5345 ELECTRONIC COUNTER

HEWLETT hp PACKARD

MEASURING WARM-UP CHARACTERISTICS AND AGING RATES OF CRYSTAL OSCILLATORS

Application Note 174-11 describes a calculator based HP Interface Bus System which automatically measures and plots warm-up characteristics and aging rates of crystal oscillators. The system uses standard ASCII compatible instruments: the 5345A Electronic Counter provides the requisite high resolution frequency measurements, the 59308A Timing Generator provides measurement timing, the 9820A Calculator performs the computations, and the HP Interface Bus is used to interface the instruments to the calculator. Use of the HP Interface Bus ensures that instruments need not be dedicated to this particular configuration. The bus allows instruments to be quickly and easily reconfigured to solve a variety of measurement problems. This measurement solution should be particularly useful to crystal oscillator manufacturers and instrument manufacturers who employ precision crystal oscillators in their instruments.

APPLICATION NOTE 174-11

hp

INTRODUCTION

The ultimate accuracy of most frequency counters and many other instruments is determined to a great extent by the accuracy of the mechanical vibrating frequency of a quartz plate used in the time base reference oscillator. To reduce variations in this reference frequency due to ambient temperature changes, the quartz plate is often placed in a crystal oven which maintains the quartz at a constant temperature, typically from 65° to 80°C. An important parameter for oven crystal oscillators is the warm-up time: the time required for the oscillator to be within specified limits of its final value frequency. For example, the 10544A oven crystal oscillator used in the 5345A Electronic Counter is specified as being within 5 parts in 10^9 of final value 15 minutes after turn-on (at 25°C).

In this application, the 5345A measures the frequency of an oscillator at user specified time intervals. The 9820A Calculator computes fractional frequency change for each data point and plots the resultant curve. By specifying longer gate times and longer times between measurements, the aging rate of the oscillator may be measured with a resolution up to 2 parts in 10^{12}.

MEASUREMENT SET-UP

The measurement system consists of the 5345A Electronic Counter (opt. 011), the 59308A Timing Generator, the 59405A opt. 020/021A HP-IB Calculator Interface, the 11221A Math ROM block, the 11220A PCI ROM block, the 9862A Calculator Plotter, and the 9820/21A Calculator with opt. 001 Extended Memory. The instruments are connected to the calculator as shown in Figure 1.

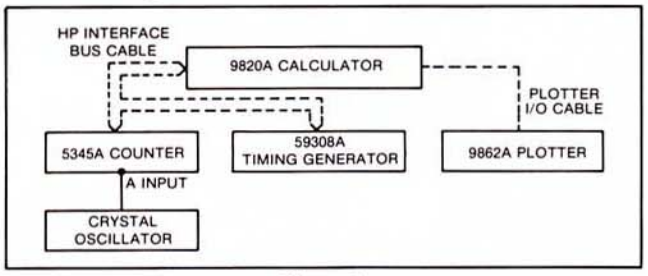

Figure 1

Set the Talk/Listen address switches on the frequency counter and timing generator as specified in Table 1. These switches are located on the rear panels of the instruments and must be set so as to agree with the Talk/Listen addresses in the program.

Table 1

	Talk/Listen Addresses	Mode Switch	A5	A4	A3	A2	A1
5345A Counter	K/* (K=computer dump)	addressable	0	1	0	1	††
59308A Timing Generator	R/2	addressable	1	0	0	1	0
9820A Calculator	U/5	ASCII Interface Card addresses preset to U/5 at factory.					

††*not used*

Place the Math, PCI, and PCII ROM blocks into ROM slots 1, 2, and 3 respectively of the 9820A Calculator. To interface the instruments to the calculator, perform the following: plug the ASCII Bus Interface Card into any of the four slots on the rear panel of the 9820A Calculator. Connect ASCII Interface Cables (10631A, B, or C) from the interface card of the Calculator to the rear panel plugs of the 5345A Counter and the 59308A Timing Generator (choose cable lengths such that the total length of ASCII cable does not exceed 18 feet). Plug the 9862A Calculator Plotter I/O Card into any of the three remaining slots on the rear panel of the calculator.

Set the following 5345A controls as a function of the oscillator under test: impedance (50 ohm or 1 Meg ohm), ac or dc, trigger level to preset (for symmetrical waveforms about 0 volts), attenuation (X1 or X20), and SEP/COM switch to separate. Since the calculator remotely controls all other front panel controls of the counter and all the controls of the timing generator, there is no need to set these controls to any particular positions.

