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# TEMPERATURE CONTROLLED QUARTZ CRYSTAL MICROBALANCE SYSTEM

*FARADAY LABORATORIES INC.  
LA JOLLA, CALIFORNIA 92037*

MAY 3, 1977

TECHNICAL REPORT AFML-TR-77-83  
Final Report for Period June 2, 1975 to May 3, 1977

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This technical report has been reviewed and is approved for publication.

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R. A. WINN  
Project Monitor

FOR THE DIRECTOR

*J. K. Sieron*

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J. K. SIERON, Chief  
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

<b>19 REPORT DOCUMENTATION PAGE</b>		<b>READ INSTRUCTIONS BEFORE COMPLETING FORM</b>
1. REPORT NUMBER <b>18</b> AFML-TR-77-83	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER <i>Final rept. 2 Jun 75-3 May 77,</i>
4. TITLE (and Subtitle) <b>6</b> TEMPERATURE CONTROLLED QUARTZ CRYSTAL MICROBALANCE SYSTEM,		6. TYPE OF REPORT & PERIOD COVERED Final, 6/2/75 - 5/3/77
7. AUTHOR(s) <b>10</b> D. McKeown, C.R./ClaySmith, W.T./Breckenridge, Jr. <del> </del> R.S./Dummer		8. PERFORMING ORG. REPORT NUMBER <b>14</b> FAR-D-810-77
		9. CONTRACT OR GRANT NUMBER(s) <b>15</b> F33615-75-C-5171
9. PERFORMING ORGANIZATION NAME AND ADDRESS Faraday Laboratories Inc. P. O. Box 2308 La Jolla, CA 92038		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS <b>16</b> ILIR0071 <b>17</b> 00
11. CONTROLLING OFFICE NAME AND ADDRESS Elastomers & Coatings Branch (MBE), Nonmetallic Materials Division, Air Force Materials Labora- tory, Wright-Patterson Air Force Base, Ohio		11. REPORT DATE <b>11</b> 3 May 77
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 80 <b>12</b> 92p.
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Distribution limited to U.S. Government agencies only; test and evaluation; April 1977. Other requests for this document must be referred to the Air Force Materials Laboratory, Nonmetallic Materials Division, Elastomers and Coatings Branch, AFML/MBE, Wright Patterson Air Force Base, Ohio 45433.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES None		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Temperature Controlled Quartz Crystal Microbalance (TQCM), TQCM System, Surface Contamination, 15-MHz Crystal, Optical Polish, Thermal Model, Second-Surface Mirrors, Radiator, Electronics and Command Logic		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The TQCM system is designed to measure surface contamination as a function of temperature on the SCATHA satellite. The TQCM system consists of two radiatively-cooled Heads and a Controller. Each Head contains a removable high-sensitivity ( $1.56 \times 10^{-9}$ g/ cm <sup>2</sup> ) mass sensor, temperature probe and heater. By ground command, the Controller can set both sensors to operate simultaneously at +100, +30, 0, -30, -60°C ± 1°C or free run. Computer thermal modeling shows that a free running Head pointed into deep space will reach an equilibrium temperature of -163°C.		

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## PREFACE

This report was prepared by D. McKeown, C.R. Claysmith W.T. Breckenridge, Jr. and R.S. Dummer of Faraday Laboratories Inc., La Jolla, CA 92038, under Contract F33615-75-C-5171. This program was initiated under IL1R0071, Laboratory Director's Funds. The program was administered under the direction of the Elastomers and Coatings Branch (MBE), Nonmetallic Materials Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, with Mr. Robert A. Winn serving as project engineer.

This report covers research and development conducted during the period of June 1975 to December 1976.

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## SUMMARY

The Final Report describes the design and construction of a Temperature-Controlled Quartz Crystal Microbalance (TQCM) system for flight on the SCATHA satellite. The TQCM system consists of two radiatively-cooled Heads and a Controller. Each Head contains a removable high-sensitivity mass sensor, temperature probe and heater. By ground command, the Controller can set both sensors to operate simultaneously at +100, +30, 0, -30, -60°C ±1 C° or free run. For free run, a Head reaches an equilibrium temperature depending on its view of space. For example, results from a computer thermal model show a Head periodically viewing the sun and deep space will reach about -67°C while a Head continuously pointed into deep space will reach about -163°C.

TQCM inputs are temperature commands, power, enable and clock. Outputs for each Head are high and low-sensitivity mass and sensor temperature 0 to 5 volt analogs and frequency vs mass.

The mass sensors are instrumented with low-power dissipation 15-MHz, aluminum plated, optically-polished quartz crystals. Mass sensitivity is  $1.56 \times 10^{-9}$  g/cm<sup>2</sup>-Hz which is over two times greater than 10-MHz crystals now being used in space.

Each Head is 5.7 x 5.7 x 3.9 in and weighs 1.4 lb.

The Controller is 4.8 x 5.6 x 3.3 in and weighs 1.8 lb.

The TQCM system operates on +28 ±4 Vdc at 2.142 W for heaters OFF and 5.07 W for heaters ON.

A structure is provided in each Head for mounting a potential analyzer to determine the effects of spacecraft charge on surface contamination.

## 1.0 Introduction

The TQCM system design is based on the Cryogenic QCM<sup>1</sup> (CQCM) constructed for flight on the NASA Shuttle. The CQCM is radiatively-cooled and operates at minimum temperatures to measure water vapor contamination.

The TQCM makes use of the CQCM thermal modeling, high-sensitivity, removable mass sensors and low-power dissipation electronics. The TQCM has the added capability of temperature control by command.

The TQCM design incorporates temperature commands because of the need to measure various species of contamination including water vapor as a function of temperature. The TQCM sensor temperature can be set by command to operate at +100, +30, 0, -30, -60°C ±1C or free run.

## 2.0 TQCM System

The TQCM system size and weight are shown in Figure 1. The enlarged view of the sensor shows location of the quartz crystals.

A photograph of the system is shown in Figure 2. The small tabs at the four corners of each mirror are for electrically grounding the radiator to the satellite. The square region in the center of the Head is for mounting a potential analyzer for studying surface contamination as a function of spacecraft charge.

Different views of the Head and Controller are shown in Figures 3, 4 and 5.

## 3.0 Thermal Analysis

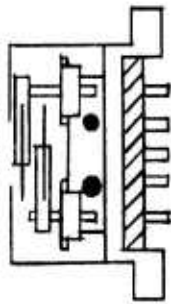
The amount of power, W, radiated by a surface is defined by

$$W = \epsilon \sigma (T_1^4 - T_0^4)$$

where  $\epsilon$  is surface emittance,  $\sigma$  the Stefan-Boltzman constant ( $5.67 \times 10^{-9} \text{ W/m}^2\text{K}^4$ ) and  $T_1$  and  $T_0$  are respectively the surface temperature and the temperature of space in °K.

The power radiated by a surface (140°K) into space (4°K) is 2.18 mW/cm<sup>2</sup>. For a 100 cm<sup>2</sup> radiator, suitable for cooling a TQCM, the

Removable Sensor  
0.88 x 1.15 in



Enlarged View

SPECIFICATIONS

- Head: 5.7 x 5.7 x 3.9 in  
1.4 lb (without RPA)
- Controller: 4.8 x 5.6 x 3.3 in  
1.8 lb
- Power: 28 Vdc  $\pm$ 4  
2.142 W Heaters OFF  
5.07 W Heaters ON

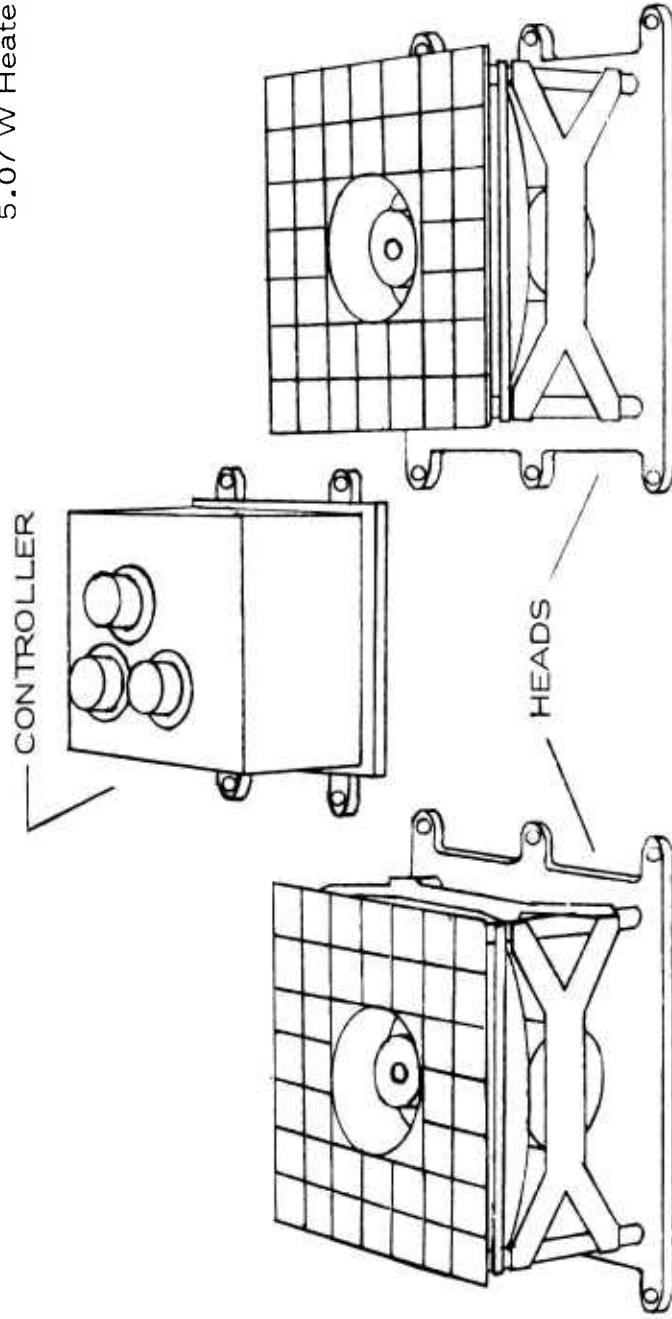


Figure 1 TQCM System Specifications

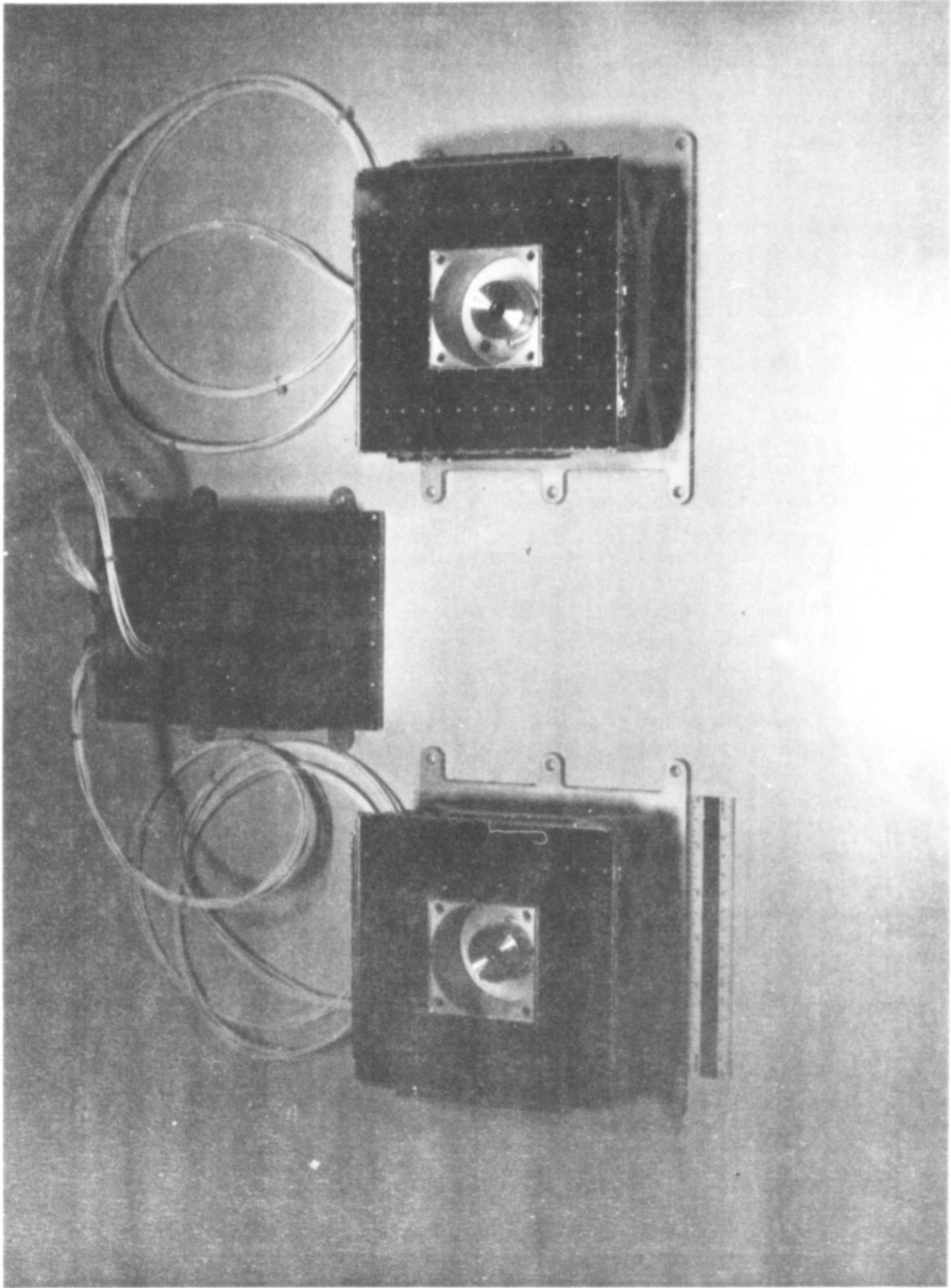


FIGURE 2 QCM SYSTEM WITHOUT RPA INSTALLED

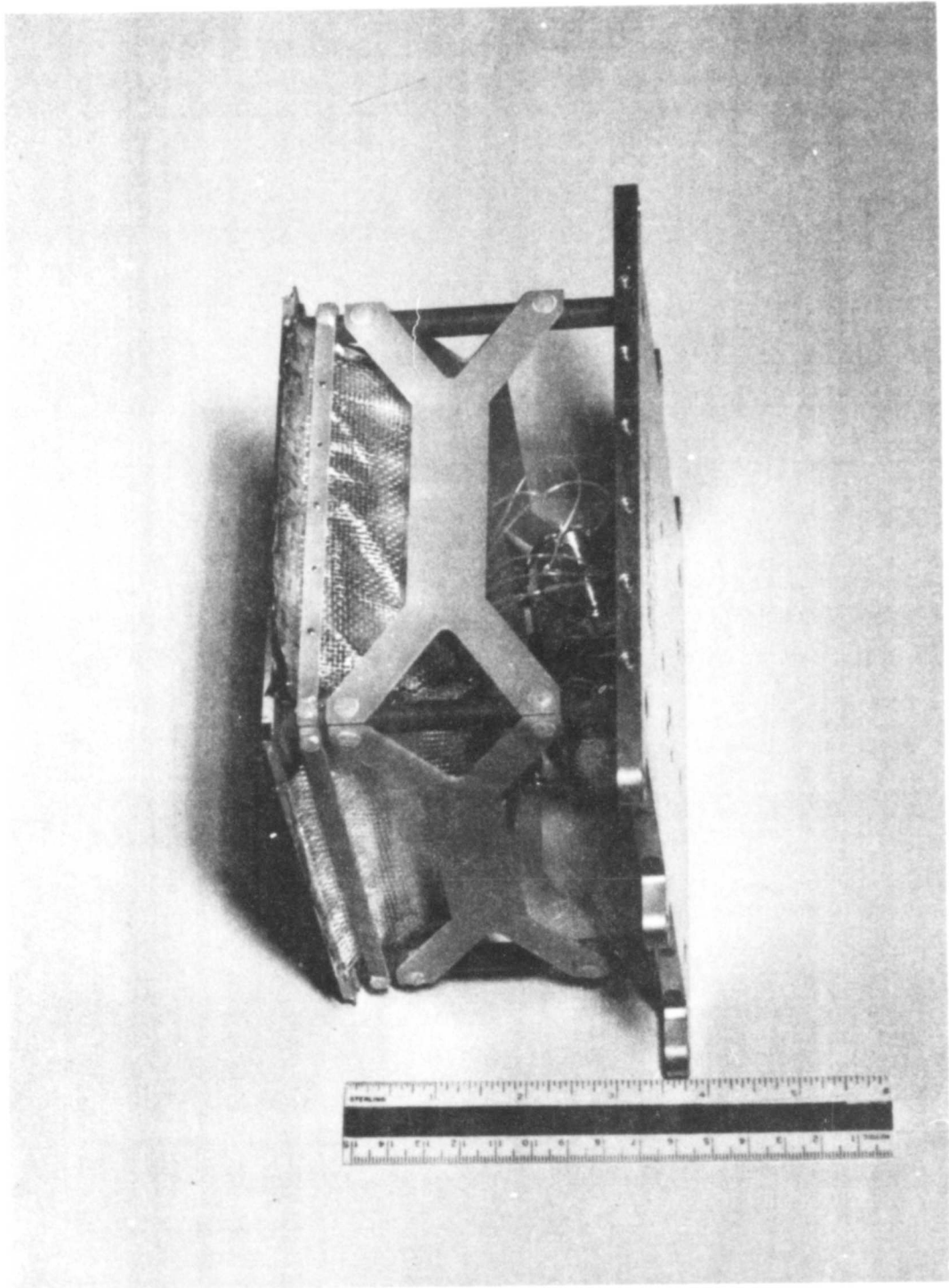


FIGURE 3 TQCM HEAD SHOWING ELECTRONICS AND SUPER INSULATION

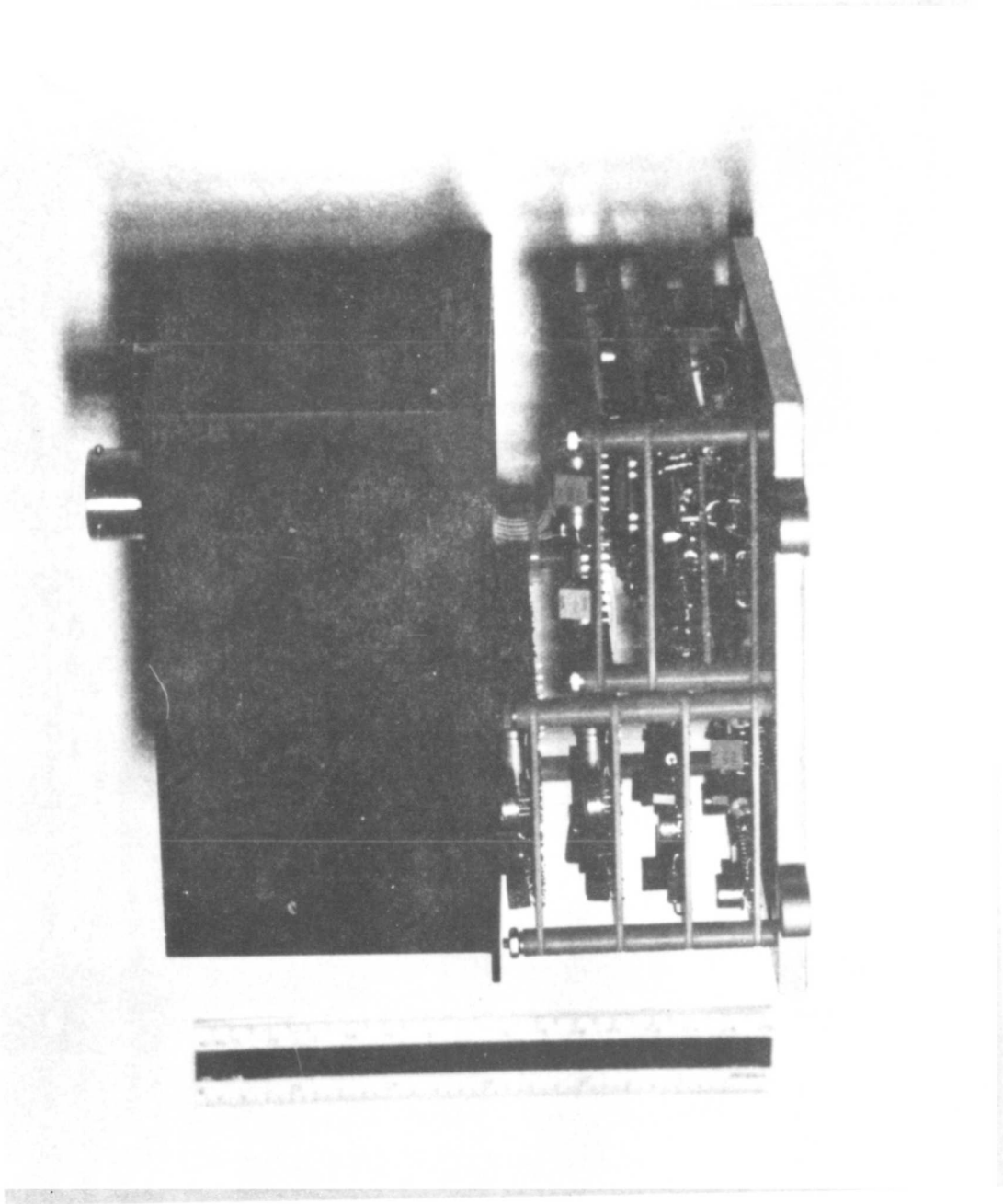


FIGURE 4 TOCM CONTROLLER SIDE VIEW

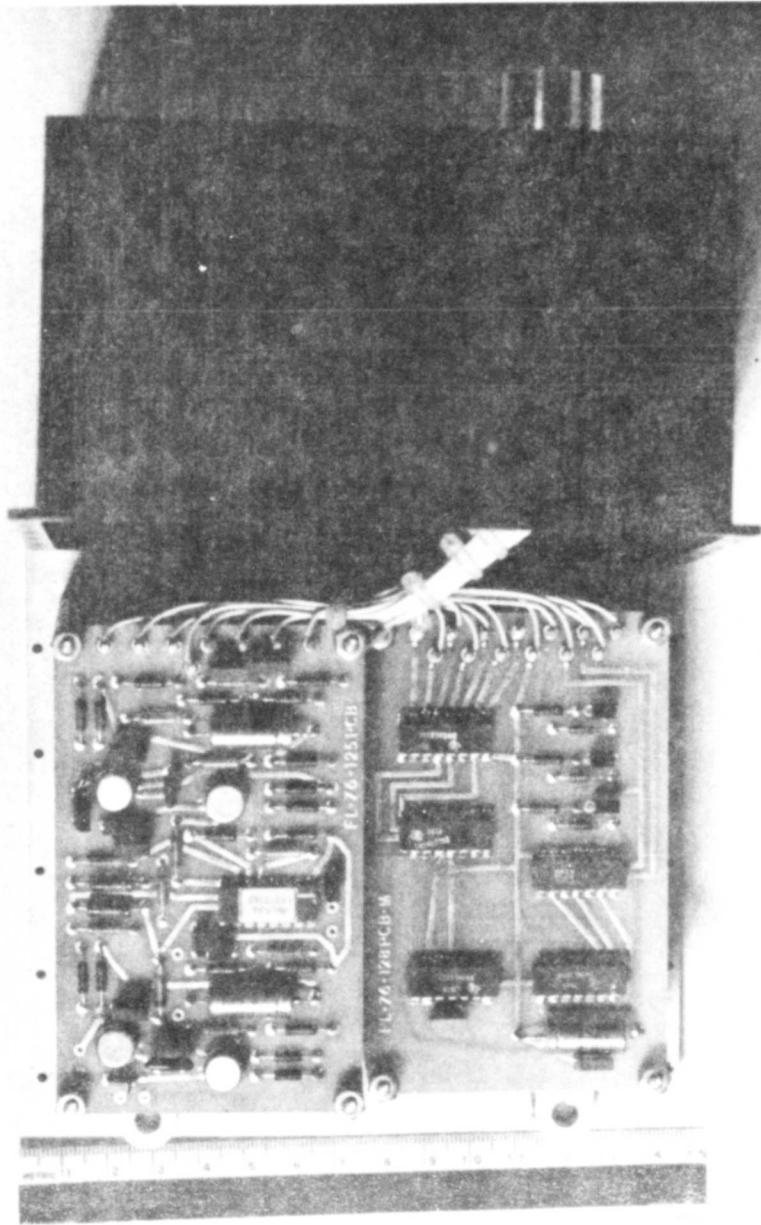


FIGURE 5 TQCM CONTROLLER SHOWING FREQ/VOLT CONVERTERS BOARD No. 125  
AND SERIAL COMMAND DECODER BOARD No. 128

power is 218 mW. In practice, the effective cooling is much less because:

- a) Surface emittance is less than unity
- b) Backside of the radiator will absorb heat from the spacecraft
- c) Conduction of heat from the spacecraft to the radiator
- d) Oscillating quartz crystal sensor dissipate power

The optimum TQCM Head design was determined by computer modeling.<sup>2</sup> Several computer runs were made on Head designs using various materials for its construction and different levels of power dissipations in the crystal sensors.

