Errata

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HP References in this Manual

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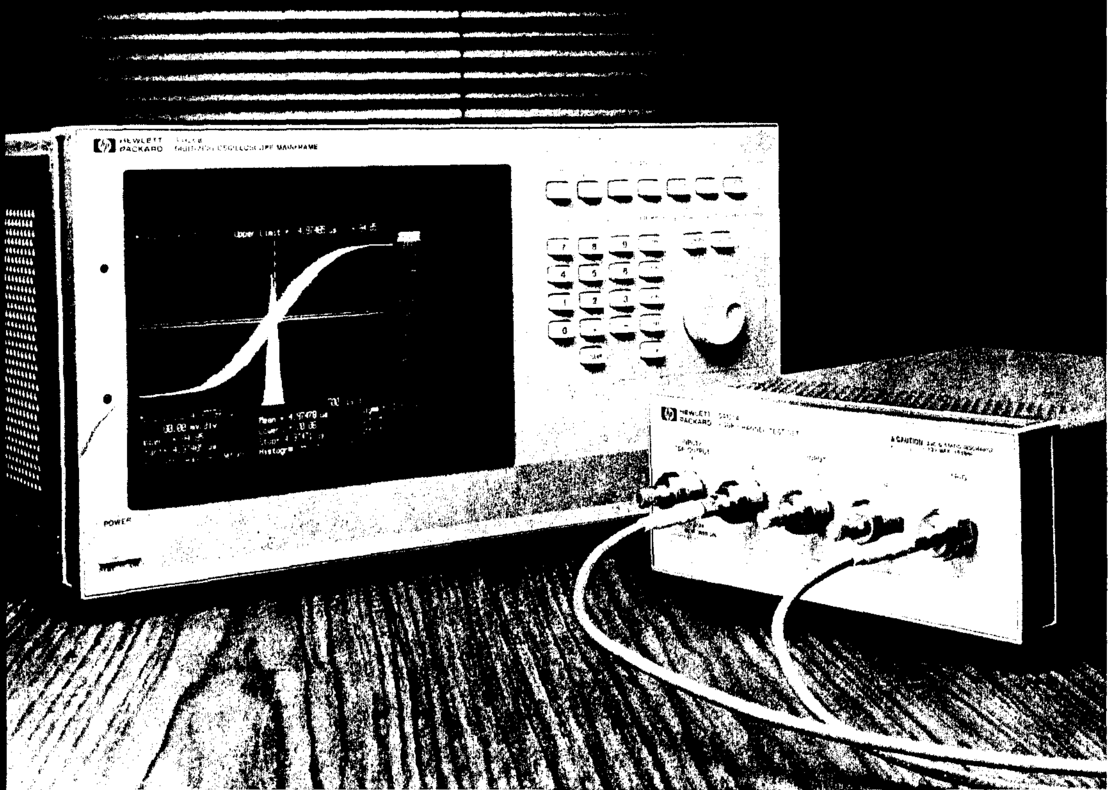
HEWLETT PACKARD

Product Note 54120-2

August 1989



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Jitter Analysis Using the HP 54120 Family of Digitizing Oscilloscopes

Introduction

The histogram techniques of the HP 54120 series of digitizing oscilloscopes allow comprehensive characterization of jitter. This product note provides the procedures for measuring common types of jitter on an HP 54120 digitizing oscilloscope using histograms. To understand how the histogram techniques of an HP 54120 can be used for jitter measurements, types of jitter and their effects will be reviewed. Jitter measurement configurations are outlined and measurement results representing a cross section of 54120's are given.

Why Jitter is Important

Jitter describes the random time uncertainty of a waveform event relative to a particular point. In digital hardware operation, data is placed on the input of a device and "clocked" into that device with a pulse edge. The device performs some operation with the data and provides an output. Timing relationships between clock, input signals, and output signals are all crucial to error-free data transfer.

The jitter between a clock and input data signal edges can cause erroneous transfers of data. Invalid data transfer becomes increasingly probable as the amount of jitter approaches the width of the time window during which data can be successfully transferred. Particularly at high data rates, it is essential to minimize jitter between signals so that the clocking device can initiate error-free transfer of information.

Types of Jitter

Three major types of jitter in digital systems are period, width, and delay. These types are described by evaluating a clock signal and a related data signal, as shown in figure 1.

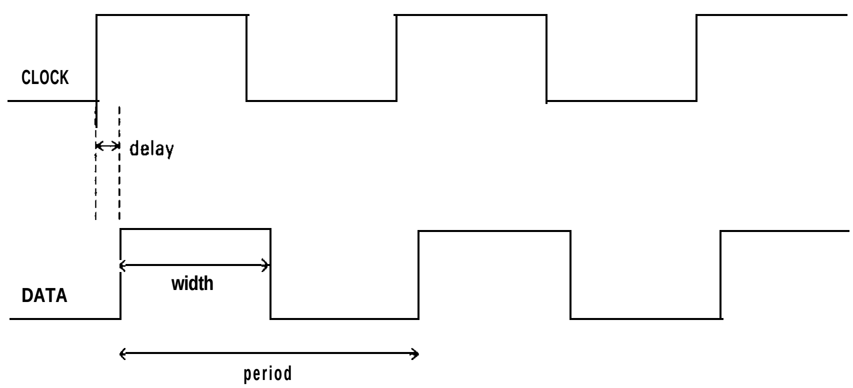

Figure 1. Clock and Data Signal

Period jitter describes the random variance in time between a triggered pulse edge and the next edge one period away, as shown in figure 2a.

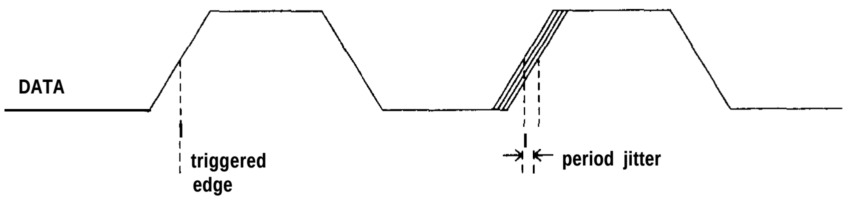

Figure 2a. Period Jitter

Width jitter describes the random variance in time between a triggered pulse edge and the next edge of opposite polarity immediately following it. Width jitter is shown in figure 2b.

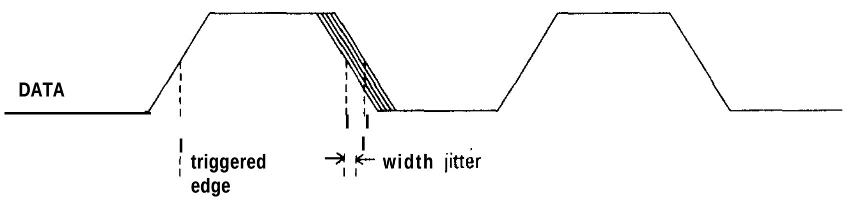

Figure 2b. Width Jitter

Delay jitter describes the random variance in time between a clock edge and an associated data edge, or between two data signals. Delay jitter is shown in figure 2c.