PROGRAM OPERATION

Key into the calculator the program listed on the back of this application note. Take care when keying in PLT (PLOT), FMT (FORMAT), WRT (WRITE), and RED (READ) statements that a PCI key is not used when a PCII key is intended (keys labeled as above appear on both PCI and PCII ROM blocks — they provide different functions and may *not* be interchanged). All statements which are used in plotting refer to the PCI keys. All statements which involve transfer of data over the HP Interface Bus refer to the PCII keys. In this program, all PLT statements refer to PCI and all FMT, WRT, and RED statements refer to the PCII keys. If the program fails to operate, ensure that PCI and PCII statements have not been interchanged. After keying in the program, record it on a magnetic card for future use.

The program will request the operator to enter values for the following parameters:

"TIME (SEC)?" — enter the time in seconds between measurements (range: 5 sec ≤ T ≤ 99,900 sec).

"NO. OF MEAS?" — enter the desired number of frequency measurements to be made. This number times the TIME gives the total time over which measurements will be made. The number of measurements must be less than 195 and is limited by the storage capacity of the 9820A Calculator (opt. 001 Extended Memory).

"GATE TIME (SEC)" — enter 1, 10, 100, 1000 to obtain frequency resolution of 2 x 10^{-9}, 2 x 10^{-10}, 2 x 10^{-11}, and 2 x 10^{-12} respectively.

"FREQ?" — enter the nominal crystal oscillator frequency. This is the reference frequency and frequency deviation is calculated with respect to this input parameter. If 0 is entered, the reference frequency is chosen by the program to be the last frequency measurement made.

After entering each parameter, push RUN PROGRAM. After all parameters have been entered, the program halts and the calculator displays "PUSH RUN PROGRAM". At this time, the operator is expected to apply power to the crystal oven (if measuring the oscillator in an instrument, power is usually applied to the oven whenever the instrument is plugged in). After applying power to the oven, push RUN PROGRAM. The counter display will go blank due to the fact that measurements are being taken in computer dump output mode to obtain a constant 2×10^{-9} resolution per second of gate time independent of input frequency.

The program flow diagram describes the various steps which occur during program execution. After request-

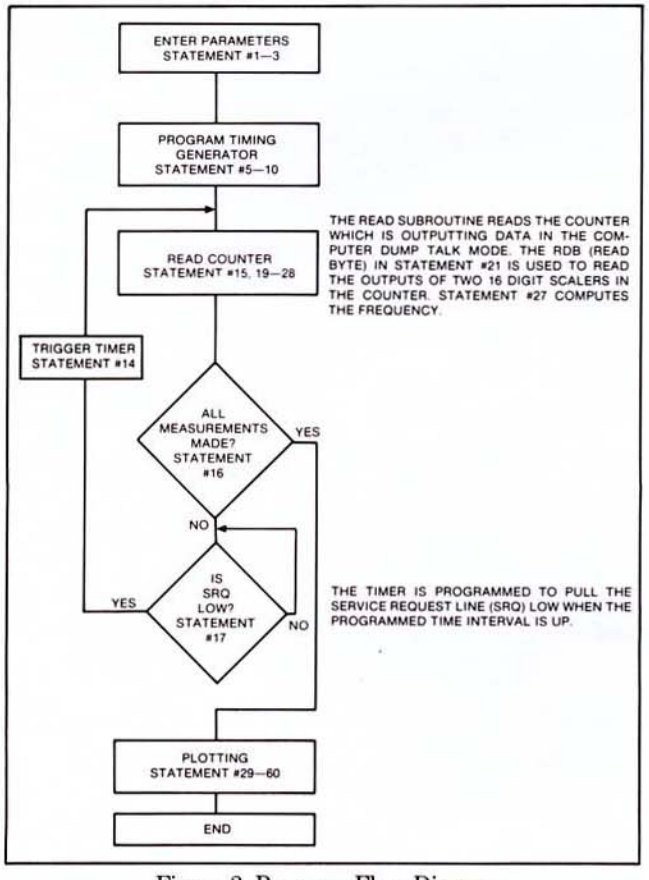

Figure 2. Program Flow Diagram

ing the measurement parameters, the timing generator is programmed to pull SRQ low the programmed number of seconds after receipt of the trigger command (R). When it is detected that SRQ is low, the counter is read. After all measurements have been made (each measurement is printed on the calculator printer), the calculation $(f_x - f_o)/f_o$ is performed and plotted as a function of time. f_x represents the oscillator frequency at a particular time and f_o represents the reference frequency which was entered into the program previously. Figure 3 is a plot of the warm-

