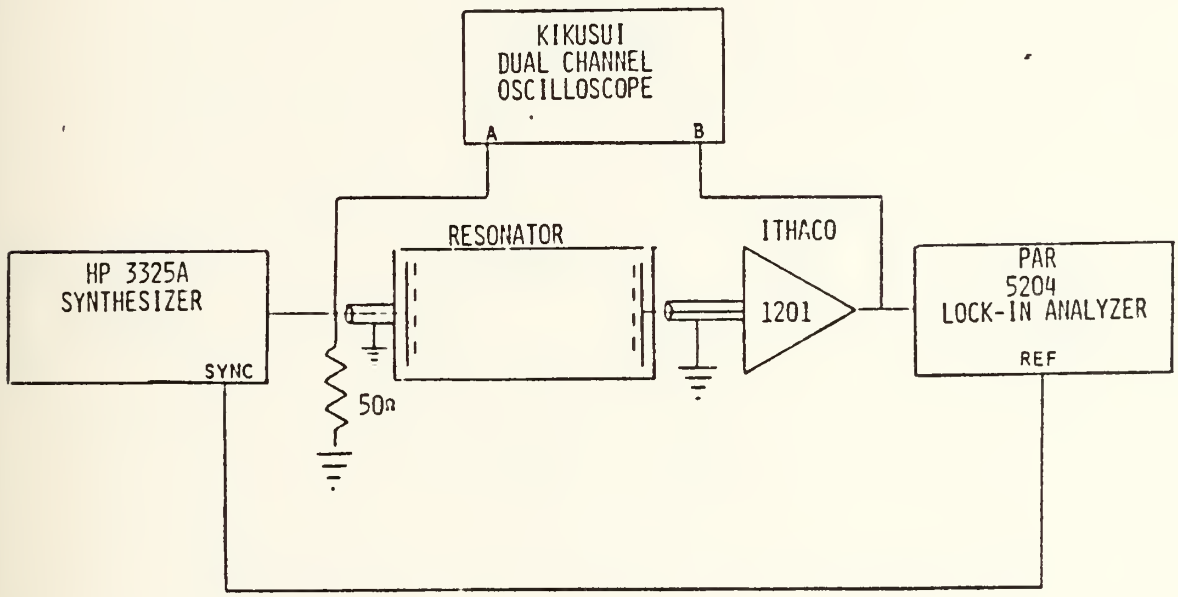

Figure 3.13 Electret/Electret Electronics Block Diagram.

The drive signal is taken from a HP-3325A Synthesizer/Function Generator. The signal passes thru a nominal 50 ohm resistor which ensures drive signal amplitude

matching between synthesizer output and the input to the electret driver. The drive signal is monitored on a KIKUSUI Dual Channel Oscilloscope Model COS-5060.

The detected or output signal passes thru an ITHACO Model-1201 Low Noise Preamplifier and again is monitored on the remaining channel of the oscilloscope. The output signal continues to the lock-in anyalyser.

2. Thermal/Electret

Figure 3.14 is a block diagram of the electronic configuration for thermal drive, electret pick up mode of generating and detecting second sound.

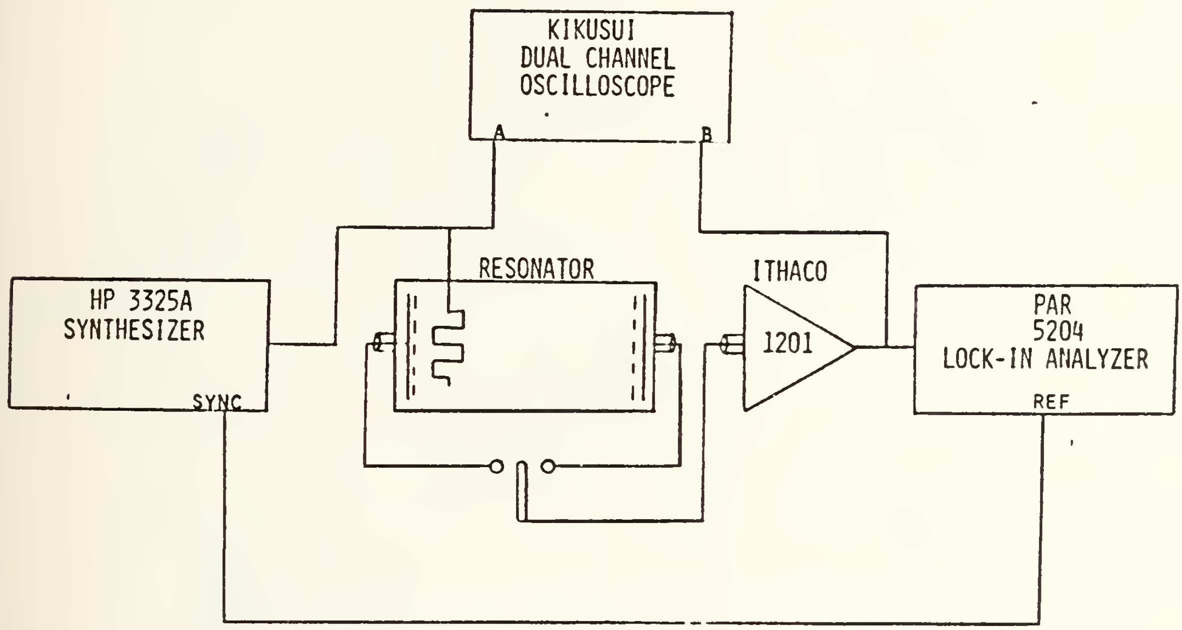

Figure 3.14 Thermal/Electret Electronics Block Diagram.

As can easily be seen by comparing the two block diagrams, there is little difference in the electronics

between Electret/Electret and Thermal/Electret. In fact the only difference is in the drive portion of the circuit. In the T/E method the nominal 50 ohm resistor has been replaced by the 63 ohm drive heater which again maintains drive amplitude continuity. Because the heating is quadratic in the heater current (see Transducer Section) the lock-in which was referenced to the synthesizer frequency was operated in the 2nd harmonic mode.

3. Thermal/Thermal

Figure 3.15 is a block diagram of the electronic set up for the thermal drive, thermal pick up mode of generating and detecting second sound.

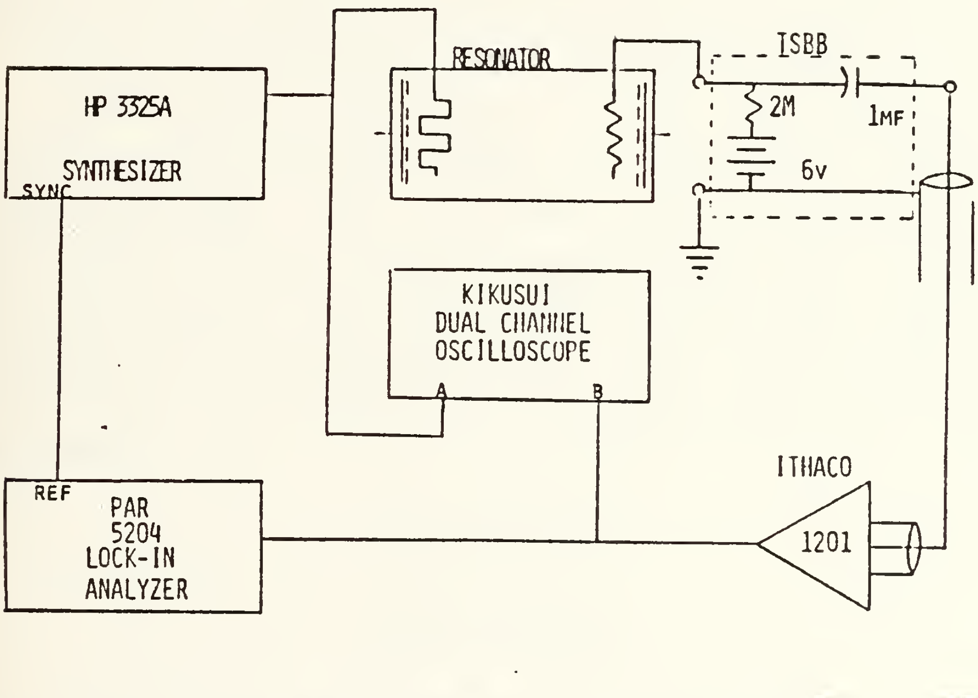

Figure 3.15 Thermal/Thermal Electronics Block Diagram.

The electonics for the drive signal is identical to that of the Thermal/Electret mode. The second sound signal

is detected by means of the induced temperature swings in a carbon resistor biased by a constant current (2.7 micro-amps). The Thermal Sound Bias Box (TSBB) is the constant current source for the detection (thermometer) resistor. The TSBB also has a DC blocking capacitor in the output circuit to ensure that only the AC component of the signal is passed to the preamplifier. From the preamplifier the signal is monitored by the oscilloscope and the lock-in simultaneously.

4. Line Loss

When the output signal is electret generated, i.e. T/E and E/E, the electret voltage output is degraded due to the capacitance of the lead between the top of the probe and the preamplifier. Figure 3.16 is an equivelent circuit representing the detecting electret and the preamplifier.

C(e) is the capacitance of the electret transducer which is detecting the signal. For simplicity we have defined the effective transducer to include the capacitance of the transducer (85 pf) plus the capacitance of the coaxial cable (155 pf) which brings the signal to the top-plate of the probe. C(i) and R(i) are the input capacitance and resistance of the preamplifier. C(l) is the capacitance of the coaxial lead connecting the probe (electret) and the preamplifier.

C(i)= 49 pf
C(l)= 35 pf
\-\-\-\-\-\-\-\-\-\-\-\-
Total= 84 pf

These values were measured using a HP-4261A LCR Meter, therefore,

$$Vg(mv) = V(output)(mv)\ [(C(e) + 84)/C(e)].$$

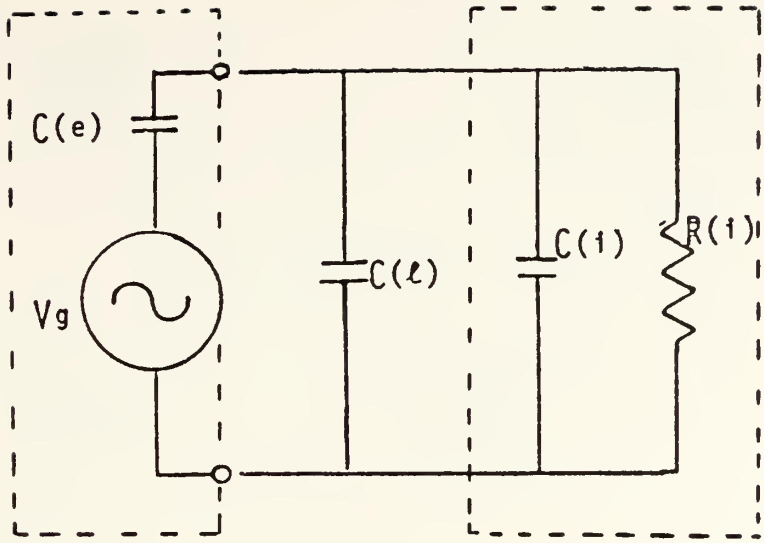

Figure 3.16 Line Loss Circuit Diagram.

Because a precise knowledge of the values of these capacitances was so important to the interpretation of the voltage measured at the lock-in in terms of the voltage at the defined "end" of the electret transducer, a special technique was used to measure the electret transducer capacitance while the system was under true operating conditions i.e. between 1 and 2 °K. This was accomplished by setting up the circuit in Figure 3.17. This circuit maintained a relatively fixed voltage while the frequency was varied from 1kHz to 10kHz. The voltage (RMS) and the current were recorded at each frequency and the capacitance at each frequency was determined using the following relationship:

$$C=I/2\pi fV$$

The capacitance for all frequencies were averaged together to give the operating condition capacitance. The typical electret capacitance, including the coaxial cable to the

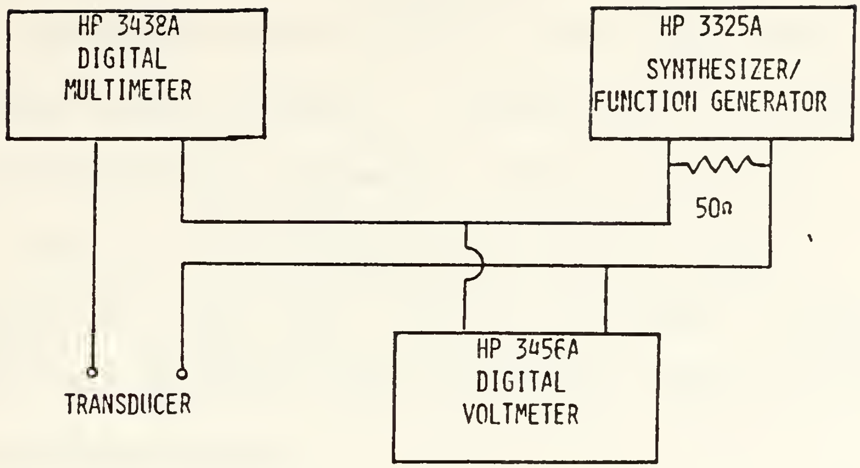

Figure 3.17 Operating Capacitance Measurement Circuit.

top-plate was 241.35 ± 0.41 pf, where the error is the standard deviation of the measurements over the range of frequencies.

5. Calibration of the Synthesizer

It was important to determine any correction between computer bus specified drive output and actual voltage which appeared at the proper device (heater, electret, etc.). It was important to know this correction not only as a fuction of drive voltage (10 to 150 mv), but also as a function of drive frequency (200 to 1500 Hz).

First it was noted that there was less than .02% difference in actual output voltage over the frequency range of concern. Next a plot of bus specified drive voltage verses actual applied voltage was made, and using the method linear regression, the following line equations for synthesizer output were developed.

1) Synthesizer driving heater (T/E & T/T)

V(actual) = 1.04887 V(syn) + 0.029067 .... r = 0.9999937

2) Synthesizer using nominal 50-ohm load (E/E)

V(actual) = 0.99319 V(syn) - 0.28676 .... r = 0.9999920

where r is the linear regression correlation value.

(Note: All voltages are in milli-volts)

These equations where then used in the data reduction to convert the bus specified voltage to the actual voltage.

6. <u>In-Line Filters</u>

Filters in the ITHACO preamplifier and the PAR lock-in analyser were utilized to minimize extraneous noise sources due primarily to pump induced vibrations.

The 30 Hz High Pass filter and the 10kHz Low Pass filters were utilized on the preamplifier while the 50 Hz High Pass filter was utilized in the lock-in anylyzer.

As the 50 Hz high pass of the lock-in dominated the low frequency response and the 10kHz low pass of the preamplifier dominated the high frequency response, the maximum system reciever response was expected at a frequency which was the geometric mean of these values, or about 707 Hz. This was observed experimentally. At 700 Hz the lock-in output was 0.9997 of the calibrated input. At the lowest frequency of interest (400 Hz) this transfer function dropped to 0.9971 while at the highest frequency of concern (1.6 kHz) it was 0.9914. These attenuation functions were considered negligible in the interpretation of the results.

IV. RESULTS

A. PROCEDURES

1. Cooldown

Prior to the commencement of cooldown, the inner vacuum jacket is purged with air and then evacuated to less than 2 mmHg. This is important to ensure that no helium gas is in the inner jacket.

The probe is placed in the experimental area. Liquid nitrogen is then added to the outer jacket to commence the cooldown. The experimental area is then evacuated to 80-100 mmHg.

The temperature of the experimental area is monitored by three different and independent methods. Quantitative results were obtained by monitoring the fundamental or a harmonic frequency of the air filled resonator. This is accomplished by using the HP 3580A Spectum Analyzer to drive and pick-up the resulting signal in the Electret/Electret mode. The following two equations

1) $f(n) = nc/2L$

2) $c^2 = \gamma RT/M$

results in

$$T(^{o}K) = 2.48 \times 10^{-5} f(n)^2/n^2$$

where the constant is a result of the length of the resonator and the previously presented thermodynamic constants.

The remaining two methods only present trends. The first is monitoring the attached carbon resistor on the probe. Although this did not provide quantitative data during the liquid nitrogen cooldown phase, it was very useful in determining the point at which we expected the liquid helium to collect in the dewar during the transfer.

As the temperature decreases the resistance increases. The remaining method is to monitor the pressure in the inner dewar. Since the volume of the inner dewar remains constant, the pressure will drop as the temperature drops in accordance with the Ideal Gas Law.

2. Liquid Helium Transfer

Once the temperature in the experimental area reaches approximately 85°K the transfer of the liquid helium may commence. This transfer of the liquid helium from the shipping dewar to the inner dewar is accomplished via a transfer tube.

The transfer tube is a double walled stainless steel tube. A vacuum is maintained between the two walls to minimize heat conduction to the liquid helium.

Immediately prior to the transfer, the transfer tube is purged with helium gas. This minimizes the possibility of air and water vapor in the tube condensing and forming a plug in the line, thereby resticting or completly stopping the transfer.

The inner dewar is also brought to atmosheric pressure by bleeding in helium gas thru the helium purge valve. Once the inner dewar is at atmospheric pressure, one end of the transfer tube is placed in the shipping dewar while the other end is placed in the helium recieving tube on the top of the probe. The shipping dewar is then pressurized to approximately 3 psig using helium gas. This commences the transfer.

3. Pump Down

Once the desired liquid helium level is obtained, keeping in mind that during the pump down the liquid helium level will drop by 1/3 to 1/2 of its original level at the commencement of pump down, the shipping dewar is vented concluding the

transfer. The transfer tube is removed from the shipping dewar and the helium recieving tube. The helium recieving tube is "capped" using a rubber stopper and the helium purge valve is closed.

The vapor pressure of the helium must be reduced in order to reduce the liquid helium temperature. This is accomplished by using the 15 cfm vaccum pump refered to in Chapter III to evacuate the inner dewar. The isolation cross-connect valve in the manostat is opened allowing the pressure inside and outside the membrane to remain equal, thereby allowing an unimpeded flow path from the inner dewar to the vaccum pump. Once the desired pressure/temperature is obtained, the isolation cross-connect valve on the manostat is shut allowing the manostat to control the pressure.

B. DATA AQUISITION

Data was obtained and analyzed by means of a computaional algorithm and a data aquisition system. The system utilized an HP-85 desk-top computer, an HP-3325A Synthesizer/Function Generator, an EG&G-5204 Lock-in Anylyzer and an HP-3497A Data Aquisition/Control Unit. The system automatically measures and tracks the center frequencies, amplitudes and quality factors (Q) of up to 9 acoustical resonances. A typical spectrum was shown in Figure 3.9.

An in depth explination of the basis for the data aquisition system is contained in a Masters Thesis by D. Conte [Ref. 45]. Due to the fact that Conte describes a system in air and uses a thermistor for temperature monitoring, slight modifications where required to the program for the HP-85. This program is listed in Appendix A.

A short and very basic discription of the aquisition system follows. The HP-85 computer directly controls all of the equipment, with the exception of the Lock-in Analyzer, via the Hewlett Packard Interface Bus (HPIB; IEEE Standard 488-1975). The computer sends a value for frequency and amplitude to the HP-3325A Synthesizer/Function Generator, which causes an excitation of the acoustic resonances. The EG&G-5204 is phased-locked to the HP-3325A and generates a D.C. voltage which is proportional to the Pythagorian sum of the amplified in-phase and quadrature components of the signal. This analog amplitude is sent to the HP-3497A which, when interrogated, sends via the HPIB, a digitization of the voltage level.

This system provided excellent results in a minimum of time. The chi-squared minimization search utilized in the program yielded precisions of better than 0.1 percent in Q, 0.01 percent in amplitude and 0.1 ppm in frequency.

C. DATA REDUCTION

Our computer controlled data acquisition system compiles, on magnetic tape, all necessary electrical reading for electret-electret (E/E) and thermal-electret (T/EA and T/EB) configurations. The computer program provided in Appendix B is then used to process this formatted "raw" data, which is provided in Appendix C. The sensitivities (MA and MB) of our slit-electret transducers are then computed using equations 3.5 to 3.10.

From the reciprocity computation of transducer sensitivities we are able to determine the corresponding temperature oscillation r.m.s. amplitude (δT_r), which is the ratio of output voltage to transducer sensitivity. The temperature oscillation that defines the upper limit (δT_u) is computed from equation 3.19. The ratio of δT_u to δT_r is an

extremely important quantity in our experiment since its value makes a definite statement about the validity of our computed thermal transducer sensitivities.

It should be pointed out that the measurements obtained for E/E and T/E contain their own values of frequency, amplitude and quality factor, with each data set occurring at essentually the same temperature. For our calculations the average frequency and temperature are used. An assemblage of reduced data is provided in Appendix D.

When looking at the output of the reduced data of Appendix D you will find the resonant modal number listed first. Recall that the necessary electrical readings for E/E, T/EA and T/EB were all taken at slightly different temperatures and therefore at slightly different center frequencies. The average temperature and frequency used for each calculation set is provided along with their standard deviation. The next item is the temperature oscillation amplitude calculated by the reciprocity method, followed by the amplitude of the temperature oscillation which has been determined to be the upper limit. The ratio of these two amplitudes is also provided at the end of the printout. Recall that the upper thermal oscillation by the thermophone principle required us to drive the heater and take the output from either electret A or B. In our calculations the output was taken from electret A; however, the upper limit has also been calculated using the output of electret B and the difference between the two is listed (Ua-Ub). Finally, the "slit-electret" sensitivities are provided for side A and B.

D. ERROR ANALYSIS

The final section of this chapter will deal with the inherent errors that are a part of every experiment. The

magnitude of these errors must be reasonable and scrutinized with our final results to determine the strength of our analysis. In order to determine the accumulated error which exists in our calculated thermal transducer sensitivities we must recall equation 3.5 :

$$M(A)M(B) = [d^2 \pi U(II) Cp \rho/16][V(m)n/(V(s)QfCT)] .$$

The factors that carry significant inherent errors are second sound speed U(II), helium density ρ, specific heat of helium Cp, frequency f, temperature T, electret capacitance C, quality factor Q and all voltages.

From the UCLA thermodynamic data [Ref. 21] we find that second sound speed is known to within 0.1% , helium density is known to within 0.45% and the specific heat is known to within 0.2% . This gives a total error for these three parameters of

$$[(0.001)^2 + (0.0045)^2 + (0.002)^2] = 0.5\%.$$

From our assembled data we have found that the accuracy of the remaining parameters is as follows :

frequency 0.6%
temperature 0.3%
capacitance 0.2%
quality factor 0.6%
voltages .... 0.5% x sqr(8) = 1.4%

The sqr(8) occurs because when equation 3.5 is used to determine the absolute sensitivity of either transducer A "or" B there are eight factors of voltage required. When all of the above errors are combined the resulting total error is found to be 1.7% .

V. CONCLUSIONS

A. VALIDITY OF RECIPROCITY IN A QUANTUM FLUID

The absolute sensitivities of the slit-electret transducers were determined using the Reciprocity Theorem. We were able to make precise measurements of temperature, resonant frequency, amplitude and quality factor. Invoking the assumption that all of the oscillatory heat dissipated in the heater was radiated as second sound, the amplitude of the upper bound for temperature oscillations was calculated.

The ratio of the temperature oscillation for the upper bound to that of reciprocity is plotted as a function of mode number at a temperature of 1.53 ^{o}K and is shown in figure 5.1 as circled data points. The dashed line exists only as a guide to the eye.

