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REPORT NO. BPAD-863-4-15096 R

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**PERFORMANCE REPORT
OF
BREADBOARD SYSTEM AMPLIFIER PACKAGE - S/N2**

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Contract No. NP-2
Under SNP-1

Report No. BPAD 863-4-15096R

PERFORMANCE REPORT

OF

BREADBOARD SYSTEM AMPLIFIER PACKAGE - S/N 2

SEPTEMBER 1963

Submitted To

Aerojet-General Corporation
Azusa, California

By

The Bendix Corporation
Bendix Products Aerospace Division
South Bend, Indiana

Prepared Under
Direction of:

B. W. Howard
Project Engineer

Approved by:

A. J. Wetzel
Project Supervisor

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JUN 2 1964

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SECTION 1

AMPLIFIER IDENTIFICATION

The S/N 2 Breadboard System Package differs from the S/N 1 Package in that the amplifiers contain radiation tolerant components throughout. Because of these changes, new part numbers and model numbers were assigned. A detailed description of these modifications is contained in Section II of this report. Table I lists the applicable document numbers pertaining to the S/N 2 System Amplifiers.

The following abbreviations are used throughout this report for amplifier identification:

TSA - Temperature Signal Amplifier
TCA - Temperature Control Amplifier
PSA - Pressure Signal Amplifier
PCA - Pressure Control Amplifier

TABLE I

SYSTEM AMPLIFIERS - MODEL AND PART NUMBERS

<u>Amplifier</u>	<u>Model No.</u>	<u>Part No.</u>	<u>S/N</u>	<u>Schematic</u>
TSA	EW-A1	2775000-2	2	2779118
TCA	None	2775002-2	2	2779119
PSA	EP-A1	2775001-2	2	2779121
PCA	EC-A1	2775003-2	2	2779120

SECTION II

DESCRIPTION OF SYSTEM AMPLIFIERS

2.1 Introduction

The electrical circuit and theory of operation for each of the four system amplifiers is contained in Section V of Report No. BPAD-863-4-15076R entitled "Design and Development of Breadboard System Amplifier, S/N 1 System Package".

This report describes the modifications included in the design and fabrication of the second breadboard package to upgrade the amplifiers to the radiation tolerant configuration.

Four major modifications have been included in the S/N 2 breadboard package, they are:

- (1) Substitution of the radiation tolerant UG-59 diode for the 1N485B conventional silicon device.
- (2) The replacement of the standard AN-3102-22-19P receptacle with a radiation tolerant Deutsch Type MDROO-540-19P receptacle.
- (3) Inclusion of copper-constantan thermocouples in and on the various amplifier components for determination of gamma heating effects.
- (4) Replacement of the gain and rate potentiometers with selected wire-wound resistors.

2.2 Diodes

The radiation tolerant UG-59 diode is a developmental unit manufactured by Texas Instruments, Inc., Dallas, Texas, specifically for the NERVA application under Bendix P/N 2775436 and Engineering Instruction CNPD-129. This diode is a thin based, PIN type construction

in which the P and N layers are heavily doped to minimize the effects of nuclear radiation upon diode performance characteristics. The performance of the UG-59 under radiation was verified in December 1962 at the Western New York Nuclear Research Center in Buffalo and, more recently, in the Ground Test Reactor at Fort Worth, Texas in May 1963. The experimental test data confirmed that the device performs in accordance with the specification out to 10^{16} nvt and, further, that manufacturing processes could be repeated since samples representing two production orders were tested. The results of the GTR test are given in Reference (1) below and the data obtained in the December 1962 test are reported in Reference (2) below.

- (1) Bendix Products Aerospace Division Report No. 863-4-14993R dated 19 June 1963.
- (2) Westinghouse Astronuclear Laboratory Report TME-250 dated 16 January 1963.

In addition to the two radiation tests mentioned previously, all UG-59 diodes are tested at room temperature and again at $+125^{\circ}$ C for forward voltage at 250 ma and reverse current leakage with 100 volts applied in the back direction. Further, complete serialization is maintained to allow comparison of post-radiation test data with the original diode performance. Table II lists the serial number of the diode and the amplifier and stage in which it has been installed. Bendix drawings 2779118 through 2779121 identify the diode symbol numbers and location. The schematic diagrams of the system amplifiers are shown in Figures 1 through 4.

