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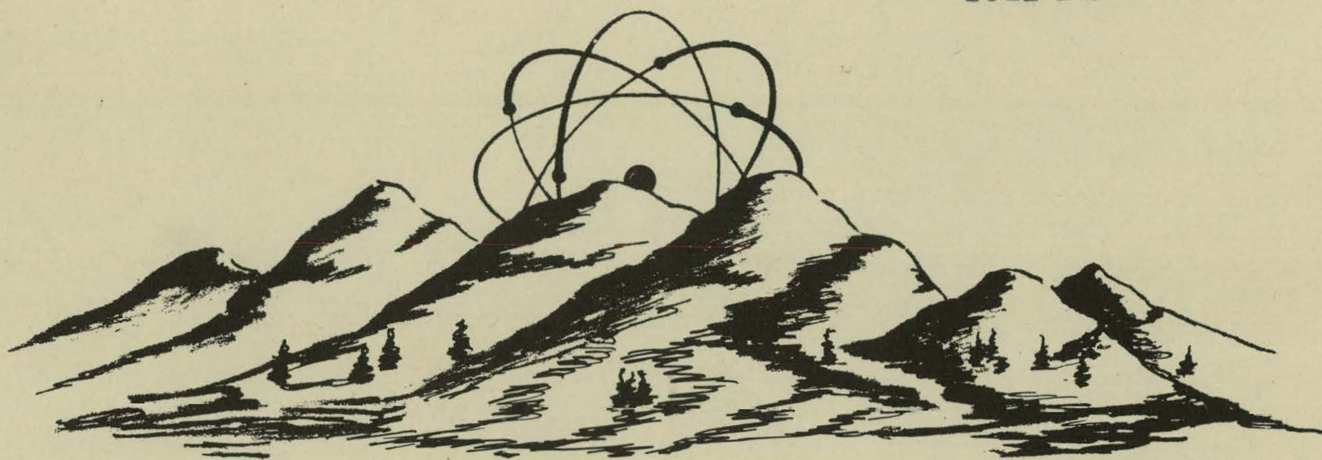

A STUDY OF THERMISTOR STABILITY

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THE DOW CHEMICAL COMPANY
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80402
U. S. ATOMIC ENERGY COMMISSION
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ABSTRACT

This study was performed to verify the stability of available thermistors that are claimed by the manufacturer to have excellent stability.

Two Fenwall GB31J1 thermistors were used and were determined to be stable within the accuracy required normally for use with accurate readout equipment.

SUMMARY

A long term test, covering a period of 84 days, was performed to verify manufacturer's statements concerning the stability of thermistors. It was necessary to obtain a very stable d.c. power supply and a zone that was under precise temperature control. Two crystal ovens were used and a stable 28 volt d.c. power supply was built to operate them. The stability of the thermistors was to be checked approximately at room temperature as this is the temperature of expected use. Therefore, one oven was set for a temperature of 20°C (68°F) and the other oven for 30°C (86°F).

One Fenwall GB31J1 (1000 ohm) thermistor was installed in each of the two ovens. The other legs of the bridge were temperature compensated precision resistors. A very stable 0.5 volt d.c. power supply served as the source for both bridge circuits. The outputs of the two bridges were alternately switched to the input of an Electro Instrument A-16 d.c. amplifier. The output of the amplifier was connected to a Varian G-11 recorder.

Of necessity, the stability as indicated by the recorder includes the stability of the oven temperature, the stability of the excitation power supply, the stability of the amplifier, and the stability of the recorder. The overall stability of the amplifier and recorder was found to be within reading accuracy. The bridge excitation voltage was found to be 0.4948 ±0.0001 volt, which is within reading accuracy. Other than the desired thermistor stability, the only lack of stability in the system was in the oven temperature.

On June 8, 1965, a towel was placed over the 20°C (68°F) oven in the hope that this would reduce the temperature fluctuations. There was only a slight improvement but the towel was left on. This caused a shift upward of about 0.30°F in the oven temperature. The 30°C oven was guaranteed to a closer temperature tolerance that the 20°C oven. The drift of each unit after a period of 15 days totaled approximately 0.15°F excursion (minimum to maximum) for each unit during the remaining 69 days. This includes both the oven and thermistor drift.

It is believed that thermistors will work quite well in place of thermocouples and will provide better accuracy. It is suggested that monthly calibrations be used at the start for thermistor sensors and a gradual reduction in frequency of calibrations as history is accumulated.

