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**ULTRA HIGH TEMPERATURE
INSTRUMENTATION AMPLIFIER**

MASTER

MRI-2942-E3

May 1977

Prepared for:

**Energy Research and Development Administration
Division of Geothermal Energy**

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May 1977

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ULTRA HIGH TEMPERATURE
INSTRUMENTATION AMPLIFIER

Midterm Progress Report
September 1976 - March 1977

Ronald D. Kelly
William L. Cannon
Charles P. Morse

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April 1977

Work performed under contract No. E(04-3)-1330

Mechanics Research, Inc.
Santa Monica, California (USA)

Prepared for

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Geothermal Energy

ULTRA HIGH TEMPERATURE
INSTRUMENTATION AMPLIFIER

MIDTERM PROGRESS REPORT, SEPTEMBER 1976 - MARCH 1977

Ronald D. Kelly
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TABLE OF CONTENTS

Section	Page
1.0 SUMMARY	1
2.0 TECHNICAL DISCUSSIONS	7
2.1 Component Testing/Selection	7
2.1.1 Ceramic Vacuum Tubes.	7
2.1.2 Resistors	16
2.1.3 Capacitors.	20
2.1.4 Inductors	24
2.1.5 Miscellaneous Components	25
2.2 Circuit Design	27
2.2.1 Amplifier	27
2.2.2 Universal Input	41
2.3 Mechanical Design.	48
2.3.1 1 11/16 Inch Sonde.	52
2.3.2 Three Inch Sonde.	53
2.3.3 Inert Atmosphere Package	55
2.3.4 Constant Temperature Package	56
2.4 Breadboard Testing	57
2.4.1 Objective and Scope	57
2.4.2 Status	57
2.5 Literature Search	58
3.0 SPECIAL TEST EQUIPMENT.	59
3.1 Inert Atmosphere Tester	59
3.2 Tube Characteristic Tester	62
4.0 PROJECT SCHEDULE STATUS	65
5.0 SUMMARY OF FUTURE ACTIVITIES.	68
6.0 RECOMMENDATIONS AND PROPOSALS	69
7.0 REFERENCES	71

TABLE OF CONTENTS (CONTINUED)

Section	Pages
APPENDIX A — CERAMIC VACUUM TUBE TEST DATA	A1 - A38
APPENDIX B — RESISTOR TEST DATA	B1 - B2
APPENDIX C — CAPACITOR TEST DATA.	C1
APPENDIX D — MISCELLANEOUS COMPONENT TEST DATA.	D1 - D2

LIST OF ILLUSTRATIONS

Figure	Page
2.1.1 Variation of Amplification Factor and Transconductance with Temperature	13
2.2.1 Circuit Design.	29
2.2.2 Circuit Design.	30
2.2.3 Circuit Design.	31
2.2.4 Circuit Design.	33
2.2.5 Circuit Design.	34
2.2.6 Circuit Design.	36
2.2.7 Circuit Design.	37
2.2.8 Circuit Design.	38
2.2.9 Circuit Design.	39
2.2.10 Circuit Design.	40
2.2.11 Resonance Bridge	41
2.3.1 Packaging of Amplifier in Figure 2.3.2.	49
2.3.2 Typical Amplifier Circuit Diagram 1	50
2.3.3 Conceptual Layout, Ultra High Temperature Amplifier, Three Inch O.D.	54
3.1.1 High Temperature Inert Gas Component Test Fixture	60
3.2.1 Circuits for Determining Tube Characteristics	63

LIST OF TABLES

Table	Page
1.1 Preliminary Specifications for an Ultra High Temperature Amplifier	2
1.2 Project Milestone Chart	5
2.1.1 Ceramic Vacuum Tube Characteristics	9
2.1.2 Vacuum Tube Test Data Summary — Effect of Increasing Temperature	12
2.1.3 Current Correlations Derived from Test for Commercial Tube Types	15
2.1.4 Resistors Tested as of 4/7/77	17
2.1.5 Capacitors Tested as of 4/8/77	21
2.2.1 Circuit Configurations	23
2.3.1 Resistors Required for the Amplifier Wiring Diagram in Figure 2.3.1.	51
4.1 Program Schedule.	66
4.2 Project Milestone Chart	67

The primary objective of contract E(04-3)-1330, Ultra High Temperature Electronic Amplifier is to develop a downhole instrumentation amplifier to support geothermal well logging without thermal protection at temperatures up to 500°C. The basic approach is to provide signal conditioning for a transducer, amplify the transducer output and transmit this amplified signal over long electrical cables to the surface for further processing and recording. The design goals are detailed in Table 1.1. Ceramic vacuum tubes are used as the active circuit elements to obtain this very high temperature capability.

To develop this amplifier, a multiphased program is being carried out. The basic program phases are, a research phase, a design phase, a development phase, and a downhole demonstration phase. The research phase consists of three tests, a literature search to locate applicable information on prior high temperature circuit design, a tube evaluation task to select the "best" tubes for use in this amplifier and a supplemental testing program to provide test data on the temperature performance of components (when it was not available from the literature or the component manufacturer).

The design phase consists of eight tasks. These are circuit design, component selection and room temperature breadboard testing of candidate designs for both the basic amplification and the input stage of the amplifier. Additional design tasks consist of designing the mechanical package and analyzing its thermal properties to assure that there are no intolerable hot spots.

The development phase consists of two tasks — circuit development on a high temperature breadboard followed by a prototype amplifier development. The downhole demonstration phase consists of test planning, test hardware development and test performance tasks. Table 1.2 is a detailed breakdown of the program plan and schedule.

**TABLE 1.1 PRELIMINARY SPECIFICATIONS FOR
AN ULTRA HIGH TEMPERATURE AMPLIFIER**

DESCRIPTION

The Ultra High Temperature Amplifier is a general purpose instrumentation amplifier designed for downhole well logging applications at temperatures up to 500°C. Unique features of this amplifier are the capabilities to accept signals from sensors with variable voltage, resistance, capacitance, or inductance outputs and to transmit the output over long cable lengths.

ELECTRICAL SPECIFICATIONS	
INPUT CHARACTERISTICS	
Input Connection	Differential or single ended
Allowable Sources	
• Voltage	0 to 20 Millivolts
• Resistance	120 to 1000 Ohms
• Capacitance	10 to 100 PF
• Inductance	10 to 100 MH
OUTPUT CHARACTERISTICS	
Output Connection	Single ended connected to circuit ground
Maximum Linear Output (1%)	± 5 Volts
Line Driving Capability	± 15,000 feet of standard logging cable
Residual Noise	± 5 Millivolts RMS

**TABLE 1.1 (CONTINUED) PRELIMINARY SPECIFICATIONS FOR
AN ULTRA HIGH TEMPERATURE AMPLIFIER**

ELECTRICAL SPECIFICATIONS (CONTINUED)	
TRANSFER CHARACTERISTICS	
Gain	40 DB
Gain Accuracy	1%
Gain Stability	Better than 1 DB with temperature and time
Frequency Response (± 1 DB)	
• Maximum Cable Load	0 to ≥ 1 kHz
• No Load	0 to ≥ 10 kHz
Linearity	$\pm 1\%$ of best straight line
POWER	
B+	40 ma at 250 volts
Filament	250 ma at 100 volts
PHYSICAL SPECIFICATIONS	
1 11/16 INCH SONDE	
Dimensions	1.447 inch diameter x 12" long
Weight	2 pounds
3 INCH SONDE	
Dimensions	2.57 inch diameter x 6" long
Weight	2 pounds
Connections	Welding lugs for inputs and outputs spare wires for electrical throughput.

**TABLE 1.1 (CONTINUED) PRELIMINARY SPECIFICATIONS FOR
AN ULTRA HIGH TEMPERATURE AMPLIFIER**

ENVIRONMENTAL SPECIFICATIONS	
OPERATING AND TEMPERATURE	0 to 500°C
SHOCK AND VIBRATION	Perform in well logging environment
OTHER	To be installed in a pressure and humidity tight sonde

PROJECT TITLE: Ultra High Temperature Amplifier
 PREPARED BY R. D. Kelly

SHEET 1 OF 1
 PROJECT 2942

Table 1.2 Project Milestone Chart

To date, all of the work on the research phase has essentially been completed, circuit design and component selection tasks on the design phase have been completed and the breadboard and mechanical design tasks of the design phase are in progress. Completed tasks are identified by the solid lines on the schedule in Table 1.2.

Details of the work accomplished to date are presented in Section 2. Special test equipment developed to support work on this contract is described in Section 3. The project schedule status is discussed in detail in Section 5 and recommendations and proposals are presented in Section 6.

2.0 TECHNICAL DISCUSSIONS

This section details the work accomplished from the beginning of the contract through this reporting period. Major activities discussed are component testing and selection, circuit design, mechanical design, breadboard testing and literature search. Each of the subsequent sections describes the objective of activity, its scope and the pertinent results obtained. Detailed data, such as raw test data are presented in the appendices.

2.1 Component Testing/Selection

This data was originally expected to be a small effort to obtain data on the variation of tube characteristics with temperature. However, passive components expected to perform adequately up to 500°C, did not. It was found that temperature coefficients for many items changed dramatically at higher temperatures. Thus, this task has been a major portion of the program to date. The subsequent sections discuss the results of temperature testing of ceramic vacuum tubes, resistors, capacitors and other components.

2.1.1 Ceramic Vacuum Tubes

Objective

Ceramic vacuum tubes were developed in Germany in 1934 and were actively promoted in the United States following World War II by the Armed Services. By 1952, the development of automatic production techniques was promoted by government contracts, and in 1958, several types were available in sample lots. Full scale production followed in the early 1960's, primarily for aircraft and missile applications.

The high temperature capabilities of ceramic tubes has always been recognized, and many of the early development types were tested in 500°C ambient temperatures. As a result, ceramic vacuum tubes represent lower risk items in the development of ultra high temperature circuits.

An evaluation of the suitability of commercial ceramic vacuum tubes for application to geothermal well logging is presented in Reference 1. The objective of component testing of ceramic tubes was not so much to determine if they will work in high ambient temperatures, but to obtain temperature related performance data that can be utilized in circuit design.

Tubes Chosen for Evaluation

Two samples each of four commercial tube types, including EIA numbers 7296, 7588, 7625, and 7462, were selected for temperature testing. These tubes were chosen to permit trade-offs of temperature performance primarily in terms of amplification, transconductance, and plate power. Other important characteristics not necessarily related to temperature are filament power requirements, physical size, and cost. Table 2.1.1 summarizes the significant nominal characteristics of the selected commercial tube types.

In addition to the four commercial tube types, samples of a special design were ordered for evaluation. The objective of the special design was to provide a tube with both a high amplification factor and moderately high transconductance. This approach, if successful, will permit a single tube type to perform both voltage amplification and line driving functions. The design goals for the tube include:

Size:	0.33 Inch Diameter
Filament Current:	215 ma @ 6.3V
Amplification Factor:	300 ± 75 @ $I_p = 5$ ma
Transconductance:	$21,000 \pm 1000$ M mho @ $I_p = 10$ ma

A total of five tubes were received from the General Electric Tube Department for evaluation. All five were within tolerance for amplification. Only one, however, was within tolerance for transconductance.

