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Infrared Radiometer for Measuring Thermophysical Properties of Wind Tunnel Models

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INFRARED RADIOMETER FOR MEASURING THERMOPHYSICAL PROPERTIES OF WIND TUNNEL MODELS

by

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ABSTRACT

This report describes an infrared radiometer which was developed to measure temperature rises of wind tunnel models undergoing transient heating over a temperature range of -17.8°C to 260°C (0°F to 500°F). This radiometer interfaces directly with a system which measures the effective thermophysical property $\sqrt{\rho c k}$. It has an output temperature fluctuation of 0.26°C at low temperatures and 0.07°C at high temperatures, and the output frequency response of the radiometer is from dc to 400 hertz.

Keywords: Thermophysical Properties Measurements
Infrared Temperature Measurements
Infrared Radiometer

FOREWORD

This final report was prepared by Beta Industries, Inc. under Contract NAS1-14678, Development of an Infrared Radiometer for Measuring Thermophysical Properties of Wind Tunnel Models. It covers the period of 15 November 1976 through 15 February 1978. This work was performed for the National Aeronautics and Space Administration, Langley Research Center, under the direction of the High-Speed Aerodynamics Division.

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Section 1

INTRODUCTION AND SUMMARY

Studies have indicated[1,2] the necessity of measuring an effective thermophysical property to describe the thermal and heat transfer characteristics of models subjected to transient heating in a wind tunnel. An electronic system has been developed[3] to measure this effective parameter using an infrared radiometer in combination with an infrared filter and a radiant heating source. This system has proven[4] to be an excellent method for measuring the effective parameter $\sqrt{\rho ck}$; however, future plans require the measurement of the effective parameter with good accuracy from -17.8°C (0°F) to 70°C (158°F). Since the present off-the-shelf radiometer can not measure these temperatures accurately, a specialized radiometer is required with increased accuracy and frequency response.

Under contract with NASA Langley, Beta Industries, Inc. has developed an infrared radiometer which measures temperature rises of wind tunnel models undergoing transient heating over a temperature range of -17.8°C to 260°C (0°F to 500°F). The radiometer has an output temperature fluctuation of 0.26°C r.m.s. at -17.8°C (0°F) and decreases to 0.07°C r.m.s. at 260°C (500°F). This fluctuation is measured with an output frequency response of from dc to 400 hertz.

As shown in Figure 1 the radiometer consists of two separate packages, the radiometer head and the control unit. The radiometer head

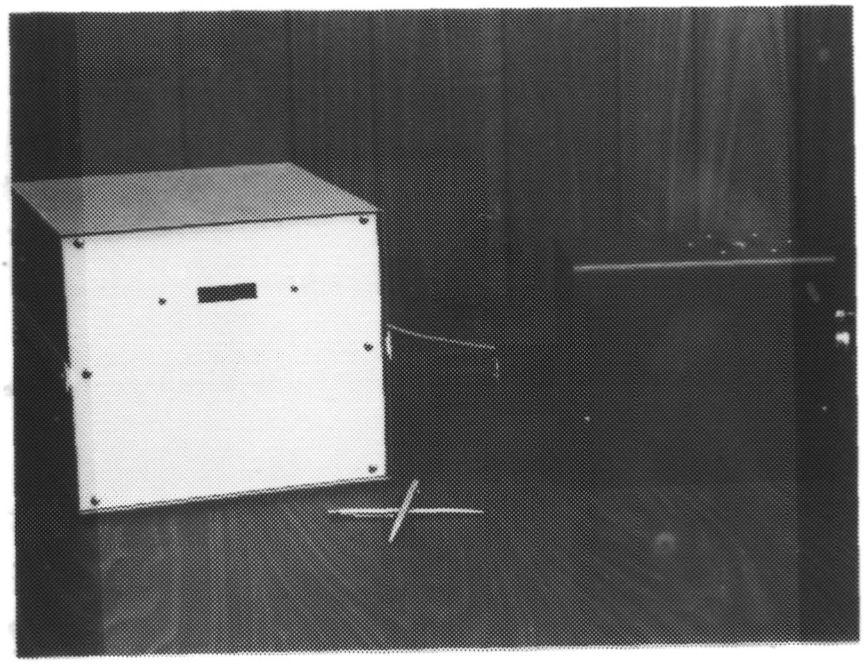


Figure 1. Photograph of Infrared Radiometer Head and Control Unit

contains an infrared detector, tuning fork light chopper, liquid nitrogen dewar, preamplifier electronics, infrared lenses and viewing optics. The control unit houses the power supply for the radiometer head and digital processing electronics for providing a direct digital readout on the front panel.

A standard technique which has proven to be the best infrared radiometer design for many years is to chop the incoming infrared radiation with some type of mechanical chopper. The infrared light is allowed to fall on an infrared detector for alternating half cycles of the chopper frequency. When the chopper blocks the incoming infrared radiation the detector sees a constant infrared source located inside of the radiometer. This usually is a blackbody whose temperature is electronically controlled to a constant value somewhat higher than ambient temperature. The detector output is a sinusoidal signal whose peak to peak value is related to the temperature differences between the target and the internal reference source. The signal is passed through a phase sensitive detector and a low pass filter. A reference signal derived from the mechanical light chopper is used to drive the phase sensitive detector.

The major difference in this design is that a tuning fork chopper is mounted just in front of a HgCdTe infrared detector, and both are mounted on a cold plate inside a liquid nitrogen dewar. Both the detector and the vanes of the chopper are cooled to 77°K. When the tuning fork vanes are closed the detector sees a reference temperature source of only 77°K. Since the radiance of this source is proportional to the absolute temperature to the fourth power, the reference signal is very small and much more stable than a conventional reference consisting of a heated blackbody and control circuitry. For targets whose temperatures are well below ambient this design technique provides for minimum noise and output temperature fluctuation.

Section 2

THEORY OF OPERATION

2.1 Introduction

The radiometer consists of two separate packages, the radiometer head and the control unit. An interconnection cable between the two packages supplies power from the control unit to the radiometer head and allows the output signal to be fed to the digital processor and display electronics contained in the control unit. A separate buffered output signal is fed from the radiometer head through this cable directly to a B.N.C. jack on the back of the control unit. This analog output is fed to the external processor for computation of thermophysical data. This is a 0 to 10 volt signal with a frequency response of dc to 400 hertz. A wiring description of the interconnection cable is given in Appendix A.

The following paragraphs give more detailed descriptions of each of the two packages.

2.2 Radiometer Head

Figure 2 shows a block diagram of the radiometer head. A primary and a secondary lens combination image the target radiation onto the infrared detector. The tuning fork chopper is located just in front of the detector so that the incoming light is chopped at a constant frequency. The output of the detector is a sinusoidal signal whose peak-to-peak value is directly related to the temperature of the target. This signal is passed through an input transformer, preamplifier,

