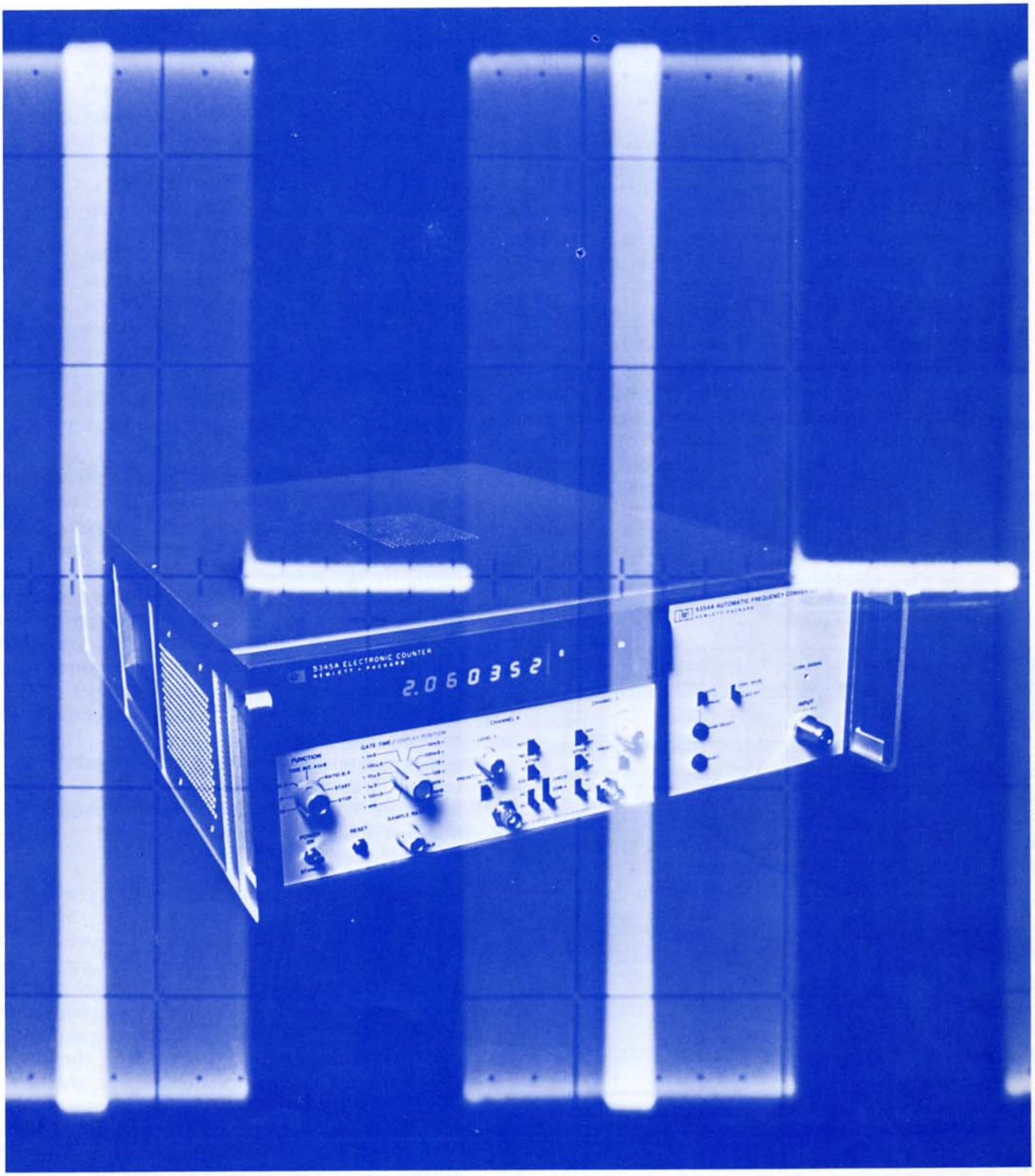
APPLICATION NOTE 173-1

Dynamic Measurement of Microwave Voltage Controlled Oscillators with the 5345A Electronic Counter



HEWLETT hp PACKARD

INTRODUCTION

This application note describes a simple measurement set-up for frequency measurement of microwave signals which move rapidly in time. The technique is ideal for characterization of the frequency-versus-time characteristics of leading and trailing edges of microwave VCO frequency steps and measurement within microwave pulses. It is also applicable to measurements of post tuning drift.