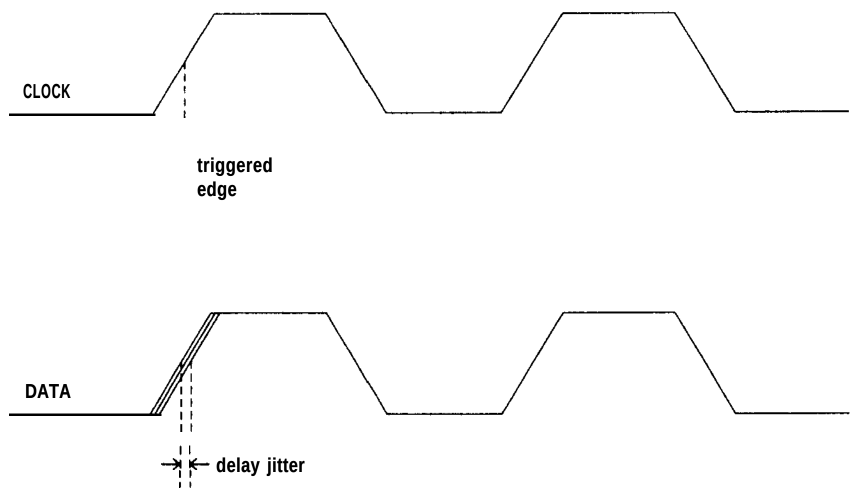

Figure 2c. Delay Jitter

Analog Oscilloscope Representation

Both analog and digitizing oscilloscopes provide direct viewing of jitter on their screens.

With a standard analog oscilloscope, jitter is seen as a band of illuminated phosphor, where the brightest section corresponds to the location where the edge occurs most often. A distribution of lower intensities indicates where the edge has lower occurrence. Typically, the CRT intensity is increased until just before blooming occurs and the limits of jitter are recorded as a peak-to-peak jitter measurement. A disadvantage in analog scopes is that the jitter measurement is dependent on the intensity setting, and the extremes of the jitter may not be sufficient to light the screen phosphor, yielding something less than peak-to-peak jitter. Analog storage scopes overcome part of this problem by building up a trace of jitter and keeping it on the screen; however, storage scopes are especially susceptible to blooming.

It follows that a digital oscilloscope can provide repeatable and quantifiable results, whereas an analog scope cannot.

Digitizing Oscilloscope Representation With Histograms

An accurate approach to measuring jitter is to use histograms in a digitizing oscilloscope to perform a statistical analysis on a distribution of jitter. Standard deviation (sigma or RMS) is the most accurate way to characterize jitter. For normal distributions, sigma provides insight to the distribution of the jitter and peak-to-peak does not. The value of peak-to-peak jitter is either six or eight times sigma depending on your definition of peak-to-peak jitter. Six times sigma equates to 99.74% of the area bounded by the peak-to-peak jitter from Gaussian noise.

Infinite persistence on digitizing scopes allows a closer view of peak-to-peak jitter over any particular time period. Consider a jittering edge viewed in infinite persistence as shown in figure 3. Statistical data is obtained when a thin voltage slice is taken through the center of the screen, and the number of times each pixel was hit within this slice is recorded. The statistical data collected is used to construct a histogram. Calculations of the mean and standard deviation of the jitter are also performed using the statistical data.

Through histograms, the digital oscilloscope gives the user a quantitative feel for the distribution of the jitter. The statistics provide reliable, repeatable results that are user-independent.

A detailed description of mean, standard deviation, distribution types, and histogram representations is given in HP Product Note 54120-I. The basics of the product note are reviewed in Appendix A.

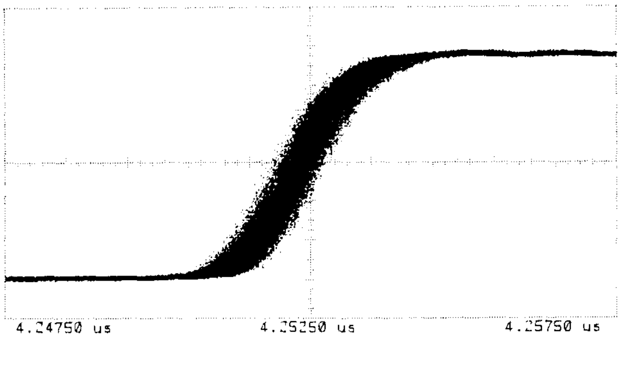

Figure 3. Edge Jitter Viewed with Infinite Persistence

Identifying Scope Jitter

An additional component of jitter due to the oscilloscope itself is inherent in any jitter measurement. It is important to characterize scope jitter and separate it from the measurement so that only the signal jitter remains. Two major sources of scope jitter are trigger threshold and scope time base delay.

Trigger threshold jitter originates in the trigger circuit. A trigger circuit contains a comparator that looks for a slope polarity and a level. All circuits produce some amount of thermal noise which is usually assumed to be Gaussian. When a signal crosses a comparator level, trigger threshold jitter is formed in the comparator output from noise originating in the trigger circuitry. See figure 4 for a pictorial description of the formation of jitter as a signal crosses a threshold. The faster the slew rate ($\Delta V/\Delta t$), the less effect this noise has on producing jitter.

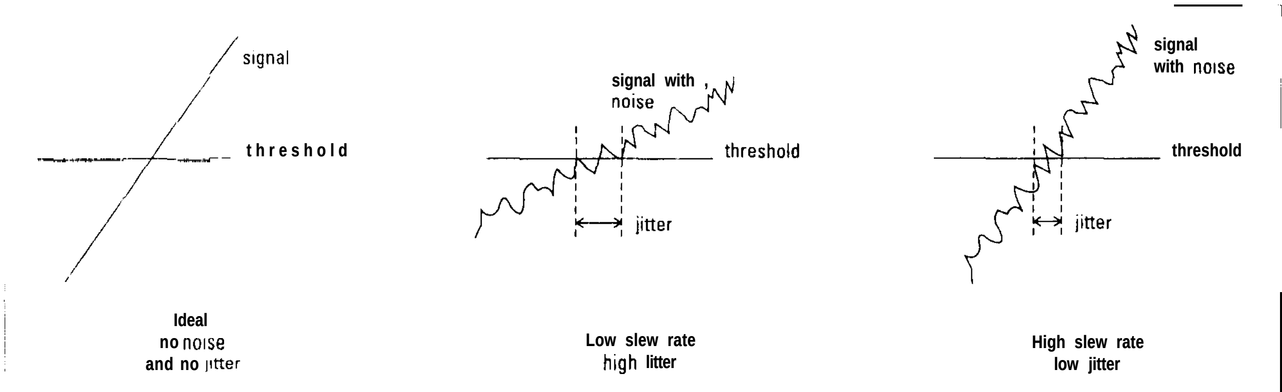

Figure 4. The Formation of Jitter as a Signal Crosses a Threshold

Time base delay jitter originates in the course and fine programmable delays of the time base. The coarse programmable delay is derived from counters driven by a 250 MHz oscillator. The 250 MHz oscillator has a 0.1% frequency accuracy which introduces a small amount of jitter. The fine programmable delay involves a ramp voltage crossing a threshold. Any signal crossing a threshold will develop some amount of jitter. The amount of jitter is dependent on the amount of noise on the signal and the slope of the signal as it crosses the threshold.

HP 54120 Specified Jitter

Oscilloscope jitter is specified to be within certain limits. Actual jitter is usually significantly less than this amount. Total scope jitter (including trigger threshold and time base delay jitter) is specified in the following equation:

Jitter (RMS) < 5 ps + (5x10-a x scope delay setting)

For example, with a scope delay setting of 100 ns, the specified jitter is 5 ps + (5x10-5 x 100 ns) = 10 ps(RMS).