The final Head design is shown in Figure 6. The Head contains the radiant cooler, mass sensors, oscillators and output amplifier. The radiant cooler is a plane surface constructed from aluminum. The sensors are mounted in a well machined in the radiator. Second-surface quartz silver plated mirrors are attached with RTV to the radiator.\* The mirror front surfaces are coated with a conducting layer of indium oxide for grounding purposes. The mirrors have a solar absorptance  $\alpha \approx 0.08$  and a thermal emittance  $\epsilon \approx 0.80$ . The radiator is attached to the base plate by four high-strength fiberglass-epoxy laminate standoffs. The electronic unit is connected to the crystal sensor by 0.005 in diameter Stablohm leads to provide thermal isolation.

Radiative heat exchange from spacecraft to the radiator is minimized using a stacked multilayer superinsulation of gold plated Kapton held in place beneath the radiator by a Teflon screen.

After the Head design was fixed, its operation in space was determined by computer analysis. Calculated minimum equilibrium temperatures are shown in Figure 7 for a Head viewing space and in Figure 8 for viewing the sun and space at 1 RPM.

The heating powers required to maintain the space oriented Head at various set temperatures are shown in Figures 9 - 13. The sensor operates at a higher temperature than the set temperature because of its power dissipation.

The heating powers required to maintain the 1 RPM sun oriented Head at various set temperatures are shown in Figures 14 - 18. The sensor operates above set temperature because of its power dissipation.

#### 4.0 TQCM Electronics

The goal of the electronics design was to minimize power dissipation in the TQCM so as not to excessively load the radiant cooler.

\* Mirror attachment was made by the Aerojet Electro Systems Co. through the assistance of Dr. M.K. Barsch.

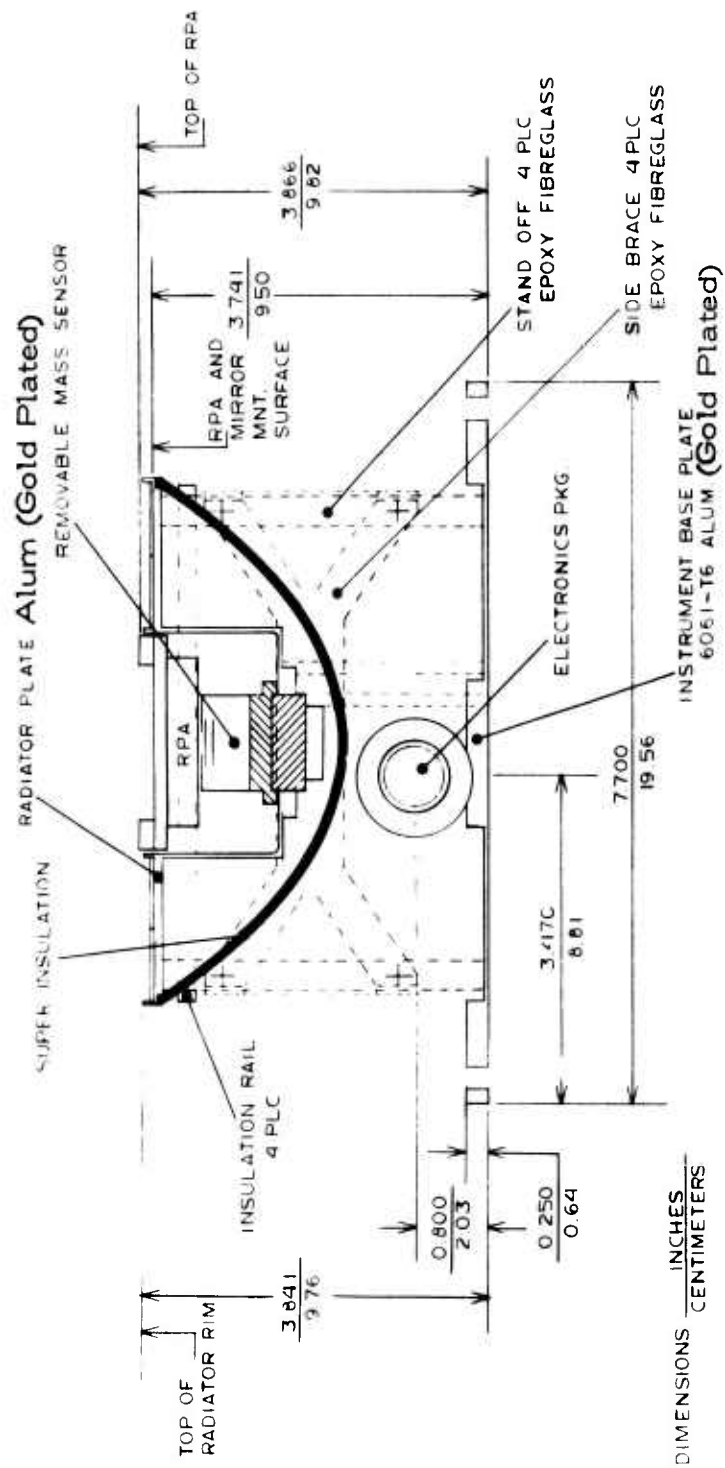


Figure 6 TQCM Head Design

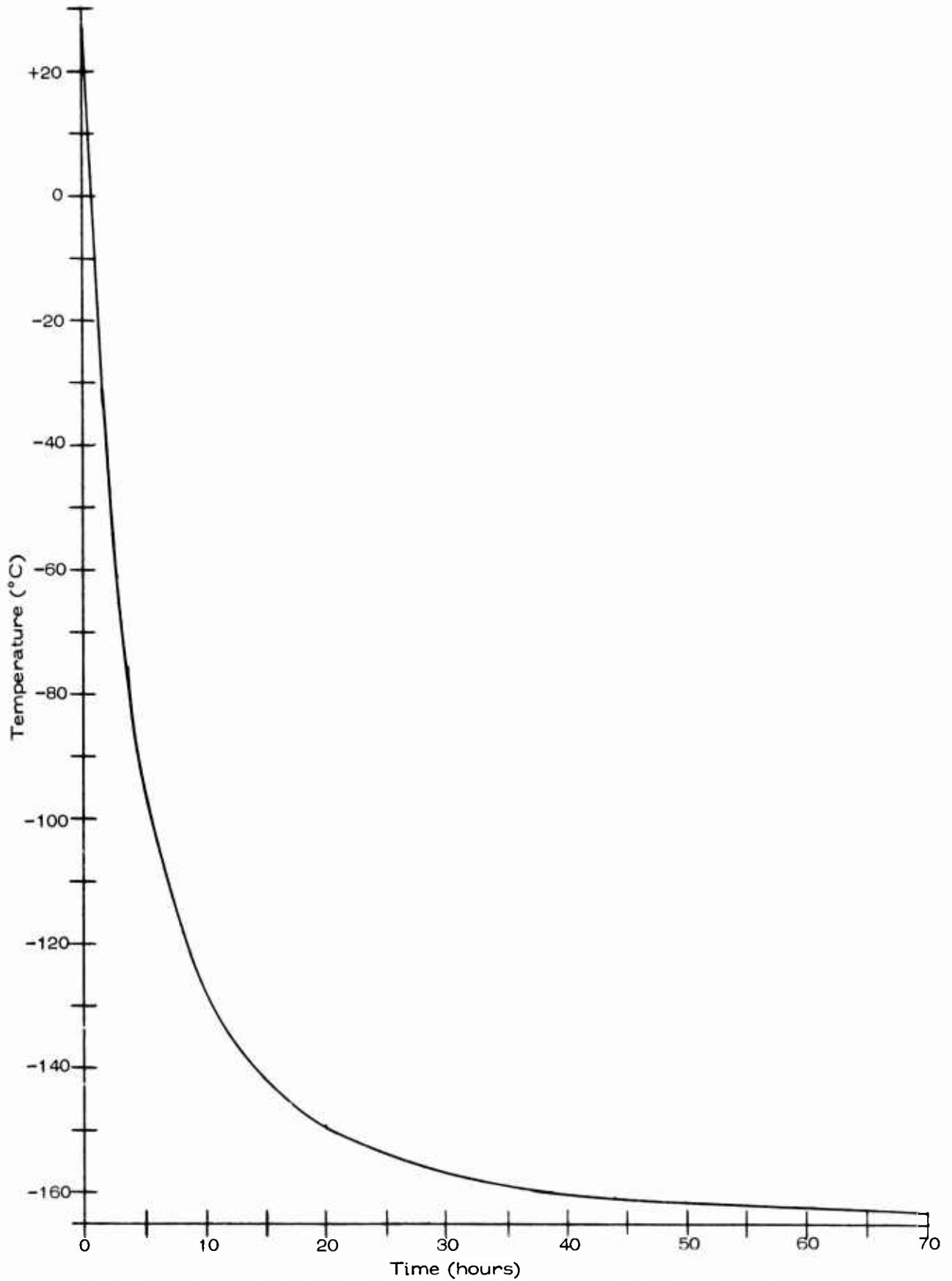


Figure 7 TQCM Sensor Crystal Cool-Down When Pointed into Deep Space

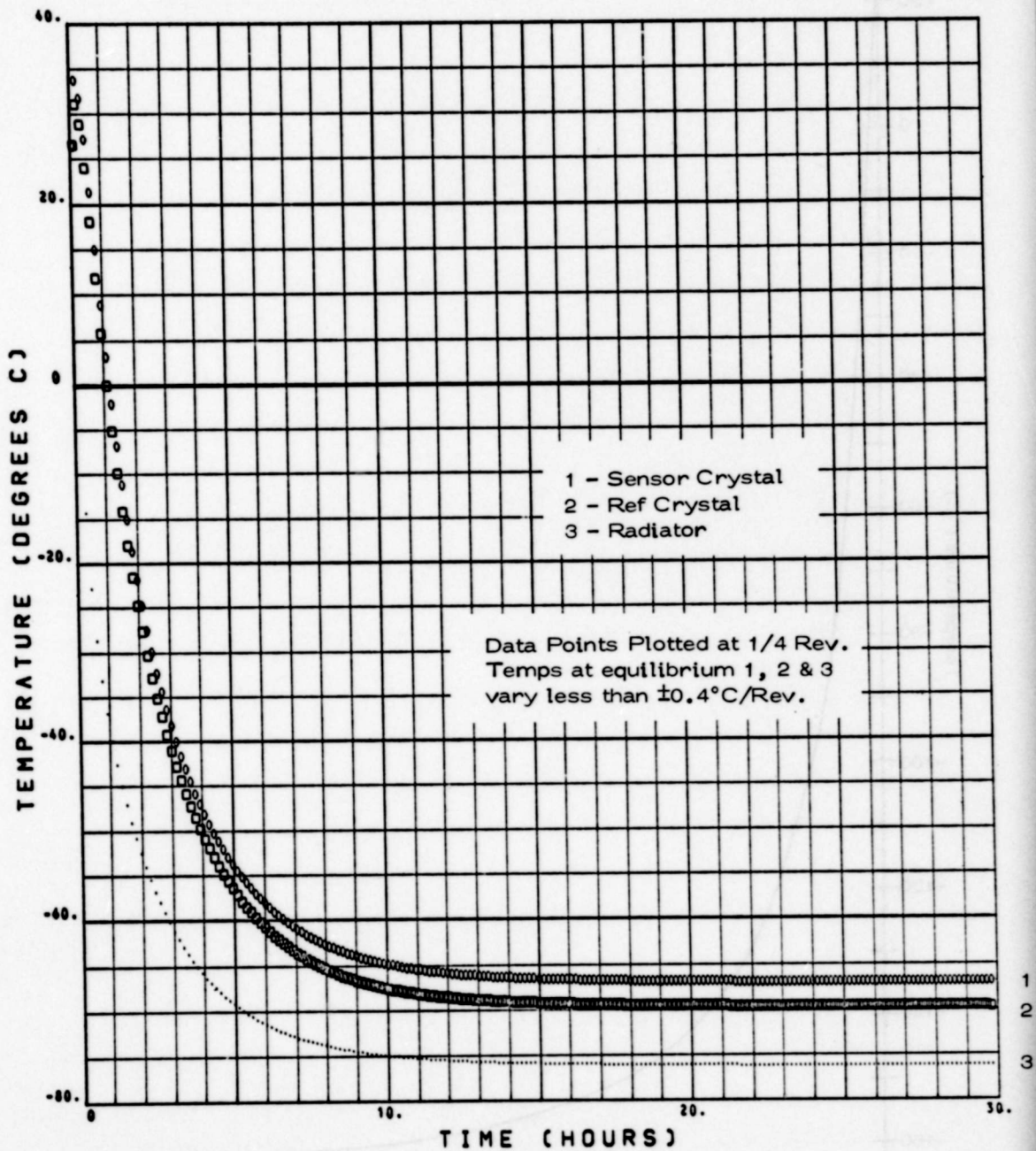


Figure 8 TQCM Cool-Down When Viewing Sun at 1 RPM

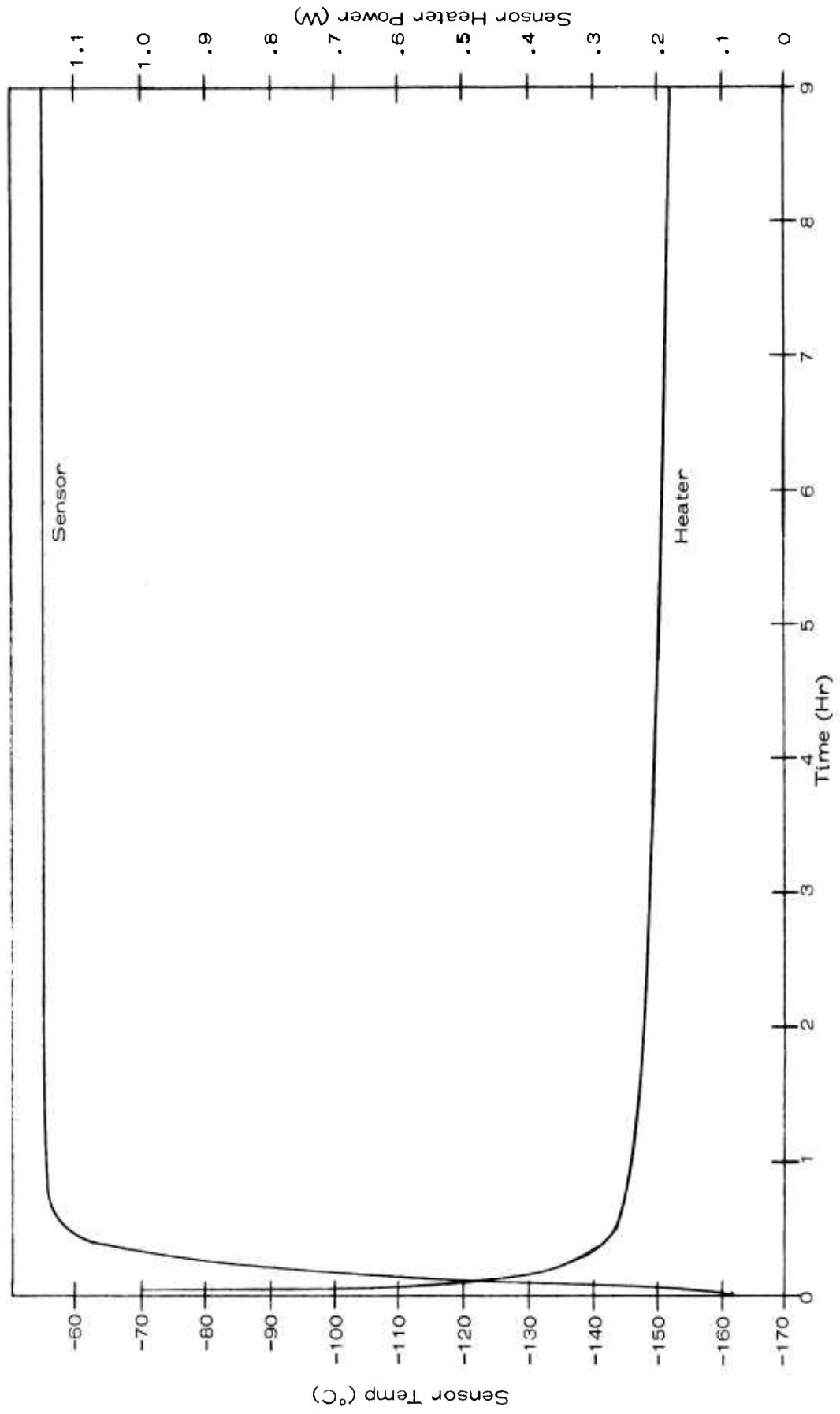


Figure 9 Sensor temperature and heater power for space oriented TQCM commanded to -60°C

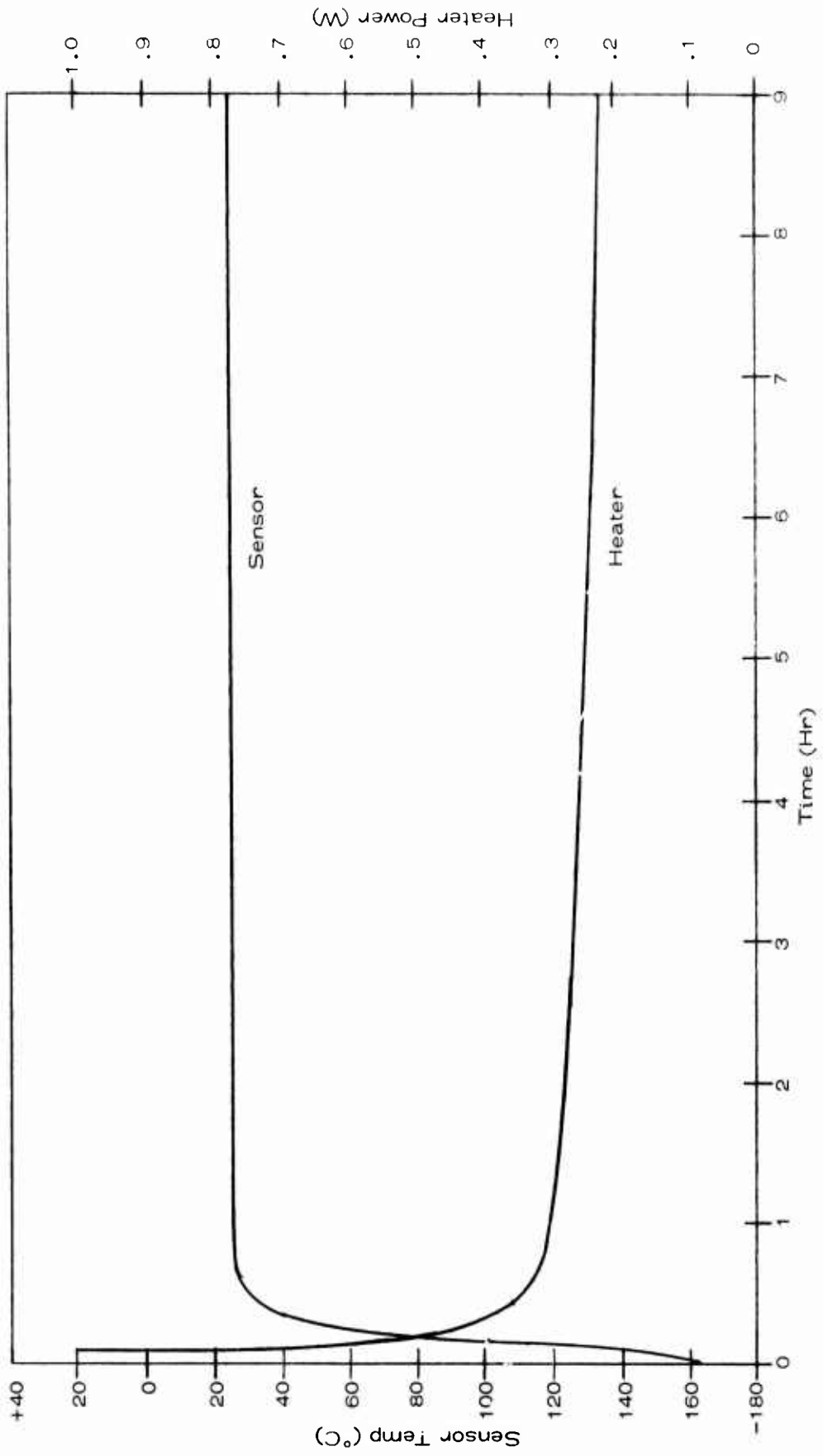


Figure 10 Sensor temperature and heater power for space oriented TQCM commanded to -30°C

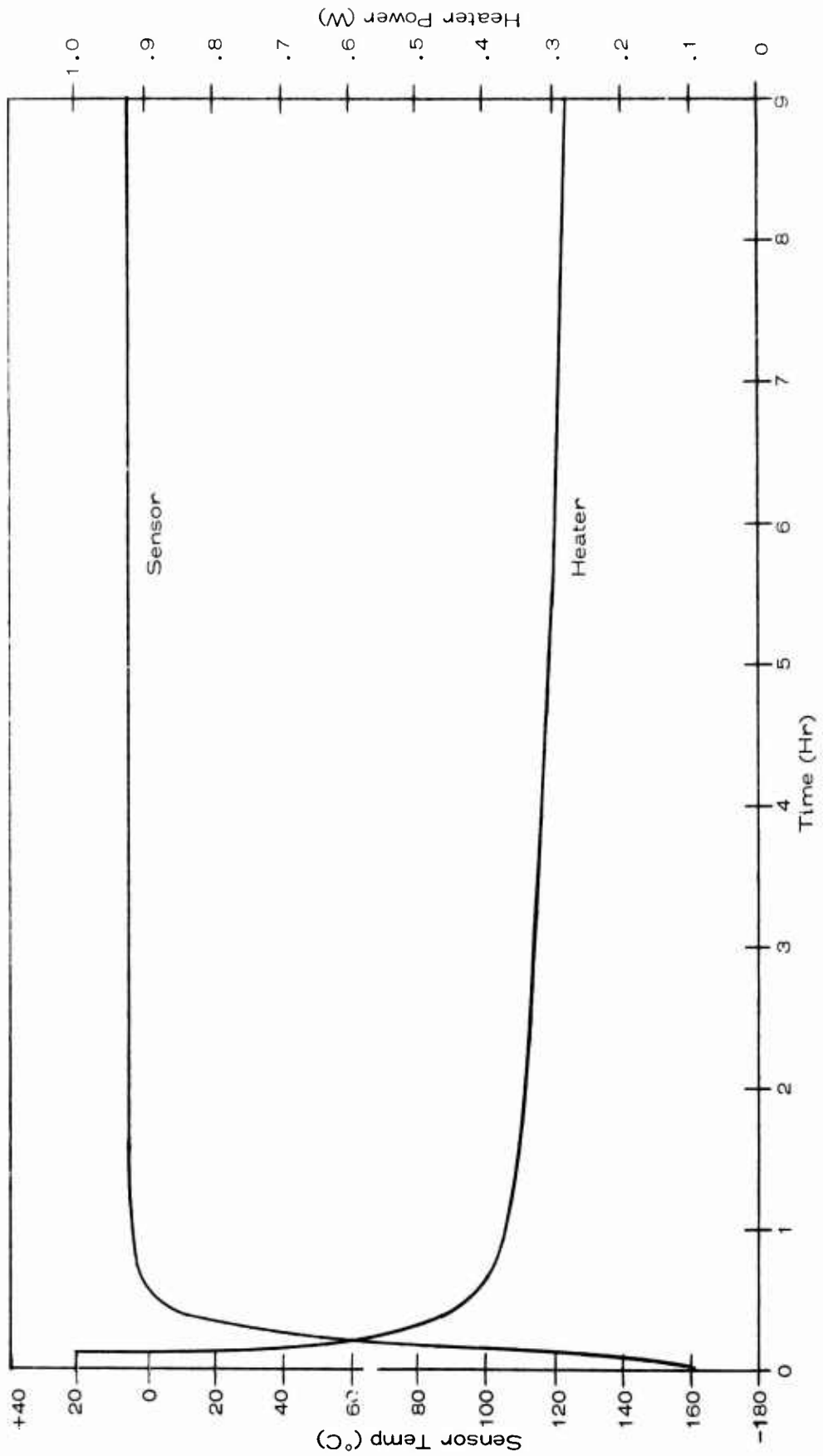


Figure 11 Sensor temperature and heater power for space oriented TQCM commanded to 0°C