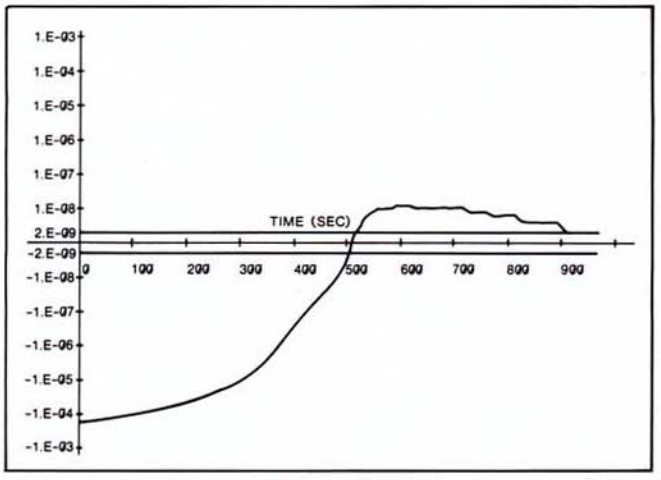

Figure 3

up curve for the 10544A crystal oscillator (used in the 5345A counter) which was generated by the program. The two horizontal lines centered about the time axis represent the resolution limit of the counter (for the gate time selected) and indicate that measurements falling within these boundaries may not be valid. Figure 4 shows aging in another oscillator over a time period of a few hours.

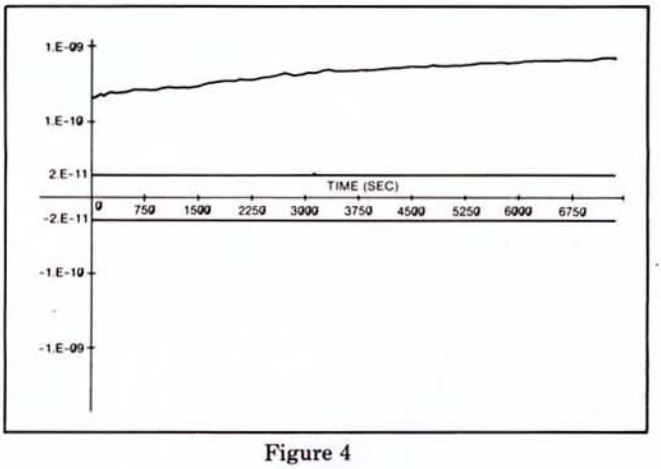

Figure 4

MEASUREMENT CONSIDERATIONS

a. To increase measurement accuracy, lock the 10544A reference oscillator in the 5345A to a "house standard". This is particularly important if the aging rate to be measured is less than the aging rate of the counter oscillator (<5×10^{-10}/day after 24 hour warm-up).

b. The computer dump mode of output allows measurement of $\Delta f/f$ to ±2 parts in 10^9 per second of gate time. The gate time must be less than the time between measurements.

c. The 9820A Calculator performs calculations with 12 digit precision (although it displays and prints only 10 digits). Even though the counter can be programmed for a 10,000 sec gate time (2 x 10^{-13} resolution), the additional resolution cannot be used since the calculator is limiting.

d. The execution time for portions of the program (specifically, reading the counter in computer dump mode) requires that frequency measurements be taken no faster than every 5 seconds.