TABLE II

UG-59 DIODE UTILIZATION CHART

<u>Amplifier & Part No.</u>	<u>Model No.</u>	<u>S/N</u>	<u>Stage & Symbol</u>		<u>Diode S/N</u>
PSA 2775001-2	EP-A1	2	AR-1	CR-1	65
			AR-1	CR-2	63
			AR-1	CR-3	64
			AR-1	CR-4	66

TABLE II (continued)
UG-59 DIODE UTILIZATION CHART

<u>Amplifier & Part No.</u>	<u>Model No.</u>	<u>S/N</u>	<u>Stage & Symbol</u>		<u>Diode S/N</u>
PCA 2775003-2	EC-A1	2	AR-1	CR-1	28
			AR-1	CR-2	26
			AR-1	CR-3	27
			AR-1	CR-4	29
			AR-2	CR-5	35
			AR-2	CR-14	36
			AR-2	CR-6	30
			AR-2	CR-15	31
			AR-2	CR-7	33
			AR-2	CR-16	32
			AR-2	CR-8	38
			AR-2	CR-17	37
			AR-3	CR-9	41
			AR-3	CR-10	39
			AR-3	CR-11	40
			AR-3	CR-12	42
			Output	CR-13	34
TSA 2775000-2	EW-A1	2	AR-1	CR-1	45
			AR-1	CR-2	43
			AR-1	CR-3	44
			AR-1	CR-4	46
			AR-2	CR-9	47
			AR-2	CR-10	48
			AR-2	CR-11	49
			AR-2	CR-12	50
			AR-3	CR-5	51
			AR-3	CR-6	52
			AR-3	CR-7	53
			AR-3	CR-8	54
			AR-4	CR-13	55
			AR-4	CR-14	56
			AR-4	CR-15	57
			AR-4	CR-16	58
			AR-5	CR-17	61
			AR-5	CR-18	59
			AR-5	CR-19	60
			AR-5	CR-20	62

TABLE II (continued)
UG-59 DIODE UTILIZATION CHART

<u>Amplifier & Part No.</u>	<u>Model No.</u>	<u>S/N</u>	<u>Stage & Symbol</u>		<u>Diode S/N</u>
TCA 2775002-2		2	AR-1	CR-1	71
			AR-1	CR-10	72
			AR-1	CR-2	67
			AR-1	CR-4	68
			AR-1	CR-3	70
			AR-1	CR-12	69
			AR-1	CR-4	74
			AR-1	CR-13	73
			AR-2	CR-5	78
			AR-2	CR-6	76
			AR-2	CR-7	77
			AR-2	CR-8	79
			Output	CR-9	75

The initial base line data for the UG-59 diodes include leakage current and diode forward drop at 25° C and the leakage current taken at +125° C. This data is included, should a post-irradiation evaluation test of the diodes be performed. Additional base line data, not shown in this report but recorded, are reverse breakdown voltage and the breakdown voltage slope.

TABLE III
UG-59 DIODE PERFORMANCE - PRE-INSTALLATION

<u>Diode S/N</u>	<u>V_f (250 ma)</u>	<u>I_R (100 V) 25° C</u>	<u>I_R (100 V) 125° C</u>
26	.889 volts	.062 μ amps	.94 μ amps
27	.929 volts	.001 μ amps	.30 μ amps
28	.899 volts	.001 μ amps	.30 μ amps
29	.899 volts	.010 μ amps	.70 μ amps
30	.929 volts	.001 μ amps	.30 μ amps
31	.890 volts	.025 μ amps	.46 μ amps

TABLE III (continued)