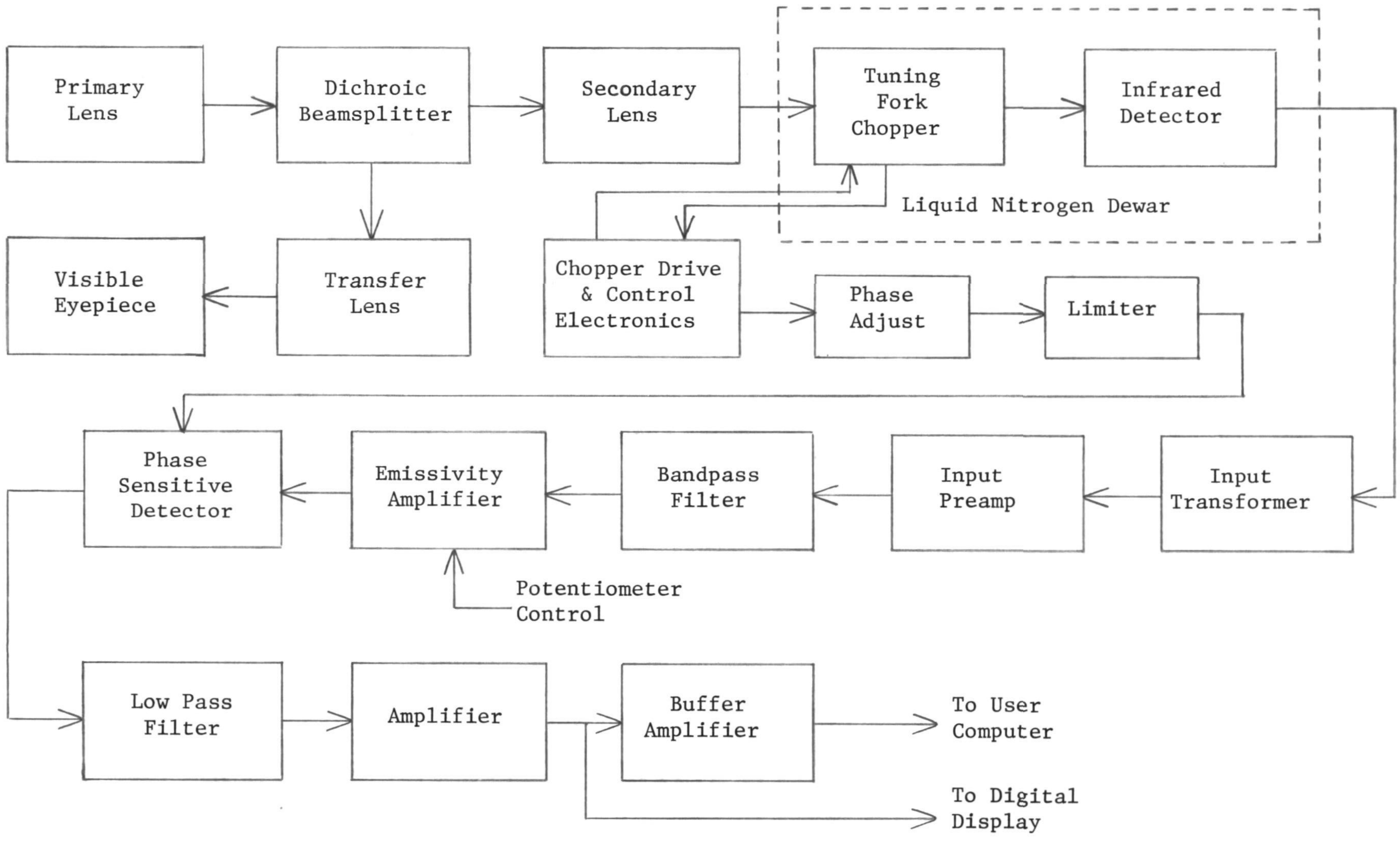


Figure 2. Block Diagram Radiometer Head

bandpass filter, and an emissivity adjust amplifier. A synchronous detector removes the amplitude information from the signal, and the resulting output is passed through a low pass filter with a cutoff frequency at 400 hertz. This signal is amplified to a nominal 10 volt level for a 260°C (500°F) target temperature. Two outputs to the control unit are provided. A dichroic beamsplitter located between the primary and secondary lenses reflects the visible light through a transfer lens and onto a reticle mounted in a focusing eyepiece. This allows the actual target area whose temperature is sampled to be viewed by an observer.

2.2.1 Design Theory

Off-the-shelf infrared radiometers use thermal detectors operating at ambient temperature, which are relatively noisy and have low frequency response. The result is that they have limited accuracy at temperatures below 70°C, particularly if high response time is also required. Since this is a laboratory application these problems can be overcome by using infrared detectors operating at a lower temperature. Three factors which are important in the design of an infrared radiometer are the noise equivalent temperature difference (NEΔT), the response time, and the dynamic range. The noise equivalent temperature difference is the temperature difference which can be resolved by a radiometer at a given temperature when the signal-to-noise is equal to one. The NEΔT is a measure of the output temperature fluctuation of a radiometer, and it is given by the following expression.[5]

$$NE\Delta T = \frac{\lambda^6 T^2 e^{1.44x10^4/\lambda T}}{1.35x10^8 \ \varepsilon t_\lambda \ \Delta\lambda} \left[\frac{\Delta f}{A_D}\right]^{1/2} \left[\frac{1}{\eta D^*}\right] \left[\frac{f}{d}\right]^2 \qquad (1)$$

where

λ = wavelength (microns)

$\Delta\lambda$ = spectral bandwidth of detector (microns)

T = temperature of source (degrees Kelvin)

Δf = noise bandwidth (hertz)

ε = emissivity of source

t_λ = transmission of path

A_D = area of detector

D* = detector figure of merit (cm-(Hz)$^{1/2}$ /watts)

η = effective reduction of geometric area by obstruction and filtering

$[f/d]$ = F number of the optical system

Referring to Equation 1, NEΔT can be minimized by

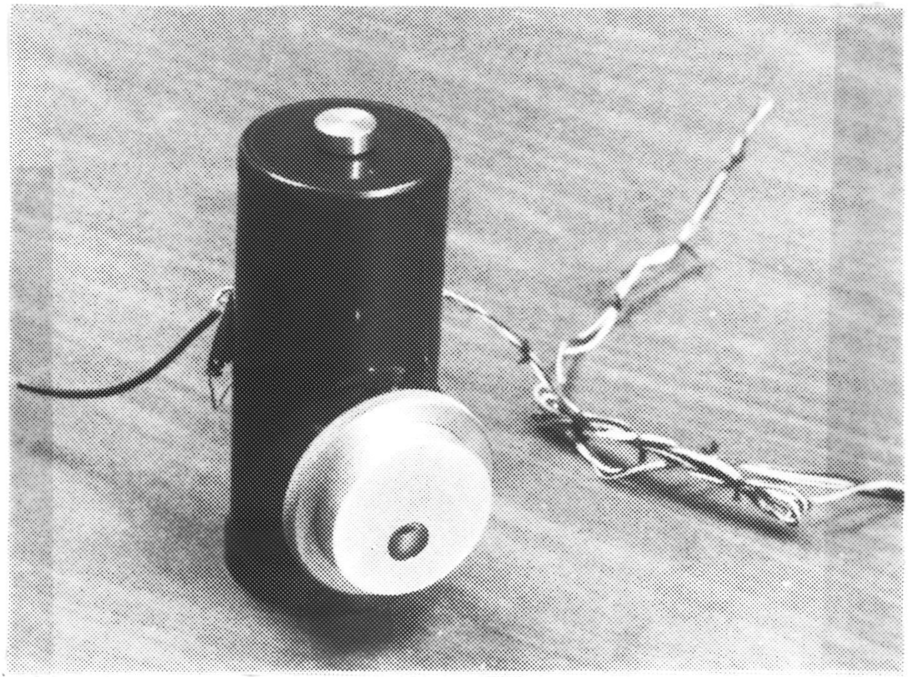
1. Using a long wavelength infrared detector since the exponential term is more significant than the λ^6 term.
2. Using a large spectral bandwidth.
3. Using a detector with a high D* and a large area which matches the image of the sampled source.
4. Maximizing the efficiency of the optics.
5. Using low F number optics.
6. Minimizing the electronic bandwidth under the constraints of this application.

The first three criteria can be satisfied by using a HgCdTe infrared detector operating at 77°Kelvin. It is sensitive over a wide spectral range centered at about 12 microns and has the highest D* at these wavelengths of any known detector. For the given spectral band of this detector Planck's Equation[5] predicts that the infrared radiation detected will increase sharply as the temperature rises. That is the slope of the output signal versus temperature will increase with rising temperature. Therefore carrier interference at the output of the demodulator (low pass filter) will give rise to higher temperature fluctuations at high temperatures. The output low pass filter was designed to suppress the carrier signal low enough to insure a low fluctuation at high temperatures.

2.2.2 Infrared Optics

The primary lens is a 100 mm focal length ZnSe lens mounted in a Pentax 35 mm camera lens housing. This is a focusable lens housing and is removable from the radiometer head.

As shown in Figure 3 the secondary lens is a 12 mm focal length germanium lens which is epoxied in a plate attached to the liquid nitrogen dewar through a vacuum O-ring seal. A germanium beamsplitter is mounted between the two lenses to reflect the visible light through a separate path to an eyepiece. All three of these infrared optical elements have antireflection coatings over the 8 to 12 micrometer wavelength interval.