9820/21A Program Listing

```
0:
DSP "CRYSTAL PLO
T";DSP ;DSP ;
DSP ⊢
1:
ENT "TIME(SEC)?"
,A;A→R39;ENT "NO
 OF MEAS",B;A(B-
1)→R38⊢
2:
ENT "GATE TIME (
SEC)",R9;9+LOG R
9→R8;CMD "?U*";
FMT Y2,Z;WRT 13;
WTB 13,71⊢
3:
WTB 13,48+LOG R9
;ENT "FREQ ?",R0
⊢
4:
FLT 5;-7→Z⊢
5:
"LP";INT (A/1.
TN↑ Z)→X;IF X≤99
9;GTO "EX"⊢
6:
Z+1→Z;GTO "LP"⊢
7:
"EX";INT (X/100)
→C;INT (X/10)-C*
10→Y⊢
8:
X-100*C-10*Y→X;Z
+6→Z⊢
9:
CMD "?U2","ST";
FMT Y2,Z;WRT 13;
WTB 13,C+48;WTB
13,Y+48;WTB 13,X
+48;WTB 13,69⊢
10:
WTB 13,Z+48⊢
11:
CMD "?U*","F0E37
9:8D0I1","?J";
DSP ⊢
12:
DSP "PUSH RUN PR
OGRAM";STP ⊢
13:
40→X⊢
14:
"STRT";CMD "?U2"
,"R"⊢
15:
GSB "READ"⊢
16:
FLT 9;PRT RX;X+1
→X;IF X=B+40;
GTO "PLT"⊢
17:
"CYC";IF RDS 13≤
1.9;GTO "STRT"⊢
18:
GTO "CYC"⊢
19:
"READ";CMD "?U*"
,"J1";CMD "?K5";
35→C;1→R32⊢
20:
"NEXT";0→R34→Z;1
→R33⊢
21:
"LOP";RDB 13-48→
Z⊢
22:
Z*R33+R34→R34⊢
23:
R32+1→R32;R33*10
→R33⊢
24:
IF R32≤16;GTO "L
OP"⊢
25:
R34→RC;C+1→C;1→R
32⊢
26:
IF C=36;GTO "NEX
T"⊢
27:
R35/(R36*2.E-9)→
RX⊢
28:
CMD "?";RET ⊢
29:
"PLT";40→X;-99→R
37;IF R0=0;R(39+
B)→R0⊢
30:
39+B→C⊢
31:
"A";(RX-R0)/R0→R
X⊢
32:
IF RX=0;GTO +2⊢
33:
IF LOG ABS RX>R3
7;LOG ABS RX→R37
⊢
34:
X+1→X⊢
35:
IF X≤C;GTO "A"⊢
36:
SCL -R38/10,1.1R
38,-(R37+R8+1),R
37+R8+1⊢
37:
IF FLG 0=1;GTO "
M"⊢
38:
AXE 0,0,B*R39/10
,1⊢
39:
PLT 0,LOG 2;PLT
R38,LOG 2;PEN ⊢
40:
PLT 0,-LOG 2;
PLT R38,-LOG 2;
PEN ⊢
41:
FXD 0;-.2→Y;0→C→
Z⊢
42:
"LTR";LTR C,Y,21
1⊢
43:
PLT C;C+B*R39/10
→C;Z+1→Z⊢
44:
IF Z≤9;GTO "LTR"
⊢
45:
FLT 0;-R38/10→X;
-1→C⊢
46:
"B";LTR X,C,211⊢
47:
PLT -1.*TN↑ (-C-
R8)⊢
48:
C-1→C;IF -C-R8≤R
37+1;GTO "B"⊢
49:
LTR X,LOG 2,211;
PLT 2.*TN↑ (-R8)
;LTR X,-LOG 2;
PLT -2.*TN↑ (-R8
);1→C⊢
50:
"C";LTR X,C,211⊢
51:
PLT 1.*TN↑ (C-R8
);C+1→C⊢
52:
IF C-R8≤R37+1;
GTO "C"⊢
53:
LTR R38/3,.1,221
⊢
54:
PLT "TIME (SEC)"
⊢
55:
"M";40→X;PEN ⊢
56:
"I";IF ABS RX≤1.
E-14;PLT (X-40)*
R39,0;GTO "H"⊢
57:
IF RX≤-1.E-13;
PLT (X-40)*R39,-
LOG ABS RX-R8;
GTO "H"⊢
58:
PLT (X-40)*R39,
LOG RX+R8⊢
59:
"H";X+1→X⊢
60:
IF X≤39+B;GTO "I
"⊢
61:
END ⊢
R237
```

USING THE 9830A CALCULATOR

The 9830A Calculator may be used in place of the 9820/21A Calculator with system operation remaining essentially unchanged. The following sections list the necessary equipment for operation with the 9830A Calculator, discuss any differences in program operation, and present the complete program listing of the 9830A software.

MEASUREMENT SET-UP

The 9830A measurement system consists of the 5345A Electronic Counter (opt. 011), the 59308A Timing Generator, the 59405A opt. 030 HP-IB Calculator Interface, the 9862A Calculator Plotter, the 9830A Calculator, the 11274B String Variables ROM, the 11271B Plotter Control ROM, and the 9866A Calculator Printer. Place the Extended I/O ROM, the String Variables ROM, and the Plotter Control ROM in any of the calculator ROM slots. The instruments are configured in precisely the same manner as in the case when the 9820A Calculator is the controller.