This class of microwave measurements is of great importance as performance requirements of microwave VCO's become more demanding. Today microwave VCO's may be required to step 500 MHz in times as short as 50 nanoseconds and rest within 1 MHz of the final frequency at the end of that interval.

Figure 1 shows typical results of a measurement made using the procedure described herein. The figure shows the leading edge of a microwave VCO step. Points are located on the time axis every 5 nanoseconds. Resolution of each measurement is better than 1 MHz. The "window" of this measurement, that is the counter's measurement time, was 20 nanoseconds for this measurement.

MEASUREMENT SET-UP

Figure 2 is a block diagram of the measurement set-up. All connections may be made with 50 ohm coaxial cable with BNC connectors, with the possible exception of signals entering and leaving the VCO. The list of equipment required for measurements of VCO frequencies to 500 MHz is as follows:

(2) 5345A Electronic Counters
(1) 8082A Pulse Generator

To increase frequency range to 4 GHz, add

(1) 5354A Frequency Converter;

to increase frequency range to 12.4 GHz, add

(1) 10590A Plug-in Adapter
(1) 5255A Frequency Converter;

or to increase frequency range to 18 GHz, add

(1) 10590A Plug-in Adapter
(1) 5256A Frequency Converter.

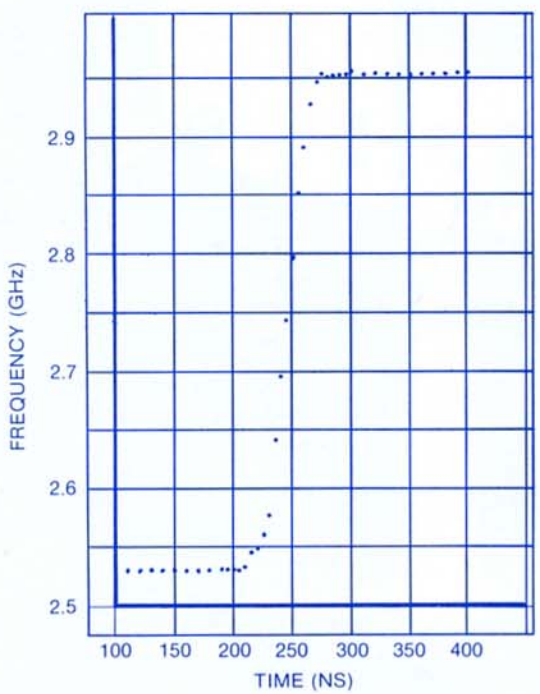


Figure 1. Frequency Profile of the Leading Edge of a Stepped Microwave VCO.

THEORY OF OPERATION

The essential feature of the 5345A Electronic Counter for these measurements is that it is capable of making frequency measurements within very short time intervals; this is accomplished by means of an "external gate". When making measurements with extremely short gate times, however, one encounters a fundamental resolution limitation. For example, a measurement made by the 5345A with its minimum external gate time of 20 nanoseconds will be limited to a resolution of 5 to 50 MHz. To increase this resolution to below 1 MHz, it is necessary to make a number of measurements and calculate an average, thereby increasing the measurement resolution. The 5345A will calculate these averages automatically with its unique "frequency averaging" capability. Application Note 173 "Recent Advances in Pulsed RF and Microwave Frequency Measurements" discusses frequency averaging in detail.