In calculating the circled data points of Figure 5.1 it was assumed that the thermal driver (webbed heater) was optimally positioned directly against the electretted endcap. Since in reality this would electrically short the electret and heater, the heater was intentionally offset by a distance that was roughly measured to be 2mm. We can assume that when our heater is driven the resulting response is reduced by a factor of

$$\cos(2n\pi/L)$$

which accounts for the lower effective thermal impedance, where L = 50mm, is the resonator length. At any temperature, the ratio of the amplitude of oscillation for any two modes must equal a constant such that

$$\cos(n\pi x/25)/\cos(m\pi x/25) = C\ ,$$

where, for our data, C is obtained by averaging the ratio of upper limit to reciprocity temperature amplitude oscillations for modes 2 and 6 at all temperatures.

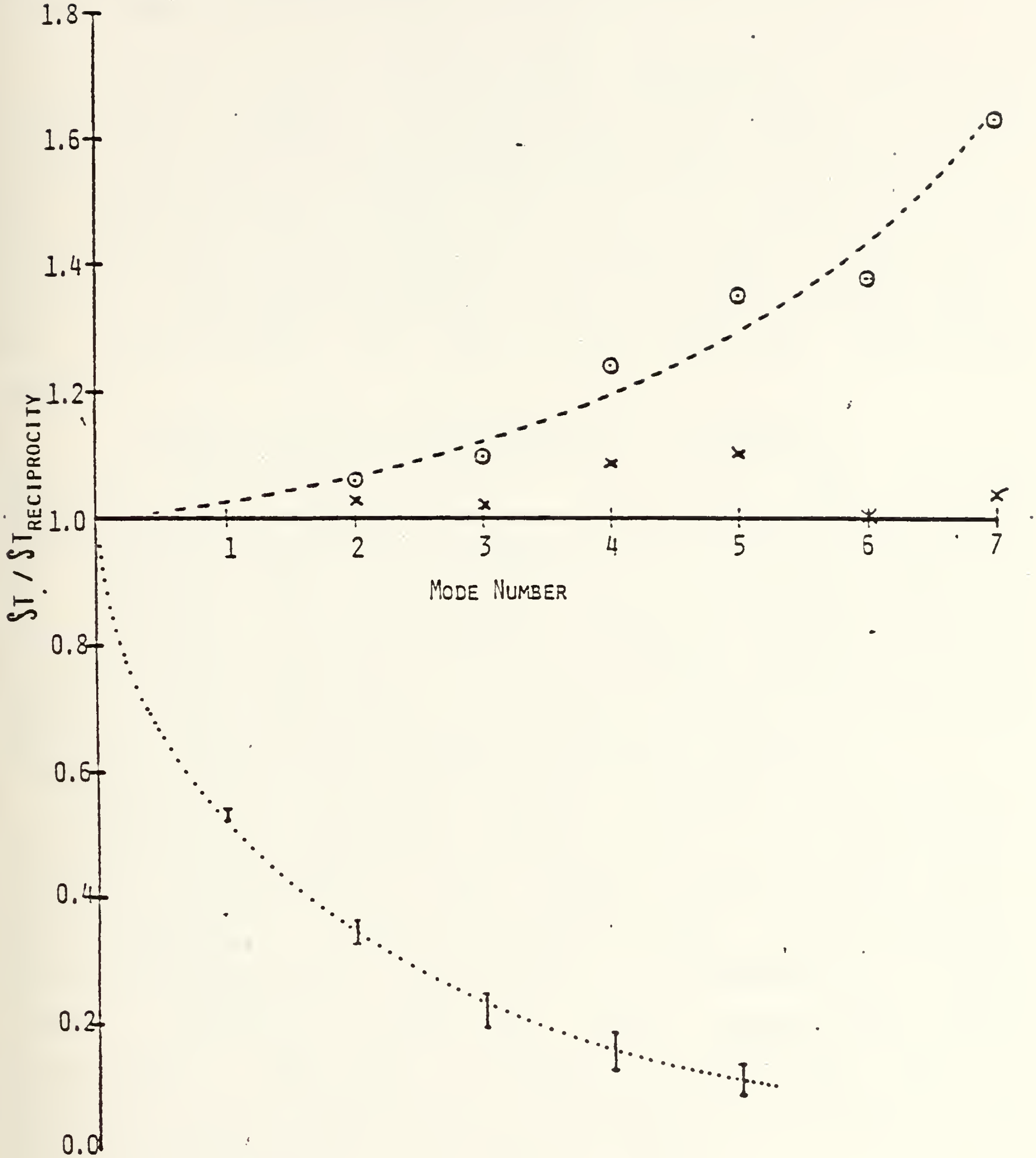

Figure 5.1 ST / ST_r

This gives us

$$C = 1.217 \pm 0.05 \ .$$

When the above transcendental equation is solved for "x" for modes 2 and 6 we find that

$$x = 1.7\text{mm}$$

which indeed supports our rough measurement of heater displacement (2mm). So we see that the effect of this heater offset is to reduce the circled data of Figure 5.1. The corrected data points, the X's, in Figure 5.1 are obtained using a displacement of 2mm for ease of calculation since the difference observed using 1.7mm is insignificant. This then requires the use of the following correction factor:

$$\delta T(\text{corrected}) / \delta T(\text{circled}) = \cos(n\pi/25) \ .$$

This data is shown in Figure 5.1 and we see that the two methods are in excellent agreement. It is important to note that Table IV shows only a sample of corrected data taken at $T = 1.53\ ^{o}K$. In actuality, Figure 5.1 illustrates the corrected data for data obtained at five different temperatures and for many more data points. As indicated in the Table, a total of twelve data points were used for each mode to obtain these truly representative ratio values.

The bars in the lower portion of figure 5.1 represent the ratio of the temperature oscillation for the lower bound to that of reciprocity. The thermal inertia of the resistive thermometer, Kapitza resistance [Ref. 22] and geometry make the temperature oscillation by thermometry a lower limit. Figure 5.1 shows that these effects are indeed significant. Data which involved the lower limit was not required for the quantitative verification of the utility of the reciprocity method in a quantum fluid.

TABLE IV

Heater Displacement Correction (T = 1.53 °K)

mode	# pts	cos(nπ/25)	$\delta T_u / \delta T_r$	corrected $\delta T_u / \delta T_r$
2	12	0.9686	1.057	1.024
3	12	0.9298	1.109	1.031
4	12	0.8763	1.241	1.087
5	12	0.8090	1.195	0.967
6	12	0.7290	1.263	0.921
		average >>>	1.173 >>>	1.006

B. SENSITIVITY OF SLIT-ELECTRET TRANSDUCERS

By assuming that the temperature oscillation amplitude calculated from the thermophone heat current is the true oscillation amplitude, it is possible to use the temperature amplitude measured by the reciprocity method to determine the specific acoustic transfer impedance, or the reciprocity constant M'(T) which is the inverse of its square root. The points plotted in figure 5.2 and connected by the dashed straight line are the values of M'(T) calculated from the UCLA thermodynamic data [Ref. 21] and shown previously in Figure 2.2.

The equation for the dashed line is a least squares fit to the data between the temperatures of 1.2 to 1.9 °K :

$$M'(T) = 2.176\, T - 1.775$$

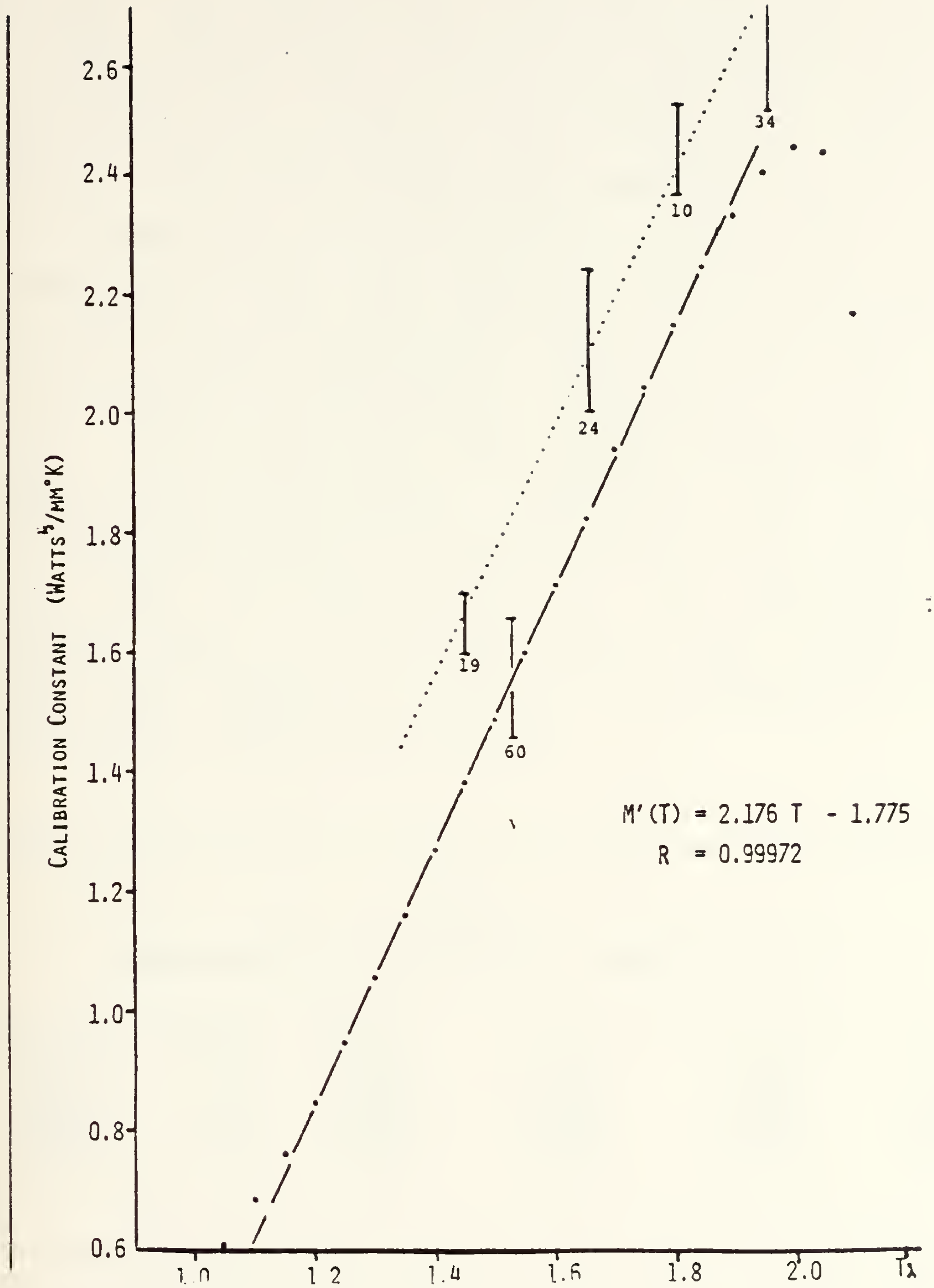

Figure 5.2 Experimental/Theoretical Determination of M'.

and the units are $(watts^{1/2}/mm\text{-}{}^{o}K)$. The mean square deviation of these fifteen (15) points from that line is less than 0.7%. The five bars are the values of M'(T) based on all of the thermal and reciprocity measurements made at those temperature. Table V is a compilation of the data in Appendix C used to prepare the experimental points in Figure 5.2. Due to the intentional redundancy in our technique we were free to mix various E/E and T/E data sets at _any_ given temperature. The choice was random and the number of "mixtures" for any given temperature and mode number is given in the Table. The number under the error bars gives the total number of points used to average M' at that temperature. The bars are two standard deviations tall, centered around the average. The dotted line connecting four of the five bars is a guide to the eye. At the present time we have no explaination for the approximate 10% discrepancy shown in Figure 5.2, but it does appear to be systematic and outside the limits of our uncertainty in the experimentally measured quantities.

TABLE V

Experimental Calibration Constant Data

Temp(°K)	#pts	$\int T_u/\int T_r$	M'(+)	M'(avg)	M'(-)
1.453	19	0.844	1.695	1.638	1.594
1.531	60	1.000	1.652	1.556	1.454
1.602	24	0.871	2.246	1.842	1.997
1.808	10	0.885	2.519	2.159	2.365
1.959	34	0.902	2.869	2.410	2.500

In conclusion, we have shown, for the first time, that it is possible to make absolute acoustical measurements of temperature oscillations in superfluid helium using the reciprocity technique. Also, in addition to illustrating an excellent application of the Conte system of precise acoustical data aquisition, we were successful in measuring absolute temperature excursions as small as 10^{-10} $^{o}K/(Hz)^{1/2}$.

A sample of the transducer sensitivities as a function of temperature and mode number is shown in Figure 5.2. All reduced sensitivities are given in Appendix D. It is worth noting that these sensitivities are a factor of 2.3 (ie, 240pf/85pf) smaller than the true sensitivity since the "effective transducer" was defined to include the coax cable which brought the signal to room temperature [see Chapter III (C.4)].

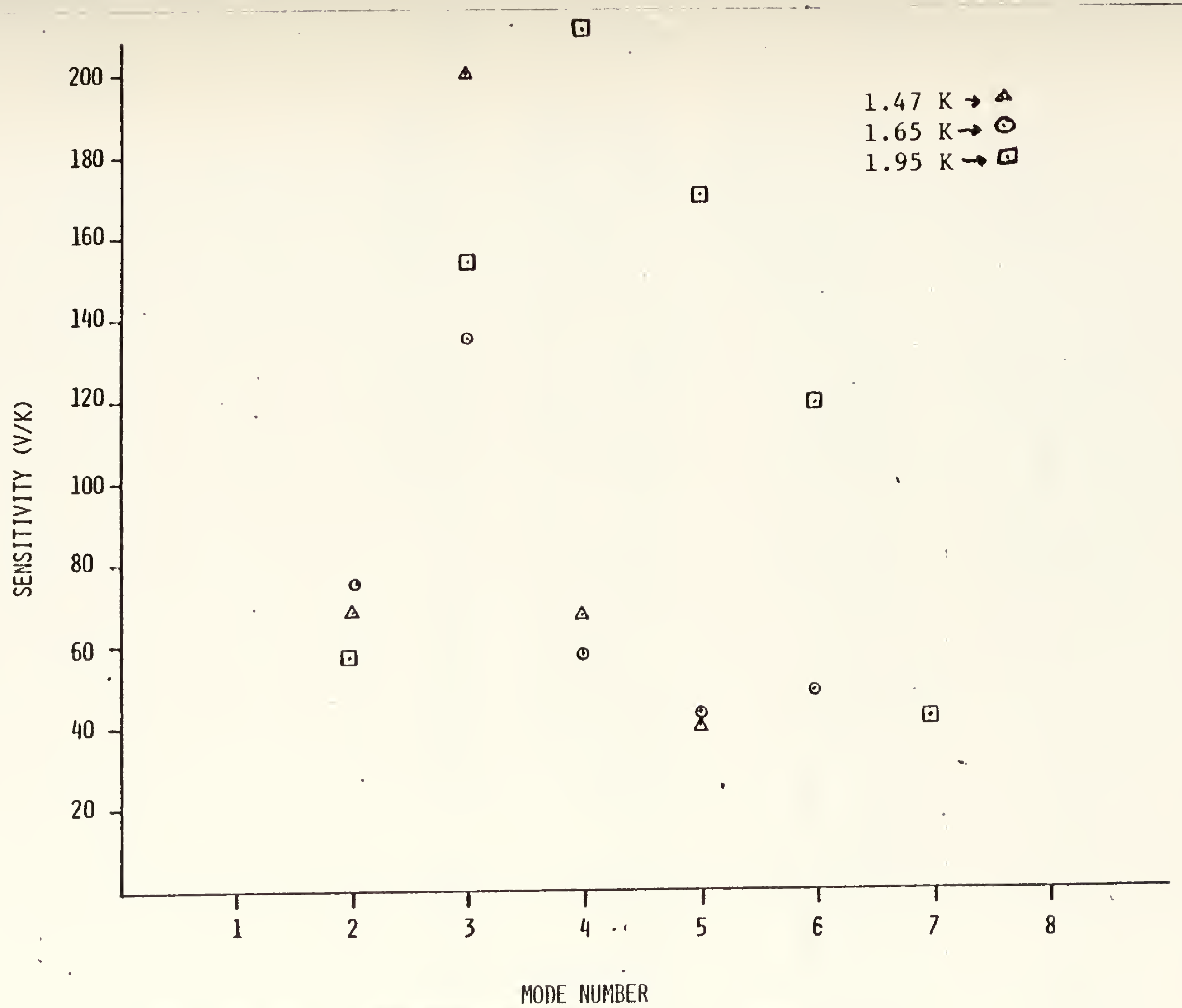

Figure 5.3 Electret Sensitivity vs Temperature.

APPENDIX A

DATA AQUISITION PROGRAMS

1) BJ#2....... Extracts necessary electrical readings; calculates Q, amplitude and center frequency; formats the output as raw data (Appendix C).

2) TMRCAL..... Monitors pressure and thermometer resistance; converts pressure to temperature; provides necessary information to determine thermometer differential resistivity.

3) COOLDN..... While monitoring a specified resonant mode, this program outputs helium temperature due to the change in sound speed during cooldown.