Hewlett-Packard guarantees performance to the extent of normal specifications. Typically, HP 54120's out-perform the jitter specifications given in this document.

Basic Measurements and Configurations Using a Digitizing Oscilloscope

In the previous sections, the implications of period, width, delay, and scope induced jitter were discussed. In this section you will learn how scope and signal jitter measurements are configured with a digitizing oscilloscope. Examples of measurements performed with a typical HP 54121T are provided to give a general idea of expected results.

Consider the following when making jitter measurements with an HP 54120:

HP 54120 Digitizing Oscilloscopes use a sequential sampling system whereby a single sample point is taken with each trigger.

There is a minimum delay of 16 ns between a trigger event and an actual acquisition. Therefore, a minimum delay line of 20 ns is required in the signal path to view the triggered edge at the center of the screen. The delay line is important because scope induced jitter must be measured on the triggered edge so that it can later be removed from the measured jitter of interest.

Measurement of HP 54120 Jitter

A number of measurements were performed to determine typical trigger threshold jitter and time base delay jitter. An HP 8341B sweeper was selected as the signal source for frequency stability and spectral purity.

Measurement of Scope Trigger Threshold Jitter

For this publication, trigger threshold jitter was measured for a number of sinusoidal inputs. Measurements were performed by dividing the signals with a power splitter, triggering the scope with one output of the power splitter, and feeding the other output through a delay line. The triggered edge then appeared on the screen as close as possible to the minimum 16 ns delay. The test setup is shown in figure 5. The triggered edge appeared at approximately 26 ns (22 ns delay line plus cabling at 1.2 ns/ft).

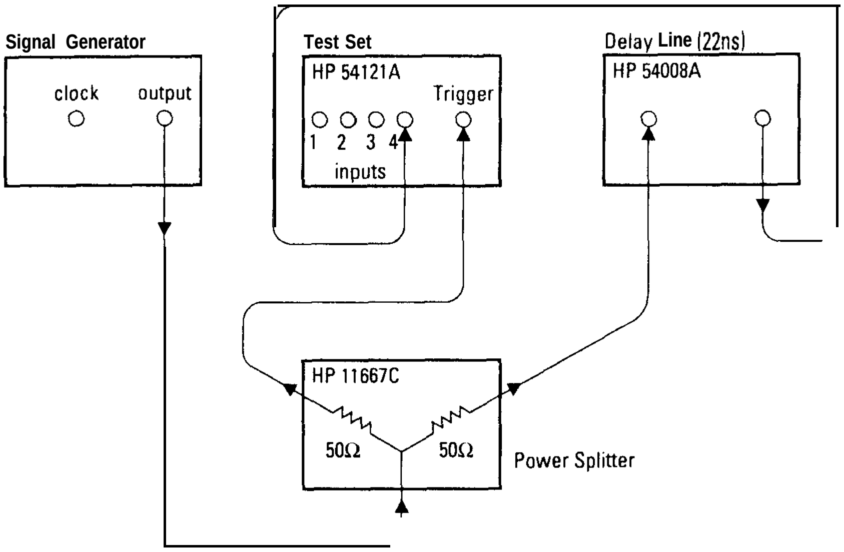

Figure 5. Test Setup for Measuring Scope Trigger Threshold Jitter, Signal Period and Signal Width Jitter.

To properly characterize any scope, scope trigger threshold jitter measurements must be made on the triggered edge of the signal to be measured. To ensure that the triggered edge was correctly identified, the source frequency was varied slightly while observing the waveform. The triggered edge remained stationary while all other edges moved. To view jitter, the waveform was expanded about the triggered edge.

To obtain the most accurate jitter measurements, always increase time base resolution and decrease channel display mV/div setting until the jitter to be measured covers at least one division on the screen. See figure 6a.

When the source has significant broadband noise, an hour glass shape appears at the exact trigger point. See figure 6b. When an hour glass ispresent, scope trigger threshold jitter is measured at the center of the hour glass. Jitter measured on the triggered edge off of the hour glass is the combined jitter from the scope trigger threshold jitter and the broadband noise of the signal being measured. Signal noise jitter can be calculated by the following equation:

$$\text{Signal Noise Jitter} = \sqrt{\begin{pmatrix}\text{Measured}\\ \text{RMS jitter}\\ \text{off of the}\\ \text{hour glass}\end{pmatrix}^2 - \begin{pmatrix}\text{Measured}\\ \text{RMS jitter}\\ \text{at center of}\\ \text{hour glass}\end{pmatrix}^2}$$

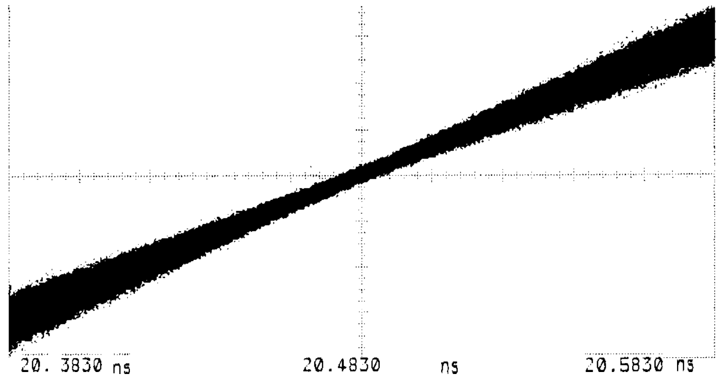

Figure 6a. Display Adjusted for Proper Measurement of Jitter on the Triggered Edge

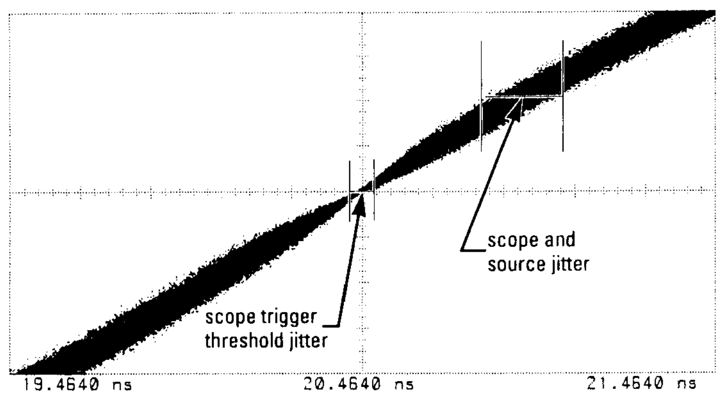

Figure 6b. Hour Glass at Trigger Point. Not Correctly Expanded for Measurement at the Center of the Hour Glass. Correctly Expanded for the Measurement Off of the Hour Glass

Scope trigger threshold jitter test results, from histogram measurements on an HP 54121T, for sine frequencies between 10 MHz and 2.5 GHz at 300 mV (peak) and 50 mV (peak) are shown in figure 7.