The measurement technique used to characterize microwave VCO's is analogous to that of a sampling oscilloscope: a repetitive waveform may be sampled by a narrow measurement gate at successive time intervals across the waveform. The aggregate of these measurements reproduces the waveform. Figure 3 shows how four measurements made at different points in time along the leading edge of a VCO frequency step may be graphed to yield the shape of the step. This measurement is accomplished by synchronizing the external gate of the 5345A to the repetition rate of the VCO driving circuit and successively delaying the external gate to create a time axis.

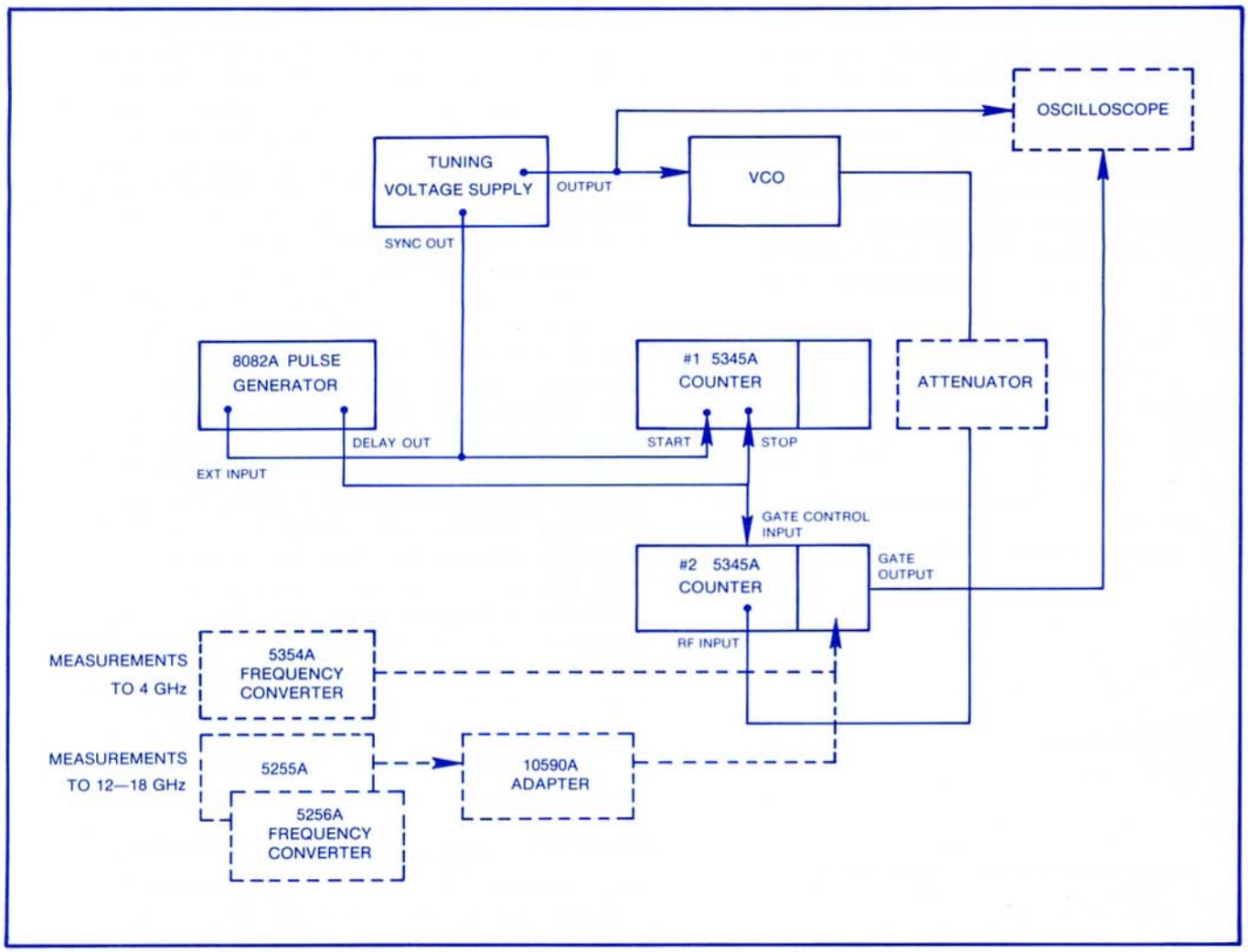


Figure 2. Measurement Set-Up

In Figure 2, the measurement sequence begins when the tuning voltage supply applies a voltage step to the VCO. Synchronous with this step is an output pulse which is used to trigger the 8082A Pulse Generator and the START channel of a 5345A Electronic Counter (#1) time interval measurement. After a time delay which is determined by settings on the 8082A, a pulse is transmitted from the 8082A to the STOP channel of the 5345A (#1) time interval measurement and to the GATE CONTROL INPUT of a second 5345A (#2). This pulse triggers a time interval measurement and causes a frequency measurement of the VCO output to be accomplished during the duration of the 8082A output pulse. The output of the VCO is directed to the input connector of 