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# PULSED CURRENT RESISTANCE THERMOMETRY

M.Kuchnir, J.Tague and H.Cranor

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## ABSTRACT

The implementation of a cryogenic thermometry system is described. It is based on measuring the resistance of carbon composition or platinum resistors using short pulses of high current in order to generate high signal levels with low self-heating effects. It makes use of recent advances in digital electronics and it is a natural technique to be used with micro-computer based systems. It is used throughout the Energy Saver.

## INTRODUCTION

For quite some time carbon composition resistors have been used as cheap thermometers for cryogenic temperatures.[1] In particular, the carbon composition resistors produced by Allen-Bradley present suitable sensitivity for thermometry in the 4.2K to 70K range. Much has been written about their stability. On the assumption that their low price led to relatively careless handling and bad reproducibility, we have proceeded to mount them in a protected and stress-free way in special printed circuit cards which, after "training" and calibration, are installed as helium-immersed temperature sensors.

Over 500 of these units are to be used throughout the cryogenic system of the Energy Saver. They are used both as monitors and control sensors for the refrigeration system. To compliment their relative low sensitivity above 70K, commercially available platinum resistors are used in the 70-300K range. The refrigeration system is electronically controlled for most of its operation. In order to take advantage of this distributed intelligence available and the low price of digital electronics, a pulsed current technique was developed for measuring the resistance of these thermometers, the implementation of which has been described by Pucci and Howard.[2] The essence of the technique is to send a pulse of current to the resistor and measure the voltage across it during the pulse. This voltage is large enough for the thermal emf corrections to be disregarded, and integrated circuit multiplexers to be used. Self-heating of the thermometer is prevented by keeping the pulse duration short and the repetition rate low (1Hz).

The minimum duration of the pulse is dictated by the time needed for the current to stabilize. A thermometer whose resistance in the operating range is not far from properly terminating the line helps in reducing this transient, but in our case it is the length of the cable (i.e., its capacity) that led us to set the voltage reading time 48μsec into the pulse and to set the pulse duration to 50μsec.

Several factors led to the selection of the resistance at operating range to be less than 100Ω: 1) this is a typical value for the impedance of a twisted wire pair (therefore cheaper cables and better terminations); 2) availability of platinum resistors in this range so the same electronics are used for both types of thermometers; 3) lower power dissipation while still providing the needed resolution of ±30mK below 5.2K. The resistors selected are Allen-Bradley 1/8w 18Ω hot molded carbon composition. They come from two manufacturer's batches: BB1805 Code 0031 and BB1805 RC05GF 180J 7901. The cable used in the system is the Belden 8728 audio cable, which contains two individually shielded twisted pairs in a single jacket, one pair for the current pulse and the other for the voltage.

## CARBON SENSOR MANUFACTURE

In order to make for simple calibration, handling and installation procedures, the carbon resistor bodies are held suspended in holes machined in special printed circuit cards by sewing thread and GE-7031 varnish. Details of their construction procedure are presented in Appendix I. The 1/16" thickness of the printed circuit card and a few loops of 1/32 o.d. insulated wire protect the resistor from mechanical contact. No effort was made to reduce the original phenolic insulation layer of the resistor, but their original leads were trimmed very short (<1/32" long) and touch soldered to 2-1/2" long .004" diameter double enamel insulated copper wires to prevent any external mechanical stress from reaching the resistor. Thermal contact to the composition is therefore expected to be mostly

mostly through the leads, but thermal time constant for these gas- or liquid-immersed sensors is short enough for all our purposes.

The thin copper wires terminate on gold-plated copper slide contacts that fit into standard printed circuit edge-board connectors. The calibration calorimeter to be described below contains such edge-board connectors[3] made of diallyl phthalate insulators and this allows the handling needed for calibration and installation to be fast and to proceed without any extrinsic stress being applied to the resistor. In order to reduce the effect of intrinsic stresses, the cards containing the resistors are cold-shocked into liquid $N_2$ and warmed up to room temperature three times before they are installed for calibration. This "training" or "aging" of the sensors should hopefully increase their reproducibility.

Figure 1 is a photograph of one such 5/8"×1-3/8" card. Two resistors are installed per card for redundancy.* The smaller holes are used for threading wires or sewing threads and the larger ones for the assembly into the final mechanically strong probe arrangement and conduit to the sealed feedthrough at room temperature. The metal strip in the card is to be engraved with the serial number of the resistor for calibration identification. The serial number is a six digit number that specifies the date of the calibration, followed by a hyphen and a number from 1 to 24 that specifies the location of the resistor in the calorimeter during calibration. For example: 810724-3 was the resistor in location 3 on the calibration run of July 24, 1981.

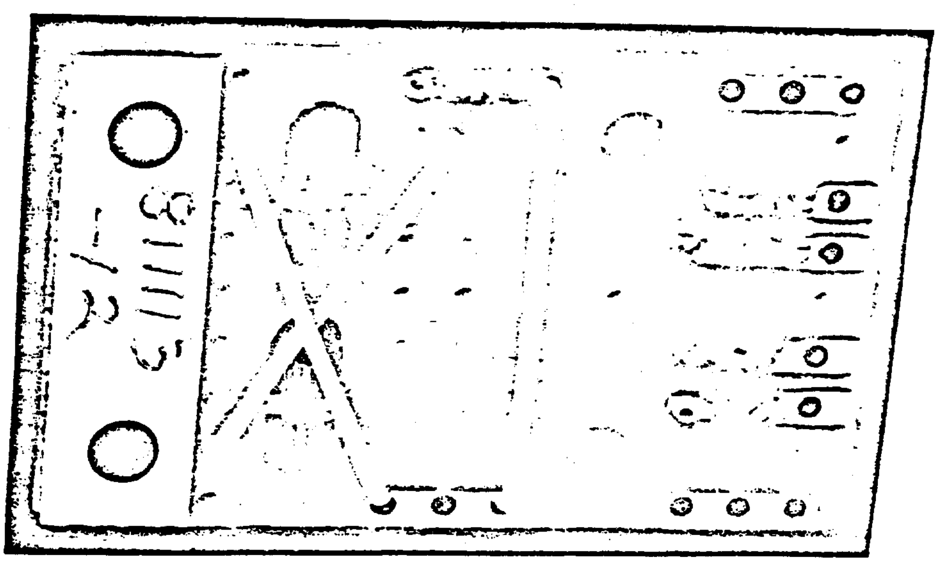


Figure 1. Carbon Temperature Sensor

*Half-cards with a single resistor are also being produced.

