WP03 -PARAMETER ANALYSIS PACKAGE

OPERATION AND PROGRAMMING MANUAL

9300 SERIES

DIGITAL STORAGE OSCILLOSCOPES

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Contents

The Value of Histograms (and Trends)

The value of histograms in data analysis and the interpretation of measurement results is well known. The WP03 option added to your oscilloscope provides this and more for waveform parameter analysis. With WP03, histograms and trends (*see Chapter 4*) of waveform parameter measurements can be created, statistical parameters determined, and graphic features quantified for analysis.

Statistical parameters alone — such as mean, standard deviation and median — are usually insufficient for determining whether the distribution of measured data is as expected. Histograms provide an enhanced understanding of the distribution of measured parameters by enabling visual assessment of the distribution. Observations based on the histogram of a parameter can indicate:

- Distribution type: normal, non-normal, etc. This is helpful in determining whether the signal behaves as expected.
- Distribution tails and extreme values, which can be observed and may be related to noise or other infrequent and non-repetitive sources.
- Multiple modes, which can be observed and could indicate multiple frequencies or amplitudes. These can be used to differentiate from other sources such as jitter and noise.

Histograms of Parameter Measurements

Generating histograms of waveform measurement parameters is a three-step process:

1. Waveform parameters of interest are selected from the "**CURSORS/MEASURE**" menu.
2. Histograms are selected and set up through the scope's "**Math Setup**" menu for the waveform parameter of interest.
3. Statistical parameters are selected for measurement of histogram characteristics.

Histogram Math Function

Histograms of user-selected waveform parameters are created using the scope's Histogram Math function. This is done by defining a trace (**A**, **B**, **C**, or **D**) as a math function, and selecting "**Histogram**" as the function to be applied to the trace. As with other traces, histograms can be positioned and expanded using the **POSITION** and **ZOOM** knobs on the instrument's front panel.

Histograms are displayed based on a set of user settings, including bin width and number of parameter events. Special parameters are provided for determining histogram characteristics such as mean, median, standard deviation, number of peaks and most-populated bin.

This broad range of histogram options and controls provides a quick and easy method of analyzing and understanding measurement results.

The "**MEASURE**" "**Parameters**" menu is accessed by pressing the **CURSORS/MEASURE** button, then selecting "**Parameters**" from the top menu that appears, as shown in *Figure 1.1*.

Parameters are used to perform waveform measurements for the section of waveform that lies between the parameter cursors (Annotation ❶ in this figure). The position of the parameter cursors is set using the "**from**" and "**to**" menus and controlled by the associated 'menu' knobs.

The top trace in *Figure 1.1* shows a sine waveform. A **freq** parameter measurement is being performed on the waveform (Annotation ❷) with a value of 202.442 kHz as the average frequency. The bottom trace shows a histogram of the **freq** parameter with an average frequency of 201.89 kHz (Annotation ❸), which is the average frequency of the data contained within the parameter cursors.

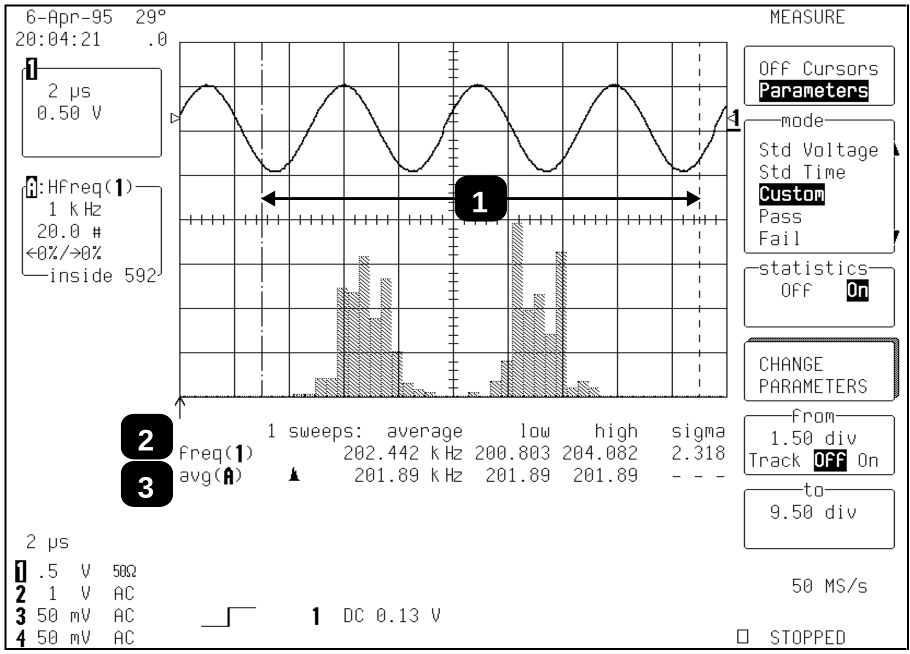


Figure 1.1

Selection of "**Custom**" from the "**mode**" menu and then "**CHANGE PARAMETERS**" displays the "**CHANGE PARAM**" menu group, shown in *Figure 1.2*. Now, up to five parameters can be selected, with each displayed on its own line below the waveform display grid. Parameter measurements can then also be selected from "**Category**" and "**measure**" using the corresponding menu buttons.

Categories are provided for related groups of parameter measurements. The "**Statistics**" category is provided for selection of histogram parameters. After selection of a category, a parameter can be selected from the "**measure**" menu. Selection of parameters is done using the menu buttons or knobs.

The parameter display line is selected from the "**On line**" menu.

In *Figure 1.2*:

- The **freq** measure parameter from the "**Cyclic**" category for Trace 1, which had earlier been selected, is displayed on Line 1 as **freq(1)** (*Annotation* ❶) .
- The **avg** measure parameter from the "**Statistics**" category for Trace A is selected for display on Line 2. The **avg** parameter provides the mean value of the underlying measurements for the Trace A histogram section within the parameter cursors (*Annotation* ❷), shown as "**avg(A)**", (*Annotation* ❸).
- No parameters have been selected for Lines 3–5.

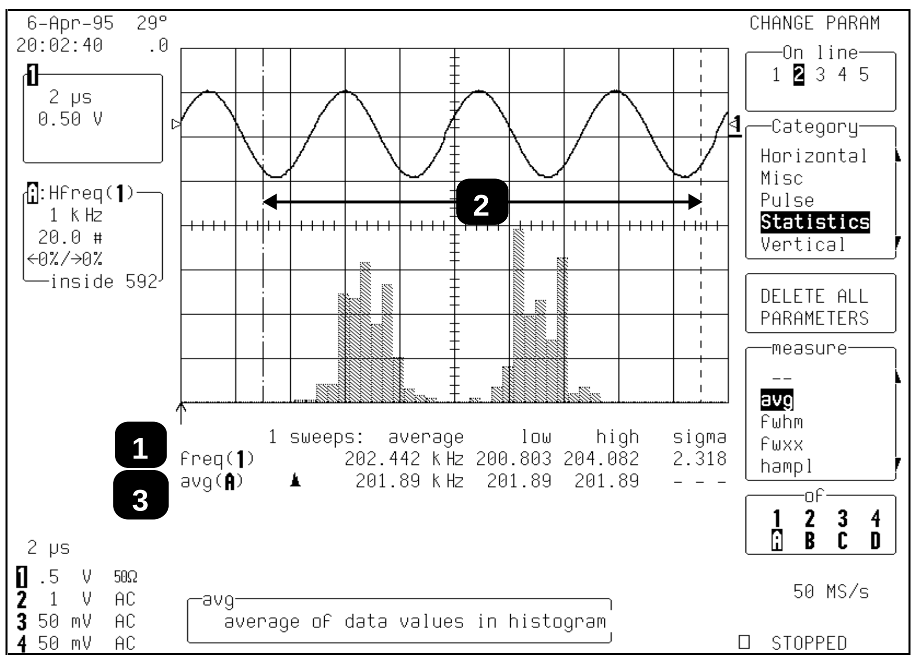


Figure 1.2

If a parameter has additional settings that must be supplied in order to perform measurements, the “**MORE ‘xxxx’ SETUP**” menu appears. But if no additional settings are required the “**DELETE ALL PARAMETERS**” menu appears, as shown in the figure above, and pressing the associated menu button results in all five lines of parameters being cleared.

Parameter Value Calculation and Display

When Persistence is *not* being used, the display for input channels shows the captured waveform of a single sweep.

For non-segmented waveforms, the display is identical to a single acquisition. But with segmented waveforms, the result of a single acquisition for all segments is displayed.

The value displayed for a chosen parameter depends on whether “**statistics**” is “**On**”. And on whether the waveform is segmented. These two factors and the parameter chosen determine whether results are provided for a single acquisition (trigger) or multiple acquisitions. In any case, only the waveform section between the parameter cursors is used.

If the waveform source is a memory (“**M1**”, “**M2**”, “**M3**” or “**M4**”) then loading a new waveform into memory acts as a trigger and sweep. This is also the case when the waveform source is a zoom of an input channel, and when a new segment or the “**All Segments**” menu is selected.

When “**statistics**” is “**Off**”, the parameter results for the last acquisition are displayed. This corresponds to results for the last segment for segmented waveforms with all segments displayed. For **zoom** traces of segmented waveforms, selection of an individual segment gives the parameter value for the displayed portion of the segment between the parameter cursors. Selection of “**All Segments**” provides the parameter results from the last segment in the trace.

When “**On**”, and where the parameter does *not* use two waveforms in calculating a result (∆dly, ∆t@lv), results are shown for all acquisitions since the **CLEAR SWEEPS** button was last pressed. If the parameter uses two waveforms, the result of comparing only the last segment per sweep for each waveform contributes to the statistics.

The statistics for the selected segment are displayed for **zoom** traces of segmented waveforms. Selection of a new segment or

"**All Segments**" acts as a new sweep and the parameter calculations for the new segment(s) contribute to the statistics.

Depending on the parameter, single or multiple calculations can be performed for each acquisition. For example, the **period** parameter calculates a period value for each of up to the first 50 cycles in an acquisition. When multiple calculations are performed, with "**statistics**" "**Off**" the parameter result shows the average value of these calculations. Whereas "**On**" displays the **average**, **low**, **high** and **sigma** values of all the calculations.

Example

In *Figure 1.3*, the upper trace shows the persistence display of a signal. The initial impression given the viewer is of some frequency drift in the signal source. The lower trace shows a histogram of the frequency as measured by the oscilloscope.