4) P vs t..... Monitors the performance of our pressure (temperature) regulator.

```
1 DIM F4(300).A(300).C(100).X8(26).X7(26).E1(25).E2(25).E6(25).E7(25)
2 CLEAR @ PRINTER IS 2 @ OUTPUT 722 ;"F4M6"
3 DISP "REMOVE PROGRAM TAPE AND INSTALL DATA TAPE" @ BEEP
4 DISP "WHEN COMPLETED. ENTER 1"
5 INPUT Y
6 IF Y=1 THEN 7 ELSE CLEAR @ BEEP @ GOTO 3
7 CLEAR @ BEEP @ DISP "DO YOU DESIRE TO ERASE AND REWIND TAPE?(Y/N)"
8 INPUT K$@ IF K$="N" THEN 11 ELSE 9
9 ERASETAPE @ GOTO 93
10 CREATE Z$.850.88 @ REWIND @ GOTO 12
11 CLEAR @ BEEP @ GOTO 97
12 CLEAR @ BEEP @ GOTO 8992
13 SETTIME 0,0
14 DISP "DO YOU WANT TO SKIP DIRECTLY TO MEASURE?(Y/N)"
15 INPUT K$
16 IF K$="N" THEN 83 ELSE 17
17 CLEAR @ BEEP
18 DISP "Enter amp of driving freq in mv (=<3500)RMS"
19 DISP "DECIMAL VALUES ARE NOT PERMITTED"
20 INPUT A ! amp of freq
21 IF A>3500 THEN CLEAR @ BEEP @ GOTO 18
22 FOR N=1 TO 9
23 A8(N)=A
24 NEXT N·
25 CLEAR @ BEEP
26 DISP "Enter largest value of amp ever desired (=<3500mv RMS)"
27 INPUT A1 ! max future amp
28 IF A1>3500 THEN CLEAR @ BEEP @ GOTO 26
29 ! these are the values to set up the 3325A
30 A$=VAL$(A)
31 A2$="AM"
32 A3$="MR"
33 OUTPUT 717 ;A2$.A$.A3$
34 CLEAR @ BEEP
35 DISP "Enter full-scale sensitivity setting from the 5204 in volts=FSS/(PREAMP
 GAIN*MULTIPL)"
36 INPUT A5 ! SENSITIVITY SETTING
37 CLEAR @ BEEP
38 DISP "Set and enter new time constant (in milli-sec)"
40 INPUT Y
41 T1=Y
42 CLEAR @ BEEP
43 DISP "How many modes do you desire to track (MAX OF 9)"
44 INPUT M ! NUMBER OF MODES
45 FOR N=1 TO M
46 CLEAR @ BEEP
47 DISP "What is center freq for mode ";N
48 INPUT F6(N) ! CENTER FREQ
52 CLEAR @ BEEP
53 DISP "What is the Q for mode ";N
54 INPUT Q(N)
55 I(N)=24
56 CLEAR @ BEEP
57 DISP "What is the amplitude of the center freq for mode ";N
58 INPUT A6(N)
59 CLEAR @ BEEP @ A6(N)=A6(N)/A5
60 NEXT N
61 DISP "I am working on standard dev. # of pts. & variance "
62 ! From 63 to 82 is the calc of the noise. st. dev.. and the number of pts. us
ed.
```

```
63 G,W=0 @ H1$="HZ" @ H2$="FR"
64 F=(F6(2)-F6(1))/4+F6(1)
65 F4$=VAL$(F)
66 OUTPUT 717 ;H2$,F4$,H1$
67 WAIT T1*12+100
68 OUTPUT 709 ;"VT1"
69 WAIT 1000
70 FOR N=1 TO 100
71 ENTER 709 ; A(N)
72 W=W+A(N)
73 NEXT N
74 W=W/100
75 FOR N=1 TO 100
76 S=(A(N)-W)^2
77 G=G+S
78 NEXT N
79 G=A5*SQR(G/99)
80 W=W*A5
81 PRINT "The mean is ";W;" and the standard dev is ";G
82 GOTO 8100
83 CLEAR @ BEEP
84 DISP "Enter lower freq"
85 INPUT F1 ! lower freq
86 CLEAR @ BEEP
87 DISP "Enter upper freq"
88 INPUT F2 ! upper freq
89 IF F2<=F1 THEN CLEAR @ BEEP @ GOTO 87
90 T=1/(4*((F2-F1)/256)) ! time constant
91 CLEAR @ BEEP
92 GOTO 101
93 DISP "DATA FILE NAME.";
94 INPUT Z$
95 GOTO 10
97 DISP "ENTER NAME OF DATA FILE"
98 INPUT Z$@ GOTO 12
101 DISP "Set time constant on 5204 at ";T;" or smaller"
111 DISP "When complete, enter value set (in Milli-sec)"
121 INPUT T1
131 IF T1>T*1000 THEN CLEAR @ BEEP @ GOTO 101
141 CLEAR @ BEEP
151 DISP "Enter amp of driving freq in mv (=<3500)RMS"
161 DISP "DECIMAL VALUES ARE NOT PERMITTED"
171 INPUT A ! amp of freq
181 IF A>3500 THEN CLEAR @ BEEP @ GOTO 151
182 FOR N=1 TO 9
183 A8(N)=A
184 NEXT N
191 CLEAR @ BEEP
201 DISP "Enter largest value of amp ever desired (=<3500mv RMS)"
211 INPUT A1 ! max future amp
221 IF A1>3500 THEN CLEAR @ BEEP @ GOTO 201
230 ! these are the values to set up the 3325A
231 A$=VAL$(A)
232 A2$="AM"
233 A3$="MR"
240 OUTPUT 717 ;A2$,A$,A3$
241 WAIT 200
251 F3=CEIL((F2-F1)/256) ! smallest int >= bandwidth
252 ! SEARCH
253 ! SEARCH
```

```
254 ! SEARCH
261 ! next group sends freq to 3325A, and gets amp from 3497A
269 CLEAR
270 DISP "I am working in SEARCH"
271 FOR N=0 TO 256
281 F4(N)=F1+N*F3
282 ! F4(N) is freq sent
290 F4$=VAL$(F4(N))
291 H1$="HZ"
292 H2$="FR"
300 OUTPUT 717 ;H2$,F4$,H1$
310 WAIT 4*T1+100
320 OUTPUT 709 ;"VT3"
330 ENTER 709 ; A(N)
350 NEXT N
351 ! F5 AND F6 ARE SCALE FACTORS
352 BEEP
360 F5=F1-.1*(F2-F1)
370 F6=F2+.1*(F2-F1)
380 GCLEAR @ CLEAR
390 SCALE F5,F6,-.1,1.2
400 XAXIS 0,1000,F1,F2
410 YAXIS F1,.1,-.1,1.2
411 FOR N=0 TO 256
413 PLOT F4(N),A(N)
414 NEXT N
415 DISP "DO YOU DESIRE A COPY? (Y/N)" @ BEEP
416 INPUT K$
417 IF K$="N" THEN 477 ELSE 418
418 GCLEAR @ CLEAR @ BEEP
419 DISP "ENTER FIGURE # TO BE PRINTED"
420 INPUT L$
421 PLOTTER IS 705
422 PEN 1
423 SCALE F1-.1*(F2-F1),F2+500,-.3,1.3
424 XAXIS 0,100,F1,F2
425 YAXIS F1,.1,0,1.2
426 PEN 2
427 FOR N=0 TO 256
429 PLOT F4(N),A(N)
430 NEXT N
431 PENUP @ PEN 1
432 LDIR 0,SIN(90) @ PENUP
433 FOR X=F1 TO F2 STEP 200 @ PENUP
434 MOVE X,-.13
435 LABEL VAL$(X)
436 NEXT X @ PENUP
440 LDIR 0
441 FOR Y=0 TO 1.2 STEP .1 @ PENUP
442 MOVE F1-.05*(F2-F1),Y
443 LABEL VAL$(Y)
444 NEXT Y @ PENUP
450 LDIR 0 @ PENUP
451 MOVE F1+(F2-F1)/3,-.21
452 LABEL "FREQUENCY IN HZ"
453 LDIR 0 @ PENUP
454 MOVE F1,-.3
455 LABEL "PLOT OF RELATIVE AMPLITUDE VS FREQUENCY (FULL SPECTRUM)"
456 LDIR 0,SIN(90) @ PENUP
457 MOVE F1-.08*(F2-F1),.3
```

```
458 LABEL "RELATIVE AMPLITUDE"
459 LDIR 0 @ PENUP
460 MOVE F1+200,1.2
461 LABEL "FIGURE ";L$
462 PENUP
476 PLOTTER IS 1
477 CLEAR @ BEEP
478 DISP "Do you desire to rerun exp with different parameters?(Y/N)"
480 INPUT K$
490 GCLEAR @ CLEAR @ BEEP
500 IF K$="N" THEN 510 ELSE 11
510 DISP "Enter decision point for amplitude (0 TO 1.2)"
520 INPUT A4 ! DECISION POINT
530 CLEAR @ BEEP
540 DISP "Enter full-scale sensitivity setting from the 5204 in volts=FSS/(PREAM
P GAIN*MULTIP)"
550 INPUT A5 ! SENSITIVITY SETTING
560 PRINT "Amplitude in volts";"   Frequency"
570 PRINT
580 FOR N=0 TO 256
590 IF A(N)<A4 THEN 630
600 A(N)=A5*A(N)
610 PRINT USING 620 ; A(N),F4(N)
620 IMAGE 1X,D.DDDDDDDD,10X,DDDDDD.DD
630 NEXT N
631 PRINT USING 632
632 IMAGE 3/
640 CLEAR @ BEEP
641 ! SORT
642 ! SORT
643 ! SORT
650 DISP "How many modes do you desire to track (MAX OF 9)"
660 INPUT M ! NUMBER OF MODES
670 FOR N=1 TO M
680 CLEAR @ BEEP
690 DISP "What is center freq for mode ";N
700 INPUT M(N) ! CENTER FREQ
710 CLEAR @ BEEP
720 DISP "What is freqwidth for mode ";N
730 DISP "MUST BE GREATER THAN ";2*F3 ! F3 IS BW
740 INPUT O(N) ! FREQ-WIDTH
750 NEXT N
760 CLEAR
761 ! From 770 to 960 is the first rough try for measuring (SORT)
770 FOR L=1 TO M
771 DISP "I am working in SORT for mode ";L
780 FOR N=0 TO 25
790 F4(N)=M(L)-O(L)/2+N*O(L)/25
800 F4$=VAL$(F4(N))
810 OUTPUT 717 ;H2$,F4$,H1$
820 WAIT 12*T1+100
830 OUTPUT 709 ;"VT3"
831 WAIT 50
840 ENTER 709 ; A(N)
850 NEXT N
851 BEEP
860 GCLEAR @ CLEAR
870 SCALE F4(0)-.1*O(L),F4(25)+.1*O(L),-.1,1.2
880 XAXIS 0,O(L)/10,F4(0),F4(25)
890 YAXIS F4(0),.1,0,1.2
```

```
900 FOR N=0 TO 25
920 PLOT F4(N),A(N)
930 NEXT N
940 MOVE F4(0),-.1
941 LABEL "MODE ";L;" ";F4(0);" TO ";F4(25)
942 DISP "DO YOU WANT A COPY?    (Y/N)" @ BEEP
943 INPUT K$
944 IF K$="N" THEN 987
945 GCLEAR @ CLEAR @ BEEP
946 DISP "ENTER FIGURE # TO BE PRINTED"
947 INPUT L$
954 PLOTTER IS 705
955 PEN 1
956 SCALE F4(0)-.2*O(L),F4(25)+.1*O(L),-.3,1.3
957 XAXIS 0,O(L)/10,F4(0),F4(25)
958 YAXIS F4(0),.1,0,1.2
959 PEN 2
960 FOR N=0 TO 25
962 PLOT F4(N),A(N)
963 NEXT N
964 PENUP @ PEN 1
965 LDIR 0,SIN(90)
966 FOR X=F4(0) TO F4(25) STEP O(L)/10 @ PENUP
967 MOVE X,-.13
968 LABEL VAL$(X)
969 NEXT X
970 LDIR 0 @ PENUP
971 FOR Y=0 TO 1.2 STEP .1 @ PENUP
972 MOVE F4(0)-.08*O(L),Y
973 LABEL VAL$(Y)
974 NEXT Y
975 LDIR 0 @ PENUP
976 MOVE F4(0)+.1*O(L),-.21
977 LABEL "FREQUENCY IN HZ"
978 LDIR 0 @ PENUP
979 MOVE F4(0)-.1*O(L),-.3
980 LABEL "PLOT OF RELATIVE AMPLITUDE VS FREQUENCY, MODE ";L
981 LDIR 0,SIN(90) @ PENUP
982 MOVE F4(0)-.17*O(L),.3
983 LABEL "RELATIVE AMPLITUDE "
984 LDIR 0 @ PENUP
985 MOVE F4(0)+.1*O(L),1.2
986 LABEL "FIGURE ";L$ @ PENUP @ PLOTTER IS 1
987 CLEAR @ BEEP
988 DISP "Do you want to change anything?(Y/N)"
989 INPUT K$
990 IF K$="N" THEN 1200 ELSE 1000
1000 DISP "Change sensitivity?  (Y/N)"
1010 INPUT K$@ CLEAR @ BEEP
1020 IF K$="N" THEN 1060
1030 CLEAR @ BEEP
1040 DISP "Enter new sensitivity setting"
1050 INPUT A5
1060 CLEAR @ BEEP
1070 DISP "Change freqwidth?    (Y/N)"
1080 INPUT K$@ CLEAR @ BEEP
1090 IF K$="N" THEN 1120
1100 DISP "Enter new freqwidth"
1110 INPUT O(L)
1120 CLEAR @ BEEP
```

```
1130 DISP "Change center freq?  (Y/N)"
1140 INPUT K$@ CLEAR @ BEEP
1150 IF K$="N" THEN 1180
1160 DISP "Enter new center freq"
1170 INPUT M(L)
1180 GCLEAR @ CLEAR
1190 GOTO 771
1191 ! From 1200 to 1680 is the first try at getting center freq and the Q
1200 CLEAR @ GCLEAR
1201 DISP "I am working on freq and Q for SORT mode ";L
1210 H,B1,B4,H1,H2,H3,H4=0
1220 B2,B3=50
1230 FOR N=1 TO 24
1240 IF A(N)<A(H) THEN 1280
1241 IF A(N)=A(H) THEN 1242 ELSE 1250
1242 PRINT A(N)
1250 A6(L)=A(N)
1260 F6(L)=F4(N)
1270 H=N
1280 NEXT N
1281 X=A(H)
1282 Y=(A(H+1)-A(H-1))/2
1283 Z=(A(H+1)+A(H-1)-2*X)/2
1284 F6(L)=-(Y/(2*Z))
1285 A6(L)=X+Y*F6(L)+Z*F6(L)^2
1286 F6(L)=F4(H)+F6(L)*(F4(H)-F4(H-1))
1290 A7(L)=A6(L)/SQR(2)
1300 FOR N=0 TO H
1310 IF A7(L)=A(N) THEN 1410
1320 IF A7(L)<A(N) THEN 1370
1330 IF A(N)<B1 THEN 1450
1340 B1=A(N)
1350 H1=N
1360 GOTO 1450
1370 IF A(N)>B2 THEN 1400
1380 B2=A(N)
1390 H2=N
1400 GOTO 1450
1410 B1,B2=A(N)
1420 H1,H2=N
1430 F7=F4(H2)
1440 GOTO 1470
1450 NEXT N
1451 X=(A7(L)-B1)/(B2-B1)
1460 F7=X*(F4(H2)-F4(H1))+F4(H1)
1470 FOR N=H TO 25
1480 IF A7(L)=A(N) THEN 1580
1490 IF A7(L)>A(N) THEN 1540
1500 IF A(N)>B3 THEN 1530
1510 B3=A(N)
1520 H3=N
1530 GOTO 1620
1540 IF A(N)<=B4 THEN 1570
1550 B4=A(N)
1560 H4=N
1570 GOTO 1620
1580 B3,B4=A(N)
1590 H3,H4=N
1600 F8=F4(H3)
1610 GOTO 1640
```

```
1620 NEXT N
1621 X=(A7(L)-B4)/(B3-B4)
1630 F8=-(X*(F4(H4)-F4(H3)))+F4(H4)
1640 Q(L)=F6(L)/(F8-F7)
1641 PRINT "MODE ";L;
1642 PRINT "CENTER FREQ IS ";F6(L);" AND AMP IS ";A6(L)*A5
1643 PRINT "Q IS ";Q(L)
1650 IF B1=0 THEN 1655
1651 IF B4=0 THEN 1655
1652 IF B2=50 THEN 1655
1653 IF B3=50 THEN 1655
1654 GOTO 1658
1655 PRINT "3dB POINT NOT FOUND. REPEATING MEASUREMENT. MODE ";L
1656 Q(L)=2*Q(L)
1657 GOTO 771
1658 IF A6(L)>.3 THEN 1664
1659 A8(L)=2*A8(L)
1660 A6(L)=2*A6(L)
1661 IF A8(L)<A1 THEN 1658
1662 A8(L)=A1
1663 GOTO 1671
1664 IF A6(L)<.95 THEN 1671
1665 A8(L)=A8(L)/2
1666 A6(L)=A6(L)/2
1667 GOTO 1664
1671 CLEAR
1672 PRINT USING 1673
1673 IMAGE 5/
1680 NEXT L
1690 CLEAR @ GCLEAR
1691 DISP "I am working on time constant"
1699 ' From 1700 to 1740 the largest Time Constant is found
1700 FOR L=1 TO M
1701 T(L)=Q(L)/(PI*F6(L))
1702 NEXT L
1705 T=T(1)
1710 FOR L=2 TO M
1711 IF T>T(L) THEN 1720
1712 T=T(L)
1720 NEXT L
1750 BEEP @ CLEAR
1755 PRINT "TIME CONST >= ";T*1000
1760 DISP "Set and enter new time constant (in milli-sec)"
1770 DISP "MUST BE GREATER THAN ";T;" sec"
1780 INPUT Y
1781 T1=Y
1782 IF 25*(T1*12+200)>153000 THEN 1783 ELSE 1785
1783 D9=INT(25*(T1*12+200)/51000)
1784 GOTO 1786
1785 D9=3
1786 CLEAR
1791 PRINT "# OF RAVINES IS ";D9
1792 PRINT "NEW TIME CONST IS ";T1
1793 PRINT USING 1794
1794 IMAGE 4/
1795 ! MEASURE
1796 ' MEASURE
1797 ' MEASURE
1798 ' MEASURE
1799 DISP "I am working on standard dev. # of pts. & variance "
```

```
1800 ! From 1800 to 1924 is the calc of the noise, st. dev., and the number of p
ts. used.
1801 G,W=0
1802 F=(F6(2)-F6(1))/4+F6(1)
1803 F4$=VAL$(F)
1804 OUTPUT 717 ;H2$,F4$,H1$
1805 WAIT T1*12+100
1806 OUTPUT 709 ;"VT1"
1807 WAIT 1000
1808 FOR N=1 TO 100
1809 ENTER 709 ; A(N)
1810 W=W+A(N)
1811 NEXT N
1812 W=W/100
1813 FOR N=1 TO 100
1814 S=(A(N)-W)^2
1815 G=G+S
1816 NEXT N
1817 G=A5*SQR(G/99)
1818 W=W*A5
1819 PRINT "The mean is ";W
1820 PRINT "The standard dev is ";G
1821 PRINT USING 1822
1822 IMAGE 4/
1825 FOR L=1 TO M
1830 I(L)=2*A6(L)*A5/(3.3*G)
1835 PRINT "NO. OF POINTS FOR MODE ";L;" IS ";I(L)
1840 IF I(L)<100 THEN 1850
1845 I(L)=100
1850 IF I(L)>50 THEN 1860
1855 I(L)=50
1860 I(L)=IP(I(L))
1861 I(L)=24
1864 PRINT "NO. CHOSEN IS ";I(L)
1865 PRINT
1866 NEXT L
1867 CLEAR @ BEEP
1880 PRINT USING 1881
1881 IMAGE 4/
1885 PRINTER IS 701,132
1887 DIM F$[20]
1888 F$="C-G RAVINE"
1889 GOTO 8999
1890 PRINT USING 1891 ; "TIME","TEMP","PRES","M #","C. FREQ","AMP.","Q","SNR","D
-AMP","# PT",F$
1891 IMAGE 4A,5X,4A,6X,5A,4X,3A,6X,7A,9X,4A,14X,1A,9X,3A,5X,5A,4X,4A,6X,10A
1892 PRINT USING 1893 ; "(SEC)","( K )","(HZ)","(Vrms)","(mV)"
1893 IMAGE 5A,4X,5A,25X,4A,10X,6A,30X,4A,/
1895 CLEAR
1896 ! From 1901 to END is the calculation for measure including center freq and
 Q and track
1897 Q7,Q8=1
1901 ON ERROR GOTO 6000 @ T9=0
1902 FOR L=1 TO M
1903 DISP "I AM IN MEASURE FOR MODE ";L
1906 F1=F6(L)-F6(L)/Q(L)
1907 F2=F6(L)+F6(L)/Q(L)
1908 U(L)=(F2-F1)/I(L)
1909 V(L)=(F2-F1)/2
1910 H=0 @ Q9=F6(L)
```

```
1921 A$=VAL$(A8(L))
1922 OUTPUT 717 ;A2$,A$,A3$
1923 WAIT 200
1924 ENTER 722 ; T6(L)
1925 IF L=1 THEN 1929 ELSE GOTO 7000
1926 GOTO 2650
1929 FOR Y9=0 TO I(L)
1930 X8(Y9)=F6(L)+U(L)*Y9-V(L)
1931 F4$=VAL$(X8(Y9))
1932 H1$="HZ"
1933 H2$="FR"
1934 OUTPUT 717 ;H2$,F4$,H1$
1935 WAIT 12*T1+100
1936 OUTPUT 709 ;"VT3"
1937 ENTER 709 ; X7(Y9)
1938 NEXT Y9
1939 ENTER 722 ; T5(L)
1940 FOR N=0 TO I(L)
1941 F4(N)=X8(N)
1942 A(N)=X7(N)
1943 NEXT N
1973 FOR N=1 TO I(L)-1
1974 IF A(N)<A(H) THEN 1978
1975 IF A(N)=A(H) THEN 1976 ELSE 1977
1976 PRINT A(N)
1977 H=N
1978 NEXT N
1979 X=A(H)
1980 Y=(A(H+1)-A(H-1))/2
1990 Z=(A(H+1)+A(H-1)-2*X)/2
2000 F6(L)=-(Y/(2*Z))
2010 A6(L)=X+Y*F6(L)+Z*F6(L)^2
2020 F6(L)=F4(H)+F6(L)*(F4(H)-F4(H-1))
2030 B1,B4,H1,H2,H3,H4=0
2040 B2,B3=50 @ PRINTER IS 701,132
2290 A7(L)=A6(L)/SQR(2)
2300 FOR N=0 TO H
2310 IF A7(L)=A(N) THEN 2410
2320 IF A7(L)<A(N) THEN 2370
2330 IF A(N)<B1 THEN 2450
2340 B1=A(N)
2350 H1=N
2360 GOTO 2450
2370 IF A(N)>B2 THEN 2400
2380 B2=A(N)
2390 H2=N
2400 GOTO 2450
2410 B1,B2=A(N)
2420 H1,H2=N
2430 F7=F4(H2)
2440 GOTO 2470
2450 NEXT N
2451 IF B2=50 THEN PRINT "COULD NOT FIND 3dB DOWN PARAMETER" @ GOTO 6020
2452 IF B1=0 THEN PRINT "COULD NOT FIND 3dB DOWN PARAMETER" @ GOTO 6020
2459 X=(A7(L)-B1)/(B2-B1)
2460 F7=X*(F4(H2)-F4(H1))+F4(H1)
2470 FOR N=H TO I(L)
2480 IF A7(L)=A(N) THEN 2580
2490 IF A7(L)>A(N) THEN 2540
2500 IF A(N)>B3 THEN 2530
```

```
2510 B3=A(N)
2520 H3=N
2530 GOTO 2620
2540 IF A(N)<=B4 THEN 2570
2550 B4=A(N)
2560 H4=N
2570 GOTO 2620
2580 B3,B4=A(N)
2590 H3,H4=N
2600 F8=F4(H3)
2610 GOTO 2631
2620 NEXT N
2621 IF B3=50 THEN PRINT "COULD NOT FIND 3dB DOWN PARAMETER" @ GOTO 6020
2622 IF B4=0 THEN PRINT "COULD NOT FIND 3dB DOWN PARAMETER" @ GOTO 6020
2629 X=(A7(L)-B4)/(B3-B4)
2630 F8=-(X*(F4(H4)-F4(H3)))+F4(H4)
2631 Q(L)=F6(L)/(F8-F7)
2632 FOR N=1 TO 24
2633 E6(N)=F4(N)
2634 E7(N)=A(N)
2635 NEXT N
2641 PRINTER IS 701,132
2642 CLEAR
2643 IF L=1 THEN 2644 ELSE GOTO 3420
2644 I5=I5+1
2645 Q9=F6(1)/O9
2646 FOR N=2 TO M
2647 F6(N)=Q9*F6(N)*O8
2648 NEXT N
2649 GOTO 3420
2650 FOR N=0 TO M-1
2651 IF L=M-N THEN X1=M-N-1 ELSE 2653
2652 IF X1=0 THEN X1=M
2653 NEXT N
2660 FOR N=1 TO 24
2661 E1(N)=E6(N)
2662 E2(N)=E7(N)
2663 NEXT N
2664 E3=A6(X1)
2665 E4=F6(X1)
2666 E5=Q(X1)
2677 !
2678 !
2679 ! VARY Q
2680 FOR B=1 TO D9
2685 FOR K=1 TO 3
2689 DISP "I AM IN RAVINE FOR Q OF MODE ";X1;" SHOT ";B;".";K
2690 J(1)=E5
2700 J(2)=1.005*E5
2710 J(3)=.995*E5
2711 R=E3
2720 E(K)=0
2730 FOR N=1 TO I(X1)
2740 C(N)=R/(J(K)*SQR((E1(N)/E4-E4/E1(N))^2+(1/J(K))^2))
2750 D=(E2(N)-C(N))^2
2760 E(K)=E(K)+D
2770 NEXT N
2775 CLEAR
2780 NEXT K
2813 V1(X1)=-((E(2)-E(3))/(2*(E(2)+E(3)-2*E(1))))
```

```
2814 E5=J(1)+V1(X1)*.005*J(1)
2876 !
2877 !
2878 !
2879 ! VARY AMP
2880 CLEAR
2881 FOR K=1 TO 3
2889 DISP "I AM IN RAVINE FOR AMPLITUDE OF MODE ";X1;" SHOT ";B;".";K
2890 J(1)=E3
2900 J(2)=1.002*E3
2910 J(3)=.998*E3
2920 E(K)=0
2930 FOR N=1 TO I(X1)
2940 C(N)=J(K)/(E5*SQR((E1(N)/E4-E4/E1(N))^2+(1/E5)^2))
2950 D=(E2(N)-C(N))^2
2960 E(K)=E(K)+D
2970 NEXT N
2975 CLEAR
2980 NEXT K
3020 V1(X1)=-((E(2)-E(3))/(2*(E(2)+E(3)-2*E(1))))
3030 E3=J(1)+V1(X1)*.002*J(1)
3176 !
3177 !
3178 !
3179 ! VARY FREQ
3180 CLEAR
3181 FOR K=1 TO 3
3189 DISP "I AM IN RAVINE FOR FREQUENCY OF MODE ";X1;" SHOT ";B;".";K
3190 J(1)=E4
3200 J(2)=.005*E4/E5+E4
3210 J(3)=-(.005*E4/E5)+E4
3211 R=E3
3220 E(K)=0
3230 FOR N=1 TO I(X1)
3240 C(N)=R/(E5*SQR((E1(N)/J(K)-J(K)/E1(N))^2+(1/E5)^2))
3250 D=(E2(N)-C(N))^2
3260 E(K)=E(K)+D
3270 NEXT N
3275 CLEAR
3280 NEXT K
3305 V1(X1)=-((E(2)-E(3))/(2*(E(2)+E(3)-2*E(1))))
3306 E4=J(1)+V1(X1)*.005*J(1)/E5
3307 NEXT B
3308 !
3309 !
3310 !
3311 ! LAST SHOT RAVINE #
3312 CLEAR
3314 DISP "I AM IN LAST SHOT R"
3316 J1=E3
3318 E=0
3319 FOR N=1 TO I(X1)
3320 C(N)=J1/(E5*SQR((E1(N)/E4-E4/E1(N))^2+(1/E5)^2))
3321 D=(E2(N)-C(N))^2
3322 E=E+D
3323 NEXT N
3326 J1=J1*A5
3327 Y=J1/G
3328 DIM G$[132]
3350 ASSIGN# 1 TO Z$
```

```
3360 T4=TIME
3371 T7=(T5(X1)+T6(X1))/2
3380 P5=-(.00765*((T7-7)/2)^2)+.07055*(T7-7)/2+1.6481
3381 A6(X1)=E3
3382 F6(X1)=E4
3383 Q(X1)=E5
3390 PRINT# 1,I5-1 : T4,P5,T7,X1,E4,J1,E5,Y,A8(X1),I5-1,E
3391 ASSIGN# 1 TO *
3392 G$="5D,2X,3D,3D,2X,D,3DE,2X,2D,4X,3DC3D,5D,4X,D,4DE,6X,3D,4D,3X,3DC3D,3X,4D
,5X,3D,6X,D,4DE"
3393 PRINT USING G$ : T4,P5,T7,X1,E4,J1,E5,Y,A8(X1),I5-1,E
3403 IF X1=L THEN 4981
3405 I5=I5+1
3406 IF Y9<24 THEN OFF TIMER# 1 @ GOTO 3407 ELSE 3415
3407 FOR Y8=Y9 TO I(L)
3408 H2$="FR" @ H1$="HZ"
3409 F4$=VAL$(X8(Y8))
3410 OUTPUT 717 ;H2$,F4$,H1$
3411 WAIT 12*T1+100
3412 OUTPUT 709 ;"VT3"
3413 ENTER 709 ; A(Y8)
3414 NEXT Y8
3415 GOTO 1939
3420 F4$=VAL$(F6(L))
3421 IF L>1 THEN 3422 ELSE 3430
3422 Q9=F6(L)/Q9
3423 IF L=M THEN 3427
3424 FOR N=L+1 TO M
3425 F6(N)=Q9*F6(N)*Q8
3426 NEXT N
3427 FOR N=1 TO L-1
3428 F6(N)=Q9*F6(N)*Q8
3429 NEXT N
3430 A$=VAL$(A8(L))
3431 Q7,Q8=1
3440 OUTPUT 717 ;A2$,A$,A3$
3450 WAIT 200
3460 OUTPUT 717 ;H2$,F4$,H1$
3470 WAIT T1*16+100
3480 OUTPUT 709 ;"VT3"
3490 ENTER 709 ; C8(L)
3491 IF T9=M THEN 3492 ELSE 4978
3492 T9=M+1
3493 X1=L
3494 GOTO 2660
4978 T9=L+1
4980 CLEAR
4981 NEXT L
4982 PRINTER IS 701,132
4983 PRINT USING 4984
4984 IMAGE /
4995 !
4996 !
4997 !
4998 ! TRACK
5000 T9=0
5010 FOR L=1 TO M
5011 DISP "I AM TRACKING MODE ";L
5020 F4$=VAL$(F6(L))
5030 A$=VAL$(A8(L))
```

```
5040 OUTPUT 717 ;A2$,A$,A3$
5041 WAIT 200
5050 OUTPUT 717 ;H2$,F4$,H1$
5060 WAIT T1*16+2000
5061 OUTPUT 709 ;"VT3"
5070 ENTER 709 : A9
5080 IF A9<=.9*C8(L) THEN 5110
5090 IF A9>=1.1*C8(L) THEN 5110
5100 GOTO 5120
5110 T9=L
5120 IF A9>.3 THEN 5210
5130 A8(L)=2*A8(L)
5140 A9=2*A9
5150 IF A8(L)<A1 THEN 5120
5160 A8(L)=A1
5170 GOTO 5250
5210 IF A9<.95 THEN 5245
5220 A8(L)=A8(L)/2
5230 A9=A9/2
5240 GOTO 5210
5245 CLEAR
5250 NEXT L
5260 ENTER 722 : T8
5270 IF ABS(T8-T7)>=.2 THEN 1901
5290 IF T9<1 THEN 5010
5301 T4=TIME
5310 PRINT "GONE TO MEASURE DUE TO AMPLITUDE AT TIME ";T4;"  MODE ";T9
5320 GOTO 1901
6000 ! ERROR ROUTINE
6001 OFF TIMER# 1
6010 PRINT "Error detected, mode ";L;" ERRL = ";ERRL;" ERRN = ";ERRN
6020 H=0
6030 FOR N=1 TO I(L)-1
6040 IF A(N)<A(H) THEN 6080
6050 IF A(N)=A(H) THEN 6060 ELSE 6070
6060 PRINT A(N)
6070 H=N
6080 NEXT N
6090 IF Q8=1 THEN 6095 ELSE 6093
6093 Q7=Q8
6095 Q8=F4(H)
6100 Q8=Q8/F6(L)
6110 Q8=Q8*Q7
6120 F6(L)=F4(H)
6121 F4$=VAL$(F6(L))
6122 A$=VAL$(A8(L))
6123 OUTPUT 717 ;A2$,A$,A3$
6124 WAIT 200
6125 OUTPUT 717 ;H2$,F4$,H1$
6126 WAIT T1*16+2000
6127 OUTPUT 709 ;"VT3"
6128 ENTER 709 ; A9
6129 IF A9>.3 THEN 6135
6130 A8(L)=2*A8(L)
6131 A9=2*A9
6132 IF A8(L)<A1 THEN 6129
6133 A8(L)=A1
6134 GOTO 6139
6135 IF A9<.95 THEN 6139
6136 A8(L)=A8(L)/2
```

```
6137 A9=A9/2
6138 GOTO 6135
6139 CLEAR
6140 OFF ERROR
6141 IF D9>3 THEN 6199
6142 CLEAR @ DISP "I AM GOING THROUGH POINTS FOR MODE ":L
6143 OUTPUT 717 ;A2$,A8(L),A3$
6144 WAIT 200
6145 F1=F6(L)-F6(L)/Q(L)
6146 F2=F6(L)+F6(L)/Q(L)
6147 U(L)=(F2-F1)/I(L)
6148 V(L)=(F2-F1)/2
6149 H=0
6150 FOR N=0 TO I(L)
6151 F4(N)=F6(L)+U(L)*N-V(L)
6152 OUTPUT 717 ;H2$,F4(N),H1$
6153 WAIT 12*T1+100
6154 OUTPUT 709 ;"VT3"
6155 ENTER 709 ; A(N)
6156 NEXT N
6157 FOR N=1 TO I(L)
6158 IF A(N)<A(H) THEN 6160
6159 H=N
6160 NEXT N
6161 IF H=0 THEN CLEAR @ GOTO 6090
6162 IF H=24 THEN CLEAR @ GOTO 6090
6163 X=.707*A(H)
6164 FOR N=0 TO H
6165 IF A(N)<X THEN 6168
6166 NEXT N
6167 CLEAR @ GOTO 6090
6168 FOR N=H TO 24
6169 IF A(N)<X THEN 6172
6170 NEXT N
6171 CLEAR @ GOTO 6090
6172 CLEAR
6199 ON ERROR GOTO 6000
6200 GOTO 1903
7000 FOR Y9=0 TO 25
7001 X8(Y9)=F6(L)+U(L)*Y9-V(L)
7006 NEXT Y9
7007 Y9=0
7010 F4$=VAL$(X8(Y9))
7015 OUTPUT 717 ;H2$,F4$,H1$
7020 ON TIMER# 1,12*T1+100 GOSUB 8000
7025 GOTO 1926
8000 IF Y9>=25 THEN 8025
8001 OFF TIMER# 1
8005 OUTPUT 709 ;"VT3"
8010 ENTER 709 ; X7(Y9)
8015 Y9=Y9+1
8016 H2$="FR" @ H1$="HZ"
8017 F4$=VAL$(X8(Y9))
8018 OUTPUT 717 ;H2$,F4$,H1$
8019 ON TIMER# 1,12*T1+100 GOSUB 8000
8020 IF Y9<25 THEN RETURN ELSE 8025
8025 OFF TIMER# 1
8030 RETURN
8100 IF 25*(T1*12+200)>153000 THEN 8101 ELSE 8103
8101 D9=INT(25*(T1*12+200)/51000)
```

```
8102 GOTO 8104
8103 D9=3
8104 PRINT "# OF RAVINES IS ";D9
8105 GOTO 1885
8990 CLEAR @ GCLEAR
8991 GOTO 9008
8992 DISP "ENTER THE STARTING # PT FOR DATA"
8993 INPUT Y
8994 I5=Y
8995 GOTO 13
8999 DISP "ENTER PREAMP GAIN" @ BEEP
9000 INPUT P$
9001 DISP "ENTER FSS FROM 5204" @ BEEP
9002 INPUT S$
9003 DISP "ENTER MULTIP. FROM 5204" @ BEEP
9004 INPUT M$
9005 PRINT "PREAMP= ";P$;"  FSS=";S$;"  MULTIP=";M$
9006 PRINT
9007 GOTO 1890
9008 DISP "THE END"
9009 END
```

```
1 ! ////////////////////////////////////////////////////////////
2 ! ////// "TMRCAL": THERMOMETER CALIBRATION //////////////////
3 ! ////////////////////////////////////////////////////////////
20 ! VALID ONLY FOR:
30 !   4mmHg < P < 9mmHg
40 ' REQUIRES VOLTMETER (722)
50 ! REQUIRES BARATRON-DAU(709)
60 !
70 DIM R(150).P(150),V(150),T(150)
80 OUTPUT 709 ;"F1"
90 OUTPUT 722 ;"F1"
100 CLEAR @ BEEP 7,300 @ DISP "THERMOMETER CALIBRATION"
120 WAIT 2500
130 CLEAR @ BEEP 7,300 @ DISP "        BIAS CURRENT (uA)"
150 INPUT I
160 PRINT "THERMOMETER CALIBRATION"
170 PRINT
180 PRINT
190 PRINT "BIAS CURRENT=";I;"uA"
200 PRINT
210 PRINT " M    V(V)     T(K)      R(KOHM)"
220 ! CREATE DATA TAPE
230 CLEAR @ BEEP @ DISP "STORE DATA ON TAPE (Y/N)"
250 INPUT R$
255 X6=1
260 IF R$="N" THEN X6=0 @ GOTO 360
270 CLEAR @ BEEP 7.300 @ DISP "FILE NAME (<=6 CHAR.)"
280 INPUT F$
290 DISP
300 DISP
310 DISP "CREATE A NEW DATA FILE (Y/N)"
320 INPUT R$
330 IF R$="N" THEN 350
340 CREATE F$.150,40
350 ASSIGN# 1 TO F$
360 CLEAR @ BEEP 7,300 @ DISP "FIRST DATA PT.#"
370 INPUT A
380 FOR M=A TO A+149
390 ENTER 722 ; P(M)
400 ENTER 709 ; V(M)
401 IF M>=2 THEN 402 ELSE GOTO 410
402 IF ABS(P(M)-P(M-1))<.1 THEN 448
410 R(M)=V(M)*.001/(I*.000001)
420 T(M)=-(.00765*((P(M)-7)/2)^2)+.07055*(P(M)-7)/2+1.6481
430 PRINT USING 435 ; M,V(M),T(M),R(M)
435 IMAGE 3D.1X.1DZ.4D.1X.1DZ.5D.2X.3DZ.5D
440 IF X6#0 THEN PRINT# 1,M ; M,P(M),V(M),T(M),R(M)
447 GOTO 450
448 M=M-1
450 NEXT M
460 ASSIGN# 1 TO *
470 END
```

```
1 ! ////////////////////////////////////////////////////////////////////
2 ! ///////"COOLDN": MONITORS THERMOM ON COOLDOWN //////////////
10 ! "Cool-down" thermometer
20 ! program.  Requires 5316
30 ! counter(#720) and 3438A
40 ! multimeter(#723).
50 !
60 !
100 ! Set-up
110 OUTPUT 720 ;"INWA1"
120 DISP "Enter mode number"
130 INPUT N
140 PRINT " Time    Temp(K)   R(ohms)"
200 ! Data
210 !
220 TRIGGER 720
230 TRIGGER 723
240 ENTER 723 ; R
250 ENTER 720 : F
260 T=.0000248*(F*F)/(N*N)
265 T1=TIME
270 PRINT USING 280 : T1,T,R
280 IMAGE X,5D,2X,DDD.DD,2X,DDDDD
290 WAIT 300000
300 GOTO 220
400 END
```

```
1 ! ////////////////////////////////////////////////////////////////////////
2 ! /////// "P vs t" : PLOTS PRESS REGULATOR TRENDS ////////////
10 DIM P(100)
12 MAT P=(6.6)
15 PRINT "    N       TIME     P(mmHg)"
16 PRINT USING 17
17 IMAGE /
20 FOR N=1 TO 100
25 GCLEAR
30 TRIGGER 709
40 ENTER 709 : P(N)
50 PRINT USING 60 : N,TIME,P(N)
60 IMAGE 2X,3D,5X,5D,4X,D.DDDD
70 GOSUB 300
80 WAIT 240000
90 NEXT N
300 SCALE 1,100,6.75,7.15
305 XAXIS 6.75,10
306 YAXIS 1,.05
310 FOR I=1 TO 100
315 DRAW I,P(I)
325 NEXT I
335 RETURN
400 END
```

