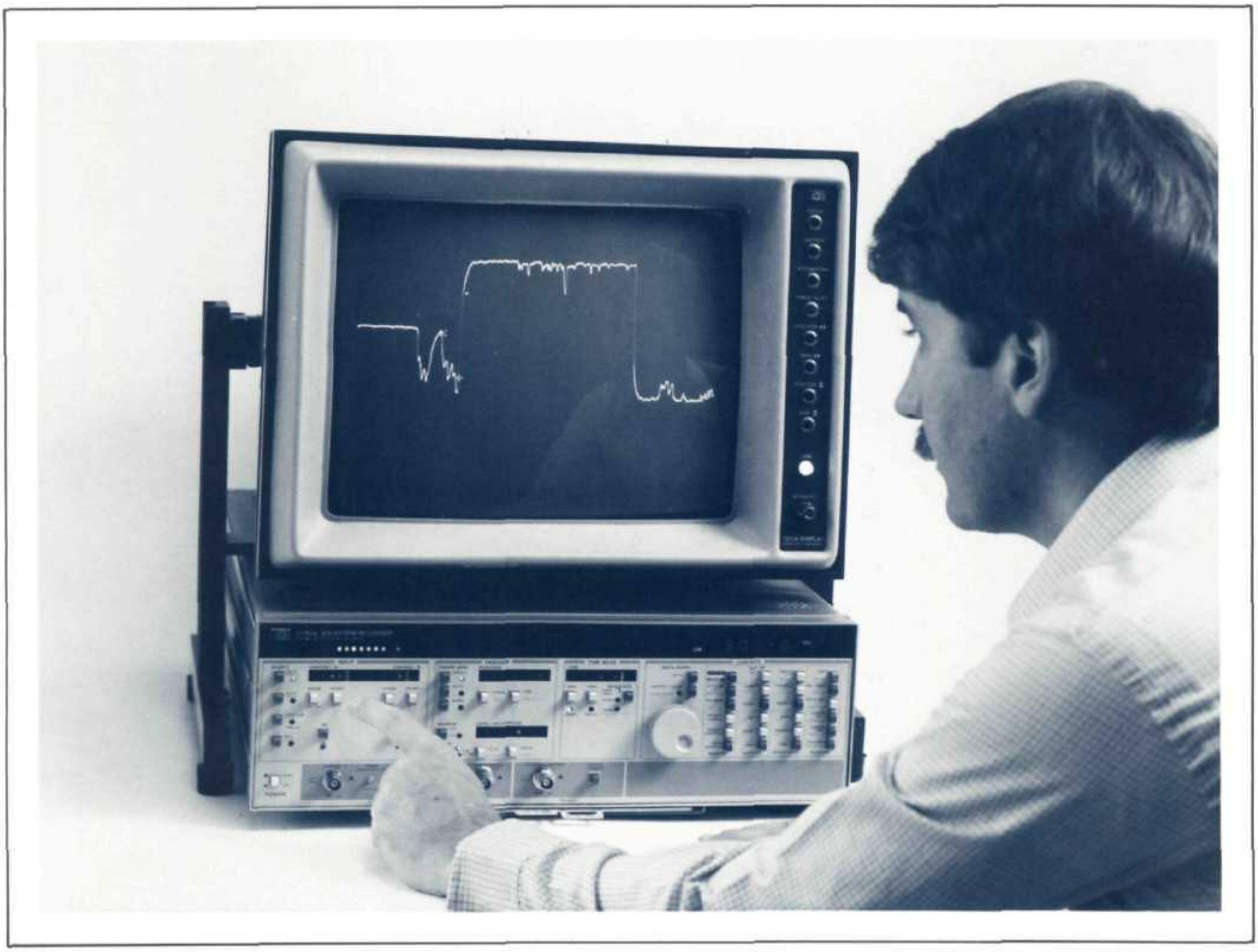
Application Note 313-3

Using the 5180A Waveform Recorder to Measure Microwave VCO Settling Time and Post Tuning Drift



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Introduction

The voltage controlled oscillator has become a key component in many modern electronic systems because it offers a unique combination of features: fast tuning speeds, high output power, wide output bandwidth, and low AM and FM noise. VCO's have evolved from basic components to sophisticated subsystems capable of 1 MHz set-on accuracies in nanosecond time-frames. Furthermore, improvements in semiconductor fabrication have made the VCO a **reliable** source of microwave energy.

As the demand for VCO capabililty has increased, so has the need to develop accurate VCO testing methods. Though each VCO type has different performance characteristics*, all VCO's are tested to evaulate the same performance parameters. Two of the most important and most difficult VCO test measurements are settling time and post tuning drift. These are transient response tests measuring the behavior of the VCO output following an abrupt change of VCO tuning voltage. Settling time is usually a relatively short time interval following the tuning step and is the time from the tuning step until the VCO output is within a specified Δf of the intended final frequency. Post tuning drift tests usually span more time than the settling time test and are defined as the largest frequency drift occurring between any two specified times. Figure 1 illustrates these tests.

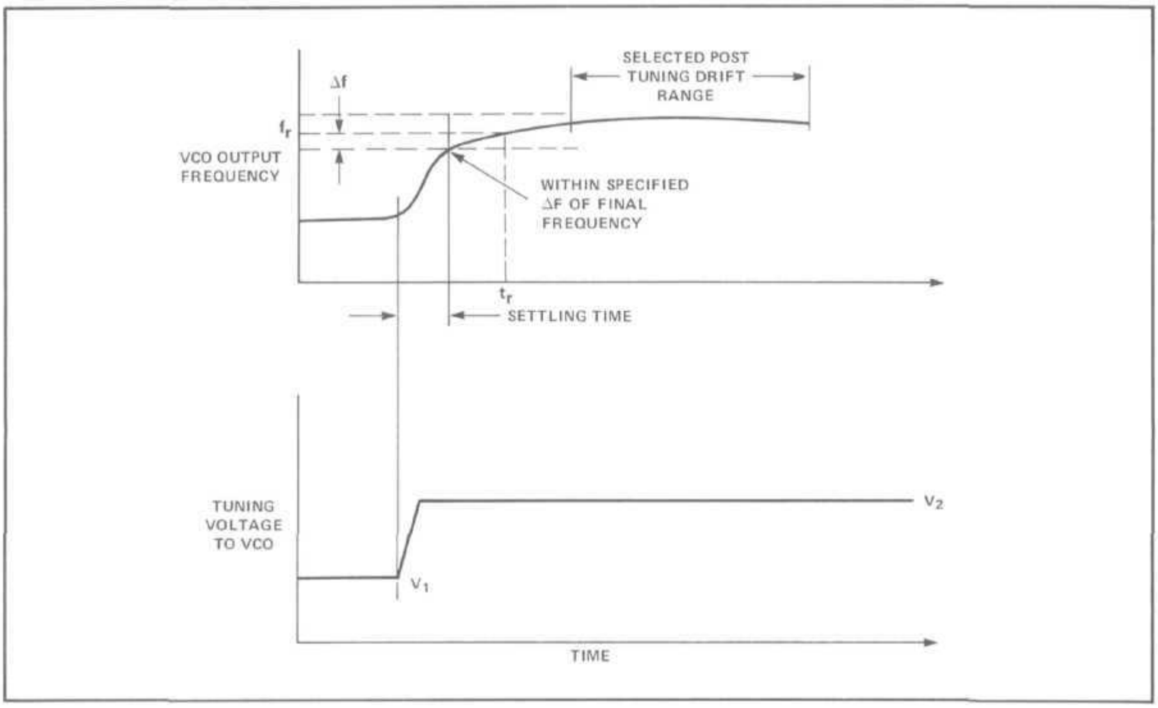

Figure 1. VCO Settling Time and Post Tuning Drift. t_r is specified time for determination of intended final frequency.

