5345 ELECTRONIC COUNTER

HEWLETT hp PACKARD

MEASURING THE TUNING STEP TRANSIENT RESPONSE OF VCO'S TO 18 GHz

Application Note 174-13 describes a calculator based HP Interface Bus System which automatically measures and plots the transient response of a voltage controlled oscillator to a step in tuning voltage. VCO's ranging in frequency from dc to 18 GHz may be measured. The 5345A Electronic Counter makes the measurement system possible due to the high resolution achievable with even narrow gate times, its compatibility with frequency extender plug-ins, and its external gating and arming capabilities. The 59308A Timing Generator permits a timing range over which frequency measurements may be made from 11 μsec to 99,900 sec with step sizes as small as 1 μsec. The system is fast, accurate, and completely automatic and should be particularly useful to users and designers of voltage controlled oscillators, phase and frequency locked loops, and frequency control systems. Use of the HP Interface Bus ensures that the instruments need not be dedicated to this particular configuration. The bus allows instruments to be quickly and easily reconfigured to solve a wide variety of measurement problems.

APPLICATION NOTE 174-13

INTRODUCTION

Figure 1 shows a response of a VCO to a step in voltage from V_0 to V_1. The time interval Δt_0 may be considered as a settling time and is defined as the time required for the VCO output frequency to be within a specified percent of the final value. Another parameter of interest is often called post-tuning drift (PTD). In Figure 1, the post-tuning drift is shown as Δf and is defined as the frequency change between arbitrarily defined times t_1 and t_2. Time t_1 has been defined by various authors anywhere from 10 μsec to 1 second. Short term PTD could be arbitrarily defined as frequency change over the period from 10 μs to 1 sec and long term PTD for the time period from 1 second to 1 hour.

The cause of PTD is usually thermal in nature. The varactors, transistors, or Gunn diodes used in the oscillator can be characterized as networks of reactive components which have non-zero temperature coefficients. Since the frequency of oscillation depends upon the values of these reactive components, any temperature change in the active device may result in a change in frequency. Conversely, a change in frequency (brought about by a change in tuning voltage) is often the cause for a change in temperature. This temperature change may be the result of any or all of the following: change in efficiency of the active devices at the new frequency; change in the power applied to the varactor at the new frequency; change in Q of the varactor at the new frequency; change in the amount of dc current through the varactor. In addition, the magnitude of the PTD is directly proportional to the amount of power dissipated by the components of the oscillator.

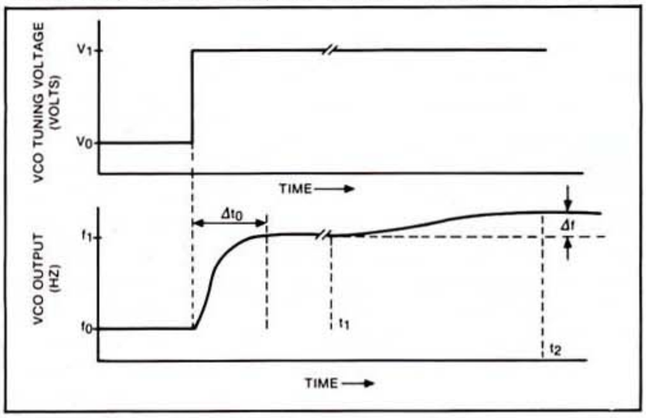

Figure 1

With the small thermal masses associated with active device junctions, junction temperature changes are usually complete in milliseconds. If the semiconductor package also changes temperature, the PTD may extend to several minutes.

This application note describes a system which can be used to measure settling time for VCO's. In addition, for those cases where thermal time constants are on the order of milliseconds, the system is useful for measuring post tuning drift.