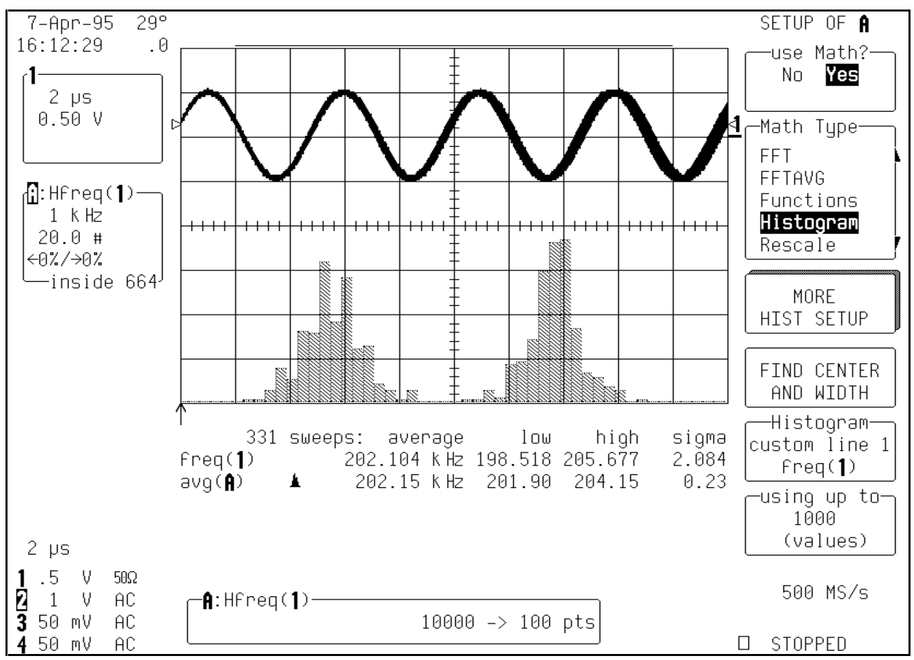


Figure 1.3

This histogram indicates two frequency distributions with dominant frequencies separated by 4000 Hz. There are two distinct and normal looking distributions, without wide variation, within each of the two. We can conclude that there are two dominant frequencies. If the problem were related to frequency drift, the distribution would have a tendency to be broader, non-normal in appearance, and normally there would *not* be two distinct distributions.

After a brief visual analysis, the measurement cursors and statistical parameters can be used to determine additional characteristics of distribution, including the most common frequency in each distribution and the spread of each distribution. *Figure 1.4*, below, shows the use of the measurement cursor (*Annotation ➊*), to determine the frequency represented by one bin of the distribution. The value of the bin, inside the Displayed Trace Field (*see Chapter 2 for a detailed description*) is indicated by *Annotation ➋*.

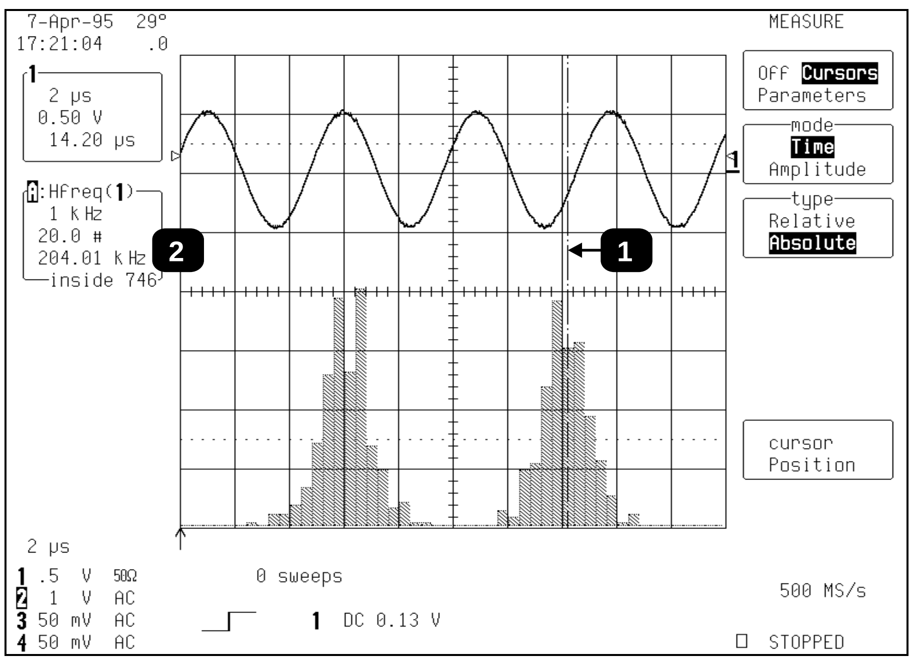


Figure 1.4

Figure 1.5, below, shows the use of the parameter cursors (*Annotations* ❶ and ❷) in determining the average frequency of the distribution located between the cursors. The average value of the measurements in the right-hand distribution is indicated by *Annotation* ❸.

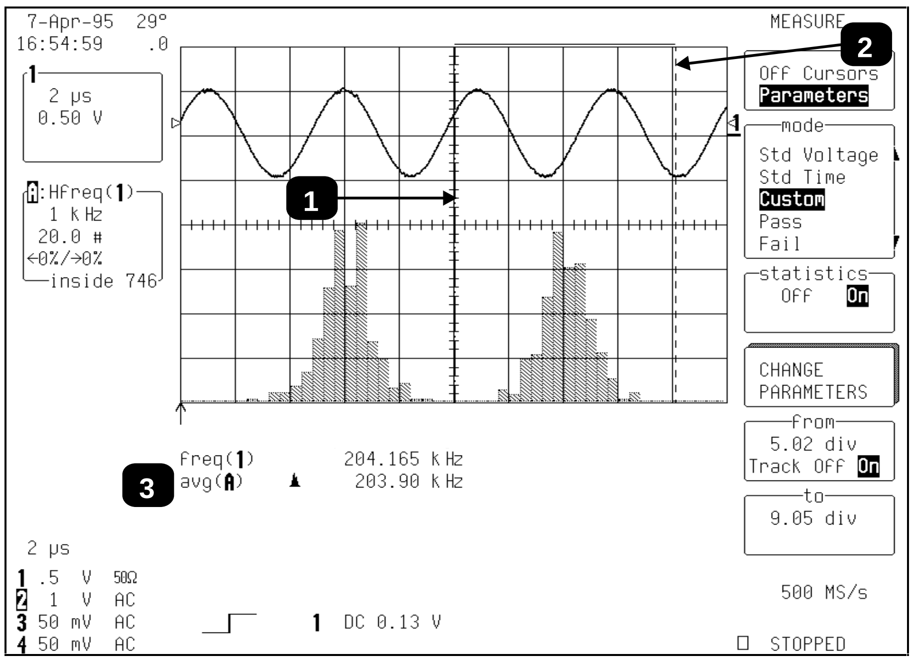


Figure 1.5

Finally, *Figure 1.6* shows the use of the measurement cursors (*Annotations* ❶ and ❷) in determining the difference in frequency between a bin in the center of each distribution. The value in k Hz, in the Displayed Trace Field, is indicated by *Annotation* ❸.

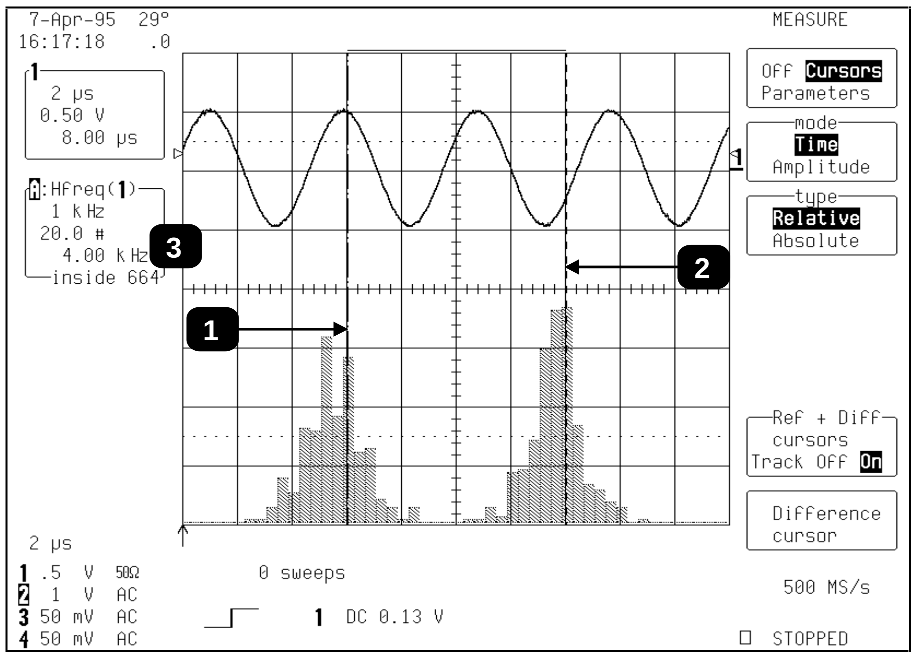


Figure 1.6

Theory of Operation

A statistical understanding of variations in parameter values is of great interest for many waveform parameter measurements. Knowledge of the average, minimum, maximum and standard deviation of the parameter may often be enough for the user, but in many other instances a more detailed understanding of the distribution of a parameter's values is desired.

Histograms provide the ability to see how a parameter's values are distributed over many measurements, enabling this detailed analysis. They divide a range of parameter values into sub-ranges called bins. Maintained for each bin is a count of the number of parameter values calculated — events — that fall within its sub-range.

While the range can be infinite, for practical purposes it need only be defined as large enough to include any realistically possible parameter value. For example, in measuring TTL high-voltage values a range of ± 50 V is unnecessarily large, whereas one of 4 V ± 2.5 V is more reasonable. It is this 5 V range that is subdivided into bins. And if the number of bins used were 50, each would have a sub-range of 5 V/50 bins or 0.1 V/bin. Events falling into the first bin would then be between 1.5 V and 1.6 V. While the next bin would capture all events between 1.6 V and 1.7 V. And so on.

After a process of several thousand events, the graph of the count for each bin — its histogram — provides a good understanding of the distribution of values. Histograms generally use the 'x' axis to show a bin's sub-range value, and the 'y' axis for the count of parameter values within each bin. The leftmost bin with a non-zero count shows the lowest parameter value measurement(s). The vertically highest bin shows the greatest number of events falling within its sub-range.

The number of events in a bin, peak or a histogram is referred to its population. *Figure 2.1* shows a histogram's highest population bin as the one with a sub-range of 4.3–4.4 V — to be expected of a TTL signal. The lowest value bin with events is that with a sub-range of 3.0–3.1 V. As TTL high voltages need to be greater than 2.5 V, the lowest bin is within the allowable tolerance. However, because of its proximity to this tolerance and the degree of the bin's separation from all other values, additional investigation may be desirable.

LeCroy DSO Process

LeCroy digital oscilloscopes generate histograms of the parameter values of input waveforms. But first, the following must be defined:

- The parameter to be histogrammed.
- The trace on which the histogram will be displayed.
- The maximum number of parameter measurement values to be used in creating the histogram.
- The measurement range of the histogram.
- The number of bins to be used.

Once these are defined, the oscilloscope is ready to make the histogram.

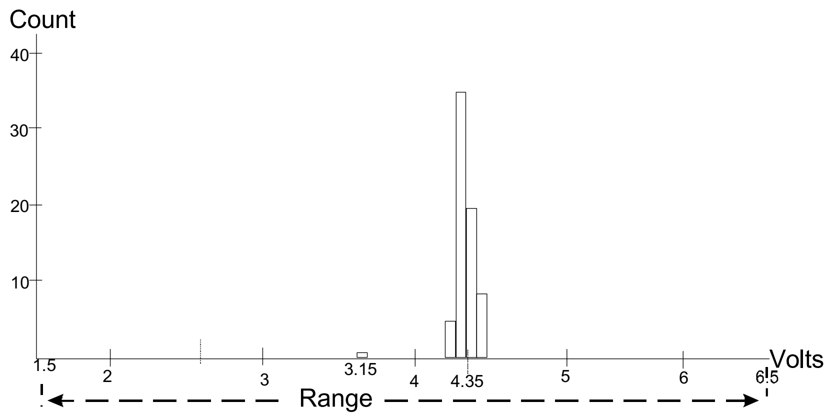


Figure 2.1

The sequence for acquiring histogram data is:

1. trigger
2. waveform acquisition
3. parameter calculation(s)
4. histogram update
5. trigger re-arm.