CARBON SENSOR CALIBRATION

Figure 2 presents a simplified schematic of the cryostat used for calibration. It is essentially a copper calorimeter immersed in a bath of LHe or $LN_2$ and isolated from them by multi-layer insulation in a vacuum space which can be filled with exchange gas for fast cooldown. The path conducting heat to the calorimeter is intercepted by a temptperature control stage containing the sensor and the heater of an electronic temperature controller.

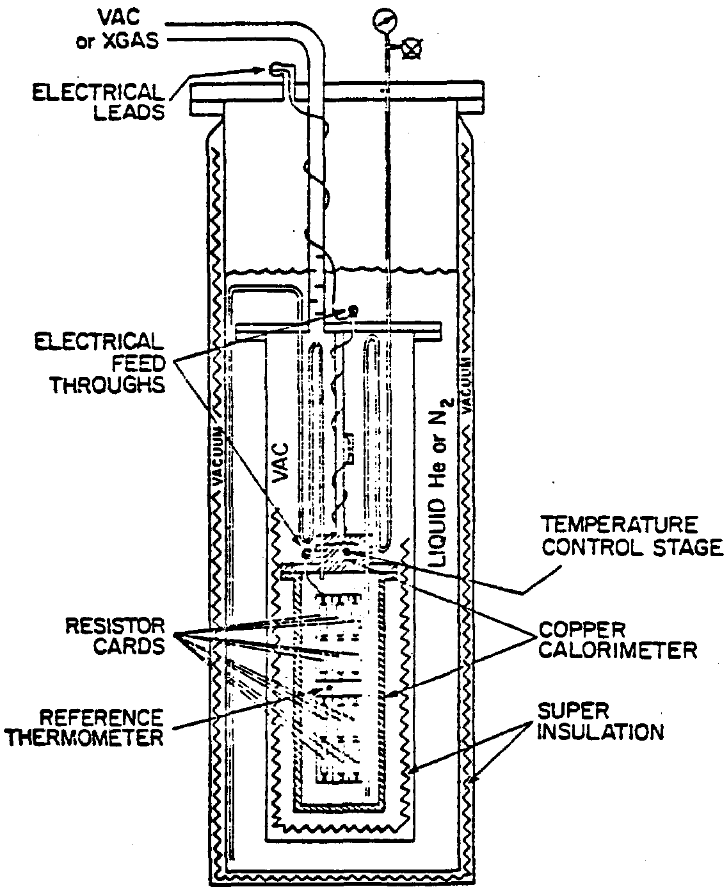



Figure 2. Calibration Cryostat Schematic

Inside the calorimeter in a copper frame, six printed circuit edge connectors[3] made of diallyl phthalate insulator and gold-plated contacts in which the cards containing the resistors to be calibrated are installed. The 1/8" thick OHFC copper walls of this calorimeter and the ~1 atm of He gas kept inside the cryostat are relied upon for stabilizing the thermal equilibrium between all of the resistors in the cards and the reference thermometer. For reference thermometer we have been using commercially calibrated carbon glass[4] and platinum resistors.

In order to have an automatically controlled atmosphere of helium inside the calorimeter, one 1/8" o.d. .006" thick stainless tube passing through the temperature control stage connects the inside of the calorimeter to the bottom of the external bath, making a vertical zigzag in the vacuum space above the calorimeter to ensure the existence of a long layer of stratified helium gas between the calorimeter and the bath. Another similar path connects the calorimeter to a manifold at room temperature, providing means to verify the calorimeter pressure and to flush it when changing the liquid in the bath. Two sets of two cryogenic feedthroughs,[5] some containing over 60 wires (mostly Manganin, .004" thick enamel insulated) are used to route the over 120 wires.

An automatic data acquisition system has been programed to measure the resistors, evaluate the approach to thermal equilibrium, calculate the temperature and record the data in magnetic diskettes. After a calibration run these data are transmitted by telephone line to the Cyber computer for general storage and access.

Although 24 resistors are calibrated per run, format limitation imposes the data to be stored in three ASCII files. The file names consist of a letter A, B or C followed by the six digits of calibration run date. The data for the first eight resistors calibrated on Jan. 26, 1982 are in file A820126, the next eight resistors, 820126-9 to 820126-16, are in file B820126, and resistors 820126-17 to 820126-24 are in file C820126.

In the Cyber the directory of these calibration tables can be listed with the command CATLIST, UN=G103, and any particular one (for example; A820126) transferred to the user's area with the command GET(TABLE=A820126/UN=G103).

Appendix II is the printout of one such file. The first line consists of labels. The first column is formed by temperature in Kelvins, but its label is the calibration date. The other columns are the corresponding resistances in ohms for the resistors identified by the labels in the first line.

The data acquisition system is based on a Cromenco Z-2D Microcomputer, a Model 225 Keithley dc current source and a Model 180 Keithley Digital Nanovoltmeter multiplexed to the resistors through HG2M1007 Clare Mercury Relays. The four lead dc method is used to read the resistors with current inversion for thermal emf compensation. The program used in the data acquisition system was originally written in 16K Extended Basic by L.Grumboski. Its present version is presented in Appendix III.