MEASUREMENT SET-UP

The measurement system consists of the 5345A Electronic Counter (Opt. 011), the 59308A Timing Generator, two 59303A D-to-A Converters, the 59405A Opt. 020/021 HP-IB Calculator Interface, the 11221A Math ROM block, the 11220A PC I ROM block, the 9862A Calculator Plotter, and the 9820/21 Calculator with Option 001 Extended Memory. For frequencies greater than 500 MHz, the 5354A Automatic Frequency Converter (to 4 GHz) or the 10590A Plug-in Adapter in combination with the 5255A Heterodyne Converter (3 GHz to 12.4 GHz) or the 5256A Heterodyne Converter (8 GHz to 18 GHz) may be used. The instruments are interconnected as shown in Figure 2. Connect the output of DAC #1 (address <, =) to the TRIGGER INPUT on the rear panel of the Timing Generator. Set the Timing Generator TRIGGER controls for positive slope and 4V, 1kΩ. Connect the ECL output of the Timing Generator to the GATE CONTROL INPUT of the 5345A Electronic Counter. Set the OUTPUT controls of the Timing Generator for 500 ns PULSE and negative slope. Also, set the BUS CONTROL switch to OFF and the FREQ STD. switch to INT. Set the GATE CONTROL INPUT switch on the 5345A Counter to EXT ARM.

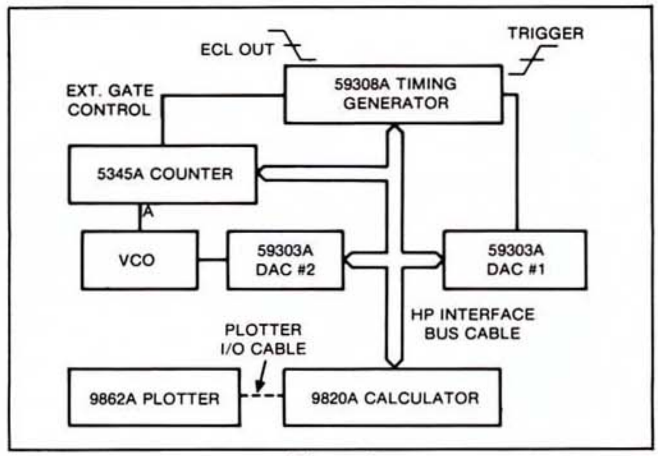

Figure 2

Set the Talk/Listen address switches on the 5345A counter, the two 59303A DAC's, and the 59308A Timing Generator as specified in Table 1. These switches are located on the rear panels of the instruments and must be set as specified so as to agree with the addresses used in the program.

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, each of the 59303A D to A Converters, and

Table 1

	Talk/Listen Address	Mode Switch	A5	A4	A3	A2	A1
5345A Counter	J/*	addressable	0	1	0	1	††
59308A Timing Generator	R/2	addressable	1	0	0	1	0
59303A DAC (#1)	/=(program) /≤(data)	addressable	1	1	1	0	††
59303A DAC (#2)	/9(program) /8(data)	addressable	1	1	0	0	††

††*not used*

the 59308A Timing Generator (choose cable lengths such that the total length of ASCII cable does not exceed 30 feet). Plug the 9862A Calculator Plotter I/O Card into any of the three remaining slots on the rear panel of the calculator.

In the program, the front panel controls of the 5345A Counter are not remotely programmed. It is therefore necessary to perform the following. Set the FUNCTION switch to frequency or PLUG-IN (if using a frequency extender plug-in), the SAMPLE RATE control to HOLD (full clockwise), and the GATE TIME to 10 μsec for a 10 μsec averaging time. Select proper input amplifier signal conditioning as a function of the VCO under test. Since the calculator remotely controls the operation of the two DAC's and the Timing Generator in the program, there is no need to set these controls to any particular positions.

THEORY OF OPERATION

The measurement system shown in Figure 2 works on a sampling principle much like a sampling oscilloscope. Since the calculator is not fast enough to sequentially gather a large number of output frequency points after a single step in tuning voltage, a sequence of identical tuning voltage steps are applied to the VCO and a single frequency point is obtained from each. By gradually increasing the time delay between the application of the voltage step and the frequency measurement, the transient response curve may be generated as shown in Figure 3.