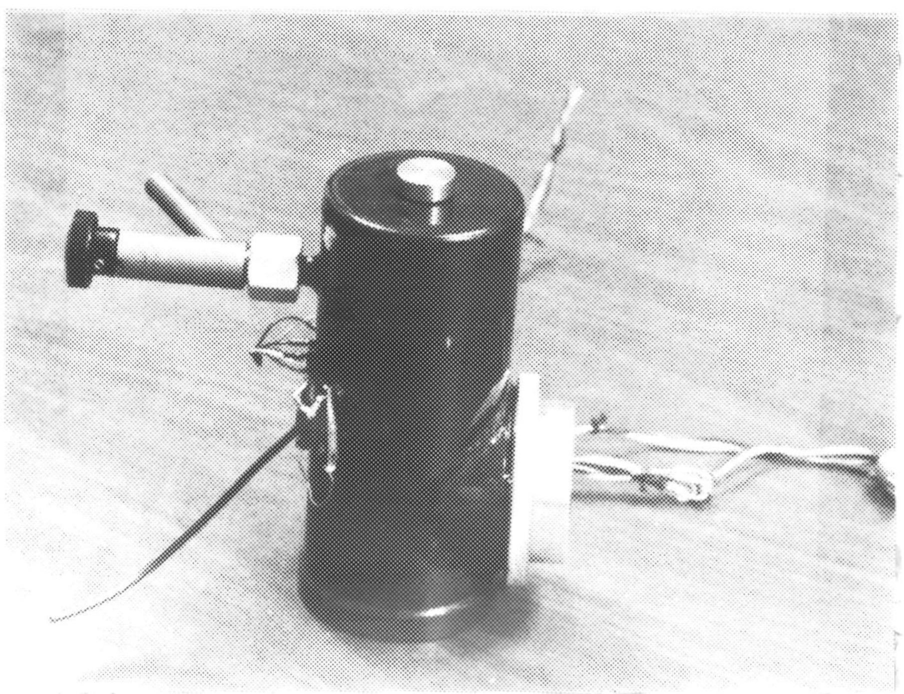


Figure 3. Two Photographic Views of the Liquid Nitrogen Dewar

These lenses were chosen and mounted in the radiometer head to give a total magnification of about 0.05 for a target located at 60 cm. This resulted in a target size of 6 mm at a distance of 60 cm.

2.2.3 Visual Sighting Optics

The germanium beamsplitter reflects visible light downward through a transfer lens to a mirror which directs the light horizontally back to a reticle mounted on a Ramsden focusing eyepiece. The focal length of the primary lens is less at visible wavelengths than it is in the infrared. Using known values of the refractive index for ZnSe, the primary lens focal length was calculated to be approximately 87 mm, using the lens makers' formula.[6] Using this value an appropriate transfer lens was chosen. Since the primary lens demagnifies a 6 mm target located 60 cm in front of the radiometer by about 1/6, the transfer lens was located in the radiometer so as to magnify the image back up to an acceptable size on the reticle located in the focusing eyepiece.

2.2.4 Liquid Nitrogen Dewar

The liquid nitrogen dewar maintains the temperature of the HgCdTe detector, the tuning fork chopper, and an aperture at 77°K. The dewar is the Model KD108M manufactured by Kadel Engineering Corporation. As shown in Figure 3, the dewar has a vacuum evacuation valve with a removable valve operator. The vacuum inside the dewar is guaranteed for a minimum of 1 year. If required it can be pumped down to a pressure of 1-30 microns with a mechanical vacuum pump. Liquid nitrogen hold time is guaranteed for a minimum of 4 hours.

2.2.5 Tuning Fork Chopper and Aperture

The tuning fork chopper is a Model L2C manufactured by Bulova Watch Company. The chopper is small (0.76 cm x 1.73 cm x 2.87 cm) and easily fits on the cold plate of the liquid nitrogen dewar. An electronic control circuit is used to insure that the vibration amplitude of the tuning fork is maintained constant for possible changes in temperature and pressure. A block diagram of the drive and control electronics manufactured by Bulova Watch Company is shown in Figure 4. Two small coils are mounted on opposite sides of the tuning fork. One coil drives the tuning fork and the other senses the vibration amplitude. The output of the sense coil is maintained at a constant value using feedback control. A reference output from this board is fed to the analog output electronics circuit to drive the phase sensitive detector in phase with the chopped infrared signal. Appendix B shows an interconnection wiring diagram between the dewar and the electronic circuits.

The maximum full aperture opening of the chopper is 0.3 millimeters. An aperture consisting of a 0.3 millimeter diameter hole in a nonmagnetic brass sheet is mounted directly in front of the chopper. This restricts the field of view of the radiometer to 6 millimeters diameter at a target distance of 60 centimeters. Since the brass sheet is cooled to 77° Kelvin it shields the background view of the detector from hot noise sources.

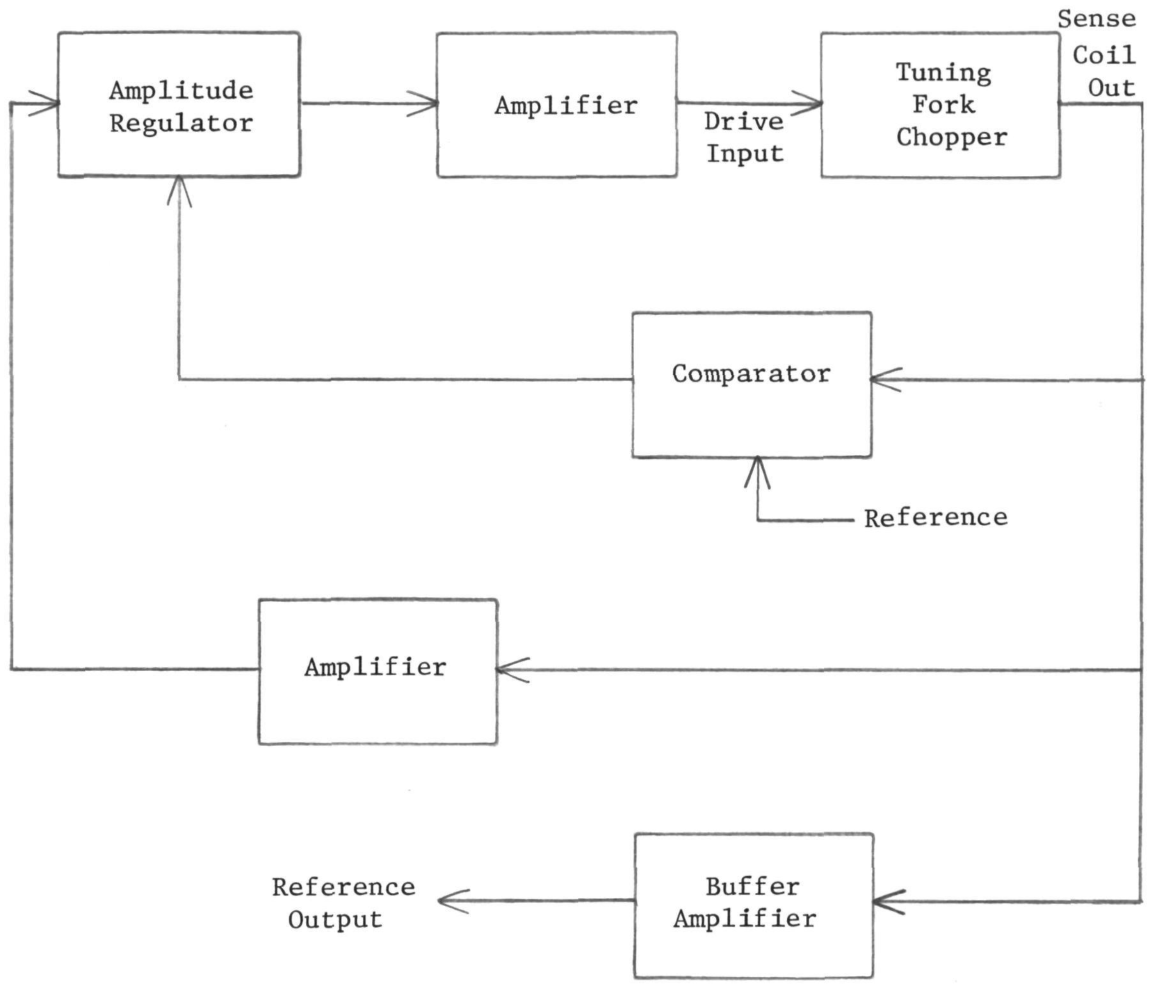


Figure 4. Block Diagram of Bulova Tuning Fork Chopper Drive and Control Electronics

2.2.6 Infrared Detector

The detector is a HgCdTe infrared detector manufactured by Santa Barbara Research Center. The sensitive area is 1 millimeter by 1 millimeter. Other specifications are listed in Appendix C. The detector is fastened to a special mounting plate which fits between the dewar cold plate and the tuning fork chopper. Detector leads are routed out through the bottom of the mounting plate and to the vacuum feed-through pins located on the back of the dewar. Figure 5 shows the detector and tuning fork chopper mounted on the liquid nitrogen cold plate. The detector is located just behind the chopper vanes in the lower center of the figure.