A special test to compare the readings of an 18Ω carbon sensor through this dc method and the pulse method described in this Technical Memorandum was carried out with the data acquisition system of the Spool Piece Testing Facility (SPTF) on Oct. 7-8, 1981. The agreement found is well within the ±30mK acceptable accuracy.

REFERENCES

1. A.C.Anderson, Fifth Symposium on Temperature, p. 773-784, Instrument Society of America (1971).
2. Greg Pucci and Douglas Howard, Fermilab TM-1069 (Oct. 1981).
3. Model 3VH18/1JN8 Printed Circuit Edge Connector by Viking Connectors, 21001 Nordhoff St., Chatsworth, CA 91311, USA.
4. Model CGR-1-2000 from Lake Shore Cryotronics, Inc., 64 East Walnut St., Westerville, Ohio 43081.
5. Fabrication of these feedthroughs is described by M.Kuchnir in Fermilab TM-596 (Aug. 1975).

APPENDIX I - Manufacturing steps for carbon sensors (by H.Cranor).
APPENDIX II - Calibration file printout.
APPENDIX III - Calibration data acquisition program (original by L.Grumboski; revisions by M.Kuchnir).

APPENDIX I

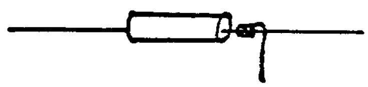
## STEPS TO BUILD CARBON RESISTOR THERMOMETERS

1. Prepare copper leads:

   Cut 0.004" double enamel copper into 2-1/2" long pieces. Strip a little over 1/4" from one end with X-var 622.

2. Prepare resistors:

   a. Wrap the stripped ends of copper wires around the leads of a 1/8W 18 $\Omega$ resistor. Begin close to resistor body and end by wrapping some unstripped wire around each lead.

   b. With a heat sink between resistor body and copper wire, solder wire to lead with #28 (.014") Sn60 Ersin solder. Be sure to cover stripped portion of wire completely.

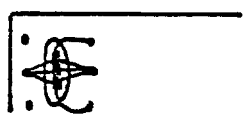
   c. Cut off resistor leads extending beyond the copper-wrapped portion.

3. Mount resistor on G-10 board:

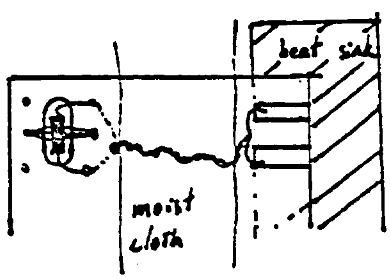
   a. Cut pieces of string into 10" lengths. Loop them around the resistors. Fasten with a little GE 7031 varnish.

   b. Using the thread, fasten the resistors to the boards. No strain should be put on the copper leads. The thread should hold the resistor firmly in the center of the oval.

   c. Secure copper leads to the board. Gently twist the copper leads together and meander (for good thermal contact) to the point where they will be soldered. Strip the copper leads at this point and solder to the contacts on the board. The copper wires between solder point and resistor should be cooled with a damp cloth to prevent damage to the resistor. The resistors themselves should remain dry. Also, a heat sink can be placed under the end of the board.

Cont'd.

4. Protect the boards by spreading a thin film of 7031 varnish on them and then wrap a piece of PVC-covered wire around them.

5. Cold shock the completed board in liquid nitrogen, allow to return to room temperature and repeat two more times.

6. Check boards for electrical continuity. Check that the resistance of each resistor is equal to original resistance.

H.Cranor:er

# APPENDIX II

## CONTENTS OF A TYPICAL CALIBRATION FILE (C820610)

Calibration date: 820610 · Slot # ↓

| 820610 | -17 | -18 | -19 | -20 | -21 | -22 | -23 | -24 |
|---|---|---|---|---|---|---|---|---|
| 304.734 | 19.32 | 19.35 | 18.96 | 18.83 | 19.43 | 19.25 | 19.11 | 19.29 |
| 78.0643 | 22.55 | 22.63 | 22.20 | 22.05 | 22.75 | 22.46 | 22.35 | 22.33 |
| 4.2133 | 108.55 | 111.63 | 101.34 | 101.06 | 111.74 | 107.81 | 101.83 | 100.49 |
| 4.5304 | 99.43 | 102.09 | 93.19 | 92.92 | 102.22 | 98.76 | 93.66 | 92.40 |
| 4.7714 | 93.60 | 95.99 | 87.95 | 87.67 | 96.14 | 92.97 | 88.41 | 87.21 |
| 5.0660 | 87.58 | 89.71 | 82.52 | 82.25 | 89.88 | 87.00 | 82.98 | 81.84 |
| 5.3948 | 78.87 | 80.64 | 74.64 | 74.39 | 80.81 | 78.36 | 75.08 | 74.03 |
| 7.1583 | 62.75 | 63.89 | 59.91 | 59.66 | 64.08 | 62.34 | 60.29 | 59.46 |
| 10.3343 | 47.87 | 48.52 | 46.16 | 45.93 | 48.69 | 47.56 | 46.46 | 45.88 |
| 14.6675 | 39.05 | 39.47 | 37.91 | 37.70 | 39.62 | 38.81 | 38.16 | 37.75 |
| 20.7310 | 33.25 | 33.53 | 32.43 | 32.24 | 33.67 | 33.05 | 32.65 | 32.36 |
| 31.3539 | 28.53 | 28.71 | 27.94 | 27.76 | 28.84 | 28.37 | 28.12 | 27.95 |
| 50.4182 | 24.90 | 25.01 | 24.46 | 24.29 | 25.13 | 24.77 | 24.62 | 24.54 |
| 128.0080 | 20.67 | 20.71 | 20.35 | 20.20 | 20.80 | 20.57 | 20.48 | 20.53 |
| 192.2880 | 19.69 | 19.71 | 19.37 | 19.22 | 19.79 | 19.60 | 19.50 | 19.60 |

↑ Temperatures (Kelvins) · ↑ Resistance (Ohms)