Type	Description	Heater Current Amps (6.3V)	Max. Plate Volts (Watts)	AVERAGE CHARACTERISTICS				
				Plate Volts	Plate Current	Mu	Gm M-mho	r_p ohm
7462	Miniature Triode Intended for low-noise VHF amplifier service.	.24	250 (1.1)	150	7.2	94	10,500	9,000
7625	Miniature Triode Intended for low-level audio frequency ampli- fier service.	.215	275 (0.85)	150	0.95	80	1,400	57,000
7296	Triode Intended for VHF oscil- lator or amplifier service.	.4	330 (5.5)	200	17.0	90	16,500	5,450
7588	Triode Intended for VHF ampli- fier service.	.4	300 (5.5)	200	24.0	175	45,000	3,900

Table 2.1.1 Ceramic Vacuum Tube Characteristics

Tube Characteristics

Ideally, the temperature performance variations, as well as power requirements and size, should be as small as possible for geothermal applications since a well log must operate over a wide range of temperatures. Performance parameters commonly used to describe electron tube operation include:

- Plate current (i_p) - current reaching the plate with constant voltages applied to the grid and plate.
- Amplification factor (μ) - variation of plate voltage with grid voltage (constant current).
- Transconductance (g_m) - variation of plate current with grid voltage (constant plate voltage).
- Dynamic plate resistance (r_p) - variation of plate voltage with plate current (constant grid voltage).

In normal operation the current is drawn from a heated cathode to the positively charged plate. In general, the hotter the cathode, the greater the current for a given grid bias and voltage difference between the plate and cathode. The normally desired operating condition for a tube is to have slightly more electrons emitted from the cathode than can be attracted to the anode so that a cloud of negatively charged electrons forms in front of the cathode and the grid has maximum effect or control on the current flow. When this condition prevails small changes in cathode temperature serve to change the electron cloud density which in effect appears as a change in cathode voltage, with respect to the grid and plate. In this case, the grid to cathode bias is more significant, and changes in cathode temperature can be cancelled by small changes in grid voltage. At high plate voltages the anode can attract all electrons emitted from the cathode, and the plate current is dependent primarily on the cathode temperature and plate voltage. This condition is referred to as temperature limited.

Results

Results of supplemental testing of ceramic vacuum tubes are presented in Appendix A. Table A1 gives data for 13 tubes of which eight were commercial (two tubes each of four types), and five were special design. Tests were conducted at room temperature and 500°C with heater voltages of 6.3 volts (room temperature only), 5.3 volts and 4.3 volts; plate voltages of 100 and 200 volts; and grid bias of 0 volts. Current measurements were also made at other grid biases for the commercial tubes. A brief summary of the data is also given in Table 2.1.2 for convenience and to show the degree of consistency (or lack of) for characteristic change with temperature. A plot of the variation in amplification factor and transconductance for all of the tubes tested in going from room temperature and a heater voltage of 6.3 volts to 500°C and 5.3 volts is also shown on Figure 2.1.1.

As indicated on Figure 2.1.1, all of the tubes exhibit significant change in going from one condition to another. The two 7462 types track each other better than the rest. This characteristic can be used to advantage in differential amplifier stages.

A convenient means of correlating temperature effects is to plot plate current and transconductance versus a voltage parameter defined as $E_g + E_b/\mu$ where E_g is grid bias (normally negative), and E_b is plate to cathode potential. In theory, the plots should be straight lines on log-log paper for high plate currents indicating that current and transconductance vary as a power of the voltage parameter. Plots are presented in Appendix A for the commercial tubes at both room temperature and 500°C. From these plots it can be seen that the data does, in fact, plot as straight lines. Therefore, plate current can be expressed analytically as:

$$i_b = C(E_g + E_b/\mu)^N$$

CHARACTERISTIC CHANGE-ROOM TEMPERATURE TO 500°C
(HEATER VOLTAGE = 5.3 VOLTS)

Tube	Plate Current ($E_b=100V$)	Amplification ($E_b=100V$)	Transconductance ($E_b=200V$)
7462-1A	+ 27%	- 2%	+ 12%
7462-2A	+ 47%	- 1%	+ 77%
7625-1A	+ 52%	- 28%	- 18%
7625-2A	+ 50%	- 17%	+ 3%
7296-2A	- 16%	+ 7%	+ 6%
7588-1A	+ 24%	- 33%	- 1%
7588-2A	- 12%	- 24%	- 35%
Y2191-1B	+241%	- 41%	+ 18%
Y2191-2B	+ 14%	- 3%	+ 10%
Y2191-3B	+166%	+ 7%	+ 55%
Y2191-4B	+163%	- 2%	+ 33%
Y2191-5B	+936%	- 11%	+ 76%

Table 2.1.2 Vacuum Tube Test Data Summary
Effect of Increasing Temperature

Figure 2.1.1. Variation of Amplification Factor and Transconductance with Temperature

For most triodes, N should lie between 1.5 and 2.0 or greater (Reference 2). The constant C is a function of tube geometry and can, therefore, be expected to change with temperature due to thermal expansions. A summary of the current correlations derived from the test data in Appendix A is given in Table 2.1.3. It can be seen from this table that the exponent for the ceramic tubes are somewhat less than expected except for tube 7296-1A. Also, the exponent and, therefore, the slope of current characteristic increases in most cases with temperature.

A similar relationship for transconductance can be derived from the definition:

$$E_m = \left(\frac{\partial I_b}{\partial E_b} \right)_{E_g} = C \cdot N (E_g + E_b / \mu)^{N-1}$$

The test data corresponding to this correlation is shown plotted in Appendix A.

Amplification factor is a function of tube geometry and is directly proportional to the grid to plate spacing. Transconductance, on the other hand, increases as the grid to cathode distance decreases up to some maximum, whereupon, it decreases as grid to cathode spacing is further decreased. Transconductance is also proportional to a power of the plate current where amplification factor is not.

The net effect of the above observations is that there is no clear cut generalization that can be made as to the effect of high ambient temperature on tube performance. In general, the net plate current should increase with temperature with a given heater current since the cathode will be hotter. Conversely, the effect of high ambient temperature can be cancelled by lowering heater voltage. Test results indicate that this is normally true. It had been expected that amplification factor would increase since thermal expansion should cause the grid to anode distance to increase. Test results showed, however, that for a fixed heater current the amplification factor in most cases either stayed relatively constant or decreased. Transconductance seemed more likely to increase with temperature as expected.

Tube	Room Temperature $E_f = 6.3 \text{ V}$	Room Temperature $E_f = 5.3 \text{ V}$	500°C $E_f = 5.3 \text{ V}$
7462-1A	$i = .0074(x)^{1.28}$	$i = .0050(x)^{1.34}$	$i = .0055(x)^{1.42}$
7462-2A	$i = .0096(x)^{1.15}$	$i = .0053(x)^{1.17}$	$i = .0072(x)^{1.19}$
7625-1A	$i = .0017(x)^{1.05}$	$i = .0013(x)^{1.26}$	$i = .0015(x)^{1.0}$
7625-1A	$i = .00125(x)^{1.17}$	$i = .0011(x)^{1.26}$	$i = .0014(x)^{1.03}$
7296-1A	$i = 0.22(x)^{1.77}$	$i = .10(x)^{2.25 *}$	$i = .09(x)^{2.4 *}$
7296-2A	$i = 0.25(x)^{1.13}$	$i = .0195(x)^{1.26}$	$i = .017(x)^{1.49}$
7588-1A	$i = .060(x)^{1.20}$	$i = .037(x)^{1.29}$	$i = .046(x)^{1.45}$
7588-2A	$i = .039(x)^{0.89}$	$i = .031(x)^{1.21}$	$i = .022(x)^{1.26}$

* $E_f = 4.3 \text{ V}$

Table 2.1.3 Current Correlations Derived From Test for Commercial Tube Types
($X = E_g + E_b/\mu u$)

2.1.2 Resistors

Objectives

The primary objective of the resistor tests was to obtain resistors capable of operating at 300 V and .5 watts at 500°C, with a ΔR of $< 1\%$ over the temperature range of 25 to 500C (denoted ΔR_T) and a ΔR of $< 1\%$ over the operating lifetime (denoted ΔR_t). An alternate objective was to obtain resistors which track well so that the resistance ratios (denoted R_R) would change very little with temperature and time even though the absolute values changed. An additional objective was to obtain small size resistors in order to minimize the overall dimensions of the amplifier.

Types Tested

Three basic types were tested as follows:

1. Dale Electronics wire wound with 3 different types of wire (Evanohm, Cupron, and Kanthal A-1) and coated with a proprietary high temperature coating.
2. Caddock thick film, coated flat type, uncoated cylindrical type and matched pairs selected by Caddock to track each other to provide nearly constant resistance ratio with changing temperature.
3. Omitronics, coated, wire wound; the same as the ones used in the 500°F amplifier.

Details regarding the type and quantity tested, resistance values, dimensions, date of starting and ending of the tests and the number of days of test are summarized in Table 2.1.4.

Tests Performed

The test procedure consisted of measuring the resistance at room temperature every morning, operating at 500C all day, measuring the

Table 2.1.4 - Resistors Tested as of 4/7/77

Manufacturer	Type	No. Tested	R, Ω	Dim., Inches	Tests		No of Days of Tests
					Start	End	
1. Dale Electronics	W W, Evanohm wire, coated, type RS5.	3	-1K	.31 dia. x 1 long	1/18	ST	55
2. " "	W W, Cupron wire, coated, RS5.	4	-1K	.31 dia. x 1 long	12/16	ST	78
3. " "	W W, Kanthal A-1 wire, coated and uncoated, HL 25	3	7.2K	5/16 dia. x 2 long	3/22	ST	11
4. Caddock	Thick film, coated, flat type, Type TK	2	24K 500K	.29 X .29 x .10	12/20 1/12	1/10 2/9	11 19
5. "	Thick film, uncoated, cylindrical	2	28K 317K	1/8 dia. x 1/2 long	1/21 2/11	ST 4/4	52 39
6. "	Same as (5) but higher power.	2	30K	.25 dia. x .5 long	4/7	4/8	1
7. "	Same as (6) but matched to track.	2	30K	"	4/7	4/8	1
8. Omitronics	W W, coated; same as in 500 Ω ampl.	1	10K	1/8 dia. x 3/8 long	12/20	2/10	35

ST = Still under test

W W = Wire Wound

resistance at 500C at about 5:00 P.M. and shutting down the oven all night and weekends.

Test Results

1. Dale wire wound. Values of ΔR_T (percent change in resistance from 25 to 500°C) are summarized in Appendix B for the past two months of testing of the three different kinds of wire wound resistors. It can be seen that the Evanohm which started out with ΔR_T of 1 to 2% have been improving with time, resulting in values of .1% during the past 10 days for two of the three on test. More have been ordered to determine if this large improvement in temperature stability with time can be accelerated by baking for a few days at 1000 or 1100F. ΔR_T for the third one (#69 in Appendix 2) has varied from .1 to .4% and back down to .1%. Further testing is required to see if it will now remain at .1%.