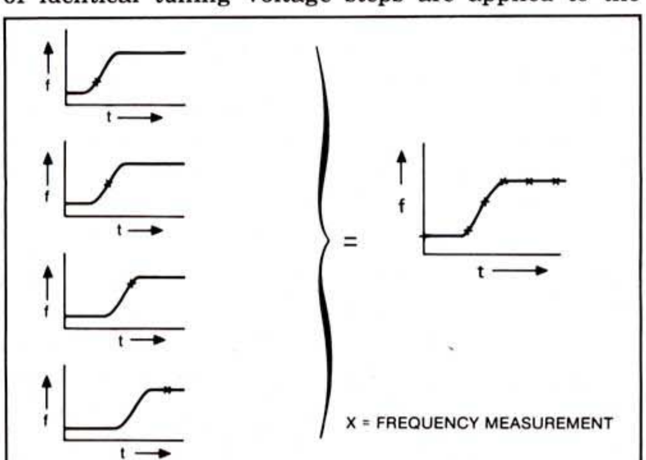

Figure 3

In Figure 2, DAC #1 outputs a voltage step from 1V to 6V which is used to trigger the Timing Generator. Simultaneously, DAC #2 outputs a user defined voltage step to the VCO under test. After passage of the programmed delay time, the timing generator outputs a 500 nsec pulse which arms the 5345A Counter. The counter starts a frequency measurement upon the next positive zero crossing of the input signal (for the counter in preset trigger level and + slope). The counter outputs the frequency to the calculator which stores the frequency and corresponding time delay. The time delay is incremented and the process repeats itself.

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.

The program will request the user to enter values for the following parameters (push RUN PROGRAM after each entry):

"START VOLTAGE" — enter the voltage level in volts which DAC #2 is to initially present to the VCO under test.

"STOP VOLTAGE" — enter the voltage level in volts which DAC #2 switches to upon command from the calculator.

"START TIME" — enter the time in seconds at which the first frequency measurement is to be made. This value must be greater than or equal to 1 μsec.

"STOP TIME" — enter the time in seconds at which the final frequency measurement is to be made. This value must be less than or equal to 99,900 sec.

"NO. OF STEPS" — enter the number of steps in time which are to be made in going between the starting time and the stopping time. This number must be less than or equal to 200 and is limited by the storage capacity of the 9820A Calculator (Option 001). The (STOP TIME-START TIME)/NO. OF STEPS should be an integer multiple of 1 μsec to avoid errors caused by rounding (the Timing Generator has 1 μsec resolution for times up to 999 μsec).

After the measurements have been made, the user must respond to the following:

"NEW AXES (1 = Y)" — enter 1 if the plot is to be made with new axes and new scale. Otherwise, the data will be plotted according to the previous axes and scale.

"PRINT?? (1 = Y)" — enter 1 if the time and frequency for each measurement point is to be printed by the calculator printer. The time is printed followed by the corresponding frequency.