## APPENDIX III: CALIBRATION DATA ACQUISITION PROGRAM

CAL26.BAS - by L.Grumboski and M.Kuchnir

```
   SFMODE : X=0.12345678 : IF X=0.12345678 THEN RUN
   ON ESC GOSUB 10000
   DSK"A:"
 10 PRINT CHR$(23)
 15 PRINT"CAL26.BAS"
 20 PRINT CHR$(20)
100 REM
120 REM                                  (S1B) OF 4PIO CNTRLS KIETHLEY 180
130 REM                                  (S1A) "     " INPUTS FROM     180
140 REM                                  PORT $C5(S2A) SELECTS POL & CAL
150 REM                                  PORT $C7 (S2B) SELECTS R1->R8
160 REM                                  PORT $C9 (S3A) SELECTS R9
170 REM                                  PORT $CB (S3B) SELECTS R10->R17
180 REM                                  PORT $CD (S4A) SELECTS R18
190 REM                                  PORT $CF (S4B) SELECTS R19->R26
195 DIM R9$(12),R8$(12)
200 DIM Z$(100)
204 DIM G1(1,100)
205 DIM G(18,1,24)
206 DIM A2(26),A3(26)
207 R9$="C1201081.CGR"
208 REM ***** JOE ***** ADD R8$="????????.RES" HERE
210 DIM S(9),T(3)
260 DIM A(27,1),Z(28)
265 K9=0.2 : REM EQUILIB. LEVEL (%)
270 R=100.092 : REM  CAL RESISTOR IN BOX #1
272 DIM Q(26)
274  FOR W=1 TO 26
276  Q(W)=18.0 : NEXT W
278 Q0=12.7 : REM ROOM TEMP OF C1201
280 DIM D$(15)
290 M1=%0080% : M2=%0040% : M3=%0010%
300 M4=%000F% : M5=%00F0%
310 C=1500
320 T8=%0017% : T9=%0014% : REM T8=CTRLW=PRINT ON T9=CTRLT PRINT OFF
330 REM S VARIABLES CONTROL LOW LEVEL BOX
340 REM               S LEVELS ARE THE INVERSE OF THE NORMAL LW LVL SWTCH BX
350 S1=%00FE% : S2=%00FD% : S3=%00FB% : S4=%00F7% : S5=%00EF% : S6=%00DF%
360 S7=%00BF% : S8=%007F% : S9=%00FC% : S0=%00FF%
370 O1=%00C5% : REM O1=S2A OUTPORT PORT
380 O2=%00C7% : REM O2=S2B OUTPUT PORT
390 O0=%00C0% : REM LOWEST ADDRESS OF PIA BOARD
400 I(0)=%00FB% : I(1)=%00FA%
410 S(0)=S0 : S(1)=S1 : S(2)=S2 : S(3)=S3
420 S(4)=S4 : S(5)=S5 : S(6)=S6 : S(7)=S7 : S(8)=S8 : S(9)=S9
430 T(0)=S0 : T(1)=S1 : T(2)=S2 : T(3)=S9
```

```
1000 REM ****************************************************************
1010 REM *                                                              *
1020 REM *                100-200 INITALIZE PIA S1 &S2                  *
1030 REM *                                                              *
1040 REM ****************************************************************
1050 REM INT THE PIA FOR THE KIETHLEY 180 S1 A-B
1060 OUT 00,%0000% : REM ENABLE THE INTERFACE REG.
1070 OUT 00+%0001%,%0000% : REM S1A 8 LINES (INPUT) USING INTERNAL PULLUPS
1080 OUT 00,%0004% : REM ENABLE THE D.D.R.
1090 OUT 00+%0002%,%0000%
1100 OUT 00+%0003%,%00FF% : REM S1B 8 LINES (OUTPUT)
1110 OUT 00+%0002%,%0004%
1130 REM ***** INT PIA FOR LOW LEVEL SWITCH BOX S2 A-B
1140 OUT 00+%0004%,%0000%
1150 OUT 00+%0005%,%00FF% : REM S2A 8 LINES (OUTPUT)
1160 OUT 00+%0004%,%0004%
1170 OUT 00+%0006%,%0000%
1180 OUT 00+%0007%,%00FF% : REM S2B 8 LINES (OUTPUT)
1190 OUT 00+%0006%,%0004%
1200 REM       INT LOW LEVEL BOX #2 S3 A-B
1210 OUT 00+%0008%,%0000%
1220 OUT 00+%0009%,%00FF% : REM S3A 8 LINES (OUTPUT)
1230 OUT 00+%0008%,%0004%
1240 OUT 00+%000A%,%0000%
1250 OUT 00+%000B%,%00FF% : REM S3B 8 LINES (OUTPUT)
1260 OUT 00+%000A%,%0004%
1265 REM       INT LOW LEVEL BOX 3 S4 A-B
1270 OUT 00+%000C%,%0000%
1280 OUT 00+%000D%,%00FF% : REM S4A 8 LINES (OUTPUT)
1290 OUT 00+%000C%,%0004%
1300 OUT 00+%000E%,%0000%
1310 OUT 00+%000F%,%00FF% : REM S4B 8 LINES (OUTPUT)
1320 OUT 00+%000E%,%0004%
1390 @"SIT BACK AND WAIT FOR FILES TO LOAD "
1400 GOSUB 13200
1410 REM ***** JOE ***** ADD GOSUB 13700 HERE TO LOAD THE 100 OHM FILE
1795 REM                              SET UP RUN
1800 GOTO 11000
1995 REM                              CAL RTN BOX #1
2000 OUT 02,%00FF%
2010  FOR K=0 TO 1
2020  OUT 01,T(3-K)
2030  GOSUB 6500
2040  NEXT K
2045 OUT 01,%00FF% : REM                               CLEAR CAL.