INTRODUCTION

For some time, thermistors have been regarded as a superior temperature sensor if they had good stability. The manufacturers of these sensors now claim stability exceeding that of thermocouples. Thermistors require rather simple equipment to obtain accuracies of 0.1°F. This study was performed to determine if thermistors have the stability required for accurate work.

EXPERIMENTAL WORK

The first piece of equipment that was built was a 1.0 volt d.c. power supply. The first power supply constructed had two transistors in the circuit to hold the voltage constant when the load changed. A test conducted over several days indicated that the voltage was not constant. This circuit was Zener controlled, but ordinary Zener diodes are sensitive to temperature changes. Therefore, a regular diode was placed in series with the Zener diode to serve as temperature correction. The output still was not as stable as required.

At this time, measurements were taken at various points in the circuit and the voltage was found to vary more after the transistors than after the Zener diode. This indicated that changes in characteristics of the transistors were giving trouble. Since the load is constant for this application, the transistors would not be required.

Another power supply was built cascading two Zener diodes and not using transistors. The Zener diodes were fastened to heavy heatsinks and protected from air movements by blocks of Styrofoam®* brand polystyrene foam. The power supply was placed in a refrigerator in order to limit the total ambient air temperature change to 2°F. The load on this power supply was constant and both bridges were excited by this equipment. Further calculations indicated that a bridge excitation voltage of 0.5 volt would be preferred. This was easily corrected by using a 2 to 1 voltage divider from the power supply. This voltage was measured as 0.4948 ±0.0001 volts on a Leeds and Northrop "pot box." This power supply was quite satisfactory.

It was also necessary to build a second power supply for the heating and control of the two ovens. The oven manufacturer specified an operating voltage of 28 volts d.c. ±0.1 percent. This was not a simple specification to meet because of the rather wide range of load, plus a significant temperature range that it endured. The two ovens were

* Trademark The Dow Chemical Company.

operated in parallel. All transistors and the Zener diode were mounted on heavy pieces of metal as heatsinks. Where the heatsinks and the Zener diode were subject to air currents, they were protected by blocks of Styrofoam®. The final circuit diagrams of both power supplies are shown in Figure 1.

Since the thermistor resistance changes drastically with temperature, it was deemed necessary to determine the actual resistance of each thermistor at the proposed operating temperature. The thermistor in the 20°C oven had a resistance of 1202.5 ohms at 20°C. The thermistor in the 30°C oven had a resistance of 816 ohms at 30°C. One Jones block terminal strip was used in each oven to hold the thermistor and the necessary temperature compensated precision resistors to form the four legs of each bridge. Figure 2 shows the test setup within each oven. In order for the ovens to maintain the desired temperatures, they had to be placed in a refrigerator. A towel was placed over the 20°C oven so that cold air did not strike the outer shell of the oven directly. A temperature sensor was taped to this shell so as to determine its temperature. The bridge excitation power supply was placed in the refrigerator, but the 28 volt supply was left out.

It was decided that the readout equipment would take an output reading first from one bridge and then from the other bridge. A timing control was built that connected the 20°C bridge to the amplifier input for 2 minutes and 21 seconds and then connected the 30°C bridge to the amplifier input for 1 minute and 39 seconds. This cycle was repeated continuously. A KRP 11AG relay with double pole double throw contacts was the switching means. The signal from this relay went to the input of an Electro Instrument A-16 d.c. amplifier. The output of this amplifier was connected to a voltage divider which fed a reduced voltage to a Varian G-11 strip chart recorder. Figure 3 is a block diagram of the test setup.

A simple method of calibrating this system was devised. To obtain a known voltage, an emf of 1.000 volts was applied to the input of a General Radio type 1454-A voltage divider. The output was controllable in steps of 0.0001 volts. By using a suitable slide switch, the input of the EI-A16 amplifier was disconnected from the relay and connected to the output of the General Radio voltage divider (see Fig. 3). The calibrating voltages used were 0.0000 to 0.0016 in steps of 0.0001 volt in both increasing and decreasing modes. The hysteresis of the recorder could be noted and the value used was the average of the upscale and downscale readings.

In general, data were obtained 5 days per week during most of the day shift. The maximum voltage (minimum temperature) was found to be in the morning and the minimum voltage (maximum temperature) was found to be in the afternoon. The relative values of the resistances forming the legs of the bridge detemine whether or not the maximum voltage will occur at the maximum temperature. The reason for th pattern of the readings versus time of day is because of the effect of the ambient temperature on the exterior of the refrigerator. As the room air temperature around the refrigerator increases, the temperature inside the refrigerator increases and the temperatures inside the crystal ovens increase. This effect inside the crystal ovens was small, but it was noticeable. This effect in the 20°C oven was 0.043°C (0.078°F) and in the 30°C oven was 0.014°C (0.025°F) (see Table I). Figure 4 is a plot of the maximum and minimum daily temperatures.