As shown in Appendix C, the Cupron ΔR_T has remained below 1.1% for the past seven weeks, varying over the range from .1 to 1.1% in a rather random manner (except for the questionable data shown on 4/4 which indicates a faulty common ground). The Kanthal A-1 resistors have been in test for 12 days and have varied up and down over the range of .1 to .6% in a random manner, after decreasing from a maximum of 1.7% on the first day.

It is concluded that the objective of $\Delta R_T < 1\%$ can be obtained by use of any one of the three types of wire wound resistors. None of those tested has failed. The Evanohm is best from the standpoint of stability, resistor size and availability. A complete set of Evanohm RS-5 and RS-10 types will be ordered for the amplifier breadboard tests as soon as it can be shown that the high stability can be obtained quickly by baking at 1000F or higher. An indication that this may be successful is shown by a test where one of the Cupron resistors (#72) was baked at 1000F for

1 day on 4/8 and its ΔR_T decreased to 0 in the following day's test from 25 to 500C. As shown in Appendix B, its ΔR prior to that had been averaging about .6% over the prior 10 days.

2. Caddock Thick Film Resistors. The ΔR_T for both of the coated thick film type (item 4 in Table 2.1 1) decreased from about 3% to < .5% during the first five days, but the coating cracked badly and both failed completely after another few days. The manufacturer was called and he found that the wrong type had been sent to us. He was amazed that they lasted so long at 500C.

Two uncoated cylindrical type resistors (item 5) were then tested. One of these has survived for 52 days and is still under test. However, its ΔR_T has varied from 3.4 to 6% during this time. The other has survived for 42 days and is still under test. However, its ΔR_T has increased from 2% to as high as 32% during this time.

Ten additional Caddock thick film resistors, including three matched pairs selected for good ratio tracking, have recently been received for test. One pair of unmatched and one pair of matched were tested on April 7 and the room temperature values increased by over 40% when measured the following day. A second unmatched pair were then tested and the room temperature values changed by only 6.5%. This variation is believed to result from the lapping procedure used to adjust the resistance value. Unlapped resistors are being sent for test.

2.1.3 Capacitors

Objectives

The primary objective of the capacitor tests was to obtain capacitors capable of operating at 300 V at 500°C, with a ΔC of <10% over the temperature range of 25 to 500°C (denoted ΔC_T) and a dissipation factor of <10% at 500°C. Additional objectives were to obtain capacitors in the range from 10pf to 10 mfd with a small change in capacitance with time, small size and long life.

Types Tested

Three basic types were tested as follows:

1. Thick film made by Sandia Laboratory in their program to obtain capacitors with good temperature stability over the range from 25 to 300°C; $C = 1000$ pf.
2. El Menco mica/silver capacitors, uncoated and coated; 60 pf (available to 500 pf).
3. Simmonds Precision mica/aluminum, hermetically sealed; .03 mfd.

Further details regarding the type and quantity tested, test identification number, dimensions, date tests started and ended and number of days of test are shown in Table 2.1.5.

Tests Performed

The test procedure consisted of measuring the capacitance and dissipation factor at room temperature every morning, operating at 500°C all day, measuring the capacitance and dissipation factor again at about 5:00 p.m., and then shutting down the oven all night and week-ends.

Table 2.1.5 Capacitors Tested as of 4/8/77

Manufacturer	Type	Test No.	C	Dim. Inches	Tests		No. of Days of Tests
					Start	End	
1. Sandia	Thick film	68B 78	1000 Pf	$1 \times 1 \times \frac{1}{16}$	12/29 1/25	ST 2/25	56 17
2. El Menco	Mica/silver, uncoated.	65 79 80	60Pf ↓	$\frac{1}{8} \times \frac{1}{2} \times \frac{3}{16}$ ↓	1/18 2/9 2/9	2/17 2/17 2/21	21 7 7
3. El Menco	Mica/silver, coated	65A 79A 65B 79B	↓	↓	2/25 2/25 3/15 3/15	2/26 2/26 3/15 3/15	2 2 1 1
4. Semetex	BN/Au thin film	76	17	$\frac{5}{16} \times \frac{5}{16} \times \frac{1}{16}$	1/20	1/28	5
5. Simmonds Precision	Mica/aluminum, herm. sealed, unimpregnated. Impregnated.	80A 80B 0* 9*	.03Mfd ↓	$\frac{1}{2} \times 2 \times \frac{3}{4}$ ↓	2/25 3/23 4/7 4/7	3/22 ST 4/8 4/8	16 9 1 1
6. El Menco	Mica, silver, uncoated	3*		$\frac{3}{8} \times \frac{7}{8} \times \frac{1}{8}$	4/7	4/8	1

ST = Still testing.

* Inert gas test fixture

Test Results

1. Sandia Thick Film. Values of ΔC_T (percent change in capacitance from 25 to 500°C) and DF (dissipation factor at 500°C in percent) are shown in Appendix C. ΔC_T varied from 51 to 72%, and DF varied from 31 to 40% for the two capacitors tested over a total of 56 test days. They failed to meet the test objectives, although they had previously met Sandia's objectives for ΔC_T and DF over their temperature range of interest from 25 to 300°C.
2. El Menco Mica. As shown in Appendix C, the first one tested (Test No. 65) met the objectives of C_T and DF < 10% for the first nine days of test, but then degraded severely after that. The other two were not as good but came fairly close to meeting the objectives. All failed due to severe oxidation of the metal parts. As shown in Table 2.1.5, four were tested with various high temperature Aremco coatings, but all of these failed due to the large decrease in resistance of the coatings at 500°C. An inert atmosphere test rig is now nearing completion to determine the temperature stability of uncoated versions of these capacitors with the oxidation problem eliminated.
3. Simmonds Precision Mica. These were wound using unimpregnated mica paper and aluminum foil inserted in a hermetically sealed ceramic tube. As shown in Appendix C, two were tested (#80A and 80B) starting on 2/25. The first one started out with $\Delta C_T = 28\%$, and DF = 16%, but steadily degraded to 51% and 28% over 15 days. It was then tested for leaks by immersing in hot water, and bubbles were observed at the interface between the nickel end caps and the ceramic tube. The second one held fairly constant with $\Delta C_T = 34$ to 36% until it suddenly increased to 51% on the 10th day, at which time it was leak tested and found to be leaking at the end of the evacuation tube. Two others, including one with a high temperature impregnant, will be

tested in the near future in the inert gas test fixture. In the meantime, the first one has been returned to the factory to see if it can be determined why the seal failed.

4. Other Capacitors Tested. As shown in Appendix C, starting on 1/21 a Semetex Boron Nitride/gold capacitor was tested, but its performance was very erratic, and the lead wire failed after three days. NASA Lewis sent 51 Westinghouse 2500 Pfd PBN/PT capacitors and associated parts to MRI for use in the amplifier development program. They were previously tested by Westinghouse at 600°C and showed exceptionally good temperature stability ($\Delta C_T = 1.7\%$ from 25 to 600°C and $DF = 1.7\%$ at 600°C).

2.1.4 Inductors

Objective

The primary objective is to obtain inductors capable of operating at 300V with a small change in inductance over the temperature range from 25 to 500°C.

Inductors to be Tested

An inductor core made of Vanadium Permanganite is being obtained from Arnold Engineering. This is a 2%V, 49Co, 49Fe alloy which decreases in permeability by only 11% from 25 to 500°C based on tests at Westinghouse in 1970. The core will be wound from .5" x .002" strip, resulting in a 1" ID x 1.5" OD x .5" high torroid. Delivery has been delayed due to problems with the annealing furnace but is now promised for shipment by 4/25. Arrangements are being made with Dale Electronics to torroidally wind the core with Gulton Industries' "Durock" ceramic insulated magnet wire rated at 1100°F continuous (recently reduced from 1500°F). A sample of the wire was sent to Dale to see if its minimum bend radius of 7X wire diameter is compatible with their winding machine. It was found to be compatible in this respect but was found to be very abrasive and is expected to cause excessive wear of the machine. This problem is now being investigated further, and other companies with this capability are being investigated in the event that Dale cannot wind the inductor.

2.1.5 Miscellaneous Components

Objectives

The objective of these tests was to obtain insulated hook up wire, breadboards, electrical connectors and other components required for testing the primary components and eventually the amplifier itself at 500°C.

Types Tested

The items tested and the test results are described briefly below:

1. Gulton Industries, "Duroflex I", 1000°F insulated 22 gage solid nickel wire for use as hook up wire. It has performed satisfactorily in use for making resistance and capacitance measurements during the component tests ever since they started on January 18, 1977.
2. Fiberglass for use as breadboards in the component tests. This material is not rated for 500°C, but it performs satisfactorily after the volatiles are driven off during the first day in the oven. It has been used for component testing since January 18, 1977.
3. Mykroy Ceramics Corporation, 6" dia. x ½" thick molded mica discs rated for continuous use at 1100F. They have performed satisfactorily in use as insulators for the components in the oven since January 18, 1977. They can be drilled with a carbide tip drill and will be used as breadboards for the amplifier tests.
4. Owens Corning B-6, 1000°F glass thread. It has performed satisfactorily in the component test program when used to tie down components in the oven air stream. It is also used to wrap around the ends of the cut insulation on the Gulton wire to prevent fraying of the insulation.

5. Anaconda MG-300-20, 20 gage nickel wire insulated with mica tape and glass braid and rated for use at 500°C continuous. It has performed satisfactorily in oven tests since March 8, 1977.
6. Simmonds Precision, 1000°F, 2 pin electrical connector. This has been temperature cycled from 25 to 500C starting on March 21, 1977 and has performed satisfactorily. The resistance between pins at 500°C > 70 MΩ.

2.2 Circuit Design

Circuit design activities consisted of two parts. The first part was the design of the basic amplifier and the second part was the design of signal conditioning circuitry to couple variable impedance sensors to the amplifiers. Each of these circuit design activities are discussed separately below:

2.2.1 Amplifier

The basic goals of the amplifier are:

- A gain of 100
- A flat frequency response from near DC to over 1 kHz
- The capability to drive over 15,000 feet of standard logging cable
- Operation at downhole temperatures from 0 to 500°C.

Ten circuit designs were examined. All of these designs are basically derived from the 260°C amplifier developed for ERDA by MRI under contract E(04-3)-1184. Table 2.2.1 summarizes the major features of each of these designs.

The circuit configuration in Figures 2.2.1, 2.2.2, and 2.2.3 are identical in concept, only the type tube is varied. All three circuits consist of a differential input stage followed by a second differential gain stage and a single ended cathode follower output stage. A single 250 volt B+ power supply is used in all three cases. Thus, there will be a quiescent DC voltage on the output (and the input when the loop is closed to get the desired gain).