UG-59 DIODE PERFORMANCE - PRE-INSTALLATION

Diode S/N	V_f (250 ma)	I_R (100 V) 25° C	I_R (100 V) 125° C
32	.911 volts	.017 μ amps	.50 μ amps
33	.909 volts	.009 μ amps	.36 μ amps
34	.889 volts	.001 μ amps	.25 μ amps
35	.901 volts	.047 μ amps	1.20 μ amps
36	.922 volts	.014 μ amps	.50 μ amps
37	.882 volts	.007 μ amps	.40 μ amps
38	.879 volts	.007 μ amps	.40 μ amps
39	.879 volts	.002 μ amps	.32 μ amps
40	.889 volts	.003 μ amps	.30 μ amps
41	.939 volts	.020 μ amps	.49 μ amps
42	.909 volts	.045 μ amps	.87 μ amps
43	.910 volts	.025 μ amps	.72 μ amps
44	.889 volts	.066 μ amps	1.00 μ amps
45	.919 volts	.004 μ amps	.50 μ amps
46	.901 volts	.021 μ amps	.50 μ amps
47	.920 volts	.007 μ amps	.51 μ amps
48	.909 volts	.001 μ amps	.30 μ amps
49	.881 volts	.002 μ amps	.50 μ amps
50	.911 volts	.001 μ amps	.44 μ amps
51	.869 volts	.001 μ amps	.52 μ amps
52	.921 volts	.039 μ amps	.82 μ amps
53	.901 volts	.010 μ amps	.68 μ amps
54	.870 volts	.058 μ amps	.83 μ amps
55	.899 volts	.003 μ amps	.43 μ amps
56	.919 volts	.013 μ amps	.61 μ amps
57	.900 volts	.001 μ amps	.44 μ amps
58	.919 volts	.023 μ amps	1.15 μ amps
59	.889 volts	.001 μ amps	.47 μ amps
60	.889 volts	.006 μ amps	.60 μ amps
61	.900 volts	.006 μ amps	.55 μ amps
62	.889 volts	.058 μ amps	.78 μ amps
63	.911 volts	.008 μ amps	.52 μ amps
64	.929 volts	.002 μ amps	.47 μ amps
65	.870 volts	.008 μ amps	.54 μ amps
66	.911 volts	.003 μ amps	.50 μ amps
67	.889 volts	.001 μ amps	.44 μ amps
68	.905 volts	.036 μ amps	1.00 μ amps

TABLE III (continued)

UG-59 DIODE PERFORMANCE - PRE-INSTALLATION

Diode S/N	V _f (250 ma)	I _R (100 V) 25° C	I _R (100 V) 125° C
69	.880 volts	.030 μ amps	.91 μ amps
70	.889 volts	.004 μ amps	.22 μ amps
71	.890 volts	.026 μ amps	.45 μ amps
72	.881 volts	.019 μ amps	.28 μ amps
73	.902 volts	.034 μ amps	.34 μ amps
74	.919 volts	.001 μ amps	.12 μ amps
75	.939 volts	.011 μ amps	.19 μ amps
76	.889 volts	.042 μ amps	.41 μ amps
77	.911 volts	.002 μ amps	.17 μ amps
78	.910 volts	.003 μ amps	.26 μ amps

2.3 Radiation Tolerant Receptacle

The standard MS receptacle used on the S/N 1 amplifiers has been replaced with a Deutsch Type MDR00-540-19P receptacle. This component utilizes a diallyl phthalate insert material which exhibits a high insulation resistance under nuclear radiation. This material has been tested and data reported in WANL TM-250 dated 16 January 1963.

The construction of the receptacle requires that the lead wires be attached to the individual pins and the pins inserted using a special tool supplied by the manufacturer. The insert tool is Deutsch P/N M15513-20. Another special tool, Deutsch P/N M15515-20, is used for removing the pins from the insert.

2.4 Thermocouple Instrumentation

Copper-constant thermocouples have been mounted in and on representative components in each of the system amplifiers to obtain temperature rise caused by gamma heating. The couples are made from No. 30 AWG wire and the hot junction is in direct contact with the point of measurement. This, in many cases, causes the "hot" junction to be at electrical ground potential and requires a balanced, floating input type thermocouple recorder. Table IV lists the thermocouple identification number and the point of measurement.

TABLE IV
THERMOCOUPLE INSTRUMENTATION

<u>Amplifier</u>	<u>TC Number</u>	<u>Location</u>
PSA	1	AR-1 Core
	2	Terminal Board Between AR-1 and T-1
	3	T-1 Power Transformer Core
	4	Body of 22 μ FD Capacitor C-2
PCA	1	AR-1 Core
	2	AR-2 Core
	3	Terminal Board Between Rate Trans- former and AR-1
	4	Power Transformer Core
	5	Rate Transformer Core
	6	Rate Transformer Winding
	7	Body of 100 μ FD Capacitor C-4
	8	Body of 500-ohm Resistor R-13
TSA	1	AR-1 Core
	2	AR-2 Control Winding
	3	AR-5 Core
	4	Terminal Board
	5	Power Transformer Core
	6	Body of 22 μ FD Capacitor C-2
TCA	1	AR-1 Core
	2	AR-2 Core
	3	Terminal Board
	4	Power Transformer Core
	5	Rate Transformer Core
	6	Rate Transformer Case
	7	Body of 100 μ FD Capacitor C-4
	8	Body of 500-ohm Resistor R-8

2.5 Gain and Rate Adjustment

The gain and rate trim potentiometers used in the S/N 1 system amplifiers have been replaced with precision wire-wound resistors with a value which provides nominal steady state and rate gains. These changes are noted on the schematic diagrams shown in Figures 1 through 4.