If the timebase is set in non-segmented mode, a single acquisition occurs prior to parameter calculations. However, in Sequence mode an acquisition for each segment occurs prior to parameter calculations. If the source of histogram data is a memory, storing new data to memory effectively acts as a trigger and acquisition. Because updating the screen can take significant processing time, it occurs only once a second, minimizing trigger dead-time (under remote control the display can be turned off to maximize measurement speed).

Parameter Buffer

The oscilloscope maintains a circular parameter buffer of the last
20 000 measurements made, including values that fall outside the set histogram range. If the maximum number of events to be used in a histogram is a number ‘N’ less than 20 000, the histogram will be continuously updated with the last ‘N’ events as new acquisitions occur. If the maximum number is greater than 20 000, the histogram will be updated until the number of events is equal to ‘N’. Then, if the number of bins or the histogram range is modified, the scope will use the parameter buffer values to redraw the histogram with either the last ‘N’ or 20 000 values acquired — whichever is the lesser. The parameter buffer thereby allows histograms to be redisplayed using an acquired set of values and settings that produce a distribution shape with the most useful information.

In many cases the optimal range is not readily apparent. So the scope has a powerful range-finding function. If required it will examine the values in the parameter buffer to calculate an optimal range and redisplay the histogram using it. The instrument will also give a running count of the number of parameter values that fall within, below and above the range. If any fall below or above the range, the range-finder can then recalculate to include these parameter values, as long as they are still within the buffer.

Parameter Events Capture The number of events captured per waveform acquisition or display sweep depends on the parameter type. Acquisitions are initiated by the occurrence of a trigger event. Sweeps are equivalent to the waveform captured and displayed on an input channel (1, 2, 3 or 4). For non-segmented waveforms an acquisition is identical to a sweep. Whereas for segmented waveforms an acquisition occurs for each segment and a sweep is equivalent to acquisitions for all segments. Only the section of a waveform between the parameter cursors is used in the calculation of parameter values and corresponding histogram events.

The following table provides, for each parameter and for a waveform section between the parameter cursors, a summary of the number of histogram events captured per acquisition or sweep.

Parameters (plus others, depending on options)	**Number of Events Captured**
data	All data values in the region analyzed.
duty, freq, period, width,	Up to 49 events per acquisition.
ampl, area, base, cmean, cmedian, crms, csdev, cycles, delay, dur, first, last, maximum, mean, median, minimum, nbph, nbpw, over+, over–, phase, pkpk, points, rms, sdev, Δdly, Δt@lv	One event per acquisition.
f@level, f80–20%, fall, r@level, r20–80%, rise	Up to 49 events per acquisition.

Histogram Parameters

Once a histogram is defined and generated, measurements can be performed on the histogram itself. Typical of these are the histogram's:

- Average value, standard deviation
- Most common value (parameter value of highest count bin)
- Leftmost bin position (representing the lowest measured waveform parameter value)
- Rightmost bin (representing the highest measured waveform parameter value).

Histogram parameters are provided to enable these measurements. Available through selecting "**Statistics**" from the "**Category**" menu, they are calculated for the selected section between the parameter cursors (*for a full description of each parameter, see Chapter 3*):

avg	average of data values in histogram
fwhm	full width (of largest peak) at half the maximum bin
fwxx	full width (of largest peak) at xx% the maximum bin
hampl	histogram amplitude between two largest peaks
hbase	histogram base or leftmost of two largest peaks
high	highest data value in histogram
hmedian	median data value of histogram
hrms	rms value of data in histogram
htop	histogram top or rightmost of two largest peaks
low	lowest data value in histogram
maxp	population of most populated bin in histogram
mode	data value of most populated bin in histogram
pctl	data value in histogram for which specified 'x'% of population is smaller
pks	number of peaks in histogram
range	difference between highest and lowest data values
sigma	standard deviation of the data values in histogram
totp	total population in histogram
xapk	x-axis position of specified largest peak.

Zoom Traces and Segmented Waveforms

Histograms of zoom traces display all events for the displayed portion of a waveform between the parameter cursors. When dealing with segmented waveforms, and when a single segment is selected, the histogram will be recalculated for all events in the displayed portion of this segment between the parameter cursors. But if "**All Segments**" is selected, the histogram for all segments will be displayed.

Histogram Peaks

Because the shape of histogram distributions is particularly interesting, additional parameter measurements are available for analyzing these distributions. They are generally centered around one of several peak value bins, known — together with its associated bins — as a **histogram peak**.

Example

In *Figure 2.2*, a histogram of the voltage value of a five-volt amplitude square wave is centered around two peak value bins: 0 V and 5 V. The adjacent bins signify variation due to noise. The graph of the centered bins shows both as peaks.

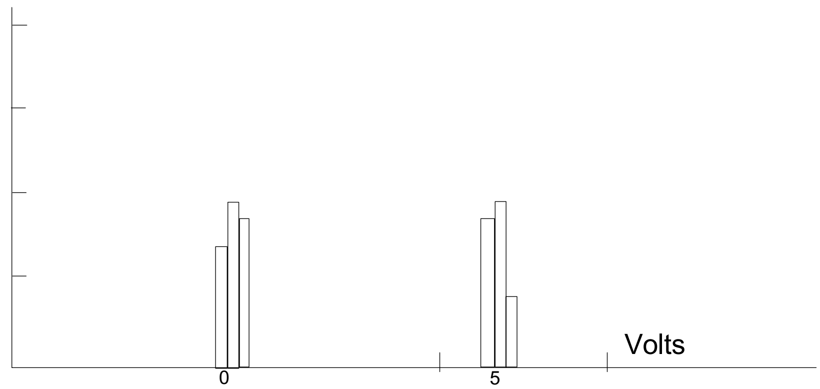


Figure 2.2

Determining such peaks is very useful, as they indicate dominant values of a signal.

However, signal noise and the use of a high number of bins relative to the number of parameter values acquired, can give a jagged and spiky histogram, making meaningful peaks hard to distinguish. The scope analyzes histogram data to identify peaks from background noise and histogram definition artifacts such as small gaps, which are due to very narrow bins.

*For a detailed description on how the scope determines peaks see the **pks** parameter description, Chapter 3.*

Binning and Measurement Accuracy

Histogram bins represent a sub-range of waveform parameter values, or events. The events represented by a bin may have a value anywhere within its sub-range. However, parameter measurements of the histogram itself, such as average, assume that all events in a bin have a single value. The scope uses the center value of each bin's sub-range in all its calculations. The greater the number of bins used to subdivide a histogram's range, the less the potential deviation between actual event values and those values assumed in histogram parameter calculations.

Nevertheless, using more bins may require performance of a greater number of waveform parameter measurements, in order to populate the bins sufficiently for the identification of a characteristic histogram distribution.

In addition, very fine-grained binning will result in gaps between populated bins that may make determination of peaks difficult.

Figure 2.3 shows a histogram display of 3672 parameter measurements divided into 2000 bins. The standard deviation of the histogram sigma (Annotation ❶) is 81.17 mV. *Note the histogram's jagged appearance.*

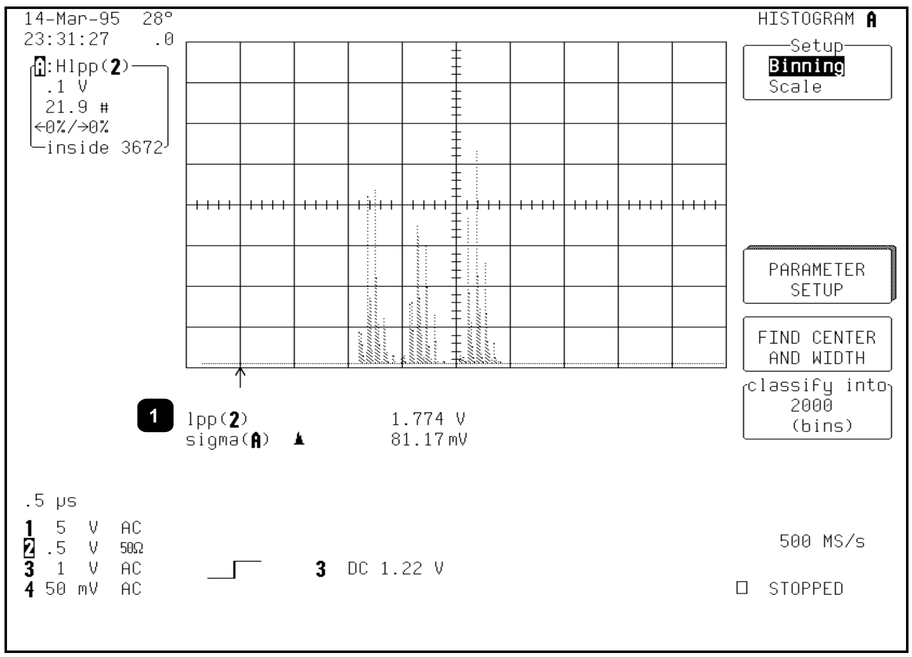


Figure 2.3

The oscilloscope's 20 000-parameter buffer is very effective for determining the optimal number of bins to be used. An optimal bin number is one where the change in parameter values is insignificant, and the histogram distribution does not have a jagged appearance. With this buffer, a histogram can be dynamically redisplayed as the number of bins is modified by the user. In addition, depending on the number of bins selected, the change in waveform parameter values can be seen.

In *Figure 2.4* the histogram shown in the previous figure has been recalculated with 100 bins. Note how it has become far less jagged, while the real peaks are more apparent. Also, the change in sigma is minimal (81.17 mV vs 81 mV).

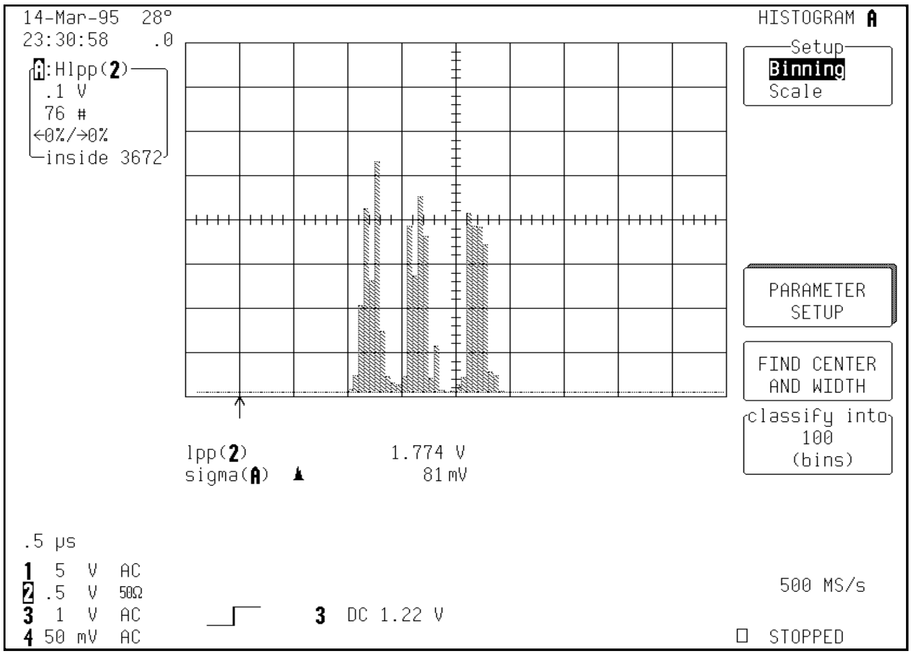


Figure 2.4

Creating and Analyzing Histograms

The following provides a description of the oscilloscope's operational features for defining, using and analyzing histograms. The sequence of steps is typical of this process.