A BETTER TEST SYSTEM

Traditional approaches to testing settling time and post tuning drift are time consuming and limited by the ability of an operator to judge deviation on an oscilloscope display. The test set-up proposed in this note is shown in Figure 2. At first glance the block diagram may appear substantially like any traditional VCO test system. The difference is that a 5180A Waveform Recorder has replaced the oscilloscope as the final measurement instrument. By replacing the scope with a 5180A, the test quality improves in several areas:

1) The VCO no longer has to be repeatedly switched from V_1 to V_2 since the 5180A can capture all the data from a single switching (the traditional scope method requires repeated VCO switching in order to see any output).

2) Because the waveform recorder needs only a single voltage tuning step of the VCO to get the data, the test method more accurately represents the operation of the VCO in actual use (there are few applications where a VCO is repeatedly retuned to the same frequency). The time-frame for a VCO subsystem to reach equilibrium (due to thermal and ion migration *effects) can range* from microseconds to minutes, depending on the quality of the VCO design. VCO subsystems

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*See Frequency Sources, Inc., 1980, *Solid State Microwave Voltage Controlled Oscillators* Catalog, pages 1-4 for VCO type comparison discussion.

having longer equilibrium times are not realistically tested by the scope method because the repetition rate of the tuning step (typically 20–50 Hz) does not allow VCO equilibrium to be reached following each step. Instead, a repetition-rate dependent equilibrium is established, thus introducing an undesirable measurement uncertainty: the test result will change if the tuning step rate or duty cycle is changed. This same effect can cause problems when testing the VCO response to a complex tuning step sequence, where more than two tuning voltages are used in the sequence. The test system using the 5180A Waveform Recorder doesn't suffer these potential drawbacks because there is no need to repeat the tuning sequence to see the test results. On the other hand, if duty-cycle and repetition-rate effects are being studied, the 5180A can be continually retriggered (like a scope), thus allowing the various VCO responses to be viewed.

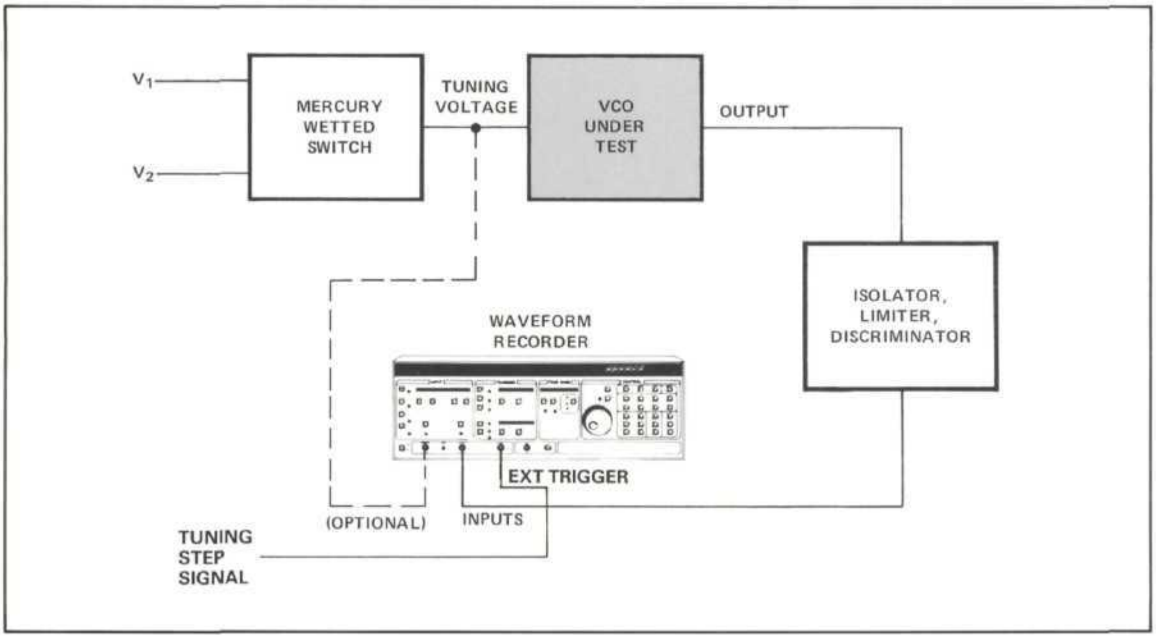


Figure 2. VCO Test System

3) VCO tuning repeatability can be evaluated since the data is single-shot (with the scope method the display represents an **average** VCO response to the particular tuning step taken over the number of repetitions needed to maintain a viewable image on the display).

4) Because the VCO output information is stored in the waveform recorder memory, the data can still be viewed after the measurement. The captured data record may be expanded horizontally and vertically for more detailed examination. Cursors can be positioned on any data point, providing time and voltage information.

   Processing of the stored data is also possible because the data is already in digital form. The stored data itself can be used as documentation of the performance of each VCO or this data may be automatically processed between any desired time limits to determine if the VCO is meeting a prescribed performance requirement. The subjective aspect of having to determine visually the extent of frequency change is completely removed by the waveform recorder.

5) The waveform recorder can capture far more information "at a glance" than can be seen using a scope. For example, using the 5180A Waveform Recorder, as many as 16,384 data points can be stored in one pass. This extensive memory, along with a mixed timebase mode, *enable capture* of data from **before** the tuning step out to 10 seconds (and more) after the tuning step, in a single measurement.

6) Test-time is drastically reduced because:

   a) One 5180A measurement can span the entire range over which the VCO is being tested.
   b) Hard copy results can be quickly generated (the 5180A can output a fully annotated plot of the captured data using an HP-GL plotter).
   c) The test system can be automated (the 5180A has extensive programming and data I/O capability).

7) The 5180A will provide better amplitude resolution than an oscilloscope. Better resolution means more accurate determination of the VCO output frequency. For example, using the HP 5180A Waveform Recorder, resolution to better than 0.1% of full-scale will be obtained.

8) The tuning voltage can be sampled (an active probe prior to the waveform recorder may be needed) while the VCO output is being captured. This may yield valuable information about one cause of VCO output fluctuation. If correlation can be established between tuning voltage and VCO output variations, a source of testing error can be eliminated.

ABOUT THE 5180A WAVEFORM RECORDER

The 5180A has 10-bit resolution (1 part in 1024) and a maximum conversion rate of 20 MHz. With its 16,384 sample memory, the 5180A is an ideal waveform recorder for VCO test systems. Detailed information about the 5180A is available in numerous technical publications.

PERFORMING THE TESTS

Having selected a discriminator appropriate for the particular test being made (see appendix, *A Brief Review of Discriminators*), the discriminator can be calibrated by using a source of known frequency and sampling the discriminator output. If a linear discriminator response approximation is unacceptable, the actual calibration values can be stored and used as a look-up table when performing the actual VCO tests. To demonstrate discriminator calibration, the set-up of Figure 3a was used. The synthesizer was stepped through the frequency range over which the VCO would later be tested. At each frequency the discriminator output level was monitored on the 5180A. This technique allows the relationship between discriminator input frequency and discriminator output level to be precisely determined. These tests resulted in the plot of Figure 3b.