5345A #2. In this way a frequency measurement during an interval prescribed by the external gate width has been accomplished at a time which is approximately equal to the delay setting on the 8082A Pulse Generator. A number of measurements with the same delay setting on the 8082A can now be averaged by the two 5345A's in order to achieve the desired resolutions of both time interval and frequency.

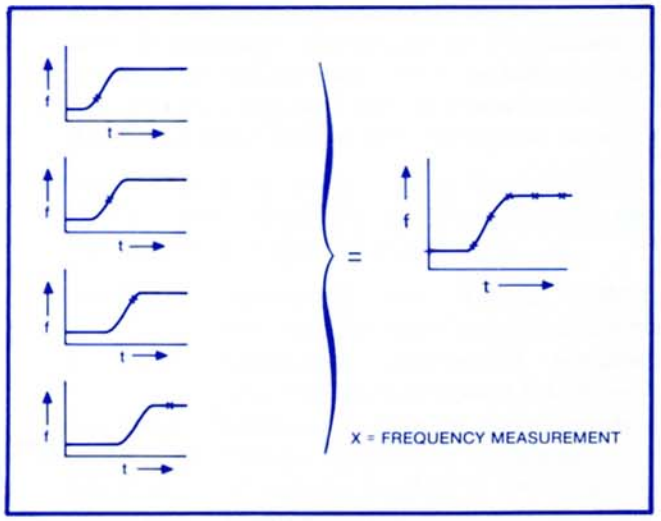


Figure 3. "Sampling" the Frequency Profile of a VCO Step.

MEASUREMENT PROCEDURE

1. Set the tuning voltage supply to the proper voltage levels. Also set rise time, fall time, repetition rate, and pulse width to the desired values. Note that in Figure 2 an oscilloscope is recommended for assistance in making these settings. It may be desirable during the setting of the tuning voltage parameters to replace the VCO with a termination on the input line, thus eliminating reactance of the VCO input circuitry from the set-up while setting the tuning voltage parameters. The oscilloscope display is also convenient later in the measurement set-up to observe the relative position of the external gate and the VCO drive waveform (see Figure 4). If a tuning voltage supply of sufficient versatility is not available, a high quality pulse generator such as the HP Model 8007A may suffice.

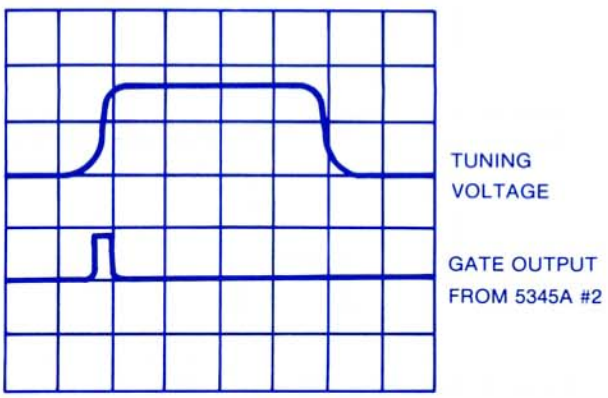


Figure 4. Oscilloscope Display of Position of External Gate Relative to Tuning Voltage Step