Table 2.2.1. Circuit Configurations

Figure No.	Tube Type	Type Input Stage	Type Gain Stages	Type Output Stage	No. of Tubes	No. of Power Supplies	Special Features	Open Loop Gain
2.2.1	7296	Differential	2 Differential	Single Ended	5	1		3,250
2.2.2	7588	Differential	2 Differential	Single Ended	5	1		11,500
2.2.3	7462	Differential	2 Differential	Single Ended	5	1		2,500
2.2.4	7462	Differential	1 Differential 2 Single Ended	Single Ended	5	2	$\pm 250V$ B+	34,000
2.2.5	7462	Differential	1 Differential 2 Single Ended	Single Ended	5	2	$\pm 150V$ B+	13,800
2.2.6	7462	Differential	1 Differential 1 Single Ended	Single Ended	4	2	0.5V Input Bias	1,300
2.2.7	7462	Differential	1 Differential, 1 Single Ended	Single Ended	4	2	1.0V Input Bias	837
2.2.8	7462	Differential	2 Differential	Differential	6	2	Interstage Positive Feedback	TBD
2.2.9	7462	Single Ended	3 Single Ended	Single Ended	4	2		10,000
2.2.10	7462	2 Single Ended	1 Single Ended 1 Differential	Single Ended	5	1		1,818

Figure 2.2.1

Figure 2.2.2

Figure 2.2.3

The difference in performance between these three circuits is in the open loop gain. With the 7296 type tubes, the open loop gain is 3,250, with the 7588 type tubes it is 11,500, and with the 7462 type tubes it is 2,500. Originally, it was planned to compare the 7625 tube circuit performance, but the interstage coupling losses were too large to merit further evaluation.

As can be seen, the best, and most expensive, tube type has the highest open open loop gain. Besides being very expensive, the 7588 tube is larger than the 7462 type. Therefore, other circuit designs were explored to get larger open loop gain from 7462 type tubes.

The circuit shown in Figure 2.2.4 has several modifications. First, the second differential stage is replaced by two cascaded single ended gain stages. Second, both a 250 volt B+ and a 250 volt B- power supply are used. The resultant open loop gain is about 34,000, a considerable improvement.

There are three significant advantages of the use of two separate plate power supplies. First, the interstage coupling loss is reduced; second, since the grid voltage is not building up in each cascading stage, there is more flexibility in selecting an "optimum" operating point for each stage and third, both the input and output can operate at a quiescent DC voltage level of zero volts. This last advantage allows simple feedback coupling without shifting operating points of the tubes, and allows zero DC volts on the transducer. The advantage of two cascaded stages over a single differential stage is much higher gain.

The circuit shown in Figure 2.2.5 is a modification of the circuit just discussed for operation at ± 150 volts. The open loop gain drops by about a factor of 3 to 13,800.

Figure 2.2.4

Figure 2.2.5

The next two circuits considered are shown in Figures 2.2.6 and 2.2.7. The basic change in both of these circuits is that only four tubes are used. The differential input stage is followed by one single ended gain stage. The circuit in Figure 2.2.6 has been designed for a 0.5 volt bias on the input stage and has an open loop gain of 1,300. The circuit in Figure 2.2.7 has been designed for a 1.0 volt bias on the input stage and has an open loop gain of 837.

The circuit shown in Figure 2.2.8 is a modification of the same basic concept of two differential gain stages. The modifications are a differential output stage and positive feedback around one of the stages. The differential output stage allows symmetric feedback to the differential input stage and, in theory, should improve balance. The positive feedback is used to increase the open loop gain to a very large number. Hopefully, this open loop gain will be of the order of 10^5 to 10^6 . (The desire is to set the feedback so that the maximum gain, consistent with stability, is obtained over an ambient temperature range of 0 to 500°C.)

The circuit shown in Figure 2.2.9 consists of three cascaded single ended amplification stages. The advantage of this design is that only four tubes are required for a gain of about 10^4 . The disadvantage is that the common mode noise rejecting properties of the differential input stage are lost.

The configuration shown in Figure 2.2.10 is a minor variation of the circuit shown in Figure 2.2.3. The input tubes have separate cathode resistors instead of a common cathode resistor. The advantage of the approach is that it permits easier matching of tube performances. The disadvantage is that large common mode voltages could cause saturation problems. The open loop gain is also only about 1800.

Because of its high open loop gain, zero quiescent output voltage and the use of the small size — and relatively lower cost 7462 tubes, the circuit shown in Figure 2.2.4 will be the design baseline for initial breadboard activities.

Figure 2.2.6

Figure 2.2.7

Figure 2.2.8

Figure 2.2.9

Figure 2.2.10

2.2.2 Universal Input

The objective of the universal input stage is to provide signal conditioning so that the output from a variable impedance (resistance, capacitance or inductance) sensor is converted into a voltage for use with the amplifier.

The ability to successfully condition variable impedance sensors is limited by the available range of 500°C passive components, the temperature coefficients of these components and the nature of excitation power downhole.

Two basic signal conditioning configurations were considered. These are the universal resonance bridge and the operational amplifier. The following figure is the universal resonance bridge configuration. The Ultra High Temperature Amplifier will be connected to the output voltage terminals to amplify the bridge output signal and drive the long transmission cable.

Figure 2.2.11. Resonance Bridge

The transducer replaces either C, R_4 , or L in the above bridge. In general, the R_1 , R_2 and R_3 values would be chosen from the nominal value of R_4 so that resistive balance is obtained. This requires

$$R_4 = \frac{R_2 R_3}{R_1} .$$

For simplicity assume $R_1 = R_2 = R_3 = R_4$.

The bridge should be excited at the resonant frequency. This causes the nominal inductive impedance to cancel out the nominal capacitive impedance. This frequency is:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

If the transducer has a variable resistance sensing element, the bridge behaves as an AC excited single active arm Wheatstone bridge. Let the resistance of the sensing element be described as:

$$R_4(t) = R_0 [1 + k y(t)]$$

when $R_4(t)$ = the instantaneous resistance of the sensor,

R_0 = the nominal resistance of the sensor,

k = the constant of proportionality (transducer sensitivity) and

$y(t)$ = the instantaneous physical property being measured by the transducer.

The normalized transfer function for constant voltage excitation of the bridge is

$$\frac{E_{out}}{E_{in} \cdot y(t)} = \frac{k}{4 + 2k y(t)}$$

For typical sensitivities, $k y(t) \ll 1$ then

$$\frac{E_{out}}{E_{in} \cdot y(t)} \approx \frac{k}{4}$$

A variable capacitance, or inductance sensor shifts the bridge off of resonance. The general output/input equation is:

$$\frac{E_{out}}{E_{in}} = \left[\frac{1}{2} - \frac{1}{2 + j \left(\frac{1}{R_0} \right) (X_L - X_C)} \right]$$

For convenience, assume that the nominal values of the magnitude of both the capacitive and inductive impedances equal R_0 at the resonant frequency.

$$|X_C| = |X_L| = R_0 \quad (\text{at resonance})$$

Let the capacitance of a sensing element be described as:

$$C(t) = C_0 [1 + k y(t)]$$

$$X_C = \frac{1}{j 2 \pi f C}$$

$$= \frac{R_0}{j} \quad \text{at } f = f_0$$

where: f_0 = resonance

$$X_C(t) = \frac{R_0}{j [1 + k y(t)]}$$

$$X_L = j 2 \pi f L$$

$$= j R_0 \quad \text{at } f = f_0$$

The input/output equation becomes

$$\frac{E_{out}}{E_{in}} = \left\{ \frac{1}{2} - \frac{1}{2 + j \left[1 - \frac{1}{1 + k y(t)} \right]} \right\}$$

For $k y(t) \ll 1$ the transfer function is approximately

$$\frac{E_{out}}{E_{in} \cdot y(t)} \approx -j \frac{k}{4}$$

Similarly, for an inductive sensor and the bridge at resonance

$$L(t) = L_0 [1 + k y(t)]$$

$$X_L(t) = R_0 [1 + k y(t)]$$

$$\frac{E_{out}}{E_{in}} = \left[\frac{1}{2} - \frac{1}{2 + j k y(t)} \right]$$

and for $k y(t) \ll 1$

$$\frac{E_{out}}{E_{in} \cdot y(t)} \approx j \frac{k}{4}$$

In all cases the sensitivity is reduced by a factor of 4.

The major feature of the resonance bridge is that it is easily adaptable to accommodate a variable resistance, capacitance or inductance bridge and its performance is basically the same for all three types. The disadvantages of the resonance bridge are the need for AC excitation, matched temperature coefficients and demodulation. Development of a downhole AC power supply is not in the scope of this contract; therefore, bridge excitation would have to be transmitted from the surface to downhole. This has several disadvantages. The need for additional wires in the logging cable, regulation problems and severe crosstalk into the data channel in standard logging cable. Matching the temperature coefficients of the inductive and capacitive elements appears difficult. The demodulation requirement is not a serious problem. The transmission cable would probably filter out most of the carrier from the bridge excitation.

The other type of signal conditioning examined was the operational amplifier configuration shown in the figure below.

The output voltage is:

$$E_{out} = E_{in} \cdot \frac{Z_F}{Z_{in}}$$

The procedure is to make the input and feedback impedances identical except for magnitude. Thus, the output is independent of frequency (to a first order approximation). The desired gain is determined by the ratio of the impedances.

The sensing element is usually put into the input loop. Let a variable resistance sensor be:

$$R(t) = R_1 [1 + k y(t)]$$

The output voltage is:

$$E_{out}(t) = E_{in} \left\{ \frac{R_F}{R_1 [1 + k y(t)]} \right\}$$

Assuming $k y(t) \ll 1$ and using a binomial expansion:

$$E_{out} \approx E_{in} \left\{ \frac{R_F}{R_1} - \frac{R_F}{R_1} k y(t) \right\}$$

The DC term can be removed if the amplifier has a differential input and an offsetting voltage is fed into the second input. In this case, the output is

$$E_{out} \approx - (E_1) \left(\frac{R_F}{R_1} \right) (k) y(t)$$

For a variable inductance sensor

$$L(t) = L_1 [1 + k y(t)]$$

$$E_{out} = E_{in} \frac{j\pi 2 f L_F}{j\pi 2 f L_1 [1 + k y(t)]}$$

$$\approx - (E_1) \left(\frac{L_F}{L_1} \right) (k) y(t) - \text{with the same assumptions as above}$$

For a variable capacitance sensor:

$$C(t) = C_1 [1 + k y(t)]$$

$$E_{out} = E_{in} \cdot \frac{j\pi 2 f C_1 [1 + k y(t)]}{j\pi 2 f C_F}$$

$$\approx (E_{in}) \left(\frac{C_1}{C_F} \right) (k) y(t) - \text{with the same assumptions as above.}$$

Note that the polarity is reversed and the gain increases for a decreasing feedback capacitor size in this case.