SYSTEM OPERATION

The system with the 9830A Calculator as controller operates basically in the same manner as the system with the 9820A Calculator as controller. The main difference is the extensive use of string variables for reading the counter in computer dump output mode and for setting delay times in the timing generator. This is solely a software difference and does not change actual system operation. The program requests the user to respond to the following:

"TIME INTERVAL (SEC)?" — enter the time in seconds between measurement (range: 5 sec ≤ T ≤ 99,900 sec).

"NUMBER OF MEASUREMENTS" — enter the desired number of frequency measurements to be made. This number must be less than 210 and is limited by the maximum allowable size of an array.

"GATE TIME (1, 10, 100, 1000, 1.E4)?" — enter the desired gate time.

"REFERENCE FREQUENCY?" — enter the reference frequency. If Ø is entered, the last frequency measurement is used for the reference.

"PUSH CONTINUE-EXECUTE" — after applying power to the oscillator, push the CONTINUE key followed by the EXECUTE key to start the measurements.

"NEW AXES—YES OR NO?" — after all measurements have been made, enter yes if it is desired to plot new axes and lettering. Otherwise, the axes and lettering will be skipped.

Figure 4 is a flow diagram of the 9830A software.

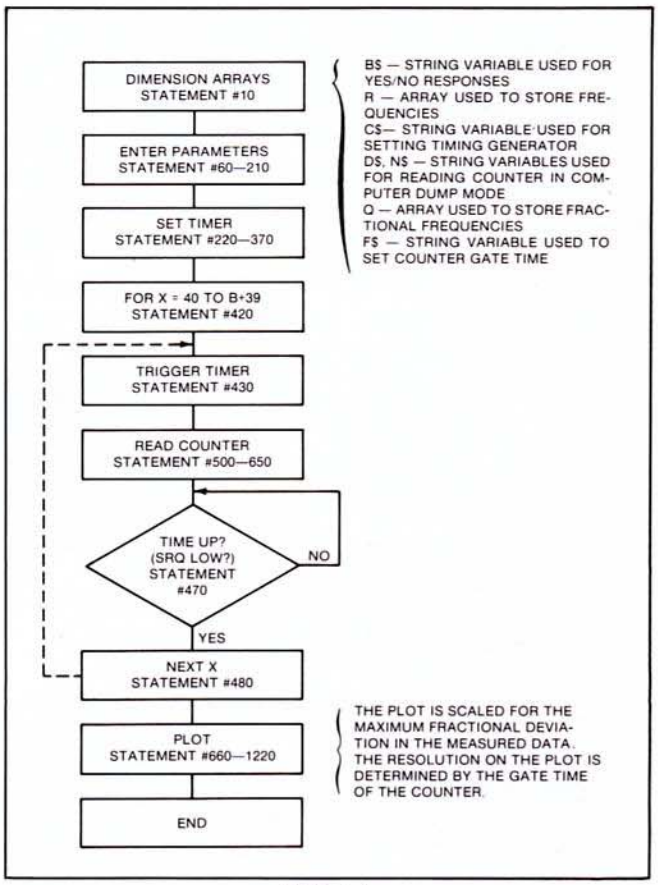

Figure 4

9830A Program Listing

```
10 DIM B$[4],R[250],C$[7],D$[17],
   N$[17],Q[250],F$[2]
20 C$="ST   E "
30 F$="G "
40 N$="                    "
50 D$="                    "
60 DISP "AN174-11: CRYSTAL WARMUP"
70 WAIT 1000
80 DISP "TIME INTERVAL (SEC)";
90 INPUT A
100 R[39]=A
110 DISP "NUMBER OF MEASUREMENTS";
120 INPUT B
130 R[38]=A*(B-1)
140 DISP "GATE TIME
    (1,10,100,1000,1.E4)";
150 INPUT R[9]
160 R[8]=9+LGT(R[9])
170 OUTPUT (F$[2,2],350)
    LGT(R[9]);
180 CMD "?U*"
190 OUTPUT (13,*)F$
200 DISP "REFERENCE FREQUENCY";
210 INPUT R
220 Z=-7
230 X=INT(A/(1*10↑Z))
240 IF X<999 THEN 270
```