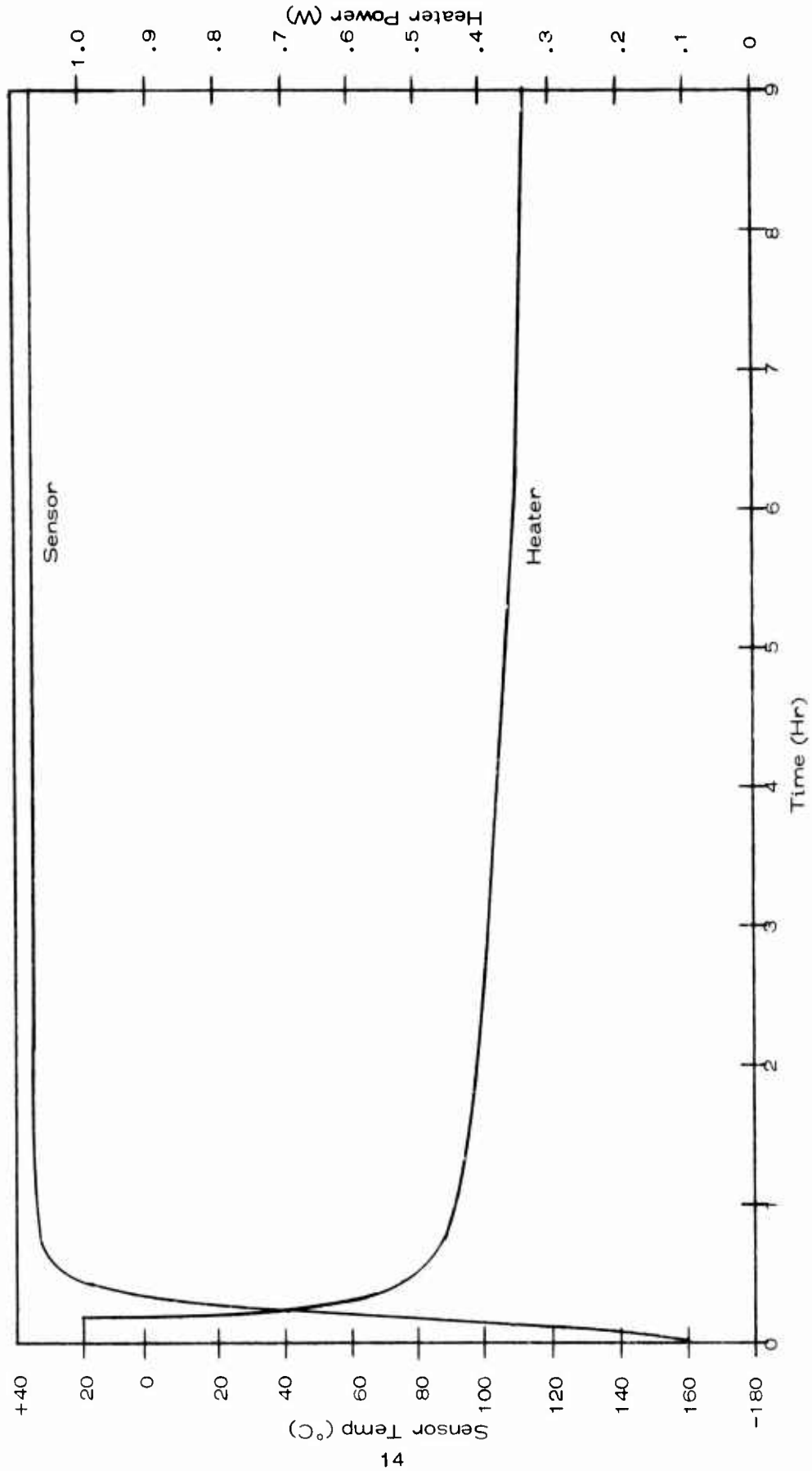


Figure 12 Sensor temperature and heater power for space oriented TQCM commanded to +30°C

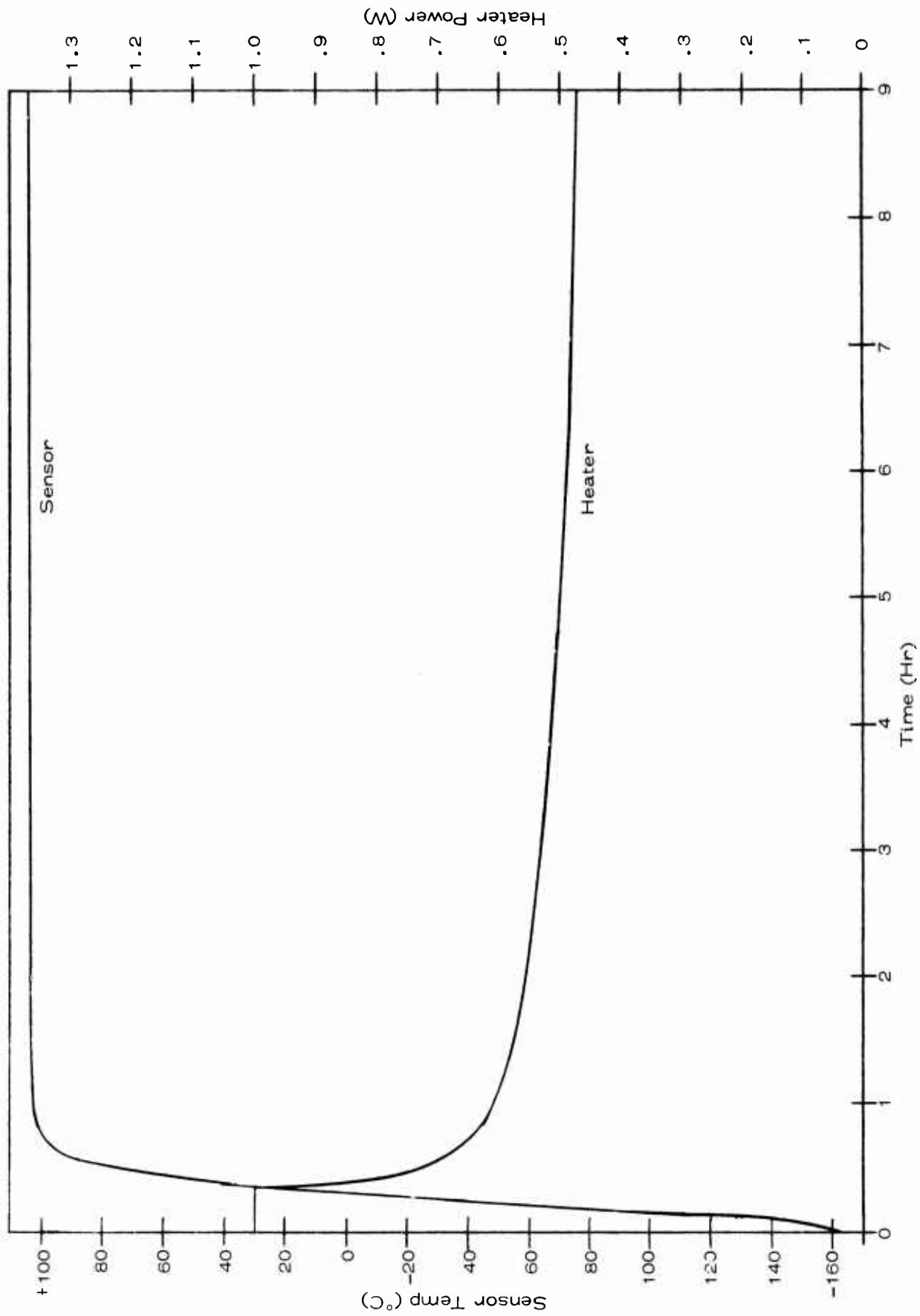


Figure 13 Sensor temperature and heater power for space oriented TQCM commanded to +100°C

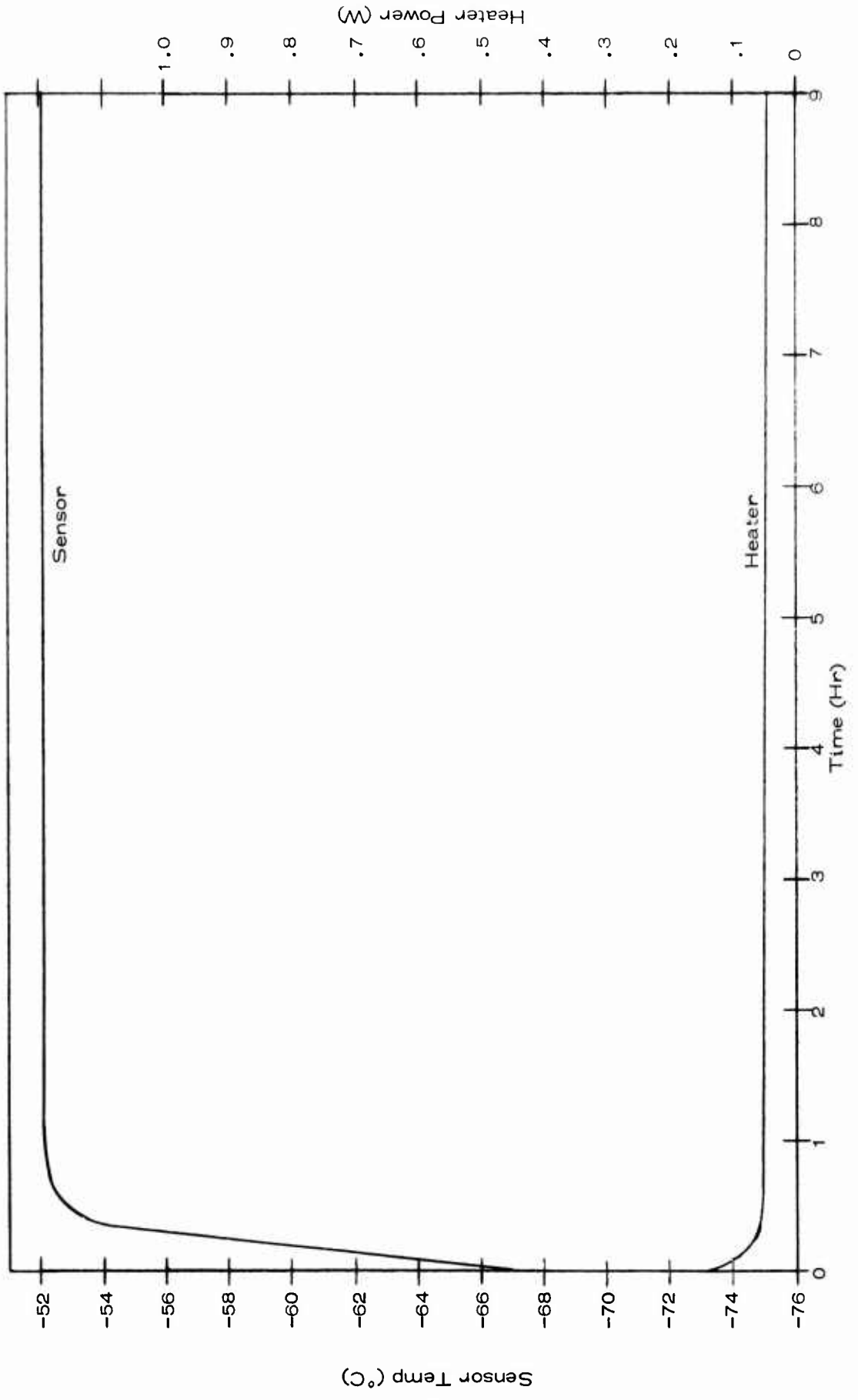


Figure 14 Sensor temperature and heater power for sun oriented TQCM commanded to -60°C

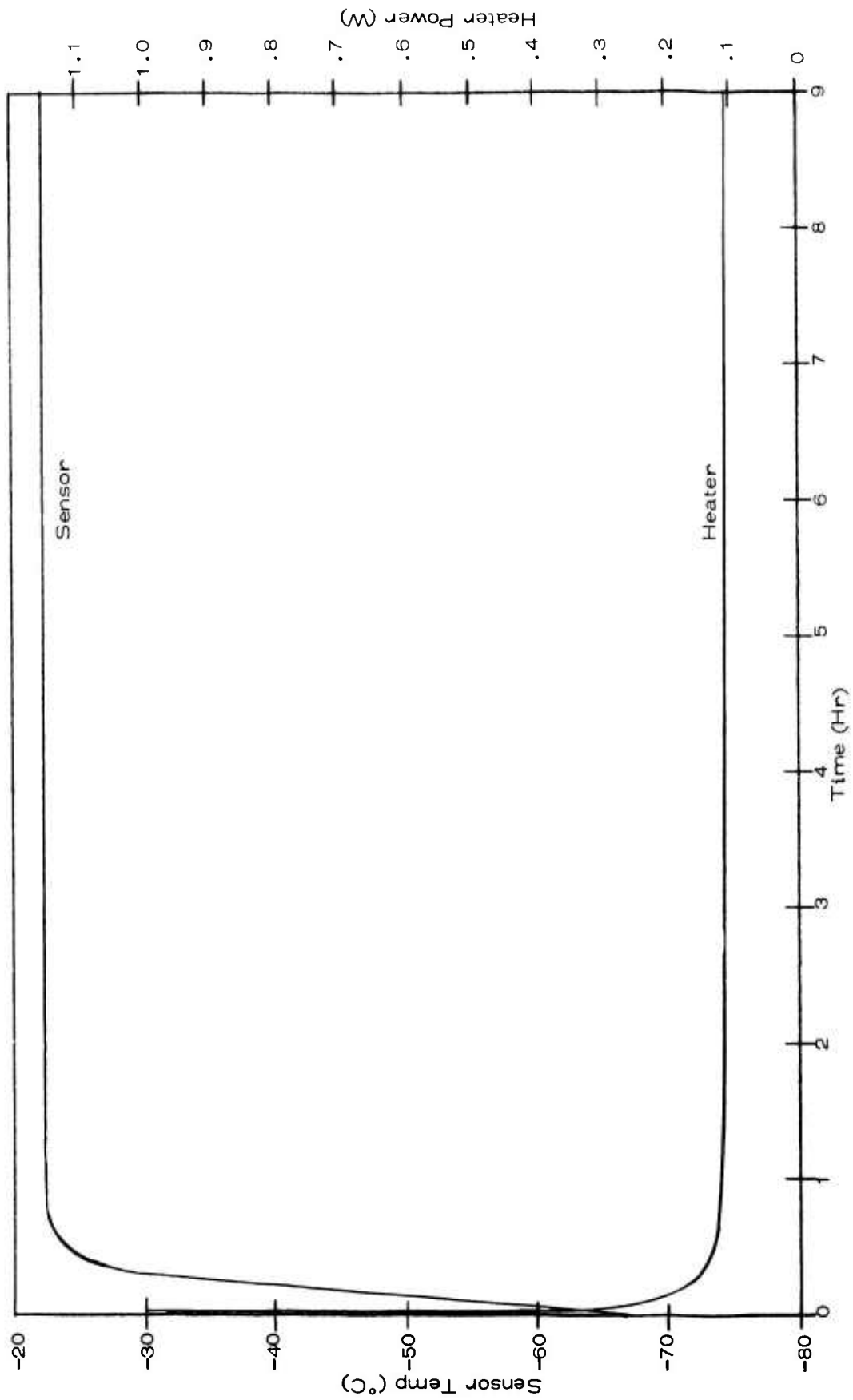


Figure 15 Sensor temperature and heater power for sun oriented TQCM commended to -30°C

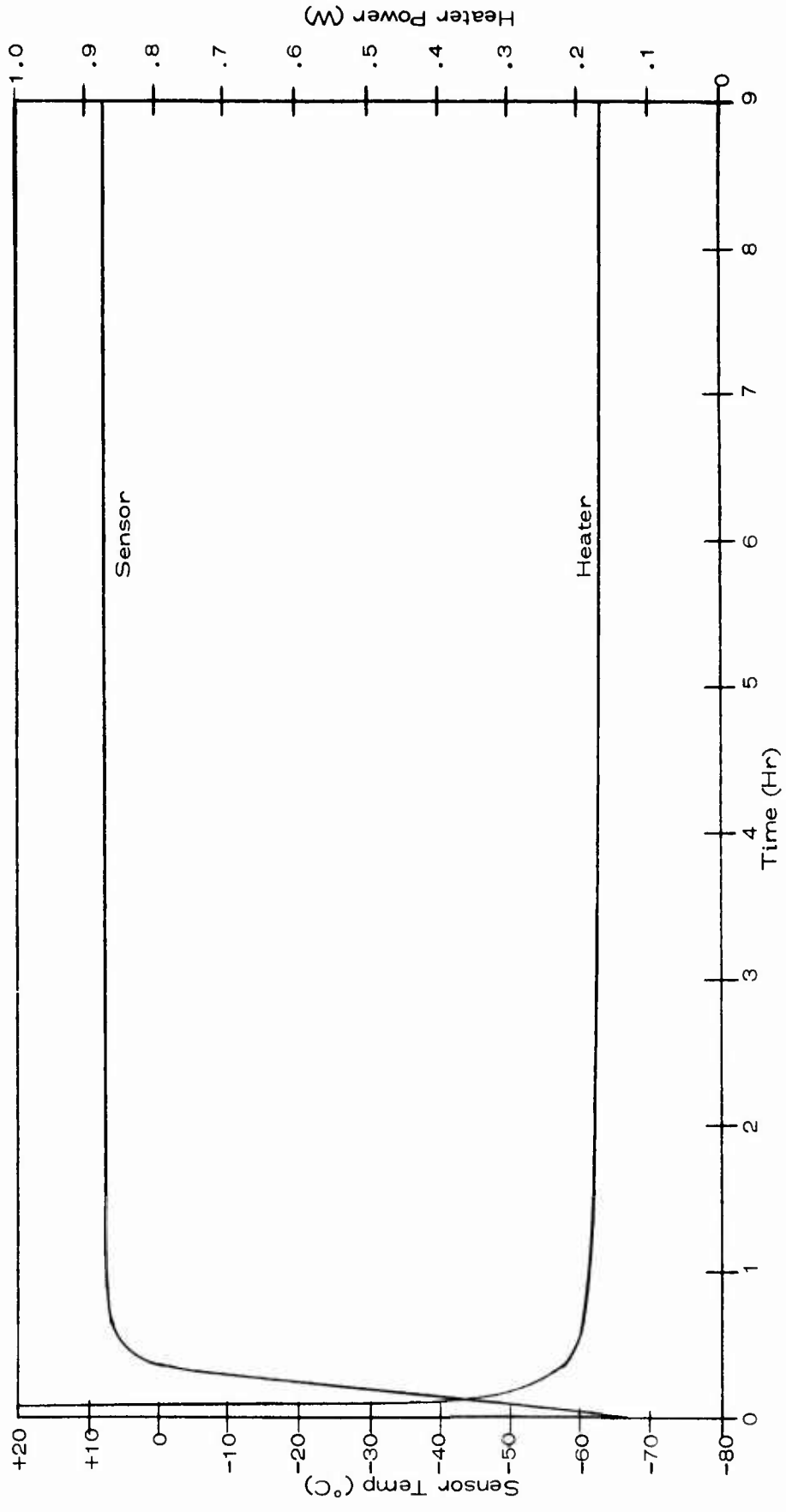


Figure 16 Sensor temperature and heater power for sun oriented TQCM commanded to 0°C

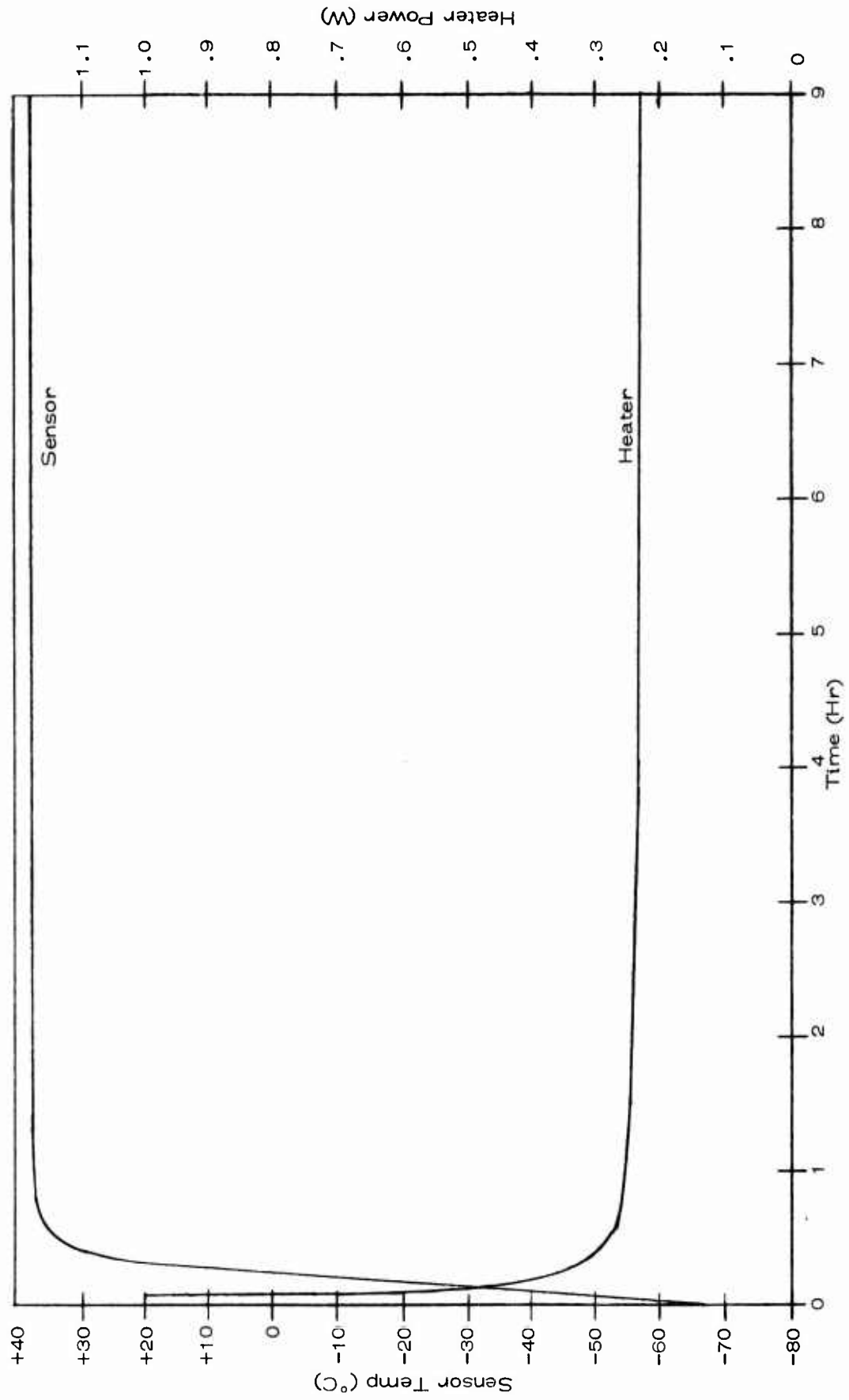


Figure 17 Sensor temperature and heater power for sun oriented TQCM commanded to +30°C

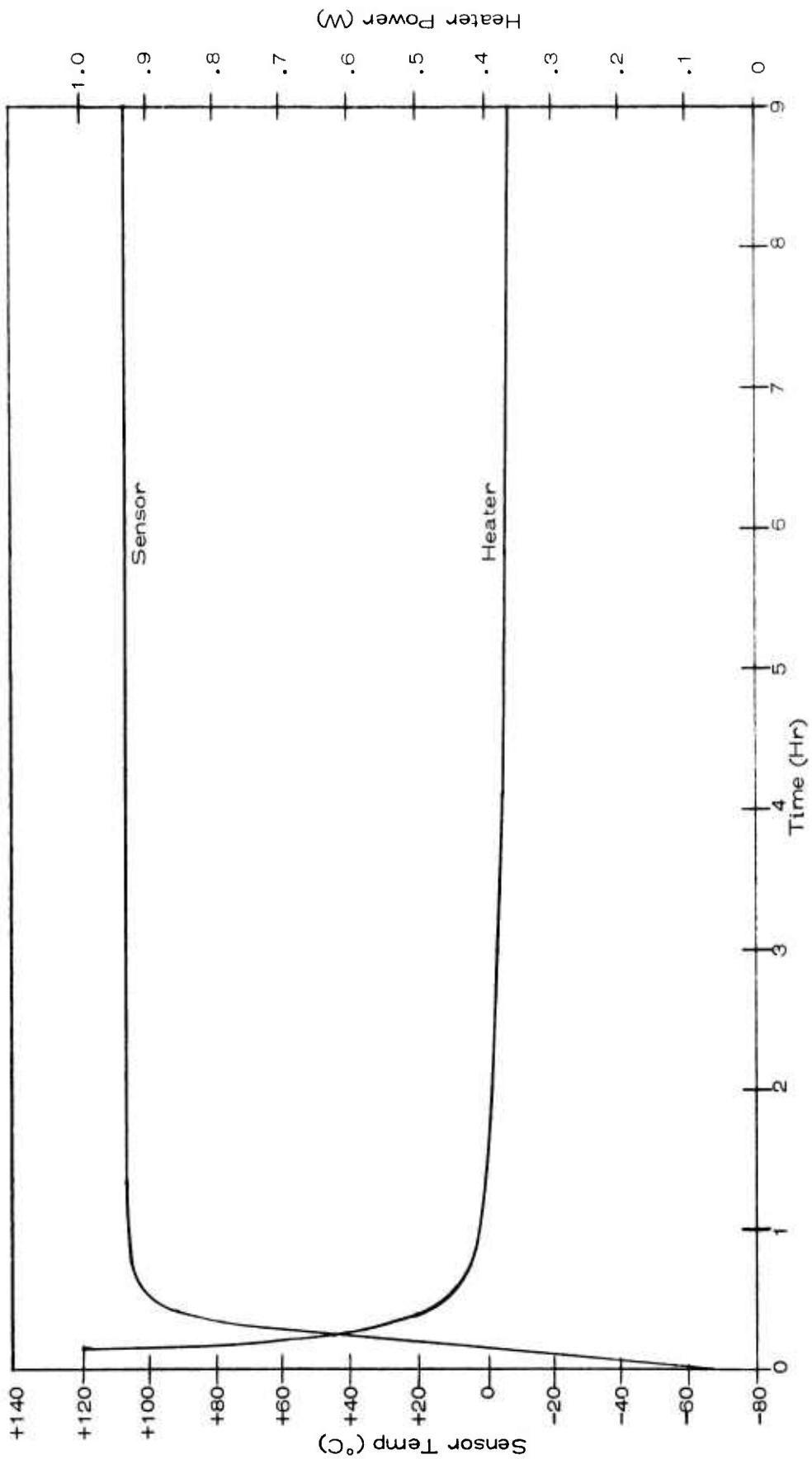


Figure 18 Sensor temperature and heater power for sun oriented TQCM commanded to +100°C

The TQCM system interconnections are shown in Figure 19.  
The Head electronics block diagram is shown in Figure 20.  
The Controller electronics block diagram is shown in Figure 21.