Selecting the Histogram Function

Histograms are created by graphing a series of waveform parameter measurements. The first step is to define the waveform parameter to be histogrammed. *Figure 2.5* shows a screen display accompanying the selection of a frequency (**freq**) parameter measurement (*Annotation* ❶) for a sine waveform on Channel 1.

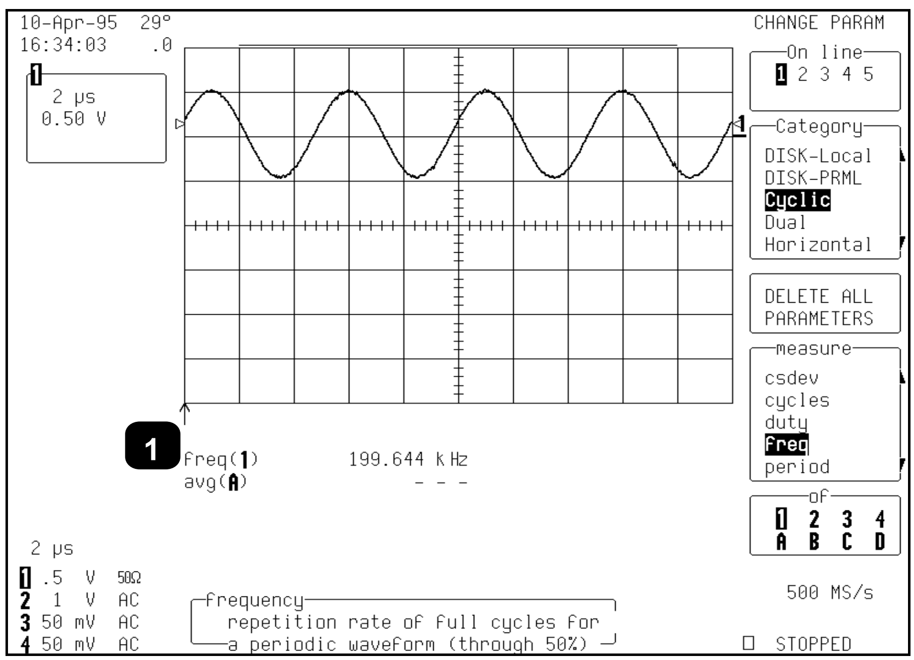


Figure 2.5

The preceding figure shows four waveform cycles, which will provide four freq parameter values for each histogram, each sweep. With a freq parameter selected, a histogram based on it can be specified.

But first the waveform trace must be defined as a histogram. This is done by pressing the **MATH SETUP** button. *Figure 2.6* shows the resulting display. To place the histogram on Trace **A**, the menu button corresponding to the "**REDEFINE A**" menu is pressed.

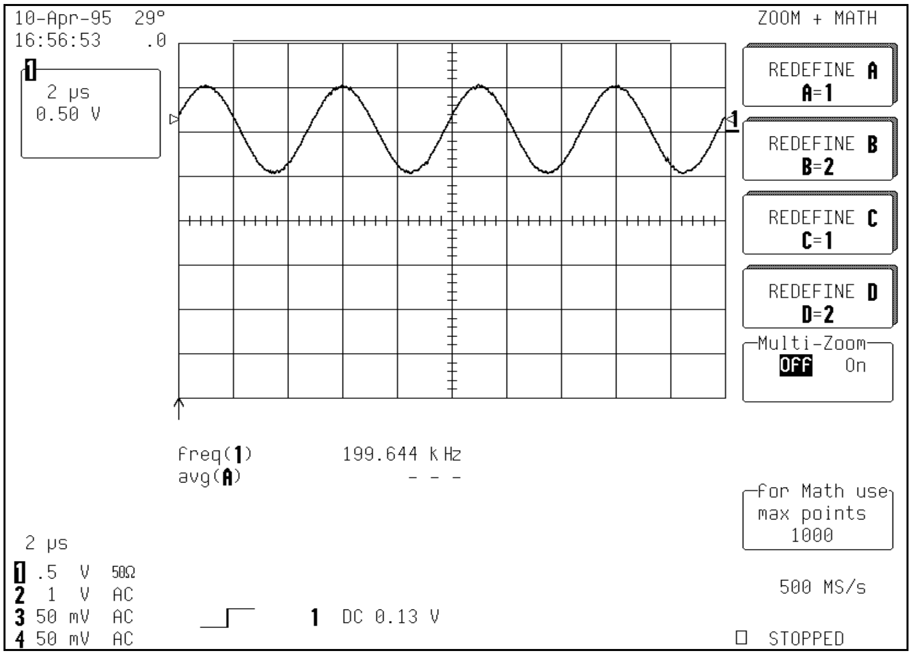


Figure 2.6

Once a trace is selected, the screen shown in *Figure 2.7* appears. Selecting “**Yes**” from the “**use Math**?” menu enables mathematical functions, including histograms.

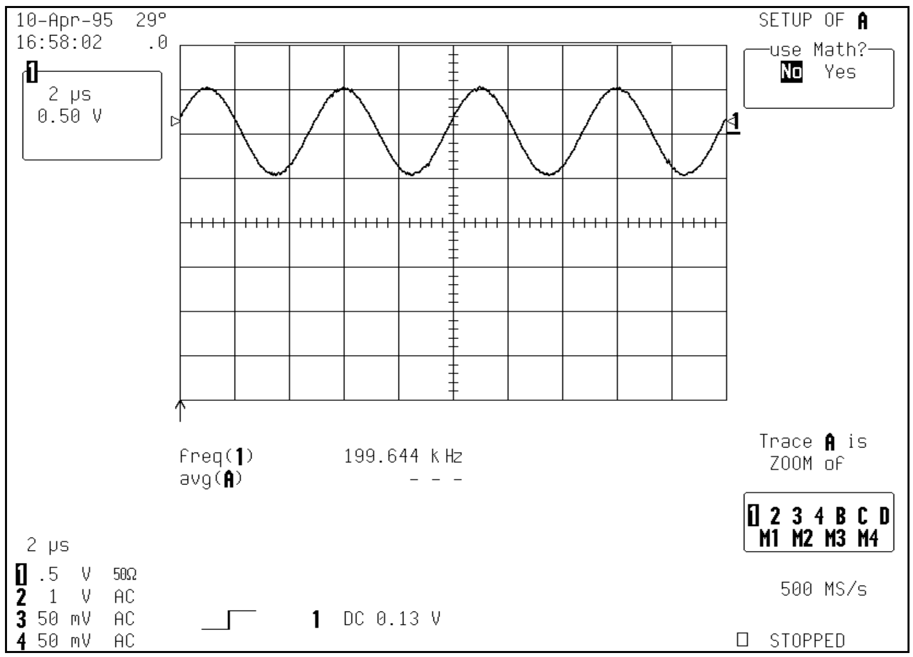


Figure 2.7

Histogram Trace Setup Menu

Figure 2.8 (*next page*) shows the display when “**Histogram**” is selected from the “**Math Type**” menu. Here, the freq parameter only has been defined. However, if additional parameters were to be defined, the individual parameter would need to be selected — by pressing the corresponding menu button or turning the associated knob until the desired parameter appeared in the “**Histogram custom line**” menu.

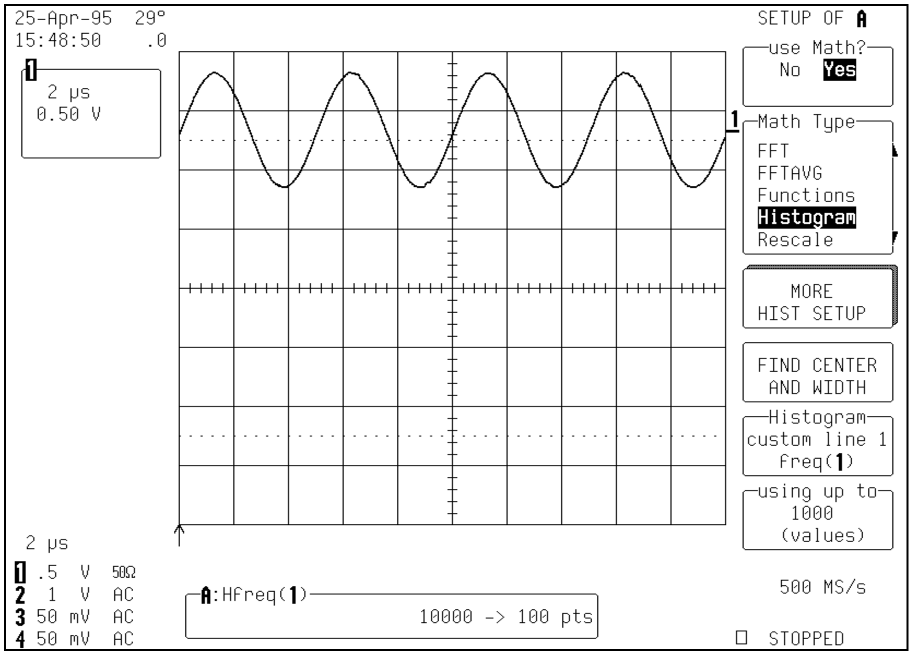


Figure 2.8

Each time a waveform parameter value is calculated it can be placed in a histogram bin. The maximum number of such values is selected from the "**using up to**" menu. Pressing the associated menu button or turning the knob allows the user to select a range from 20 to 2 billion parameter value calculations for histogram display.

To see the histogram, turn the trace display on by pressing the appropriate **TRACE ON/OFF** button, for a display similar that shown in *Figure 2.9*.

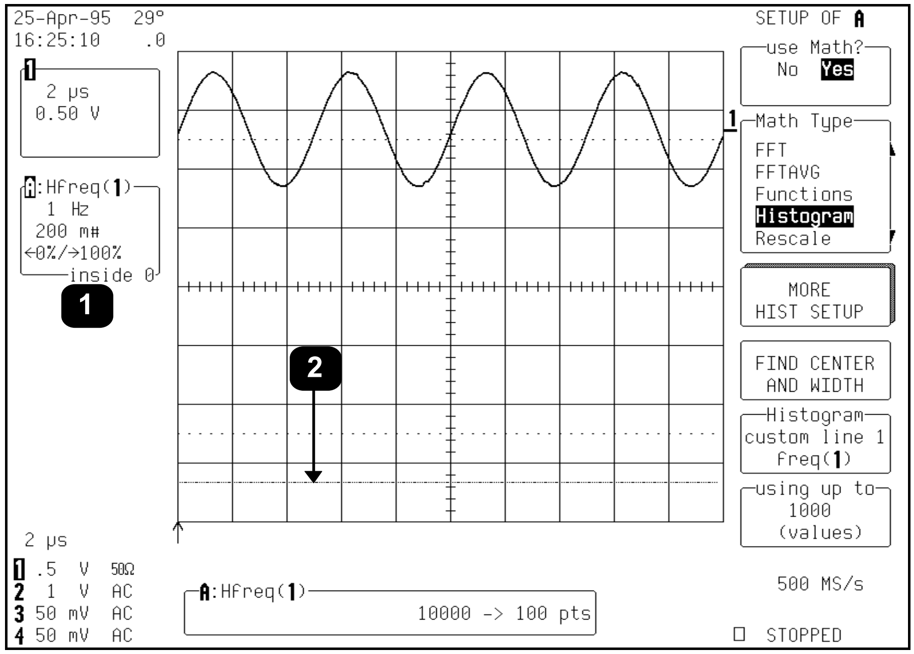


Figure 2.9

Each histogram is set by the user to capture parameter values falling within a specified range. As the scope captures the values in this range the bin counts increase. Values not falling within the range are not used in creating the histogram.