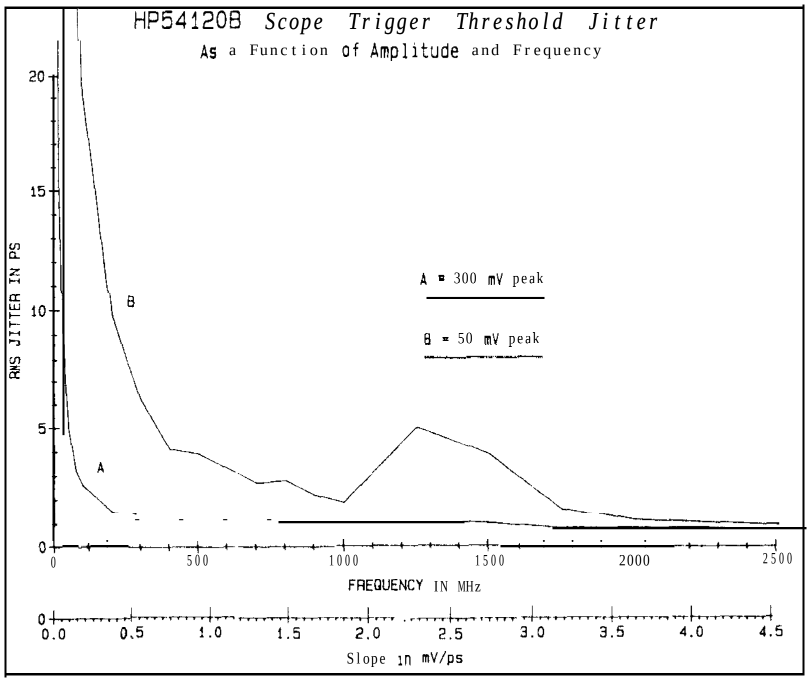

Figure 7. Scope Trigger Threshold Jitter (RMS) as a Function of Sinusoid Amplitude and Frequency, and as a Function of Slope

Sine inputs can be compared to pulse rise and fall times. Typical slopes, sine frequencies, pulse waveforms, and measured scope induced jitter are shown in table B1 (Appendix B). The following formula applies to the slope (slew rate) of sine frequencies

Slope = $(f_{max})(2\pi\ V_{max})$ where V_{max} = 300 mV peak.

Also for pulse waveforms

$$\text{Slope} = \frac{\text{(pulse amplitude) (0.8)}}{\text{(pulse rise time)}}$$

The slope on the trigger edge is a major contributing factor in the amount of scope trigger threshold jitter experienced. Steeper slopes equate to less jitter. Therefore, at a constant amplitude, the faster the rise time of a signal edge, the smaller the amount of scope jitter. Also, with a constant rise time, less scope trigger threshold jitter is induced with larger signal amplitudes.

HP 54120 digitizing oscilloscopes have a DC to 2.5 GHz trigger built into their test sets. Trigger bandwidth can be extended to 18 GHz using the HP 54118A external trigger. Typical jitter for sinusoidal inputs between 500 MHz and 18 GHz, using the HP 54118A, can be seen in figure 8 and table B2 (Appendix B).

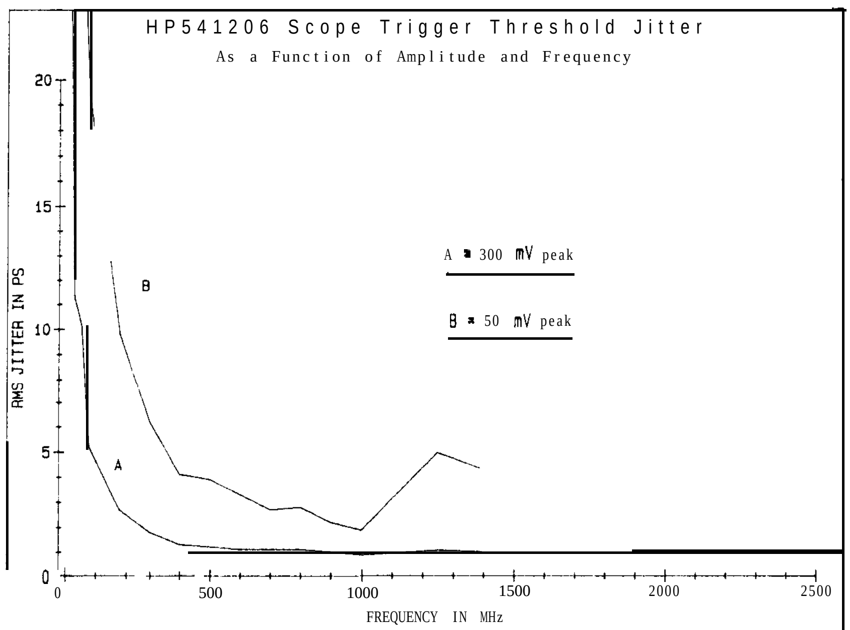

Figure 8. Typical Jitter (RMS) in High Bandwidth Triggering Using the HP 54118A

Measurement of Scope Time Base Delay Jitter

Scope time base delay jitter can be of concern in any measurement where scope delay is used to bring an edge of interest on to the screen.

Measurements of the time base delay jitter of a typical HP 54121T were made using a 500 mV p-p, 500 MHz sine wave from an HP 8341B sweeper.

The trigger edge was brought to screen using a power splitter and a delay line as in figure 5. The amount of jitter was noted so that scope induced jitter could be removed from the signal jitter measurement. Next, pieces of precision high-bandwidth cable were inserted, one at a time, and scope delay was increased each time to bring the edge back on screen. Jitter results are shown in table 1. Removing scope jitter from measurements is discussed in a following section. The equation used for the corrected results in table 1 is

$$\text{Scope Delay Jitter} = \sqrt{\begin{pmatrix}\text{Measured}\\ \text{RMS jitter}\\ \text{at delayed}\\ \text{edge}\end{pmatrix}^2 - \begin{pmatrix}\text{Measured*}\\ \text{RMS jitter}\\ \text{at triggered}\\ \text{edge}\end{pmatrix}^2}$$

* Measurernentmade off of the hourglass if present

This data indicates that scope time base delay jitter is negligible within the first 60 ns of scope delay.

Table 1. Scope Delay vs Jitter

Scope Delay (ns)	Measured RMS Jitter (ps)	Corrected RMS Delay Jitter (ps)
22.58	1.0	N. A.
26.09	1.1	0.46
29.78	1.1	0.46
33.46	1.1	0.46
37.14	1.1	0.46
40.88	1.1	0.46
43.55	1.1	0.46
46.20	1.1	0.46
49.68	1.1	0.46
53.37	1.1	0.46
57.06	1.2	0.66
60.74	1.3	0.83

Similar scope time base delay jitter results were obtained by observing the highly stable output signal from an HP 8341B sweeper at various scope delay settings and noting the amount of scope time base delay jitter. The signal used for the measurement was 500 MHz, 500 mV p-p. Uncorrected and corrected test results are shown in figure 9. Minimum jitter of 0.9 ps RMS is only seen at the exact trigger point. Measured jitter immediately increases to 3.0 ps on either side of the trigger point due to broadband noise in the sweeper. This noise is the cause of the hour glass appearance of the triggered edge. Delays over 500 ns were not considered, since the delay is restricted to 10^3 x screen diameters.