DISCUSSION

The room temperature varied during the day in a manner similar to the outside air temperature during the summer. The room was cool at the start of the day and temperature increased throughout the day. The room temperature affected the temperature within the refrigerator, which in turn affected the temperature within the two ovens. The amount of this effect depends upon the accuracy of the temperature control elements in the ovens. The temperature of the 30°C oven varied 0.012°C per 1°C temperature change of the air in the refrigerator. The temperature of the 20°C oven varied 0.044°C per 1°C temperature change of the air in the refrigerator. The average daily temperature range for the 30°C oven was 0.014°C and the average daily temperature range of the 20°C oven was 0.043°C. A Delta chamber has been delivered after this work was completed, and closer temperature control would have been possible with it.

A very important factor to be considered in testing or in using thermistors is the self-heating which results in the process of measuring their resistances. In the present instance 0.019 milliwatts were dissipated in the thermistor located in the 30°C oven and 0.0135 milliwatts were dissipated in the thermistor located in the 20°C oven. These powers raise the thermistor temperatures by 0.03°C and 0.02°C in the 30°C and 20°C ovens respectively. While these figures are constant and should not introduce much, if any, error in comparative readings, the writer would reduce the bridge voltage in any future work.

There was a rather large shift in temperature as recorded by the thermistor in the 20°C oven (see Fig. 5). A towel was placed over the 20°C oven on June 8, 1965, to minimize the temperature fluctuations but it probably caused the approximately 0.3°F change that occurred between June 8 and June 11, 1965.

After 14 days (June 15, 1965), the 30°C (86°F) oven became quite stable as far as day-to-day readings were concerned,

although a lowering trend was apparent (see Fig. 6). Perhaps the transistors used in the oven control were stabilizing themselves and this might have occurred in both ovens. The readout system appeared to be very stable and gave the same indication day after day. The long term stability of the El-A16 amplifier is very good. The Varian recorder broke down twice, but it was repaired with little loss of data. The day-by-day insertion of a known signal into the system insures continuity of calibration accuracy.

CONCLUSIONS

1. The thermistor in the 30°C (86°F) oven indicates an average temperature shift of less than 0.1°F per month. This assumes an oven temperature that is held constant within ±0.01°F. There is no way to monitor the temperature of this oven to the required accuracy. The construction of these ovens will not permit the insertion of the required platinum resistance thermometer.

2. The thermistor in the 20°C (68°F) oven indicates an average temperature shift of approximately 0.1°F per month, but this figure has a large margin of doubt. This is indicated by the large day-to-day variations.

3. To obtain information more accurate than is presented in this report, it will be necessary to obtain an improved and more stable temperature zone in which to test the thermistors. Although not available at the beginning of this study, equipment is now on hand to yield better information.

4. The downward trend indicated by the 30°C (86°F) oven thermistor could be caused by a drift in the oven temperature or a drift in the thermistor characteristics.

5. The curve for the 20°C (68°F) oven (Fig. 5) indicates a larger day-to-day variation, but a definite trend is not apparent after the first two weeks.

6. These thermistors are satisfactory sensors to be used in place of thermocouples and will give greater readout accuracy.

7. The power consumed by the 30°C thermistor was 0.000019 watts, which corresponds to a temperature rise of 0.0272°C because of self heating. The power consumed by the 20°C thermistor was 0.0000135 watts, which corresponds to a temperature rise of 0.0193°C because of self heating. Since these figures remain constant, no error results from a day-to-day comparison.

8. To obtain an absolute value of temperature to an accuracy of 0.01°C or better, it is necessary to reduce the bridge excitation to a lower voltage.

Recommendation: Since the use of thermistors at Rocky Flats may involve these sensors in locations subject to radiation, it is recommended that these thermistors be subjected to a high level of radiation and rechecked for a short period of time. In some instances, radiation does modify the characteristics of semiconductors.