The advantages of this signal conditioning circuit over the resonance bridge are:

- The compensation should be easier to attain since only the ratio of the sensor impedance and the fixed impedance (feedback in the above examples) needs to be constant. Since the active and passive impedances are of the same type this requires only that their temperature coefficients be similar. In fact, the change in parasitic impedance with temperature (increase in dissipation factor) will impact the frequency response. The importance of this variation and the imperfections in the amplifier, such as non-infinite input impedance cannot be evaluated until data on the nature of variable impedance high temperature well-logging sensors is obtained.
- This configuration can operate with a DC voltage. This voltage can be obtained across a small resistance in series with constant current filament excitation.
- Theoretically, the sensor can be placed in the feedback loop extending the range of impedances that can be conditioned.

2.3 Mechanical Design

A decision has been made to develop two packaging designs. One design will be for a 1 11/16" OD sonde using the Caddock flat, thick film resistors. The other design will be a 3" OD sonde using the Dale Evanohm wire wound resistors.

The design shown in Figure 2.3.1 is an improved version of a previously reported design for a 1 11/16" OD sonde using Evanohm wire wound resistors. Its length has been reduced from 19.6" to 11 7/8". The design is based on the wiring diagram shown in Figure 2.3.2. The resistors required are summarized on Table 2.3.1. Resistance values from 200Ω to 40K are provided by the .31" d x 1" long RS-5 type and resistance values from 200 K to 1000 K are provided by the use of 1 to 4 of the 3/8" d x 1 7/8" long RS-10 type (for which the maximum resistance is 263 KΩ).

Item	Qty.	Description
1	5	Ceramic Vacuum Tube, .33" dia.
2	13	200Ω to 40KΩ Wire Wound Resistor, .312d x 1" long
3	22	200KΩ to 275KΩ Wire Wound Resistor, 3/8" dia. x 1 7/8" long.
4	5	~100 PF Capacitor, Mica

MECHANICS RESEARCH INC. Figure 2.3.1. Packaging of Amplifier in Figure 2.3.2

Figure 2.3.2. Typical Amplifier Circuit Diagram 1

Table 2.3.1

Resistors Required for the Amplifier Wiring Diagram in Figure 2.3.1

<u>R, Ω</u>	<u>Quantity in Wiring Diagram</u>	<u>Evanohm Type</u>	<u>No. Req'd for Each</u>	<u>Total</u>	
200	1	RS5**	1	1	13
low R*	6	↓	1	6	
10K	1		1	1	
31.25K	1		1	1	
40K	4		1	4	
202K	2	RS10***	1	2	22
203K	1	↓	1	1	
400K	3		2	6	
500K	3		2	6	
600K	1		3	3	
1000K	<u>1</u>		4	<u>4</u>	
	24			35	

* 6 low values not yet identified.

** Dale Electronics, Type RS-5 wire wound coated resistor using Evanohm wire. Dimensions are .312 dia x 1" long. They are available in resistance values from .1 Ω to 95K Ω and are rated at 5W at room temperature.

*** Dale Electronics, Type RS-10 wire wound coated resistor using Evanohm wire. Dimensions are 3/8" dia x 1-7/8" long. They are available in resistance values from .1 Ω to 273K Ω and are rated at 13W at room temperature.

2.3.1 1 11/16 Inch Sonde

Design Objectives

The OD of the amplifier will be 1.45" so that it will fit in a standard 1 11/16" OD sonde. Due to the small size of the Caddock thick film resistors, the length is expected to be only 2 or 3" compared to the 12" length shown in Figure 2.3.1. The design must be capable of dissipating the internal heat generated without producing excessive internal temperatures which adversely affect the performance of the components.

Design Details

Subsequent to the Caddock cylindrical thick film resistor tests described in Section 2.1.2, an uncoated type TK 133 flat resistor was tested for several days and found to have a ΔR_T of about 1%. This is far better than the Caddock cylindrical ΔR_T of 3 - 6%. Also, they are much smaller with dimensions of .25 x .20 x 1/32" versus .25d. x .5" for the cylindrical. Several more have now been received for test. The rated power for these resistors is only .4W. The power dissipation required for the plate resistors is about 1W or .5W if two are used in parallel or series. The power dissipation for the other resistors in the circuit is much less. The ΔT above ambient for the TK 133 resistors for .5W is about 120°C according to the manufacturer. These resistors are fired during manufacture at 900°C so that operation at 620°C will not harm them. Tests are now being made to determine the effect on ΔR_T of applying .5W power at 500°C. If necessary, the power dissipation can be improved by cementing the resistor to the breadboard by means of high thermal conductivity, high temperature Areenco 552 ceramic cement. The use of gold leads will also help to reduce the ΔT above ambient due to the high thermal conductivity of gold (75% of of copper). Until further information is obtained regarding power dissipation, ΔR_T and method of attaching leads, this packaging design cannot be finalized.

2.3.2 Three Inch Sonde

Design Objectives

The basic goal of the packaging design is to reduce the size of the 500°C amplifier from that of the previously developed 260°C amplifier. The 260°C amplifier was packaged in a 3 inch O.D. cylinder of eight inches length. This configuration and alternate configurations for reducing the size are shown in Figure 2.3.3.

Design Details

This design has not been completed yet. Work on this design is awaiting final selection of the type of wire for use in the resistors. The Kanthal A-1 resistors have exhibited the best temperature coefficients of resistance (TCR) but they have considerably lower resistivity than the Evanohm resistors. In addition, initial set up charges make these resistors considerably more expensive in the small quantities required and the delivery time is substantial. On the other hand, the Evanohm resistors required considerable temperature aging before attaining a low temperature coefficient of resistance.

Sample Evanohm resistors have been ordered to determine if the TCR stabilization can be accelerated.

Top View

Bottom View

260°C Amplifier

Top View

Bottom View

260°C Amplifier Without Capacitor

Disc Circuit Board With
"Cordwood" Resistor Stacking

Disc Top
Disc Circuit Board

Figure 2.3.3. Conceptual Layout, Ultra High Temperature Amplifier, Three Inch O.D.

2.3.3 Inert Atmosphere Package

Design Objective

The objective is to evaluate the design of an amplifier package in which all or some of the components operate in an inert atmosphere. This is definitely required for the El Menco mica capacitors and may be required for the Simmonds mica capacitors if the hermetic seal design cannot be improved. Tests on the uncoated Caddock thick film resistors in the inert atmosphere test fixture (item 3.0) will show if they must also be operated in an inert atmosphere.

Design Details

The primary problem is the connector to carry electric power and signals through the package wall. As discussed in Section 3.0, difficulties are being encountered in obtaining connectors with sufficiently high resistance between pins at 500C.

2.3.4 Constant Temperature Package

Design Objective

The objective is to evaluate the design of an amplifier package with the capability of maintaining approximately constant internal temperature with ambient temperatures varying over the range of 25 to 500°C. This approach alleviates the problem of change in operating characteristics of the components with temperature.

Design Details

A high temperature switch was ordered for evaluation and was recently shipped by the manufacturer. The probe is rated for continuous operation at 1750°F, but the head is only rated for 800°F. Under these conditions, it is capable of controlling temperature to $\pm 1^\circ\text{F}$ according to the manufacturer. In our application it is proposed to use the switch to control the current to a heating element in the amplifier package, to maintain the inside at about 960F while the ambient varies from 70 to 930F (500°C). This requires the head of the switch to operate at 930F. The manufacturer has never tested it under these conditions, but thought it might operate satisfactorily and consequently sent one for test by MRI. Various concepts are being investigated to reduce the heater current required to a low value in spite of the large change in ΔT across the sonde wall.

2.4 Breadboard Testing

2.4.1 Objective and Scope

Evaluation of the circuit designs described in Section 2.2 will be accomplished by breadboarding several of the circuits and testing at both room temperature and at 500°C. For the room temperature tests, ceramic vacuum tubes will be used with ordinary five percent tolerance carbon resistors. Potentiometers will be used to determine the best values for critical resistors. It is initially planned to breadboard circuits 2.2.4, 2.2.8, and 2.2.10. Also, one and two tube circuits will be assembled and tested utilizing the high mu special design tubes that were obtained for component testing. The object of the special design tubes was to have a single tube that can serve both as an amplifier and line driver. The most promising circuit(s) as determined by the room temperature tests will be breadboarded for 500°C tests. The main constraint on the high temperature breadboard is that the components will have to be welded together in order to have reliable connections. Therefore, it is a breadboard in name only.

2.4.2 Status

Type 7462 ceramic tubes have been purchased for use in the breadboard circuits. The tubes are being screened and matched for use in the differential stages. A breadboard utilizing patch cord connections has been assembled and is being utilized. The breadboard has separate tube and resistor modules which can be conveniently interchanged. While one is under tests, therefore, a second can be assembled off to the side to minimize the time spent on set-up and take-down.

A literature search was conducted to located documents relating to the application of ceramic vacuum tubes in high temperature environments. The search which was limited to unclassified literature on "Ceramic and/or Metal Electron Tubes" and "High Temperature Electronics", is documented in Reference 3. The primary source of information on recent literature (post 1970) was the SDC Search Service (NTIS) prepared by the Department of Commerce and containing citations and abstracts of government sponsored R & D reports; and 2) Engineering Index Monthly (Compendex) prepared by Engineering Index, Inc. A total of 24 citations were found relating to ceramic tubes and 24 relating to high temperature electronics. These citations coupled with bibliographies in the referenced documents and those found by backtracking through references provided over 1,000 titles relating to ceramic tubes. Very little of this multitude of literature, however, related to the application of ceramic tubes in high temperature environments which was the primary goal of the search even though it has been recognized for some time, that ceramic electron tubes can function in ultra high temperatures. Also, there has been no extensive development of other electronic components (i.e., resistors, capacitors, and inductors) needed to make them practical in high temperature circuits. As indicated by the lack of recent literature on the subject in contrast to the large amount that appeared prior to 1960, the use of ceramic tubes has settled into a few applications in microwave and radar circuitry where their extreme ruggedness and insensitivity to shock is of more value than tolerance to high temperature.

3.0 SPECIAL TEST EQUIPMENT

A small amount of special test equipment has been developed to date to support the Ultra High Temperature Amplifier program. Specifically, an inert atmosphere tester was designed and built to test the temperature performance of uncoated passive elements in an "oxidation free" environment. Also, a tube characteristic test unit was built to determine the variation of ceramic vacuum tubes with temperature. These equipment are discussed in the following sections.

3.1 Inert Atmosphere Tester

The test fixture shown in Figure 3.1.1 was designed and fabricated to permit the testing of resistors and capacitors in an inert atmosphere (nitrogen) at 500°C. A breadboard was made up with an El Menco mica capacitor, the two Simmonds capacitors and various uncoated Caddock flat and cylindrical resistors to determine the improvement in ΔC_T and ΔR_T which could be obtained by operation in an inert atmosphere.

Initially, Swageloc fittings swaged around lengths of Gulton insulated wire were used as electrical penetrations in the inert gas test rig. The resistance between the wires was 500 M Ω at 500C with the two fittings clamped together, indicating that this arrangement would be satisfactory. However, it was later found that in order to make the penetrations pressure tight, the fittings had to be tightened to the point where the insulation failed.