FIGURE 1 PRESSURE SIGNAL AMPLIFIER - SCHEMATIC DIAGRAM

FIGURE 2

FIGURE 3 TEMPERATURE SIGNAL AMPLIFIER - SCHEMATIC DIAGRAM

FIGURE 4 TEMPERATURE CONTROL AMPLIFIER - SCHEMATIC DIAGRAM

2.6 Construction and Component Arrangement

The amplifier construction is similar to the S/N 1 amplifiers with the exception of the thermocouple installation. At least 18 inches of lead wire is provided for making thermocouple connections to the main test cable. Figures 5 through 13 show amplifier construction, component location, and identification of magnetic stages for each of the four amplifiers.

FIGURE 5 PRESSURE SIGNAL AMPLIFIER ASSEMBLY

FIGURE 6 PRESSURE SIGNAL AMPLIFIER COMPONENT ARRANGEMENT

FIGURE 7 PRESSURE CONTROL AMPLIFIER ASSEMBLY

FIGURE 8 PRESSURE CONTROL AMPLIFIER COMPONENT ARRANGEMENT

FIGURE 9 TEMPERATURE SIGNAL AMPLIFIER ASSEMBLY

FIGURE 10 TEMPERATURE SIGNAL AMPLIFIER COMPONENT ARRANGEMENT

FIGURE 11 TEMPERATURE CONTROL AMPLIFIER ASSEMBLY

FIGURE 12 TEMPERATURE CONTROL AMPLIFIER COMPONENT ARRANGEMENT

FIGURE 13 TEMPERATURE CONTROL AMPLIFIER - BOTTOM VIEW

SECTION 3

AMPLIFIER PERFORMANCE DATA

Amplifier performance data was taken over the temperature range from -260°F to $+260^{\circ}\text{F}$. Although these amplifiers are of the breadboard design, this data provides an indication of the magnitude of temperature compensation which will be required by the later designs. It also substantiates the fact that no permanent damage occurred due to the cold soak test at -260°F . This is of particular importance since most component manufacturers do not have environmental test data below -65°F .

3.1 Pressure Signal Amplifier

The rated output voltage of the PSA amplifier is equal to the closed loop amplifier gain times the potentiometer output voltage at rated chamber pressure and is 5.76 volts. The null drift percentage shown on the performance chart is based upon the 5.76-volt value. The deviation percentage from linearity is also calculated using this reference.

TABLE V

PSA PERFORMANCE DATA

Ambient Temp. $^{\circ}\text{F}$	75 $^{\circ}\text{F}$			+250 $^{\circ}\text{F}$			-260 $^{\circ}\text{F}$		
Line Voltage	103	115	127	103	115	127	103	115	127
Line Frequency	360	400	440	360	400	440	360	400	440
Null Voltage - mv (input volts for zero output)	-2.1	+1.2	+2.6	-3.0	-1.4	+0.5	+4.1	+3.5	+1.8
Gain - volts/volt (at +4.0 volts output)	1.31	1.31	1.32	1.31	1.31	1.31	1.31	1.31	1.32
Linearity - % Rated Output	0.17	0.21	0.20	0.18	0.15	0.15	0.08	0.08	0.10
Saturation Level - volts	8.65	9.65	10.9	8.1	9.1	9.8	12.0	13.1	14.2

PSA PERFORMANCE DATA

Input Impedance	
Operating	50,000 ohms minimum
Non-Operating	8,000 ohms
Output Impedance	
Operating	12 ohms
Frequency Response	3 db down at 19.5 cps
Ripple Voltage (Reflected to 10-ohm command source)	4.0 millivolts
Power Consumption	
Zero Signal	1.8 watts
At Saturation	2.5 watts
Weight	1.35 pounds
Size	4" x 5" x 3"
Receptacle	Deutsch MDR00-540-19P

Figure 14 illustrates deviation from true linearity as a function of output voltage at 115 volts and 400 cps. Deviation curves taken at -260° F and +250° F are similar in characteristics although maximum deviations may differ as well as the axis cross-over. Figure 15 shows the PSA Input-Output Characteristic and the effect of line voltage variation on amplifier saturation level.