Information on the histogram is provided in the **Displayed Trace Field** (*Annotation* ❶) for the selected trace. This shows:

- The current horizontal per division setting for the histogram ("1 Hz" in this example). The unit type used is determined by the waveform parameter type on which the histogram is based.
- The vertical scale in #bin counts per division (here, "200 m").
- The number of parameter values that fall within the range ("inside 0")
- The percentage that fall below ("←0%")

- The percentage of values above the range ("100%→").

This figure shows that 100% of the captured events are above the range of bin values set for the histogram. As a result, the baseline of the histogram graph (*Annotation* ❷) is displayed, but no values appear.

Selecting the "**FIND CENTER AND WIDTH**" menu allows calculation of the optimal center and bin-width values, based on the up to the most recent parameter values calculated. The number of parameter calculations is chosen with the "**using up to**" menu (or 20 000 values if this is greater than 20 000). *Figure 2.10* shows a typical result.

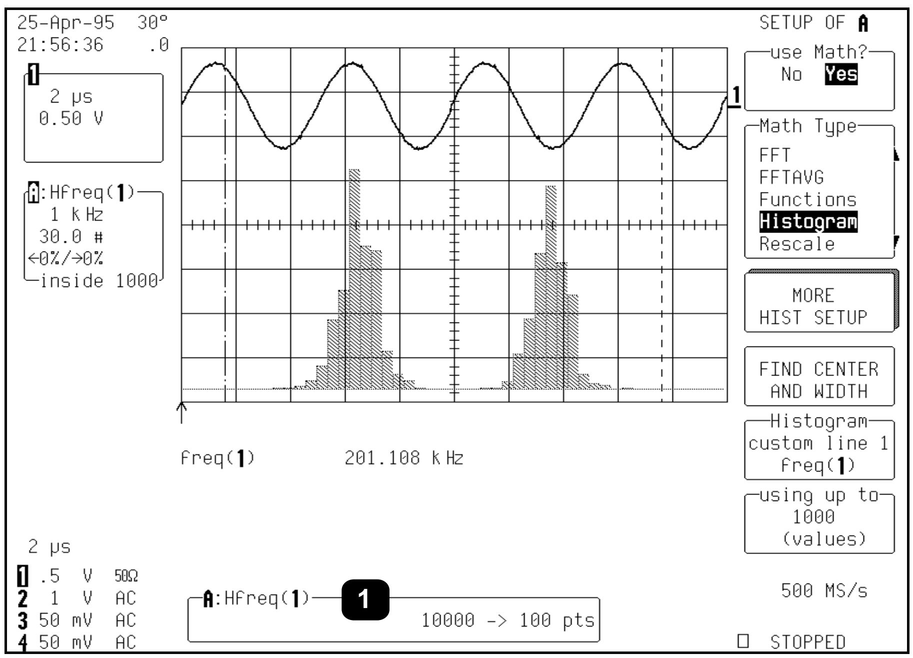


Figure 2.10

If the trace on which the histogram is made is not a zoom, then all bins with events will be displayed. Otherwise, press **RESET** to reset the trace and display all histogram events.

The **Information Window** (*Annotation* ❶) at the bottom of the previous screen shows a histogram of the **freq** parameter for Channel 1 (designated as "**A:Hfreq(1)**") for Trace A. The "**1000 → 100 pts**" in the window indicates that the signal on Channel 1 has 1000 waveform acquisition samples per sweep and is being mapped into 100 histogram bins.

Selecting "**MORE HIST SETUP**" allows additional histogram settings to be specified, resulting in a display similar to that of *Figure 2.11*, below.

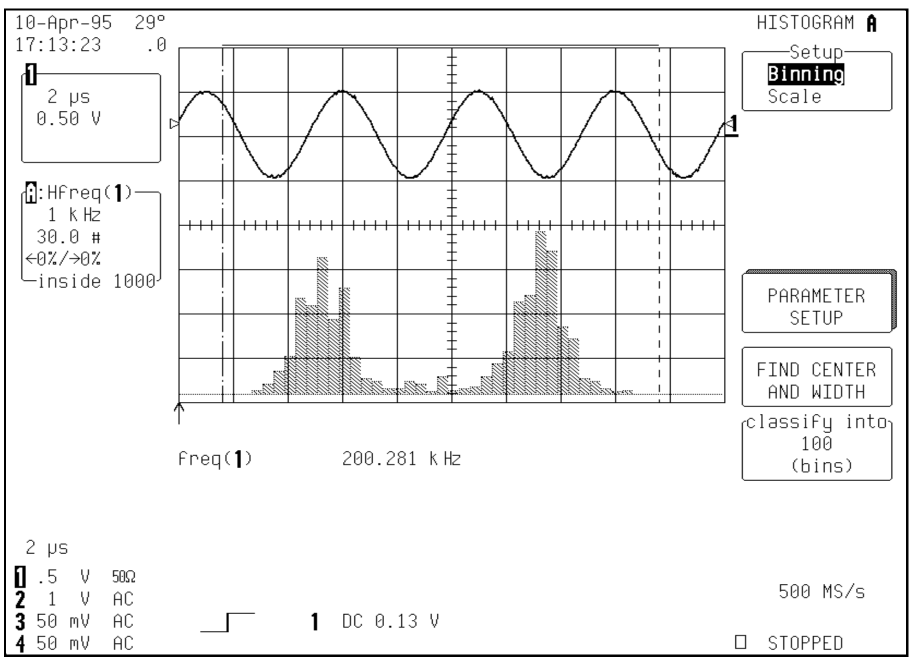


Figure 2.11

Setting Binning & Histogram Scale

The “**Setup**” menu allows modifcation of either the “**Binning**” or the histogram “**Scale**” settings. If “**Binning**” is selected, the “**classify into**” menu appears, as shown in the figure above.

The number of bins used can be set from a range of 20–2000 in a 1–2–5 sequence, by pressing the corresponding menu button or turning the associated knob.

If “**Scale**” is selected from the “**Setup**” menu, a screen similar that of *Figure 2.12* will be displayed.

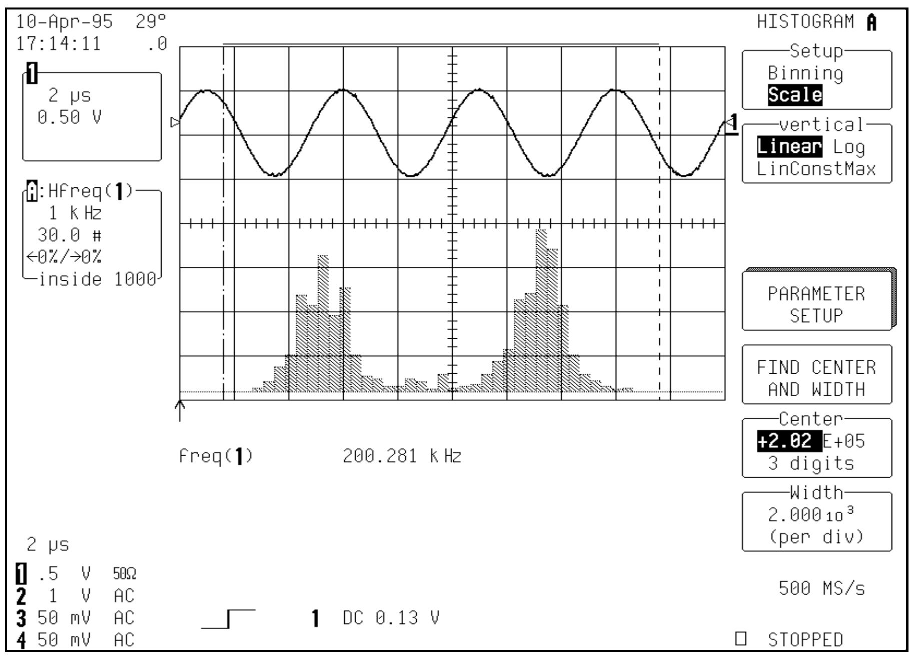


Figure 2.12

Three options are offered by the "**vertical**" menu for setting the vertical scale:

1. "**Linear**" sets the vertical scale as linear (*see previous figure*). The baseline of the histogram designates a bin value of 0. As the bin counts increase beyond that which can be displayed on screen using the current vertical scale, this scale is automatically increased in a 1–2–5 sequence.
2. "**Log**" sets the vertical scale as logarithmic (*Fig. 2.13*). Because a value of '0' cannot be specified logarithmically, no baseline is provided.

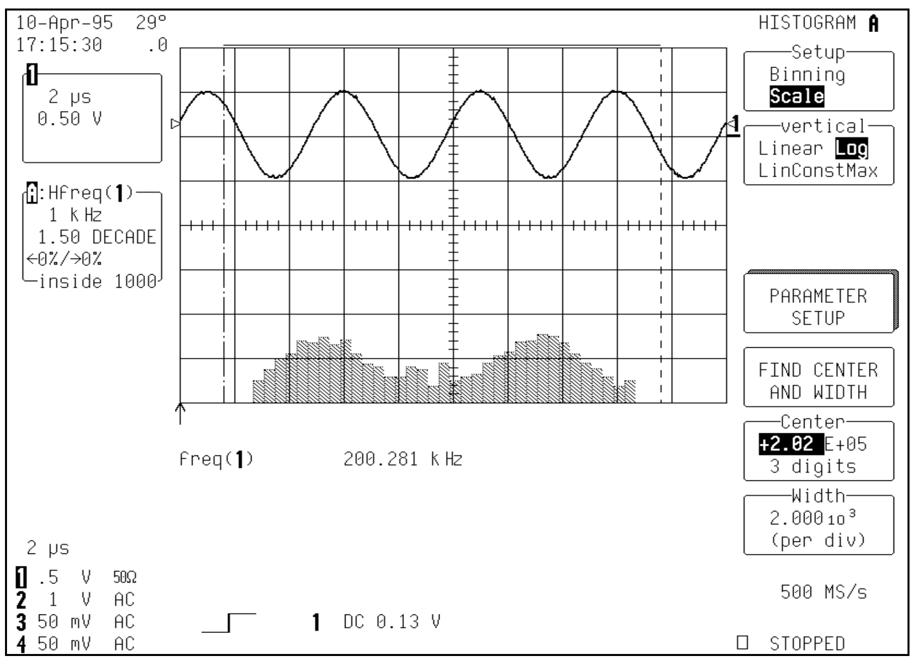


Figure 2.13

3. "**LinConstMax**" sets the vertical scaling to a linear value that uses close to the full vertical display capability of the scope (*Fig. 2.14*). The height of the histogram will remain almost constant.