2050 RETURN
2095 REM                              CHANGE POL AND READ
2100  FOR K=1 TO 0 STEP-1
2110  OUT 01,T(K) : REM                     CHANGE POL.
2120  GOSUB 6500
2130  NEXT K
2140 RETURN
```

```
4995 REM                                 READOUT RTN
5000 REM
5002 REM SKIP IF BEEPER IS ON BUT FAR FROM EQUIL
5003 IF K8=1 AND K7=0 THEN RETURN
5004 NOESC
5005  FOR X=0 TO 8 STEP 4
5010  OUT 02+X,%00FF% : REM              CLEAR ALL RELAYS
5015  OUT 01+X,%00FF% : REM              I SAID ALL
5020  NEXT X
5030 REM
5040 REM                                 BOX #1
5050 REM                                 CAL RESISTOR 1ST.
5055 W=0 : REM                           CAL. #1 A(0,K)
5060 GOSUB 2000
5070  FOR W=1 TO 8
5080  OUT 02,S(W) : REM                          RESISTOR BOX #1
5090  REM                                GO & CHANGE POL. & READ
5100  GOSUB 2100
5110  NEXT W
5120 OUT 02,%00FF% : REM                         ALL RELAYS OFF
5130 REM                                 BOX#2
5140 OUT%00C9%,S2 : REM                          R9 (CAL. POSITION BOX #2)
5150 W=9 : REM                           R9
5160 GOSUB 2100
5170 OUT%00C9%,%00FF% : REM              CLEAR R9
5180  FOR W=10 TO 17
5190  OUT 02+4,S(W-9) : REM              RESISORS BOX #2
5200  GOSUB 2100
5210  NEXT W
5220 OUT 02+4,%00FF% : REM               CLEAR ALL RELAYS
5230 REM                                 BOX #3
5240 OUT%00CD%,S2 : REM                          R18 (CAL.POSITION BOX #3)
5250 W=18 : REM                                  R18
5260 GOSUB 2100
5270 OUT%00CD%,%00FF% : REM              CLEAR R18
5280  FOR W=19 TO 26
5290  OUT 02+8,S(W-18) : REM             RESISTORS BOX #3
5300  GOSUB 2100
5310  NEXT W
5320 OUT 02+8,%00FF% : REM               CLEAR ALL RELAYS BOX #3
5330 REM                                 CAL 2
5340 W=27 : REM                                  CAL 2=A(27,K)
5350 GOSUB 2000
5360 OUT B1,R9 : REM                     SELECT DEFAULT RESISTOR
5370 REM                                 SELECT DEFAULT POL. & RECORDER ON
5380  FOR X=0 TO 8 STEP 4
5382  REM             TURN ON REC,BE CAREFUL ABOUT POL. & DEFAULT RES
5385  IF 01+X=B1 THEN 05=BINAND(R9,I(P)) : OUT B1,05 : GOTO 5400
5390  OUT 01+X,I(P)
5400  NEXT X
5410 C9=((A(0,0)+A(27,0))/2)-((A(0,1)+A(27,1))/2)
5415 04=0 : REM COMPARE READOUTS FOR INTERNAL EQUIL.
```

```
5420  FOR W=1 TO 26
5430  Z(W)=((A(W,0)-A(W,1))/C9)*R
5435  Z(W)=ABS(Z(W))
5436  IF W>24 THEN 5438
5437  Q4=Q4+ABS(Z(W)-Q(W))/Q(W)
5438  Q(W)=Z(W)
5440  NEXT W
5441 Q5=100.0*Q4
5442 REM SET BEEPER FLAG
5443 Q6=100.0*((Z(25)-Q0)/Q0) : K6=ABS(Q6)
5444 IF K6<K9 THEN K7=1 : GOTO 5446
5445 K7=0
5446 Q0=Z(25)
5450 REM PRINT OUT
5460 PRINT CHR$(T8)
5470 GOSUB 8530
5480  FOR W=1 TO 26
5481  IF W=26 THEN PRINT"     ";Z(W) : GOTO 5510
5490  PRINT USING"######.##",Z(W);
5500  IF W=8 OR W=16 OR W=24 THEN PRINT : PRINT"
5510  NEXT W
5515 PRINT CHR$(T9) : REM              TURN OFF PRINTER
5517 GOSUB 14000
5518 Q3=0
5519 ESC
5520 RETURN
6500 REM                               READ KEITHLEY 180
6510 REM                               DELAY LOOP LETS 180 SETTLE DOWN
6520  FOR Y=1 TO C
6530  D3=0 : NEXT Y
6540 REM                               LOOP FOR STAT,D1,D2,D3,D4
6550  FOR L=0 TO 2
6560  J0=L+10 : REM 10=D1,D2 12=STAT 6=D3,D4
6570  IF J0=11 THEN J0=6
6580  REM                              CONTROL & READ KEITHLEY
6590  GOSUB 9000
6600  NEXT L
6610 REM                               RELEASE KEITHLEY
6620 GOSUB 9020
6630 REM
6640 REM                               CALCULATE VOLTAGE FROM 180
6650 GOSUB 9040
6660 REM                               GO BACK AND DO ANOTHER
6670 RETURN
8080 REM *****TIMER SUBROUTINE*******
8090 C1=160 : REM              ***** MOD 3-3-80 *****
8100 REM D0=TENS,MINUTES
8110 D0=INP(C1+7) : REM                       ***** MOD 3-3-80 *****