3.2 Temperature Signal Amplifier

The temperature signal amplifier generates an output voltage proportional to the average value of four input signals derived from resistance thermometers connected in a bridge circuit as shown in Figure 16. The output voltage of the amplifier is dependent upon the bridge impedance and bridge excitation voltage. The amplifier gain shown in Table VI was measured using the equivalent bridge impedance of the network shown in Figure 16. The X-Y linearity plot shown in Figure 17 indicates a 15% higher gain than shown in Table VI and is due to the lower impedance of the ramp voltage generator used in the linearity test.

FIGURE 14 PRESSURE SIGNAL AMPLIFIER LINEARITY DEVIATION

FIGURE 15 PRESSURE SIGNAL AMPLIFIER INPUT-OUTPUT CHARACTERISTIC

TABLE VI
TSA PERFORMANCE DATA

Ambient Temp. °F	75°F			+250°F			-260°F		
Line Voltage	103	115	127	103	115	127	103	115	127
Line Frequency	360	400	440	360	400	440	360	400	440
Null Voltage - mv (input volts for zero output)	+ .47	+ .15	+ .08	+4.0	- .77	.00	+5.4	+4.6	+4.2
Gain - volts/volt (at 4.0 volts output)	1.30	1.30	1.30	1.30	1.30	1.30	1.25	1.25	1.26
Linearity - % Rated Output	±.07	±.05	±.06	±.15	±.08	±.08	±.25	±.16	±.11
Saturation Level - volts	8.95	10.0	11.3	8.6	9.85	10.0	9.6	11.0	11.0

TSA PERFORMANCE DATA

Input Stage Gain (volts/volt)	Channel #1 (AR-1) 1.047 Channel #2 (AR-2) 1.049 Channel #3 (AR-3) 1.010 Channel #4 (AR-4) 1.047
Input Impedance	6000 ohms/channel
Output Impedance	2.54 ohms
Frequency Response	3 db at 47 cps
Ripple Voltage (Reflected to 10-ohm command source)	5.75 millivolts
Power Consumption Zero Signal	1.8 watts
Saturation	2.2 watts
Weight	2.8 pounds
Size	6" x 3.5" x 8"

R_T VARIES FROM 100 OHMS (300°R) TO 1250 OHMS (4000°R)

FIGURE 16 TEMPERATURE SIGNAL AMPLIFIER TEMPERATURE PROBE SIMULATION CIRCUIT

FIGURE 17 TEMPERATURE SIGNAL AMPLIFIER INPUT-OUTPUT CHARACTERISTIC

The averaging capability of the TSA amplifier was measured for several simulated input temperatures in accordance with Table VII.

TABLE VII
TSA AVERAGING PERFORMANCE DATA
GAIN OF 1.3 VOLTS/VOLT

Simulated Probe Resistance	Amplifier Output Voltage		Deviation Volts
	Measured	Theoretical	
100 ohms each	.0009	0	+.0009
400 ohms each	2.07	2.00	+.07
*1250 ohms each	6.50	6.50	0
2 at 100 ohms			
2 at 1250 ohms	3.25	3.55	-.30

* Calibration Point

3.3 Pressure Control Amplifier

The static characteristics and frequency response of the pressure control amplifier were determined at -260, +75, and +250° F. The results of this test are presented in Tables VIII and IX and in Figures 18, 19, and 20.

TABLE VIII
PCA PERFORMANCE DATA

Ambient Temperature	+75° F			+250° F			-260° F		
Line Voltage	103	115	127	103	115	127	103	115	127
Line Frequency	360	400	440	360	400	440	360	400	440
Input Millivolts For Zero Output	.67	.34	-.13	-.59	1.2	-1.7	1.5	1.2	1.2
Velocity Constant Volts/Sec./Volt	20.6	21.3	20.6	27.5	27.5	28.1	12.5	12.5	12.5
Saturation Voltage	10.5	11.8	12.9	11.0	12.0	13.5	13.7	15.2	17.0
Negative Clamping Voltage	-.79	-.79	-.79	-.63	-.63	-.63	-1.05	-1.05	-1.05