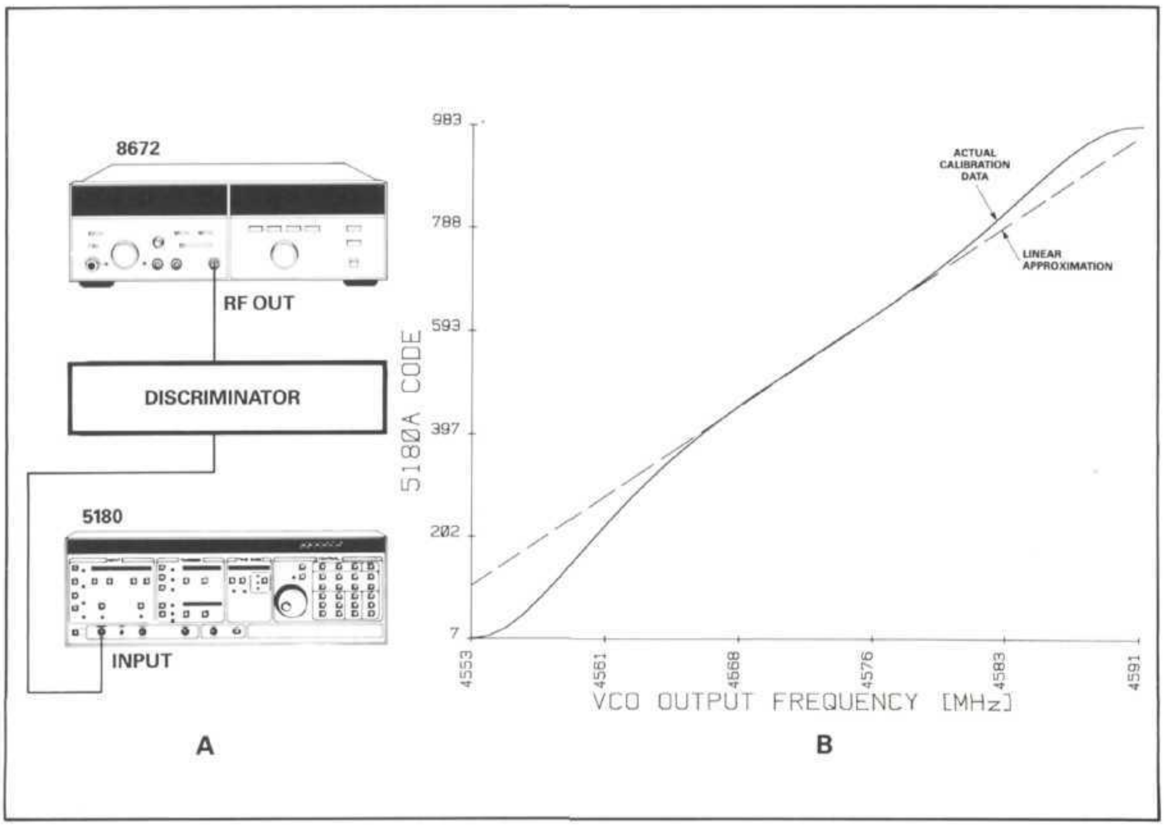


Figure 3. 3a shows the equipment set-up for discriminator calibration. 3b shows the calibration data – relating the discriminator output voltage to the discriminator input frequency.

Although discriminator characteristics vary, the plot of Figure 3 is probably typical. This plot illustrates several important points about discriminator use:

The discriminator does not precisely follow its theoretical sinusoidal voltage versus frequency transfer function. This is not of any consequence as long as the transfer function is repeatable (i.e., the same discriminator input frequency always produces the same discriminator output voltage). To verify repeatability the calibration was performed several times. The results of each calibration were essentially identical.

A linear assumption of the discriminator transfer function may be adequate over small ranges, but the validity of this assumption for wider ranges is questionable. As the plot shows, in this case, a linear assumption can result in errors as large as ~4 MHz.

The range for unambiguous use of this discriminator is 38 MHz, which means that, on the average, each vertical code in the 5180A represents 38 MHz/1024 ~37 kHz.

Using the configuration shown in Figure 2, settling time and post-tuning drift measurements can be made. In the most likely implementation of the test system, the 5180A is externally triggered by the tuning step signal. This is a convenient trigger because it is readily available and well defined, and it references the 5180A data to the time the tuning step is applied, which is the reference for all the VCO tests. The HP 5180A provides digital triggering, which results in greater control of setting the trigger level (2 mV increments) and greater confidence that triggering will occur when intended (the 5180A actually displays the trigger level while it's being set). Along with setting the trigger level, other 5180A parameters are selected prior to the actual measurement:

Input Range — Similar to selecting input range on an oscilloscope. The 5180A provides ±10-volt to ±100-millivolt full-scale ranges, selectable in a 1, 2, 5, sequence. The appropriate setting will depend on the discriminator output level.

Trigger Position — Unlike an oscilloscope, with the 5180A the user can capture data prior to the occurrence of the trigger. This pre-trigger capability allows monitoring of the VCO output frequency prior to the tuning step. The 5180A allows as much as 100% of the captured data to be pre-trigger. By selecting a small amount of pre-trigger (a −2% trigger position means that 2% of the captured data will be before the trigger, 98% will be following the trigger), it is possible to verify that the VCO has stabilized before application of the tuning step.

Sample Rate — This setting will depend on the desired time resolution (selectable from 50 ns per sample to 50 ms per sample on HP 5180A). Typically, in VCO testing, a fast sample rate is required for measurement of settling time, which usually spans several microseconds after the tuning step is applied. This range can be completely captured at a high sample rate by the 5180A waveform recorder (the 5180A can capture up to 16,384 points in a single measurement — 16384 × 50 ns ~ 1 millisecond). For post-tuning drift measurement, where the VCO output is usually changing less rapidly, a slower sample rate of 500 microseconds per point will span nearly 10 seconds.

The facing page shows several examples of captured VCO data.