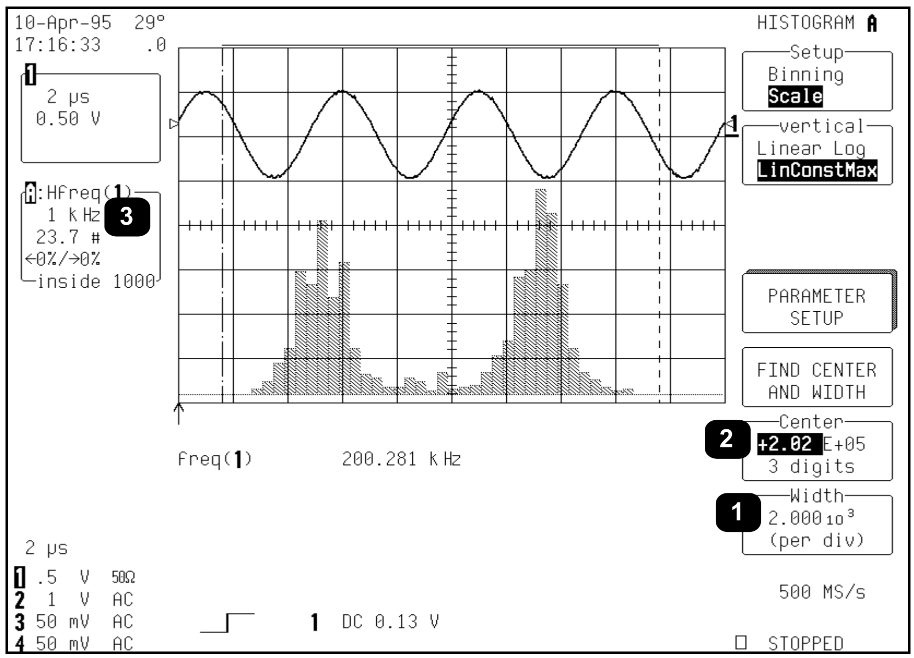


Figure 2.14

For any of these options, the scope automatically increases the vertical scale setting as required, ensuring the highest histogram bin does not exceed the vertical screen display limit.

The "**Center**" and "**Width**" menus allow specification of the histogram center value and width per division. The width per division times the number of horizontal display divisions (10) determines the range of parameter values centered on the number in the "**Center**" menu, used to create the histogram.

In the previous figure, the width per division is 2.000 $\times$ 10^3 (*Annotation* ❶). As the histogram is of a frequency parameter, the measurement parameter is hertz.

The range of parameter values contained in the histogram is therefore:

(2 k Hz/division) x (10 divisions) = 20 k Hz

with a center of 2.02 E+05 Hz (❷).

In this example, all freq parameter values within 202 k Hz ± 10 k Hz — from 192 k Hz to 212 k Hz — are used in creating the histogram. The range is subdivided by the number of bins set by the user. Here, the range is 20 k Hz, as calculated above, and the number of bins 100. Therefore, the range of each bin is:

20 k Hz / 100 bins, or

.2 k Hz per bin.

The "**Center**" menu allows the user to modify the center value's mantissa (here, 2.02), exponent (E+05) or the number of digits used in specifying the mantissa (three). The display scale of 1 k Hz/division, shown in the Trace Display Field, is indicated by *Annotation* ❸. This scale has been set using the horizontal zoom control and can be used to expand the scale for visual examination of the histogram trace.

The use of zoom in this way does *not* modify the range of data acquisition for the histogram, only the display scale. The range of measurement acquisition for the histogram remains based on the center and width scale, resulting in a range of 202 k Hz ± 10 k Hz for data acquisition.

Any of these can be changed using the associated knob. And the width/division can be incremented in a 1–2–5 sequence by selecting "**Width**", using button or knob.

Histogram Parameters

Once the histogram settings are defined, selecting additional parameter values is often useful for measuring particular attributes of the histogram.

Selecting "**PARAMETER SETUP**", as shown in the previous figure, accesses the "**CHANGE PARAM**" menus, shown in *Figure 2.15.*

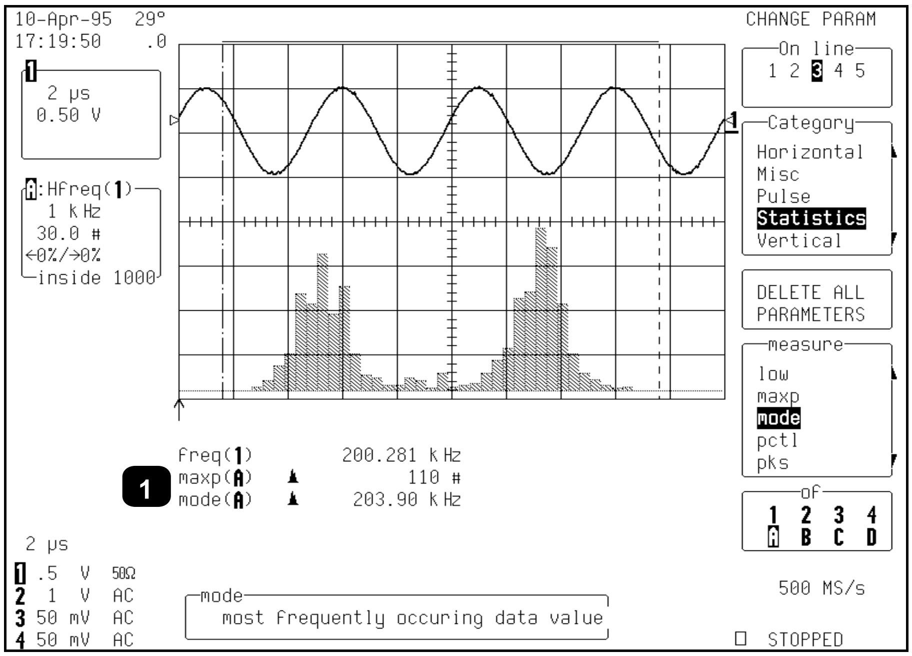


Figure 2.15

New parameters can now be selected or previous ones modified. In this figure, the histogram parameters **maxp** and **mode** (*Annotation* ❶) have been selected. These determine the count for the bin with the highest peak, and the corresponding horizontal axis value of that bin's center.

Note that both "**maxp**" and "**mode**" are followed by "**(A)**" on the display. This designates the measurements as being made on the signal on Trace A, in this case the histogram. Note:

- The value of "**maxp(A)**" is "110 #", indicating the highest bin has a count of 110 events.
- The value of **mode(A)** is "203.90 k Hz", indicating that this bin is at 203.90 k Hz.

- The icon to the left of “**mode**” and “**maxp**” parameters indicates that the parameter is being made on a trace defined as a histogram.

However, if these parameters were inadvertently set for a trace with no histogram they would show ‘---’.

Using Measurement Cursors

The parameter cursors can be used to select a section of a histogram for which a histogram parameter is to be calculated.

Figure 2.16 shows the average, “**avg(A)**” (*Annotation* ❶) of the distribution between the parameter cursors for a histogram of the frequency (“**freq**”) parameter of a waveform. The parameter cursors (❷) are set “**from**” 4.70 divisions (❸) “**to**” 9.20 divisions (❹) of the display.

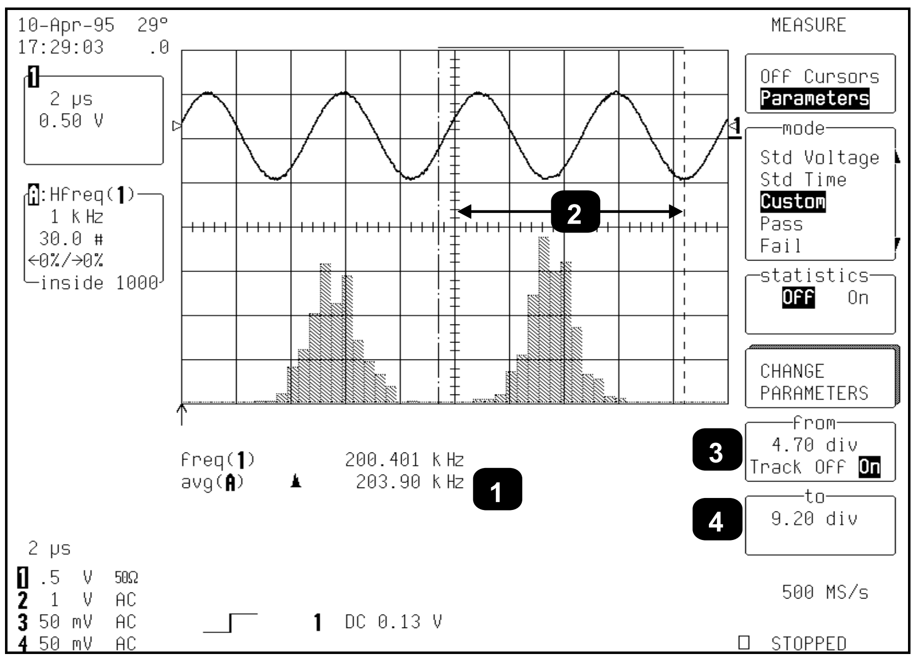


Figure 2.16

It is recommended that this capability be used only after the input waveform acquisition has been completed. Otherwise, the parameter cursors will also select the portion of the input waveform used to calculate the parameter during acquisition. This will create a histogram with only the local parameter values for the selected waveform portion.

Zoom Traces and Segmented Waveforms

Histograms can also be displayed for traces that are zooms of segmented waveforms. When a segment from a zoomed trace is selected, the histogram for that segment will appear. Only the portion of the segment displayed and between the parameter cursors will be used in creating the histogram. The corresponding Displayed Trace Field will show the number of events captured for the segment.

Figure 2.17 shows "**Selected**" a histogram of the frequency ("**freq**") parameter for "**Segment 1**" (*Annotation* ❶) of Trace "**A**", which is a zoom of a 10-segment waveform on Channel 1.

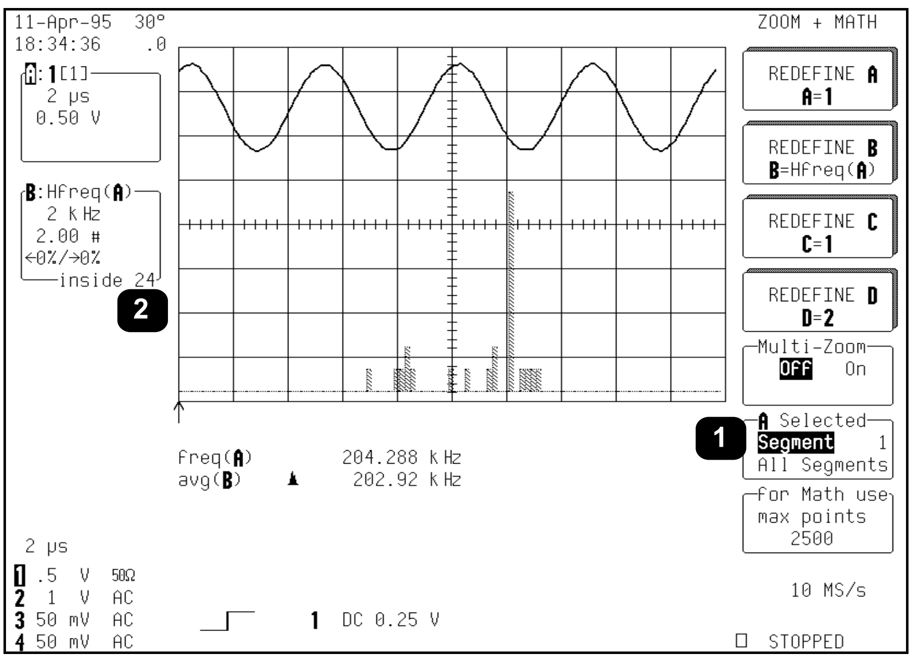


Figure 2.17

The Displayed Trace Field shows that 24 parameter events (*Annotation* ❷) have been captured into the histogram. The average value for the freq parameter is displayed as the histogram parameter, "**avg(B)**".

Figure 2.18 shows the result of selecting "**All Segments**".