#### 4.1 Oscillators

Oscillators are designed with a wide band width to operate 15-MHz crystal sets.\* The power dissipation for the oscillators is 5 mW. The oscillator diagram is shown in Figure 22.

#### 4.2 Beat Frequency

The oscillators drive a mixer-beat-frequency operational amplifier having a low impedance high-gain output. The total power dissipation of the TQCM oscillators and operational amplifier is only 16 mW and represents a reduction of better than 2/3 over the best QCM now available. The frequency output of the amplifier is proportional to sensor crystal contamination loading. This frequency is provided as an output for direct monitoring of contamination. The frequency is also fed into a converter to provide an analogue output for spacecraft telemetry. The mixer and output amplifier diagram is shown in Figure 23.

#### 4.3 Frequency Converter

The analogue output of frequency is provided by a two frequency-analogue (F/A) converter. The high and low sensitivity converters are shown in Figure 24. Capacitor/resistor networks on the outputs protect the converters from damage by telemetry voltage surges.

#### 4.4 Heater Driver

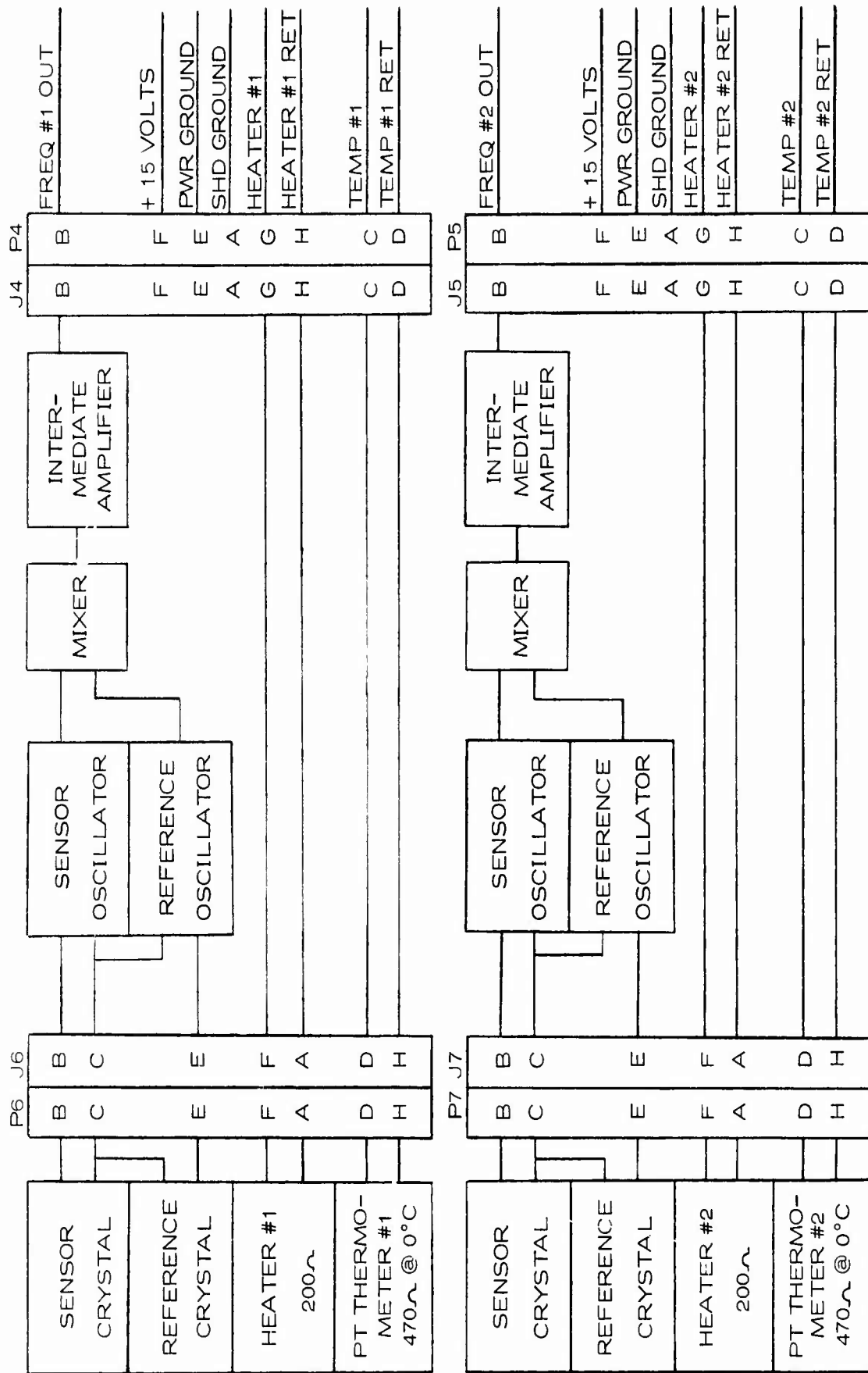
The sensor heater requires about 1 W during operation. The heater driver shown in Figure 25 provides this heavy power.

#### 4.5 Temperature Bridge

The temperature of mass sensors is monitored by a precision helium-filled platinum thermometer linear to 0.5%. The bridge output

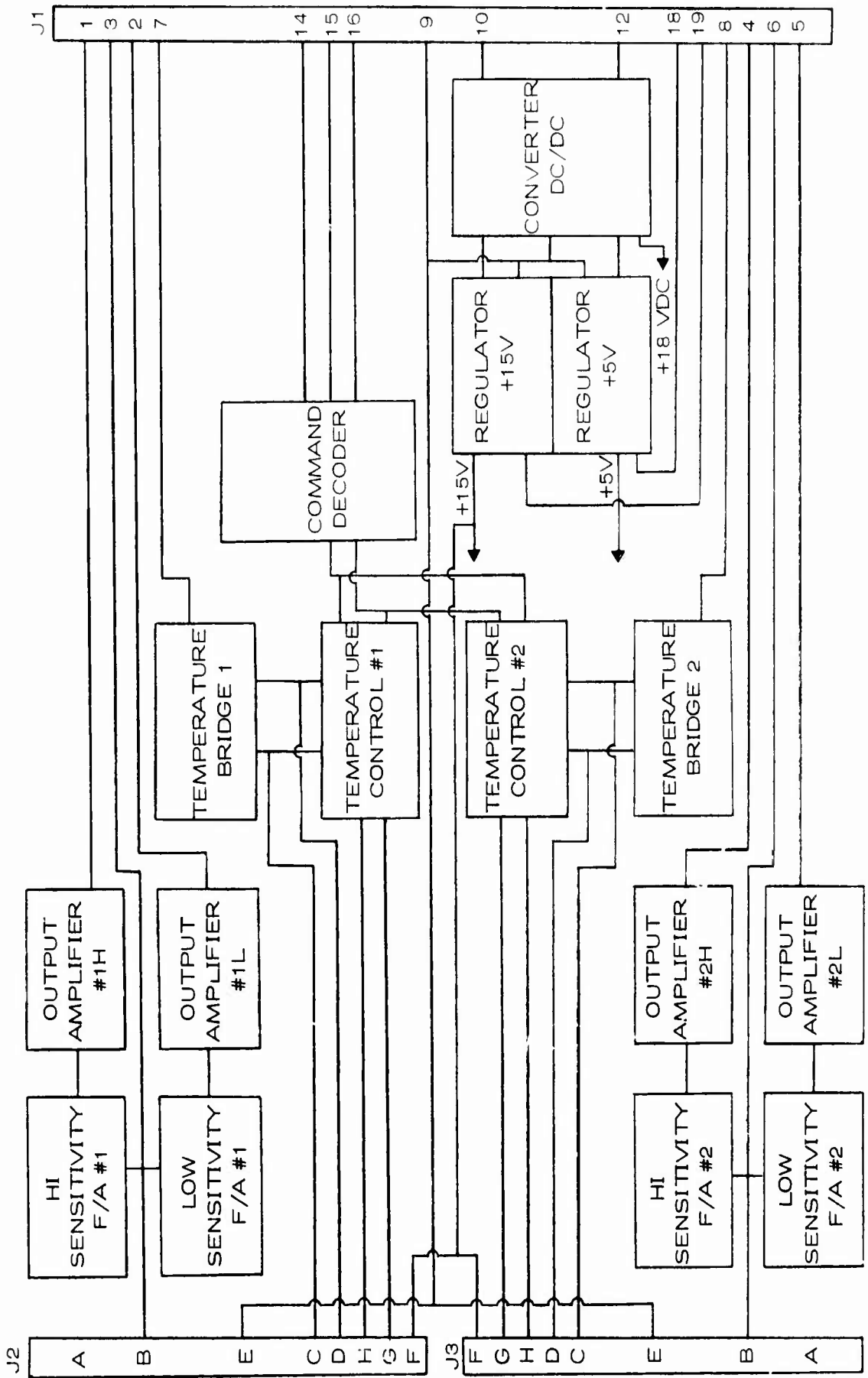
\* Crystal set dissipates  $< 100 \mu$  W depending on drive level





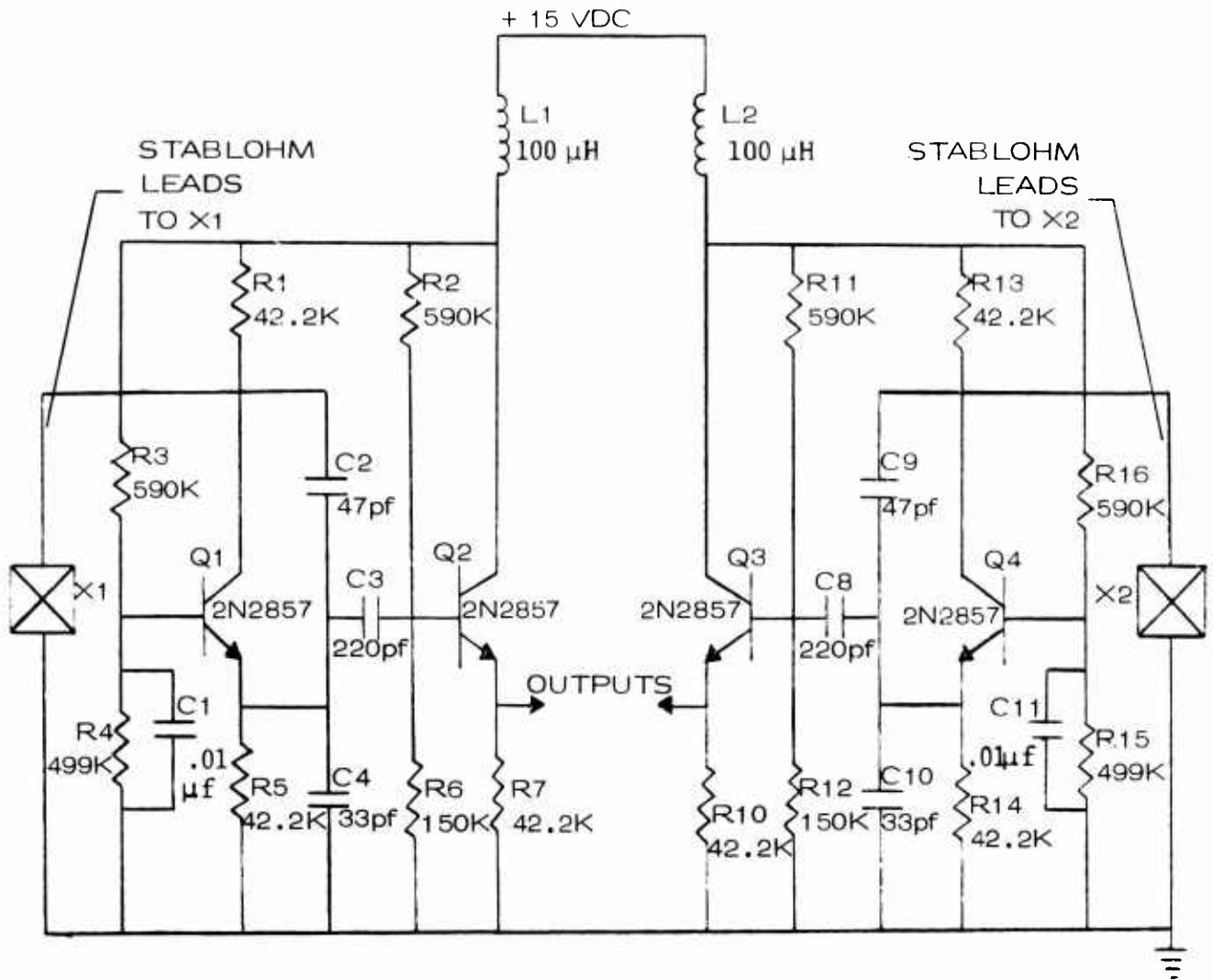
TQCM HEAD ELECTRONICS BLOCK DIAGRAM

Figure 20



TQM CONTROLLER ELECTRONICS BLOCK DIAGRAM

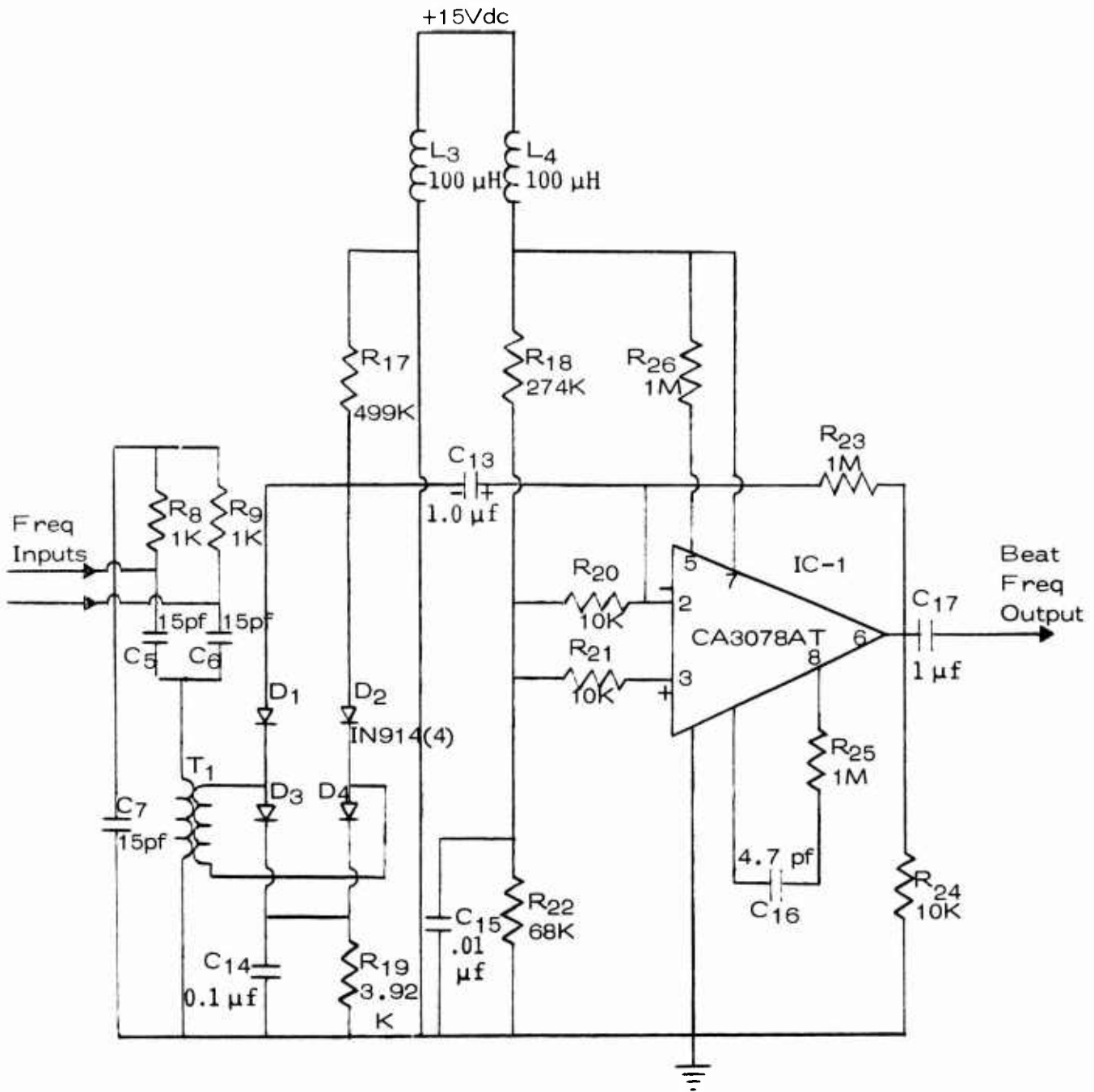
Figure 21



X1 - 15 MHz QUARTZ CRYSTAL (SENSOR)  
 X2 - 15 MHz QUARTZ CRYSTAL (REF)

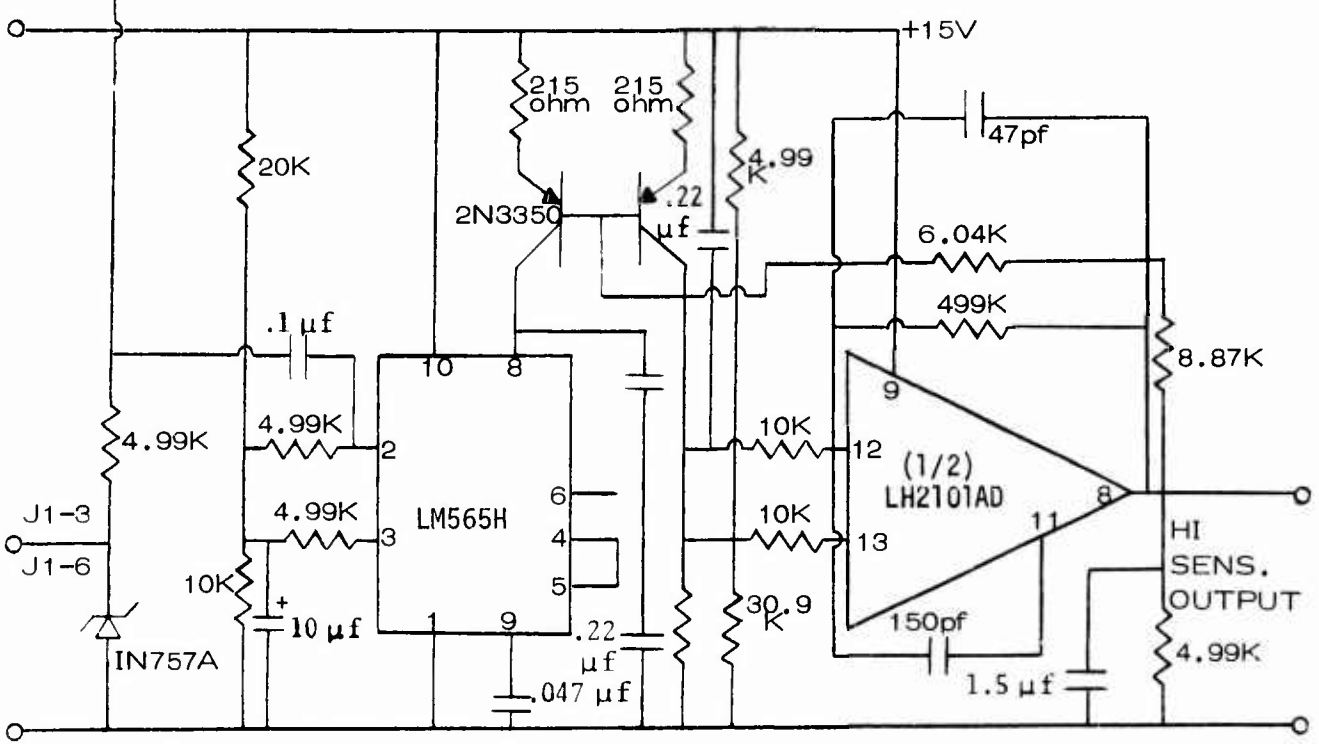
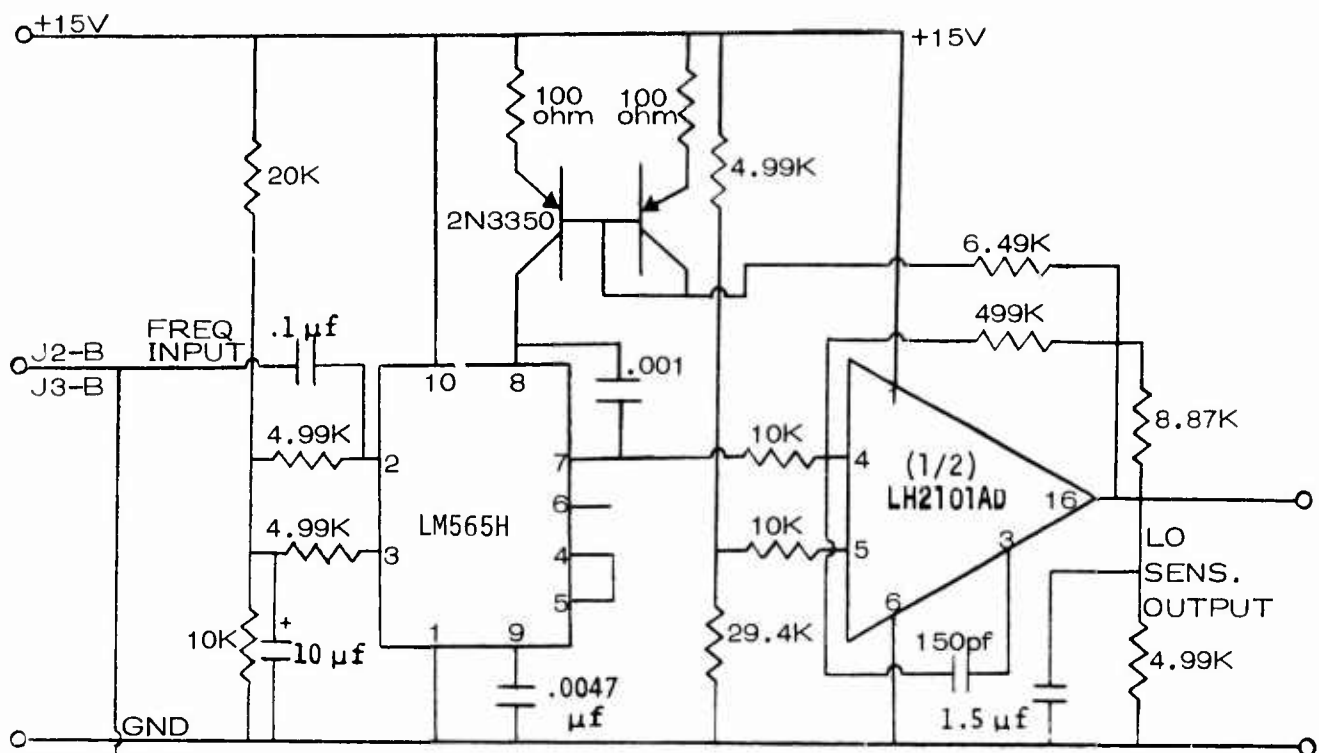
### TQCM HEAD MATCHED 15-MHz OSCILLATORS

Figure 22



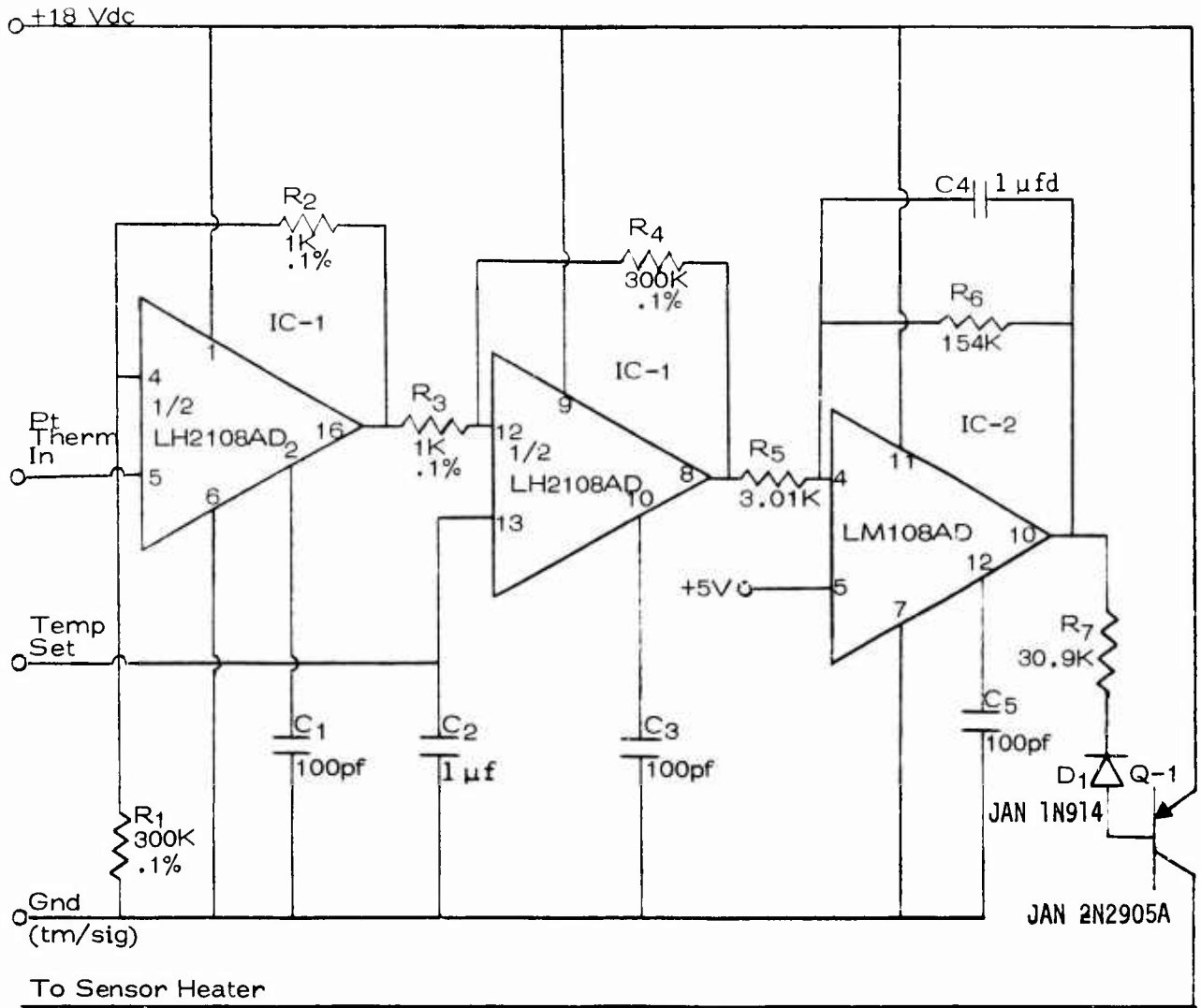
TQCM HEAD MIXER AND OUTPUT AMPLIFIER

Figure 23



TQCM CONTROLLER FREQ/VOLT CONVERTERS

Figure 24



TQCM CONTROLLER HEATER DRIVER

Figure 25

provided the signal to maintain a commanded set temperature. The bridge is shown in Figure 26.