2. Measure the level of the VCO output and attenuate as necessary (see "Measurement Considerations" below). The VCO output may now be connected to 5345A #2 as shown in Figure 2.
3. Connect the synchronous output of the tuning voltage supply to the 8082A Pulse Generator EXT INPUT. Then connect the delayed output of the 8082A to the GATE CONTROL INPUT (the external gate) of 5345A #. This counter will now be performing a frequency measurement of the VCO output.
4. Set the desired external gate width, which is determined by the PULSE WIDTH control of the 8082A Pulse Generator. This pulse width may be measuree on 5345A #2 merely by placing the counter in CHECK mode and moving the function switch to the position TIME INT A TO B. Note that the minimum external gate allowable is 20 nanoseconds.
5. By manipulating the PULSE DELAY control of the 8082A Pulse Generator, position the external gate at the desired location in the tuning voltage waveform. Once again, an oscilloscope display is useful for observing the position of the external gate in the tuning voltage waveform as in Figure 4. Note also that numerous systematic delays built into this measurement may cause the external gate to appear to be in the wrong position on the oscilloscope display. This problem may be corrected either by inserting a delay line between the tuning voltage supply and VCO or, if possible, delaying the tuning voltage output to the VCO with respect to the synchronous output.
6. Connect the START and STOP inputs to 5345A #1 for time interval measurements, and set the input impedances and trigger levels appropriately. This counter will now provide a precision time interval measurement between synchronous output of the tuning voltage supply and the external gate delivered to the second counter. This time interval measurement provides a high resolution time axis for the data.
7. The set-up is now complete. By varying the delay out of the 8082A Pulse Generator, the external gate of 5345A #2 may be "walked" through the leading edge or any other interesting portion of a microwave VCO output which undergoes a repetitive frequency shift.

MEASUREMENT CONSIDERATIONS

A. The ability of the 8082A Pulse Generator to maintain settings of its analog controls may be a limitation on the accuracy of these measurements. Both the PULSE WIDTH and the PULSE DELAY settings are governed by the following accuracy considerations: (1) during a short time (10 minutes or less), settings may drift one part in 10^4; (2) for periods of time in excess of 10 minutes, accuracies of one part in 10^3 may be achieved throughout the full range of environmental specifications of the 8082A.

B. For measurements of frequencies above 500 MHz, frequency converter plug-ins for the 5345A Electronic Counter are required as indicated in Figure 2. It is important that inputs to these frequency converters be as low level as possible (below –10 dBm). High level inputs of fast changing microwave frequencies may cause distortions in the video sections of these converters. It is recommended that the video

output of the converter (available from a BNC connector) be displayed on an oscilloscope to insure that minimal amplitude fluctuations are present in the video circuitry during the course of the measurement.

C. The frequency measurement performed by the 5345A Electronic Counter is an average of the VCO output frequency for the duration of the external gate input. This averaging will have a smoothing effect on any excursions in the VCO output frequency which occur in a time frame on the order of the external gate or shorter than the gate. Figure 5 shows this smoothing effect in the measurement of a hypothetical instantaneous frequency step. In this measurement an external gate of 50 nanoseconds width is being positioned in 10 nanosecond increments. The counter begins to measure an increase in frequency when the gate is opened at the 160 nanosecond point of the time axis. When the gate arrives at the 200 nanosecond position the counter measures a constant frequency. Thus, the instantaneous frequency step appears to be taking place during a 50 nanosecond time interval, which is equal to the width of the external gate.

D. The input frequency to the 5345A must always be greater than $(\frac{1}{\text{external gate}})$, and should be considerably greater than this value if possible. The 5345A Counter always makes a measurement during the course of an integral number of periods of the input frequency. Therefore, the actual position of the measurement time may vary from the external gate input if the period of the input frequency is on the order of the width of the external gate.