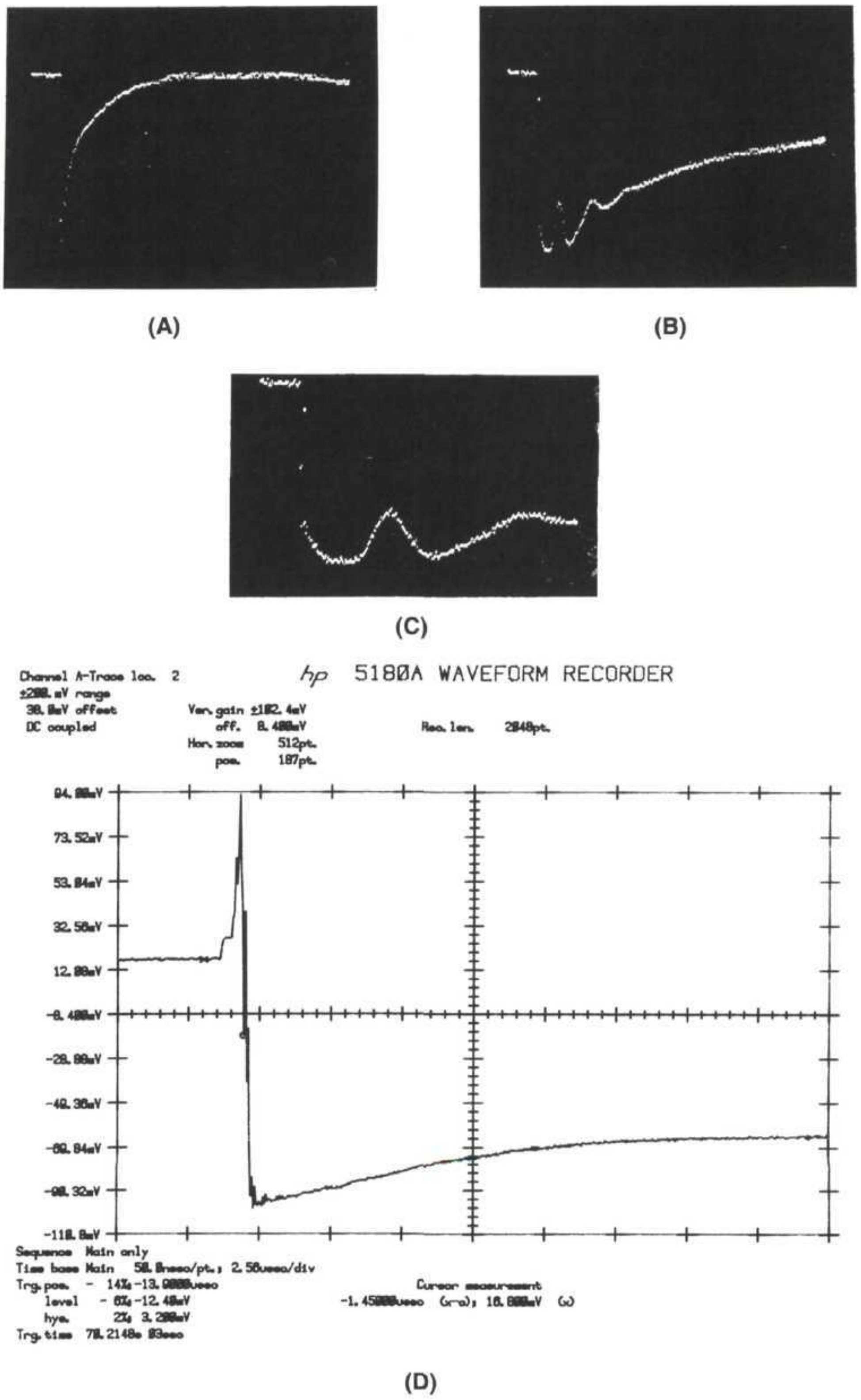


Figure 4. Discriminator output is shown with the time scale zoomed out in each successive photograph. The top display represents 16384 data points. In the middle photograph, detail after the tuning step is shown (1024 points). The lower display is fully zoomed (256 points). The time per sample is 50 ns. The plot (d) shows another VCO waveform captured by the 5180A.

USE MIXED MODE FOR A COMPLETE VCO TEST FROM A SINGLE MEASUREMENT

Because of the test requirements for settling time and post tuning drift, the most efficient way to sample the discriminator output is at a high rate during the settling time, and then more slowly after the initial settling. By changing the sample rate during the measurement, a greater time span can be encompassed in a single measurement. The 5180A has a mixed sampling mode that provides the timebase change capability. When this mode is selected, the triggering should be modified as shown in Figure 5. The addition of a fixed delay in the trigger input allows the timebase transition to be properly positioned. A delay of several microseconds will generally be adequate. Many of the pulse generators that are used to send the tuning step command (such as the HP 8007B) have the desired delay capability built-in. The trigger output from the pulse generator supplies the tuning step command, while a delayed output pulse triggers the 5180A. Figure 6 illustrates the mixed mode measurement process.

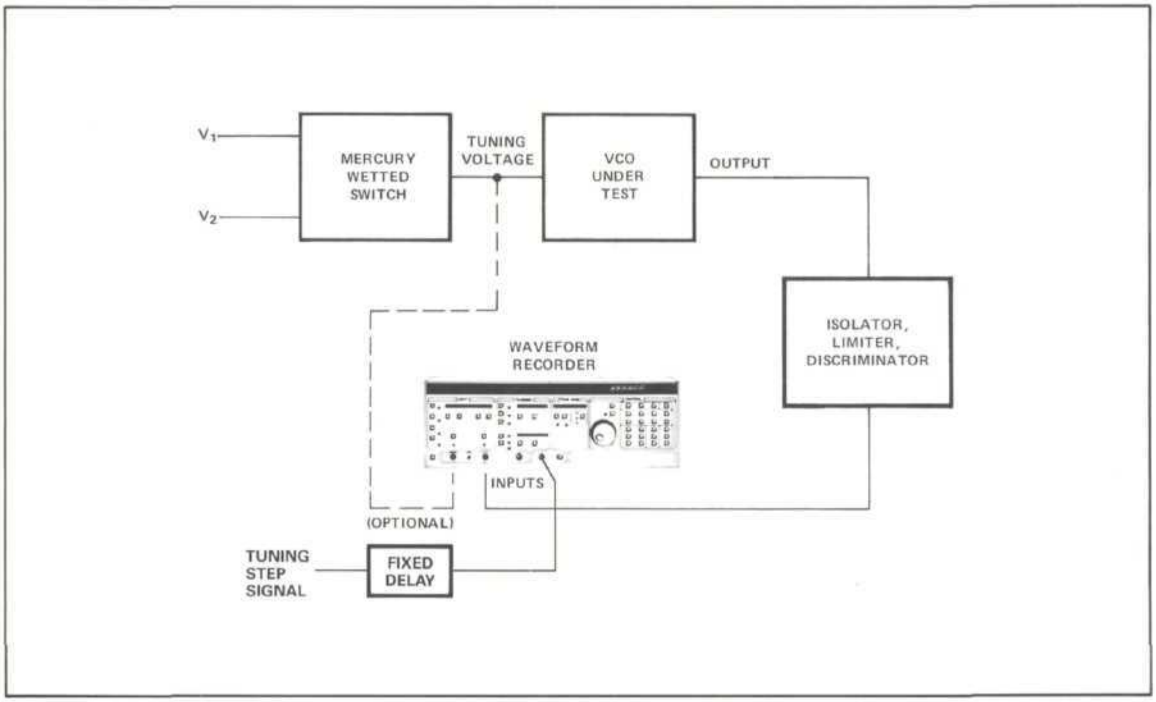


Figure 5. Set-up for mixed mode VCO measurement.