Figure 3.1.1 High Temperature Inert Gas Component Test Fixture

The penetration was then redesigned to use two 7 pin electrical connectors shown in Figure 3.1.1. The connectors were purchased from Co-Operative Industries, Inc. They are rated for 500°C continuous operation. Tests were made at the factory to determine the resistance between pins at 500°C. The pin to pin insulation resistance was only 5 MΩ at 100V initially, but this increased to 40 MΩ after a few hours exposure at 500°C. (A value of 20 MΩ is required in order to get reasonably accurate measurement of the capacitors performance with temperature.) In subsequent tests at MRI, the resistance between pins was only .3 MΩ at 10V and 20 MΩ at 100V after baking for several hours at 500C. After baking at 500C the following day, the resistance increased to 20 MΩ at both 10 and 100V, but during the next few days it decreased to 3 and 10 MΩ, respectively. Further investigation is being made to try to account for this behavior.

3.2 Tube Characteristic Tester

A test device for measuring tube characteristics was built utilizing the circuit shown in Figure 3.2.1. The circuit is essentially a Miller bridge. An advantage of the circuit is that the characteristics are measured under actual operating conditions.

Amplification factor is determined with the configuration shown in Figure 3.2.1a by varying R_1 and/or R_2 until the bridge is balanced, and there is no signal on the scope. When this occurs, the plate current is zero and the grid potential is:

$$E_g = IR_1 + e$$

where e is an arbitrary d-c bias that fixes the d-c plate current. For a small signal input:

$$-\mu \Delta E_g + R_2 \Delta I = 0$$

so that by combining:

$$\mu = R_2/R_1$$

Transconductance is measured by the circuit modification shown in Figure 3.1b, which has resistor R_3 added between the plate and cathode. Measurement is again made by adjusting resistors R_1 and/or R_2 until the bridge is balanced, and there is no output to the scope. For a small signal input when the bridge is balanced:

$$\Delta E_g = R_1 \Delta I$$

$$R_3 \Delta I_p + r_p \Delta I_p - \mu \Delta E_g = 0$$

and

$$R_2 \Delta I - R_3 \Delta I_p = 0$$

Figure 3.2.1 Circuits for Determining Tube Characteristics

by using the previously measured amplification factor, the plate resistance can be determined by:

$$r_p = R_3 \left(\mu \frac{R_1}{R_2} - 1 \right)$$

and transconductance:

$$g_m = \mu / r_p$$

This section describes the status of work schedule on this contract. The initially planned schedule is compared to the present schedule and the schedule to completion is described.

Table 4.1 shows the initial schedule developed for this contract. Table 4.2 shows the present schedule status. By comparing these schedules it is immediately apparent that most of the tasks in the contract phases 1 through 4 have slipped by about one month. Half of this one month slip is because the official contract start date was two weeks prior to the time that the contract was actually authorized to start.

The major factors leading to the remaining schedule slippage were slower than anticipated delivery on documents from the literature survey, slower than anticipated delivery of components and failure of some passive components to perform as predicted. The supplemental testing task was the most affected by the latter two factors. Since many of the components are being graciously developed, especially for this program and provided at no cost, their delivery cannot be accelerated.

ACTIVITY	MONTHS AFTER CONTRACT											
	1	2	3	4	5	6	7	8	9	10	11	12
PHASE 1 - INCREASED TEMPERATURE RANGE AMPLIFIER DESIGN												
Task												
1 Circuit Design												
2 Component Selection												
3 Breadboard Development												
PHASE 2 - INCREASED PACKING DENSITY DESIGN												
Task												
4 Packaging Design												
5 Thermal Analysis												
PHASE 3 - UNIVERSAL TRANSDUCER INPUT DESIGN												
Task												
6 Concept Selection												
7 Circuit Design												
8 Breadboard Development												
PHASE 4 - CERAMIC VACUUM TUBE INVESTIGATION												
Task												
9 Literature Search												
10 Tube Evaluation												
11 Supplemental Testing												
PHASE 5 - AMPLIFIER DEVELOPMENT												
Task												
12 High Temperature Breadboard												
13 Prototype Amplifier												
PHASE 6 - REPORTS												
Task												
14 Status Reports/Liaison/Project Mgmt.												
15 Final Report on the Amplifier												
16 Report on High Temp. Elec. Components												
PHASE 7 - DOWNHOLE TEST												
Task												
17 Test Planning												
18 Test Hardware												
19 Test Conduct												

PROJECT TITLE: Ultra High Temperature Amplifier
 PREPARED BY R. D. Kelly

SHEET 1 OF 1
 PROJECT 2942

LEGEND: CURRENT PLAN INITIAL PLAN SUPERSEDED RESCHEDULED ITEM (DATE) COMPLETED BEHIND SCHEDULE AHEAD OF SCHEDULE

ACTIVITY:

DELIVERABLE ITEM: ▲ ✗ ▲ ▲ ▲ ▲

Table 4.2. Project Milestone Chart

Table 4.2 presents the schedule for completion of this work. Presently, there appears to be no problem in completing the work on schedule. However, realistically, the work is just starting into the hardware development phase which can often develop many unforeseen problems and the downhole demonstration will undoubtedly have to fit into a geothermal well utilization schedule which may have its own set of schedule slips.

To maximize our probability of success on schedule, the following actions have been taken:

Room Temperature Breadboard Development (Tasks 3 and 8)

Two room temperature breadboards are being built for parallel evaluation of candidate circuits in a minimum amount of time.

High Temperature Breadboards (Task 12)

Two high temperature breadboards will be built. One breadboard will use wire wound resistors and the other breadboard will use thick film resistors. The plan here is to permit parallel development with these candidate resistors.

Packaging Design and Thermal Analysis (Tasks 4 and 5)

Mechanical designs for amplifiers employing both wire wound and thick film resistors are being developed. The design employing wire wound resistors will be sized for a 3 inch O.D. sonde and the design employing thick film resistors will be sized for a 1 11/16 inch O.D. sonde. By completing both mechanical designs, the fabrication of the prototype can proceed immediately upon completing the high temperature breadboard tests. (These tests will identify whether the wirewound or thick film resistor circuits work best.)

Ceramic vacuum tubes provide a solid basis for the immediate development of much of the high temperature downhole electronics required for geothermal well logging. These tubes have the capabilities to survive both the high temperature and severe shock environments present in geothermal well logging. Therefore, two courses of action are recommended to accelerate development of high temperature logs for near term use in support of geothermal exploration and production.

The first course of action recommended is to build one or more sondes with the ceramic vacuum tube amplifiers to get these devices into use. This will be of mutual benefit to the operators in extending their logging capabilities and to DGE in determining what modifications/improvements are desirable.

A sonde containing the ceramic vacuum tube amplifiers could serve as a basic building block for total high temperature logging system development. As they are developed, new high temperature transducers can be used on the input, new high temperature electrical cables can be added to the output, new cable heads can be added to the sonde/cable interface. Meanwhile, the sonde is being usefully employed.

The second course of action recommended is to expand the range of downhole electronic functions performed by ceramic vacuum tube circuits. The type of circuits that appear to be most applicable across a broad spectrum of well logging applications are 1) a downhole power supply, 2) a downhole multiplexer and 3) a downhole wireless transmitter.

The downhole power supply could be used with either power transmitted from the surface or generated downhole. A downhole power supply would permit optimization and maximization of the power transmitted by tailoring the power to fit the line resistance drop, insulation dielectric strength, etc. For power generated downhole, the power supply would condition the raw power into low noise, stable levels.

For power transmitted from the surface via standard logging cable, DC power would probably be used to reduce power frequency pickup on the data wires. For shielded cable, 3 phase AC might be used.

Assuming that DC voltage is supplied from the surface, the power supply would consist of DC to DC converters to provide filament, B+ and transducer excitation power.

The multiplexer circuit would permit multiple signal transmission over a single communication path. An FM multiplex is envisioned in which the outputs of n transducers modulate the frequencies of n subcarrier oscillators (SCO). (One transducer per subcarrier oscillator.) The outputs of the subcarrier oscillators are summed together and transmitted over a single transmission link. The SCO's can be designed to work with either voltage or variable impedance inputs, so they can work directly with a broad range of sensors.

With the capability of transmitting multiple data signals over a single transmission path, some interesting opportunities are opened to solve the electrical cable temperature limitations. Only a single conductor is required if the strength member of the cable is used for a signal return. Adequate high temperature insulated conductors are presently available. Thus, the design problem boils down to making the strength member waterproof and the fabrication costs economical.

With a single transmission channel, and a downhole power source, high temperature wireless transmission appears quite attractive. Ceramic vacuum tubes are commercially available with CW ratings in both the 10 and 100 watt ranges — with peak power ratings in the 1000 watt range. With these power capabilities, it should be possible to get useful signal to noise ratios at the surface with both good data accuracies and bandwidths.

Combination of these techniques opens up the capabilities for a logging-while-drilling system that should result in significant drilling cost reductions.

7.0

REFERENCES

1. R. D. Kelly, "Ceramic Vacuum Tubes for Geothermal Well Logging", MRI-2942-TR1, 12 January 1977, Mechanics Research, Inc., 2500 Colorado Avenue, Santa Monica, California.
2. J. W. Gewatowski and H. A. Watson, Principles of Electron Tubes, D. Van Nostrand Company, Inc., 1965
3. W. L. Cannon, "Literature Search for Ceramic Vacuum Tubes", MRI-2942-TR2, 12 January 1977, Mechanics Research, Inc., 2500 Colorado Avenue, Santa Monica, California.