APPENDIX B

DATA ANALYSIS COMPUTER PROGRAMS

1) REDUCE..... Uses raw data to calculate upper, lower and reciprocity temperature amplitude oscillations; provides the capability of entering raw data by magnetic tape, by hand or a combination of both.

2) QUICK...... Like REDUCE, except no lower limits are calculated and raw data is entered only by magnetic tape; therefore, a much faster output of reduced data is obtained (Appendix D).

3) KERRY...... Extracts and prints raw data from magnetic tape when a hard copy of this data is required.

4) GETDAT..... A short program used to retrieve and print thermometer calibration data from a magnetic tape.

5) SPLINE..... Incorporates the basic program suggested in reference 38 to compute absolute helium temperature from a given pressure.

```
1 ! ///////////// "REDUCE": He DATA REDUCTION .... WITH T/T
2 ! ///////////// THIS PROGRAM DOES NOT HAVE CUBIC SPLINE TEMPS
3 ! ////////////// THIS PROGRAM DOES NOT HAVE E/E INPUT VOLTAGE CORRECTION
4 ! ////////////// THIS PROGRAM DOES NOT AUTOMATICALLY TAKE CARE OF THERMO. CONST
ANT
5 ! ////////////// TEMPERATURE SWINGS ARE REFERENCED TO THERMAL DRIVE
10 OPTION BASE 1
20 DIM A(5),M(5),Y(5),X(150,2)
30 DIM F(40),M9(40),Q(40),T(40),V0(40),V1(40),Y2(40)
40 ! He DATA REDUCTIN PROGRAM
50 X4=1
70 CLEAR @ BEEP 7,300
80 IF X4=1 THEN 100
90 RETURN
100 X4=0
110 DISP "THIS PROGRAM WILL OBTAIN UPPER  AND LOWER THERMAL LIMITS FROM He DATA.
"
120 DISP @ DISP "RECIPROCITY CALCULATIONS ARE    ALSO PERFORMED."
122 WAIT 7000
124 GOSUB 70
130 DISP "DATA CAN BE ENTERED BY KEYBOARD  AND/OR TAPE."
132 DISP @ DISP "THERMOM. CALIB.,T/T,E/E,T/E DATA WILL BE ENTERED:"
134 DISP @ DISP
135 DISP "    (A) BY TAPE                       (B) BY KEYBOARD                    (C)
 KEYBOARD & TAPE"
136 INPUT L$
137 IF L$="A" OR L$="B" OR L$="C" THEN GOTO 138 ELSE BEEP 70,370 @ GOTO 135
138 IF L$="A" OR L$="C" THEN BEEP @ DISP "INSERT DATA TAPE FOR LATER USE." @ WAI
T 3500
139 GOSUB 70
140 DISP "THERMOMETER CALIBR. AND ALL He  DATA SHOULD BE ON THE SAME TAPE, BUT I
TS NOT REQ'D."
142 DISP
150 DISP "CHANGING RESONATOR DEPENDENT    DATA IS AN AVAILABLE OPTION IN  THIS P
ROGRAM."
155 WAIT 8000
160 GOSUB 70
170 DISP "PART 1:FINDING dR/dT FROM THERMOM. CALIB. DATA."
175 WAIT 4000
180 BEEP @ DISP
190 DISP "PRINT TEMP AND RESIST VALUES ON INPUT.(Y/N)"
200 INPUT R$
210 X6=0 @ IF R$="N" THEN 232
220 IF R$#"Y" THEN 190
230 X6=1
232 IF L$="A" THEN 420
234 IF L$="B" THEN 280
236 CLEAR
240 BEEP 7,300 @ DISP "TEMP vs RESIST DATA FROM KEYBD  OR TAPE. (K/T)"
250 INPUT R$
260 IF R$="T" THEN 420
270 IF R$#"K" THEN BEEP 70,370 @ GOTO 240
280 IF X6#1 THEN 320
290 PRINT
300 PRINT TAB(4);"N";TAB(13);"T(N)";TAB(27);"R(N)"
310 PRINT TAB(13);"(K)";TAB(26);"(KOHM)" @ PRINT
315 GOSUB 70
320 DISP "HOW MANY T&R DATA PAIRS. (2-150)"
330 INPUT N@ DISP
```

```
340 IF N>150 OR N<=1 THEN BEEP 70,370 @ DISP "INVALID NUMBER OF T&R PAIRS" @ GOS
UB 320
342 GOSUB 70
350 FOR I=1 TO N
352 FOR I=1 TO N
360 DISP "T(";I;"),R(";I;")=";
370 INPUT X(I,1),X(I,2)
380 IF X6=1 THEN PRINT USING 390 ; I,X(I,1),X(I,2)
390 IMAGE 4D,3X,3DZ.4D,2X,6DZ.4D
400 NEXT I
402 BEEP @ WAIT 300 @ BEEP
410 DISP "DATA ENTERED" @ WAIT 2000 @ GOTO 610
420 BEEP @ CLEAR @ DISP "RESIST. CALIB. DATA FILE NAME";
430 INPUT F$
440 ASSIGN# 1 TO F$
450 BEEP @ DISP "FIRST ";F$;" DATA PT.#"
460 INPUT K1
470 BEEP @ DISP "LAST ";F$;" DATA PT.#"
480 INPUT K2
490 FOR N=K1 TO K2
500 READ# 1 ; N,P,V,X(N,1),X(N,2)
510 NEXT N
520 ASSIGN# 1 TO *
530 IF X6<>1 THEN 770 ELSE T=1
540 PRINT TAB(4);"N";TAB(13);"T(N)";TAB(27);"R(N)"
550 PRINT TAB(13);"(K)";TAB(26);"(KOHM)" @ PRINT
560 FOR I=K1 TO K2
570 PRINT USING 390 ; I,X(I,1),X(I,2)
580 NEXT I
590 PRINT
600 IF T=1 THEN 770
610 ! CLEAR @ BEEP @ DISP "STORE YOUR!DATA. (Y/N)"
620 ! INPUT R$
630 ! IF R$="N" THEN 770
632 ! IF R$#"Y" THEN BEEP 70,370 @ GOTO 610
640 ! DISP @ BEEP @ DISP "FILE NAME...<7 CHARACTERS"
650 ! INPUT F$
660 ! DISP @ BEEP @ DISP "CREATE ";F$;" FILE.   (Y/N)"
670 ! INPUT R$
680 ! IF R$="N" THEN 700
682 ! IF R$#"Y" THEN 660
690 ! CREATE F$,150,24
700 ! ASSIGN# 1 TO F$
710 ! DISP @ BEEP @ DISP "FIRST ";F$;" DATA PT.#"
720 ! INPUT K1
730 ! FOR M=K1 TO K2
740 ! PRINT# 1 ; M,T,R
750. ! NEXT M
760 ! ASSIGN# 1 TO *
770 ! SETTING UP dR/dT
800 Y(1),Y(3)=INF @ Y(2),Y(4)=-INF @ A(1),A(2),A(3),A(4),A(5)=0
805 IF L$="B" OR R$="K" THEN K1=1 @ K2=N
810 FOR I1=K1 TO K2
820 IF Y(2)<X(I1,1) THEN Y(2)=X(I1,1)
830 IF Y(1)>X(I1,1) THEN Y(1)=X(I1,1)
840 IF Y(4)<X(I1,2) THEN Y(4)=X(I1,2)
850 IF Y(3)>X(I1,2) THEN Y(3)=X(I1,2)
860 A(1)=A(1)+X(I1,1) @ A(2)=A(2)+X(I1,1)*X(I1,1) @ A(3)=A(3)+X(I1,2)
870 A(4)=A(4)+X(I1,2)*X(I1,2) @ A(5)=A(5)+X(I1,1)*X(I1,2)
880 NEXT I1
```

```
885 N=K2-K1+1
890 M(1)=A(1)/N @ M(2)=(A(2)-A(1)*A(1)/N)/(N-1) @ M(3)=A(3)/N
900 M(4)=(A(4)-A(3)*A(3)/N)/(N-1) @ M(5)=(A(5)-A(1)*A(3)/N)/(A(2)-A(1)*A(1)/N)
910 R5=M(3)-M(1)*M(5)
920 GOSUB 70
947 ! EXPONENTIAL REGRESSION BEGINS
950 PRINT @ PRINT
960 IF Y(1)<=0 OR Y(3)<=0 THEN CLEAR @ BEEP 70,370 @ DISP "CAN'T TAKE LOG OF A N
EG.  TEMP." @ GOTO 970
965 GOTO 990
970 DISP
980 DISP "CHECK RESIST. CALIB. DATA AND    ENTER 'Y'  IF YOU WANT TO ENTER NEW D
ATA."
982 INPUT S$
984 IF S$="Y" THEN 315
986 IF S$#"Y" THEN 980
990 Q1=A(3) @ Q2=A(4) @ Q3=A(5) @ A(3),A(4),A(5)=0
1000 FOR I=K1 TO K2
1010 T1=LOG(X(I,1)) @ T2=LOG(X(I,2)) @ A(3)=A(3)+T2 @ A(4)=A(4)+T2*T2
1020 A(5)=A(5)+X(I,1)*T2
1030 NEXT I
1035 N=K2-K1+1
1040 C=M(5) @ D=M(3) @ E=M(4) @ F=R5 @ M(3)=A(3)/N
1050 M(4)=(A(4)-A(3)^2/N)/(N-1) @ M(5)=(A(5)-A(1)*A(3)/N)/(A(2)-A(1)*A(1)/N) @ R
5=M(3)-M(1)*M(5)
1060 S=M(5)*(A(5)-A(1)*A(3)/N)
1070 R2=S/(A(4)-A(3)*A(3)/N)
1080 PRINT USING 1090 ; R2
1090 IMAGE "CORRELATION COEFF.=",2DZ.8D,2/
1100 PRINT USING 1110 ; EXP(R5),M(5)
1110 IMAGE "RHAT=",5DZ.4D,"EXP(",4DZ.4D,"T)"
1130 DISP "CARE TO ESTIMATE A RESISTANCE.     (Y/N)"
1140 INPUT R$
1150 IF R$="N" THEN 1390
1155 IF R$#"Y" THEN 1130
1160 PRINT @ PRINT
1162 DISP @ BEEP
1170 DISP "WANT ESTIMATE AND RESIDUALS FOR ALL PREVIOUSLY ENTERED DATA.      (Y/N
)"
1180 INPUT R$
1190 IF R$="N" THEN 1290
1192 IF R$#"Y" THEN BEEP @ GOTO 1170
1200 PRINT "  T(I)     R(I)     RHAT     RESID"
1210 PRINT
1220 FOR I=K1 TO K2
1230 Y=FNV(X(I,1))
1240 PRINT USING "2DZ.3D,4DZ.2D,4DZ.2D,4DZ.3D" ; X(I,1),X(I,2),Y,X(I,2)-Y
1250 NEXT I
1252 G8=0 @ PRINT
1260 CLEAR @ BEEP @ DISP "...EST. FOR ANY OTHER TEMP.(Y/N)"
1270 INPUT R$
1280 IF R$="N" THEN 1390
1281 IF R$#"Y" THEN BEEP 70,370 @ GOTO 1260
1282 IF G8=1 THEN 1310
1290 PRINT "    T(I)            RHAT"
1310 CLEAR @ BEEP @ DISP "YOU WANT RESIST. AT TEMP.="
1320 INPUT T
1330 Y=FNV(T)
1340 PRINT USING "2DZ.5D,5X,4DZ.5D" : T,Y
1342 G8=1
```

```
1350 GOTO 1260
1360 DEF FNV(X)
1370 FNV=EXP(R5+M(5)*X)
1380 FN END
1390 GOSUB 70
1400 DISP "OBTAINING EXPRESSION FOR dR/dT"
1410 WAIT 1500
1420 Y=EXP(R5)*M(5) @ PRINT @ PRINT
1430 PRINT USING 1440 ; Y,M(5)
1440 IMAGE "dR/dT=",5DZ.3D,"EXP(",4DZ.4D,"T)"
1450 GOSUB 70
1460 DISP "PART 2: UPPER & LOWER LIMITS      FROM T/T DATA."
1470 ! THE LOWER LIMIT PART
1475 DISP
1480 DISP "ENTER I(BIAS) USED IN THERMOM.     CALIB. (uA)"
1490 INPUT B2
1491 IF L$="A" THEN 1790
1492 IF L$="B" THEN 1540
1493 GOSUB 70
1500 DISP "TH/TH DATA FROM KEYBD. OR TAPE.(K/T)"
1510 INPUT R$
1520 IF R$="T" THEN 1790
1530 IF R$#"K" THEN 1500
1540 GOSUB 70
1550 DISP "FIRST T/T DATA PT.#"
1560 INPUT K3
1570 BEEP @ DISP "LAST T/T DATA PT.#"
1580 INPUT K4
1590 GOSUB 70
1600 X6,Z,X3=0
1605 DISP "WILL YOU ENTER TEMP OR PRESS      VALUES.  (T/P)"
1607 INPUT R$
1610 FOR I5=K3 TO K4
1620 CLEAR @ BEEP @ DISP "F(";I5;"),Vout(";I5;"),Q(";I5;"),  Vi(";I5;")="
1630 INPUT F(I5),VO(I5),Q(I5),V1(I5)
1640 IF X6=1 THEN 1690
1650 IF Z=1 THEN 1760
1680 IF R$="T" THEN Z=1 @ GOTO 1760 ELSE X6=1
1690 GOSUB 1710
1700 GOTO 1750
1701 DISP "PART 1:FINDING dR/dT FROM THERMOM. CALIB. DATA."
1710 BEEP @ DISP @ DISP "ENTER PRESSURE"
1720 INPUT P
1730 T=-(.00765*((P-7)/2)^2)+.07055*(P-7)/2+1.6481
1732 Z1=1
1740 RETURN
1750 T(I5)=T @ GOTO 1920
1760 DISP "T(";I5;")="
1770 INPUT T(I5)
1780 Z=1 @ GOTO 1920
1790 GOSUB 70
1800 DISP "T/T DATA FILE NAME."
1810 INPUT F$
1830 DISP "T/T....FIRST ";F$;" DATA PT.#"
1840 INPUT K3
1850 DISP "T/T....LAST ";F$;" DATA PT.#"
1860 INPUT K4
1862 X3=0
1865 ASSIGN# 1 TO F$
1868 I5=1
```

```
1870 FOR H5=K3 TO K4
1880 READ# 1.H5 ; T1.T.P.M.F.V0.Q.S.V1.H5.C
1890 T(I5)=T @ V0(I5)=V0 @ V1(I5)=V1 @ Q(I5)=Q @ F(I5)=F
1920 Y2(I5)=FNU(T(I5))
1922 IF X3=1 THEN 2420
1930 ! THE UPPER LIMIT PART
1940 GOSUB 70
1950 DISP "NOTE:";
1960 DISP " (1)RESONATOR GEOMETRY IAW...                LAB BOOK P.29"
1970 DISP " (2)CONSTANTS ARE REF. TO               T= 1.65K"
1980 DISP @ DISP
1990 G1=2.0564 @ G2=56.406 @ C1=.1453 @ C2=2041 @ C3=1.867
2000 DISP "DIAM.(SQU'D)=";G1;"SQR. cm"
2010 DISP "HEATER RESIST.=";G2;"Ohms"
2020 DISP "He DENSITY=";C1;"g/cc"
2030 DISP "SPEED (U2)=";C2;"cm/S"
2040 DISP "SPEC. HEAT (Cp)=";C3;"J/(g-K)"
2050 DISP @ BEEP 7,300
2060 DISP "CHANGE ANYTHING ?? (Y/N)"
2070 INPUT R$
2080 IF R$="N" THEN 2410
2082 IF R$#"Y" THEN 2060
2090 GOSUB 70
2100 DISP "DIAMETER...(Y/N)"
2110 INPUT R$
2120 IF R$="N" THEN 2160
2122 IF R$#"Y" THEN 2100
2130 DISP "ENTER DIAMETER: (cm)"
2140 INPUT G
2150 G1=G^2
2160 BEEP @ DISP "HEATER RESIST...(Y/N)"
2170 INPUT R$
2180 IF R$="N" THEN 2220
2182 IF R$#"Y" THEN 2160
2190 DISP "ENTER HEATER RESIST: (Ohms)"
2200 INPUT G
2210 G2=G
2220 CLEAR @ BEEP @ DISP "IS THAT ALL. (Y/N)"
2230 INPUT R$
2240 IF R$="Y" THEN 2410
2242 IF R$#"N" THEN 2220
2250 CLEAR @ BEEP @ DISP "He DENSITY.... (Y/N)"
2260 INPUT R$
2270 IF R$="N" THEN 2310
2272 IF R$#"Y" THEN 2250
2280 DISP "ENTER He DENSITY: (g/cc)"
2290 INPUT C
2300 C1=C
2310 CLEAR @ BEEP @ DISP "SPEED (U2)....(Y/N)"
2320 INPUT R$
2330 IF R$="N" THEN 2370
2332 IF R$#"Y" THEN 2310
2340 DISP "ENTER SPEED: (cm/s)"
2350 INPUT C
2360 C2=C
2370 CLEAR @ BEEP @ DISP "SPEC. HEAT....(Y/N)"
2380 INPUT R$
2390 IF R$="N" THEN 2410
2392 IF R$#"Y" THEN 2370
2394 DISP "ENTER SPEC. HEAT... J/(g-K)"
```

```
2396 INPUT C
2398 C3=C
2410 X3=1
2420 I5=I5+1
2430 NEXT H5
2435 ASSIGN# 1 TO *
2440 DEF FNU(T)
2450 FNU=M(5)*EXP(R5)*1000*EXP(M(5)*T)
2460 FN END
2470 GOSUB 70
2480 DISP "PART 3: RECIPROCITY" @ DISP
2482 IF L$="A" THEN 2700
2484 IF L$="B" THEN 2520
2490 ! THE E/E PART
2492 X7,Z1=0
2494 DISP "E/E DATA FROM KEYBD. OR TAPE (K/T)"
2496 INPUT B$
2500 IF B$="T" THEN 2700
2510 IF B$#"K" THEN BEEP 70,370 @ GOTO 2494
2520 DISP @ BEEP @ DISP "FIRST  E/E DATA PT.#"
2530 INPUT K5
2540 DISP @ BEEP @ DISP "LAST  E/E DATA PT.#"
2542 INPUT K6
2544 DISP @ BEEP @ DISP "ENTER DRIVER CAPACITANCE: (pf)"
2546 INPUT G
2552 GOSUB 70
2554 DISP "WILL YOU ENTER TEMP OR PRESS VALUES. (T/P)"
2556 INPUT R$
2560 FOR I5=K5 TO K6
2570 CLEAR @ BEEP @ DISP "F(";I5;"),Vout(";I5;"),Q(";I5;"),      Vi(";I5;")="
2580 INPUT F(I5),V0(I5),Q(I5),V1(I5)
2590 IF Z1=1 THEN 2650
2630 IF R$="T" THEN 2670
2640 IF R$#"P" THEN 2554
2650 GOSUB 1710
2660 T(I5)=T @ GOTO 2690
2670 DISP "T(";I5;")="
2680 INPUT T(I5)
2690 GOTO 2800
2700 DISP @ BEEP @ DISP "E/E DATA FILE NAME"
2710 INPUT F$
2712 CLEAR @ BEEP @ DISP "CAPACITANCE SIDE A"
2714 INPUT P1
2716 BEEP @ DISP @ DISP "CAPACITANCE SIDE B"
2718 INPUT P2
2720 ASSIGN# 1 TO F$
2730 DISP @ BEEP @ DISP "E/E....FIRST ";F$;" DATA PT.#"
2740 INPUT K5
2750 DISP @ BEEP @ DISP "E/E....LAST ";F$;" DATA PT.#"
2760 INPUT K6
2762 DISP @ BEEP @ DISP "E/E...DRIVING SIDE A OR B. (A/B)"
2763 INPUT A$
2764 IF A$="A" THEN G=P1 @ U9=P2
2765 IF A$="B" THEN G=P2 @ U9=P1
2767 I5=10
2770 FOR H5=K5 TO K6
2780 READ# 1,H5 : T1,T,P,M,F,V0,Q,S,V1,H5,C
2790 F(I5)=F @ V0(I5)=V0 @ Q(I5)=Q @ V1(I5)=V1 @ T(I5)=T
2795 I5=I5+1
2800 NEXT H5
```

```
2860 ! DEVELOPING  (MA*MB)
2892 IF B$="K" OR L$="B" THEN 2910
2900 ASSIGN# 1 TO *
2910 ! DEVELOPING  MA/MB
2920 ! ENTERING T/EA & T/EB DATA
2930 X6=0
2940 GOSUB 70
2941 IF X6=0 THEN N$="A"
2942 IF X6=1 THEN N$="B"
2943 IF L$="A" THEN 3100
2944 IF L$="B" THEN 3000
2945 IF X6=1 THEN 2960
2950 DISP "T/EA DATA FROM KEYBD. OR TAPE.      (K/T)" @ DISP
2952 IF X6=0 THEN 2970
2960 DISP "T/EB DATA FROM KEYBD. OR TAPE.      (K/T)" @ DISP
2970 INPUT R$
2980 IF R$="T" THEN 3100
2990 IF R$#"K" THEN BEEP 70,370 @ GOTO 2940
3000 DISP "FIRST  T/E";N$;"  DATA PT.#"
3002 IF X6=1 THEN INPUT K9@ GOTO 3020
3010 INPUT K7
3020 BEEP @ DISP "LAST  T/E";N$;"  DATA PT.#"
3022 IF X6=1 THEN INPUT B1@ GOTO 3040
3030 INPUT K8
3040 IF X6=1 THEN 3222
3042 GOSUB 70
3050 FOR I5=K7 TO K8
3060 DISP "Vout(";I5;"),Vi(";I5;")="
3070 INPUT V0(I5),V1(I5)
3080 NEXT I5
3090 GOTO 3220
3100 DISP "T/E";N$;" DATA FILE NAME"
3110 INPUT F$
3120 ASSIGN# 1 TO F$
3130 DISP @ BEEP @ DISP "T/E";N$;"....FIRST ";F$;" DATA PT.#"
3132 IF X6=1 THEN INPUT K9@ GOTO 3150
3140 INPUT K7
3150 DISP @ BEEP @ DISP "T/E";N$;"....LAST ";F$;" DATA PT.#"
3152 IF X6=1 THEN INPUT B1@ GOTO 3170
3160 INPUT K8
3170 IF X6=1 THEN 3280
3175 I5=20
3180 FOR H5=K7 TO K8
3190 READ# 1,H5 ; T1,T,P,M,F,V0,Q,S,V1,H5,C
3204 V0(I5)=V0 @ V1(I5)=V1
3205 I5=I5+1
3206 NEXT H5
3210 ASSIGN# 1 TO *
3220 X6=1 @ GOTO 2940
3222 GOSUB 70
3230 FOR I5=K9 TO B1
3240 DISP "Vout(";I5;"),Vi(";I5;")="
3250 INPUT V0(I5),V1(I5)
3260 NEXT I5
3270 GOTO 3330
3280 I5=30
3285 FOR H5=K9 TO B1
3290 READ# 1,H5 ; T1,T,P,M,F,V0,Q,S,V1,H5,C
3300 V0(I5)=V0 @ V1(I5)=V1
3305 I5=I5+1
```

```
3310 NEXT H5
3320 ASSIGN# 1 TO *
3330 ! CALCULATIONS START HERE