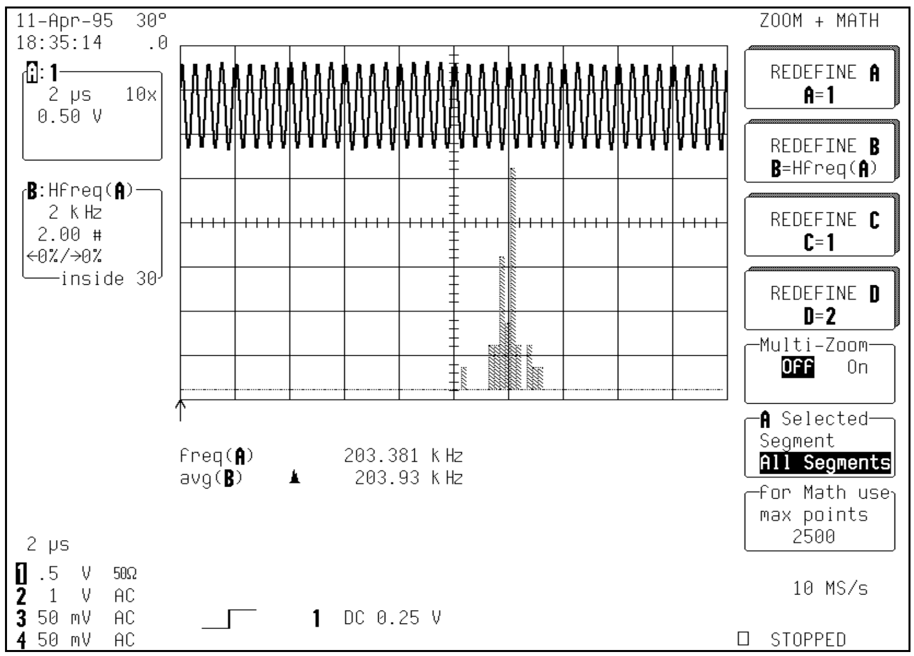


Figure 2.18

Note that the Displayed Trace Field indicates 30 events in the histogram for all segments, and the change in "**avg(B)**".

Histogram events can be cleared at any time by pushing the **CLEAR SWEEPS** button. All events in the 20-k parameter buffer are cleared at the same time. The vertical and horizontal **POSITION** and **ZOOM** control knobs can be used to expand and position the histogram for zooming-in on a particular feature of it. The resulting vertical and horizontal scale settings are shown in the Displayed Trace Field. However, the values in the "**Center**" and "**Width**" menus do *not* change, since they determine the range of the histogram and *cannot* be used to determine the parameter value range of a particular bin. If the histogram is repositioned using the horizontal **POSITION** knob the histogram's center will be moved from the center of the screen. Horizontal measurements will then require the use of **CURSORS/MEASURE**.

The scope's measurement cursors are useful for determining the value and population of selected bins. *Figure 2.19* shows the "**Time**" cursor (❶) positioned on a selected histogram bin. The value of the bin (❷) and the population of the bin (❸) are also shown.

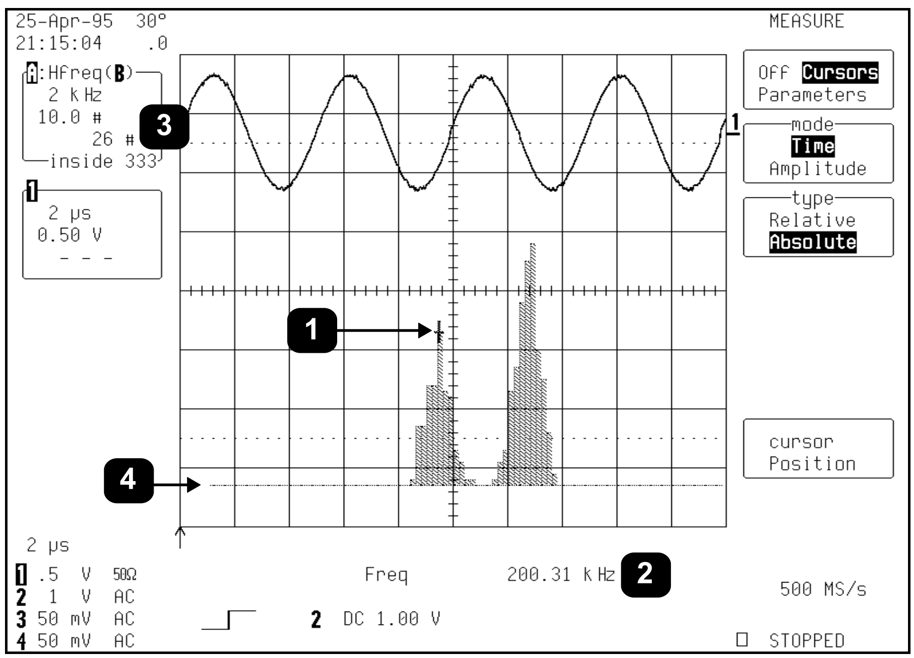


Figure 2.19

A histogram's range is represented by the horizontal width of the histogram baseline. As the histogram is repositioned vertically the left and right sides of the baseline can be seen. In this final figure of the chapter, the left edge of the range is visible (❹).

avg Average

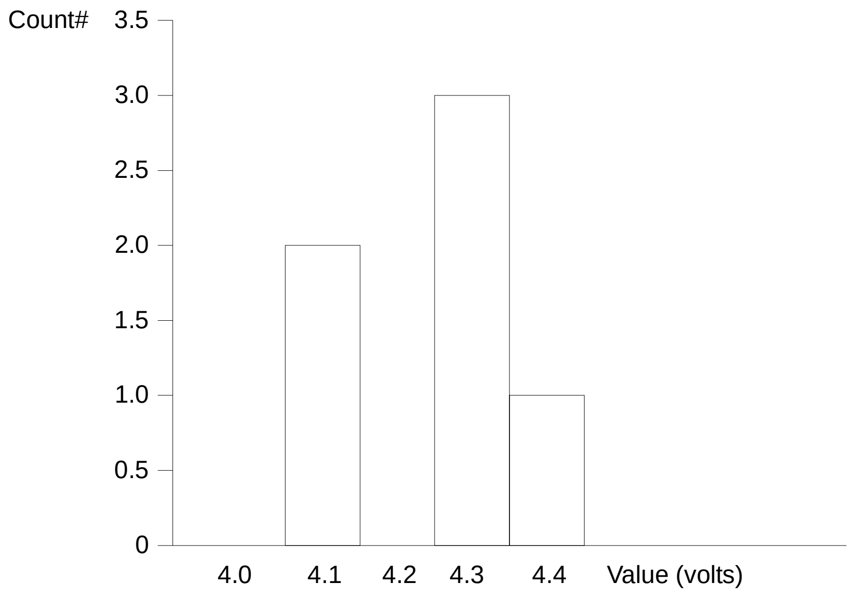
Definition Average or mean value of data in a histogram.

Description The average is calculated by the formula:

$$avg = \sum_{i=1}^{n} (\text{bin count})_i \, (\text{bin value})_i \Big/ \sum_{i=1}^{n} (\text{bin count})_i ,$$

where n is the number of bins in the histogram, bin count is the count or height of a bin, and bin value is the center value of the range of parameter values a bin can represent.

Example



The average value of this histogram is:

(4.1 * 2 + 4.3 * 3 + 4.4 * 1) / 6 = 4.25.

fwhm Full Width at Half Maximum

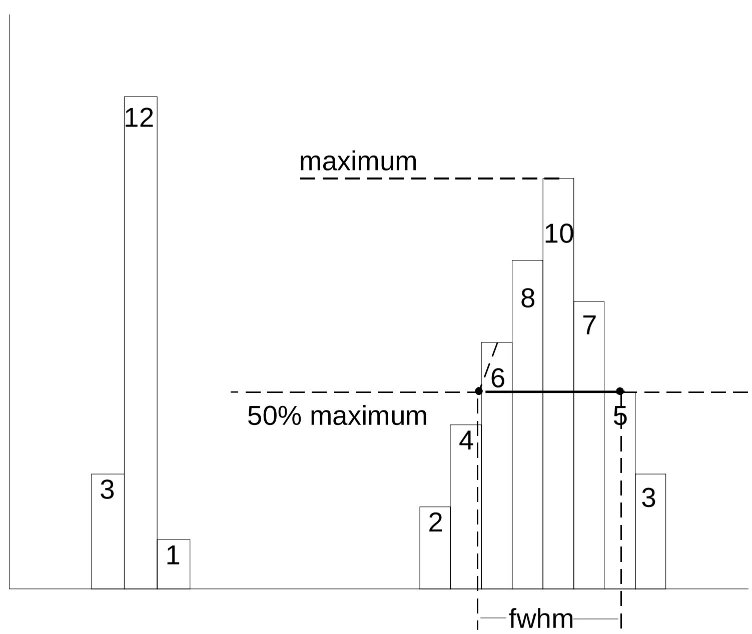
Definition

Determines the width of the largest area peak, measured between bins on either side of the highest bin in the peak that have a population of half the highest's population. If several peaks have an area equal to the maximum population, the leftmost peak is used in the computation.

Description

First, the highest population peak is identified and the height of its highest bin (population) determined (*for a discussion on how peaks are determined see the **pks** parameter description*). Next, the populations of bins to the right and left are found, until a bin on each side is found to have a population of less than 50% of that of the highest bin's. A line is calculated on each side, from the center point of the first bin below the 50% population to that of the adjacent bin, towards the highest bin. The intersection points of these lines with the 50% height value is then determined. The length of a line connecting the intersection points is the value for **fwhm**.

Example



fwxx Full Width at xx% Maximum

Definition

Determines the width of the largest area peak, measured between bins on either side of the highest bin in the peak that have a population of xx% of the highest's population. If several peaks have an area equal to the maximum population, the leftmost peak is used in the computation.

Description

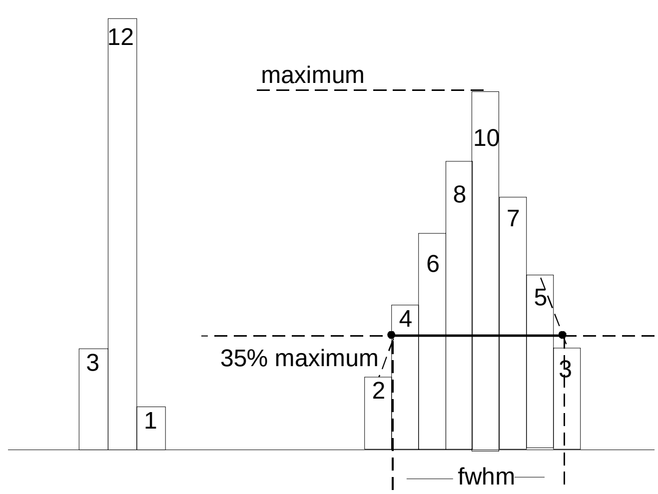
First, the highest population peak is identified and the height of its highest bin (population) determined (*see the **pks** description*). Next, the bin populations to the right and left are found until a bin on each side is found to have a population of less than xx% of that of the highest bin. A line is calculated on each side, from the center point of the first bin below the 50% population to that of the adjacent bin, towards the highest bin. The intersection points of these lines with the xx% height value is then determined. The length of a line connecting the intersection points is the value for **fwxx**.

Parameter Settings

Selection of the **fwxx** parameter in the "CHANGE PARAM" menu group causes the "MORE fwxx SETUP" menu to appear. Pressing the corresponding menu button displays a threshold setting menu that enables the user to set the 'xx' value to between 0–100% of the peak.