#### 4.6 Command Electronics

The decoder for input temperature commands is shown in Figure 27. The Zener capacitor network on the clock, enable, and data lines protects the decoder from input voltage surges.

The relay network is driven by the decoder for operating the heater driver. It is shown in Figure 28.

#### 4.7 Power Supply

The TQCM requires a highly stable DC/DC isolation from satellite  $+28 \pm 4$  Vdc power. Separate high and low power outputs for electronics and heaters are needed. The high-efficient, switching supply, manufactured for Faraday Laboratories Inc. by Transistor Devices Inc., is shown in Figure 29.

### 5.0 Calibration

#### 5.1 Mass Sensor

The heart of the TQCM is its high mass sensitivity 15-MHz mass sensor. The design goal for sensor temperature vs frequency stability was  $\pm 75$  between  $-60$  and  $+60^\circ\text{C}$ . This difficult objective was exceeded for the two sensors. Table 1 shows the matched crystals to have stabilities of  $\pm 35$  Hz and  $\pm 14$  Hz between  $-60$  and  $+60^\circ\text{C}$ .

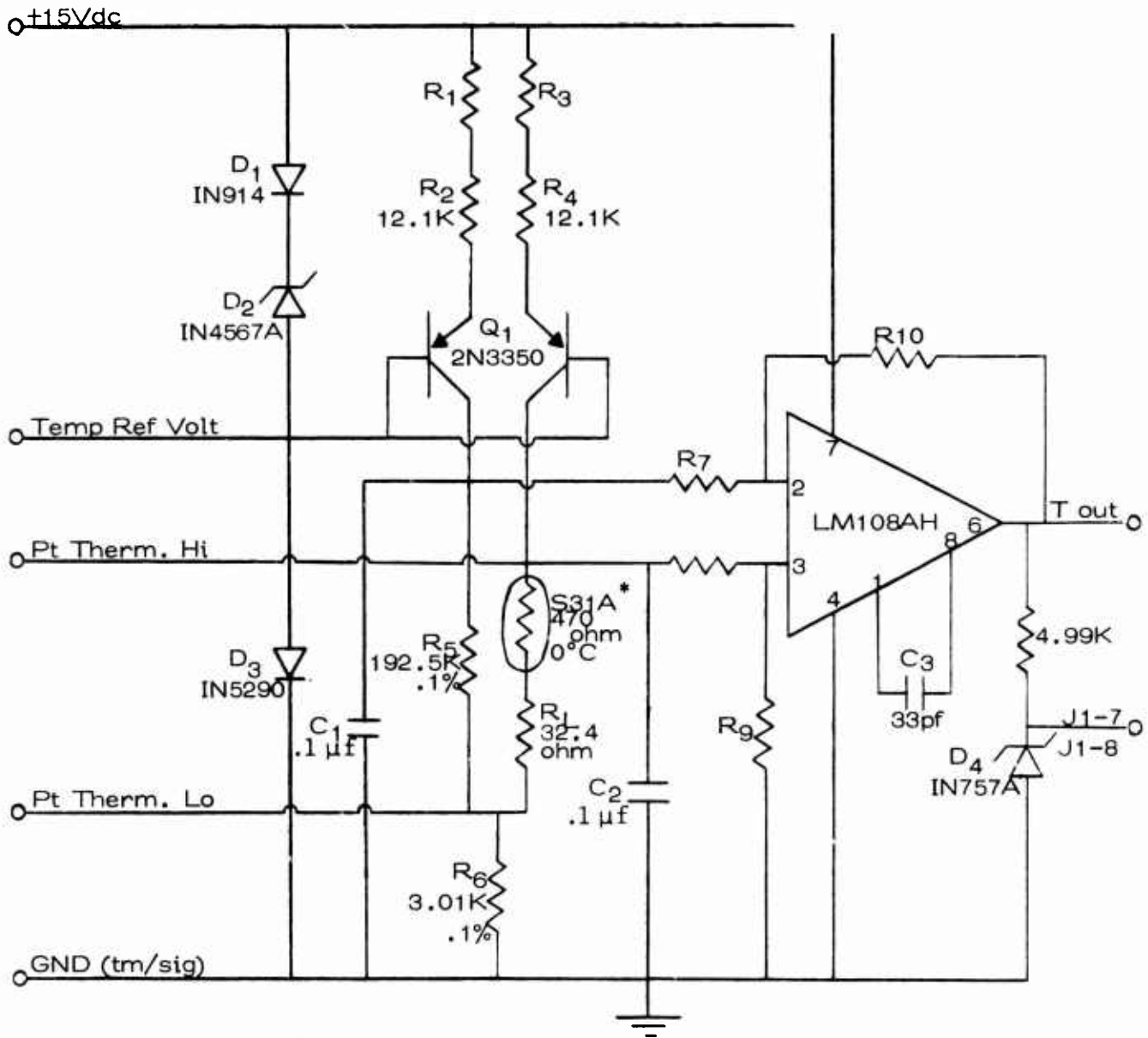
Frequency vs temperature plots for the crystal sets used in TQCM Heads 1 and 2 respectively are shown between  $-60$  and  $+100^\circ\text{C}$  in Figure 30.

After the sensors were calibrated, the sensor crystals were overlaid with aluminum to give the matched set a beat frequency of 2kHz required for driving the F/A converters.

#### 5.2 Controller

Calibration data of the TQCM Controller outputs for various input voltages at various ambient temperatures are shown in Tables 2 - 14.

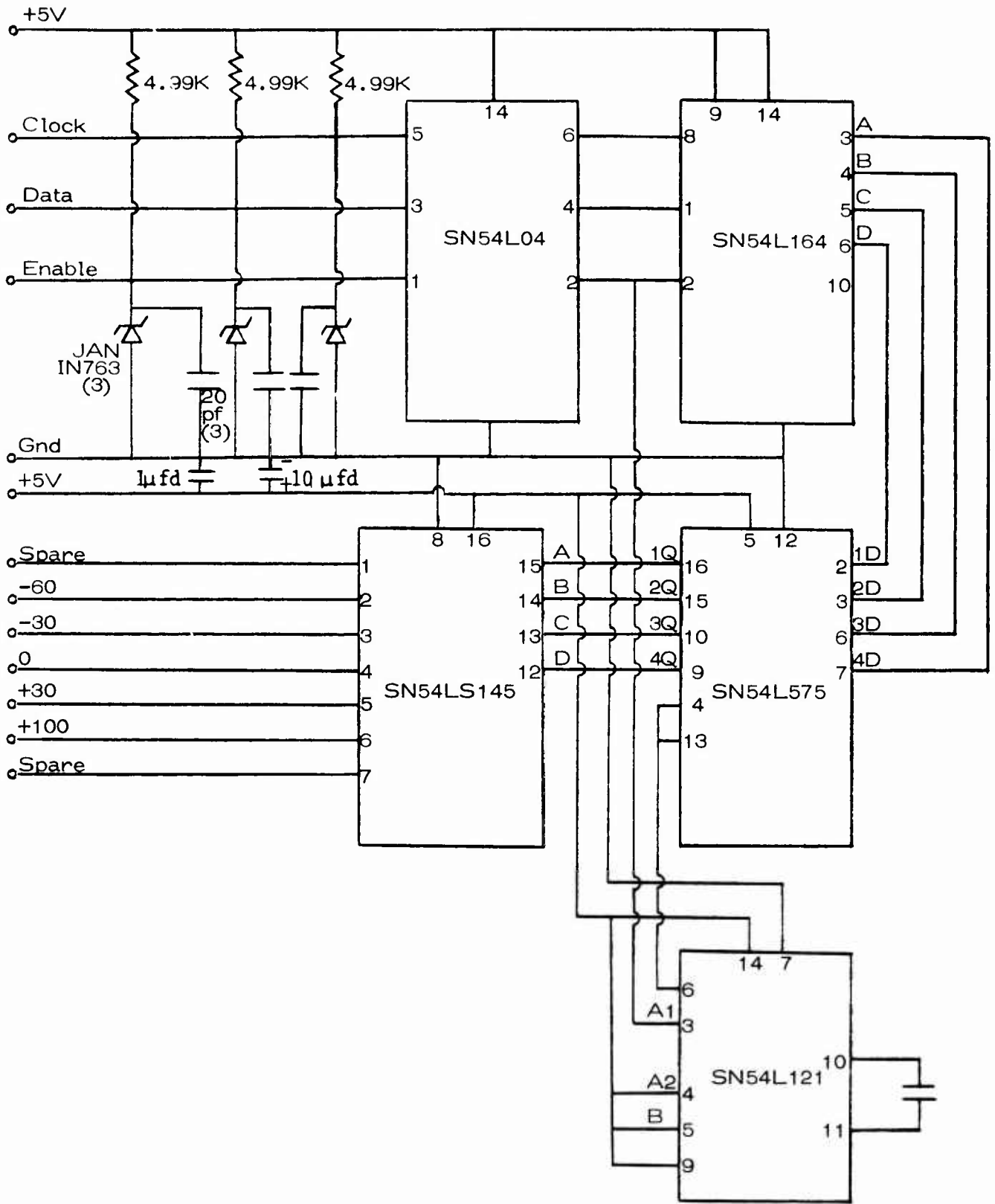
The tabulated calibration data are plotted in Figures 31 - 37 for TQCM Heads 1 and 2. Ambient temperature variations and input voltage changes are not called out in the figures. Changes in voltage and temperature produce Controller output changes of less than a few per cent and are



\* Pt Thermometer  
in TQCM Head

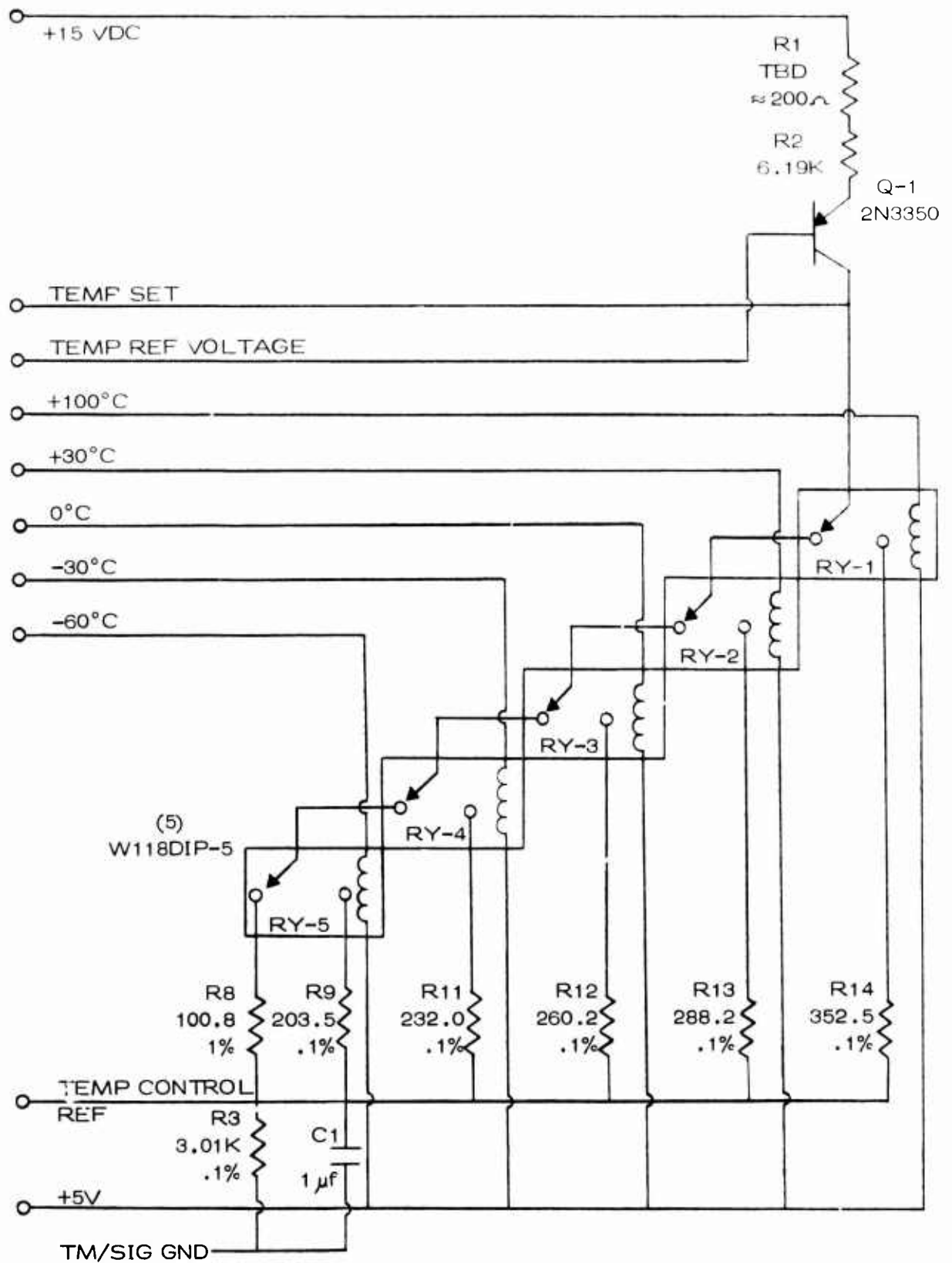
### TQCM CONTROLLER TEMP BRIDGE

Figure 26



TQCM CONTROLLER SERIAL COMMAND DECODER

Figure 27



TQCM CONTROLLER DECODER RELAY NETWORK

Figure 28



Table 1 Freq vs Temp Calibration of TQCM 15-MHz Sensor Crystals in  $1 \times 10^{-7}$  Torr Vacuum

Matched Crystal Set No. 1 Installed in TQCM Head No. 1

$\Delta$ Beat Freq with Temp Decrease from +20°C

Crystal	+20°C		0°C		-20°C		-40°C		-60°C	
	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)
494 (Sensor)	15,095,145		15,095,082	-19	15,095,087	-22	15,094,837	-36	15,094,230	-66
333 (Ref)	15,082,204		15,082,151		15,082,159		15,081,923		15,081,346	

$\Delta$ Beat Freq with Temp Increase from +20°C

Crystal	+20°C		+40°C		+60°C		+80°C		+100°C	
	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)
494 (Sensor)	15,095,030		15,095,002	+4	15,094,937	-8	15,094,882	-46	15,095,290	-15
333 (Ref)	15,081,994		15,081,962		15,081,909		15,081,892		15,082,269	

Matched Crystal Set No. 2 Installed in TQCM Head No. 2

$\Delta$ Beat Freq with Temp Decrease from +20°C

Crystal	+20°C		0°C		-20°C		-40°C		-60°C	
	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)
457 (Sensor)	15,082,128		15,082,123	+15	15,082,111	+11	15,081,908	-4	15,081,241	-13
324 (Ref)	15,082,284		15,082,294		15,082,278		15,082,060		15,081,394	

$\Delta$ Beat Freq with Temp Increase from +20°C

Crystal	+20°C		+40°C		+60°C		+80°C		+100°C	
	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)	Freq (Hz)	$\Delta$ Beat (Hz)
457 (Sensor)	15,082,018		15,082,005	+3	15,081,976	-7	15,081,993	+2	15,032,105	+38
324 (Ref)	15,082,209		15,082,199		15,082,160		15,082,186		15,082,324	

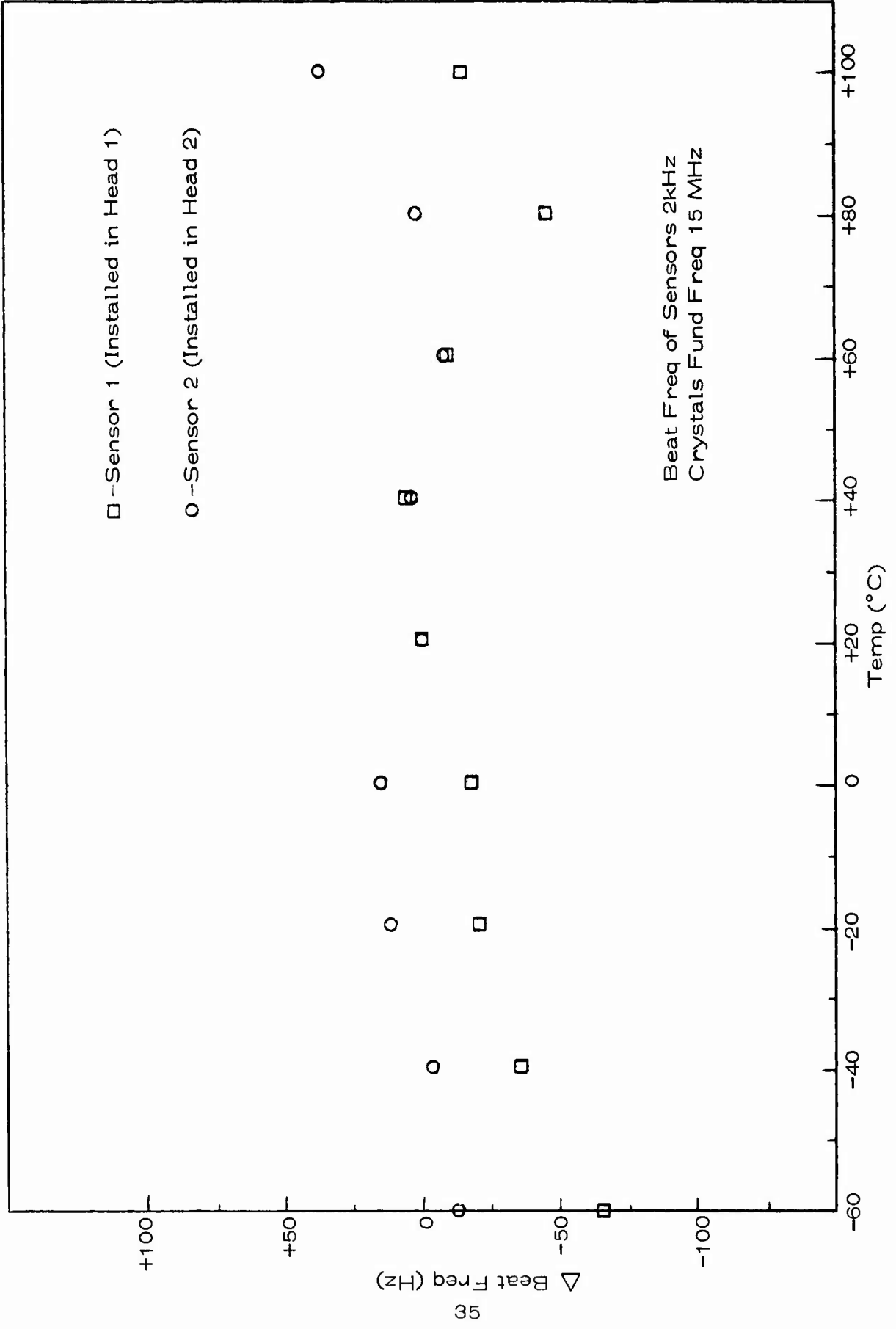


Figure 30 TQCM Sensors Frequency vs Temperature Calibration

Table 2 TQCM Freq/Volt Converter Output at 0°C Ambient for Input Power Voltage of +28 Vdc ± 4V. Sensor Beat Freq at Zero Loading 2KHz

<u>Sensor Beat Freq Change</u>	<u>Mass Loading Change</u>	<u>Hi-Sens. Out. No. 1</u>	<u>Lo-Sens. Out. No. 1</u>	<u>Hi-Sens. Out. No. 2</u>	<u>Lo-Sens. Out. No. 2</u>
(Hz)	(g/cm <sup>2</sup> x 10 <sup>-6</sup> )	(V)	(V)	(V)	(V)
-200	0.312	4.87	5.07	4.97	5.05
-150	0.234	4.72	5.07	4.80	5.05
-100	0.156	4.56	5.06	4.64	5.05
-50	0.078	4.40	5.06	4.48	5.04
0	0	4.24	5.06	4.31	5.04
100	0.156	3.94	5.05	4.00	5.03
200	0.312	3.62	5.04	3.67	5.02
300	0.468	3.31	5.03	3.35	5.01
400	0.624	2.99	5.03	3.02	5.00
500	0.780	2.67	5.02	2.69	5.00
600	0.936	2.36	5.01	2.37	4.99
700	1.092	2.04	5.00	2.04	4.98
800	1.248	1.73	5.00	1.72	4.98
900	1.404	1.41	4.99	1.39	4.97
1,000	1.560	1.09	4.98	1.06	4.96
1,100	1.716	.77	4.97	.73	4.95
1,200	1.872		4.96		4.94
3,000	4.680		4.83		4.81
8,000	12.480		4.43		4.41
18,000	28.080		3.66		3.63
28,000	43.680		2.88		2.85
38,000	59.280		2.11		2.07
48,000	74.880		1.34		1.29
58,000	90.480		.68		.66
59,000	92.040		.63		.62
60,000	93.60		.57		.56

Table 3 TQCM Freq/Volt Converter Output at +20°C Ambient for Input Power Voltage of +28 Vdc ± 4V. Sensor Beat Freq at Zero Loading 2KHz

<u>Sensor Beat Freq Change</u>	<u>Mass Loading Change</u>	<u>Hi-Sens. Out. No. 1</u>	<u>Lo-Sens. Out. No. 1</u>	<u>Hi-Sens. Out. No. 2</u>	<u>Lo-Sens. Out. No. 2</u>
(Hz)	(g/cm <sup>2</sup> x 10 <sup>-6</sup> )	(V)	(V)	(V)	(V)
-200	0.312	5.06	5.09	5.15	5.07
-150	0.234	4.90	5.09	5.00	5.07
-100	0.156	4.75	5.08	4.83	5.06
-50	0.078	4.60	5.08	4.68	5.06
0	0	4.45	5.07	4.52	5.06
100	0.156	4.14	5.07	4.20	5.05
200	0.312	3.84	5.06	3.89	5.04
300	0.468	3.53	5.05	3.57	5.03
400	0.624	3.22	5.05	3.25	5.03
500	0.780	2.92	5.04	2.94	5.02
600	0.936	2.61	5.03	2.62	5.01
700	1.092	2.30	5.02	2.31	5.00
800	1.248	1.99	5.01	1.99	4.99
900	1.404	1.68	5.01	1.67	4.99
1,000	1.560	1.38	5.00	1.35	4.90
1,100	1.716	1.07	4.99	1.04	4.97
1,200	1.872	.76	4.98		4.96
3,000	4.680		4.84		4.82
8,000	12.480		4.45		4.43
18,000	28.080		3.67		3.65
28,000	43.680		2.90		2.86
38,000	59.280		2.12		2.09
48,000	74.880		1.35		1.30
58,000	90.480		.68		.66
59,000	92.040		.63		.62
60,000	93.60		.56		.55

Table 4 TQCM Freq/Volt Converter Output at +30°C Ambient for Input Power Voltage of +28 Vdc  $\pm$  4V. Sensor Beat Freq at Zero Loading 2KHz