TABLE I

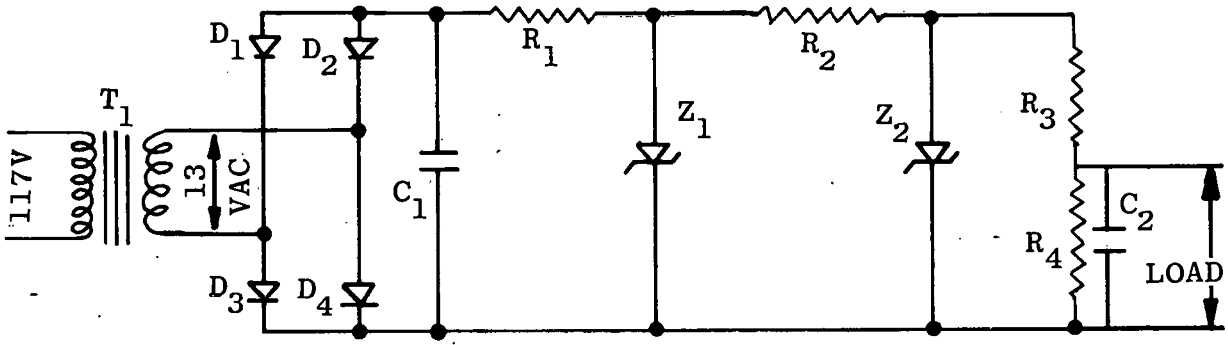
TEMPERATURE VARIATION TABLE

	20°C (68°F) Av.	30°C (86°F) Av.
6/ 1/65	0.0202°F (1.065 mv)	0.006°F (1.130 mv)

The above will serve as a base; 1.065 mv is considered to be 68°F and 1.130 mv is considered to be 86°F.

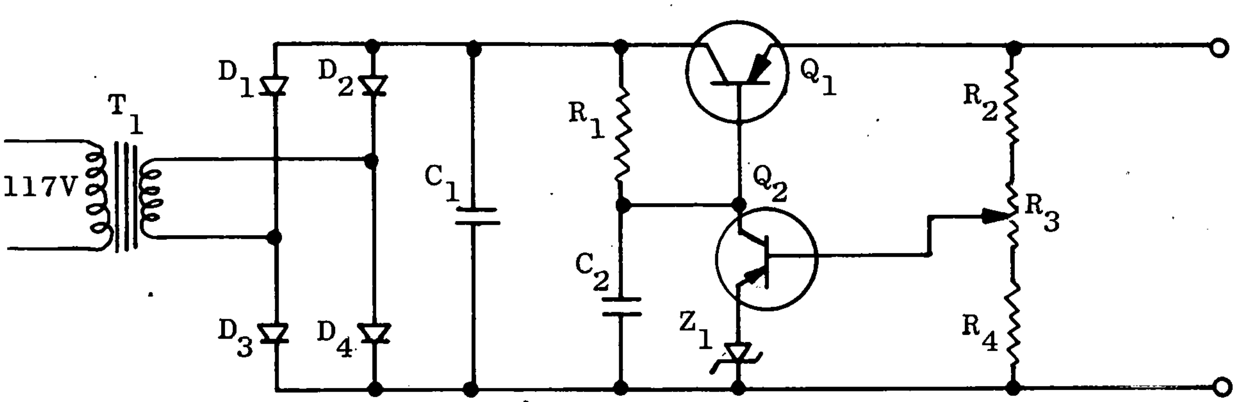
	68° Thermistor			86° Thermistor		
	Min.	Max.	°F Range	Min.	Max.	°F Range
6/ 2/65	67.962	68.150	0.188	85.975	86.037	0.062
6/ 3/65	67.997	68.123	0.126	85.974	86.016	0.042
6/ 4/65	68.050	68.090	0.040	85.950	85.980	0.030
6/ 7/65	67.972	68.043	0.071	85.889	85.947	0.058
	(towel over 20°C oven)					
6/ 8/65	68.129	68.149	0.020	85.947	85.958	0.011
6/10/65	68.225	68.240	0.015	85.926	85.942	0.016
6/11/65	68.312	68.332	0.020	85.984	85.995	0.011
6/14/65	68.298	68.324	0.026	85.963	85.976	0.013
6/15/65	68.334	68.366	0.032	86.002	86.016	0.014
6/16/65	68.348	68.370	0.022	85.992	86.012	0.020
6/17/65	68.351	68.391	0.040	85.988	85.999	0.011
6/18/65	68.332	68.357	0.025	85.982	85.990	0.008
6/21/65	68.299	68.375	0.076	85.966	85.984	0.018
6/22/65	68.296	68.380	0.084	85.960	85.984	0.024
6/23/65	68.296	68.402	0.106	85.958	85.984	0.026
6/24/65	68.321	68.402	0.081	85.958	85.984	0.026
6/25/65	68.286	68.369	0.083	85.942	85.976	0.034
6/28/65	68.312	68.363	0.050	85.941	85.956	0.015
6/29/65	68.346	68.422	0.076	85.951	85.968	0.017
6/30/65	68.330	68.426	0.096	85.937	85.966	0.029
7/ 1/65	68.319	68.402	0.083	85.934	85.950	0.016