8120 D0=D0-INT(D0/16)*16
8130 REM D1=UNITS,MINUTES
8140 D=INP(C1+6) : REM                       ***** MOD 3-3-80 *****
8150 D=D-INT(D/16)*16
8160 REM F5=TENS+UNITS,MINUTES
8170 F5=D0*10+D
8180 RETURN
```

```
8190 REM *****************************************************************
8200 REM KIETHLEY READ SUBROUTINE
8210 REM DATE AND TIME
8220 GOSUB 8270
8230 PRINT D$
8240 GOSUB 8530
8250 PRINT
8260 RETURN
8270 REM THIS TO GET THE DATE FROM TIME BOARD
8280 C1=160 : REM                ***** MOD 3-3-80 *****
8290 Y=1980 : REM                ***** MOD 3-3-80 *****
8300 M=1
8310 T5=INP( C1+10 )
8320 T4=INP( C1+11 )
8330 T3=INP( C1+12 )
8340 T2=INP( C1+13 )
8350 T5=BINAND( T5,15 )
8360 T4=BINAND( T4,15 )
8370 T3=BINAND( T3,15 )
8380 T2=BINAND( T2,15 )
8390 T1=BINAND( T1,15 )
8400 T6=( T1*10000.0 )+( T2*1000 )+( T3*100 )+( T4*10 )+T5
8410 RESTORE 8450
8420 IF T6>364 THEN Y=Y+1 : T6=T6-365 : GOTO 8420
8430 READ B
8440 IF T6>B THEN T6=T6-B : M=M+1 : GOTO 8430
8450 DATA 31,28,31,30,31,30,31,31,30,31,30,31
8460 RESTORE 8510
8470  FOR A=1 TO M
8480  READ B$
8490  NEXT A
8500 D$=B$+" "+STR$( T6 )+", "+STR$( Y )
8510 DATA"JAN.","FEB.","MAR.","APR.","MAY","JUNE","JULY","AUG.","SEPT.","OCT.","NOV.","DEC
8520 RETURN
8530 REM TIME IN MILITARY TIME
8540 C1=160 : REM                ***** MOD 3-3-80 *****
8560  FOR I=9 TO 4 STEP-1
8570  D=INP( C1+I ) : REM REMOVE TOP 4 BITS
8580  D=BINAND( D,15 ) : REM REMOVE TOP 4 BITS
8590  PRINT D; : REM PRINT DIGIT
8600  IF I=8 OR I=6 THEN PRINT":";
8610  NEXT I
8620 RETURN
9000 REM KIETHLEY READ
9010 OUT O0+%0003%,J0 : B( L )=INP( O0+%0001% ) : RETURN
9020 REM RELEASE 180
9030 OUT O0+%0003%,%00FF% : RETURN
9040 REM CHANGE DATA TO SOME THING THAT MAKES SENSE ON SCREEN
9050 REM ****************************************************
9060 REM D1=LSD D4=MSD
9070 D1=BINAND( B( 0 ),M4 )*1.0
9080 D2=BINAND( B( 0 ),M5 )*10.0/16.0
9090 D3=BINAND( B( 1 ),M4 )*100.0
9100 D4=BINAND( B( 1 ),M5 )*1000.0/16.0
```

```
9110 REM ********************************************************
9120 REM R1=POL R2=FUNCTION R3=OVER RANGE R4=D.P.
9130 R1=BINAND(B(2),M1) : IF R1=0 THEN R1=-1 : GOTO 9150
9140 R1=1
9150 R2=BINAND(B(2),M2) : IF R2=0 THEN R2=-3 : GOTO 9170
9160 R2=-6
9170 R3=BINAND(B(2),M3) : IF R3=0 THEN GOTO 9190
9180 R3=1
9190 R4=BINAND(B(2),M4) : R4=(LOG(R4)/LOG(2))
9200 IF INT(R4)=0 THEN R3=R3*1 : GOTO 9250
9210 IF INT(R4)=1 THEN R3=R3*10 : GOTO 9250
9220 REM ********************************************************
9230 IF INT(R4)=2 THEN R3=R3*100 : GOTO 9250
9240 IF INT(R4)=3 THEN R3=R3*1000 : GOTO 9250
9250 REM *****DUMMY
9260 A(W,K)=(((D1+D2+D3+D4)*10**(R4-4))+R3)*R1*10**R2
9270 RETURN
10000 REM ********** ESC ROUTINE **********
10001 REM
10002 NOESC
10005 PRINT CHR$(T9) : REM PRINTER OFF
10006 PRINT"INPUT 1=MSG 2=CMD MODE 3=START READOUT 4=FILE LAST READOUT"
10007 INPUT M9
10008 IF M9<1 OR M9>6 THEN 10006
10009 ON M9 GOSUB 10090,10150,10190,10200
10010 GOSUB 8090
10011 REM                              KEEP THE CLOCK WORKING
10012 F6=F5+F1
10013 F7=F1 : F8=F5
10014 IF F6>60.0 THEN F6=F6-60.0
10016 IF F6=F5 THEN F6=F6-1.0
10018 IF F6=60 THEN F6=59
10019 ESC
10020 RETURN
10090 PRINT : PRINT : PRINT : PRINT"MESSAGE= " : INPUT Z$
10100 PRINT CHR$(T8) : REM TURN PRINTER ON
10110 PRINT Z$
10130 PRINT CHR$(T9) : REM PRINTER OFF
10140 RETURN
10150 PRINT"RETURN TO PROGRAM USING:  GOTO 10155" : STOP
10155 RETURN
10160 REM
10170 PRINT TAB(30);"PLEASE USE 1 THRU 3 ONLY"
10180 GOTO 10060
10190 GOSUB 5000
10192 RETURN
10200 REM  * * * FILE LAST READOUT
10204 GOTO 10210
10205 OPEN\2,80,2\K2$ : OPEN\3,80,2\K3$ : OPEN\4,80,2\K4$
10210  FOR K5=2 TO 4
10215  PRINT\K5\USING"###.####",Z(27); : NEXT K5
10220  FOR K5=1 TO 8
10225  PRINT\2\USING" ####.## ",Z(K5); : NEXT K5
10230 PRINT\2\
```

```