3340 PRINT @ GOSUB 70
3350 DISP "NOW TO PUT IT ALL TOGETHER"
3352 U=0 @ WAIT 2500
3354 GOSUB 70
3356 J5=10 @ J6=20 @ J7=30
3360 FOR I5=1 TO K4-K3+1
3370 W=IP(F(I5)/100) ! T/T
3380 L=VO(I5)/(-(B2*.000001*Y2(I5)))
3385 V1(I5)=.0290666667+1.0488675*V1(I5)
3390 U=8*Q(I5)*(V1(I5)*.001)^2/(PI^2*G1*G2*C1*C2*C3*SQR(2)*W)
3400 ! E/E
3410 V1(J5)=.0290666667+1.0488675*V1(J5)
3412 VO(J5)=VO(J5)*(1+B4/U9)
3420 RO=VO(J5)*W*PI*G1*C2*C3*C1/(V1(J5)*.001*16*F(J5)*G*.000000000001*Q(J5)*T(J5
))
3430 ! T/EA
3435 V1(J6)=.0290666667+1.0488675*V1(J6)
3438 VO(J6)=VO(J6)*(1+B4/P1)
3440 R8=VO(J6)/(V1(J6)*.001)^2
3445 PRINT "V1(";J5;")=";V1(J5)
3446 PRINT "VO(";J5;")=";VO(J5)
3447 PRINT "RO=";RO
3450 ! T/EB
3455 V1(J7)=.0290666667+1.0488675*V1(J7)
3458 VO(J7)=VO(J7)*(1+B4/P2)
3460 R9=VO(J7)/(V1(J7)*.001)^2
3470 B8=R8/R9
3472 H8=(V1(I5)/V1(J6))^2
3474 H9=(V1(I5)/V1(J7))^2
3475 PRINT "T/EA...Vout/(Vin)^2=";R8
3476 PRINT "T/EB...Vout/(Vin)^2=";R9
3477 PRINT "V(TA)/V(TB)=";B8
3480 M1=VO(J6)/SQR(RO*B8)
3490 M2=VO(J7)*B8/SQR(RO*B8)
3492 M1=M1*H8
3494 M2=M2*H9
3500 IF W=0 THEN U=U+1
3510 IF U=3 THEN 4044
3520 PRINT @ PRINT "       MODE ";W @ PRINT
3530 PRINT "LOWER LIMIT= ";L/.000001;"uK"
3540 PRINT "delta T(A)= ";M1/.000001;"uK"
3550 PRINT "delta T(B)= ";M2/.000001;"uK"
3560 PRINT "UPPER LIMIT= ";U/.000001;"uK"
3565 PRINT
3570 IF L<=M1 AND M1<=U AND L<=M2 AND M2<=U THEN PRINT "MODE ";W;" HAS CORRECT D
ISTRIBUTION."
3575 IF L>U THEN PRINT "MODE ";W;" HAS REVERSED LIMITS."
3580 IF M1<L OR M1>U THEN PRINT "MODE ";W;" HAS RECIPROCITY BEYOND LIMITS."
3581 PRINT "ABS. SENS.(A)=";SQR(RO*B8)
3582 PRINT "ABS. SENS.(B)=";SQR(RO*B8)/B8
3585 FOR I=1 TO 32
3590 PRINT "*";
3595 NEXT I
4042 IF U#3 THEN 4046
4044 I5=K4
4046 J5=J5+1 @ J6=J6+1 @ J7=J7+1
4050 NEXT I5
```

```
4052 IF U=3 THEN BEEP 70,370 @ DISP "NO MORE DATA."
4062 GOSUB 70
4064 FOR I=1 TO 5
4070 DISP
4080 NEXT I
4090 DISP TAB(11);"THAT'S ALL"
5000 END
```

```
1 ! ////////////////////////////////////////////////////////////////
2 ! //////// QUICK .....He DATA REDUCTION /////////////////////
3 ! ///////// THIS PROGRAM HAS ALL CORRECTIONS AS OF 7 SEP 83
4 ! /////////////////////////////////////////////////////////////////
10 OPTION BASE 1
30 DIM F(40),G(13),Q(40),T(40),V0(40),V1(40),K(13),B(25),Z(29),D(4)
35 INTEGER I,J,K
38 U$="X"
39 ! //////// SETTING UP (40-100) ////////
40 CLEAR @ BEEP @ DISP "DO YOU DESIRE COLUMN HEADINGS."
42 INPUT V$
44 IF V$#"Y" AND V$#"N" THEN 40
50 X4=1
70 CLEAR @ BEEP 7,300
72 IF X4=1 THEN 76
74 RETURN
76 X4=0
82 DISP "CHANGING  'ONLY'  DATA POINTS ? (Y/N)"
84 INPUT P$@ IF P$="Y" THEN 108
86 IF P$#"N" THEN CLEAR @ GOTO 82
92 CLEAR @ BEEP @ DISP "E/E AND T/E DATA WILL BE ENTERED:" @ DISP @ DISP
94 DISP "    (A) BY TAPE                          (B) BY KEYBOARD"
96 DISP "    (C) BY KEYBOARD & TAPE"
97 INPUT L$
98 IF L$="A" OR L$="B" OR L$="C" THEN GOTO 100 ELSE BEEP 70,370 @ GOTO 92
100 IF L$="A" OR L$="C" THEN CLEAR @ BEEP @ DISP "INSERT DATA TAPE." @ WAIT 4500

101 ! //////// INPUT (102-116) ////////
102 CLEAR @ BEEP @ DISP "ENTER FOUR ARGUEMENTS"
104 DISP @ DISP @ DISP "  RUN #, FILE NAME, CAP'S  A,B"
106 INPUT R,F$,P1,P2
108 CLEAR @ BEEP @ DISP "ENTER 3 PAIR OF DATA END-POINTS (6 ARGUEMENTS) FOR:"
110 DISP @ DISP "   E/E, T/EA, T/EB"
112 INPUT K5,K6,K7,K8,K9,B1
114 DISP @ BEEP @ DISP "DRIVING SIDE A OR B ?"
116 INPUT A$
230 X6=1
904 DISP @ DISP
1930 ! //////// SQR. AREA & RESISTANCE ////////
1990 G1=2.0564 @ G2=56.406
2410 X3=1
2720 ASSIGN# 1 TO F$
2725 ! //////// SET CAPACITANCE ////////
2730 IF A$="A" THEN G=P1 @ U9=P2
2740 IF A$="B" THEN G=P2 @ U9=P1
2750 I5=10
2760 IF U$="Y" THEN 2770
2765 Y=0
2769 ! //////// READ E/E DATA ////////
2770 FOR H5=K5 TO K6
2780 READ# 1,H5 ; T1,T,P,M,F,V0,Q,S,V1,H5,C
2785 CLEAR @ DISP "IN SEARCH OF...TEMPERATURE" @ GOSUB 6000
2786 Y=4
2790 F(I5)=F @ V0(I5)=V0 @ Q(I5)=Q @ V1(I5)=V1 @ T(I5)=T
2795 I5=I5+1
2800 NEXT H5
2900 ASSIGN# 1 TO *
2930 X6=0
2941 IF X6=0 THEN N$="A"
```

```
2942 IF X6=1 THEN N$="B"
3120 ASSIGN# 1 TO F$
3170 IF X6=1 THEN 3280
3175 I5=20 @ Y=4
3178 ! /////// READ T/EA DATA ////////
3180 FOR H5=K7 TO K8
3190 READ# 1,H5 ; T1,T,P,M,F,V0,Q,S,V1,H5,C
3195 CLEAR @ DISP "GONE FISHIN' FOR...TEMPERATURE" @ GOSUB 6000
3204 V0(I5)=V0 @ V1(I5)=V1 @ T(I5)=T @ F(I5)=F @ Q(I5)=Q
3205 I5=I5+1
3206 NEXT H5
3210 ASSIGN# 1 TO *
3220 X6=1 @ GOTO 2941
3280 I5=30 @ Y=4
3283 ! //////// READ T/EB DATA ////////
3285 FOR H5=K9 TO B1
3290 READ# 1,H5 ; T1,T,P,M,F,V0,Q,S,V1,H5,C
3295 CLEAR @ DISP "WAIT...FINDING TEMPERATURE" @ GOSUB 6000
3300 V0(I5)=V0 @ V1(I5)=V1 @ T(I5)=T @ F(I5)=F @ Q(I5)=Q
3305 I5=I5+1
3310 NEXT H5
3320 ASSIGN# 1 TO *
3330 ! //////// SET HEADINGS (3331-3362) ////////
3331 PRINTER IS 701,132
3332 PRINT CHR$(27)&"&k2S"
3334 IF V$="N" THEN PRINT @ GOTO 3345
3340 PRINT @ GOSUB 70
3342 PRINT TAB(58);"RUN # ";R
3344 PRINT TAB(56);"DATA REDUCTION" @ PRINT @ PRINT
3345 PRINT " E/E  (";K5;" TO ";K6;") "
3346 PRINT " T/EA (";K7;" TO ";K8;")     ";"T/EB (";K9;" TO ";B1;")"
3347 IF V$="N" THEN PRINT @ GOTO 3365
3350 B$="Ua - Ub"
3353 PRINT @ PRINT USING 3354 ; "T","r","F","r","STr","STu",B$,"S(A)","S(B)","ST
u/STr",">1"
3354 IMAGE 10X,1A,11X,1A,2(10X,1A),8X,3A,9X,3A,7X,7A,2(9X,4A),8X,7A,7X,2A
3355 PRINT USING 3356 ; "avg","avg","avg"
3356 IMAGE 9X,3A,20X,3A,30X,3A
3357 PRINT USING 3358 ; "MODE","(K)","(K)","(Hz)","(Hz)","(uK)","(uK)","(uK)","(
V/K)","(V/K)"
3358 IMAGE 4A,5X,3A,9X,3A,2(7X,4A),6X,4A,2(8X,4A),10X,5A,8X,5A
3360 FOR I=1 TO 132
3361 PRINT "_";
3362 NEXT I
3363 IF U$="Y" THEN 3365
3364 U7=0
3365 J6=20 @ J7=30
3366 ! //////// CALCULATIONS ////////
3367 FOR J5=10 TO K6-K5+10
3370 W=IP(F(J5)/200) ! ....................... MODE
3385 V1(J6)=.0290666667+1.0488675*V1(J6)
3388 W9=0 @ GOSUB 7000
3390 U=8*Q(J6)*(V1(J6)*.001)^2/(PI^2*G1*G2*C1*SQR(2)*W) ! ...........STu(A)
3392 W9=2 @ GOSUB 7000
3400 U8=8*Q(J7)*(V1(J6)*.001)^2/(PI^2*G1*G2*C1*SQR(2)*W) ! .......... STu(B)
3410 V1(J5)=-.28676+.99319*V1(J5)
3412 V0(J5)=V0(J5)*(1+84/U9)
3415 W9=1 @ GOSUB 7000
3417 ! //////// PROD. of SENS's ////////
3420 R0=V0(J5)*W*PI*G1*C1/(V1(J5)*.001*16*F(J5)*G*.000000000001*Q(J5)*T(J5))
```

```
3438 V0(J6)=V0(J6)*(1+84/P1)
3440 R8=V0(J6)/(V1(J6)*.001)^2
3450 ! T/EB
3455 V1(J7)=.0290666667+1.0488675*V1(J7)
3458 V0(J7)=V0(J7)*(1+84/P2)
3460 R9=V0(J7)/(V1(J7)*.001)^2
3470 B8=R8/R9
3472 H8=1
3474 H9=(V1(J6)/V1(J7))^2
3480 M1=V0(J6)/SQR(R0*B8) ! .................. ST(A)
3490 M2=V0(J7)*B8/SQR(R0*B8) ! ............... ST(B)
3492 M1=M1*H8
3494 M2=M2*H9
3496 S1=SQR(R0*B8) ! ................ ABS. SENS.(A)
3498 S2=SQR(R0*B8)/B8 ! ///////// ABS. SENS.(B)
3520 F1=(F(J5)+2*F(J6)+2*F(J7))/3
3530 T=(T(J5)+T(J6)+T(J7))/3
3532 C3=SQR((T(J5)^2+T(J6)^2+T(J7)^2)/3-T^2) ! ................. st. dev. TEMP
3534 S8=(U+U8)/2 ! .................. avg STu
3535 C4=SQR((F(J5)^2+(2*F(J6))^2+(2*F(J7))^2)/3-F1^2) ! ........ st. dev. FREQ
3536 IF M2<=S8 THEN H$="YES"
3537 IF M2>S8 THEN H$="NO"
3539 S9=U-U8
3540 ! //////// OUTPUT ////////
3541 PRINT USING 3550 ; W,T,C3,F1,C4,M2/.000001,S8/.000001,S9/.000001,S1,S2,S8/M
2,H$
3550 IMAGE 3D,2(5X,1D.4D),4X,4D.3D,4X,1D.3D,3(4X,4D.3D),7X,3D.2D,7X,3D.2D,7X,3D.
3D,7X,3A
4046 J6=J6+1 @ J7=J7+1
4050 NEXT J5
4052 CLEAR @ BEEP @ DISP "MORE DATA"
4054 INPUT U$@ IF U$="Y" THEN 40
4056 IF U$#"N" THEN 4052
4060 CLEAR
4064 FOR I=1 TO 5
4070 DISP
4080 NEXT I
4090 BEEP @ DISP TAB(11):"THAT'S ALL"
5000 END
5999 ! //////// CUBIC SPLINE TEMP SUBR. ////////
6000 IF Y=4 THEN 6080
6020 FOR I=1 TO 29
6030 READ Z(I)
6040 NEXT I
6050 FOR I=1 TO 25
6060 READ B(I)
6070 NEXT I
6080 P=P*1000
6110 P=LGT(P)
6120 T1=1 @ T2=4.215
6130 X=(T1+T2)/2
6140 I=0 @ J=22
6150 K=(I+J)/2
6160 IF J-I<=1 THEN 6200
6170 IF X>Z(K+4) THEN 6190
6180 J=K @ GOTO 6150
6190 I=K @ GOTO 6150
6200 FOR I=1 TO 4
6210 D(I)=B(I+J-1)
6220 NEXT I
```

```
6230 FOR K=1 TO 3
6240 FOR I=1 TO 4-K
6250 P8=X-Z(I+J+K-1)
6260 P9=Z(I+J+3)-X
6270 P3=1/(Z(I+J+3)-Z(I+J+K-1))
6280 D(I)=(P8*D(I+1)+P9*D(I))*P3
6290 NEXT I
6300 NEXT K
6310 IF ABS(D(1)-P)<.0001 THEN 6370
6320 IF D(1)>P THEN 6350
6330 T1=X
6340 GOTO 6130
6350 T2=X
6360 GOTO 6130
6370 T=X
6380 RETURN
6390 DATA 1,1,1,1
6400 DATA 1.15105499,1.2876575,1.43202085,1.59832713,1.74054982,1.89959361,2.101
7899
6410 DATA 2.17601406,2.18321995,2.28846654,2.57937753,2.74048335,2.88959932,3.04
057357
6420 DATA 3.18965645,3.34056636,3.47966198,3.63056679,3.77966011,3.92027624,4.07

6430 DATA 4.125,4.125,4.125,4.125
6440 DATA 2.0792053,2.2904182,2.64118049,3.06764295,3.43487191,3.74460242,4.0167
357
6450 DATA 4.26906294,4.45301104,4.55807916,4.62414591,4.76041382,4.92371929,5.07
893104
6460 DATA 5.18829011,5.28706835,5.37948565,5.46374572,5.54338324,5.61826745,5.68
927627
6470 DATA 5.75653645,5.82003175,5.86106883,5.88081358
6999 ! ///////// THERMODYNAMIC CONSTANT SUBR. /////////
7000 IF U7=1 THEN 7080
7020 FOR I=1 TO 13
7030 READ G(I)
7040 NEXT I
7050 FOR I=1 TO 13
7060 READ K(I)
7070 NEXT I
7080 IF W9=0 THEN W5=T(J6)
7090 IF W9=1 THEN W5=T(J5)
7095 IF W9=2 THEN W5=T(J7)
7100 FOR I=1 TO 13
7110 IF W5<G(I) THEN 7145
7140 NEXT I
7145 L=I
7150 C1=K(L-1)-(K(L-1)-K(L))/(G(L-1)-G(L))*(G(L-1)-W5) ! ..... LINEAR INTERPOL
7155 U7=1
7160 RETURN
7170 DATA 1.4,1.45,1.5,1.55,1.6,1.65,1.7,1.75,1.8,1.85,1.9,1.95,2
7180 DATA 223.61,274.73,333.03,399.27,472.97,554.27,643.58,738.02,837.52,939.43
7190 DATA 1039.44,1133.34,1213.43
```

```
1 ! ////////////////////////////////////////////////////////////////////
2 ! //////// "KERRY": TRANSFERS DATA FROM TAPE TO PRINTER //////
3 ! ////////////////////////////////////////////////////////////////////
10 CLEAR @ PRINTER IS 701,132
20 DISP "REMOVE PROGRAM TAPE AND INSTALL DATA TAPE" @ BEEP
30 DISP "WHEN COMPLETED, ENTER 1"
31 INPUT Y
32 IF Y=1 THEN 300 ELSE CLEAR @ BEEP @ GOTO 30
40 F$="C-G RAVINE"
41 PRINT USING 50 ; "TIME","TEMP","PRES","M #","C. FREQ","AMP","Q","SNR","D-AMP"
,"# PT",F$
50 IMAGE 4A,5X,4A,6X,5A,4X,3A,6X,7A,9X,4A,14X,1A,9X,3A,5X,5A,4X,4A,6X,10A
60 PRINT USING 70 ; "(SEC)","(K)","(HZ)","(VRMS)","(mV)"
70 IMAGE 5A,4X,5A,25X,4A,10X,6A,
80 PRINT
90 BEEP @ CLEAR @ DISP "DATA FILE NAME";
100 INPUT H$
110 ASSIGN# 1 TO H$
120 BEEP @ DISP "FIRST ";H$;" PT #"
130 INPUT K1
140 BEEP @ DISP "LAST ";H$;" PT #"
150 INPUT K2
160 FOR N=K1 TO K2
170 READ# 1,N ; T1,T,P,M,F,V0,Q,S,V1,N,C
180 IMAGE 5D,4X,D.3D,4X,D.3D,5X,2D,6X,4D.3D,6X,D.4DE,7X,3D.3D,2X,2DC3D.2D,2X,4D.
D,4X,3D,7X,D.4DE
181 PRINT USING 180 ; T1,T,P,M,F,V0,Q,S,V1,N,C
190 IF N=K2 THEN 192 ELSE 191
191 NEXT N
192 BEEP @ DISP "DO YOU WANT TO LOOK AT MORE DATA? Y/N"
193 INPUT Z
194 IF Z=Y THEN 300 ELSE GOTO 195
195 ASSIGN# 1 TO *
200 END
300 DISP "ENTER PREAMP GAIN" @ BEEP
310 INPUT P$
320 DISP "ENTER FSS FROM 5204" @ BEEP
330 INPUT S$
340 DISP "ENTER MULTIP FROM 5204" @ BEEP
350 INPUT M$
360 DISP "ENTER TRANSMIT/RECEIVE" @ BEEP
370 INPUT K$
380 DISP "ENTER RUN NUMBER" @ BEEP
390 INPUT Z$
400 DISP "ENTER FIG NUMBER" @ BEEP
410 INPUT W$
415 FOR I=1 TO 132
416 PRINT "*";
417 NEXT I
420 PRINT "PREAMP=";P$,"FSS=";S$,"MULTIP=";M$,K$,"RUN#";Z$,"FIG#";W$
430 PRINT
440 GOTO 40
```

```
1 ! /////// "GETDAT": PULLS THERMOM CAL DATA FROM TAPE /////////
2 ! //////////////////////////////////////////////////////////////
10 ASSIGN# 1 TO "DATA11"
20 FOR I=1 TO 8
30 READ# 1,I : I,P,V,T,R
40 PRINT USING 45 : I,V,T,R
45 IMAGE 3D,1X,1DZ.4D,1X,1DZ.5D,2X,3DZ.5D
55 NEXT I
65 ASSIGN# 1 TO *
75 END
```

```
6000 ! //////// "SPLINE": CUBIC SPLINE TEMP FROM PRESS /////////
6001 ! //////////////////////////////////////////////////////////
6005 DIM B(25),Z(29),D(4)
6010 INTEGER I,J,K
6020 FOR I=1 TO 29
6030 READ Z(I)
6040 NEXT I
6050 FOR I=1 TO 25
6060 READ B(I)
6070 NEXT I
6072 CLEAR @ BEEP @ DISP "INPUT VALUE OF PRESSURE(mmHg)."
6074 INPUT P
6076 CLEAR @ DISP "INPUT EXPECTED TEMP" @ INPUT T8
6077 CLEAR @ DISP
6078 DISP "  PRESS     TEMP        TEMP"
6079 DISP "           (TABLE)     (SPLINE)"
6080 P=P*1000
6110 P=LGT(P)
6120 T1=1 @ T2=4.215
6130 X=(T1+T2)/2
6140 I=0 @ J=22
6150 K=(I+J)/2
6160 IF J-I<=1 THEN 6200
6170 IF X>Z(K+4) THEN 6190
6180 J=K @ GOTO 6150
6190 I=K @ GOTO 6150
6200 FOR I=1 TO 4
6210 D(I)=B(I+J-1)
6220 NEXT I
6230 FOR K=1 TO 3
6240 FOR I=1 TO 4-K
6250 P8=X-Z(I+J+K-1)
6260 P9=Z(I+J+3)-X
6270 P3=1/(Z(I+J+3)-Z(I+J+K-1))
6280 D(I)=(P8*D(I+1)+P9*D(I))*P3
6290 NEXT I
6300 NEXT K
6310 IF ABS(D(1)-P)<.0001 THEN 6370
6320 IF D(1)>P THEN 6350
6330 T1=X
6340 GOTO 6130
6350 T2=X
6360 GOTO 6130
6370 D(1)=10^D(1)
6372 DISP USING 6373 : D(1)/1000,T8,X
6373 IMAGE 2DZ.4D, 3X.1D.4D, 6X.1D.4D.7/
6374 DISP @ BEEP @ DISP "ENTERING ANOTHER PRESSURE? (Y/N)"
6376 INPUT B$
6378 IF B$="Y" THEN 6072
6380 IF B$#"N" THEN 6374
6382 CLEAR @ BEEP @ DISP TAB(10);"THAT'S ALL"
6384 END
6390 DATA 1,1,1,1
6400 DATA 1.15105499,1.2876575,1.43202085,1.59832713,1.74054982,1.89959361,2.101
7899
6410 DATA 2.17601406,2.18321995,2.28846654,2.57937753,2.74048335,2.88959932,3.04
057357
6420 DATA 3.18965645,3.34056636,3.47966198,3.63056679,3.77966011,3.92027624,4.07
```

```
6430 DATA 4.125,4.125,4.125,4.125
6440 DATA 2.0792053,2.2904182,2.64118049,3.06764295,3.43487191,3.74460242,4.0167357
6450 DATA 4.26906294,4.45301104,4.55807916,4.62414591,4.76041382,4.92371929,5.07893104
6460 DATA 5.18829011,5.28706835,5.37948565,5.46374572,5.54338324,5.61826745,5.68927627
6470 DATA 5.75653645,5.82003175,5.86106883,5.88081358
```