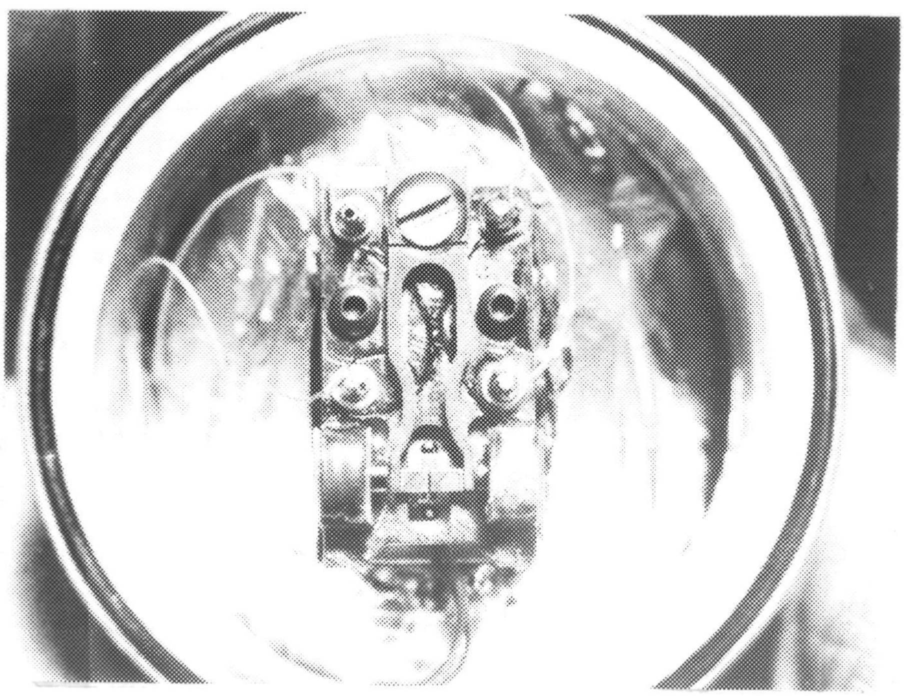


Figure 5. Photographic View of the Tuning Fork Chopper and Infrared Detector Mounted on the Liquid Nitrogen Dewar

2.2.7 Analog Output Electronics

The analog output electronics are a group of electronic circuits whose function is to amplify and condition the output of the infrared detector. This output is used by both the digital display in the control unit and by an external NASA computer. The analog output electronics are contained on a printed circuit board mounted inside the radiometer head.

The output signal of the infrared detector can be characterized as a 1 mv, 3 kHz sine wave. The frequency is determined by the chopper drive and control electronics. The amplitude is directly related to the observed temperature. The analog output electronics produces a signal within the range of 0-10 volts dc and has a bandwidth of 400 Hz.

A block diagram of the analog output electronics is contained in Figure 2. The infrared detector signal is coaxially cabled from the dewar to the analog output electronics board. On the analog board the signal is transformer coupled with a step-up turns ratio of 15. From the transformer secondary the signal is sent to a preamplifier where the amplitude is increased by 1,000.

The signal is then fed to a unity gain inverting bandpass filter that is centered at the chopper frequency and has a bandwidth of 1,600 Hz. The signal is then processed by the emissivity amplifier. This circuit amplifies the signal by the reciprocal of the rear panel emissivity potentiometer setting. The emissivity control is a 10 turn dialpot with a range of 0.1 to 1.0. The output of the emissivity amplifier is the input to the phase sensitive detector.

The phase sensitive detector receives a reference 3 kHz signal that originates in the chopper drive and control electronics. This reference signal is phase shifted appropriately and limited on the analog output electronics board. The phase sensitive detector operates as a unity gain inverter/non-inverter in synchronism with the conditioned radiometer signal. This signal is low pass filtered using a 4 pole Butterworth filter with a cutoff of 400 Hz.

Finally the signal is amplified to the nominal 10 volt level at 260°C and sent to the control unit for digital presentation. A buffered output is also sent to NASA computer, via a BNC connector on the control unit.

2.3 Control Unit

The control unit is a group of circuits housed in approximately a 30 cm cubic enclosure. The control unit has the following detachable cables: a 110 vac power cable, a coaxial cable to the NASA computer, and a multiconductor cable interconnecting the control unit with the radiometer head.

The control unit performs two major functions. It supplies power to the radiometer head, and it provides a digital display of observed temperature. A block diagram of the control unit is presented in Figure 6.

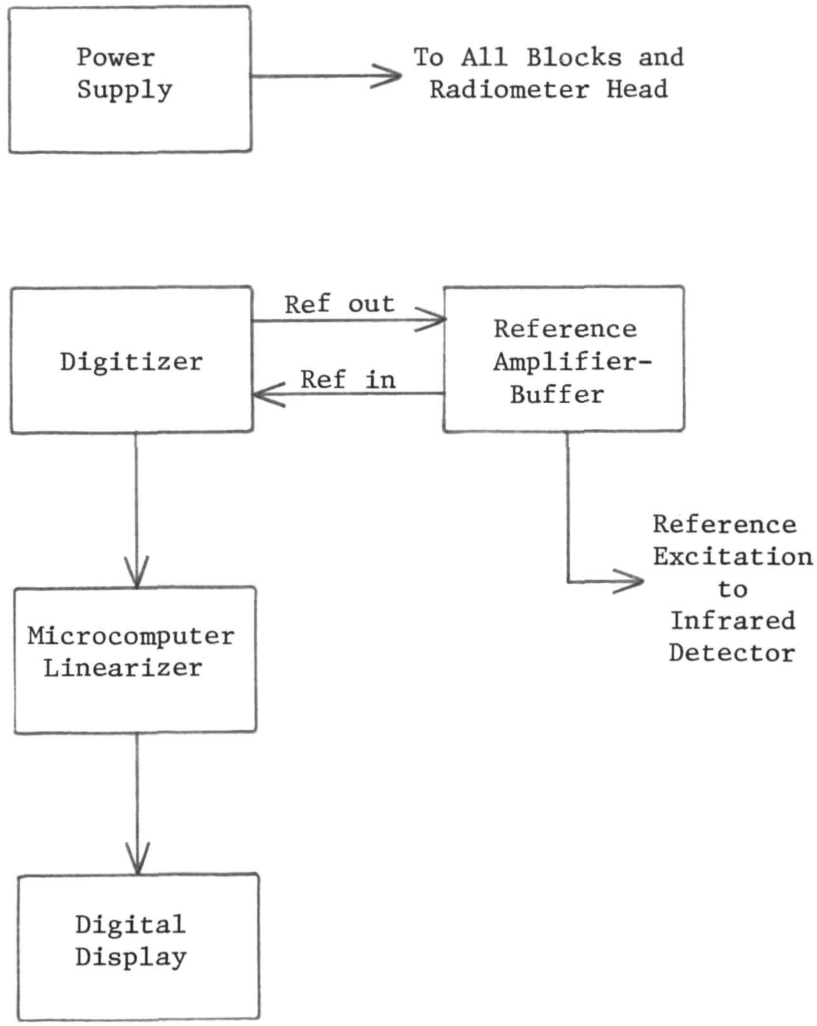


Figure 6. Control Unit Block Diagram

2.3.1 Power Supply

The power supply is a forced air cooled, circuit breaker protected, triple output device. All system power is provided by its +5 volts dc and ±15 volts dc outputs. The power supply is conservatively operated at about one third of its full load rating. It is housed near the top rear of the control unit enclosure.