Figure 4 is a flow diagram of the program. Figure 5,

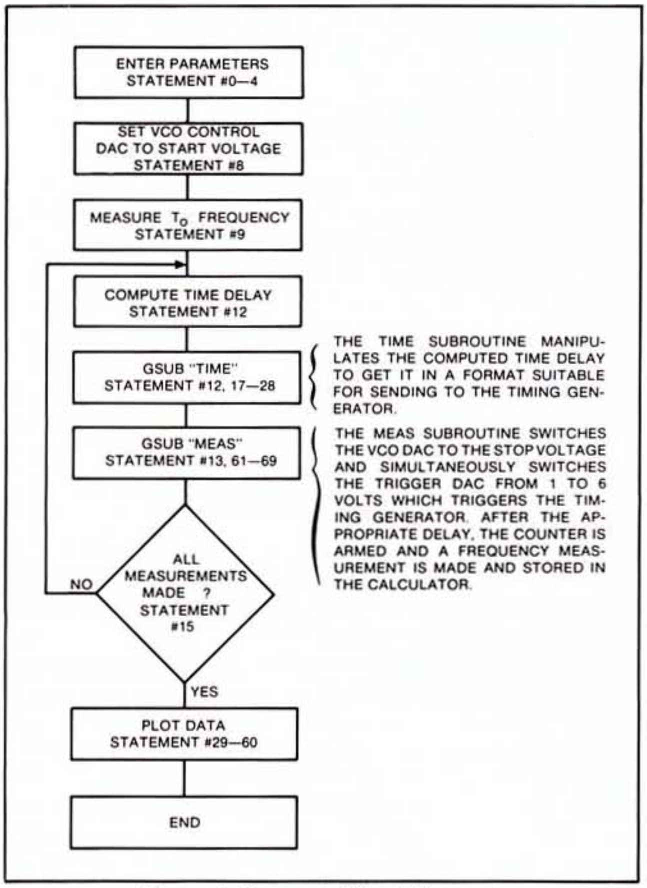

Figure 4. Program Flow Diagram

6, and 7 show actual plots made by the system with the HP 8601 Sweeper/Generator used as the VCO. Figure 5 is a family of curves for different step inputs into the VCO—the gate time used was 10 μsec. Figure 6 expands the time scale about the origin and Figure 7 expands the time scale about 250 μsec.