7/ 2/65	68.329	68.404	0.075	85.934	85.958	0.024
7/ 6/65	68.304	68.393	0.089	85.916	85.942	0.026
7/ 7/65	68.311	68.379	0.068	85.915	85.930	0.015
7/ 8/65	68.319	68.397	0.078	85.917	85.937	0.020
7/ 9/65	68.311	68.414	0.103	85.910	85.939	0.029
7/12/65	68.331	68.396	0.065	85.905	85.935	0.030
7/13/65	68.331	68.406	0.075	85.911	85.933	0.022
7/14/65	68.344	68.418	0.074	85.910	85.940	0.030
7/15/65	68.343	68.418	0.075	85.908	85.933	0.025
7/16/65	68.347	68.417	0.070	85.904	85.929	0.025
7/19/65	68.364	68.448	0.084	85.904	85.933	0.029
7/20/65	68.380	68.483	0.103	85.905	85.942	0.037
7/21/65	68.388	68.492	0.104	85.912	85.945	0.033
7/22/65	68.405	68.489	0.084	85.912	85.939	0.027
7/23/65	68.390	68.486	0.096	85.900	85.937	0.037
7/26/65	68.353	68.458	0.105	85.901	85.934	0.033
7/27/65	68.364	68.447	0.083	85.906	85.926	0.020
7/30/65	68.371	68.458	0.087	85.896	85.921	0.025
8/ 2/65	68.325	68.433	0.108	85.885	85.906	0.021
8/ 6/65	68.324	68.408	0.084	85.867	85.896	0.029
8/10/65	68.301	68.407	0.106	85.852	85.882	0.030
8/11/65	68.309	68.409	0.100	85.855	85.881	0.026
8/13/65	68.316	68.433	0.117	85.855	85.878	0.023
8/16/65	68.321	68.429	0.108	85.839	85.873	0.034
8/17/65	68.354	68.457	0.103	85.850	85.877	0.027
8/18/65	68.346	68.450	0.104	85.835	85.869	0.034
8/19/65	68.375	68.450	0.075	85.836	85.868	0.032
8/20/65	68.329	68.442	0.113	85.839	85.881	0.042
8/24/65	68.336	68.447	0.111	85.834	85.876	0.042