<u>Sensor Beat Freq Change</u>	<u>Mass Loading Change</u>	<u>Hi-Sens. Out. No. 1</u>	<u>Lo-Sens. Out. No. 1</u>	<u>Hi-Sens. Out. No. 2</u>	<u>Lo-Sens. Out. No. 2</u>
(Hz)	(g/cm <sup>2</sup> x 10 <sup>-6</sup> )	(V)	(V)	(V)	(V)
-200	0.312	5.05	5.09	5.15	4.94
-150	0.234	4.90	5.09	4.99	5.08
-100	0.156	4.74	5.09	4.84	5.07
-50	0.078	4.59	5.08	4.67	5.07
0	0	4.44	5.08	4.52	5.06
100	0.156	4.14	5.07	4.21	5.05
200	0.312	3.83	5.06	3.89	5.04
300	0.468	3.52	5.06	3.58	5.04
400	0.624	3.21	5.05	3.26	5.03
500	0.780	2.90	5.04	2.94	5.02
600	0.936	2.59	5.03	2.62	5.02
700	1.092	2.28	5.02	2.30	5.01
800	1.248	1.98	5.02	1.98	5.00
900	1.404	1.67	5.01	1.66	4.99
1,000	1.560	1.35	5.00	1.34	4.98
1,100	1.716	1.05	4.99	1.03	4.98
1,200	1.872	.74	4.98		4.97
3,000	4.680		4.85		4.83
8,000	12.480		4.46		4.44
18,000	28.080		3.67		3.65
28,000	43.680		2.90		2.87
38,000	59.280		2.12		2.09
48,000	74.880		1.35		1.31
58,000	90.480		.68		.66
59,000	92.040		.62		.62
60,000	93.60		.56		.55

Table 5 TQCM Freq/Volt Converter Output at +50°C Ambient for Input Power Voltage of +28 Vdc  $\pm$  4V. Sensor Beat Freq at Zero Loading 2KHz

<u>Sensor Beat Freq Change</u>	<u>Mass Loading Change</u>	<u>Hi-Sens. Out. No. 1</u>	<u>Lo-Sens. Out. No. 1</u>	<u>Hi-Sens. Out. No. 2</u>	<u>Lo-Sens. Out. No. 2</u>
(Hz)	(g/cm <sup>2</sup> x 10 <sup>-6</sup> )	(V)	(V)	(V)	(V)
-200	0.312	5.16	5.12	4.96	4.84
-150	0.234	5.01	5.11	4.95	5.12
-100	0.156	4.86	5.11	4.97	4.95
-50	0.078	4.71	5.10	4.81	4.99
0	0	4.56	5.10	4.66	5.08
100	0.156	4.26	5.09	4.36	5.07
200	0.312	3.96	5.09	4.05	5.06
300	0.468	3.65	5.08	3.73	5.06
400	0.624	3.35	5.07	3.42	5.05
500	0.780	3.04	5.06	3.10	5.04
600	0.936	2.73	5.05	2.79	5.04
700	1.092	2.43	5.04	2.48	5.03
800	1.248	2.12	5.03	2.16	5.02
900	1.404	1.81	5.03	1.85	5.01
1,000	1.560	1.51	5.02	1.54	5.00
1,100	1.716	1.21	5.01	1.22	4.99
1,200	1.872	.90	5.01	.91	4.99
3,000	4.680		4.87		4.85
8,000	12.480		4.47		4.45
18,000	28.080		3.69		3.67
28,000	43.680		2.91		2.88
38,000	59.280		2.13		2.10
48,000	74.880		1.35		1.32
58,000	90.480		.67		.67
59,000	92.040		.61		.61
60,000	93.60		.54		.54

Table 6 TQCM Temp Outputs for Different Input Power Voltages at 0°C Ambient

Temp (°C)	<u>+32 Vdc</u>		<u>+28 Vdc</u>		<u>+24 Vdc</u>	
	Temp Output #1	Temp Output #2	Temp Output #1	Temp Output #2	Temp Output #1	Temp Output #2
-110	1.00	1.03	1.00	1.03	1.00	1.03
-100	1.20	1.23	1.20	1.23	1.20	1.22
- 73	1.72	1.75	1.72	1.75	1.72	1.75
- 23	2.67	2.70	2.68	2.70	2.67	2.70
0	3.11	3.13	3.11	3.13	3.11	3.13
+ 27	3.61	3.64	3.61	3.64	3.61	3.64
+ 52	4.08	4.10	4.08	4.10	4.08	4.10
+100	4.96	4.98	4.96	4.98	4.96	4.98
+110	5.14	5.17	5.14	5.17	5.14	5.17

Table 7 TQCM Temp Outputs for Different Input Power Voltages at +20°C Ambient

Temp (°C)	<u>+32 Vdc</u>		<u>+28 Vdc</u>		<u>+24 Vdc</u>	
	Temp Output #1	Temp Output #2	Temp Output #1	Temp Output #2	Temp Output #1	Temp Output #2
-110	1.00	1.03	1.00	1.03	1.00	1.03
-100	1.20	1.23	1.20	1.23	1.20	1.23
- 73	1.72	1.75	1.72	1.75	1.72	1.75
- 23	2.68	2.70	2.68	2.70	2.68	2.70
0	3.11	3.13	3.11	3.13	3.11	3.13
+ 27	3.62	3.63	3.62	3.64	3.62	3.64
+ 52	4.08	4.10	4.08	4.10	4.08	4.10
+100	4.96	4.98	4.96	4.98	4.96	4.98
+110	5.15	5.17	5.15	5.16	5.15	5.17

Table 8 TQCM Temp Outputs for Different Input Power Voltages at +30°C Ambient

Temp (°C)	<u>+32 Vdc</u>		<u>+28 Vdc</u>		<u>+24 Vdc</u>	
	Temp Output #1	Temp Output #2	Temp Output #1	Temp Output #2	Temp Output #1	Temp Output #2
-110	1.00	1.03	1.00	1.03	1.00	1.03
-100	1.20	1.23	1.20	1.23	1.20	1.23
- 73	1.72	1.75	1.72	1.75	1.72	1.75
- 23	2.68	2.70	2.68	2.70	2.68	2.70
0	3.11	3.14	3.11	3.14	3.11	3.14
+ 27	3.62	3.64	3.62	3.64	3.62	3.64
+ 52	4.08	4.10	4.08	4.10	4.08	4.10
+100	4.97	4.99	4.97	4.99	4.97	4.99
+110	5.15	5.17	5.15	5.17	5.15	5.17

Table 9 TQCM Temp Outputs for Different Input Power Voltages at +50°C Ambient

Temp (°C)	<u>+32 Vdc</u>		<u>+28 Vdc</u>		<u>+24 Vdc</u>	
	Temp Output #1	Temp Output #2	Temp Output #1	Temp Output #2	Temp Output #1	Temp Output #2
-110	1.01	1.03	1.01	1.03	1.01	1.03
-100	1.20	1.23	1.20	1.23	1.20	1.23
- 73	1.73	1.75	1.73	1.75	1.73	1.75
- 23	2.68	2.70	2.68	2.70	2.68	2.70
0	3.12	3.13	3.11	3.13	3.12	3.13
+ 27	3.62	3.64	3.62	3.63	3.62	3.64
+ 52	4.09	4.10	4.09	4.10	4.09	4.10
+100	4.97	4.98	4.97	4.98	4.97	4.98
+110	5.15	5.16	5.15	5.16	5.15	5.16



Table 11 Power Supply Calibration at 0°C Ambient

TQCM Electronics ON and Heaters OFF

<u>Volts In</u> (Vdc)	<u>Current In</u> (mA)	<u>Power In</u> (W)	<u>+5V Monitor</u> (Vdc)	<u>+15V Monitor</u> (Vdc)
24	91.0	2.184	2.58	2.22
28	82.0	2.296	2.57	2.22
32	72.5	2.304	2.57	2.22

TQCM Electronics and Heaters ON

<u>Volts In</u> (Vdc)	<u>Electronics &amp; Heater 1</u> (W)	<u>Electronics &amp; Heater 2</u> (W)	<u>Electronics &amp; Heaters 1 &amp; 2</u> (W)	<u>Monitors Max Pwr</u> 5V 15V (Vdc) (Vdc)
24	3.528	3.648	5.016	2.59 2.22
28	3.696	3.836	5.012	2.58 2.22
32	3.712	3.808	4.960	2.52 2.22

Note: Test points for monitoring +5V and +15V supplies are in series with voltage dividers to protect supplies from accidental grounding and possible burn out. Hence, values given indicate supplies are properly functioning.

Table 12 Power Supply Calibration at +20°C Ambient

<u>TQCM Electronics ON and Heaters OFF</u>					
<u>Volts In</u> (Vdc)	<u>Current In</u> (mA)	<u>Power In</u> (W)	<u>+5V Monitor</u> (Vdc)	<u>+15V Monitor</u> (Vdc)	
24	87.0	2.088	2.60	2.22	
28	76.5	2.142	2.59	2.22	
32	70.0	2.240	2.59	2.22	

<u>TQCM Electronics and Heaters ON</u>					
<u>Volts In</u> (Vdc)	<u>Electronics &amp; Heater 1</u> (W)	<u>Electronics &amp; Heater 2</u> (W)	<u>Electronics &amp; Heaters 1 &amp; 2</u> (W)	<u>Monitors Max Pwr 5V</u> (Vdc)	<u>Monitors Max Pwr 15V</u> (Vdc)
24	3.62	3.72	5.09	2.57	2.22
28	3.81	3.86	5.07	2.57	2.22
32	3.87	3.93	5.09	2.49	2.22

Table 13 Power Supply Calibration at +30°C Ambient

<u>TQCM Electronics ON and Heaters OFF</u>					
<u>Volts In</u> (Vdc)	<u>Current In</u> (mA)	<u>Power In</u> (W)	<u>+5V Monitor</u> (Vdc)	<u>+15V Monitor</u> (Vdc)	
24	87.0	2.088	2.60	2.22	
28	77.0	2.156	2.59	2.22	
32	70.0	2.240	2.59	2.22	
47					

<u>TQCM Electronics and Heaters ON</u>					
<u>Volts In</u> (Vdc)	<u>Electronics &amp; Heater 1</u> (W)	<u>Electronics &amp; Heater 2</u> (W)	<u>Electronics &amp; Heaters 1 &amp; 2</u> (W)	<u>Monitors Max Pwr</u> 5V 15V	
24	3.528	3.576	4.968	2.60 2.22	
28	3.695	3.752	4.984	2.60 2.22	
32	3.680	3.712	4.960	2.63 2.22	

Table 14 Power Supply Calibration at +50°C Ambient

<u>TQCM Electronics ON and Heater OFF</u>					
<u>Volts In</u> (Vdc)	<u>Current In</u> (mA)	<u>Power In</u> (W)	<u>+5V Monitor</u> (Vdc)	<u>+15V Monitor</u> (Vdc)	
24	86.0	2.064	2.61	2.22	
28	76.0	2.128	2.61	2.23	
32	70.0	2.240	2.60	2.23	
<u>TQCM Electronics and Heaters ON</u>					
<u>Volts In</u> (Vdc)	<u>Electronics &amp; Heater 1</u> (W)	<u>Electronics &amp; Heater 2</u> (W)	<u>Electronics &amp; Heaters 1 &amp; 2</u> (W)	<u>Monitors Max Pwr</u>	
24	3.552	3.600	5.040	5V	15V
29	3.724	3.752	5.040	2.62	2.23
32	3.744	3.776	4.960	2.54	2.23