APPENDIX A

CERAMIC VACUUM TUBE TEST DATA

TABLE A1
CERAMIC VACUUM TUBE TEST DATA

TUBE		TEST CONDITIONS			MEASUREMENTS - ROOM TEMP			MEASUREMENTS - 500°C		
Type	Sample Number	Heater Voltage	Plate Voltage	Grid Voltage	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)
7462	1A	6.3	100	0	8.44	108	9,500	-	-	-
				-.25	6.15					
			200	0	16.9	107	11,900	-	-	-
		5.3	100	-.25	12.3					
				0	3.9	111	7,120	4.95	109	7,760
			200	-.25	2.3			3.1		
		4.3	100	0	11.4	108	9,050	13.3	107	10,100
				-.25	9.2			10.7		
			200	0	1.35	109	3,600	2.5	109	5,840
		2A	100	-.25	0.63			1.25		
				0	5.3	113	4,200	9.15	108	8,100
			200	-.25	4.1			7.16		
	2A	6.3	100	0	9.15	98	11,100	-	-	-
				-.25	6.67					
			200	0	22.3	96	12,700	-	-	-
		5.3	100	-.25	19.0					
				0	5.04	100	7,000	7.41	99	6,460
			200	-.25	3.47			4.04		
		4.3	100	0	12.3	98	5,940	17.2	97	10,510
				-.25	10.5			13.4		
			200	0	0.96	102	561	3.5	100	6,090
			100	-.25	0.58			2.1		
				0	1.4	101	344	12.0	99	7,020
			200	-.25	1.0			9.1		

TABLE A1 (Continued)
CERAMIC VACUUM TUBE TEST DATA

TUBE		TEST CONDITIONS			MEASUREMENTS - ROOM TEMP			MEASUREMENTS - 500°C		
Type	Sample Number	Heater Voltage	Plate Voltage	Grid Voltage	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)
7625	1A	6.3	100	0	2.74	57	1,490	-	-	-
				-.2	2.39					
				0	5.57	62	1,860	-	-	-
		5.3	100	0	5.14					
				-.2	1.98	69	1,410	3.0	50	1,304
				0	1.78					
		4.3	100	0	4.3	76	1,830	6.1	50	1,507
				-.2	3.9					
				0	.71	76	259	2.1	56	1,090
		200	200	0	.64					
				-.2	.94	72	144	4.3	61	1,490
				0						
	2A	6.3	100	0	2.35	56	1,370	-	-	-
				-.2	2.05					
				0	5.03	62	1,860	-	-	-
		5.3	100	0	4.62					
				-.2	1.63	72	1,320	2.45	60	1,280
				0	1.35					
		4.3	100	0	3.55	78	1,470	5.02	58	1,510
				-.2	3.25					
				0	.32	95	109	1.98	59	1,130
		200	200	0	.27					
				-.2	.45	107	99	4.31	65	1,540
				0	.42					

TABLE A1 (Continued)
CERAMIC VACUUM TUBE TEST DATA

TUBE		TEST CONDITIONS			MEASUREMENTS - ROOM TEMP			MEASUREMENTS - 500°C		
Type	Sample Number	Heater Voltage	Plate Voltage	Grid Voltage	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)
7296	1A	6.3	100	0	26.1	91.5	31,350	-	-	-
				-.25	19.7					
			200	0	58.3	115.	47,520	-	-	-
		5.3	100	0	49.7					
				-.25	10.4	-	-	12.5	105	19,090
			200	0	7.1					
		4.3	100	0	21.6	-	-	36.3	120	39,180
				-.25	18.2					
			200	0	3.2	134.	11,000	8.3	103	14,170
		2A	100	0	2.2					
				-.25	5.2	173.	12,000	29.4	120	24,850
			200	0	-					
	2A	6.3	100	0	23.7	97.	30,000	-	-	-
				-.25	17.8					
			200	0	42.3	120.	37,300	-	-	-
		5.3	100	0	34.6					
				-.25	15.3	115.	21,000	12.9	123	18,840
			200	0	10.5					
		4.3	100	0	33.1	134.	25,500	31.8	130	26,920
				-.25	26.9					
			200	0	8.4	135.	11,800	10.2	126	17,170
				0	-					
				-.25	14.2	151.	5,290	27.6	129	23,760
				-.25	-					

TABLE X1 (Continued)
CERAMIC VACUUM TUBE TEST DATA

TUBE		TEST CONDITIONS			MEASUREMENTS - ROOM TEMP			MEASUREMENTS - 500°C		
Type	Sample Number	Heater Voltage	Plate Voltage	Grid Voltage	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)
7588	1A	6.3	100	0	22.2	209	52,000	-	-	-
				-.25	10.6	187				
			200	0	56.6	215	68,000			
				-.25	38.7	215				
		5.3	100	0	12.1	228	30,000	15.0	153	37,000
				-.25	3.8					
			200	0	32.6	223	47,000	48.4	177	46,500
				-.25	18.1					
		4.3	100	0	3.2	206		12.9	163	11,850
				-.25	0.95					
			200	0	11.4	222		26.0	141	3,980
				-.25	7.0					
	2A	6.3	100	0	24.0	164	42,300	-	-	-
				-.25	7.36					
			200	0	42.6	182	53,100	-	-	-
				-.25	26.8					
		5.3	100	0	15.0	181	33,100	13.24	138	17,500
				-.25	4.02					
			200	0	33.2	187	38,300	26.9	177	25,000
				-.25	16.4					
		4.3	100	0	7.6	192	23,900	8.5	171	14,000
				-.25	1.42					
			200	0	21.0	192	28,500	14.7	140	6,000
				-.25	6.04					

A4

TABLE A1 (Continued)
CERAMIC VACUUM TUBE TEST DATA

TUBE		TEST CONDITIONS			MEASUREMENTS - ROOM TEMP			MEASUREMENTS - 500°C		
Type	Sample Number	Heater Voltage	Plate Voltage	Grid Voltage	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)
6A5	1B	6.3	100	0	4.1	303	7,360	-	-	-
			200		9.0	317	19,020	-	-	-
		5.3	100		1.47	319	2,950	5.02	187	8,420
			200		4.4	357	9,980	10.43	210	11,820
		4.3	100		0.28	305	570	2.59	252	7,210
			200		1.22	330	3,490	5.66	277	8,850
	2B	6.3	100	0	6.07	300	12,850	-	-	-
			200		10.7	359	16,160	-	-	-
		5.3	100		2.88	335	9,294	3.28	326	10,470
			200		5.86	394	11,258	6.88	343	12,340
		4.3	100		.66	359	3,590	1.57	330	6,410
			200		1.90	396	5,120	4.24	352	10,120
	3B	6.3	100	0	5.3	263	12,930	-	-	-
			200		10.9	289	17,030	-	-	-
		5.3	100		1.82	261	7,930	4.84	278	12,630
			200		5.10	303	9,920	9.59	301	15,400
		4.3	100		0.35	265	2,130	2.16	309	9,270
			200		1.12	324	1,220	5.54	324	11,580
	4B	6.3	100	0	5.71	304	10,710	-	-	-
			200		13.42	362	25,050	-	-	-
		5.3	100		1.41	330	6,290	3.71	325	13,260
			200		4.38	378	13,460	9.16	340	17,880

TABLE A1 (Continued)
CERAMIC VACUUM TUBE TEST DATA

TUBE		TEST CONDITIONS			MEASUREMENTS - ROOM TEMP			MEASUREMENTS - 500°C		
Type	Sample Number	Heater Voltage	Plate Voltage	Grid Voltage	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)	Pl. Current i_p (ma)	Amplification μ	Transcond. g_m (M-mho)
Y2191	4B	4.3	100	0	0.16	305	1,260	1.66	245	6,430
			200		0.88	353	3,490	5.42	314	9,600
	5B	6.3	100		2.10	234	7,930	-	-	-
			200		8.58	287	20,300	-	-	-
		5.3	100		0.5	234	3,050	5.18	209	16,590
			200		3.36	279	10,830	12.05	233	19,080
		4.3	100		0.1	216	570	2.71	186	11,260
			200		0.89	270	3,580	8.17	221	15,410

A6

Figure A1, Measured Plate Current, Tube 7462-1A, Room Temperature

Figure A2, Measured Plate Current, Tube 7462-1A, 500°C.

Figure A3, Measured Transconductance, Tube 7462-1A, Room Temperature

EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO. 347 L22 DIETZGEN GRAPH PAPER
LOGARITHMIC
2 CYCLES X 2 CYCLES

Figure A4, Measured Transconductance, Tube 7 62-2A, 500°C.

Figure A5, Measured Plate Current, Tube 7467-2A, Room Temperature

Figure A6, Measured Plate Current, Tube 7462-2A, 500°C.

Figure A7, Measured Transconductance, Tube 7462-2A, Room Temperature.

Figure A8, Measured Transconductance, Tube 7462-2A, 500°C.

Figure A10, Measured Plate Current, Tube 7625-1A, 500°C.

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LOGARITHMIC
2 CYCLES X 2 CYCLES
E. I. DIETZGEN CO.
MADE IN U. S. A.

Figure A11, Measured Transconductance, Tube 7625-1A, Room Temperature.

EURENE DIETZGEN CO.
MADE IN U. S. A.

NO. 341-LC DIETZGEN GRAPH PAPER
LOGARITHMIC
2 CYCLES X 2 CYCLES

Figure A12, Measured Transconductance, Tube 7625-1A, 500°C.

Figure A13, Measured Plate Current, Tube 7625-2A, Room Temperature

Figure A14, Measured Plate Current, Tube 7625-2A, 500°C

Figure A15, Measured Transconductance, Tube 7625-2A, Room Temperature

Figure A16, Measured Transconductance, Tube 7625-2A, 500°C.

Figure A17, Measured Plate Current, Tube 7296-1A, Room Temperature

Figure A18, Measured Plate Current, Tube 7296-1A, 500°C.

Figure A19, Measured Transconductance, Tube 7296-1A, Room Temperature

Figure A20, Measured Transconductance, Tube 7296-1A, 500°C.

Figure A21, Measured Plate Current, Tube 7296-2A, Room Temperature

Figure A22, Measured Plate Current, Tube 7296-2A, 500°C.

Figure A23, Measured Transconductance, Tube 7296-2A, Room Temperature

Figure A24, Measured Transconductance, Tube 7296-2A, 500°C.

Figure A25, Measured Plate Current, Tube 7588-1A, Room Temperature

Figure 26, Measured Plate Current, Tube 7588-1A, 500°C.

Figure A27, Measured Transconductance, Tube 7588-1A, Room Temperature

Figure A28, Measured Transconductance, Tube 7588-1A, 500°C.

Figure A29, Measured Plate Current, Tube 7588-2A, Room Temperature

Figure A30, Measured Plate Current, Tube 7588-2A, 500°C.

Figure A31, Measured Transconductance, Tube 7588-2A, Room Temperature

ELECTRO-DIETZGEN CO.
MADE IN U. S. A.

NO. 341-122 DIETZGEN GRAPH PAPER
LOGARITHMIC
2 CYCLES X 2 CYCLES

Figure A32, Measured Transconductance, Tube 7588-2A, 500°C.