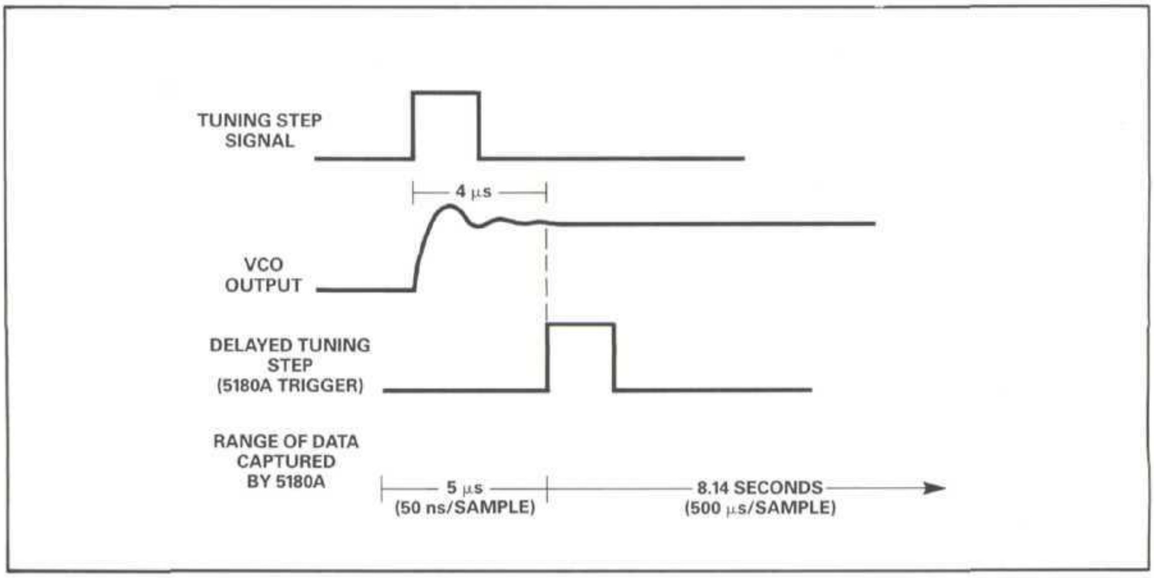


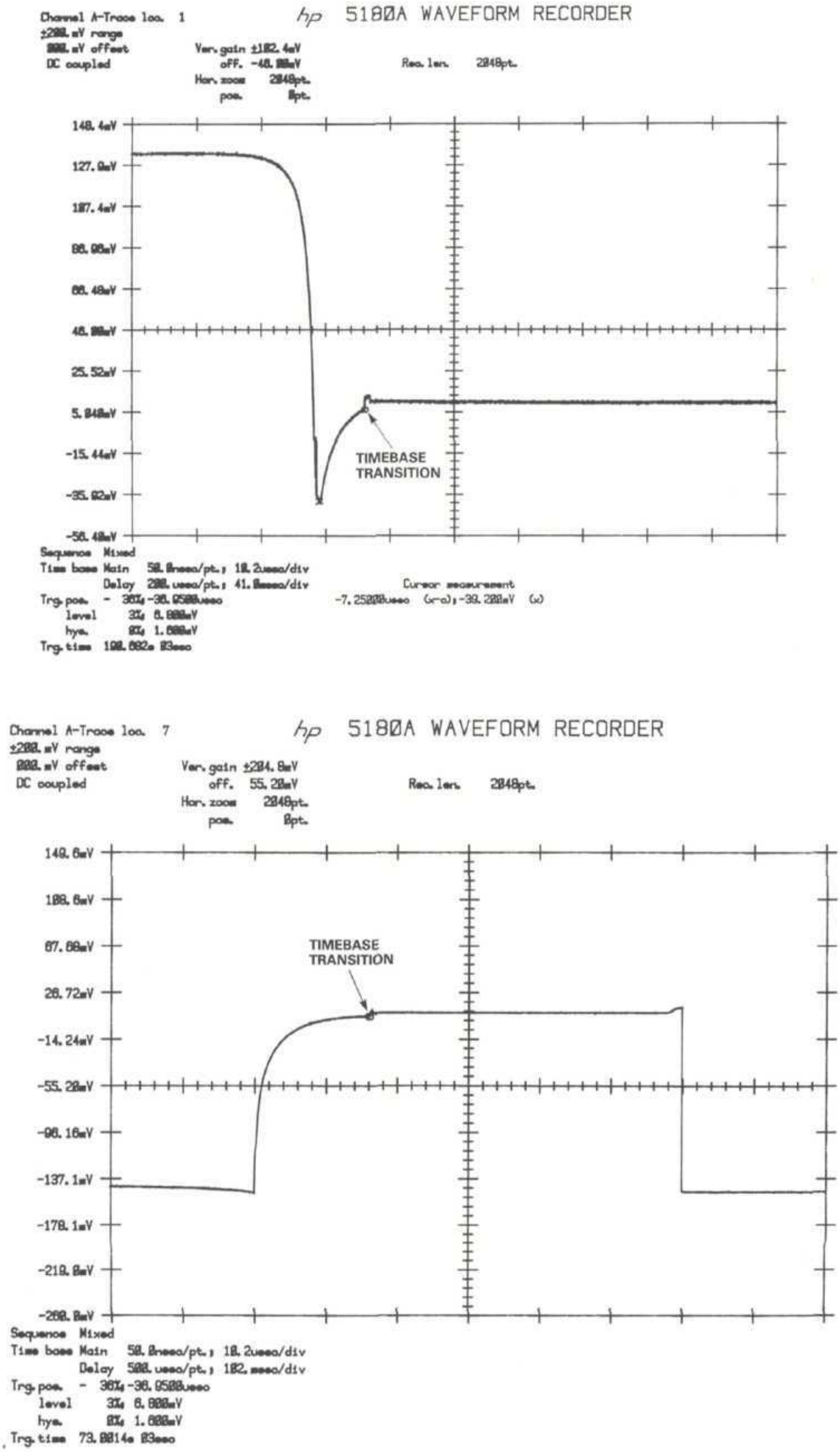
Figure 6. Signal relationships for mixed mode VCO measurment. In this example a 16,384 sample record is captured in the 5180A, with a -5 µs trigger position.

In mixed timebase mode with pre-trigger selected, the 5180A will sample at the MAIN timebase rate until the trigger, and at the DELAY timebase rate after the trigger. The timebase transition takes 150 nanoseconds. This time is automatically added to the data record, so that cursor time measurements made across the timebase transition will be accurate.

To set up for the mixed-mode VCO measurement:

1) Select the MIXED timebase mode.
2) Press the light grey MAIN timebase key and use the control knob to select the sample rate before the trigger.
3) Press the light grey DELAY timebase key and use the control knob to select the sample rate after the trigger.
4) Press the TIME trigger position key and use the control knob to select a pre-trigger (negative value) amount slightly in excess of the trigger delay time. This will allow data to be captured before the tuning step.
5) To see the time span of the data being collected at either sample rate, press the blue shift key followed by either the MAIN or DELAY timebase key. If either of the timebases doesn't span the desired amount of time, change the sample rate or the trigger position.
6) Make sure the 5180A is in external trigger mode and that the trigger level is appropriate.
7) Arm the 5180A by pressing the SINGLE key, and issue the tuning step signal to the VCO.

Examples of VCO test data using mixed mode are shown in the figure below.



```
Channel A-Trace loc.  1
±200. mV range
 000. mV offset
 DC coupled             Ver. gain ±102.4mV
                             off. -46.00mV            Rec. len.   2048pt.
                        Hor. zoom    2048pt.
                             pos.       0pt.

Sequence  Mixed
Time base Main   50.0nsec/pt.; 10.2usec/div
          Delay  200. usec/pt.; 41.0msec/div                Cursor measurement
Trg. pos.  -  30%; -30.0500usec                    -7.25000usec  (x-o); -39.200mV  (x)
   level       3%; 6.000mV
   hys.        0%; 1.000mV
Trg. time  100.002e 03sec
```

```
Channel A-Trace loc.  7
±200. mV range
 000. mV offset
 DC coupled             Ver. gain ±204.8mV
                             off.  55.20mV            Rec. len.   2048pt.
                        Hor. zoom    2048pt.
                             pos.       0pt.

Sequence  Mixed
Time base Main   50.0nsec/pt.; 10.2usec/div
          Delay  500. usec/pt.; 102. msec/div
Trg. pos.  -  30%; -30.0500usec
   level       3%; 6.000mV
   hys.        0%; 1.000mV
Trg. time  73.0014e 03sec
```

Figure 7. Two VCO measurements made using the mixed mode on the 5180A to capture a wider measurement range.

USING THE TEST DATA

Once the VCO data has been captured by the 5180A, it can be utilized in many ways:

1) Since the data is now stored in memory, it may be viewed at leisure. Because viewing the entire 16K sample record at once crowds the data too closely for detailed analysis, selected portions of the record may be zoomed out, thus making the display a window detailing any desired region of the data record (5180A allows zooming to 256 samples on the screen — 1/64th of the entire memory). The position of the window may be changed using the position display control. Vertical gain and offset controls allow greater amplitude resolution to be displayed. Having identified an area of interest, absolute voltage and time (with respect to the trigger) information can be obtained directly from the waveform recorder by positioning a cursor on any sample point. Using these controls minimum and maximum values, which indicate the peak VCO frequency excursions, can easily be determined over any selected time span. Figure 8 shows the cursors.

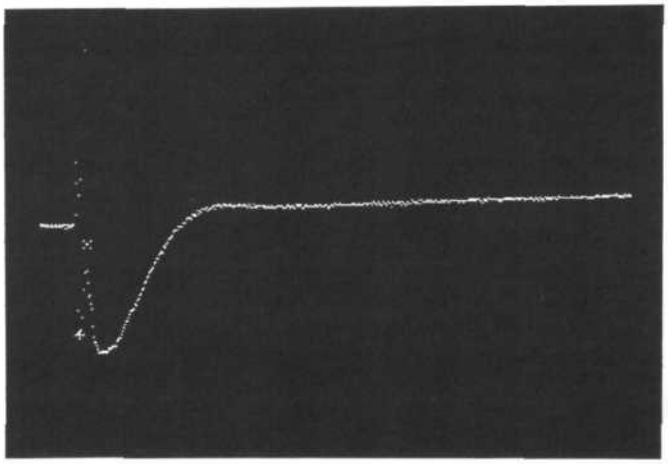


Figure 8. The ∵ and ⁘ shaped cursors can be placed on any sample for measurement of voltage or time difference.