APPENDIX C

RAW DATA

PREAMP=1000 FSS=100MV MULTIP=X1 EA/EB RUN#14 FIG#1

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP (VRMS)(mV)	Q	SNR	D-AMP	# PT	C-G RAVINE
1178	1.647	6.955	1	410.541	5.3723E-005	447.257	1,859.24	250.0	1	8.0810E-005
1374	1.647	6.970	2	615.491	1.2408E-004	69.055	4,294.21	250.0	2	1.8422E-001
1570	1.648	6.985	3	817.549	9.7666E-005	427.357	3,379.97	250.0	3	3.5883E-004
1766	1.648	6.997	4	1020.198	6.1003E-005	314.598	2,111.18	250.0	4	1.9276E-004
1962	1.649	7.016	5	1222.494	4.8319E-005	216.189	1,672.20	250.0	5	1.9017E-005
2149	1.649	7.017	6	1426.145	3.6346E-005	189.206	1,257.85	500.0	6	4.9847E-004
2494	1.649	7.035	1	410.563	5.3656E-005	445.411	1,856.91	250.0	7	4.5311E-005
2688	1.649	7.032	2	614.967	1.2348E-004	124.968	4,273.28	125.0	8	1.5032E-001
2988	1.649	7.032	2	614.957	1.2673E-004	133.229	4,385.94	125.0	9	1.4070E-001
3190	1.650	7.053	3	817.591	4.8743E-005	427.026	1,686.86	125.0	10	2.0736E-005
3386	1.650	7.058	4	1020.239	6.1393E-005	323.198	2,124.67	250.0	11	9.7127E-005
3582	1.650	7.064	5	1222.538	4.8375E-005	216.047	1,674.13	250.0	12	7.5379E-006
3775	1.650	7.066	6	1426.188	3.6416E-005	188.323	1,260.26	500.0	13	4.6697E-004
4114	1.651	7.079	1	410.575	5.3616E-005	447.244	1,855.52	250.0	14	3.0518E-005
4314	1.651	7.079	2	614.773	1.2298E-004	260.071	4,255.97	62.5	15	7.9941E-002
4517	1.651	7.085	3	817.608	4.8641E-005	424.482	1,683.36	125.0	16	1.2699E-005
4713	1.651	7.088	4	1020.258	6.1308E-005	323.038	2,121.73	250.0	17	8.8040E-005
4913	1.651	7.092	5	1222.553	4.8405E-005	216.394	1,675.20	250.0	18	7.4657E-006
5108	1.652	7.099	6	1426.203	3.6482E-005	187.411	1,262.57	500.0	19	4.3042E-004
5451	1.652	7.103	1	410.581	5.3560E-005	446.828	1,853.57	250.0	20	2.4242E-005
5650	1.652	7.106	2	614.752	9.8822E-005	485.800	3,419.98	31.3	21	6.5543E-004
5854	1.652	7.112	3	817.619	4.8637E-005	424.922	1,683.20	125.0	22	9.7365E-006
6052	1.652	7.115	4	1020.270	6.1225E-005	322.555	2,118.85	250.0	23	8.6328E-005
6252	1.652	7.118	5	1222.566	4.8410E-005	216.457	1,675.35	250.0	24	8.1967E-006
6448	1.652	7.123	6	1426.215	3.6530E-005	186.846	1,264.20	500.0	25	4.4379E-004
7004	1.653	7.130	1	410.589	5.3720E-005	454.124	1,859.13	250.0	26	6.1117E-005
7302	1.653	7.130	1	410.589	5.3710E-005	453.850	1,858.77	250.0	27	6.0964E-005
7504	1.653	7.140	2	614.756	4.9895E-005	492.187	1,726.73	15.6	28	8.5261E-005

PREAMP=100 FSS=100MV MULTIP=X10 E3/EA RUN#14 FIG#2

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP (VRMS)(mV)	Q	SNR	D-AMP	# PT	C-G RAVINE
482	1.659	7.302	1	410.603	1.0100E-004	458.394	210.62	500.0	34	4.9158E-004
1102	1.659	7.302	1	410.603	1.0102E-004	458.561	210.65	500.0	35	4.9141E-004
1307	1.659	7.326	2	614.778	1.0187E-004	489.885	212.42	31.3	36	4.2782E-003
1716	1.659	7.326	2	614.778	1.0197E-004	491.223	212.63	31.3	37	4.2683E-003
1921	1.660	7.345	3	817.650	9.3640E-005	431.947	195.27	250.0	38	9.3867E-005
2125	1.660	7.348	4	1020.332	1.0787E-004	316.011	224.95	500.0	39	4.9960E-004
2325	1.660	7.356	5	1222.748	8.3212E-005	220.554	173.52	500.0	40	8.1658E-006
2519	1.661	7.363	6	1426.063	3.4822E-005	192.996	72.61	500.0	41	3.8978E-003
2869	1.661	7.372	1	410.598	4.9565E-005	456.920	103.36	250.0	42	1.8618E-004
3073	1.661	7.379	2	614.769	5.1365E-005	507.340	107.11	15.6	43	2.1820E-003
3377	1.661	7.379	2	614.768	5.1009E-005	496.331	106.37	15.6	44	2.0143E-003
3583	1.662	7.389	3	817.640	9.3623E-005	431.475	195.23	250.0	45	4.4685E-004
3781	1.662	7.399	4	1020.310	5.7315E-005	324.568	119.52	250.0	46	1.1326E-004
3978	1.662	7.402	5	1222.729	8.3351E-005	221.071	173.81	500.0	47	1.2128E-005
4175	1.662	7.408	6	1426.220	3.4679E-005	185.698	72.32	500.0	48	3.1921E-004

PREAMP=100 FSS=100MV MULTIP=X10 -- T/EA RUN#14 FIG#3

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP (VRMS)(mV)	Q	SNR	D-AMP	# PT	C-6 RAVINE
572	1.663	7.444	1	205.330	1.2048E-004	124.892	332.25	50.0	49	1.6071E-001
770	1.663	7.442	2	307.469	1.2253E-004	110.042	337.92	50.0	50	1.6865E-001
975	1.663	7.442	3	408.812	1.0973E-004	434.278	302.63	50.0	51	4.7166E-004
1178	1.663	7.443	4	510.116	4.7497E-005	327.307	130.99	50.0	52	7.5799E-006
1380	1.664	7.449	5	611.279	2.9348E-005	217.229	80.94	50.0	53	5.7766E-006
1587	1.664	7.452	6	713.234	1.4535E-005	189.340	40.08	50.0	54	7.9015E-006
1785	1.664	7.455	7	814.110	1.4698E-005	303.535	40.53	50.0	55	9.8763E-006
2191	1.664	7.460	1	205.295	8.0047E-005	452.021	220.76	25.0	56	4.8957E-004
2395	1.664	7.463	2	307.369	2.5519E-005	472.238	70.38	12.5	57	3.6652E-003
2597	1.664	7.464	3	408.811	1.0950E-004	432.417	301.99	50.0	58	8.9240E-005
2801	1.664	7.465	4	510.112	4.7508E-005	327.362	131.02	50.0	59	6.7835E-006
3003	1.664	7.466	5	611.276	2.9282E-005	216.637	80.76	50.0	60	4.3406E-006
3209	1.664	7.472	6	713.232	5.7668E-005	188.002	159.04	100.0	61	4.2014E-005
3404	1.664	7.471	7	814.100	5.8371E-005	302.547	160.98	100.0	62	5.7759E-005

PREAMP=100 FSS=100MV MULTIP=X10 T/EB RUN#14 FIG#3

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP (VRMS)(mV)	Q	SNR	D-AMP	# PT	C-6 RAVINE
3761	1.664	7.474	1	205.292	9.9649E-005	456.198	274.82	50.0	63	2.0665E-005
4064	1.664	7.474	1	205.292	9.9640E-005	456.048	274.79	50.0	64	2.0530E-005
4267	1.664	7.476	2	307.375	3.4645E-005	497.076	95.55	12.5	65	6.3169E-005
4470	1.665	7.479	3	408.804	2.6297E-005	431.030	72.52	25.0	66	7.7832E-006
4672	1.665	7.479	4	510.112	6.5831E-005	326.220	181.55	50.0	67	4.3282E-006
4877	1.665	7.483	5	611.375	3.4846E-005	216.959	96.10	50.0	68	2.5225E-004
5083	1.665	7.485	6	713.348	6.0512E-005	187.141	166.88	100.0	69	4.8786E-004
5278	1.665	7.488	7	814.221	3.2539E-005	299.613	89.74	100.0	70	2.6419E-004
5845	1.665	7.491	1	205.290	2.4797E-005	460.469	68.39	25.0	71	7.2761E-006
6149	1.665	7.491	1	205.290	2.4789E-005	460.006	68.36	25.0	72	7.1876E-006
6351	1.665	7.499	2	307.372	3.4754E-005	503.714	95.85	12.5	73	2.6717E-005
6556	1.665	7.497	3	408.799	1.0596E-004	440.636	292.21	50.0	74	3.2138E-004
6759	1.665	7.499	4	510.108	6.5763E-005	326.922	181.36	50.0	75	1.4110E-006
6959	1.665	7.497	5	611.369	3.4810E-005	216.779	96.00	50.0	76	2.3568E-004
7166	1.665	7.496	6	713.347	6.0480E-005	186.958	166.80	100.0	77	4.6125E-004
7362	1.665	7.496	7	814.220	3.2488E-005	299.638	89.60	100.0	78	2.6949E-004

PREAMP=100 FSS=100MV MULTIP=X10 EB/EA RUN#14 FIG#4

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP (VRMS) (mV)	Q	SNR	D-AMP	# PT	C-G RAVINE
1844	1.471	2.886	1	225.944	6.0730E-005	180.979	63.86	500.0	146	4.3409E-002
2473	1.471	2.886	1	225.945	6.0848E-005	181.755	63.99	500.0	147	4.3405E-002
2680	1.471	2.896	2	397.614	1.1540E-004	333.124	121.35	500.0	148	4.4630E-004
2886	1.471	2.900	3	596.191	1.2393E-004	39.305	130.32	250.0	149	1.7931E-001
3095	1.471	2.900	4	791.859	1.2109E-004	217.721	127.34	250.0	150	4.4149E-002
3305	1.472	2.908	5	988.613	6.5895E-005	226.724	69.29	250.0	151	2.3543E-003
3510	1.472	2.909	6	1185.286	5.7196E-005	198.548	60.15	1000.0	152	8.8665E-005
3717	1.472	2.914	7	1381.842	3.0711E-005	223.312	32.30	500.0	153	5.7340E-005
3916	1.472	2.914	8	1576.916	3.5456E-005	295.109	37.29	1000.0	154	1.7420E-005
4282	1.472	2.919	1	1558.791	5.2322E-005	2.176	55.02	3500.0	155	3.7910E-003
4593	1.472	2.919	1	1558.861	5.2326E-005	2.176	55.03	3500.0	156	3.7910E-003
4798	1.472	2.922	2	397.791	5.7572E-005	339.016	60.54	250.0	157	2.3866E-004
5007	1.473	2.928	3	595.991	1.2331E-004	70.520	129.67	125.0	158	1.7590E-001
5218	1.473	2.932	4	792.129	1.1855E-004	194.589	124.66	250.0	159	8.3408E-002
5428	1.473	2.934	5	989.097	6.6080E-005	232.583	69.49	250.0	160	4.7951E-004
5634	1.473	2.940	6	1185.884	5.8519E-005	199.139	61.54	1000.0	161	7.6838E-005
5839	1.474	2.945	7	1382.569	3.0626E-005	222.414	32.21	500.0	162	6.4057E-005
6038	1.474	2.947	8	1577.790	3.5444E-005	294.717	37.27	1000.0	163	1.8516E-005