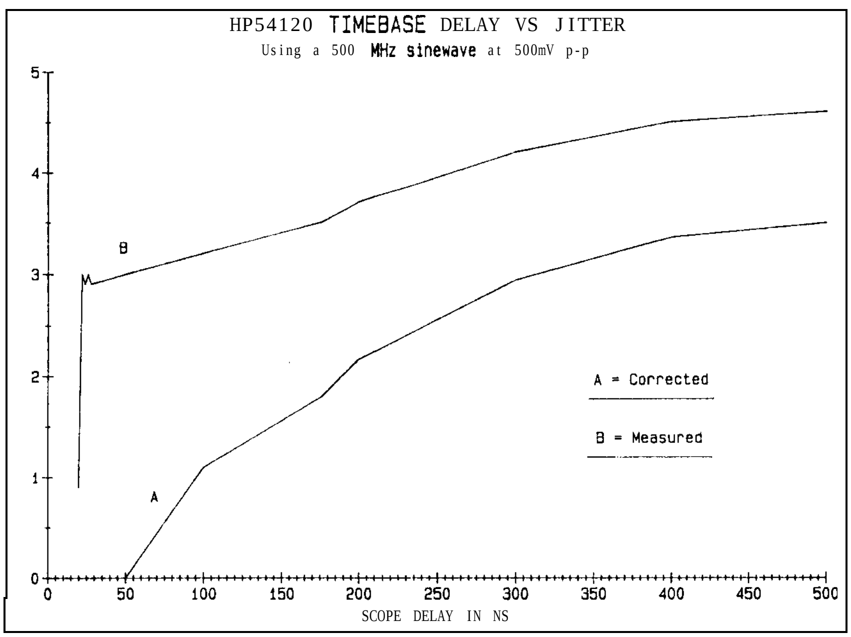

Figure 9. Uncorrected Measured Scope Delay Jitter as a Function of Scope Delay

The corrected data in figure 9 indicates that the scope delay jitter was very small. For the particular HP 541211' tested, the corrected value of scope delay jitter appeared to be very small, less than 1.1 ps RMS at delays below 100 ns (the specification at a 100 ns delay is 10 ps RMS). The HP 54120 specification has a safety margin built in to cover the full operating temperature range of 0 to 35 °C and the 0.1% (delta t) time base accuracy.

Measurement Configuration for Period and Width Jitter of a Signal

For period and width jitter measurements of a signal, only the signal to be measured is required. The scope triggers on an edge, and the next similar edge, **one** period later, is observed for period jitter. The edge immediately following of opposite transition is observed for width jitter.

To view the triggered edge for width and period jitter measurements, use the configuration shown in figure 5. A power splitter provides signals for the scope trigger input and an HP 54008A delay line, which then feeds into **a** scope channel.

Measurement, Configuration for Delay Jitter of a Signal

The configuration shown in figure 10 is used to view delay jitter. When viewing delay jitter, the random variations in time between two signals, typically a clock and data signal or two data signals, are of interest. The scope is triggered on the clock edge, and the related data edge is viewed on the scope. A delay line is necessary to view the triggered edge and thereby identify the amount of scope jitter.

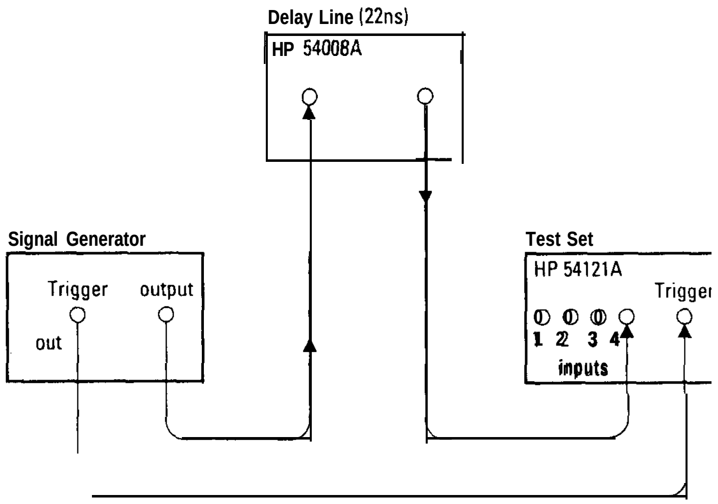

Figure 10. Test Setup to Measure Delay Jitter

Jitter Measurement on an Example Signal

Typical HP 54120 performance data presented in this note is useful for rough estimates of measurement feasibility. Actual measurements of scope induced jitter should be made on the scope to be used in a measurement. The measurement for scope trigger threshold jitter should be performed using the actual trigger edge available in the real measurement. The amount of oscilloscope time base delay jitter should be determined from measurements with a stable source. Characterization of an individual scope's time base delay jitter can be performed once and retained for reference in any measurement.

Consider an example of measuring the period, width, and delay jitter of a clock and data signal. The signals used for this product note were at 25 MHz and 250 MHz, 400 mV p-p, with 1 ns edges.

Measurement of Period and Width Jitter

For period and width jitter measurements, the same basic configuration of figure 5 was used. The results are listed in table 2.

Table 2. Uncorrected Period and Width Jitter

Frequency	Scope Jitter (RMS)	Period Jitter (RMS)	Width Jitter (RMS)
25 MHz	1.5 ps	14.4 ps	1.5 ps
250 MHz	1.4 ps	4.2 ps	2.7 ps

The histogram responses of these measurements for 25 MHz are shown in figures 11, 12, and 13.