2) Hard copy of the data can be easily generated by connecting the 5180A to any HP-GL plotter with an HP-IB cable, setting the 5180A device address to 50, placing the plotter in a "listen always" mode, and pressing the output key on the 5180A. An example of the fully annotated plot that results is shown in the figure below. If the 5180A is under external control, the plot can be

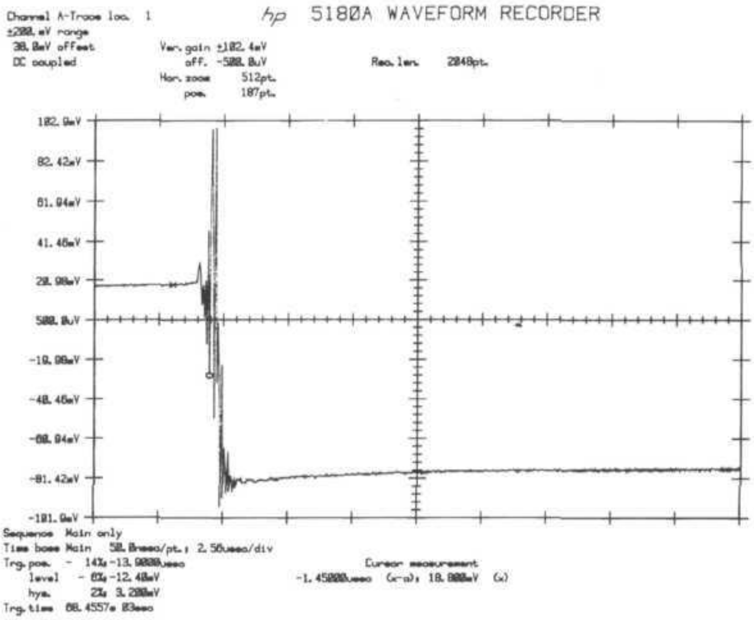


Figure 9. 5180A generated plot.

generated without changing the 5180A's device address. For example, if a 9825A controller is being used, the statement

wrt 704, "OP"; cmd 7, "?D%"

will initiate the plot (the 98034A interface select code is 7, the 5180A address is 04).

This plot is a convenient and simple way to document the VCO test results.

3) One step beyond manual manipulation of the captured data, the entire 5180A sample record (or selected portions of the record) can be output to a controller for data analysis. An example program, using an HP 9825 controller, is listed below. This program allows the user to select any number of time ranges over which to locate maximum and minimum frequency values. Selection of these time ranges would presumably be based on specific test limit requirements. This program automatically converts the 5180A codes to VCO output frequency, using the look-up table conversion values that were generated during discriminator calibration. The results of the analysis are output to a printer. Figure 11 shows analysis data generated using the calibration of Figure 3b and a voltage step that tuned the VCO into the range over which the calibration was performed.

```
0: "HP 5180A VCO MEASUREMENT PROGRAM":
1:
2: "MAIN":
3: dim A$[512],Y[1024];conv 69,101;flt 2
4: ldf 5,Y[*]
5: dev "HP5180",704
6: gsb "LEARN"
7: gsb "RANGES"
8: gsb "SORT"
9: gsb "CONVERT"
10: gsb "OPTIMIZE"
11: gsb "GET-DATA"
12: end
13:
14: "LEARN":
15: wrt "HP5180","OA0";red "HP5180",A$
16: val(A$[pos(A$,"le")+2])→L
17: val(A$[pos(A$,"mm")+2])→M
18: val(A$[pos(A$,"dm")+2])→D
19: val(A$[pos(A$,"pt")+2])→P
20: val(A$[pos(A$,"tb")+2])→F
21: ret
22:
23: "RANGES":
24:
25: ent "How many ranges?",Q
26: dim M[Q],N[Q],O[Q],P[Q],R[Q],S[Q],T[Q],Q[Q]
27: fxd 0;for I=1 to Q;dsp "Start time-range",I;ent "",M[I]
28: dsp "stop time-range",I;ent "",N[I];next I
29: flt 2;ret
30:
31: "SORT":
32:
33: for I=1 to Q-1
34: for J=I+1 to Q
35: if M[I]>M[J];M[J]→C;M[I]→M[J];C→M[I];N[J]→D;N[I]→N[J];D→N[I]
36: next J
37: next I
38: fmt 2,c,fz,c,6el2,c,6el2,c,/
39: fmt 3,1/
40: for I=1 to Q
41: wrt 701.2,"Range ",I," = ",M[I]," to ",N[I]," seconds"
42: next I
43: wrt 701.3
44: ret
45:
46: "CONVERT":
47:
48: for I=1 to Q
```

Determines state of various 5180A front panel settings

Determine ranges for min./max. analysis

Sort ranges

Figure 10. VCO analysis program.

```
49: if M[I]>0 and F=2;int(1-P/M+M[I]/D)→M[I];gto 51
50: int(1+(M[I]-P)/M)→M[I]
51: if N[I]>0 and F=2;int(1-P/M+N[I]/D)→N[I];gto 53
52: int(1+(N[I]-P)/M)→N[I]
53: if N[I]<0 or M[I]<0 or M[I]>L or N[I]>L;prt "RANGE ERROR";stp
54: next I
55: ret
```

Convert range limits from time units to sample number

```
56:
57: "OPTIMIZE":
58:
59: for I=1 to Q;1e99→R[I];-1e99→Q[I]→P[I];next I
60: 1→T→K→J
61: for I=1 to Q
62: if I+J>Q;Q→I;gto 66
63: if N[I]<M[J+I];gto 65
64: J+1→J;gto 62
65: if J#1;J-1→J;gto 71
66: M[T]→O[K]
67: for H=T to I
68: if N[H]>P[K];N[H]→P[K]
69: next H
70: K+1→K;I+1→T;1→J
71: next I
72: ret
73:
```

Determine most efficient scheme for reading data from 5180A

```
74: "GET-DATA":
75:
76: for I=1 to Q;0→Q[I];1e99→R[I];next I
77: for I=1 to K-1
78: wrt "HP5180","bs0"
79: wrt "HP5180",O[I]
80: wrt "HP5180",P[I]-O[I]
81: for J=1 to P[I]-O[I]
82: rdb("HP5180")*32+rdb("HP5180")/8→A
83: for U=1 to Q
84: if O[I]+J<M[U] or O[I]+J>N[U];gto 87
85: if Y[A]>Q[U];Y[A]→Q[U];O[I]+J→S[U]
86: if Y[A]<R[U];Y[A]→R[U];O[I]+J→T[U]
87: next U
88: next J
89: next I
90: for I=1 to Q
91: (S[I]-1)*M+P→r1;(T[I]-1)*M+P→r2
92: if F=2 and S[I]>1-P/M;(S[I]-1+P/M)*D→r1
93: if F=2 and T[I]>1-P/M;(T[I]-1+P/M)*D→r2
```

Read and process VCO data from 5180A

```
94: flt 4
95: fmt 1,c,fz,c,6e12,c,6e12,c,/
96: wrt 701.1,"Max. freq. in range ",I," was ",Q[I]," MHz at ",r1," seconds"
97: wrt 701.1,"Min. Freq. in range ",I," was ",R[I]," MHz at ",r2," seconds"
98: wrt 701.3
99: next I
100: ret
*20920
```