PREAMP=100 FSS=100MV MULTIP=X10 EB/EA RUN#14 FIG#4

TIME (SEC)	TEMP (K)	-PRES	M #	C. FREQ (HZ)	AMP (VRMS) (mV)	Q	SNR	D-AMP	# PT	C-G RAVINE
1627	1.471	2.899	1	212.541	-.6053E-004	-58.023	-77.52	125.0	136	4.2126E-001
2037	1.471	2.399	1	212.295	-.5602E-004	-43.071	-71.75	125.0	137	3.9478E-001
2247	1.470	2.867	2	397.580	1.1617E-004	344.826	148.78	500.0	138	1.0751E-003
2457	1.469	2.862	3	595.712	1.2426E-004	72.428	159.14	125.0	139	1.5640E-001
2764	1.469	2.862	3	595.682	1.2753E-004	77.147	163.32	125.0	140	1.4844E-001
2976	1.469	2.852	4	791.493	7.7214E-005	314.226	98.89	125.0	141	4.1177E-004
3184	1.469	2.847	5	987.916	6.6476E-005	235.701	85.13	250.0	142	1.6505E-004
3386	1.468	2.843	6	1184.371	5.5440E-005	199.161	71.00	1000.0	143	9.6177E-005
3595	1.468	2.842	7	1380.659	3.0825E-005	223.821	39.48	500.0	144	6.0150E-005
3795	1.468	2.840	8	1575.466	3.5594E-005	296.500	45.58	1000.0	145	1.1072E-005

##

PREAMP=100 FSS=100MV MULTIP=X10 EA/EB RUN#14 FIG#5

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP (VRMS) (mV)	Q	SNR	D-AMP	# PT	C-6 RAVINE
1808	1.476	2.997	1	398.422	6.0673E-005	358.268	2,192.74	250.0	79	6.9689E-005
2013	1.475	2.976	2	597.511	1.2370E-004	44.878	4,470.62	250.0	80	1.3991E-001
2216	1.474	2.954	3	792.865	1.2212E-004	226.171	4,413.66	250.0	81	4.6972E-002
2422	1.474	2.946	4	989.720	7.0541E-005	229.346	2,549.40	250.0	82	1.0413E-003
2627	1.473	2.938	5	1187.178	3.0973E-005	222.857	1,119.38	500.0	83	6.6473E-003
2826	1.472	2.915	6	1382.358	3.7302E-005	228.557	1.348.12	500.0	84	4.8271E-004
3023	1.471	2.899	7	1576.943	4.0116E-005	303.478	1,449.81	1000.0	85	1.8448E-006
3700	1.468	2.842	1	397.275	6.0897E-005	340.619	2,200.86	250.0	86	6.0304E-005
3907	1.468	2.835	2	595.190	1.2293E-004	72.068	4,442.68	125.0	87	1.7130E-001
4213	1.468	2.835	2	595.171	1.2638E-004	77.307	4,567.55	125.0	88	1.5931E-001
4421	1.467	2.820	3	790.949	8.0348E-005	304.479	2,903.82	125.0	89	2.0261E-004
4627	1.467	2.819	4	987.305	7.0328E-005	238.870	2,541.68	250.0	90	1.4932E-004
4831	1.467	2.821	5	1184.615	5.1898E-005	217.713	1,875.63	1000.0	91	1.1473E-002
5037	1.467	2.823	6	1380.018	3.7731E-005	222.172	1,363.60	500.0	92	9.2207E-005
5232	1.467	2.825	7	1574.881	4.0059E-005	294.543	1,447.74	1000.0	93	3.1634E-006
5906	1.469	2.847	1	397.369	6.1000E-005	336.283	2,204.58	250.0	94	7.7867E-005
6113	1.469	2.852	2	595.081	1.2295E-004	144.024	4,443.36	62.5	95	9.5399E-002
6418	1.469	2.852	2.	595.083	1.2561E-004	151.762	4,539.73	62.5	96	8.9233E-002
6624	1.470	2.870	3	791.731	7.9090E-005	299.873	2.858.37	125.0	97	9.3958E-005
6931	1.470	2.870	3	791.732	7.9066E-005	299.523	2,857.48	125.0	98	9.2936E-005
7139	1.470	2.881	4	988.581	6.9696E-005	233.717	2,518.87	250.0	99	5.6483E-004
7450	1.470	2.881	4	988.580	6.9814E-005	234.983	2,523.13	250.0	100	5.4568E-004
7652	1.471	2.891	5	1186.274	5.5701E-005	218.639	2,013.06	1000.0	101	1.6162E-002
8064	1.471	2.891	5	1186.267	5.5910E-005	221.328	2,020.62	1000.0	102	1.6098E-002
8271	1.471	2.901	6	1382.031	7.4883E-005	230.499	2,706.32	1000.0	103	1.9229E-003
8467	1.471	2.901	7	1577.121	3.9999E-005	297.281	1,445.59	1000.0	104	4.7321E-006
9143	1.472	2.908	1	397.822	6.0913E-005	341.071	2,201.44	250.0	105	6.2201E-005
9451	1.472	2.908	1	397.822	6.0919E-005	341.160	2,201.63	250.0	106	6.2170E-005
9656	1.472	2.912	2	595.726	1.2005E-004	333.375	4,338.81	31.3	107	9.0220E-003
9961	1.472	2.912	2	595.725	1.2096E-004	339.594	4,371.64	31.3	108	8.4295E-003
10173	1.472	2.919	3	792.433	7.7971E-005	307.668	2,817.91	125.0	109	1.9590E-004
10376	1.472	2.919	4	989.290	1.1737E-004	162.714	4,241.65	500.0	110	4.2809E-002
10581	1.472	2.922	5	1186.996	9.9262E-005	216.426	3,587.40	2000.0	111	5.0562E-002
10998	1.472	2.922	5	1186.992	9.9521E-005	218.274	3,596.74	2000.0	112	5.0464E-002

Run 15

T= 1.53°

EA/EB

PREAMP= 100 FSS=100mv MULTIP=110

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP. (Vrms)	Q	SNR	D-AMP (mV)	# PT	C-G RAVINE
558	1.539	4.307E+000	1	405.25836	1.2175E-004	247.3145	791	1000	1	6.1187E-002
753	1.539	4.306E+000	2	606.77315	1.2353E-004	133.9092	803	1000	2	6.7318E-002
949	1.539	4.303E+000	3	807.06781	7.6528E-005	318.1870	497	1000	3	1.1597E-003
1147	1.539	4.304E+000	4	1,007.65601	5.9766E-005	293.3300	388	1000	4	1.1637E-003
1345	1.539	4.302E+000	5	1,208.48755	2.6054E-005	276.9710	169	1000	5	3.7399E-004
1534	1.539	4.303E+000	6	1,409.55426	9.9363E-006	289.4748	65	1000	6	8.6439E-005

GONE TO MEASURE DUE TO AMPLITUDE AT TIME 1588.492 MODE 1

COULD NOT FIND 3dB DOWN PARAMETER

2090	1.539	4.302E+000	1	405.27994	8.2836E-005	380.8350	538	500	7	1.0421E-003
2286	1.539	4.299E+000	2	606.64945	1.2206E-004	241.1968	793	500	8	5.2554E-002
2486	1.539	4.298E+000	3	807.04418	7.6411E-005	320.6333	497	1000	9	5.9708E-004
2685	1.539	4.299E+000	4	1,007.68094	5.9094E-005	285.2036	384	1000	10	4.0620E-004
2882	1.539	4.303E+000	5	1.208.51861	4.2292E-005	295.7761	275	2000	11	7.6480E-004
3075	1.539	4.296E+000	6	1,409.73558	2.8513E-005	287.9521	185	3500	12	2.8447E-004

GONE TO MEASURE DUE TO AMPLITUDE AT TIME 3130.296 MODE 1

3422	1.539	4.295E+000	1	405.26371	8.1939E-005	376.4119	533	500	13	4.8784E-004
3618	1.539	4.299E+000	2	606.65064	9.6125E-005	400.7547	625	250	14	5.6629E-004
3817	1.539	4.301E+000	3	807.08492	7.6360E-005	320.1370	496	1000	15	6.9354E-004
4019	1.539	4.301E+000	4	1,007.74889	5.9243E-005	287.1363	385	1000	16	4.1511E-004
4217	1.539	4.305E+000	5	1,208.63369	4.2377E-005	284.5039	275	2000	17	6.6593E-004
4411	1.539	4.306E+000	6	1,409.91306	2.8245E-005	288.6126	184	3500	18	2.5215E-004

GONE TO MEASURE DUE TO AMPLITUDE AT TIME 4467.397 MODE 1

4762	1.539	4.308E+000	1	405.34731	8.2304E-005	376.2451	535	500	19	2.4362E-004

COULD NOT FIND 3dB DOWN PARAMETER

5061	1.539	4.308E+000	1	405.34724	8.2315E-005	376.4501	535	500	20	2.4339E-004
5260	1.539	4.308E+000	2	606.77581	5.1379E-005	409.6290	334	125	21	2.5133E-004
5466	1.539	4.310E+000	3	807.22421	7.7056E-005	312.3438	501	1000	22	3.3716E-004
5666	1.539	4.311E+000	4	1,007.91961	5.9293E-005	286.4070	385	1000	23	3.8713E-004
5864	1.539	4.311E+000	5	1,208.84002	4.2310E-005	283.2952	275	2000	24	4.9920E-004
6059	1.539	4.312E+000	6	1,410.15310	2.8105E-005	286.1372	183	3500	25	2.5658E-004

Run 15

EZ/EA

GONE TO MEASURE DUE TO AMPLITUDE AT TIME 6113.254 MODE 6

COULD NOT FIND 3dB DOWN PARAMETER

6620	1.539	4.309E+000	1	405.40063	6.2691E-005	388.3066	407	500	26	2.2162E-003

COULD NOT FIND 3dB DOWN PARAMETER

6925	1.539	4.309E+000	1	405.40075	6.2752E-005	389.5023	408	500	27	2.2112E-003
7130	1.537	4.263E+000	2	606.61222	4.5013E-005	433.4483	293	125	28	4.5553E-004
7333	1.536	4.235E+000	3	806.79715	6.4937E-005	314.1135	422	1000	29	5.6455E-004
7535	1.534	4.203E+000	4	1,006.91695	5.1066E-005	265.5433	332	500	30	1.0330E-003
7741	1.533	4.173E+000	5	1,207.44429	6.5027E-005	276.7008	423	2000	31	1.0144E-003
7934	1.532	4.150E+000	6	1,407.84448	3.7978E-005	294.4354	247	3500	32	2.3195E-003

GONE TO MEASURE DUE TO AMPLITUDE AT TIME 9908.872 MODE 5

Time	Temp	press.	mode	f	Vout	Q	SNR	Vin (mv)	=	C-C.
10203	1.533	4.179E+000	1	404.96053	6.3842E-005	334.0217	415	500	33	1.2084E-003
10405	1.533	4.177E+000	2	606.28487	4.6350E-005	422.4375	301	125	34	8.3784E-004
10611	1.532	4.148E+000	3	806.11048	6.4280E-005	313.8499	418	1000	35	3.7772E-004
10817	1.531	4.131E+000	4	1,006.27962	5.2326E-005	263.9542	340	500	36	9.1603E-004
11018	1.531	4.127E+000	5	1,206.94399	6.5053E-005	271.4878	423	2000	37	2.0094E-003
11212	1.531	4.125E+000	6	1,407.65800	3.7616E-005	284.7029	244	3500	38	1.3920E-003

GONE TO MEASURE DUE TO AMPLITUDE AT TIME 11360.704 MODE 1

11655	1.531	4.129E+000	1	404.78207	3.6458E-005	386.0625	237	250	39	3.2961E-004
11855	1.531	4.130E+000	2	605.90718	4.5583E-005	422.2190	296	125	40	4.5442E-004
12060	1.531	4.133E+000	3	805.98866	6.4911E-005	304.6058	422	1000	41	2.2427E-003
12265	1.531	4.132E+000	4	1,006.32658	5.2342E-005	256.8240	340	500	42	4.7634E-004
12466	1.531	4.137E+000	5	1,207.12201	6.5391E-005	269.1062	425	2000	43	1.0031E-003
12657	1.532	4.139E+000	6	1,407.88873	3.7832E-005	285.6657	246	3500	44	1.8187E-003

T/EA Run 15

PREAMP= 100 FSS=100mv MULTIP=X10

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP. (Vrms)	Q	SNR	D-AMP (mV)	# PT	C-G RAVINE
1426	1.533	4.165E+000	1	202.47173	7.0650E-005	386.2587	357	25	45	1.5649E-004
1628	1.532	4.156E+000	2	303.06088	1.0504E-004	420.7115	531	25	46	3.0370E-004
1829	1.532	4.145E+000	3	403.11845	3.2022E-005	320.4392	162	25	47	2.0546E-004
2034	1.532	4.145E+000	4	503.24461	3.9907E-005	270.5780	202	25	48	6.4248E-003
2237	1.532	4.144E+000	5	603.81868	4.8723E-005	272.5283	246	50	49	5.0342E-005
2432	1.532	4.145E+000	6	704.06380	5.4844E-005	297.2491	277	100	50	3.5364E-003
GONE TO MEASURE DUE TO AMPLITUDE AT TIME 2489.553 MODE 2										
2785	1.532	4.146E+000	1	202.47544	7.0824E-005	388.3903	358	25	51	3.3513E-004
COULD NOT FIND 3dB DOWN PARAMETER										
3088	1.532	4.146E+000	1	202.47545	7.0806E-005	388.0710	358	25	52	3.3465E-004
3268	1.532	4.151E+000	2	303.07832	2.6279E-005	418.3591	133	13	53	2.9156E-004
3494	1.532	4.148E+000	3	403.13020	3.1983E-005	309.5326	162	25	54	1.0576E-004
3699	1.532	4.149E+000	4	503.30842	3.9540E-005	250.8825	200	25	55	1.1607E-003
3902	1.532	4.151E+000	5	603.85709	4.8737E-005	272.7888	247	50	56	6.1796E-005
4100	1.532	4.150E+000	6	704.11569	5.4801E-005	294.8096	277	100	57	2.4275E-003

T=1.53 °K T/EB

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP. (Vrms)	Q	SNR	D-AMP (mV)	# PT	C-G RAVINE
GONE TO MEASURE DUE TO AMPLITUDE AT TIME 4155.673 MODE 6										
4452	1.532	4.147E+000	1	202.46911	9.7031E-005	389.8695	491	50	58	7.0727E-004
Error detected, mode 2 ERRL = 1980 ERRM = 55										
4862	1.532	4.147E+000	1	202.46912	9.6951E-005	388.8644	490	50	59	6.9855E-004
5063	1.532	4.144E+000	2	303.07603	7.3542E-005	421.4043	372	50	60	2.9594E-004
5266	1.532	4.144E+000	3	403.22495	5.6235E-005	296.5188	284	100	61	1.3171E-003
5469	1.532	4.144E+000	4	503.43100	3.3297E-005	254.4382	168	100	62	8.6769E-005
5676	1.532	4.147E+000	5	603.89437	2.3334E-005	267.7471	118	100	63	4.0175E-005
5874	1.532	4.151E+000	6	704.27995	1.5936E-005	289.2337	81	100	64	1.7446E-005
GONE TO MEASURE DUE TO AMPLITUDE AT TIME 5975.657 MODE 1										
6271	1.532	4.157E+000	1	202.49185	9.7514E-005	393.1862	493	50	65	5.1500E-004
6476	1.532	4.156E+000	2	303.11235	7.3536E-005	421.5481	372	50	66	3.9340E-004
6680	1.532	4.154E+000	3	403.27262	5.6426E-005	297.6555	285	100	67	1.5544E-003
6887	1.532	4.153E+000	4	503.47985	3.3369E-005	257.0193	169	100	68	3.7238E-005
7090	1.532	4.153E+000	5	603.97813	2.3340E-005	267.8227	118	100	69	3.0247E-005
7289	1.532	4.150E+000	6	704.40096	1.5924E-005	291.9000	81	100	70	7.7820E-006

PREAMP= 100 FSS=100mv MULTIP=X10 EA/EB T = 1.95K Run 15

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP. (Vrms)	Q	SNR	D-AMP (mV)	# PT	C-G RAVINE
1668	1.777	2.042E+001	1	360.89830	1.2112E-004	623.7043	1.801	500	71	9.8873E-003
1872	1.777	2.041E+001	2	540.45590	6.6918E-005	546.1371	995	500	72	1.7490E-002
2075	1.777	2.041E+001	3	718.28436	1.0440E-004	476.6407	1,552	500	73	1.9352E-003
2281	1.777	2.042E+001	4	896.83800	6.6851E-005	252.3626	994	500	74	1.3144E-002
2486	1.777	2.043E+001	5	1,076.35295	3.9063E-005	293.8991	581	1000	75	3.6082E-004
2681	1.777	2.043E+001	6	1,254.92225	3.4875E-005	363.7131	519	2000	76	1.2858E-003
Error detected, mode 1 ERRL = 1980 ERRN = 55										
3246	1.776	2.046E+001	1	360.67858	6.7934E-005	765.7112	1,010	250	77	2.7818E-004
3451	1.776	2.047E+001	2	539.83214	6.5029E-005	529.9967	967	500	78	5.1324E-003
3656	1.776	2.047E+001	3	717.38728	5.9447E-005	513.8104	884	250	79	8.4790E-005
3862	1.776	2.048E+001	4	895.78256	6.6711E-005	245.4899	992	500	80	6.6520E-003
4066	1.776	2.049E+001	5	1,075.07730	3.9366E-005	294.5354	585	1000	81	3.1494E-004
4263	1.776	2.050E+001	6	1,253.46822	3.4869E-005	359.3887	519	2000	82	1.4347E-003
COULD NOT FIND 3dB DOWN PARAMETER										
4827	1.776	2.052E+001	1	360.28699	6.7486E-005	754.9505	1,004	250	83	5.2638E-004
COULD NOT FIND 3dB DOWN PARAMETER										
5134	1.776	2.052E+001	1	360.28706	6.7555E-005	757.4384	1,005	250	84	5.1981E-004
5341	1.775	2.053E+001	2	539.15315	6.4341E-005	523.8348	957	500	85	5.2656E-003
5548	1.775	2.054E+001	3	716.51033	6.0024E-005	521.8238	893	250	86	1.3993E-004
5754	1.775	2.054E+001	4	894.69600	6.6748E-005	242.6665	993	500	87	6.6777E-003
5959	1.775	2.055E+001	5	1,073.82880	3.9722E-005	294.8095	591	1000	88	3.1860E-004
6158	1.775	2.055E+001	6	1,252.04177	3.4941E-005	358.3107	520	2000	89	1.5672E-003
6509	1.775	2.056E+001	1	359.96680	6.7246E-005	766.8375	1,000	250	90	1.3919E-003
6713	1.775	2.057E+001	2	538.76764	6.4055E-005	530.4363	953	500	91	5.7108E-003
EB/EA T = 1.95 °K										
6920	1.775	2.057E+001	3	715.99789	6.0333E-005	522.2449	897	250	92	1.2293E-004
7123	1.774	2.058E+001	4	894.10242	6.0792E-005	252.0081	904	500	93	8.2292E-002
7329	1.774	2.058E+001	5	1,073.11317	5.0729E-005	266.1861	754	1000	94	4.5066E-004
7528	1.774	2.059E+001	6	1,251.21594	4.1617E-005	332.1528	619	2000	95	7.0670E-003
7881	1.774	2.060E+001	1	359.71076	5.5179E-005	767.2260	821	250	96	1.5943E-003
8086	1.774	2.060E+001	2	538.40319	5.6699E-005	527.4866	843	500	97	4.4594E-003
8292	1.774	2.061E+001	3	715.50319	5.7593E-005	545.1621	856	250	98	7.1486E-005
8499	1.774	2.061E+001	4	893.42434	5.9592E-005	220.5541	886	500	99	5.9354E-003
8707	1.774	2.062E+001	5	1,072.38714	5.0981E-005	266.1808	758	1000	100	5.5928E-004
8904	1.774	2.062E+001	6	1,250.36289	4.2070E-005	354.4867	626	2000	101	1.6248E-002
9260	1.774	2.063E+001	1	359.47747	5.4578E-005	763.6972	812	250	102	4.0731E-004
9467	1.774	2.063E+001	2	538.06841	5.6073E-005	514.7377	834	500	103	4.5694E-003
9670	1.773	2.064E+001	3	715.05769	5.7870E-005	544.4851	861	250	104	3.1696E-004
9875	1.773	2.065E+001	4	892.84067	5.9858E-005	223.1621	890	500	105	8.0660E-003
10076	1.773	2.065E+001	5	1,071.73192	5.1223E-005	266.2014	762	1000	106	6.0749E-004
10272	1.773	2.065E+001	6	1,249.59383	4.1934E-005	351.2061	624	2000	107	1.7715E-002

Run 15

T=1.3°K   EC/EA

PREAMP= 100 FSS=100mv MULTIP=X10

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP. (Vrms)	Q	SNR	D-AMP (mV)	# PT	C-G RAVINE
1223	1.788	1.275E+001	1	400.27203	6.4345E-005	635.9986	87	350	183	3.6307E-003
1434	1.788	1.276E+001	2	599.11563	1.1799E-004	525.6730	159	350	184	1.5831E-002
1647	1.788	1.276E+001	3	796.31935	5.9109E-005	382.7345	80	350	185	1.9467E-003
1858	1.788	1.277E+001	4	994.49679	9.3185E-005	255.3855	126	700	186	1.6860E-002
2058	1.788	1.278E+001	5	1,194.19908	5.4312E-005	257.7108	73	1400	187	8.4315E-003

COULD NOT FIND 3dB DOWN PARAMETER

2620	1.788	1.280E+001	1	400.10539	6.3768E-005	634.0055	86	350	188	1.4629E-003
2828	1.788	1.281E+001	2	598.85966	6.4348E-005	540.7803	87	175	189	1.3911E-003
3039	1.789	1.281E+001	3	796.02285	5.9868E-005	381.8053	79	350	190	1.1063E-003
3252	1.789	1.282E+001	4	994.13663	9.2515E-005	250.3845	125	700	191	1.3580E-002
3453	1.789	1.282E+001	5	1,193.78456	5.4113E-005	246.6109	73	1400	192	8.2602E-003

T=1.5°K   T|EA

PREAMP= 100 FSS=100mv MULTIP=X10

TIME (SEC)	TEMP (K)	PRES	M #	C. FREQ (HZ)	AMP. (Vrms)	Q	SNR	D-AMP (mV)	# PT	C-G RAVINE
1314	1.789	1.286E+001	1	199.94982	6.8578E-005	633.0589	6	25	193	1.0078E-003
1523	1.789	1.287E+001	2	299.24974	9.6033E-005	556.0446	9	25	194	4.9395E-004
1733	1.789	1.287E+001	3	397.83246	5.0084E-005	382.9991	4	25	195	3.3663E-005
1944	1.789	1.288E+001	4	496.90643	9.6016E-005	255.0396	9	50	196	5.5341E-003
2144	1.789	1.288E+001	5	596.22575	1.1815E-004	173.9125	11	100	197	5.6798E-002