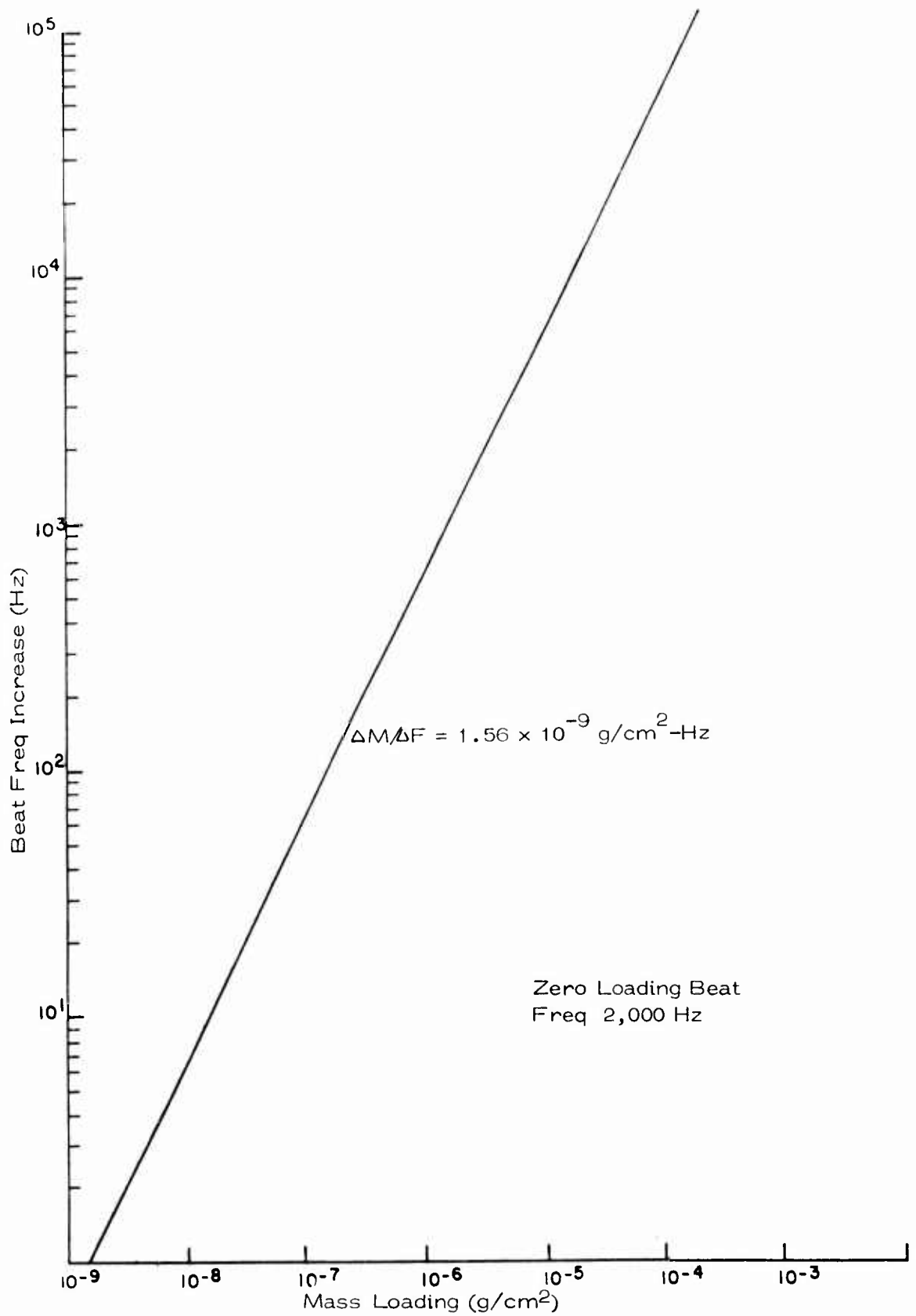


Figure 31 TQCM 15-MHz Sensor Calibration

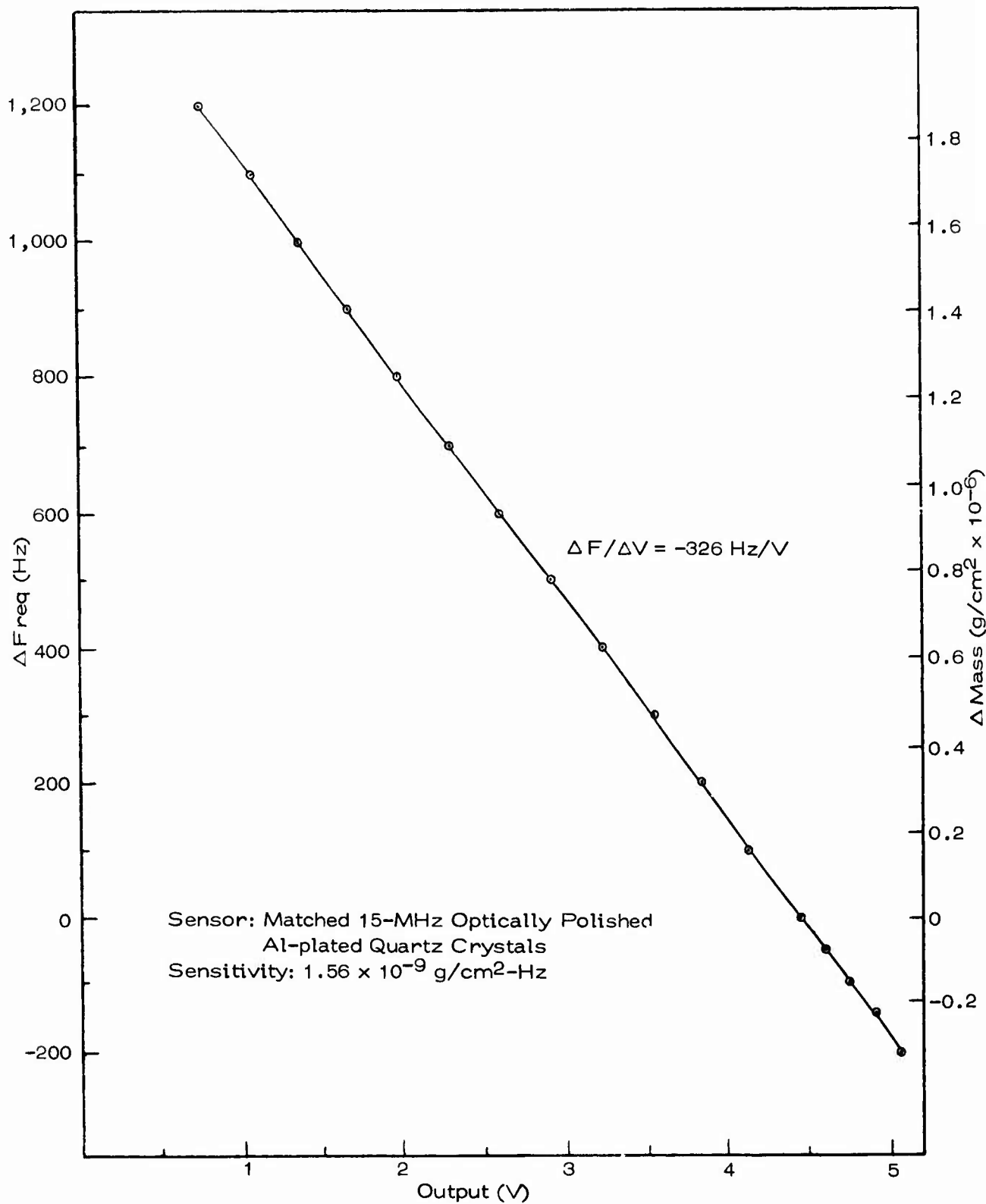


Figure 32 TQCM Head H-1 High-Sensitivity Analog Mass Calibration

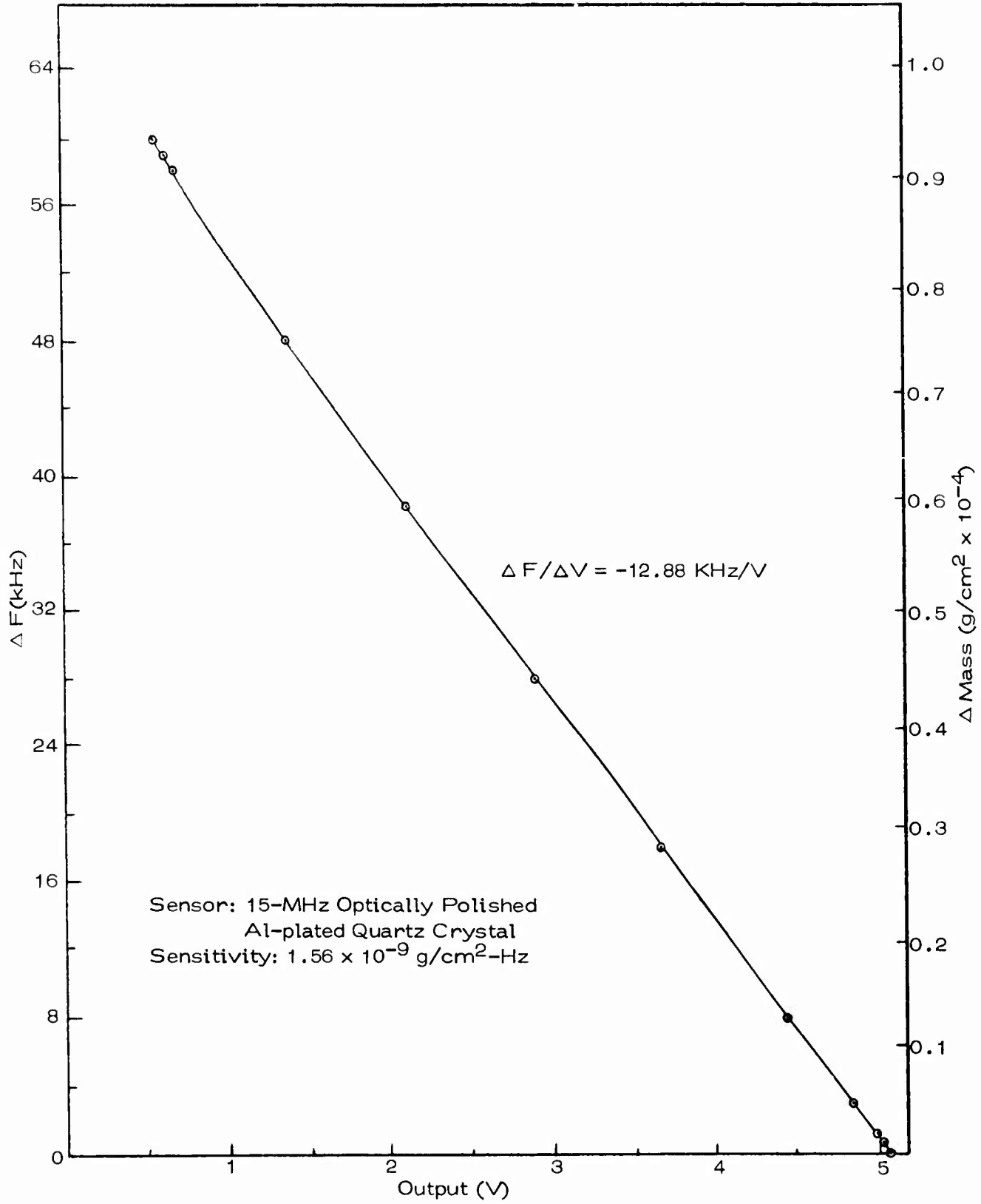


Figure 33 TQCM Head H-1 Los-Sensittivity Analog Mass Calibration

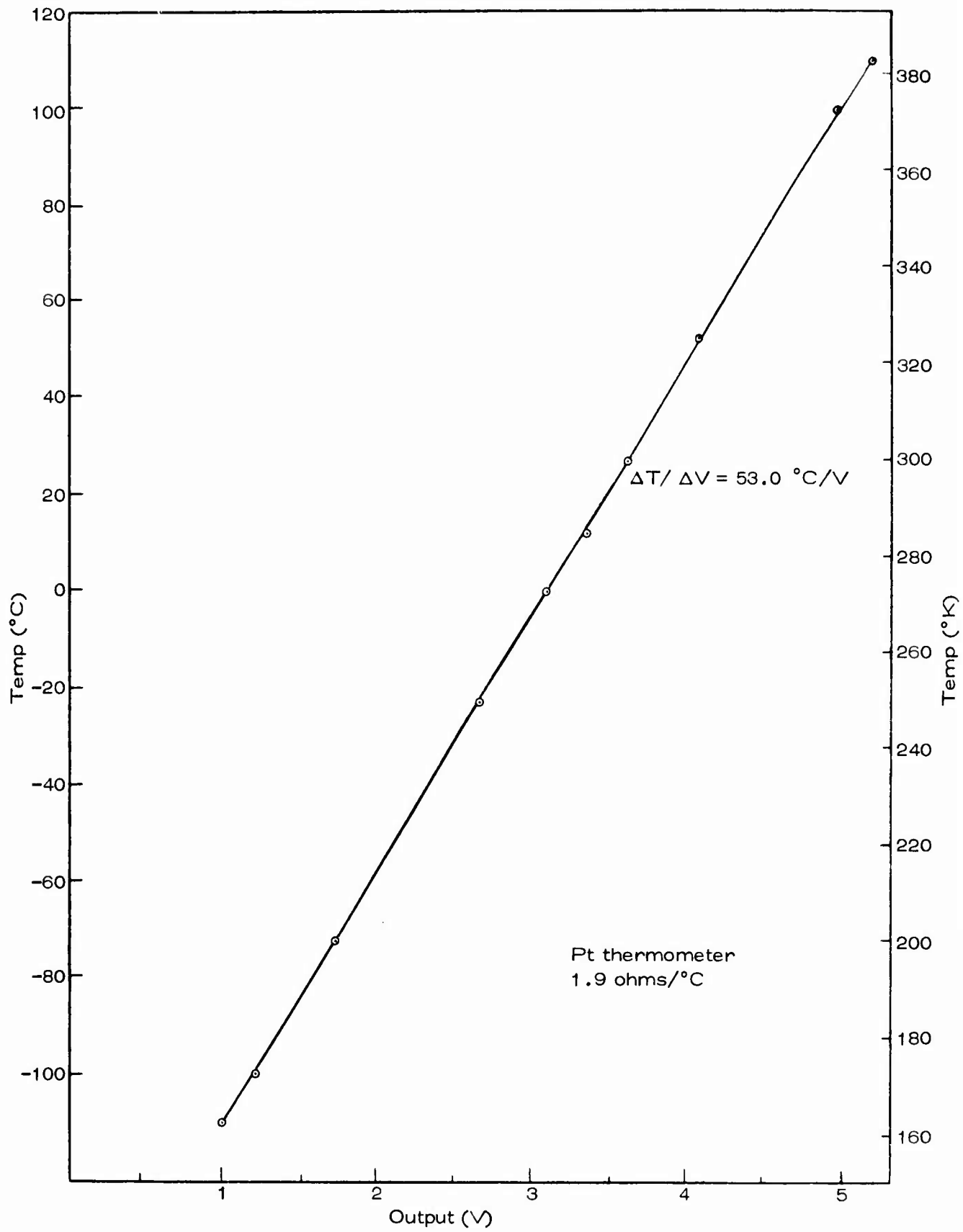


Figure 34 TQCM Head H-1 Temp Calibration

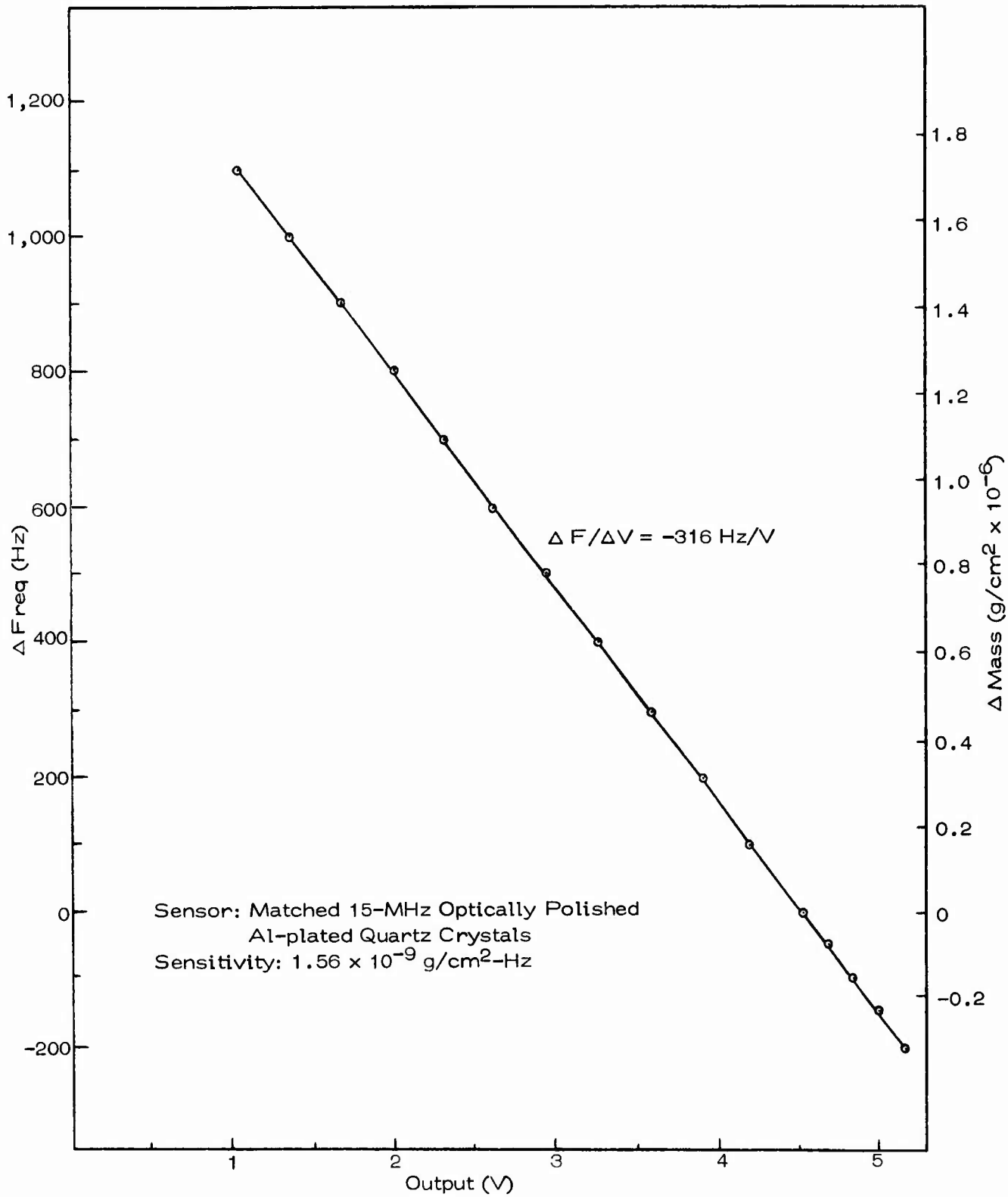


Figure 35 TQCM Head H-2 High-Sensitivity Analog Mass Calibration

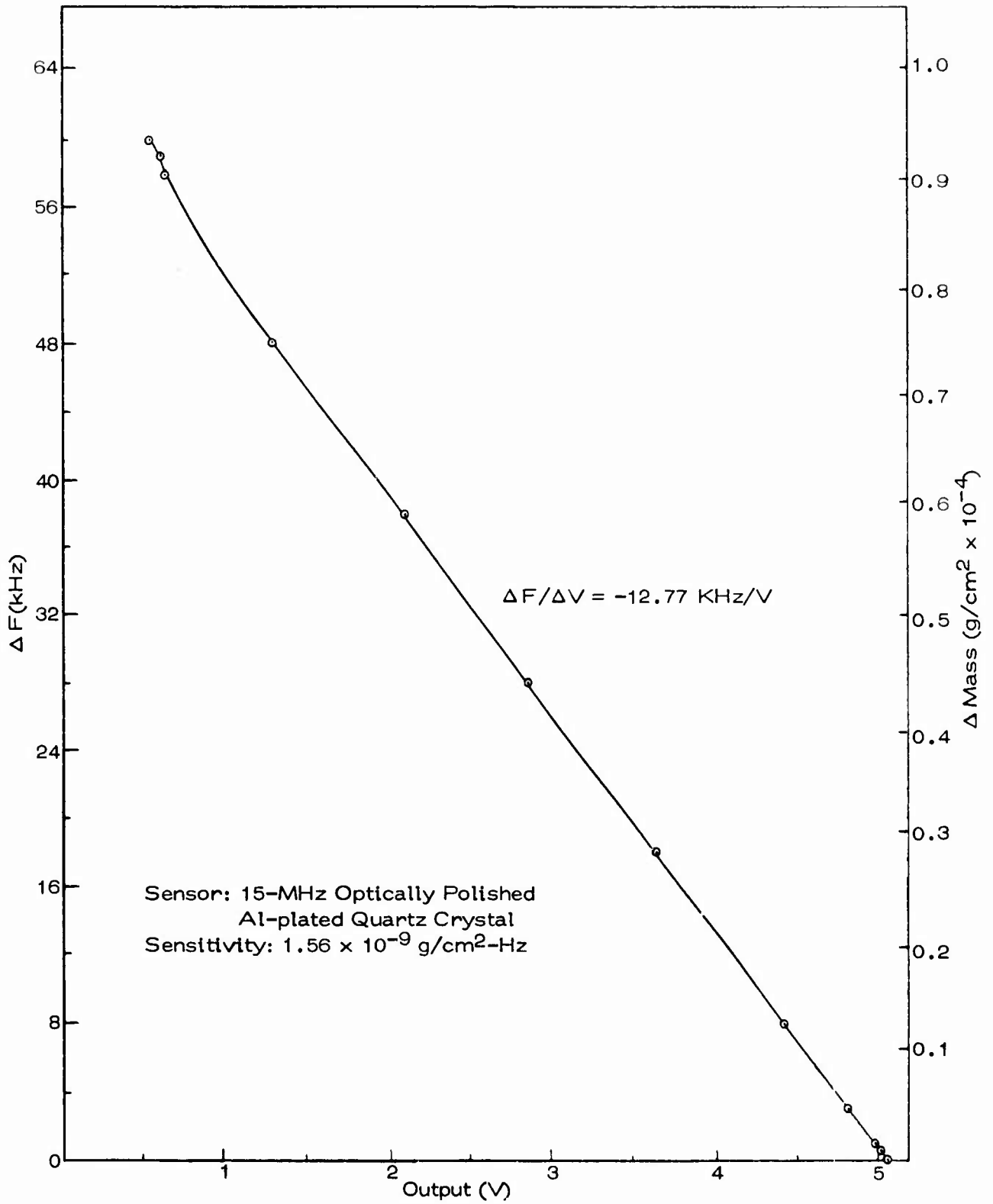


Figure 36 TQCM Head H-2 Low-Sensitivity Analog Mass Calibration

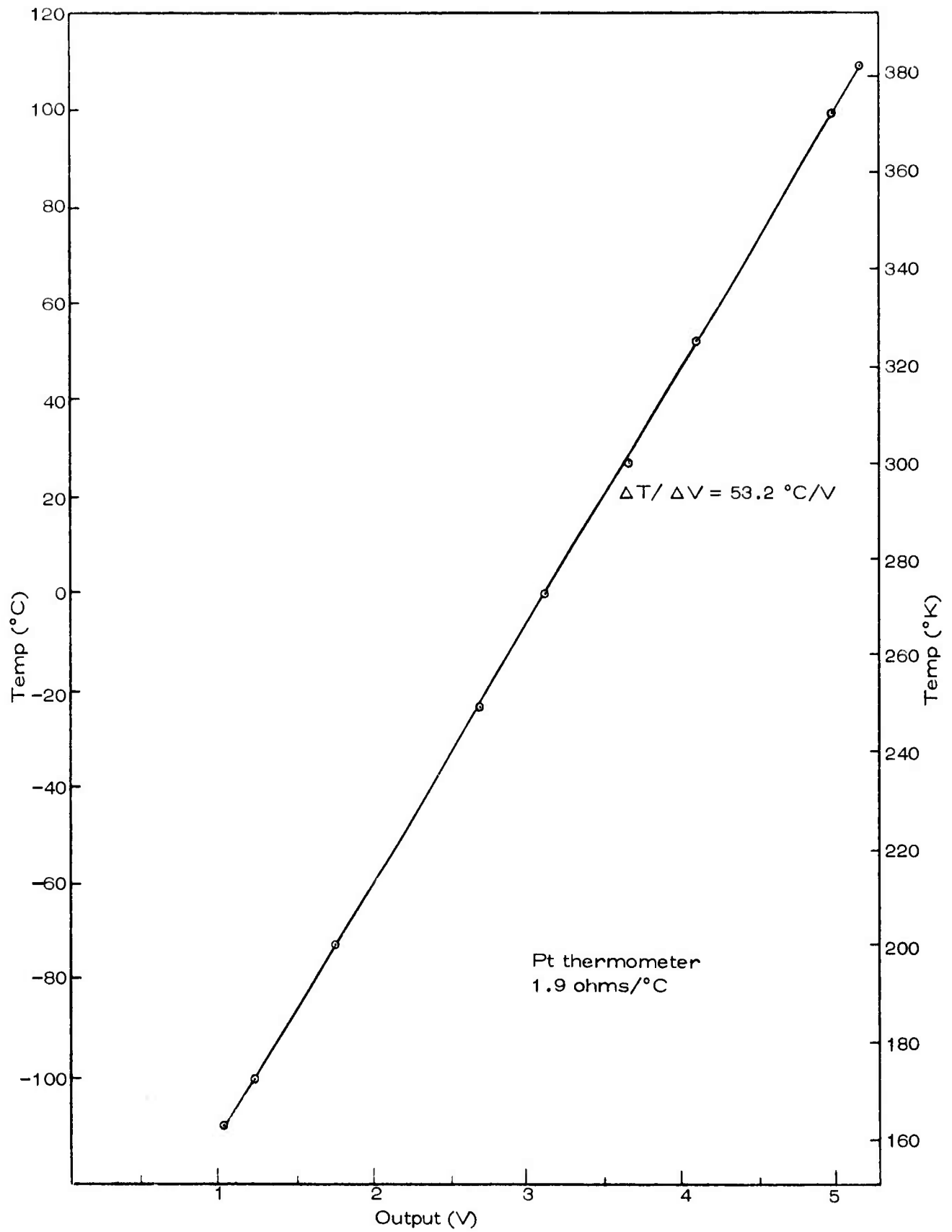


Figure 37 TQCM Head H-2 Temp Calibration

too small to plot. If these variations are to be observed, tabulated data must be used.

## 6.0 Command Logic

The TQCM System command logic is shown in Table 15.

When the TQCM is commanded to free run, the decoder relay (Figure 28) places 100.8 ohms ( $R_g$ ) into the temperature control circuit. The nulling temperature for this resistance is  $-164.6^\circ\text{C}$  or slightly less than the minimum calculated TQCM operating temperature. The reason this resistance value was chosen was to minimize power dissipation during free run but provide a null temperature commensurate to the minimum TQCM operating temperature.

Table 15 TQCM System Serial Command Logic

<u>Serial Bits</u>					<u>Temperature Command</u>
1-18	19	20	21	22	
X	0	0	0	0	Free Run (min temp)
X	1	0	0	0	$-60^\circ\text{C}$
X	0	1	0	0	$-30^\circ\text{C}$
X	1	1	0	0	$0^\circ\text{C}$
X	0	0	1	1	$+30^\circ\text{C}$
X	1	0	1	0	$+100^\circ\text{C}$

## REFERENCES

1. McKeown, D., Sonnenschein, G. and Fox, M.G., Cryogenic Quartz Crystal Microbalance, Final Report, FAR-D-001-76, Faraday Laboratories Inc., Prepared for NASA, MSFC, Jan. (1976).
2. McKeown, D., Sonnenschein, G. and Fox, M.G., "CQCM", 8th Space Simulation Conference, NASA SP-379, p. 343, Nov. (1975).

APPENDIX

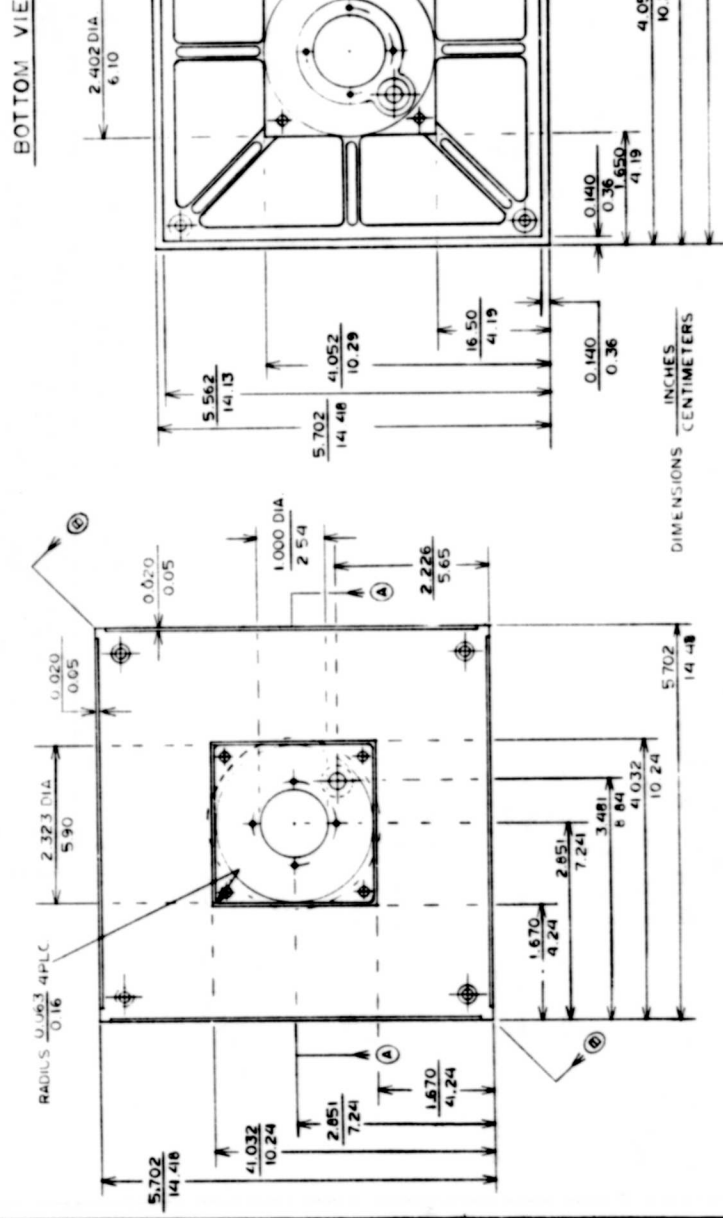
TQCM SYSTEM

MECHANICAL DESIGN



REVISED	DATE	APPROVED
DESCRIPTION	10/68	DM
CHG DIMENSIONS		
CIR NO.		
SIZE LIST	A	

TOP VIEW



BOTTOM VIEW

DIMENSIONS INCHES CENTIMETERS

SEE FL-75-118 MA  
 FL-76-108  
 FL-76-109  
 MATL - 6061-T6 ALUM  
 AU PLATE

QTY	SYM	CODE	IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL OR REFERENCE DESIGNATION	SPECIFICATION OR PROCEDURE DATA	ITEM NO.
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES								
TOLERANCES								
DECIMAL XX * ANGLES								
XXX * XXX *								
DO NOT SCALE DRAWING								
SURFACE ROUGHNESS PER ASA B46.1								
FINISH								
RELEASED 17 MAY 76								
NEXT ASSY USED ON APPLICATION								
DASH NO.								
PARTS LIST								
<p>Continuing Information</p> <p>TQCM HEAD</p> <p>RADIATOR PLATE</p> <p>FL-76-107A</p>								

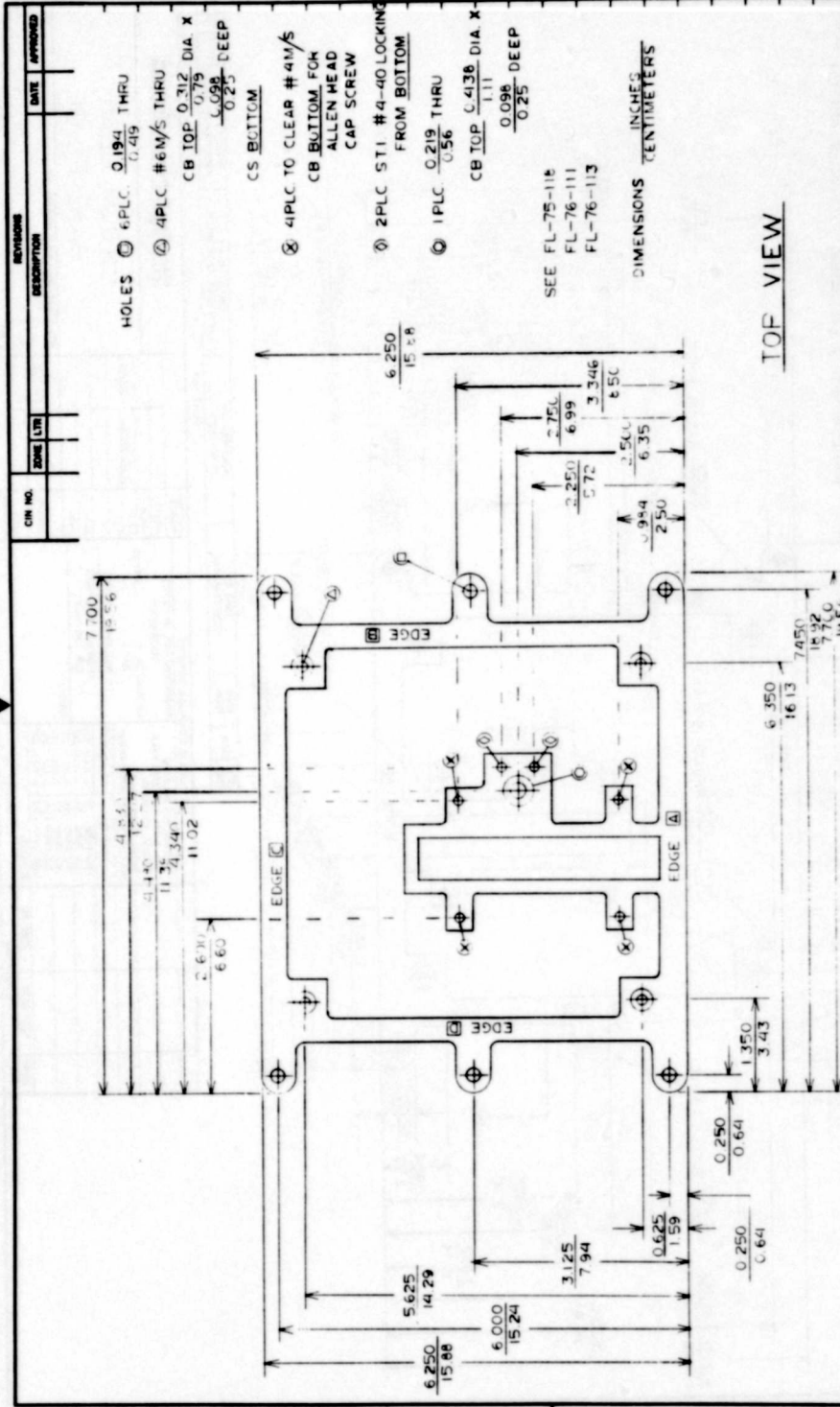
Figure 39











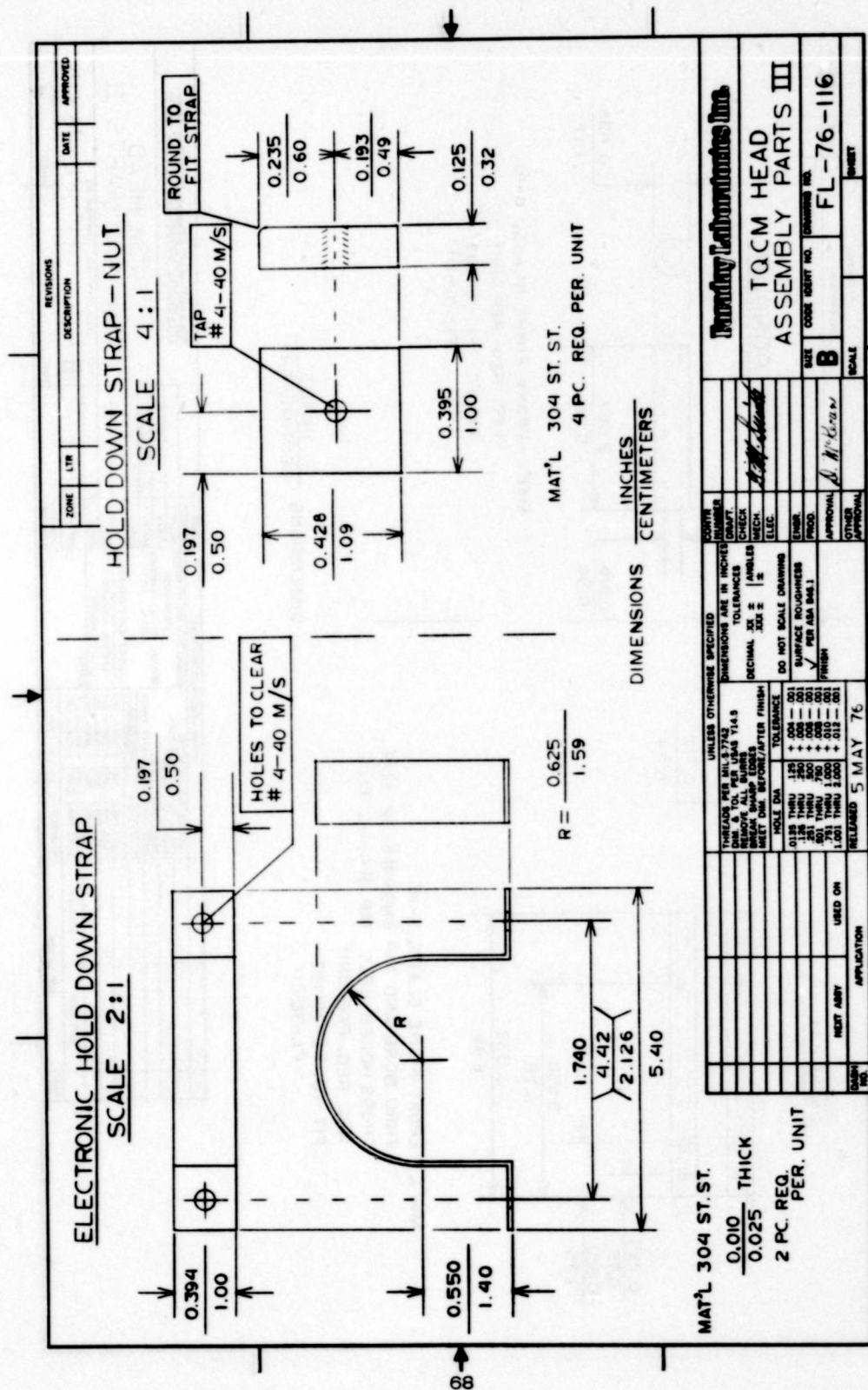
REV'S		DATE	APPROVED
DESCRIPTION			
CIN NO.	ZONE	UTL	
HOLES (1) 6PLC. 0.194 THRU 0.419 (2) 4PLC #6M/S THRU CB TOP 0.312 DIA. X 0.098 DEEP CS BOTTOM (3) 4PLC TO CLEAR #4M/S CB BOTTOM FOR ALLEN HEAD CAP SCREW (4) 2PLC ST1 #4-40 LOCKING FROM BOTTOM (5) 1PLC 0.219 THRU CB TOP 0.436 DIA. X 0.098 DEEP SEE FL-75-115 FL-76-111 FL-76-113 DIMENSIONS INCHES CENTIMETERS			
TOP VIEW			
MATERIAL OR REFERENCE DESIGNATION		SPECIFICATION OR PROCEDURE DATA	
PARTS LIST		ITEM NO.	
NOMENCLATURE OR DESCRIPTION		FORM NO.	
<b>Engineering Laboratories Inc.</b> TQCM HEAD HOLE LAYOUT (BASE PLATE)			
DRAWN		SCALE	
CHECK		C	
ILL.		FL-76-112	
ENG.		SIZE	
APP.		CODE IDENT NO.	
OTHER		DRAWING NO.	
APPROVAL		FL-76-112	
OTHER APPROVAL		SHEET	