APPENDIX B
RESISTOR TEST DATA

APPENDIX B - DALE WIRE WOUND RESISTORS ΔR_T VERSUS TIME

(ΔR_T = Percent change in resistance from 25 to 500C)

Evanohm 1K				Cupron 1K (Note 1)				Kanthal 7K		
Date	66	69	70	67	71	72	73	← Test Number		
2/9	-1.6	-1.1	-1.6	.77	.85	-.19	.85			
2/10	-1.6	-1.1	-1.6	.86	1.03	1.03	1.03			
2/11	-1.4	-.95	-1.4	-	-	.65	.65			
2/14	-1.5	-1.0	-1.5	1.26	1.4	1.5	1.5			
2/15	-1.4	-1.0	-1.3	1.36	1.51	1.50	1.5			
2/16	-1.5	-1.0	-1.4	1.35	1.70	1.60	1.6			
2/17	-1.3	-.76	-1.2	.58	.65	.65	.65			
2/21	-	-.76	-	.29	.47	.46	.42			
2/22										
2/23										
2/25	-1.2	-.7	-1.2	.9	.9	1.0	1.1			
2/28	-.7	-.4	-.8	-.1	-.1	-.1	-.1			
3/1	-1.0	-.7	-1.0	.3	.5	.5	.5			
3/2	-1.2	-	-1.3	.3	.5	.5	.6			
3/3	-1.0	-.4	-1.0	.2	.5	.5	.5			
3/4	-1.3	-.4	-1.0	.3	.4	.5	.3			
3/7	-1.3	-.476	-1.13	-.573	-.74	-.83	-.83			
3/8	-.851	-.76	-.757	.765	.83	.83	.92			
3/9	-.99	-.48	-.76	.38	.92	.64	.64			
3/10	-.76	-.38	-.75	.48	1.11	.73	.73			
3/11	-.67	-.38	-.67	.57	.92	.92	1.01			
3/4	-.96	.09	-.86	.57	.82	.82	.82			
3/15	-.96	-.28	-.29	.47	.64	.82	.83	Test Number		
3/16	-.96	-.28	-.57	.18	.55	.55	.64	24	25	26
3/17	-.38	-.19	-.38	.37	.55	.55	.55	Coating		
3/18	-.38	-.09	-.29	.47	.82	.73	.82	none	thin	thick
3/21	-.38	-.09	.29	.57	.82	.81	-	-1.63	-1.73	1.34
3/22	-.09	-.19	-.09	.09	.46	.45	.36	-.08	-.08	.03
3/23	-.09	-.09	0	.76	.91	1.00	1.00	.1414	-.1557	-.0706
3/24	-.096	.096	-.096	.47	.63	.73	.73	.06	-.28	-.14
3/25	-.19	.096	-.096	.18	.55	.54	.54	.071	-.23	.26
3/28	.096	.29	.096	.37	.64	.72	.72	-.042	-.24	-.24
3/29	-.096	.29	0	-5.0	.181	.27	.27	.028	-.25	-.14
3/30	.096	.38	.10	.28	.45	.45	.54	.057	-.28	-.20
3/31	0	Open	Open	0	.36	.36	.37	.07	-.33	-.21
4/1	0	.10	.10	.10	.18	.27	.36	.63	.16	.27
4/4	0	.10	.10	1.05	1.6	1.2	1.3	.33	-.10	-.04
4/7	Board removed			.47	.73	.72	.72			

Note 1. All + except as noted.

Appendix B (Continued)

Caddock and Omnitronics Resistors ΔR_T Versus Time

(ΔR_T = Percent change in resistance from 25 to 500°C)

Caddock, Flat, Thick Film, Coated			Omnitronics WW Coated		Caddock, Cyl. Thick Film, Uncoated			
Test #	→	68A	75	74			71	81
Start Date		12/20	1/12	Date	10KΩ	Date	28KΩ	317KΩ
Resistance Ω		22K	500K	12/20	1.4	2/9	5.4	
Day No.		ΔR _T , %		12/21	- 1.1	2/10	5.4	
1		2.6	3.7	12/22	- 1.6	2/11	5.4	6.9
2		2.2	2.3	12/23	- 2.1	2/14	5.5	9.4
3		.90	.50	12/28	- 2.2	2/15	5.6	6.9
4		0	-	12/29	- 2.1	2/16	5.9	9.2
5		0	5.2	1/4	- 2.7	2/17	4.3	4.9
6		-	.50	1/5	- 2.6	2/21	1.2?	3.9
7		9.4	1.0	1/6	- 2.6	2/25	4.9	-
8			1.0	1/7	- 2.6	2/28	4.5	-
9			1.1	1/12	- 2.6	3/1	4.7	-
10			2.1	1/13	- 2.7	3/2	5.2	2.1
11			.8	1/14	- 2.7	3/3	5.2	- .6
12			6.9	1/17	-	3/4	5.2	- .7
13			33	1/18	- 2.2	3/7	4.8	- 4.8
14			19	1/19	- 2.7	3/8	5.1	- 3.2
15			19	1/20	- 2.6	3/9	5.0	- 3.8
16			29	1/21	- 2.4	3/10	4.9	- 2.3
17			25	1/24	- 2.9	3/11	5.1	- 2.2
18			33	1/25	- 2.8	3/14	5.0	- 7.8
19				1/26	- .10	3/15	4.8	-10.3
20				1/27	- 2.3	3/16	4.8	-10.3
21				1/28	- 2.5	3/17	4.7	-11.0
22				1/31	- 2.6	3/18	4.5	-10.4
23				2/1	- 2.7	3/21	4.7	- 9.3
24				2/3	- 2.5	3/22	4.5	-13.8
25				2/4	- 2.2	3/23	4.3	- 9.9
26				2/7	- 2.6	3/24	4.2	-19.2
27				2/8	- 2.6	3/25	4.2	-20.7
28				2/9	- 2.4	3/28	3.4	-20.7
29						3/29	3.9	-23.7
30						3/30	4.0	-32.0
31						3/31	3.9	-29.0
32						4/1	4.0	-32.0
33						4/4	4.0	-23.9
34						4/7	-	-27.1
35						4/8	4.2	-

APPENDIX C
CAPACITOR TEST DATA

APPENDIX C - CAPACITOR TEST DATA

ΔC_T = % change in capacitance from 25 - 500°C

DF = Dissipation factor at 500°C, percent

Date	Sandia thick film No. 68		Sandia thick film No. 78		El Menco mica No. 65		Semetex BN/Au #76		El Menco mica #80	
	ΔC_T	DF	ΔC_T	DF	ΔC_T	DF	ΔC_T	DF	ΔC_T	DF
12/29	5.9?	-								
1/4	69	31								
1/5	61	31								
1/10	58	32								
1/12	62	34								
1/13	57	32								
1/14	56	32								
1/18	55	50?			7.5	7.6				
1/19	57	37			6.4	7.7				
1/21	52	33			4.7	7.5	-61	1.6		
1/24	57	34			-5 ?	8.1	-43	-		
1/25	62	35	54	37	2.7	8.3	-4.5	1.0		
1/26	65	37	74	37	20?	9.5	48	1.4		
1/27	63	34	70	38	7.8	10	15	1.2		
1/28	66	37	71	38	-1.0	9.5				
1/31	68	35	66	37	-1.0	9.5				
2/1	65	37	69	39	11.7	9.4				
2/3	64	37	66	38	5.8	9.5				
2/4	55	35	63	37	15	7				
2/7	67	35	70	37	13	10	El Menco mica #79			
2/8	63	37			8	15				
2/9	63	37	61	38	24	15	26	11	16	6.7
2/10	64	38	61	39	17	17	7	15	25	21
2/11	63	38	65	39	20	21	16	27	17	20
2/14	64	38	65	39	18	21	28	40	19	19
2/15	62	38	65	39	34	29	33	38	26	20
2/16	63	38	65	39	36	35	36	40	22	20
2/17	58	37	65	40	129	70	53	44	27	19
2/21	62	37	-	-					Simmonds mica #1 No. 80A	
2/25	61	36	65	38					28	16
2/28	51	33							28	15
3/1	56	35							36	20
3/2	59	35							37	20
3/3	59	35							37	20
3/4	58	35							36	20
3/7	60	35							38	21
3/8	61	36							45	25
3/9	63	38							48	26
3/10	68	39							48	26
3/11	68	39							46	27
3/14	68	39							46	26
3/15	68	39							50	27
3/16	69	39							51	28
3/17	68	39							51	28
3/18	69	39							-	-
3/21	70	40							49	26*
3/22	72	40							Simmonds mica #2 No. 80B	
3/23	72	40							36	19
3/24	61	37							34	18
3/25	60	38							26	35
3/28	60	39							36	24
3/29	64	35							35	26
3/30	59	34							36	16
3/31	55	37							36	16
4/1	55	37							36	16
4/4	55	37							35	16
4/12	59	38							51	30*

* Hermetic seal was found to be leaking when tested by immersing in hot water.

APPENDIX D

MISCELLANEOUS COMPONENT TEST DATA

Component Test Record - Chronological Order

Test No.	R or C	Component	Valued R or C	Start Test	End Test
65	C	El Menco mica cap #1.	67 Pf.	1/18	2/17
66	R	Dale Evanohm res.	1 K Ω	1/18	ST*
67	R	Dale Cupron w w res.	1 K Ω	12/14	ST
68A	R	Caddock thick film, coated, #1.	22 K	12/20	1/10
68B	C	Sandia thick film cap. #2	10 ³ Pf.	12/29	ST
69	R	Dale Evanohm w w res.	1 K Ω	1/18	ST
70	R	Dale Evanohm w w res.	1 K Ω	1/18	ST
71	R	Dale Cupron w w res.	1 K Ω	12/16	ST
72	R	Dale Cupron w w res.	1 K Ω	12/16	ST
73	R	Dale Cupron w w res.	1 K Ω	12/16	ST
74	R	Omitronics w w res.	10 K Ω	12/20	2/10
75	R	Caddock thick film, coated, #2.	500 K	1/12	2/9
76	C	Semetex BN/Au Capac.		1/20	1/28
77	R	Caddock thick film res. (cyl. #1).	28 K	1/21	ST
78	C	Sandia thick film cap. #21	10 ³ Pf.	1/25	2/21
79	C	El Menco mica cap #2		2/9	2/21
80	C	El Menco mica cap #3		2/9	2/21
81	R	Caddock thick film, res. (cyl. #2)	317 K	2/11	4/4
82	R	Hoskins Mfg. Co. alloy 815 res. wire.	12 Ω	2/17	4/4
65A	C	El Menco capac. thin coat	60 Pf.	2/25	2/26
79A	C	El Menco capac. thick coat	60 Pf.	2/25	2/26
80A	C	Simmonds capac. #1	.03 Mfd.	2/25	3/22
-	-	3 Continental insul. wire samples	-	3/8	ST
-	-	Res. test of 6" dia. Mykroy disc.		3/14	3/16
-	-	Res. test of Simmonds 2 pin connector		3/21	ST
65B	C	El Menco capac. new coating		3/15	3/15
79B	C	El Menco capac. new coating		3/15	3/15

*ST = Still testing as of 4/8

Component Test Record - Chronological Order (Cont'd)

Test No.	R or C	Component	Valued R or C	Start Test	End Test
24	R	Dale Kanthal A-1, no coating		3/21	ST
25	R	Dale Kanthal A-1, thin coat		3/21	ST
26	R	Dale Kanthal A-1, thick coat		3/21	ST
-	-	Res. test, Swagelok/Insul. wire		3/21	ST
-	-	Res. test, 2 insulated wires in paral.		3/21	ST
<u>Inert Gas Test Fixture</u>					
80B	C	Simmonds cap. #2	.03 Mfd.	3/23	ST
0	C	Simmonds cap. #3	.03 Mfd.	4/7	4/8
9	C	Simmonds cap. #4	.03 Mfd.	4/7	4/8
1	R	Caddock thick film res. }	30 K	4/7	4/8
2	R	Caddock thick film res. }	30 K	4/7	4/8
4	R	Caddock thick film res. }	30 K	4/7	4/8
8	R	Caddock thick film res. }	30 K	4/7	4/8
6	R	Caddock thick film res., flat		4/7	4/8
3	R	Caddock thick film res., flat		4/7	4/8