T=1.5°K   T/EB

COULD NOT FIND 3dB DOWN PARAMETER

?.2389E-005

APPENDIX D

REDUCED DATA

RUN # 14
DATA REDUCTION

E/E (82 TO 85)
T/EA (171 TO 174) T/EB (215 TO 218)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
5	1.4543	.0042	987.437	1.688	2.183	2.433	.184	42.55	68.16	1.115	YES
6	1.4540	.0039	1184.183	2.140	1.461	1.649	.066	46.89	13.95	1.129	YES
7	1.4535	.0031	1380.016	1.726	5.485	6.560	-.038	26.09	29.33	1.196	YES
8	1.4533	.0027	1574.573	1.767	5.894	7.158	-.220	18.70	16.54	1.215	YES

E/E (89 TO 93)
T/EA (183 TO 187) T/EB (222 TO 226)

4	1.4528	.0029	790.835	.612	.941	.938	.004	67.94	71.27	.997	NO
5	1.4539	.0042	987.468	1.119	2.193	2.150	-.362	40.01	67.51	.981	NO
6	1.4541	.0043	1184.367	1.004	1.583	1.592	.022	42.34	12.91	1.006	YES
7	1.4543	.0045	1380.522	1.505	1.314	1.466	-.350	25.72	30.33	1.116	YES
8	1.4546	.0048	1575.323	1.640	5.847	7.308	.100	18.87	16.59	1.250	YES

E/E (98 TO 98)
T/EA (182 TO 182) T/EB (221 TO 221)

4	1.4539	.0027	725.735	.	1.680	1.036	-.193	38.03	128.73	.617	NO

E/E (100 TO 101)
T/EA (184 TO 185) T/EB (223 TO 224)

5	1.4553	.0037	987.893	1.215	2.168	2.150	-.362	40.46	68.28	.992	NO
6	1.4557	.0037	1184.920	1.376	1.519	1.592	.022	44.11	13.45	1.048	YES

E/E (102 TO 104)
T/EA (185 TO 187) T/EB (216 TO 218)

6	1.4552	.0043	1184.675	1.709	1.524	1.609	-.012	43.97	13.38	1.056	YES
7	1.4557	.0044	1380.948	1.922	1.338	1.468	-.354	25.25	30.06	1.097	YES
8	1.4560	.0047	1575.780	2.182	5.844	7.313	.090	18.88	16.68	1.251	YES

E/E (106 TO 107)
T/EA (201 TO 202) T/EB (220 TO 221)

2	1.4525	.0032	397.021	.567	2.290	2.039	.026	69.04	24.06	.891	NO
3	1.4522	.0036	594.437	.920	.409	.376	-.005	204.66	132.37	.918	NO

E/E (108 TO 109)
T/EA (203 TO 204) T/EB (213 TO 214)

3	1.4518	.0039	594.329	.987	.412	.379	-.010	203.52	131.66	.920	NO
4	1.4519	.0041	790.552	1.330	.962	.938	-.003	67.68	70.19	.975	NO

RUN # 14
DATA REDUCTION

E/E (151 TO 154)
T/EA (205 TO 208)   T/EB (215 TO 218)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
5	1.4517	.0038	986.551	1.465	.559	.605	.038	42.47	66.59	1.081	YES
6	1.4518	.0037	1183.002	1.655	.335	.417	.026	48.79	14.36	1.174	YES
7	1.4520	.0038	1379.204	1.889	.370	.422	.020	24.63	27.23	1.141	YES
8	1.4520	.0038	1573.783	2.251	.381	.464	.017	18.32	16.01	1.217	YES

E/E (160 TO 163)
T/EA (205 TO 208)   T/EB (223 TO 226)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
5	1.4527	.0044	986.877	1.607	.563	.603	.040	42.21	65.85	1.073	YES
6	1.4530	.0045	1183.444	1.847	.351	.413	.034	49.39	14.57	1.177	YES
7	1.4532	.0046	1379.692	2.120	.367	.421	.021	24.84	27.21	1.150	YES
8	1.4531	.0047	1574.364	2.536	.379	.463	.018	18.44	16.04	1.224	YES

E/E (141 TO 144)
T/EA (183 TO 186)   T/EB (222 TO 225)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
4	1.4535	.0026	791.017	.694	.953	.938	.004	67.09	70.37	.985	NO
5	1.4545	.0038	987.672	1.126	2.190	2.150	-.362	40.05	67.59	.982	NO
6	1.4546	.0040	1184.286	.990	1.432	1.592	.022	46.79	14.26	1.112	YES
7	1.4548	.0042	1380.736	1.463	1.428	1.466	-.350	23.67	27.91	1.027	YES

RUN # 14
DATA REDUCTION

E/E (37 TO 41)
T/EA (57 TO 61) T/EB (65 TO 69)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr - (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
3	1.6633	.0023	614.755	.016	.243	.237	-.012	142.35	196.04	.975	NO
4	1.6636	.0020	817.627	.017	2.434	2.527	.012	61.06	59.43	1.038	YES
5	1.6636	.0019	1020.260	.051	1.429	1.530	.008	45.11	63.41	1.071	YES
6	1.6637	.0019	1222.684	.093	.776	.846	.000	51.23	61.84	1.090	YES
7	1.6639	.0018	1426.408	.261	2.073	2.507	.015	37.75	40.18	1.209	YES

E/E (44 TO 48)
T/EA (57 TO 61) T/EB (73 TO 77)

3	1.6641	.0017	614.751	.013	.243	.239	-.014	142.41	196.74	.981	NO
4	1.6643	.0015	817.620	.017	2.438	2.553	-.040	60.94	59.82	1.047	YES
5	1.6644	.0014	1020.250	.043	1.401	1.531	.008	46.02	64.62	1.092	YES
6	1.6644	.0013	1222.673	.086	.774	.845	.002	51.34	61.91	1.091	YES
7	1.6646	.0012	1426.459	.193	2.034	2.504	.020	38.48	40.94	1.231	YES

E/E (16 TO 19)
T/EA (51 TO 54) T/EB (74 TO 77)

4	1.6606	.0061	817.610	.011	2.452	2.561	-.023	60.72	59.48	1.044	YES
5	1.6607	.0061	1020.235	.018	1.396	1.532	.011	46.17	64.84	1.097	YES
6	1.6607	.0061	1222.617	.086	.735	.847	.006	54.20	65.21	1.152	YES
7	1.6609	.0060	1426.455	.200	.517	.629	.011	38.17	40.30	1.218	YES

E/E (10 TO 13)
T/EA (51 TO 54) T/EB (66 TO 69)

4	1.6600	.0065	817.608	.014	2.450	2.536	.028	60.78	59.03	1.035	YES
5	1.6601	.0064	1020.232	.007	1.398	1.532	.011	46.10	64.81	1.096	YES
6	1.6603	.0064	1222.615	.096	.736	.848	.004	54.13	65.20	1.152	YES
7	1.6603	.0064	1426.451	.208	.519	.630	.009	37.97	40.11	1.213	YES

E/E (20 TO 25)
T/EA (56 TO 61) T/EB (72 TO 77)

2	1.6609	.0059	410.584	.004	1.404	1.336	-.019	77.39	24.31	.952	NO
3	1.6611	.0060	614.745	.005	.253	.239	-.014	136.68	188.82	.942	NO
4	1.6611	.0059	817.613	.010	2.448	2.553	-.040	60.70	59.58	1.043	YES
5	1.6612	.0058	1020.237	.024	1.395	1.531	.008	46.23	64.91	1.097	YES
6	1.6612	.0058	1222.619	.085	.733	.845	.002	54.19	65.35	1.152	YES
7	1.6614	.0057	1426.457	.195	2.052	2.504	.020	38.14	40.58	1.220	YES

RUN # 14
DATA REDUCTION

E/E (20 TO 25)
T/EA (56 TO 61) T/EB (64 TO 69)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(3) (V/K)	STu/STr	>1
2	1.6607	.0058	410.585	.003	1.408	1.331	-.010	77.16	24.38	.945	NO
3	1.6608	.0058	614.747	.006	.253	.237	-.012	136.89	188.52	.938	NO
4	1.6609	.0057	817.616	.005	2.438	2.527	.012	60.95	59.33	1.037	YES
5	1.6610	.0057	1020.240	.022	1.395	1.530	.008	46.20	64.94	1.097	YES
6	1.6611	.0057	1222.623	.090	.734	.846	.000	54.16	65.38	1.153	YES
7	1.6612	.0056	1426.458	.197	2.052	2.507	.015	33.13	40.59	1.221	YES

RUN # 15
DATA REDUCTION

E/E (13 TO 18)
T/EA (45 TO 50)   T/EB (59 TO 64)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5326	.0034	405.048	.152	1.599	1.768	-.017	59.63	21.13	1.106	YES
3	1.5324	.0036	606.308	.242	1.142	1.282	-.005	124.10	22.44	1.123	YES
4	1.5323	.0038	806.591	.360	.553	.705	.055	78.19	8.87	1.276	YES
5	1.5323	.0038	1007.033	.528	.510	.480	.030	105.56	5.69	.941	NO
6	1.5324	.0039	1208.020	.438	1.569	1.645	.030	41.90	5.18	1.048	YES
7	1.5325	.0038	1408.867	.761	4.490	6.115	.174	16.48	4.94	1.362	YES

E/E (20 TO 25)
T/EA (52 TO 57)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5327	.0038	405.094	.180	1.601	1.784	-.020	59.70	21.23	1.115	YES
3	1.5327	.0037	606.386	.277	.279	.320	-.002	126.97	22.99	1.147	YES
4	1.5327	.0038	806.677	.404	.544	.693	.028	79.37	9.05	1.275	YES
5	1.5327	.0038	1007.165	.551	.507	.464	-.011	105.20	5.74	.915	NO
6	1.5328	.0038	1208.170	.484	1.567	1.644	.031	41.97	5.19	1.049	YES
7	1.5327	.0039	1409.063	.807	4.477	6.117	.061	16.52	4.95	1.366	YES

E/E (27 TO 32)
T/EA (45 TO 50)   T/EB (59 TO 64)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5328	.0036	405.094	.217	1.780	1.768	-.017	53.55	18.98	.993	NO
3	1.5318	.0027	606.295	.224	1.179	1.282	-.005	120.26	21.75	1.088	YES
4	1.5312	.0022	806.495	.231	.572	.705	.055	75.61	8.58	1.234	YES
5	1.5306	.0014	1006.756	.190	.360	.480	.030	149.40	8.05	1.332	YES
6	1.5302	.0007	1207.623	.141	1.208	1.645	.030	54.42	6.73	1.362	YES
7	1.5299	.0001	1408.177	.294	3.788	6.115	.174	19.54	5.86	1.614	YES

E/E (33 TO 38)
T/EA (52 TO 57)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5305	.0007	404.965	.014	1.704	1.784	-.020	56.06	19.94	1.047	YES
3	1.5305	.0006	606.222	.052	.289	.320	-.002	122.80	22.24	1.109	YES
4	1.5299	.0002	806.305	.180	.578	.693	.028	74.63	8.51	1.199	YES
5	1.5297	.0005	1006.619	.278	.356	.464	-.011	150.06	8.18	1.305	YES
6	1.5296	.0006	1207.538	.432	1.201	1.644	.031	54.77	6.77	1.369	YES
7	1.5295	.0006	1408.230	.467	3.747	6.117	.061	19.74	5.92	1.632	YES

E/E (39 TO 44)
T/EA (45 TO 50)   T/EB (59 TO 64)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5298	.0008	404.888	.075	1.664	1.768	-.017	57.29	20.31	1.063	YES
3	1.5296	.0005	606.060	.109	1.167	1.282	-.005	121.50	21.97	1.099	YES
4	1.5294	.0003	806.225	.188	.567	.705	.055	76.22	8.65	1.244	YES
5	1.5294	.0003	1006.559	.224	.352	.480	.030	153.04	8.25	1.365	YES
6	1.5296	.0002	1207.516	.285	1.191	1.645	.030	55.19	6.82	1.381	YES
7	1.5297	.0003	1408.192	.278	3.742	6.115	.174	19.78	5.93	1.634	YES

RUN # 15
DATA REDUCTION

E/E (77 TO 82)
T/EA (167 TO 172)   T/EB (159 TO 164)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.9585	.0060	357.331	2.375	1.168	1.101	-.041	58.73	45.92	.943	NO
3	1.9585	.0059	534.768	3.591	.543	.540	.019	158.53	11.79	.994	NO
4	1.9585	.0059	710.752	4.703	.395	.406	.006	218.15	16.22	1.027	YES
5	1.9586	.0058	887.750	5.698	.498	.508	.001	168.46	24.68	1.020	YES
6	1.9587	.0058	1065.346	6.896	.596	.513	-.002	106.30	9.61	.861	NO
7	1.9587	.0057	1241.989	8.127	2.111	2.446	-.351	40.55	9.15	1.158	YES

E/E (84 TO 89)
T/EA (167 TO 172)   T/EB (159 TO 164)

2	1.9588	.0056	357.200	2.191	1.164	1.101	-.041	58.94	46.09	.946	NO
3	1.9588	.0055	534.541	3.271	.542	.540	.019	158.78	11.80	.996	NO
4	1.9589	.0054	710.460	4.291	.396	.406	.006	217.76	16.19	1.025	YES
5	1.9589	.0054	887.388	5.188	.495	.508	.001	169.66	24.85	1.027	YES
6	1.9590	.0054	1064.930	6.309	.593	.513	-.002	106.83	9.66	.865	NO
7	1.9590	.0053	1241.513	7.456	2.104	2.446	-.351	40.70	9.18	1.163	YES

E/E (96 TO 101)
T/EA (167 TO 172)   T/EB (159 TO 164)

2	1.9592	.0050	357.008	1.921	1.241	1.101	-.041	55.30	43.24	.888	NO
3	1.9592	.0049	534.291	2.919	.555	.540	.019	155.17	11.54	.973	NO
4	1.9593	.0049	710.124	3.818	.396	.406	.006	217.99	16.20	1.026	YES
5	1.9593	.0048	886.964	4.591	.478	.508	.001	175.66	25.73	1.063	YES
6	1.9593	.0049	1064.449	5.632	.476	.513	-.002	133.05	12.03	1.077	YES
7	1.9594	.0048	1240.953	6.666	1.826	2.446	-.351	46.89	10.58	1.340	YES

E/E (102 TO 107)
T/EA (167 TO 172)   T/EB (159 TO 164)

2	1.9594	.0047	356.930	1.811	1.244	1.101	-.041	55.16	43.13	.885	NO
3	1.9594	.0047	534.180	2.762	.551	.540	.019	156.30	11.62	.980	NO
4	1.9594	.0047	709.975	3.609	.394	.406	.006	218.76	16.26	1.030	YES
5	1.9595	.0046	886.770	4.317	.480	.508	.001	175.12	25.65	1.060	YES
6	1.9595	.0046	1064.231	5.324	.475	.513	-.002	133.44	12.07	1.080	YES
7	1.9595	.0046	1240.697	6.304	1.819	2.446	-.351	47.06	10.62	1.344	YES

E/E (78 TO 82)
T/EA (177 TO 181)   T/EB (152 TO 156)

3	1.9585	.0059	534.886	3.532	.546	.546	-.007	156.76	11.92	1.000	YES
4	1.9586	.0059	710.902	4.627	.398	.409	-.004	218.19	16.21	1.027	YES
5	1.9586	.0059	887.938	5.604	.499	.510	.004	168.46	24.67	1.023	YES
6	1.9587	.0058	1065.585	6.769	.596	.512	-.004	106.43	9.60	.860	NO
7	1.9587	.0058	1242.281	7.960	2.114	2.428	-.365	40.47	9.17	1.149	YES

RUN # 15
DATA REDUCTION

E/E (13 TO 18)
T/EA (52 TO 57)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5325	.0035	405.066	.140	1.605	1.784	-.020	59.52	21.17	1.111	YES
3	1.5326	.0035	606.344	.219	.286	.320	-.002	124.01	22.46	1.120	YES
4	1.5326	.0036	806.630	.342	.553	.693	.028	78.01	8.89	1.253	YES
5	1.5326	.0036	1007.108	.474	.508	.464	-.011	104.96	5.72	.913	NO
6	1.5327	.0037	1208.101	.389	1.570	1.644	.031	41.90	5.18	1.047	YES
7	1.5326	.0037	1408.982	.698	4.486	6.117	.061	16.48	4.94	1.363	YES

E/E (27 TO 32)
T/EA (52 TO 57)   T/EB (59 TO 64)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5325	.0039	405.097	.215	1.782	1.776	-.003	53.61	18.96	.996	NO
3	1.5318	.0028	606.307	.216	.295	.321	-.003	120.17	21.76	1.086	YES
4	1.5313	.0022	806.502	.222	.571	.693	.029	75.56	8.58	1.213	YES
5	1.5307	.0014	1006.799	.130	.359	.462	-.007	148.71	8.09	1.287	YES
6	1.5303	.0006	1207.649	.148	1.208	1.645	.029	54.43	6.73	1.361	YES
7	1.5299	.0000	1408.212	.292	3.787	6.088	.118	19.53	5.86	1.608	YES

E/E (33 TO 38)
T/EA (45 TO 50)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5308	.0004	404.963	.016	1.703	1.777	-.034	56.00	19.96	1.044	YES
3	1.5306	.0006	606.210	.067	1.153	1.281	-.003	122.89	22.22	1.111	YES
4	1.5299	.0002	806.298	.183	.579	.706	.054	74.67	8.50	1.220	YES
5	1.5296	.0005	1006.576	.284	.357	.482	.026	150.75	8.14	1.350	YES
6	1.5295	.0006	1207.513	.423	1.201	1.644	.032	54.76	6.77	1.369	YES
7	1.5294	.0006	1408.196	.469	3.748	6.144	.116	19.75	5.92	1.639	YES

E/E (39 TO 44)
T/EA (52 TO 57)   T/EB (59 TO 64)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5295	.0004	404.890	.077	1.666	1.776	-.003	57.36	20.28	1.066	YES
3	1.5295	.0004	606.072	.117	.292	.321	-.003	121.41	21.99	1.097	YES
4	1.5295	.0003	806.233	.189	.567	.693	.029	76.17	8.65	1.222	YES
5	1.5295	.0004	1006.602	.219	.350	.462	-.007	152.33	8.29	1.319	YES
6	1.5297	.0003	1207.542	.298	1.191	1.645	.029	55.20	6.32	1.380	YES
7	1.5298	.0003	1408.227	.274	3.740	6.088	.118	19.77	5.93	1.628	YES

RUN # 15
DATA REDUCTION

E/E (85 TO 89)
T/EA (177 TO 181) T/EB (152 TO 156)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
3	1.9588	.0055	534.660	3.215	.545	.546	-.007	157.01	11.94	1.002	YES
4	1.9590	.0054	710.609	4.217	.399	.409	-.004	217.79	16.18	1.025	YES
5	1.9590	.0054	887.576	5.097	.495	.510	.004	169.67	24.85	1.030	YES
6	1.9590	.0054	1065.169	6.186	.593	.512	-.004	106.96	9.65	.864	NO
7	1.9590	.0053	1241.806	7.292	2.106	2.428	-.365	40.61	9.20	1.153	YES

E/E (97 TO 101)
T/EA (177 TO 181) T/EB (152 TO 156)

3	1.9592	.0049	534.410	2.866	.558	.546	-.007	153.44	11.67	.979	NO
4	1.9593	.0049	710.274	3.748	.398	.409	-.004	218.02	16.20	1.026	YES
5	1.9594	.0049	887.152	4.506	.478	.510	.004	175.66	25.73	1.066	YES
6	1.9594	.0049	1064.688	5.514	.476	.512	-.004	133.21	12.02	1.076	YES
7	1.9594	.0048	1241.246	6.508	1.828	2.428	-.365	46.80	10.61	1.328	YES

E/E (103 TO 107)
T/EA (177 TO 181) T/EB (152 TO 156)

3	1.9594	.0047	534.298	2.711	.554	.546	-.007	154.56	11.75	.986	NO
4	1.9595	.0047	710.125	3.541	.397	.409	-.004	218.80	16.26	1.030	YES
5	1.9595	.0047	886.958	4.235	.480	.510	.004	175.12	25.65	1.063	YES
6	1.9596	.0046	1064.470	5.209	.475	.512	-.004	133.59	12.05	1.079	YES
7	1.9596	.0046	1240.990	6.149	1.821	2.428	-.365	46.96	10.64	1.333	YES

E/E (96 TO 97)
T/EA (175 TO 176) T/EB (159 TO 160)

2	1.9592	.0050	356.984	1.941	1.247	1.111	-.022	55.58	43.02	.891	NO
3	1.9592	.0049	534.256	2.948	.553	.536	.010	154.64	11.57	.969	NO

E/E (77 TO 78)
T/EA (175 TO 176) T/EB (159 TO 160)

2	1.9585	.0060	357.306	2.395	1.174	1.111	-.022	59.03	45.69	.947	NO
3	1.9585	.0059	534.732	3.619	.541	.536	.010	157.99	11.83	.990	NO

E/E (84 TO 85)
T/EA (175 TO 176) T/EB (159 TO 160)

2	1.9588	.0056	357.176	2.211	1.170	1.111	-.022	59.24	45.86	.950	NO
3	1.9588	.0055	534.506	3.300	.541	.536	.010	158.24	11.84	.991	NO

RUN # 15
DATA REDUCTION

E/E (20 TO 25)
T/EA (45 TO 50)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr - (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5330	.0035	405.091	.182	1.599	1.777	-.034	59.63	21.26	1.111	YES
3	1.5328	.0037	606.374	.287	1.116	1.281	-.003	127.06	22.98	1.149	YES
4	1.5326	.0038	806.669	.412	.544	.706	.054	79.42	9.04	1.298	YES
5	1.5326	.0039	1007.123	.595	.510	.482	.026	105.69	5.71	.946	NO
6	1.5326	.0039	1208.145	.509	1.567	1.644	.032	41.96	5.19	1.049	YES
7	1.5326	.0039	1409.028	.843	4.478	6.144	.116	16.53	4.95	1.372	YES

E/E (27 TO 32)
T/EA (52 TO 57)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr - (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5327	.0038	405.112	.205	1.787	1.784	-.020	53.46	19.01	.998	NO
3	1.5320	.0026	606.331	.201	.295	.320	-.002	120.18	21.76	1.085	YES
4	1.5315	.0020	806.534	.219	.572	.693	.028	75.43	8.60	1.212	YES
5	1.5309	.0013	1006.831	.153	.359	.464	-.011	148.55	8.10	1.292	YES
6	1.5304	.0005	1207.705	.209	1.209	1.644	.031	54.42	6.73	1.360	YES
7	1.5299	0.0000	1408.293	.393	3.785	6.117	.061	19.54	5.86	1.616	YES

E/E (39 TO 44)
T/EA (45 TO 50)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr - (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5299	.0008	404.903	.087	1.669	1.777	-.034	57.13	20.36	1.065	YES
3	1.5298	.0006	606.085	.132	1.167	1.281	-.003	121.50	21.97	1.098	YES
4	1.5296	.0005	806.257	.228	.568	.706	.054	76.09	8.66	1.243	YES
5	1.5296	.0004	1006.592	.268	.352	.482	.026	152.87	8.26	1.369	YES
6	1.5297	-.0003	1207.572	.344	1.191	1.644	.032	55.19	6.82	1.380	YES
7	1.5297	.0002	1408.273	.387	3.741	6.144	.116	19.79	5.93	1.643	YES

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