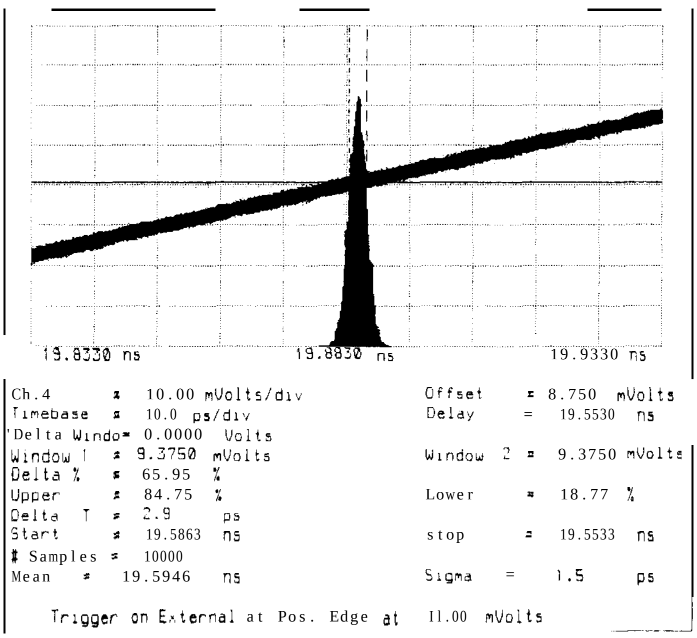

Figure 11. Scope Jitter

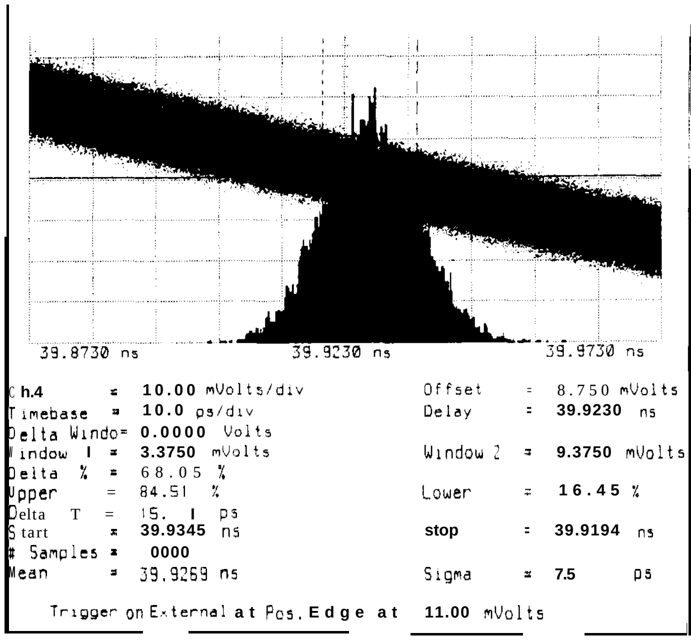

Figure 12. Width Jitter

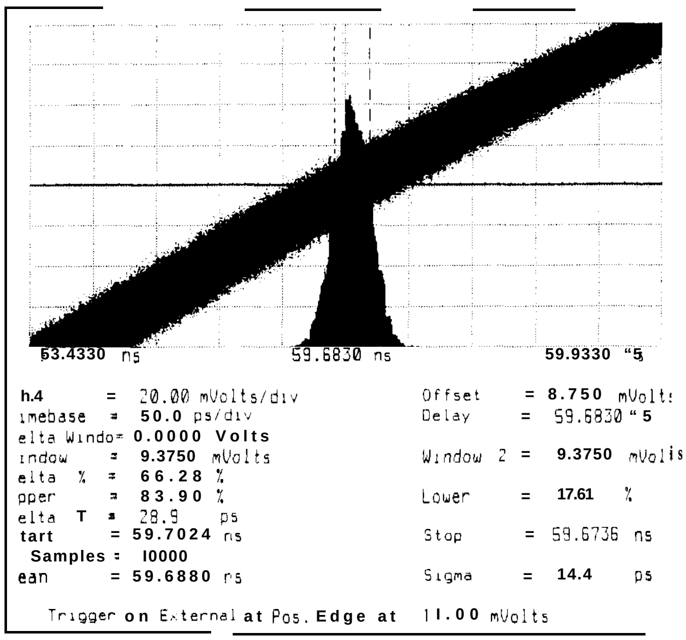

Figure 13. Period Jitter

Measurement of Delay Jitter

Consider the measurement of delay jitter between the clock output of the signal generator and data output at 25 MHz. On this particular device under test (DUT), there was a fixed delay between clock and data, and an additional delay up to one period could be added.

Scope trigger threshold jitter was determined by looking at the triggered edge of the DUT clock output. The measurement was performed by replacing the data input to the power splitter in the configuration shown in figure 5 with the DUT clock output. Scope jitter was measured as 1.6 ps.

Next, the delay line was removed, the clock was fed into the scope trigger input, and the delay line was inserted between the data output and the scope input, as shown in figure 10.

Jitter was measured on the delayed data edge, both at a minimum delay setting and maximum delay setting on the DUT. The uncorrected measured jitter results were 2.9 ps and 19.4 ps respectively.

Correcting for Scope Error

At this point, the scope jitter has been identified, although it is still part of the measurement. Now an approach will be outlined which quantifies the error caused by scope jitter and partially corrects for it.

If Y is a sum of random variables Xl and X2, and these random variables are uncorrelated (one does not affect the other),

Then

the mean of Y $= E(Y) = E(X1) + E(X2)$

which is the sum of the means of Xl and X2.

And

the variance of Y $= \sigma_y^2 = \sigma_1^2 + \sigma_2^2$.

Therefore the variances add directly. (1)

If the variances add, since the variance equals the square of the standard deviation, then this implies that the standard deviations of two normal uncorrelated distributions add via a quadratic equation. Thus, the standard deviation is the square root of the sum of the squares.

Therefore, for uncorrelated scope jitter and signal jitter,

$$\text{Signal Jitter (actual)} = \sqrt{\begin{pmatrix}\text{Measured}\\ \text{actual}\\ \text{jitter}\end{pmatrix}^2 - \begin{pmatrix}\text{Scope}\\ \text{trigger}\\ \text{threshold}\\ \text{jitter}\end{pmatrix}^2 - \begin{pmatrix}\text{Scope}\\ \text{time base}\\ \text{delay}\\ \text{jitter}\end{pmatrix}}$$

where jitter for each term is RMS.

In the example with the 25 MHz square wave, the scope jitter was measured at 1.5 ps, and measured period jitter of 14.4 ps.

$$\text{Period Jitter (actual)} = \sqrt{(14.4)^2 - (1.5)^2} = 14.3\ \text{ps}$$

Recall that at the scope delays used to measure period and width jitter in this example (39.9 ns and 59.7 ns beyond triggered edge) scope time base delay jitter was hardly measurable. Therefore, only the trigger threshold jitter was important for this calculation. In this case, scope trigger threshold jitter caused only a 0.6% error. In general, if the scope jitter is less than three times the jitter to be measured, the scope error contribution should be less than 5.0%, since jitter adds via a quadratic equation. Keeping this 3:1 margin between signal jitter and scope jitter is a good rule of thumb, which will reduce the need to back out scope induced error.

Table 3 shows the corrected results of the example DUT measurements after backing out the scope jitter.

TABLE 3. Corrected DUT Jitter

Frequency	Period	Width	Delay (+0)	Delay (+49 ns)
25 MHz	14.3 ps	7.3 ps	2.4 ps	19.3 ps
250 MHz	4.0 ps	2.3 ps	not taken	not taken

Instructions for Measuring Jitter

This section will provide step-by-step procedures for measuring width, period, and delay jitter. To supplement these procedures, section 3 of the Getting Started Guide for the HP 54121T Digitizing Oscilloscope provides step-by-step procedures for histogram measurements.

Width and Period Jitter Measurements

The procedures for measuring width and period jitter are as follows:

1) Connect your equipment as shown in figure 5, with your signal to be measured replacing the signal generator.

2) Select Autoscale on your HP 54120.

3) Determine which edge is the triggered edge by varying the frequency of the source and observing that the triggered edge remains stationary. Or, if the amount of delay in the signal path is known, set the center of the scope time base delay to the value of the delay.

4) Expand the scope time/div until the edge spans the entire screen. Keep the edge centered on the screen with the oscilloscope time base delay setting.

5) If needed, expand the scope volts/div to obtain a minimum of one-half a major division of jitter. See figure 6a for an example of a proper display of jitter.

6) Select the histogram menu on the HP 54120. Obtain a time histogram with the windowed area at the center of the edge. If an hour glass is apparent, window at the center of the it for scope trigger threshold jitter only. Window off the hour glass for a measurement of trigger threshold and signal noise jitter. (See figure 6a.) The window markers should be on top of one another so that the delta window is 0.0 V.

7) Set the number of samples to be acquired to a minimum of 500. Acquire the statistical data, by pushing the Acquire button.

8) Select results and then select sigma. The statistical results of the data will be displayed at the bottom of the screen. Record sigma for use in calculations later. This value of sigma is the scope trigger threshold jitter, when measured at the center of the hour glass if present.

9) To measure width jitter, increase the scope time base delay to view the next edge of opposite polarity. Measure width jitter in the same manner that the jitter on the triggered edge was measured. See steps 6 – 8. Record the measured width jitter.

10) To measure period jitter, increase the scope time base delay to view the next edge of the same polarity as the triggered edge. Measure period jitter in the same manner that the jitter of the triggered edge was measured. See steps 6 – 8. Record the measured period jitter.