2.3.2 Digitizer

The digitizer is an analog to digital converter that accepts an analog input from the radiometer head that is within the range of 0 to 10 volts dc. The analog to digital converter produces a digital output that is fed to the microcomputer linearizer. The digital output is a 14 bit (TTL or CMOS compatible) word that is encoded in a binary two's complement format. The high-resolution digitizer operates at a rate of 2 conversions per second. The digitizer employs a quartz crystal controlled clock to obtain good 60 Hz power line interference rejection characteristics. The conversion technique used is dual slope A/D with auto-zero drift correction. This technique is the most appropriate for high resolution and low conversion rate applications. The digitizer also contains a precision ±0.1%, 1 volt dc reference source. This reference source and the reference amplifiers are tandemly connected for ratiometric operation.

2.3.3 Reference Amplifier-Buffer

The reference amplifier-buffer accepts the digitizers 1 volt dc reference source, buffers it and then amplifies it by 5 to produce a 5 volt reference. The 5 volt reference is sent to the radiometer head to bias the infrared detector. The buffered 1 volt dc is sent back to the digitizer's reference input (a characteristic of dual slope converters). Ratiometric operation is achieved because two electronic processes employ the same reference source and differential reference source drift errors are minimized. The detector's output varies in direct proportion to the input reference voltage. On the other hand the digitizer produces an output inversely proportional to its reference input. Because these two blocks are cascaded, reference stability requirements are greatly relaxed. The digitizer and reference buffer-amplifier circuits are mounted on a wire-wrapped perf-board located behind the digital display.

2.3.4 Digital Display

The digital display is a group of 4 adjacent integrated opto-electronic devices. Each display is capable of receiving a 4 bit BCD character, storing that character and then decoding and driving an array of light emitting diodes. The appropriate diodes in the array are illuminated in order to display the correct decimal number that corresponds to the BCD code character received. The display elements are mounted on a small perf-board behind the front panel with an embedded plexiglass window. The digital display produces a readout resolution of 0.1°F. The digital display receives the four BCD words from the microcomputer linearizer.

2.3.5 Microcomputer Linearizer

The microcomputer is a group of circuits including a microprocessor, random-access-memories (RAMS), a programmable-read-only-memory (PROM), and two peripheral interface adapters (PIAs). One PIA is used to interface the microcomputer to the digitizer and the other for display interface requirements. The PROM is used for program storage, the RAM for data storage, and the microprocessor does the computations.

The microcomputer is contained on one printed circuit board mounted in the bottom of the control unit.

The function of the microcomputer is to accept the digital word presented by the digitizer (directly related to observed temperature) and send appropriate BCD words to the digital display.

During development it was predicted that a direct analytical transfer function of radiometer output voltage versus temperature could not be obtained with adequate certainty of accuracy. On the other hand output voltage versus temperature could not be measured until the majority of hardware was operational. The hardware and software design of the microcomputer was strongly influenced by these considerations.

The microcomputer has only three tasks to accomplish:

1. Read input port (digitizer)
2. Linearize data
3. Write to output port (digital display)

Tasks 1 and 3 are easily accomplished by simple read/store and retrieve/write commands. Task 2 is the major difficulty for the microcomputer because this operation is dependent upon final calibration.

Task 2 (linearize data) was accomplished by straight line approximation. In general, a single valued function can be approximated by breaking the smooth curve of the function into short straight line segments. Each straight line segment can be characterized by only two parameters, slope and intercept. Furthermore, a simple comparator look up table can be constructed such that the machine can determine which straight line segment to apply for any valid input.

Given then that the machine has a comparator look up table, a slope table, and an intercept table; the machine simply has to multiply the current input voltage times the appropriate slope and add on the intercept to produce the required temperature readout. In this design a code conversion from binary to BCD is also performed because binary arithmetic and code conversion was easier to implement than BCD arithmetic.

Section 3

CALIBRATION AND TEST RESULTS

3.1 Field of View and Visual Alignment

The field of view of the radiometer was measured with a hot wire mounted on a motor-driven traversing mechanism. A mechanical digital counter was mounted on the traversing mechanism where each 100 units of the counter equaled 6.35 mm of wire travel. As the hot wire was traversed across the field of view of the radiometer, its output would rise from a background level to a maximum and down to the background level. The counter difference between the two background levels was a measure of the field of view. For a given radiometer to hot wire distance the counter difference could be minimized for a given setting of the primary lens barrel. To obtain the desired field of view a 0.3 mm diameter aperture had to be placed inside of the dewar just in front of the chopper and detector. After this was done the field of view was measured to be 6 mm at a target distance of 60 cm. Under these conditions the counter difference was minimized at 6 mm when the lens barrel was set at 2.5 on the outermost markings of the barrel. Thus, this setting represented the correct location of the primary lens when the infrared optical system was imaging a target at a distance of 60 cm.

Using this same setting on the primary lens barrel the optical viewing system was aligned with the infrared system. This was done by placing a piece of cardboard with a 6 mm diameter hole in front of the aperture of the blackbody at a distance of 60 cm. The radiometer was positioned laterally until the output signal was maximized. Thus the infrared optics were imaged exactly on the 6 mm hot target. Both the radiometer and the blackbody were clamped to the table to prevent accidental movement of either. Then, while observing the target through the eyepiece, the transfer lens and the bottom mirror were positioned so that the 6 mm target was in focus and just outlined by the circular reticle.

3.2 Calibration

After the infrared and visual optics were aligned, the final calibration data for the radiometer was recorded. The experimental apparatus for accomplishing this is shown in Figure 7. The radiometer

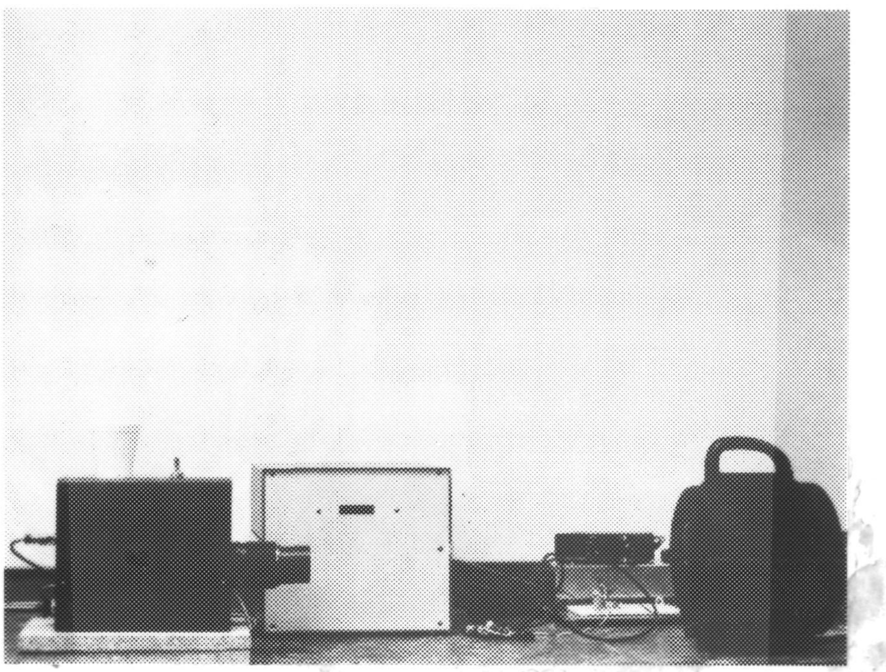


Figure 7. Photograph of Experimental Apparatus for Calibrating the Radiometer

was focused on the blackbody aperture and located at a distance of 60 cm. The temperature of the blackbody was stabilized at 260°C for 1 hour, and the radiometer was stabilized for approximately two hours before beginning the calibration. A copper constantan thermocouple was fastened to the cone of the blackbody less than 1/2" from the center of the cone, and the reference junction was a terminal block. A thermometer was placed physically in contact with the block using a heat conductive grease. The following data were taken during the calibration tests: thermocouple junction temperature, thermocouple output voltage, radiometer output voltage, radiometer output noise, and time of day.

With the blackbody at 260°C (500°F), the radiometer output was set at 9.9 volts. Then the gain adjustment potentiometer was glued with RTV to prevent any movement. The temperature was then lowered very slowly, and data were recorded every few minutes for approximately a 12 hour period. This procedure was repeated once with reproducible results. The cold temperature calibration was accomplished by putting the blackbody overnight in the deep freeze of a local supermarket. Then it was placed back in the calibration apparatus, and as the blackbody slowly rose in temperature, data were recorded every few minutes. The blackbody was allowed to warm up naturally until it reached 15°C. Then the blackbody heater was turned on very gradually, and data were taken to approximately 50°C.