Variable List

A$ [*] : String used to store learn string info. from 5180A
Y [*] : Array containing 5180A code to frequency conversion
L : 5180A record length
M : 5180A main timebase rate
D : 5180A delay timebase rate
P : 5180A trigger position
F : Flag to determine 5180A mixed or main timebase mode
Q : Number of min./max. ranges
M [*] : Start time for each range
N [*] : Stop time for each range
O [*] : Position in record of first sample in each range
P [*] : Position in record of last sample in each range
Q [*] : Max. freq. in range
r1 : Time of max. freq.
R [*] : Min. freq. in range
r2 : Time of min. freq.

```
Range 1 =    -7.25e-06 to    0.00e 00 seconds
Range 2 =     0.00e 00 to    1.00e-02 seconds
Range 3 =     0.00e 00 to    2.00e-01 seconds


Max. freq. in range 1 was   4.5716e 03 MHz at   0.0000e 00 seconds
Min. Freq. in range 1 was   4.5666e 03 MHz at  -7.1500e-06 seconds


Max. freq. in range 2 was   4.5723e 03 MHz at   2.0000e-03 seconds
Min. Freq. in range 2 was   4.5716e 03 MHz at   2.0000e-04 seconds


Max. freq. in range 3 was   4.5723e 03 MHz at   2.0000e-03 seconds
Min. Freq. in range 3 was   4.5716e 03 MHz at   2.0000e-04 seconds
```

Figure 11. Automatic analysis of VCO data using program listed in figure 10.

A FULLY AUTOMATED VCO TEST SYSTEM

Complete automation of the VCO test system may not be practical in many applications, but most VCO production facilities could derive cost saving benefits by automating. Along with the primary benefit of substantial test time reduction, more complete and meaningful test data can be generated. Figure 12 shows an automated VCO test system for measuring post tuning drift and settling time.

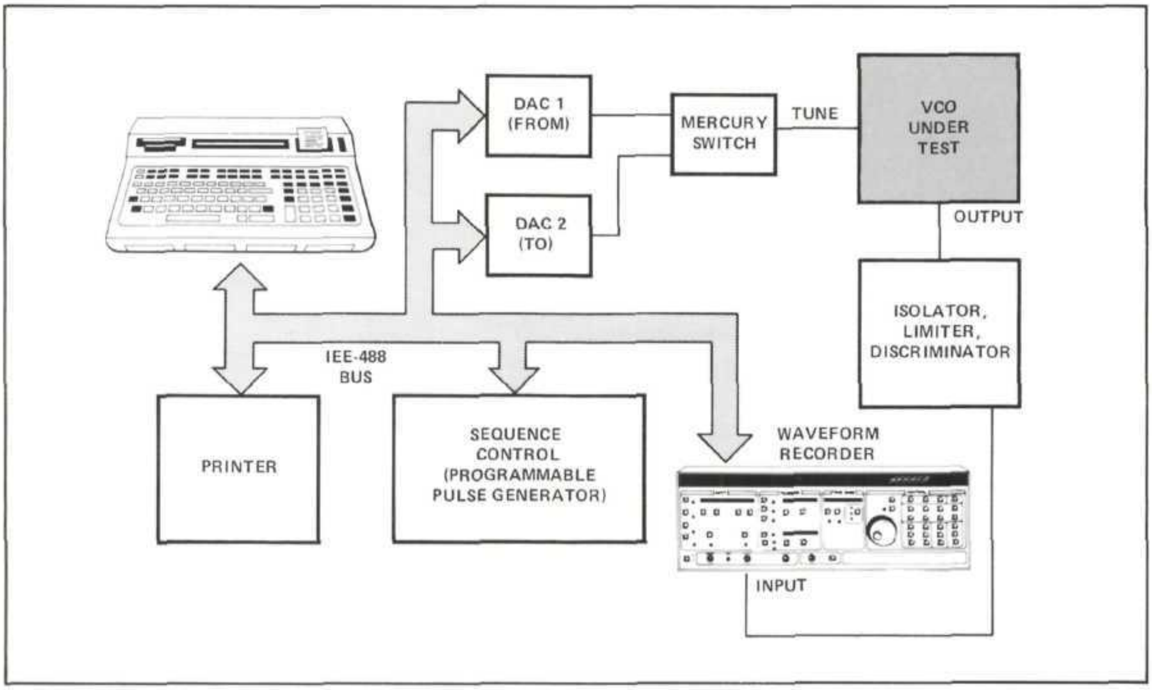


Figure 12. Automated VCO test system.

Such a system could perform an entire series of tests on a VCO at the touch of a button. Here's how it might work:

1) The desired sequence of "to" and "from" tuning voltages is stored in the controller. The operator could enter these values or, if the sequence is often used, the sequence could be loaded from a disc or cassette.
2) The operator enters the spans for testing. From a single measurement, many spans can be analyzed. For instance, min/max information might be required from tuning to 1 microsecond (settling time) and from 30 microseconds to 100 milliseconds (post-tuning drift). The controller would automatically determine waveform recorder sampling rates and the timebase transition point to optimally capture data over the desired span.
3) DAC's 1 and 2 are programmed to the first test voltages.
4) The waveform recorder set-up is programmed. Once armed the 5180A is ready to capture VCO data.

5) The controller programs the pulse generator to output a single pulse. This pulse throws the mercury wetted relay (thus changing the VCO tuning voltage from DAC 1 output level to DAC 2 output level) and triggers the waveform recorder to begin capturing data. If the tuning voltage is being captured along with the discriminator output, the waveform recorder will have been programmed to accept data from 2 channels (the 5180A waveform recorder has a chop AB mode, with a maximum sampling rate of 5 MHz per channel).

6) The data is output from the waveform recorder to the controller for data reduction. Discriminator output values can be converted directly to frequency using the conversions determined during discriminator calibration. If tuning voltage data has been taken, this data is searched for level variations. Any variations will cause a VCO output variation. The degree of output change will depend on the VCO tuning sensitivity* and is easily computed from the relation

$$\Delta f_{\text{VCO OUTPUT}} = \Delta V_{\text{tuning}} \times \text{tuning sensitivity}$$

7) The results of the data analysis are tabulated on a printer (information such as DAC 1 and 2 tuning voltages, test time, span limits, and the extreme frequency deviations within these regions could be printed).

8) New DAC voltages are programmed and the measurement process repeats. Single-shot repeatability tests could be performed by leaving the DAC voltages unchanged and repeating the measurement. This could lead to worst case and typical VCO performance specifications, since statistical information could be generated from several single-shot tests.

The program listing in the previous section could serve as a core for developing the VCO test system software, since this program already performs most of the required analysis. Developing an algorithm for determining the optimum 5180A sample rates is not difficult. For example, if the maximum sample rate is always required at the beginning of the measurement and the fixed delay between the tuning step and the 5180A external trigger pulse is about 10 microseconds, the minimum DELAY sample interval to collect data out to time t is:

$$\frac{t}{\left[\text{16384 samples} - \dfrac{10 \times 10^{-6}\ \text{seconds}}{50 \times 10^{-9}\ \dfrac{\text{seconds}}{\text{sample}}}\right]}$$

The optimum 5180A DELAY sample interval would be the first sample interval (in the 1-2-5 sequence) longer than the value determined by this calculation.

Conclusion

Waveform Recorders, such as the HP 5180A provide fundamental measurement capabilities, in the testing of VCO's, that have previously been unavailable. The measurement benefits of using the 5180A instead of traditional testing methods are numerous, including faster and more meaningful test results. The waveform recorder based VCO test system is a necessary step toward ensuring that VCO testing methods maintain pace with ever-increasing VCO capabilities.

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*The first derivitive of the VCO frequency versus voltage tuning curve.