11) Calculate the actual width and/or period jitter with the following equation

$$\text{Actual Jitter} = \sqrt{\begin{pmatrix}\text{Measured}\\\text{jitter}\end{pmatrix}^2 - \begin{pmatrix}\text{* Scope}\\\text{trigger}\\\text{jitter}\end{pmatrix}^2 - \begin{pmatrix}\text{** Scope}\\\text{time base}\\\text{jitter}\end{pmatrix}^2}$$

* NOTE. This value can also include the signal noise if there is an hour glass and the measurement is taken off of the hour glass

** NOTE Scope time base delay jitter may be negligible. Characterize your scope once for time base delay jitter and then use your results for all future litter measurements. The procedure for characterizing the scope time base delay jitter is described earlier in this application note

Delay Jitter Measurements

The procedures for measuring delay jitter are as follows:

1) Using steps 1 – 8 of the procedures for width and period jitter measurements, obtain the scope trigger threshold and signal noise jitter measurement.

2) Connect your equipment **as** shown in figure 10.

3) Measure the jitter on the delayed data edge. See figure 2c and reference steps 6 – 8 of the procedures for width and period jitter measurements.

4) Calculate the actual delay jitter with the equation given in step 11 of the previous procedures for width and period jitter measurements.

Improving the Throughput of Jitter Measurements

For some applications it may be desirable to decrease the time to collect the data samples used in jitter measurements. When increased throughput is needed, it can be obtained with a trade off of measurement accuracy for decreased acquisition time.

Rather than place the window markers for a delta voltage of 0.0 V, as in step 6 of the width and period jitter measurement instructions given earlier in this publication, select a larger window. The larger the window the more error introduced into the measurement. To compensate for the error in the measured jitter with a window greater than 0.0 V, the slope of the edge being measured must be known. The following formula can be used to minimize measured error:

$$\text{Actual Jitter (RMS)} = \sqrt{\begin{pmatrix}\text{Measured}\\ \text{RMS}\\ \text{jitter}\\ \text{of edge}\end{pmatrix}^2 - \frac{\left(\dfrac{\Delta V}{\text{slope}}\right)^2}{12} - \begin{pmatrix}\text{Any other}\\ \text{RMS jitter to be}\\ \text{removed, i.e.}\\ \text{scope noise, etc.}\end{pmatrix}^2}$$

The measurement of the slope should be from the center of the edge. The accuracy of the slope measurement is proportional to the accuracy of the calculated jitter. Larger windows allow data to be collected in less time at the cost of additional measurement error, individual users should determine the most desirable combination of throughput and accuracy for their applications.

(Reference Meyer, page 126, example 7.18)

Conclusions:

- For greatest accuracy in jitter measurements, individual oscilloscopes need to be characterized prior to making jitter measurements. Simple techniques, described in this paper, can be used to identify scope jitter in a measurement and separate scope jitter from the measured jitter of a signal. When the scope jitter is uncorrelated to the measured signal jitter, scope and signal jitter add as the square root of the sum of the squares. Thus, one should either ensure that scope jitter is small compared to the jitter of interest (perhaps 3 times smaller) or mathematically remove the effect of scope jitter on the measurement.

- Slew rate and noise on a trigger edge significantly effect scope trigger threshold jitter. Considering measurements of 0.6 ps (RMS) scope jitter best case, measurements of jitter as small as 1.8 ps should be possible on fast slew rate signals. Signals with slower slew rates cause increased scope trigger threshold jitter. The amount of jitter should be measured to determine its effect on a measurement.

- Higher amplitude signals produce less trigger threshold jitter. Thus, scope trigger threshold jitter can be reduced by amplifying the signal to be measured. The amplifier must not have excessive noise which counteracts the benefits of amplification.

- Scope time base delay jitter can be a factor in jitter measurements. By specification, total jitter can be 5 ps + (5x10-5 x scope delay setting). However, for many measurements, particularly at delays less than 60 ns, scope time base delay jitter may be negligible

Appendix A: Statistical Analysis of Signals and Histograms

The purpose of this appendix is to provide an over view of the statistical analysis used in the HP 54120 family of oscilloscopes and to provide an understanding of the formation of histograms.

This appendix contains excerpts from HP Product Note 54120-1, "Histograms and Statistical Analysis of Signals For Use With HP 54120 Digitizing Oscilloscope."

Basics of Statistics

The sample mean, denoted $\bar{X}$, is the most common way of measuring the center of a set of data. Equation 1 defines the mean as

$$\bar{X} = (1/n) \sum_{i=1}^{n} X_i \quad .$$

Equation 1.

Note that $\bar{X}$ is an unbiased estimator of the true mean of the population, μ (mu). Therefore, the sample mean approaches the true mean for a large sample number, n.

The sample standard deviation, denoted σ, is a measure of the extent to which the data points deviate from the mean. Equation 2 is the definition of σ.

$$\sigma = \sqrt{\left(\frac{1}{(n-1)}\right) \sum_{i=1}^{n} (X_i - \bar{X})^2}$$

Equation 2.

σ is a biased estimator of the true standard deviation, σ (sigma) of the entire population. For a large sample, σ is commonly used to estimate sigma.

Another statistical value of concern is the root-mean-square (RMS). Equation 3 is the definition of RMS. The RMS value and sigma approach the same value as the number of samples increases. The RMS value for a normal distribution, to be discussed next, is one sigma.

$$\text{RMS} = \sqrt{(1/n) \sum_{i=1}^{n} X_i^2}$$

Equation 3.

The normal distribution, the bell-shaped curve, and the Gaussian distribution all describe the distribution shown in figure Al. The distribution is symmetric about the mean and the shape of the distribution is a function of the standard deviation. Equation 4 defines the Gaussian distribution.

$$f(x,\mu,\sigma) = \left(1/\left(\sqrt{2\pi}\,\sigma\right)\right) \exp\left(\frac{-1}{2}\left[\frac{x-\mu}{\sigma}\right]^2\right) \qquad \begin{array}{c} -\infty < x < \infty \\ -\infty < \mu < \infty \\ \sigma \geq 0 \end{array}$$

Equation 4.

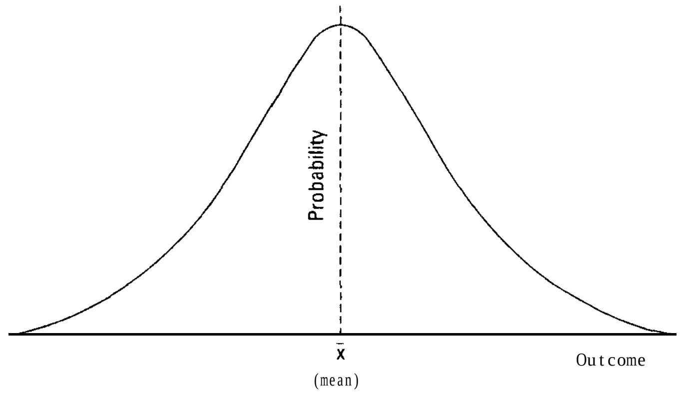

Figure Al. The Normal Distribution

In a normal distribution, the area under the curve to the right of the positive one standard deviation (sigma) point is 15.8% of the total area under the curve. Therefore the area under the curve bounded by the one standard deviation points is 68.26% of the total. Similarly, the area bounded by the two and three standard deviation points is 95.44% and 99.74% respectively.