0.5 VOLT POWER SUPPLY



C_1 = 50mfd C_2 = 4000mfd
$D_1 = D_2 = D_3 = D_4$ =DIODES (SD500, IN2071, etc.)
R_1 = 499 OHM, R_2 = 464 OHM, R_3 & R_4 CHOSEN TO GIVE CORRECT OUTPUT VOLTAGE. T_1 = 117/13 VOLT TRANSFORMER
Z_1 = 10V ZENER DIODE, Z_2 = 6.8 V ZENER DIODE

28 VOLT POWER SUPPLY

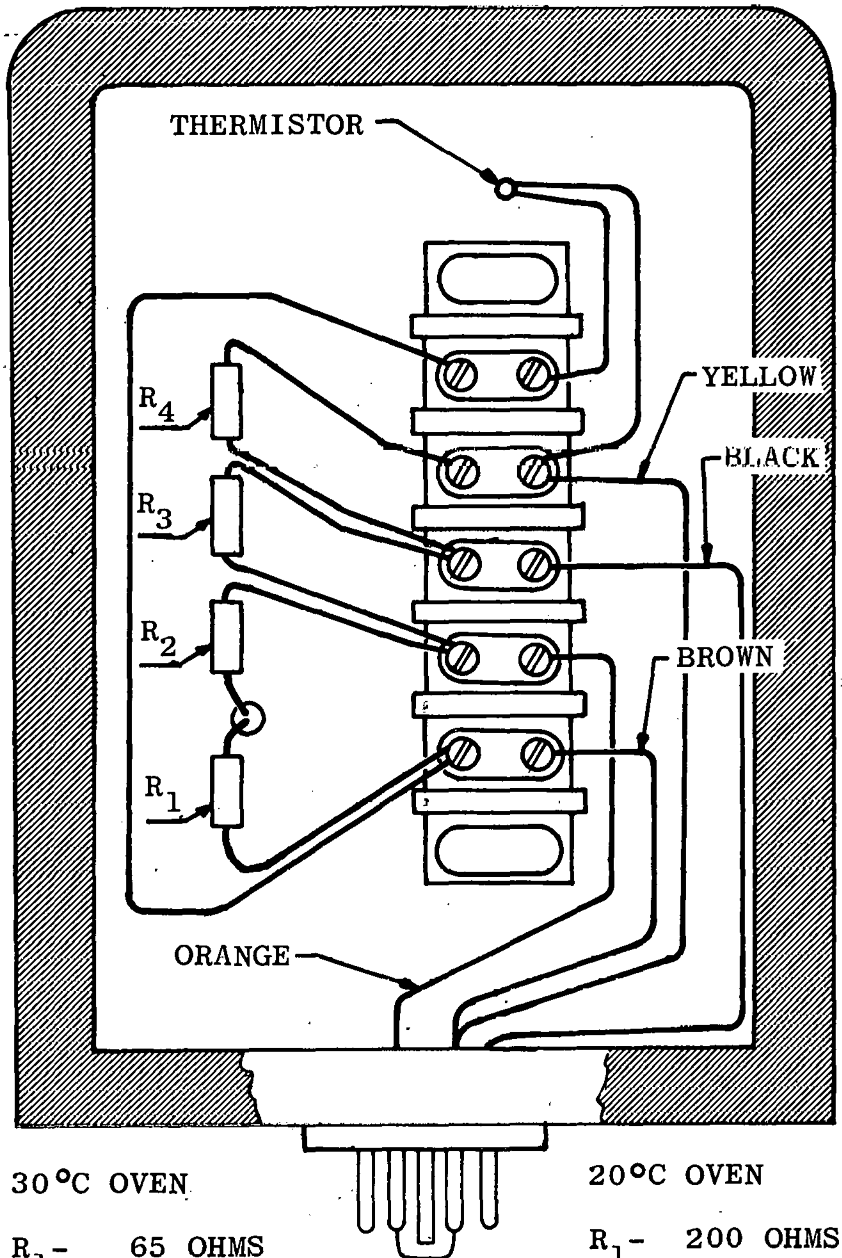


C_1 = 2000mfd C_2 = 50mfd
$D_1 = D_2 = D_3 = D_4$ = DIODES (SD500, IN2071, etc.)
R_1 = 330 OHM 2W., $R_2 = R_4$ = 1000 OHM, R_3 = 50 OHM POT.
T_1 = 117/26-1/2V TRANSFORMER
Q_1 = 2N669 Q_2 =2N1039 Z_1 = 12V ZENER DIODE

ALL TRANSISTORS AND ZENER DIODES HAVE MASSIVE HEAT SINKS AND PROTECTED ON OUTSIDE BY BLOCKS OF STYROFOAM®.

Figure 1. STABLE POWER SUPPLIES

CRYSTAL OVEN



30°C OVEN		20°C OVEN	
R_1-	65 OHMS	R_1-	200 OHMS
R_2-	750 OHMS	R_2-	1,005 OHMS
R_3-	2,425 OHMS	R_3-	3,474 OHMS
R_4-	2,427 OHMS	R_4-	3,474 OHMS