3.3 Final Programming

Final programming encompassed that part of the microcomputer program that was dependent upon the calibration data. Because of the nature of the control unit's software design, final programming consisted of providing data for the comparator, slope and intercept tables mentioned in section 2.3.4.

The data derived during final programming were obtained in the following manner. The analog voltage output of the infrared radiometer was plotted versus the observed blackbody temperature. The resulting curve showed a gradual increase in slope from -17.8°C (0°F) to 260°C (500°F). The ratio of slopes at 260°C and at -17.8°C was found to be less than 4. A linear temperature assignment of comparisons was used. Since the temperature span was equal to 277.8°C (500°F) and the control unit software could accomodate 16 straight line segments, 17 data pairs were extracted from the calibration data. The selection criteria for a data pair were that it be the closest pair to the linearly spaced temperature points of 0, 32, 64, ... 512, and that the resulting straight line segment fit the plotted curve of the calibration data. Data pairs were selected in two ways: directly from calibration data or by linear extrapolation from close data points. The latter was done to use the full range of the digitizer. Once the 17 data pairs had been selected each of the 16 line segments was characterized by evaluating the slope and intercept of adjacent pairs. Finally a table was constructed of data pairs, comparison points, slopes and intercepts. Their binary equivalents were entered into a PROM (memory) table. These data are shown in Table I.

3.4 Final Testing and Measurements

Certain final tests and measurements on the radiometer were performed. One test was to verify that the calibration software would produce the desired readout of temperature versus radiometer head output voltage. The radiometer head voltage was slowly increased while monitoring the digital temperature readout and the output voltage with a digital voltmeter. The result of this test indicated that the digital electronics in the control unit, including the software, were performing satisfactorily.

The equivalent noise temperature was computed over the output temperature span. Equivalent noise temperature is defined as the ouput noise voltage multiplied by the operating point slope in degrees centigrade per volt. The noise voltage was measured through the calibration run and found to be essentially constant at 3 millivolts r.m.s. The noise temperatures are tabulated in Table I where they were found to vary from extremes of 0.26°C at low temperatures to 0.07°C at high temperatures.

Data Pairs			Comparison	Slope		Intercept		Noise Equivalent Temperature (°C)
Output (volts)	Temperature °C	Temperature °F	Value (volts)	°C/volt	°F/volt	°C	°F	
1.441	-17.8	0.0	1.441	85.95	154.71	-141.6	-222.9	0.26
1.645	0.0	32.0	1.645	85.95	154.71	-141.6	-222.9	0.26
1.850	17.8	64.0	1.850	85.95	154.71	-141.6	-222.9	0.26
2.054	35.6	96.0	2.054	85.95	154.71	-141.6	-222.9	0.26
2.258	52.4	126.4	2.258	44.53	80.16	-48.1	-54.60	0.13
2.636	69.3	156.7	2.636	42.48	76.47	-42.7	-44.87	0.13
3.163	91.7	197.0	3.163	37.37	67.26	-26.5	-15.74	0.11
3.609	108.3	227.0	3.609	32.88	59.18	-10.3	13.42	0.10
4.099	124.4	256.0	4.099	31.17	56.11	-3.3	26.00	0.09
4.639	141.3	286.3	4.639	28.81	51.85	7.6	45.76	0.09
5.366	162.2	324.0	5.366	24.28	43.71	31.9	89.45	0.07
6.121	180.9	357.7	6.121	23.83	42.89	35.1	95.17	0.07
6.797	197.1	386.7	6.797	21.81	39.26	48.8	119.85	0.07
7.551	213.5	416.3	7.551	21.17	38.10	53.7	128.61	0.06
8.383	231.1	448.0	8.383	17.51	31.52	84.3	183.76	0.05
9.435	249.5	481.16	9.435	22.35	40.23	38.7	101.59	0.07
10.000	262.2	503.89	--	--	--	--	--	--

Table I. Radiometer Calibration Data

Section 4

OPERATING AND MAINTENANCE PROCEDURES

4.1 Installation

The radiometer contains a detector and light chopper which were designed to operate at liquid nitrogen temperatures; therefore, care should be taken to make certain the dewar has a vacuum and is full of liquid nitrogen before the radiometer is turned on. Operation under other than these conditions could cause permanent damage to the detector and chopper.

To evacuate the dewar it must be connected to a vacuum pump capable of pumping to at least 30 microns of mercury and preferably down to 1 micron. Access to the rear of the dewar, where the vacuum pump must be connected, is gained by removing the four screws holding the upper rear panel of the radiometer head and removing the panel. Next remove the blue plastic cap on the dewar and apply a thin film of vacuum grease on the outside of the valve stem. Now loosen the nut on the valve operator supplied with the radiometer and carefully slip the operator onto the dewar tightening the nut to secure the operator valve in place. Push the black knob on the operator toward the dewar until it stops then turn the knob in a clockwise direction while gently applying pressure toward the dewar. Connect the hose from the vacuum pump to the tube on the side of the valve operator and turn on the vacuum pump. Pulling out the black knob on the valve operator will permit the vacuum pump to evacuate the dewar. When the dewar is evacuated, push the black knob on the valve operator all the way in, turn the knob counterclockwise to release the operator from the valve, and remove the operator. Replace the plastic dust cap on the dewar and the back cover plate on the radiometer head.

The interconnecting cable between the radiometer head and control box should now be connected and the a.c. power cord should be connected at the rear panel of the control box. The type BNC connector on the rear of the control box is the nonlinearized ouput signal from the radiometer. This signal can vary from 0 to 10 v.d.c. with a 400 hz bandwidth and is not common to the chassis of the control box or radiometer head.

The radiometer head may be mounted flat on a table top or on a stand with a 1/4 - 20 bolt. The radiometer head may be mounted at angles as large as $\pm 70°$ from the horizontal before spilling of liquid nitrogen occurs.

4.2 Operating Procedure

4.2.1 Using the styrofoam cup funnel supplied, fill the dewar with liquid nitrogen. This takes 10 - 15 minutes and usually requires approximately 3 cups of liquid nitrogen. The first 1 or 2 cups will boil out of the dewar since the interior walls will have to be cooled before the nitrogen will pour freely into the dewar. When the dewar is full, the liquid nitrogen may spurt out of the filler hole when the funnel is removed. The level of the liquid nitrogen should be checked occasionally using a wire or other probe.

4.2.2 Check to be sure all cables are connected between the control box and radiometer head as explained in section 4.1 and that the a.c. power switch is in the off position (down) before plugging the power cord to 125 v.a.c. 60 Hz.

4.2.3 Turn on the radiometer and push the processor reset switch on the left lower rear of the control box. Allow approximately one hour before attempting any accurate measurement to allow the radiometer to stabilize.

4.2.4 Focus the radiometer on the specimen by twisting the outer lens barrel.

4.2.5 Set the emissivity control on the back of the radiometer head so that the digital readout temperature reads the same as the specimen temperature.

4.3 Maintenance

4.3.1 Optical Alignment

Optical alignment is easily determined by placing a 6 mm aperture in front of a hot blackbody located 60 cm from the radiometer. Align the radiometer such that the 6 mm hole is centered in the eyepiece reticle, and focus the radiometer on the aperture. Turn on the radiometer and allow 1 hour warm up time. A maximum temperature should be observed on the digital display. If moving the radiometer horizontally or vertically increases the temperature reading, the visual optics should be realigned. To realign the radiometer optics, remove the top cover on the radiometer head. The radiometer head should be placed 60 cm from the 6 mm aperture of the blackbody and at the point where maximum signal or highest temperature reading is obtained. While looking through the eyepiece adjust the lower mirror so that the edges of the aperture are aligned with the reticle. Some adjustment of the transfer lens may be necessary.