Appendix: A Brief Review of Discriminators

The function of the discriminator in the VCO test set-up is, of course, to convert frequency to voltage. The details about the conversion process may not be so obvious, yet an understanding of these details is needed to properly choose a discriminator for a given VCO test.

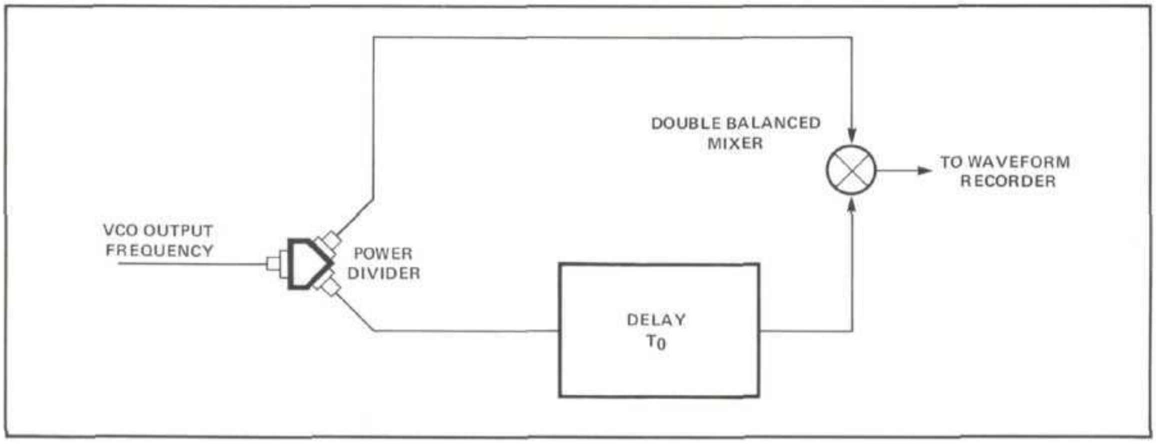

Figure A1. Delay Line Discriminator.

Consider a delay line discriminator having the characteristics shown in Figure A1. The delay time through the lower branch is longer than the delay time of the upper branch by T_0, regardless of frequency. The added phase delay of a signal passing through the lower branch will be $\emptyset(\omega) = \omega T_0$. Now, the mixer sees at its input ports, the VCO output and this same output shifted by $\emptyset(\omega)$. If the VCO output is A sine (ωt), the input to the mixer will be:

$$A\sin(\omega t)\ AK\sin(\omega t + \emptyset(\omega))$$

$$= \frac{A^2K}{2}[\mathrm{COS}\ \emptyset - \mathrm{COS}\ (2\omega t + \emptyset)]$$

Where k is an attenuation factor due to insertion loss in the delay line. Using a low pass filter, or letting the input bandwidth of the waveform recorder act as an LPF, the equation becomes:

$$\frac{A^2K}{2}\ \mathrm{COS}\ \emptyset = \frac{A^2K}{2}\ \mathrm{COS}\ (\omega T_0)$$

This relation says that the discriminator output level will vary in proportion to the square of the VCO output amplitude and in proportion to the cosine of the VCO output frequency. Since the purpose of the discriminator in the VCO test set-up is to detect frequency change, a limiter often must precede the discriminator, in order to maintain a constant input level to the discriminator and ensure that changes at the discriminator output are due only to frequency changes from the VCO.

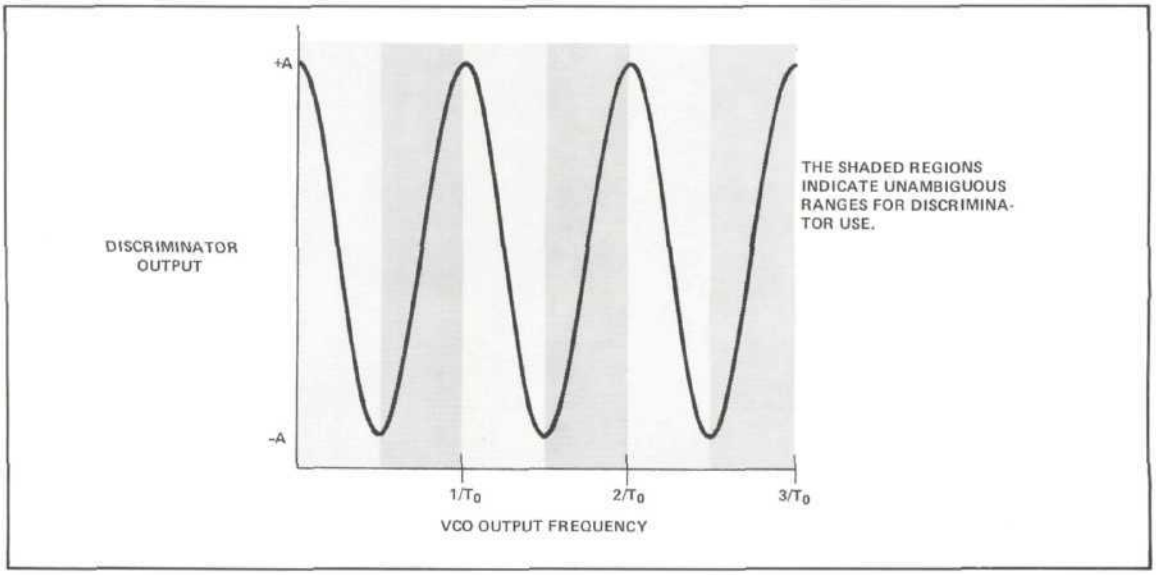

Figure A2. The relationship between VCO output, Discriminator Delay Time (T_o), and Discriminator Output.

Because the discriminator output is proportional to COS (ωT_o), the output will be cyclic with $\frac{2\pi}{T_o}$ radian period. Assuming a best case, where the initial argument is a $\frac{\pi}{T_o}$ multiple, the range for unambiguous frequency measurement will be $\frac{\pi}{T_o}$ radians $= \frac{1}{2T_o}$ Hz (see Figure A2). Besides determining the ambiguous frequency range, T_o plays a role in determining the sensitivity of the test system to frequency change. Unfortunately, but as might be expected, decreasing T_o increases the useful frequency range but reduces the frequency sensitivity. The relationships are:

$$\Delta f = \frac{R}{2T_o} \text{ Hz and } f_{UN} = \frac{1}{2T_o} \text{ Hz}$$

where Δf is the smallest detectable frequency change, R is the resolution of the waveform recorder (compared to full-scale), and f_{UN} is the unambiguous frequency range of the discriminator.

Looking at this in a more useful way, we have:

$$T_o \geq \frac{R}{2\Delta f} \text{ to guarantee a desired } \Delta f \text{, and}$$

$$T_o \leq \frac{1}{2f_{UN}} \text{ to guarantee a desired unambiguous measurement range.}$$

As an example, suppose a 100 kHz sensitivity is needed. The 5180A Waveform Recorder can resolve around 1 part in 1000. The minimum allowable delay time is $\frac{R}{2\Delta f} = \frac{10^{-3}}{2(10^5)} = 5$ nanoseconds. If an unambiguous measurement bandwidth of 50 MHz is also required, then $T_o \leq \frac{1}{2f_{UN}} = \frac{1}{(2)(50 \times 10^6)} = 10$ nanoseconds. thus, only discriminators with T_o in the 5–10 nanosecond range will have the desired properties.

Because the tuning step from V_1 to V_2 usually changes the VCO output frequency far beyond the unambiguous frequency range of the discriminator, there is a period during the transition where the discriminator output isn't a valid indicator of frequency. This generally isn't a problem, though, because the important aspect of the settling time test is how fast the VCO can settle to within a specified error band of the final frequency. By proper choice of discriminator, this error band will be well within the unambiguous frequency range of the discriminator.

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