Figure 44









REVISIONS		DATE	APPROVED
ZONE	LTR	DESCRIPTION	

ELECTRONIC HOLD DOWN STRAP SCALE 2:1		HOLD DOWN STRAP - NUT SCALE 4:1	
MAT'L 304 ST. ST. 0.010 THICK 0.025 2 PC. REQ. PER. UNIT		MAT'L 304 ST. ST. 4 PC. REQ. PER. UNIT	
DIMENSIONS INCHES		DIMENSIONS CENTIMETERS	

THREADS PER MIL. 3774 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS TOLERANCES ANGLES CHECK CHECK ELEC.	CHECK DRAWN CHECK CHECK ELEC.	TITANUM TECHNOLOGIES INC. TQCM HEAD ASSEMBLY PARTS III SIZE CODE USARY NO. 000000000000 B FL-76-116 SCALE
--	---	---

TITANUM TECHNOLOGIES INC. TQCM HEAD ASSEMBLY PARTS III SIZE CODE USARY NO. 000000000000 B FL-76-116 SCALE	RELEASED 5 MAY 76
---	-------------------

Figure 48

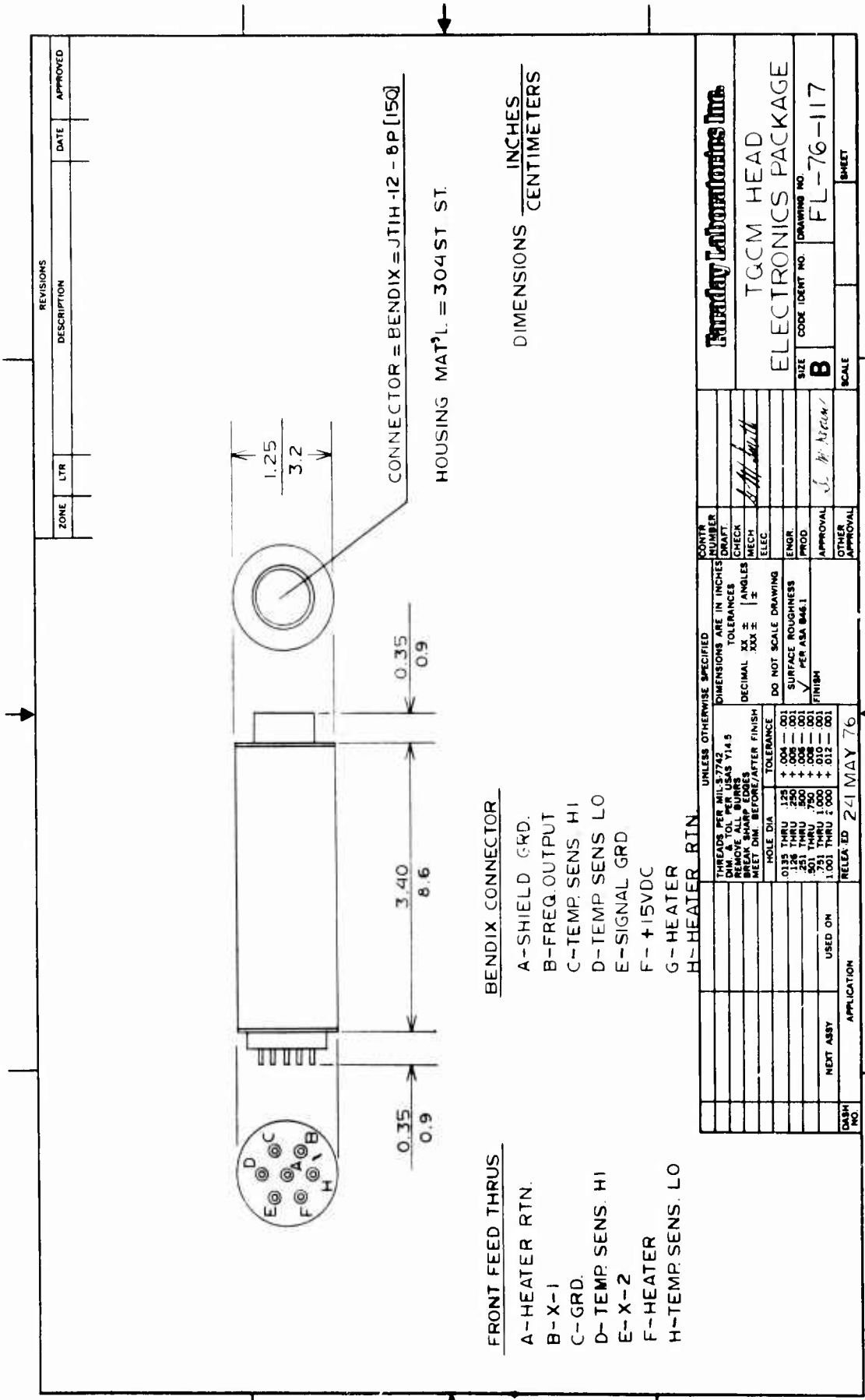


Figure 49

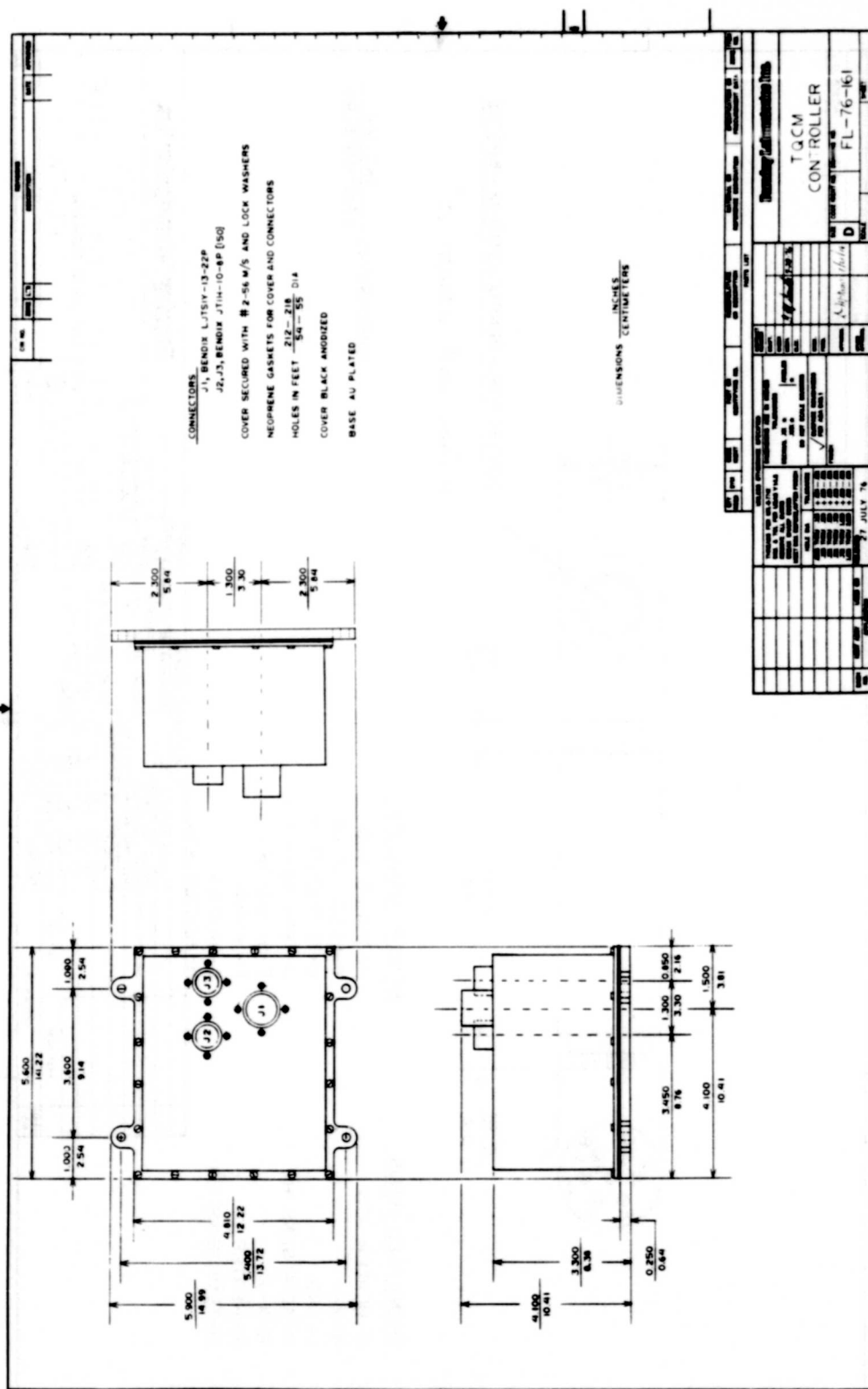
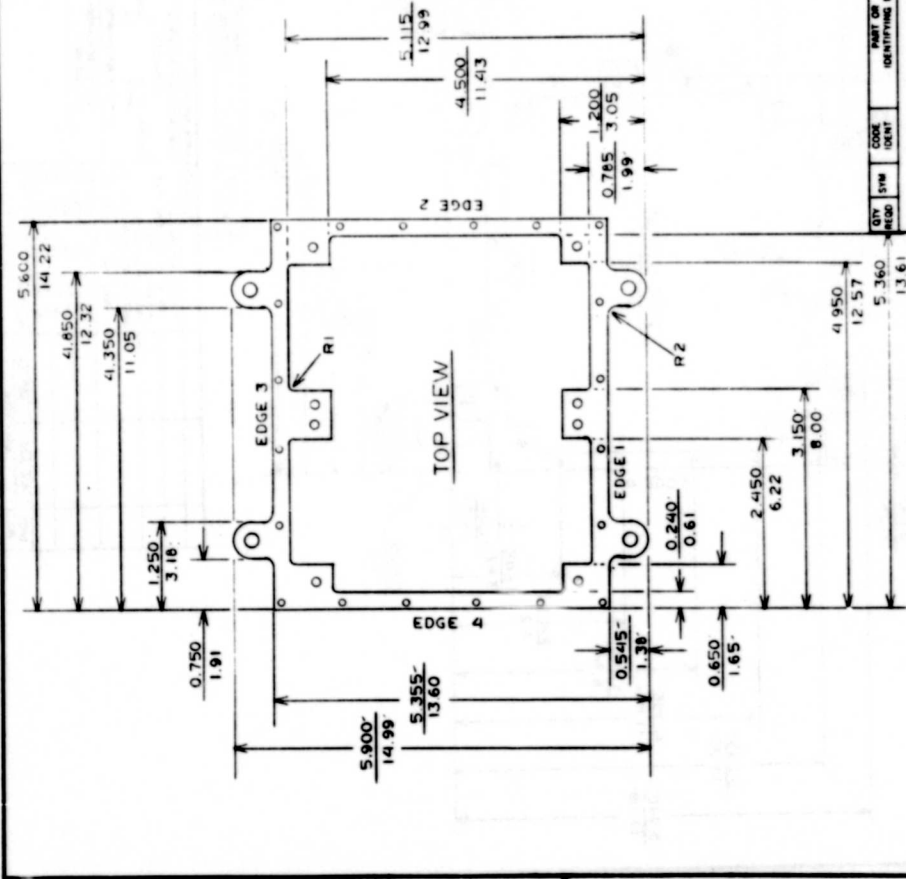


Figure 50

REV. NO.	DESCRIPTION	DATE	APPROVED



MAT'L - ALUM 6061-T6, 1PC REQ PER UNIT

RIM  $\frac{0.250}{0.64}$  THICK

FLOOR  $\frac{0.062}{0.16}$  THICK

R1 =  $\frac{0.062}{0.16}$  [12 PLC]

R2 =  $\frac{0.125}{0.32}$  [8 PLC]

BOTTOM FLATNESS  $\frac{0.005}{0.013}$

FINISH 63μ, AU PLATE

SEE: FL-76-163  
FL-76-164  
FL-76-165

DIMENSIONS INCHES  
CENTIMETERS

QTY	SYN	CODE	IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL OR REFERENCE DESIGNATION	SPECIFICATION OR PROCEDURE DATA	ZONE NO.	ITER NO.

UNLESS OTHERWISE SPECIFIED		DIMENSIONS ARE IN INCHES	
THREADS PER INCH	14	DECIMAL INCH	0.005
DIAM & TOL PER UNAS Y14		ANGLES	
REMOVE ALL BURRS		DO NOT SCALE DRAWING	
REMOVE ALL SHARP EDGES		FINISH	
MEET DIM BEFORE AFTER FINISH		SURFACE ROUGHNESS	
		PER ABA B61	

DRWING									
CHECK									
MECH									
ELEC									
ENGR									
PROD									
APPROVA									
DATE									

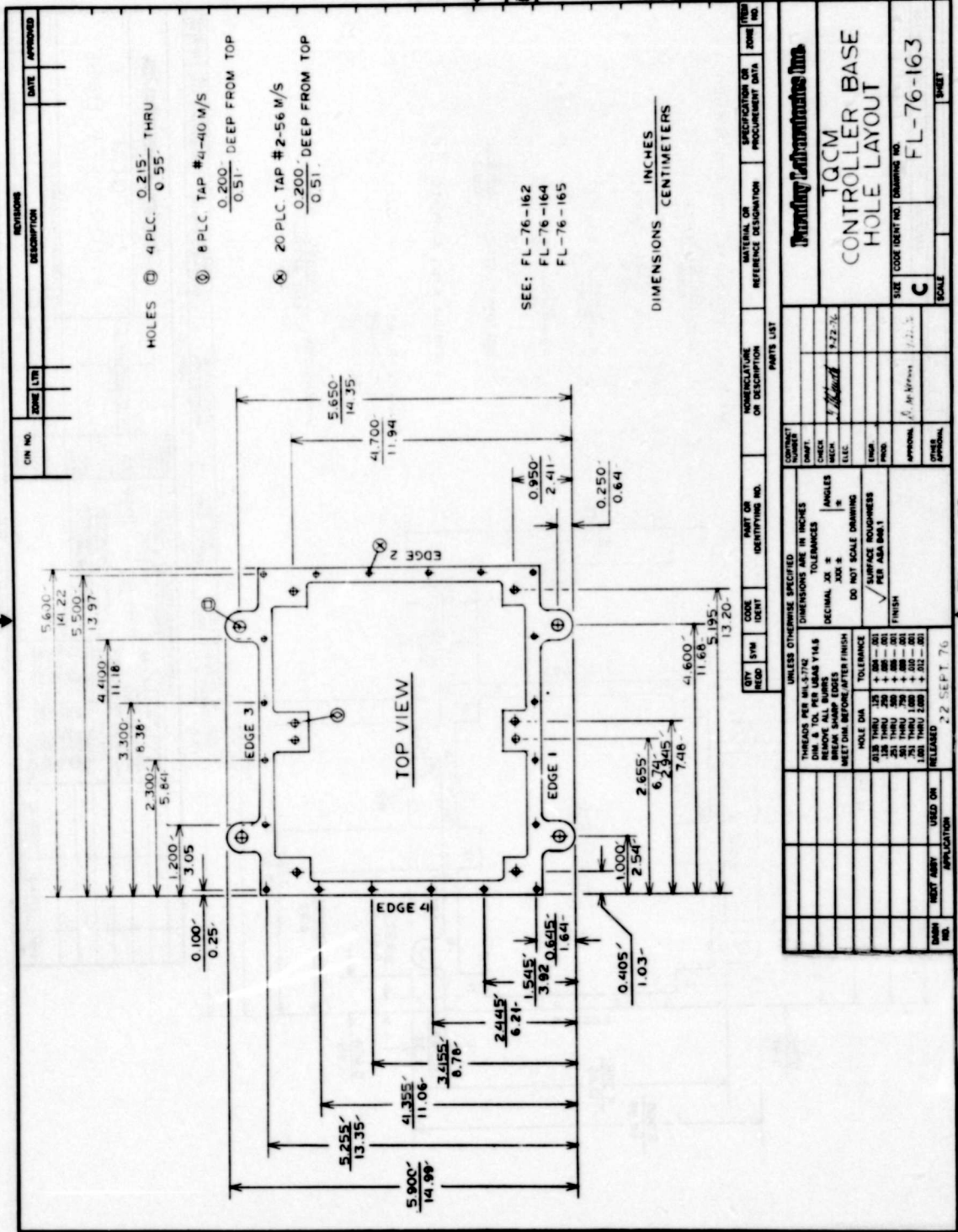
  

SIZE	CODE	DATE NO	DRAWING NO
			FL-76-162

SCALE	SHEET

↑ Figure 51





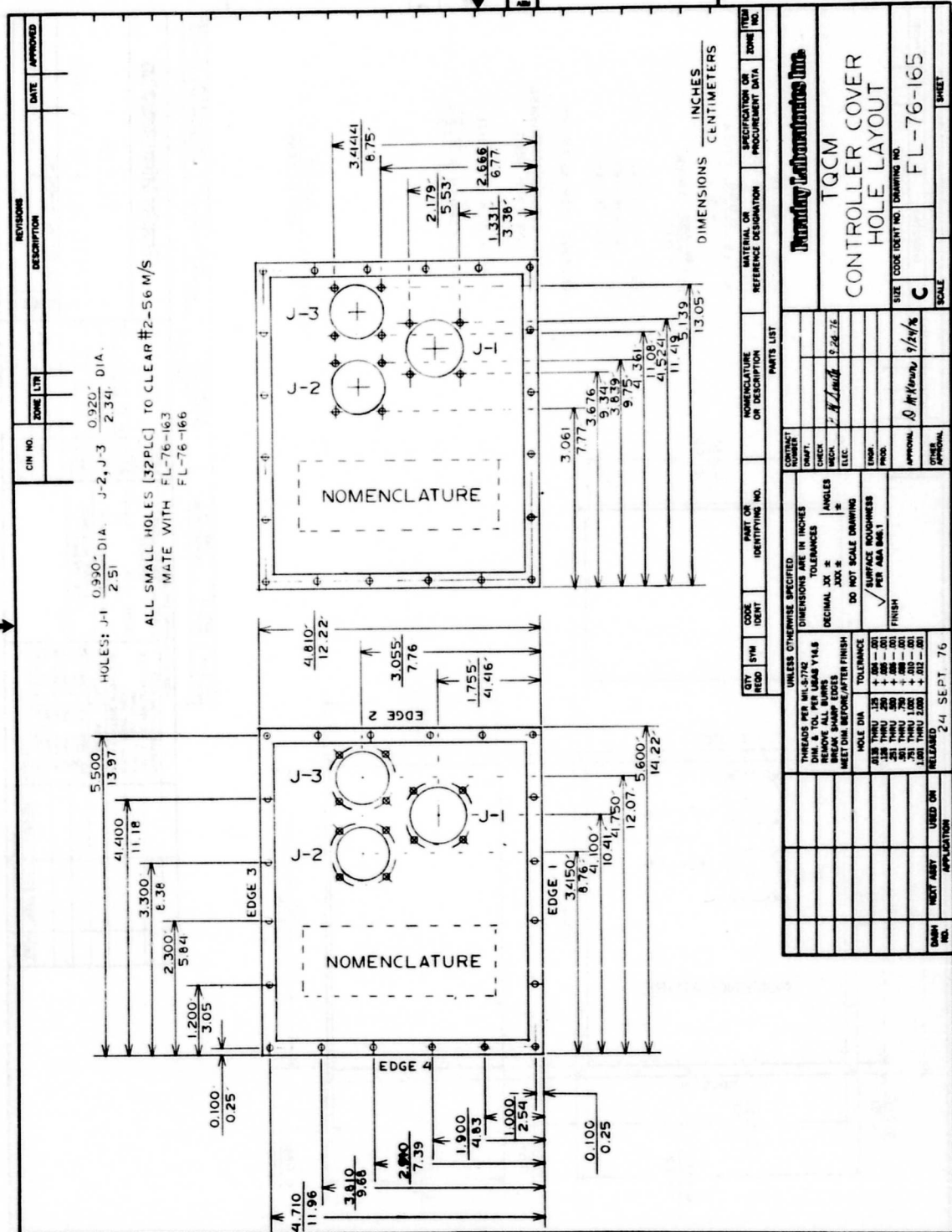


Figure 54

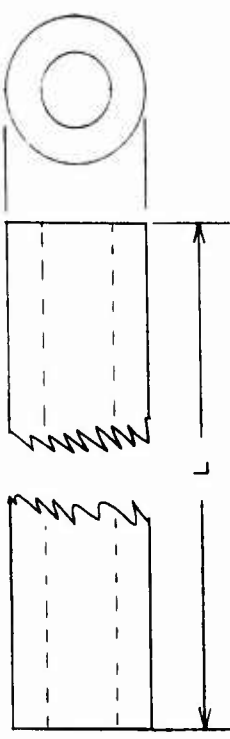




ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED

SPACER



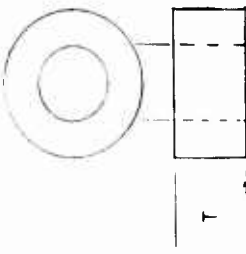
OD  $\frac{0.250}{0.64}$

ID  $\frac{0.113}{0.29}$  #33 DRILL

L # SPACER  $\frac{0.560}{1.42}$  12 PC REQ.

# 2 SPACER  $\frac{0.660}{1.68}$  4 PC REQ.

WASHER



OD AND ID SAME AS SPACER

T  $\frac{0.125}{0.32}$  20 PC REQ.

MAT'L - EPOXY FIBRE GLASS, G-10

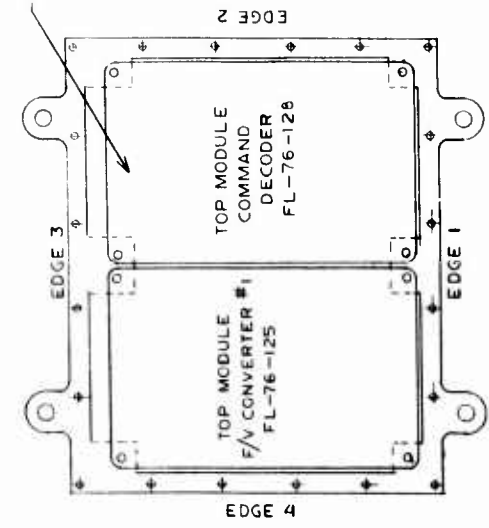
DIMENSIONS INCHES  
CENTIMETERS

Figure 57



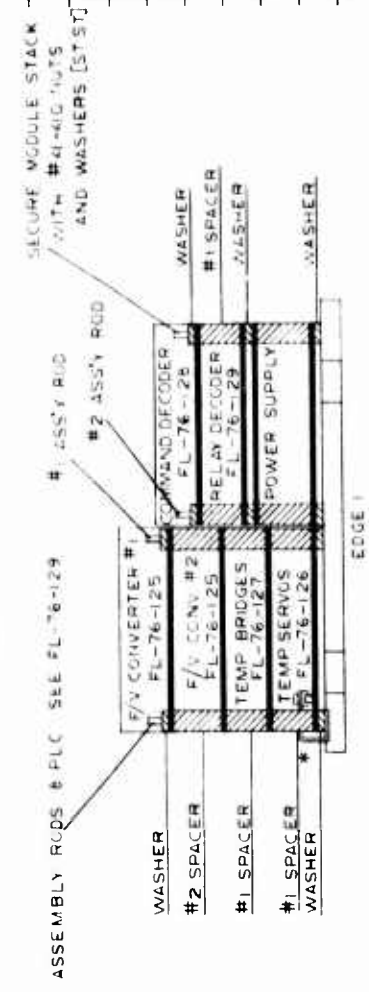
CIN NO		ZONE LTR		REVISIONS		DATE		APPROVED	
				DESCRIPTION					

VIEW FROM TOP



TERMINAL E.D. OF MODULES

VIEW FROM EDGE 1



WASHERS AND SPACERS SEE FL-76-168

\* If Controller to be evacuated, heat sink servo transistors with 0.02 in thick x 4.0 in wide copper strap to base plate

QTY	SYN	CODE	IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL OR REFERENCE DESIGNATION	SPECIFICATION OR PROCUREMENT DATA	ZONE	ITEM NO
PARTS LIST									
UNLESS OTHERWISE SPECIFIED		DIMENSIONS ARE IN INCHES							
TOLERANCES		DECIMAL XX ±							
ANGLES		XX ±							
DO NOT SCALE DRAWING		SURFACE ROUGHNESS PER ASA B46.1							
FINISH		FINISH							
THREADS PER MIL-S-772		DIMENSIONS Y & Z							
REMOVE ALL BURRS		MEET DIM BEFORE/AFTER FINISH							
BREAK SHARP EDGES		HOLE DIA TOLERANCE							
		0.125 THRU .250 + .002 - .001							
		.251 THRU .500 + .008 - .001							
		.501 THRU .750 + .008 - .001							
		.751 THRU 1.000 + .010 - .001							
		1.001 THRU 2.000 + .015 - .001							
		RELEASED 31 SEPT 76							
DAWN NO.	NEXT ASSY	USED ON	APPLICATION						
<b>TQCM</b> <b>CONTROLLER</b> <b>MODULE PLACEMENT</b>									
SITE CODE IDENT NO							DRAWING NO		
C							FL-76-170		
SCALE							SHEET		

Figure 59



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