4.3.2 Analog Output Electronics Alignment

Electronics alignment will require a general purpose oscilloscope and a digital voltmeter. Figure 8 shows a photograph of the analog output electronics, and a circuit diagram of this board is shown in Appendix D. The phase sensitive detector should be checked before

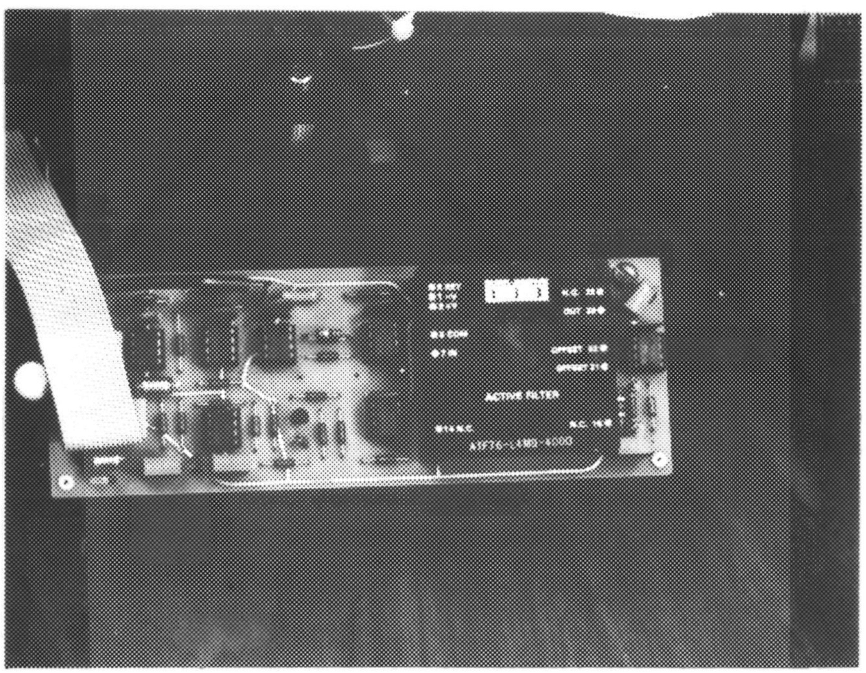


Figure 8. Photograph of the Analog Output Electronics

any output voltage calibrations are attempted. To adjust the phase sensitive detector turn on the radiometer as described in section 4.2, remove the cover, and release the clip on the top center of the electronics board so that the component side of the board is accessible. With the radiometer pointed at a hot object, connect an oscilloscope to the input pin on the Burr Brown low pass filter. A test point is provided in the center of the board just to the left of the Burr Brown filter. The phase adjustment potentiometer is 10 kilohms and is located at the lower left hand side of the board with the duty cycle adjustment potentiometer located to its right. Adjust the oscilloscope to display a few cycles of this signal. The signal should look as shown in Figure 9 using the minus input of the oscilloscope and inverted using the plus input of the scope. If this wave is distored adjust the duty cycle potentiometer so that each half cycle looks as close as possible to a half cycle of a pure sine wave. The final fine adjustment of this control should be an adjustment of it so that the output of the radiometer head is a maximum.

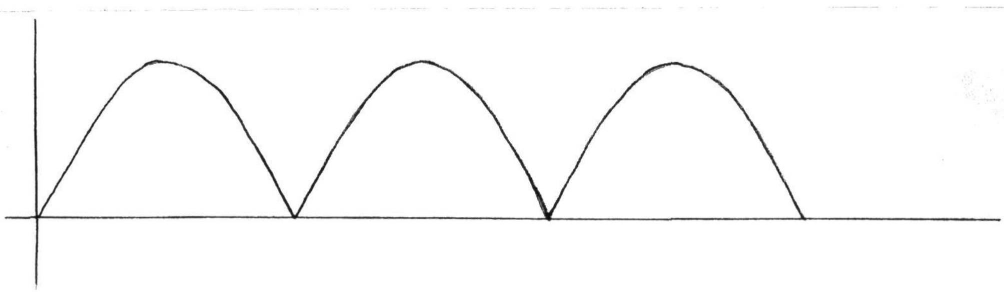


Figure 9. Oscilloscope Wave for Proper Adjustment of the Phase Sensitive Detector

Next the full scale output voltage can be set to 260°C (500°F). Point and focus the radiometer onto a calibrated blackbody located at a distance of 60 cm. Set the emmissivity control to 1.0. Adjust the voltage output potentiometer, located at the top right corner of the electronics board, so that the digital voltmeter reads 9.9 volts. Glue can be applied to the potentiometers to insure that their settings will not change.

4.3.3 Alignment of Tuning Fork Chopper Drive and Control Electronics

Figure 10 shows the tuning fork chopper drive and control electronics. To align this circuit connect a digital voltmeter across the chopper sense coil (see (Appendix B) and adjust the potentiometer on the chopper board (Figure 10) until the voltmeter reads 1.600 volts rms.

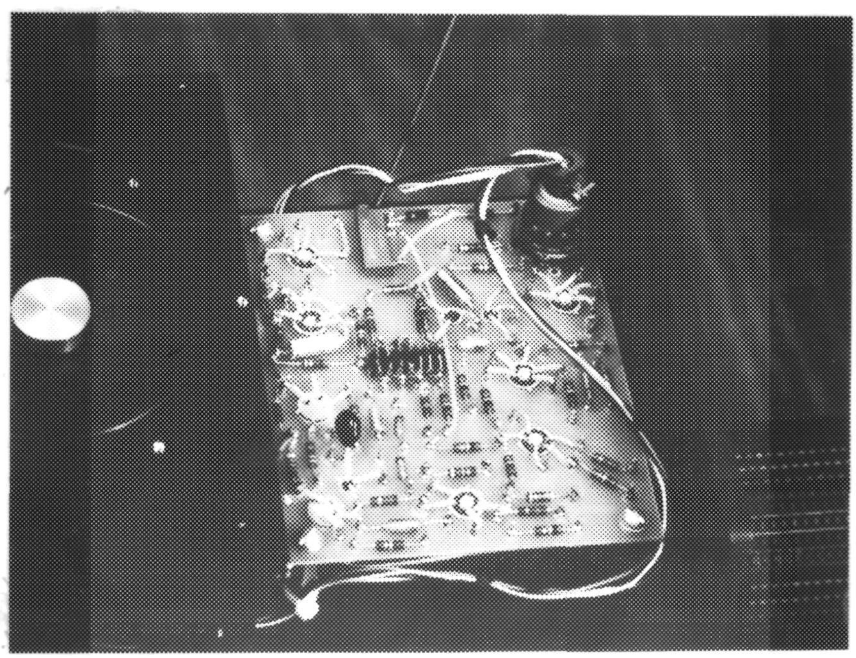


Figure 10. Photograph of Tuning Fork Chopper Drive and Control Electronics Circuit Board

4.3.4 Other Maintenance

Other maintenance which may be required periodically includes cleaning the optics, reevacuating the dewar to acceptable vacuum levels, and checking the PROM in the control unit.

Lens cleaning is generally not recommended. If absolutely necessary dry compressed air may be used to remove dust.

Reevacuating the dewar should be done as described in Section 4.1.

The PROM has a limited lifetime and may require reprogramming. According to the manufacturer's data, constant exposure to room level fluorescent lighting could erase the 2716 PROM in approximately 3 years, while it would take 1 week to cause erasure when exposed to direct sunlight. There is an opaque covering over the window to block any outside light from entering the PROM. Under these conditions the life expectancy is in excess of 10 years.

4.4 Recalibration

If the radiometer is to be recalibrated, the procedure discussed in Section 3 can be followed.