10235  FOR K5=9 TO 16
10240  PRINT\3\USING" #####.##",Z(K5); : NEXT K5
10245 PRINT\3\
10250  FOR K5=17 TO 24
10255  PRINT\4\USING" #####.##",Z(K5); : NEXT K5
10260 PRINT\4\
10265 REM CLOSE
10268 PRINT CHR$(T8)
10270 PRINT"ABOVE POINT SELECTED FOR TABLE"
10272 PRINT CHR$(T9)
10275 RETURN
10300 REM * * SET BEEPER ON
10310 K8=1 : RETURN
10350 REM * * SET BEEPER OFF
10360 K8=0 : RETURN
11000 PRINT CHR$(26) : PRINT : PRINT : PRINT
11010 PRINT TAB(20);"THE CAL RESISTOR IS ";R;" OHMS DO YOU WANT TO CHANGE IT"
11020 PRINT TAB(20);"        (Y=YES RETURN=NO)"
11030 INPUT T$
11040 IF T$=""THEN 11080
11050 IF T$<>"Y"THEN 11000
11060 PRINT CHR$(26) : PRINT : PRINT : PRINT
11070 PRINT TAB(20);"WHAT IS THE VALUE FOR R "; : INPUT R
11080 PRINT CHR$(26) : PRINT : PRINT : PRINT
11090 PRINT TAB(20);"THE DELAY IS SET FOR 5 SEC/POINT. DO"
11100 PRINT TAB(20);"DO YOU WISH TO CHANGE IT  Y=YES RETURN=NO ";
11110 INPUT T$;
11120 IF T$=""THEN 11180
11130 IF T$<>"Y"THEN 11080
11140 PRINT CHR$(26) : PRINT : PRINT : PRINT
11150 PRINT TAB(20);"INPUT DELAY 3SEC/1000 UNITS I.E. IF YOU INPUT 1500";
11160 PRINT TAB(20);"THE DELAY WILL BE 4.5 SECS."
11170 PRINT TAB(20);"DELAY= "; : INPUT C
11180 REM
11200 PRINT CHR$(26) : REM             CLEAR SCREEN
11210 PRINT CHR$(T8) : REM             TURN ON PRINTER
11220 GOSUB 8210
11230 PRINT CHR$(T9) : REM             TURN OFF PRINTER
11250 PRINT"TYPE IN MINUTES HOW OFTEN YOU WISH A READOUT !";
11260 INPUT F1
11270 PRINT
11280 PRINT"TYPE IN RESISTOR # THAT YOU WISH CONNECTED TO KIETHLEY AFTER"
11290 PRINT"AUTO SCAN 'R' CAN BE BETWEEN 1 AND 26 " : PRINT
11300 PRINT" BOX#  POSITION--> --CAL---1---2---3---4---5---6---7---8--"
11310 PRINT"-----------------------------------------------------------"
11320 PRINT"  1                   CAL   1   2   3   4   5   6   7   8  "
11330 PRINT"  2                     9  10  11  12  13  14  15  16  17  "
11340 PRINT"  3                    18  19  20  21  22  23  24  25  26  "
11350 PRINT
11355 INPUT R9
11360 IF R9>26 OR R9<1 THEN 11280
11365 GOSUB 12000
11370 P=1
```

```
11420 REM * * CREATE FILES
11428 PRINT"INSERT DATA DISKETTE IN DRIVE B:"
11430 INPUT"ENTER CALIBRATION NUMBER ON RESISTORS:",K1$
11431 PRINT CHR$(T8)
11432 DSK"B:"
11435 K2$="B:A"+K1$
11440 K3$="B:B"+K1$
11445 K4$="B:C"+K1$
11450 CREATE K2$ : CREATE K3$ : CREATE K4$
11451 OPEN\2,80\K2$ : OPEN\3,80\K3$ : OPEN\4,80\K4$
11452 PRINT\2\K1$;"    - 1      - 2      - 3      - 4      - 5      - 6";
11453 PRINT\2\"      - 7      - 8   "
11454 PRINT\3\K1$;"    - 9      -10      -11      -12      -13      -14";
11455 PRINT\3\"      -15      -16   "
11456 PRINT\4\K1$;"    -17      -18      -19      -20      -21      -22";
11457 PRINT\4\"      -23      -24   "
11458 REM CLOSE
11459 PRINT CHR$(T9)
11490 PRINT CHR$(26) : REM              CLEAR SCREEN
11500 PRINT CHR$(27);"=71"; : REM       GO TO BOTTOM OF SCREEN
11510 PRINT CHR$(T8)
11550 REM ***** GO AND READ ALL RESISTORS *****
11560 GOSUB 5000
11570 REM ***** GO AND READ THE TIME (JUST MINUTES) *****
11580 GOSUB 8090
11590 F7=F1 : F8=F5
11600 F6=F5+F1
11610 IF F6>60.0 THEN F6=F6-60.0
11620 IF F6=F5 THEN F6=F6-1.0
11630 IF F6=60 THEN F6=59
11640 GOSUB 15080
11650 GOSUB 8090
11660 REM ***** STAY IN LOOP TILL ITS TIME TO DO ANOTHER RUN *****
11670 GOSUB 15000
11680 IF F6<>F5 THEN GOTO 11650
11690 REM                               CLEAR ROW
11700 GOSUB 15120
11710 REM GO READ CAL AND PRINT OUT ALL RESISTORS
11720 GOSUB 5000
11730 GOTO 11580
11995 REM                               DEFAULT RESISTOR
12000 R8=R9
12005 IF R9>8 THEN 12020
12010 B1=02 : R9=S(R9) : RETURN
12020 IF R9=9 THEN B1=%00C9% : R9=%00FD% : RETURN
12030 IF R9>17 THEN 12050
12040 B1=02+4 : R9=R9-9 : R9=S(R9) : RETURN
12050 IF R9=18 THEN B1=%00CD% : R9=%00FD% : RETURN
12060 B1=02+8 : R9=R9-18 : R9=S(R9) : RETURN