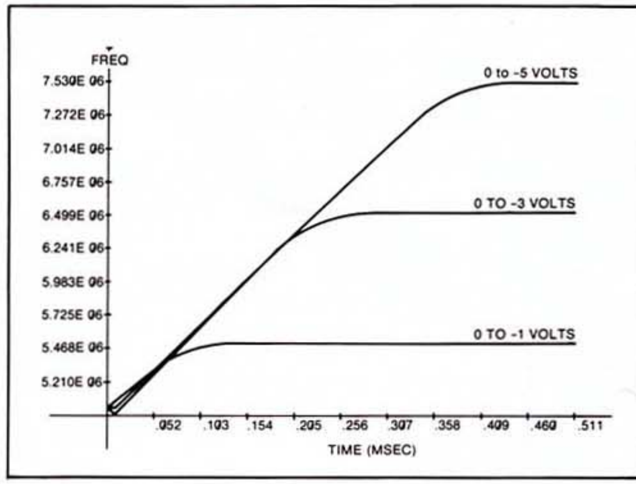

Figure 5

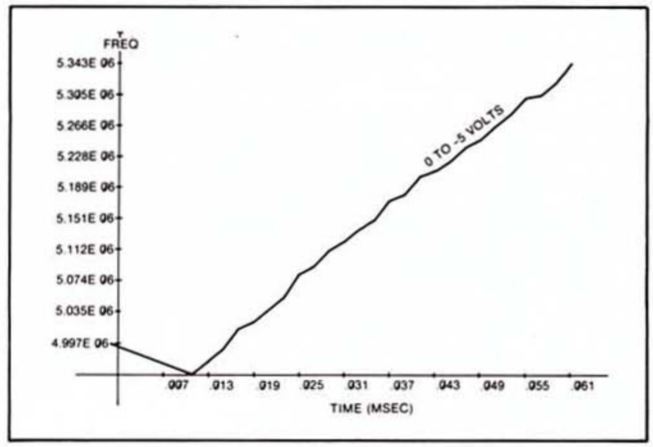

Figure 6

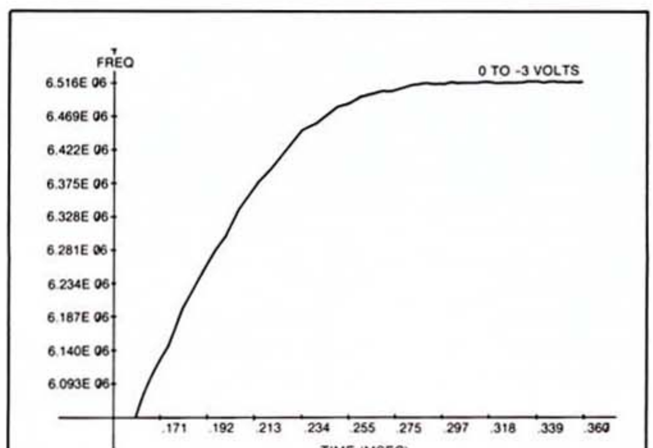

Figure 7

MEASUREMENT CONSIDERATIONS

a. The 59303A D to A Converter is specified as having a worst case settling time to ±1/2 LSB of 30 μsec. This specification is applicable to a + full scale to - full scale step change. For smaller step changes, the settling time is less. If a faster step change is desired, DAC #2 could be used to trigger a fast rise time pulse generator which could then drive the VCO.

b. There is approximately 10 μseconds of extra delay between the time of the application of the voltage step to the VCO and the time the counter is armed for a measurement. This is due to the rise time of DAC #1 in passing from 1 volt to 6 volts (which triggers the Timing Generator) and the delay through the Timing Generator. This time is accounted for in statement #6 of the program and means that the first measurement point which can be taken actually occurs at least 11 μsec after application of the voltage step to the VCO. The actual delay for a particular system can be measured and used to replace the 10 μsec value stored in R211 in the program.

c. The counter gives 9 digits of information in 1 second of gate time. The gate time chosen should be small enough so as not to average out the frequency changes which are to be observed. Using a 10 μsec Gate time, 4 digits of information may be obtained. To obtain greater resolution, the VCO output frequency could be mixed with a stable Local Oscillator and low pass filtered. With the LO properly selected, the counter would only "see" those digits which are actually changing. For example, if the VCO is varying from 150 MHz to 155 MHz, the counter with a 10 μsec gate would give 100 kHz resolution. By mixing with a 146 MHz L.O. and low pass filtering, the counter would measure frequencies from 4 MHz to 9 MHz and give 1 kHz resolution. This may be most easily accomplished by using the 10590A Plug-in Adapter and the 5253B Heterodyne Converter which gives an IF in the range of 100 kHz to 10 MHz.

d. For frequencies greater than 500 MHz, the HP 5354A Automatic Frequency Converter Plug-in (range of 15 MHz to 4 GHz) could be used. For frequencies from 3 GHz to 12.4 GHz, use the 10590A Plug-in Adapter and the 5255A Heterodyne Converter. For frequencies from 8 GHz to 18 GHz, use the 10590A and the 5256A Heterodyne Converter. Choose a band of operation which will allow the converter to remain in the same band for the extremes in frequency from the VCO.

e. When measuring post tuning drift caused by temperature changes in the tuning diode and other components, thermal time constants must be allowed to die out between each measurement. In the program, the time between returning the tuning voltage to the START VOLTAGE and raising it to the STOP VOLTAGE is approximately .5 second (each DSP in statement #63 takes up .17 seconds). To increase this time, more DSP commands could be inserted.