E. For measurements above 500 MHz, the maximum excursion of frequency during the course of a measurement is limited by the video bandwidth of the frequency converter used. For measurements to 4 GHz, the measured frequency within a set-up is confined to 500 MHz bands, that is, 1.5 to 2.0 GHz, etc. It is also possible to use the 5354A Frequency Converter in a manual mode of operation, with the input frequency now allowed to move between two adjacent 500 MHz bands, for a maximum allowable excursion of 1 GHz. For measurements from 4 GHz to 18 GHz, frequency excursions are confined to 200 MHz bands, that is 6.4 to 6.6 GHz, 13.0 to 13.2 GHz, etc.

F. If the frequency source is to be turned on and off during measurements (i.e., operated in a pulse mode), minimum pulse widths are required for frequency measurements above 500 MHz: for measurements to 4 GHz the minimum pulse width is 50 nanoseconds, and for measurements from 4 GHz to 18 GHz a minimum pulse width of 2 microseconds is required (special modifications to the 5255A and 5256A Frequency Converter Plug-ins allow measurements within pulses as narrow as 250 nanoseconds).

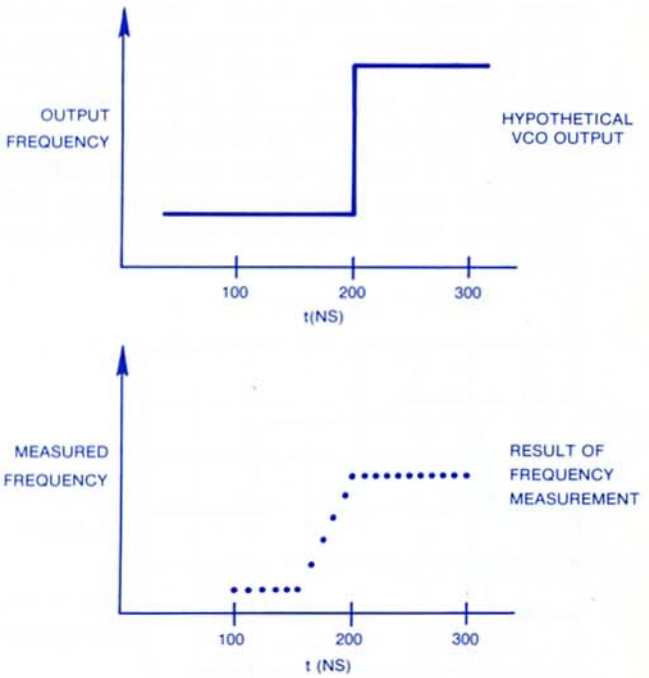


Figure 5. Smoothing Effect of a 50 ns External Gate on Measurement of an Instantaneous Frequency Step

REFERENCES

Application Note 173 "Recent Advances in Pulsed RF and Microwave Frequency Measurements" contains a thorough discussion of the above measurement considerations. It is recommended that AN 173 be consulted for all measurements using the set-up described in this application note.

The following application notes describe other uses of the 5345A Electronic Counter in characterizing the frequency output of VCO's:

AN 174-1	Measuring the Transfer Characteristic of a Voltage Controlled Oscillator
AN 174-2	Measuring Differential Nonlinearity of a Voltage Controlled Oscillator
AN 174-3	Measuring Integral Nonlinearity of a Voltage Controlled Oscillator
AN 174-4	Measuring Dual VCO Tracking Error
AN 174-13	Measuring the Tuning Step Transient Response of VCO's to 18 GHz

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For more information, call your local HP Sales Office or East (301) 948-6370 • Midwest (312) 677-0400 • South (404) 434-4000 • West (213) 877-1282. Or, write: Hewlett-Packard, 1501 Page Mill Road, Palo Alto, California 94304. In Europe, Post Office Box 349, CH-1217 Meyrin 1, Geneva, Switzerland. In Japan, Yokogawa-Hewlett-Packard, 1-59-1, Yoyogi, Shibuya-Ku, Tokyo, 151.

02-5952-7412 November 1975 Printed in U.S.A.