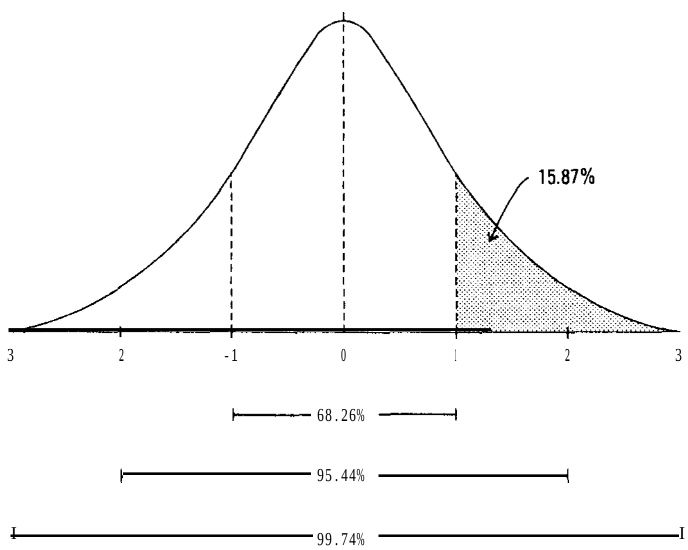

Figure A2. Area Bounded by *no*

Histograms

Consider a sampling of some distribution, made by simple measurements, where the results are placed in a table. The distribution of the data will be a function of some variable, such as time along a scope axis, and at each value of the variable there will be a value for the frequency of occurrences. In histograms from an HP 54120, the variable is not continuous, but rather stepped. Each step is called a class, and there are *i* number of classes, and *n* number of samples. When data is plotted, with one axis as the distribution variable, and the other as the frequency of occurrences, a histogram such as figure A3 results.

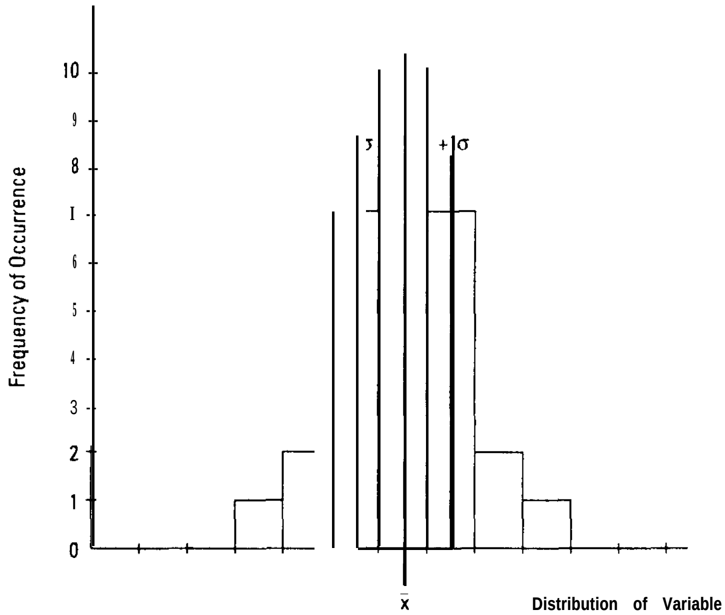

Figure A3. Typical Histogram

Note that the histogram graphically shows the shape of a probability density function. One can then see if the distribution of the density function is fairly close to the normal distribution shown in figure Al.

The Digitizing Scope Histogram Representation With Mean and Standard Deviation:

Using the Histogram menu on an HP 54120 digitizing oscilloscope, a voltage slice is selected, the data points are collected, and a histogram is displayed. An example histogram taken with 1,000 samples is shown in figure A4. Notice that the percentage of hits about the mean indicate a fairly normal distribution. The mean and sigma of the distribution can also be determined from the data points and are available at the push of the Sigma button on the HP 54120 histogram menu.

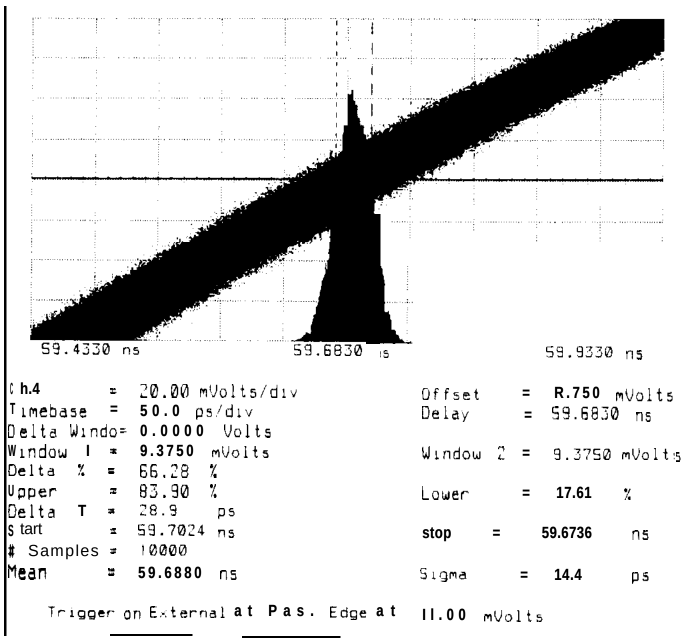

Figure A4. Digitizing Oscilloscope Histogram Measurement

Appendix B
Data Tables

TABLE B1. Slope, Sine Frequency, Rise lime, And Jitter Relationships

Sine Freq, 300 mV (peak)	Slope (sr) mV/ps	Jitter Rms	Equiv Rise lime Pulse*	Jitter RMS
5 MHz	0.009	53.4 ps	32.0 ns 375 mV	56.4 ps
10 MHz	0.019	29.3 ps	15.8 ns 375 mV	25.5 ps
25 MHz	0.047	10.8 ps	6.4 ns 375 mV	10.5 ps
50 MHz	0.094	5.0 ps	3.2 ns 375 mV	5.3 ps
75 MHz	0.141	3.2 ps	2.1 ns 375 mV	3.6 ps
100 MHz	0.189	2.6 ps	1.6 ns 375 mV	2.6 ps
250 MHz	0.471	1.2 ps	317.0 ps 186 mV	1.2 ps
500 MHz	0.942	0.9 ps	317.0 ps 373 mV	0.8 ps
750 MHz	1.414	0.8 ps	317.0 ps 560 mV	0.7 ps
1.0 GHz	1.885	0.7 ps	317.0 ps 746 mV	0.7 ps
1.5 GHz	2.827	0.8 ps	133.0 ps 469 mV	0.8 ps
2.0 GHz	3.768	0.8 ps	133.0 ps 634 mV	0.7 ps
2.5 GHz	4.710	0.6 ps	133.0 ps 781 mV	0.7 ps

* NOTE When measuring rise times, do not use a delay line. Delay lines can distort the rising edge of a pulse

TABLE B2. Sine Frequency and Jitter Measurements With The HP 54118A, 500 MHz to 18GHz Trigger

Sine Freq	Measured Jitter (RMS) 300 mV peak	100 mV peak	50 mV peak
500 MHz	3.0 ps	7.2 ps	38.0 ps
1 GHz	2.0 ps	2.9 ps	15.4 ps
2 GHz	1.6 ps	1.9 ps	9.7 ps
4 GHz	1.1 ps	1.2 ps	2.2 ps
6 GHz	0.9 ps	1.0 ps	1.9 ps
8 GHz	0.8 ps	0.8 ps	1.4 ps
10 GHz	0.9 ps	0.9 ps	1.0 ps
12 GHz	0.9 ps	0.9 ps	1.0 ps
14 GHz	0.9 ps	0.8 ps	0.9 ps
16 GHz	0.8 ps	0.9 ps	1.1 ps
18 GHz	0.8 ps	1.0 ps	2.5 ps
20 GHz	1.0 ps	2.0 ps	3.7 ps

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