9820/21A Program Listing

```
0:
ENT "START VOLTA
GE",A⊢
1:
ENT "STOP VOLTAG
E",B⊢
2:
ENT "START TIME"
,X⊢
3:
ENT "STOP TIME",
Y⊢
4:
Z-10→Z;ENT "NO.
OF STEPS",Z⊢
5:
CMD "?U*","I2E99
:I1","?J";DSP ⊢
6:
10→C;10.E-6→R211
⊢
7:
(Y-X)/Z→R0⊢
8:
CMD "?U8≤";FMT "
100,",FXD *.0;
WRT 13,100*A;
DSP ;DSP ;DSP ⊢
9:
CMD "?U*","J1","
?J5";FMT *;RED 1
3,R9;CMD "?U*","
I2E:I1";"?J";
DSP ;DSP ⊢
10:
Z+10→Z⊢
11:
CMD "?U*","I2E:I
1","?J";DSP ;
DSP ⊢
12:
"LP";X+(C-10)*R0
→R1;GSB "TIME"⊢
13:
GSB "MEAS"⊢
14:
C+1→C⊢
15:
IF C>Z;GTO "PLT"
⊢
16:
GTO "LP"⊢
17:
"TIME";-6→R2⊢
18:
IF R1≤9.E-6;9→R8
;GTO "L"⊢
19:
IF R1≤99.E-6;99→
R8;GTO "L"⊢
20:
999→R8⊢
21:
"L";INT (R1/1.
TN↑ R2)→R3;IF R3
≤R8;GTO "EX"⊢
22:
R2+1→R2;GTO "L"⊢
23:
"EX";INT (R3/100
)→R4;INT (R3/10)
-R4*10→R5;R3-100
*R4-10*R5→R3⊢
24:
R2+6→R2⊢
25:
CMD "?U2","DT";
```

```
FMT Y2,Z;WRT 13;
WTB 13,R4+48;
WTB 13,R5+48;
WTB 13,R3+48⊢
26:
WTB 13,69;WTB 13
,R2+48⊢
27:
CMD "?U2","R";
DSP ;DSP ;CMD "?
J"⊢
28:
RET ⊢
29:
"PLT";10→C;ENT "
NEW AXIS (1=Y)?"
,R8;IF R8≠1;GTO
"V"⊢
30:
IX-(Y-X)/8,Y+(Y-
X)/10+R211,R10-(
RZ-R10)/10,RZ+.1
*(RZ-R10)⊢
31:
JX,R10,(Y+R211-X
)/10,(RZ-R10)/10
⊢
32:
1→R6⊢
33:
"Z";X+R6*(Y+R211
-X)/10→A⊢
34:
LA,R10-(RZ-R10)/
20,211⊢
35:
FXD 3;MA/1.E-3⊢
36:
R6+1→R6;IF R6>10
;JMP 2⊢
37:
GTO "Z"⊢
38:
LX+(Y-X)/3,R10-(
RZ-R10)/10,241⊢
39:
M"TIME (MSEC)";1
→R6⊢
40:
"X";L-(Y-X)/8,R1
0+R6*(RZ-R10)/10
,211⊢
41:
FLT 3;MR10+R6*(R
Z-R10)/10⊢
42:
R6+1→R6;IF R6>10
;JMP 2⊢
43:
GTO "X"⊢
44:
L-(Y-X)/10,RZ+.0
5*(RZ-R10),241⊢
45:
M"FREQ"⊢
46:
"V";ENT "PRINT??
(1=Y)",R8⊢
47:
IF R8≠1;JMP 3⊢
48:
FLT 5;PRT 0⊢
49:
FLT 5;PRT R9⊢
50:
M0,R9⊢
51:
SPC 1⊢
52:
"W";IF R8≠1;JMP
3⊢
53:
FLT 5;PRT X+(C-1
0)*R0+R211⊢
54:
FLT 5;PRT RC;
SPC 1⊢
55:
MX+(C-10)*R0+R21
1,RC⊢
56:
C+1→C⊢
57:
IF C>Z;JMP 2⊢
58:
GTO "W"⊢
59:
K⊢
60:
GTO 0⊢
61:
"MEAS";0→R7⊢
62:
CMD "?U=","E0","
?U9","M0"⊢
63:
CMD "?U8≤";FMT "
100,",FXD *.0;
WRT 13,100*A;
DSP ;DSP ;DSP ⊢
64:
CMD "?U8≤";FMT "
600,",FXD *.0;
WRT 13,100*B⊢
65:
"A";IF RDS 13≤1.
5;JMP 3⊢
66:
R7+1→R7;IF R7>20
;CMD "?";GTO "ME
AS"⊢
67:
GTO "A"⊢
68:
CMD "?J5";FMT *;
RED 13,RC;CMD "?
"⊢
69:
RET ⊢
70:
GTO 0⊢
71:
END ⊢
R231
```