TABLE IX
PCA ELECTRICAL & MECHANICAL REQUIREMENTS

<u>Item</u>	<u>Measured</u>	<u>Required</u>
Input Impedance	1160 ohms	1000 ohms minimum
Output Impedance	-50 ohms	Less than 25 ohms
Ripple Voltage (Reflected to 10-ohm command source)	14 millivolts	10 millivolts maximum
Power Dissipation		
Null	3 watts	5 watts maximum
Saturation	5 watts	5 watts maximum
Weight	3.55 pounds	2-pound goal
Volume	168 in. ³	100 in. ³ goal

Figure 18 shows the frequency response of the PCA at 25° C for maximum and minimum rate settings compared with the calculated response of the desired transfer function. Figure 19 illustrates the change in amplifier response over the temperature range from -260° F to +75° F. The rate gain adjustment was replaced by a fixed 1000-ohm resistor which provides a rate gain of 21.75 volts/second/volt at 25° C. The design target is 22.0 volts/second/volt. Figure 20 shows the dynamic linearity of the PCA using the test circuit illustrated in Figure 17 of Report No. BPAD 863-4-15076R.

The initial specification for the PCA transfer function was a lag-lead having a characteristic as shown in equation (1) below.

$$(1) \quad \frac{e_{out}}{e_{in}} = K \frac{(1 + .107 S)}{(1 + 60 S)^*} \quad * 60 \text{ Seconds Minimum}$$

Referring to the dashed curve shown in Figure 18, the actual characteristic is defined by equation (2).

$$(2) \quad \frac{e_{out}}{e_{in}} = K \frac{(1 + .132 S)}{(1 + 106 S)}$$

FIGURE 18 PRESSURE CONTROL AMPLIFIER FREQUENCY RESPONSE RANGE AT +75° F

FIGURE 19 PRESSURE CONTROL AMPLIFIER FREQUENCY RESPONSE AT -260° F

FIGURE 20 PRESSURE CONTROL AMPLIFIER DYNAMIC LINEARITY

3.4 Temperature Control Amplifier

The TSA amplifier performance was measured at -260° F, +75° F, and +250° F. Static performance data are presented in Table X and the amplifier frequency response at +75° F is shown in Figure 21. The dotted curve is the linearized Bode plot of the desired amplifier transfer function. Table XI lists the electrical and mechanical design requirements of the TSA amplifier.

TABLE X

TCA PERFORMANCE DATA

Ambient Temperature	+75°F			+250°F			-260°F		
Line Voltage	103	115	127	103	115	127	103	115	127
Line Frequency	360	400	440	360	400	440	360	400	440
Input Millivolts For Zero Output	8.0	49.0	16.0	27.0	72.0	120.0	400.0	580.0	810.0
Velocity Constant Volts/Sec./Volt	.201	.201	.201	.279	.335	.305	.052	.041	.038
Saturation Voltage	11.7	13.2	14.7	10.8	12.2	13.6	13.0	14.0	15.0
Negative Clamping Voltage	-.76	-.77	-.78	-.61	-.62	-.63	-.99	-.99	-1.00

TABLE XI

TCA ELECTRICAL & MECHANICAL REQUIREMENTS

<u>Item</u>	<u>Measured</u>	<u>Required</u>
Input Impedance	4800 ohms	1000 ohms minimum
Output Impedance	0.8 ohms	Less than 25 ohms
Ripple Voltage (Reflected to 10-ohm command source)	8 mv	10 mv maximum
Power Dissipation		
Null	4 watts	5 watts maximum
Saturation	5 watts	5 watts maximum
Weight	4.84 pounds	2-pound goal
Volume	168 in. ³	100 in. ³ goal

FIGURE 21 TEMPERATURE CONTROL AMPLIFIER FREQUENCY RESPONSE AT +75° F

Figure 22 shows the dynamic linearity of the TCA amplifier using the test circuit described in Report No. BPAD 863-4-15076R, Figure 20.

The comparison of the generated transfer function shown in Figure 21 and the specified transfer function are shown in equations (1) and (2) respectively.

(1) GENERATED TRANSFER FUNCTION

$$\frac{e_{out}}{e_{in}} = K \frac{(1 + 3.4 S)}{(1 + 93 S)}$$

(2) SPECIFIED TRANSFER FUNCTION

$$\frac{e_{out}}{e_{in}} = K \frac{(1 + 4.07 S)}{(1 + 60 S)^*}$$

* 60 Seconds Minimum

FIGURE 22 TEMPERATURE CONTROL AMPLIFIER DYNAMIC LINEARITY