Figure 2. BRIDGE DIAGRAM

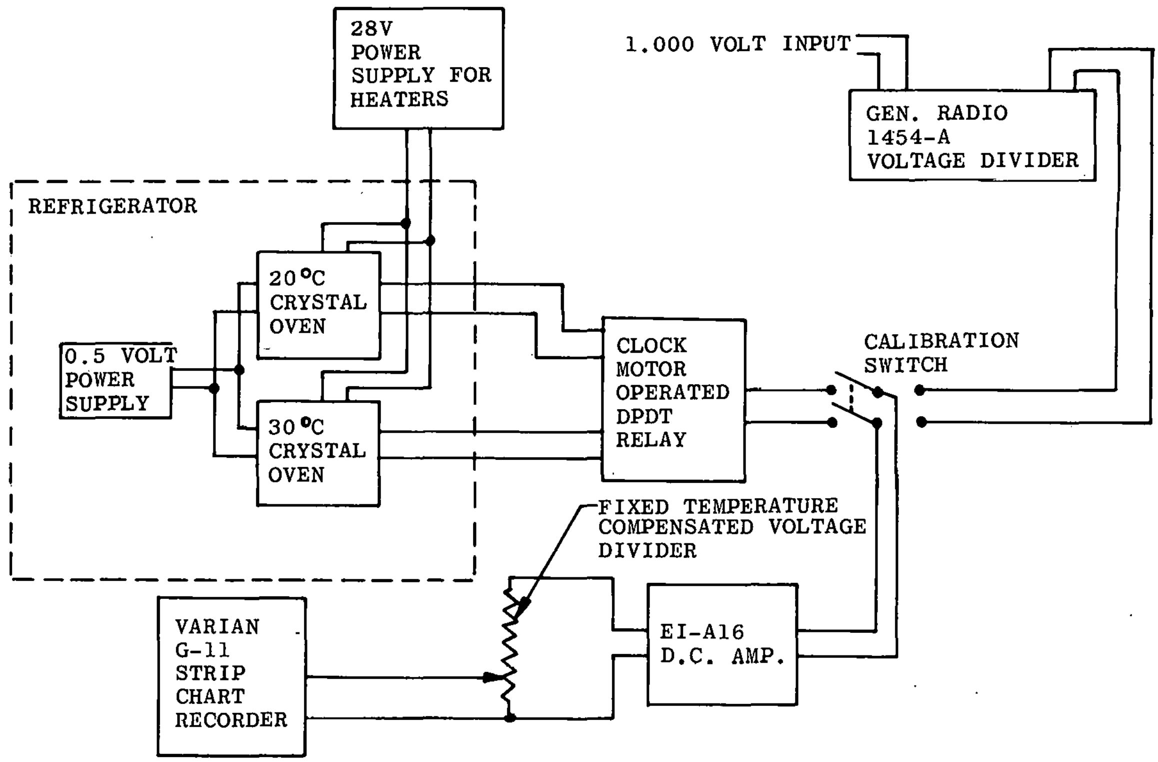


Figure 3. BLOCK DIAGRAM OF EQUIPMENT

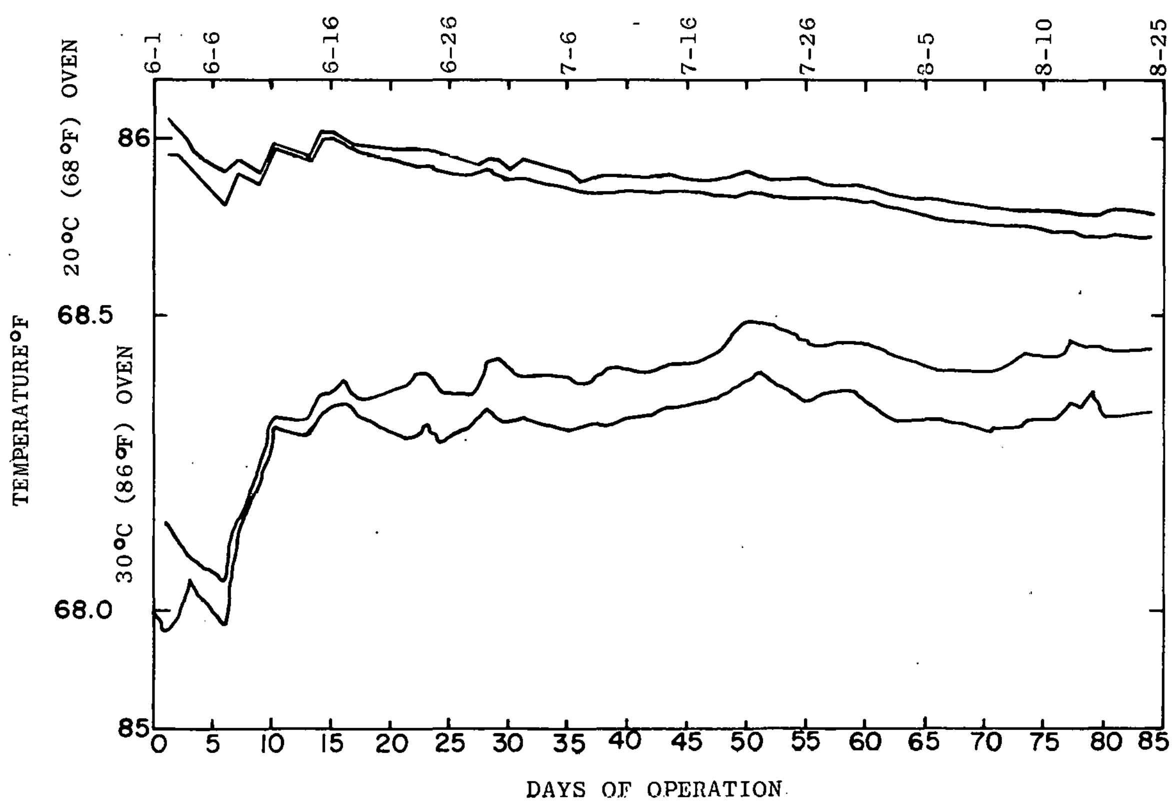


Figure 4. MAXIMUM AND MINIMUM TEMPERATURE PLOTS