Appendix A

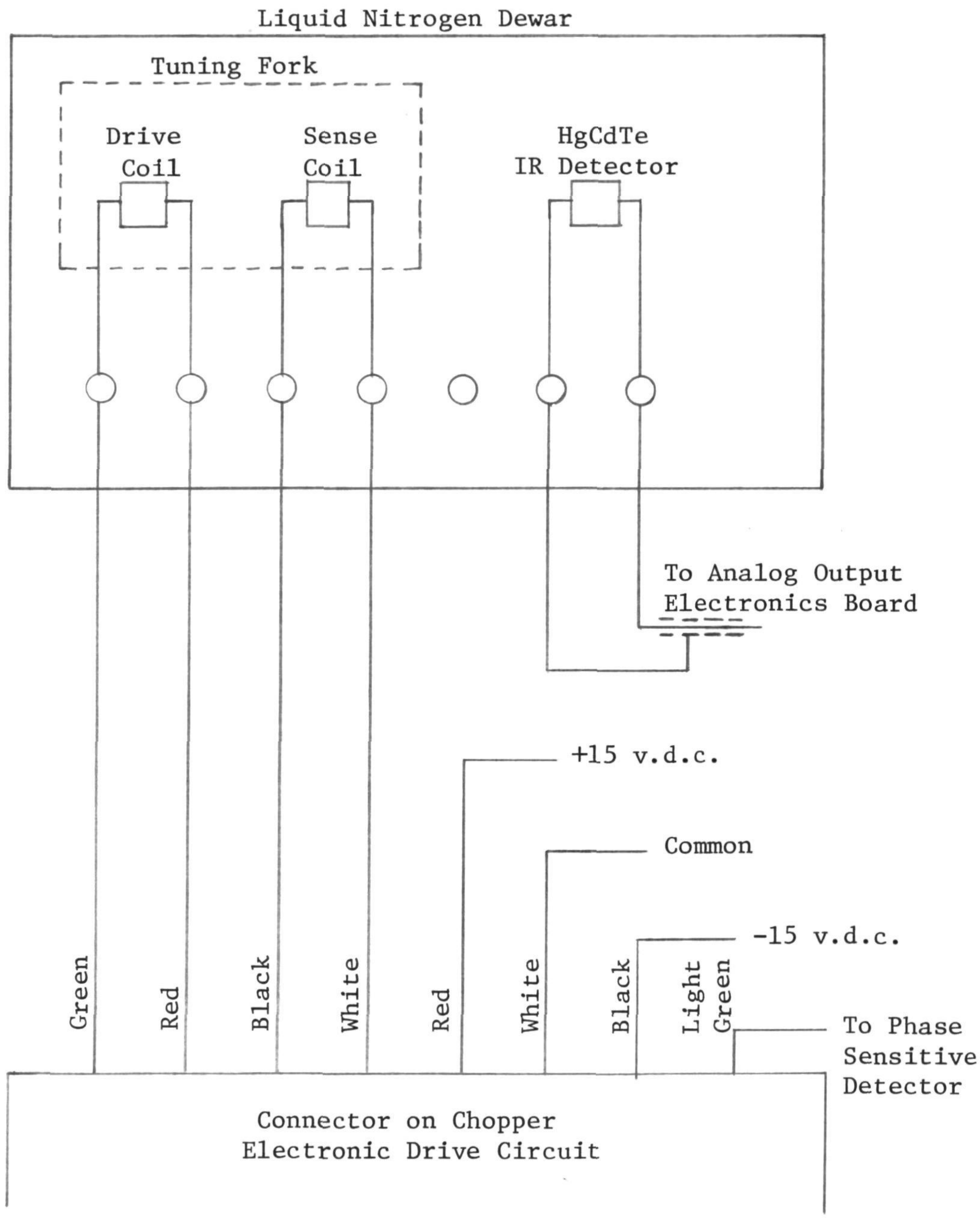
INTERCONNECTION CABLE BETWEEN THE RADIOMETER HEAD AND THE CONTROL UNIT

This interconnection cable consists of 2 Amphenol No. 57-30140 plugs and Alpha #3308 shielded PVC 8 conductor wire. This cable is wired symmetrically so that either end of the cable can be connected to identical jacks on either the radiometer head or the control unit. Below is a description of the wire color and plug pin number.

Use	Wire Color	Plug Pin Number
Supply Common	White	1
+15 Volt Supply	Red	2
-15 Volt Supply	Black	3
Signal Ground	Green	5
Signal to Digital Readout	Orange	6
Signal to User Computer	Red/Black	8
HgCdTe Detector Common	White/Black	10
HgCdTe Detector +5 Volt Bias	Blue	11
Chassis Ground	Shield	13, 14

Appendix B

INTERCONNECTION WIRING DIAGRAM BETWEEN LIQUID NITROGEN DEWAR AND ELECTRONIC CIRCUITS



Appendix C

SPECIFICATIONS FOR HgCdTe INFRARED DETECTOR

Manufacturer: Santa Barbara Research Center
75 Coromar Drive
Goleta, CA

Detector Serial Number: M164

Total Field of View: 180°

Sensitive Area: 1 mm x 1 mm

Detectivity (λm): 1.6×10^{10} cm $(hz)^{1/2}$/watt

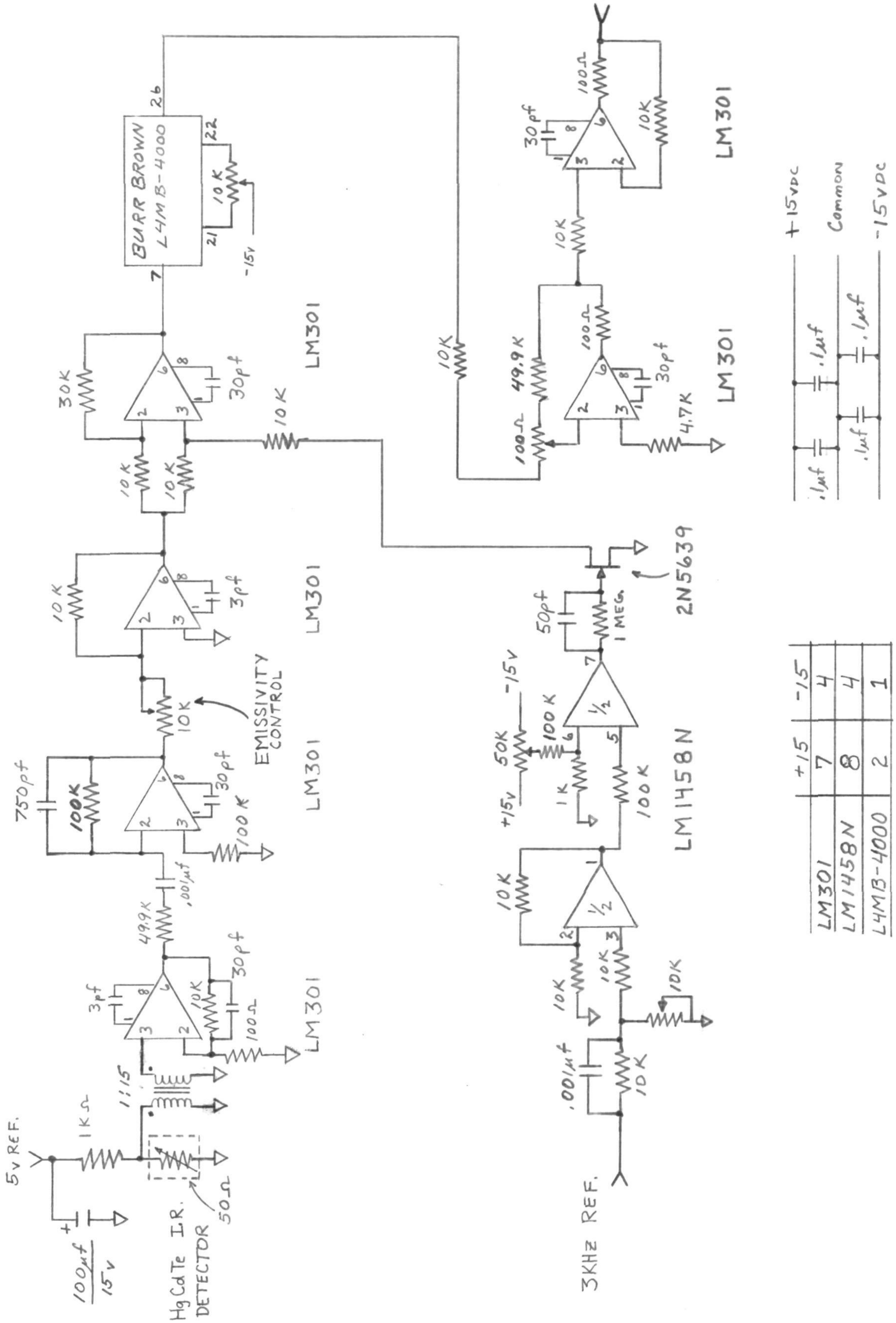
Responsivity (λm): 240 volts/watt

Resistance (E/I): 51.2 ohms

Time Constant: 0.25 microseconds

Appendix D

CIRCUIT DIAGRAM OF THE ANALOG OUTPUT ELECTRONICS



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