9830A Program Listing

```
250 Z=Z+1
260 GOTO 230
270 C=INT(X/100)
280 Y=INT(X/10)-C*10
290 X=X-100*C-10*Y
300 Z=Z+6
310 OUTPUT (C$[3,3],350)C;
320 OUTPUT (C$[4,4],350)Y;
330 OUTPUT (C$[5,5],350)X;
340 OUTPUT (C$[7,7],350)Z;
350 FORMAT F1000.0
360 CMD "?U2"
370 OUTPUT (13,*)C$
380 CMD "?U*","F0E379:8D0I1","?J"
390 WAIT 100
400 DISP "PUSH CONTINUE-EXECUTE"
410 STOP
420 FOR X=40 TO B+39
430 CMD "?U2","R"
440 GOSUB 500
450 FLOAT 9
460 PRINT R[X]
470 IF STAT13>1.9 THEN 470
480 NEXT X
490 GOTO 660
500 CMD "?U*","J1"
510 CMD "?K5"
520 FOR I=1 TO 16
530 W=RBYTE13-48
540 OUTPUT (N$[17-I,17-I],550)W;
550 FORMAT F1000.0
560 NEXT I
570 FOR J=1 TO 16
580 W=RBYTE13-48
590 OUTPUT (D$[17-J,17-J],550)W;
600 NEXT J
610 N=VAL(N$)
620 D=VAL(D$)
630 R[X]=N/(D*2E-09)
640 CMD "?"
650 RETURN
660 R[37]=-99
670 IF R#0 THEN 690
680 R=R[39+B]
690 C=39+B
700 FOR X=40 TO C
710 Q[X]=(R[X]-R)/R
720 IF Q[X]=0 THEN 750
730 IF LGT(ABS(Q[X]))
    <= R[37] THEN 750
740 R[37]=LGT(ABS(Q[X]))
750 NEXT X
760 SCALE -R[38]*0.1,1.05*R[38],
    -INT(R[37]+R[8]+1.5),INT(R[37]
    +R[8]+1.5)
770 DISP "NEW AXES-YES OR NO";
780 INPUT B$
790 IF B$[1,1]#"Y" THEN 1130
800 XAXIS 0,R[38]/10
810 YAXIS 0,1
820 PLOT 0,LGT(2),1
830 PLOT R[38],LGT(2),2
840 PLOT 0,-LGT(2),1
850 PLOT R[38],-LGT(2),2
860 Y=-0.2
870 C=0
880 FOR Z=1 TO 10
890 PLOT C,Y,1
900 CPLOT -3,-0.1
910 LABEL (920,2,2,0,8/11)C
920 FORMAT F4.0
930 C=C+R[38]/10
940 NEXT Z
950 X=-R[38]/10
960 C=-1
970 PLOT X,C,1
980 LABEL (990)-1*10↑(-C-R[8])
990 FORMAT E7.0
1000 C=C-1
1010 IF -C-R[8] <= R[37]+1 THEN 970
1020 PLOT X,LGT(2),1
1030 LABEL (990)2*10↑(-R[8])
1040 PLOT X,-LGT(2),1
1050 LABEL (990)-2*10↑(-R[8])
1060 C=1
1070 PLOT X,C,1
1080 LABEL (990)1*10↑(C-R[8])
1090 C=C+1
1100 IF C-R[8] <= R[37]+1
     THEN 1070
1110 PLOT R[38]/3,0.1,1
1120 LABEL (*)"TIME(SEC)"
1130 FOR X=40 TO B+39
1140 IF ABS(Q[X])>1E-14 THEN 1170
1150 PLOT (X-40)*R[39],0
1160 GOTO 1210
1170 IF Q[X]>-1E-13 THEN 1200
1180 PLOT (X-40)*R[39],-LGT
     (ABS(Q[X]))-R[8]
1190 GOTO 1210
1200 PLOT (X-40)*R[39],
     LGT(Q[X])+R[8]
1210 NEXT X
1220 PEN
1230 GOTO 10
1240 END
```

For more information, call your local HP Sales Office or East (201) 265-5000 • Midwest (312) 677-0400 • South (404) 436-6181 • West (213) 877-1282. Or, write: Hewlett-Packard, 1501 Page Mill Road, Palo Alto, California 94304. In Europe, Post Office Box 85, CH-1217 Meyrin 2, Geneva, Switzerland. In Japan, Yokogawa-Hewlett-Packard, 1-59-1, Yoyogi, Shibuya-Ku, Tokyo, 151.

02-5952-7327 NOVEMBER 1974 Printed in U.S.A.