```

```
13200 REM ****************************************************************************
13210 REM *                               CGR RTN
13220 REM ******************************************************************************
13230 REM
13600 OPEN\1,200\R9$
13602 X=25
13605  FOR Y1=0 TO 100
13610   FOR X1=0 TO 1
13615   INPUT\1\G1(X1,Y1)
13620   NEXT X1
13625  NEXT Y1
13630 CLOSE\1\
13635 RETURN
13640 REM ***********************************************************************
13700 REM *                               18 OHM RTN
13710 REM ************************************
13720 GOTO 13780
13730 OPEN\1,50\R8$ : X=18
13740  FOR Y1=0 TO 24
13750   FOR X1=0 TO 1
13760   INPUT\1\G(X,X1,Y1)
13770   NEXT X1
13772  NEXT Y1
13775 CLOSE\1\
13780 RETURN
14000 REM GO DO CTR RTN
14010 @CHR$(T8);
14020 X=25 : REM R25=C1201
14030 GOSUB 14400
14035 Z(25)=ABS(Z(25))
14037 @"      ";
14040 IF A2(X)=1 THEN@"R1201= ";Z(25),"TEMPERATURE OUT OF RANGE" : GOTO 14090
14050 @"C1201= ";Z(25),"TEMPERATURE= ";A3(25);"K"
14051 PRINT"DRIFT OF CALIBRATEES SINCE LAST READOUT= ";Q5;"%"
14052 PRINT"DRIFT OF CALIBRATOR DURING THIS READOUT= ";Q6;"%"
14055 Z(27)=A3(25)
14090 @CHR$(T9); : RETURN
14100 REM DO 100 OHM RTN
14102 GOTO 14350
14105 Z(18)=ABS(Z(18))
14110 @CHR$(T8);
14120 X=18 : REM R100 IS IN SLOT 18
14130 GOSUB 14200
14135 @"      ";
14140 IF A2(X)=1 THEN@"R100= ";Z(18),"TEMPERTURE IS OUT OF RANGE" : GOTO 14190
14150 @"R100= ";Z(18),"TEMPERTURE= ";A3(18);" oK"
14190 @CHR$(T9); : RETURN
14200 REM ***********************************************************
14210 REM                                 18 TABLE LOOKUP
14215 REM
14220 A2(X)=0 : REM                       RESET RNG ERR FLAG
14230 IF Z(X)>G(X,1,0)THEN A2(X)=1 : RETURN
14240  FOR X1=0 TO 23
14245  IF G(X,0,X1)=0 THEN A2(X)=1 : RETURN
```

```
14250  IF Z(X)>G(X,1,X1)THEN 14270
14260  NEXT X1
14265 A2(X)=1 : RETURN
14266 REM ↑ NOT IN TABLE SO PRINT ***
14270 E=(LOG(G(X,0,X1-1)/G(X,0,X1)))/(LOG(G(X,1,X1-1)/G(X,1,X1)))
14280 Z3=Z(X)/G(X,1,X1-1)
14290 Z4=EXP(E*LOG(Z3))
14300 A3(X)=Z4*G(X,0,X1-1)
14350 RETURN
14360 REM
14400 REM ***************************************************************
14410 REM                               C.G.R. TABLE LOOK UP
14420 REM
14430 A2(X)=0 : REM            RESET RNG ERR FLAG
14440 IF Z(X)>G1(1,0)THEN A2(X)=1 : RETURN
14450  FOR X1=0 TO 98
14455  IF Z(X)>G1(1,X1)THEN 14470
14460  NEXT X1
14465 A2(X)=1 : RETURN
14470 E=(LOG(G1(0,X1-1)/G1(0,X1)))/(LOG(G1(1,X1-1)/G1(1,X1)))
14480 Z3=Z(X)/G1(1,X1-1)
14490 Z4=EXP(E*LOG(Z3))
14500 A3(X)=Z4*G1(0,X1-1)
14600 RETURN
15000 REM ************************************************************
15010 REM DISPLAY TIME TO GO
15020 REM
15030 IF F5<>F8 THEN 15050
15040 RETURN
15050 F8=F5
15060 F7=F7-1
15070 REM                               PRINT ON LINE 24 50
15080 PRINT CHR$(13);
15100 PRINT F7;
15110 RETURN
15120 PRINT CHR$(27);"=7 ";
15130 RETURN
15200 REM BEEPER SUBROUTINE
15210 IF K7*K8=0 THEN RETURN
15220 GOSUB 15300
15230 RETURN
15290 REM C1201 EQUIL. CHECKING SUBROUTINE
15300  FOR X=0 TO 8 STEP 4
15310  OUT 02+X,%00FF% : REM CLEAR BOXES
15320  OUT 01+X,%00FF% : NEXT X
15340 W=0 : REM CAL
15350 GOSUB 2000
15360 OUT 02,%00FF%
15370 W=25 : REM C1201
15380 OUT 02+8,S(W-18)
15390 GOSUB 2100
15400 OUT 02+8,%00FF%
15410 OUT B1,R9 : REM RECORDER
15420  FOR X=0 TO 8 STEP 4
```

```
15430  IF O1+X=B1 THEN O5=BINAND(R9,I(P)) : OUT B1,O5 : GOTO 15450
15440  OUT O1+X,I(P)
15450  NEXT X
15460 Q1=((A(25,0)-A(25,1))/(A(0,0)-A(0,1)))*R
15465 Q1=ABS(Q1)
15470 Q2=100.0*(Q1-Q0)/Q0 : Q0=Q1
15475 K6=ABS(Q2) : IF K6<K9 THEN K7=1 : GOTO 15480
15476 K7=0 : REM BEEPER
15480 PRINT CHR$(T8); : PRINT USING" ###.##%",Q2;
15490 Q3=Q3+1 : IF Q3=10 THEN PRINT : Q3=0
15500 PRINT CHR$(T9); : PRINT CHR$(7); : REM BEEP
15510 RETURN
```