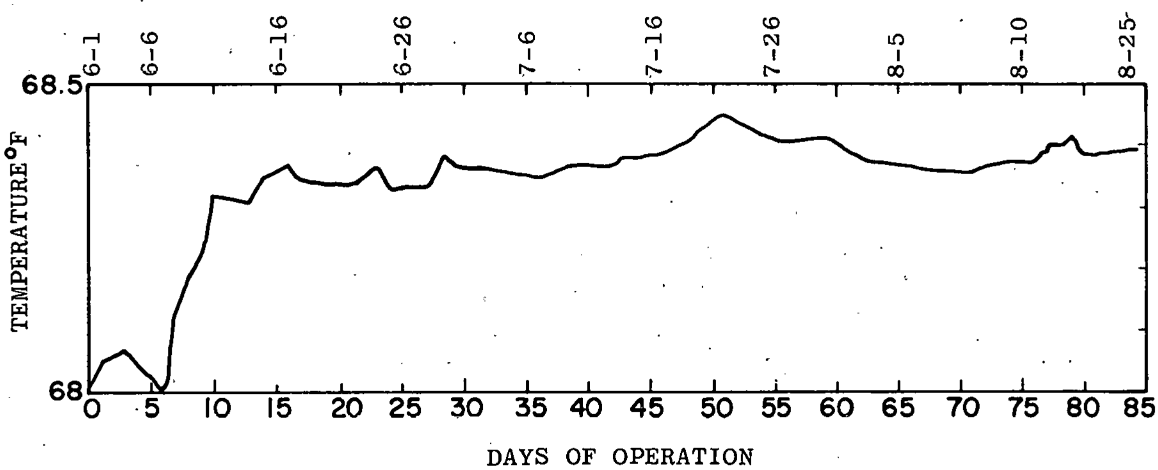


Figure 5. AVERAGE TEMPERATURE PLOT FOR 68°F OVEN

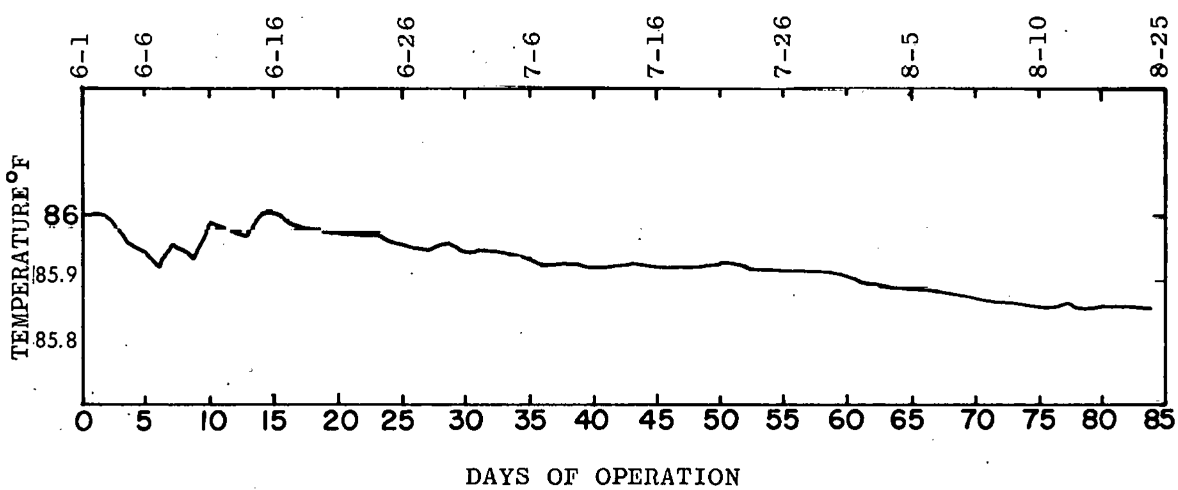


Figure 6. AVERAGE TEMPERATURE PLOT FOR 86°F OVEN