USING THE 9830A CALCULATOR

The 9830A Calculator may be used in place of the 9820/21A Calculator with system operation remaining virtually unchanged. The following sections list the necessary equipment for operation with the 9830A Calculator, discuss any differences in program operation, and present a 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, two 59303 D-to-A Converters, 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 9820/21A 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. One difference is that multiple plots such as shown in Figure 5 may not be generated since the SCALE statement must be executed each time the program is run in 9830A operation and therefore each individual plot will rescale the plotting area. The program requests the user to respond to the following:

"START VOLTAGE?" — same as 9820 program.

"STOP VOLTAGE?" — same as 9820A program.

"START TIME?" — same as 9820A program.

"STOP TIME?" — same as 9820A program.

"NUMBER OF STEPS?" — enter the number of steps in time which are to be made in going between the starting time and the stopping time. This number must be less than 250 and is limited by the maximum allowable size for an array.

"LETTERING — YES OR NO?" — after all measurements have been made, enter YES if the plot is to be lettered.

"PRINT VALUES — YES OR NO?" — enter yes if the time and frequency for each measurement point is to be printed on the calculator printer.

Figure 8 is a flow diagram of the 9830A program.

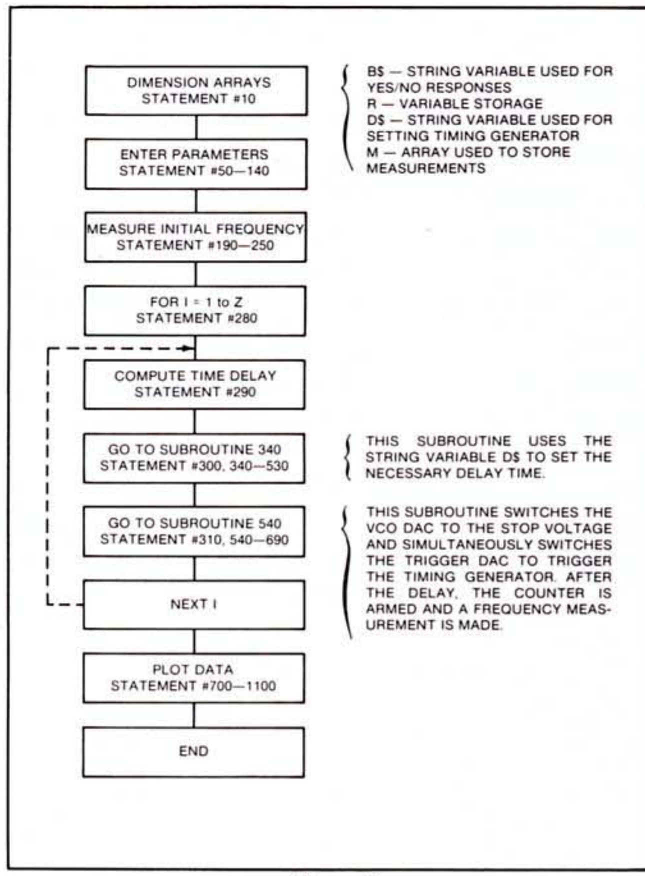

Figure 8

9830A Program Listing

```
10 DIM B$[3],R[10],D$[7],M[250]
20 D$="DT    E  "
30 DISP "AN174-13:VCO
   STEP RESPONSE"
40 WAIT 1000
50 DISP "START VOLTAGE";
60 INPUT A
70 DISP "STOP VOLTAGE";
80 INPUT B
90 DISP "START TIME";
100 INPUT X
110 DISP "STOP TIME";
120 INPUT Y
130 DISP "NUMBER OF STEPS";
140 INPUT Z
150 CMD "?U*","I2E89:I1","?J"
160 WAIT 100
170 E=1E-05
```

```
180 R=(Y-X)/Z
190 CMD "?U9","M0","?U=","E0"
200 CMD "?U8<"
210 OUTPUT (13,220)100*A
220 FORMAT "100,",F1000.0
230 WAIT 100
240 CMD "?U*","J1","?J5"
250 ENTER (13,*)R[9]
260 CMD "?U*","I2E:I1","?J"
270 WAIT 100
280 FOR I=1 TO Z
290 R[1]=X+I*R
300 GOSUB 340
310 GOSUB 540
320 NEXT I
330 GOTO 700
340 L=-6
350 M=INT(R[1]/(10↑L))
360 IF M <= 999 THEN 390
370 L=L+1
380 GOTO 350
390 N=INT(M/100)
400 P=INT(M/10)-N*10
410 M=M-100*N-10*P
420 L=L+6
430 OUTPUT (D$[3,3],440)N;
440 FORMAT F1000.0
450 OUTPUT (D$[4,4],440)P;
460 OUTPUT (D$[5,5],440)M;
470 OUTPUT (D$[7,7],440)L;
480 CMD "?U2"
490 OUTPUT (13,*)D$
500 CMD "?U2","R"
510 WAIT 500
520 CMD "?J"
530 RETURN
540 R[7]=0
550 CMD "?U=","E0","?U9","M0"
560 CMD "?U8<"
570 OUTPUT (13,580)100*A
580 FORMAT "100,",F1000.0
590 WAIT 500
600 OUTPUT (13,610)100*B
610 FORMAT "600,",F1000.0
620 IF STAT13<1.9 THEN 670
630 R[7]=1+R[7]
640 IF R[7]<20 THEN 620
650 CMD "?"
660 GOTO 540
670 CMD "?J5"
680 ENTER (13,*)M[I]
690 RETURN
700 DISP "LETTERING-YES OR NO";
710 INPUT B$
720 Q=(Y-X)/10
730 S=(M[Z]-M[1])/10
740 SCALE X-2*Q,Y+Q+E,
    M[1]-S,M[Z]+S
750 IF B$[1,1]#"Y" THEN 950
760 XAXIS M[1],Q,X+E,Y+E
770 YAXIS X+E,S,M[1],M[Z]
780 FOR J=1 TO 10
790 A=X+E+J*Q
800 PLOT A,M[1]-S/2,1
810 LABEL (*,1.7,2.5,0)
820 CPLOT -4,0
830 LABEL (840,1.7,2.5,0,
    8/11)A/1E-03
840 FORMAT F6.3
850 NEXT J
860 PLOT X+(Y-X)/3,M[1]-S,1
870 LABEL (*,3,2,0)"TIME (MSEC)"
880 FOR K=0 TO 10
890 PLOT X-1.8*Q,M[1]+K*S,1
900 LABEL (910,1.7,3,0)M[1]+K*S
910 FORMAT E11.4
920 NEXT K
930 PLOT X-Q,M[Z]+S/2,1
940 LABEL (*,3,2,0)"FREQ"
950 DISP "PRINT VALUES-YES OR NO";
960 INPUT B$
970 IF B$[1,1]#"Y" THEN 1010
980 FLOAT 5
990 PRINT 0
1000 PRINT R[9]
1010 PLOT 0,R[9]
1020 PRINT
1030 FOR I=1 TO Z
1040 IF B$[1,1]#"Y" THEN 1080
1050 PRINT X+I*R+E
1060 PRINT M[I]
1070 PRINT
1080 PLOT X+I*R+E,M[I]
1090 NEXT I
1100 PEN
1110 GOTO 10
1120 END
```

For more information, call your local HP Sales Office or East (301) 948-6370 • Midwest (312) 255-9800 • South (404) 955-1500 • West (213) 877-1282. Or, write: Hewlett-Packard, 1501 Page Mill Road, Palo Alto, California 94304. In Europe, Post Office Box, CH-1217 Meyrin 2, Geneva, Switzerland. In Japan, Yokogawa-Hewlett-Packard, 1-59-1, Yoyogi, Shibuya-Ku, Tokyo, 151.

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