Example

fwxx with threshold set to 35%:



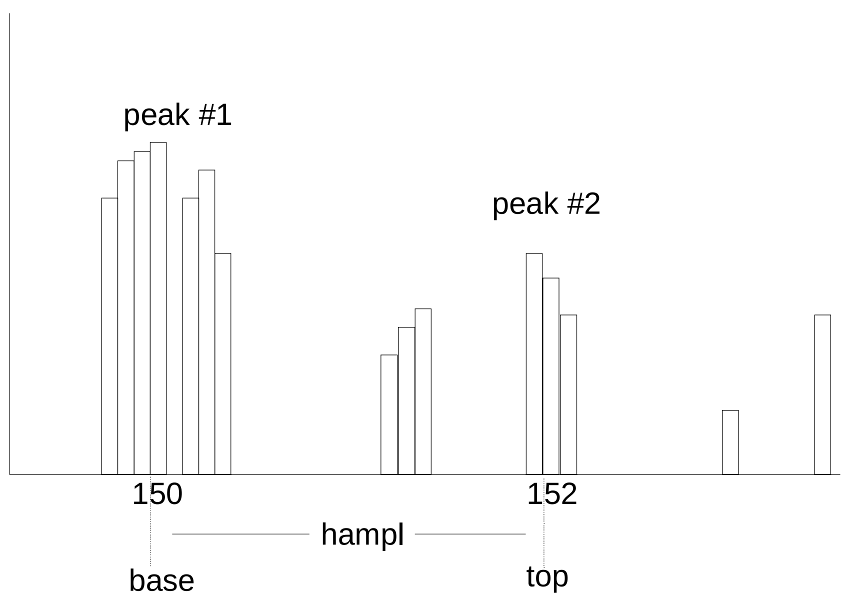
hampl **Histogram Amplitude**

Definition The difference in value of the two most populated peaks in a histogram. This parameter is useful for waveforms with two primary parameter values, such as TTL voltages, where **hampl** would indicate the difference between the binary ‘1’ and ‘0’ voltage values.

Description The values at the center (line dividing the population of peak in half) of the two highest peaks are determined (*see* ***pks*** *parameter description*). The value of the leftmost of the two peaks is the histogram base (*see* **hbase**). While that of the rightmost is the histogram top (*see* **htop**). The parameter is then calculated as:

hampl = htop – hbase

Example



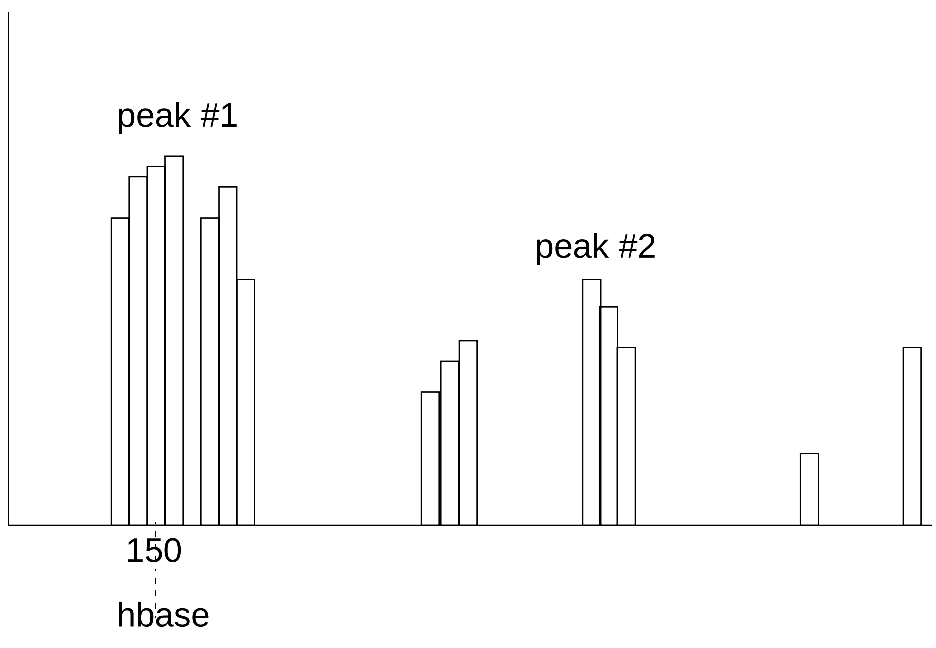
In this histogram, **hampl** is 152 mV – 150 mV = 2 mV.

Hbase Histogram Base

Definition The value of the leftmost of the two most populated peaks in a histogram. This parameter is primarily useful for waveforms with two primary parameter values such as TTL voltages where **hbase** would indicate the binary '0' voltage value.

Description The two highest histogram peaks are determined. If several peaks are of equal height the leftmost peak among these is used (*see* ***pks***). Then the leftmost of the two identified peaks is selected. This peak's center value (line that divides population of peak in half) is the **hbase**.

Example

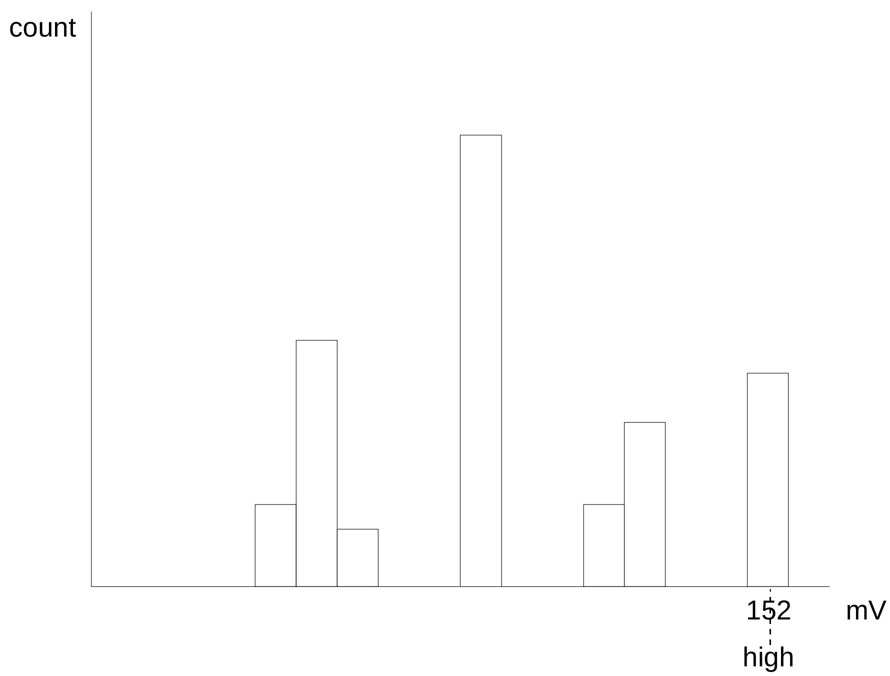


high High

Definition The value of the rightmost populated bin in a histogram.

Description The rightmost of all populated histogram bins is determined: **high** is its center value, the highest parameter value shown in the histogram.

Example



In this histogram **high** is 152 mV.

hmedian Histogram Median

Definition

The value of the 'x' axis of a histogram, dividing the histogram population into two equal halves.

Description

The total population of the histogram is determined. Scanning from left to right, the population of each bin is summed until a bin that causes the sum to equal or exceed half the population value is encountered. The proportion of the population of the bin needed for a sum of half the total population is then determined. Using this proportion, the horizontal value of the bin at the same proportion of its range is found, and returned as **hmedian**.

Example

The total population of a histogram is 100 and the histogram range is divided into 20 bins. The population sum, from left to right, is 48 at the eighth bin. The population of the ninth bin is 8 and its sub-range is from 6.1–6.5 V. The ratio of counts needed for half- to total-bin population is:

2 counts needed / 8 counts = .25

The value for **hmedian** is:

6.1 volts + .25 * (6.5 – 6.1) volts = 6.2 volts

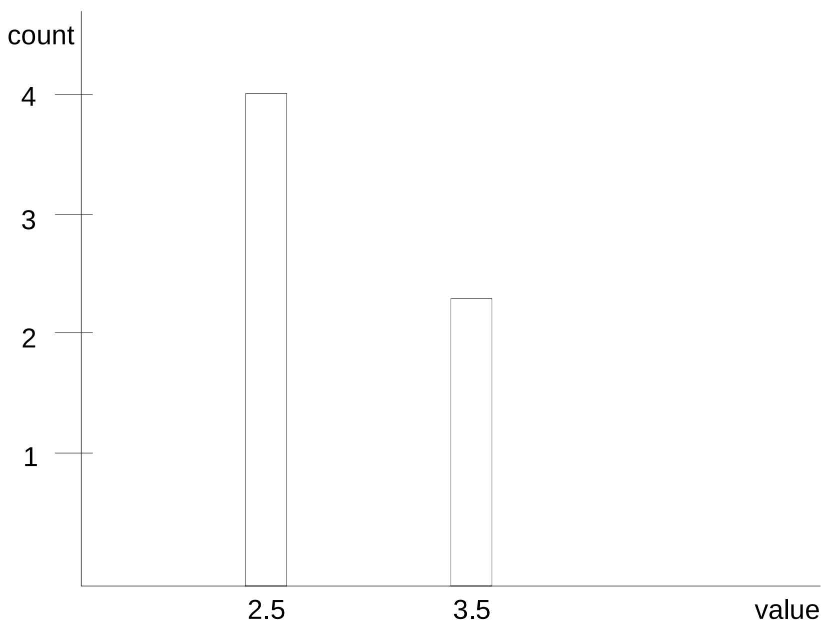
hrms Histogram Root Mean Square

Definition The rms value of the values in a histogram.

Description The center value of each populated bin is squared and multiplied by the population (height) of the bin. All results are summed and the total is divided by the population of all the bins. The square root of the result is returned as **hrms**.

Example Using the histogram shown here, the value for **hrms** is:

$$\text{hrms} = \sqrt{(3.5^2 * 2 + 2.5^2 * 4)/6} = 2.87$$



htop Histogram Top

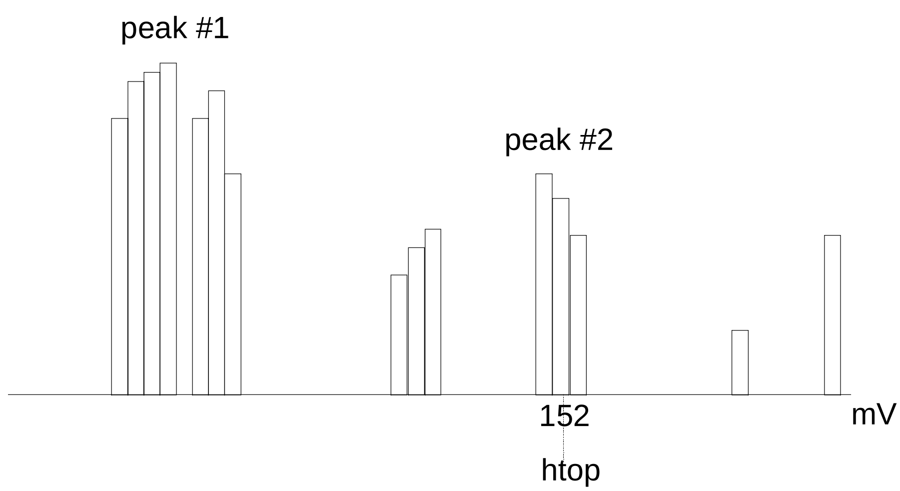
Definition

The value of the rightmost of the two most populated peaks in a histogram. This parameter is useful for waveforms with two primary parameter values, such as TTL voltages, where **htop** would indicate the binary ‘1’ voltage value.

Description

The two highest histogram peaks are determined. The rightmost of the two identified peaks is then selected. The center of that peak is **htop** (center is the horizontal point where the population to the left is equal to the area to the right).

Example



low Low

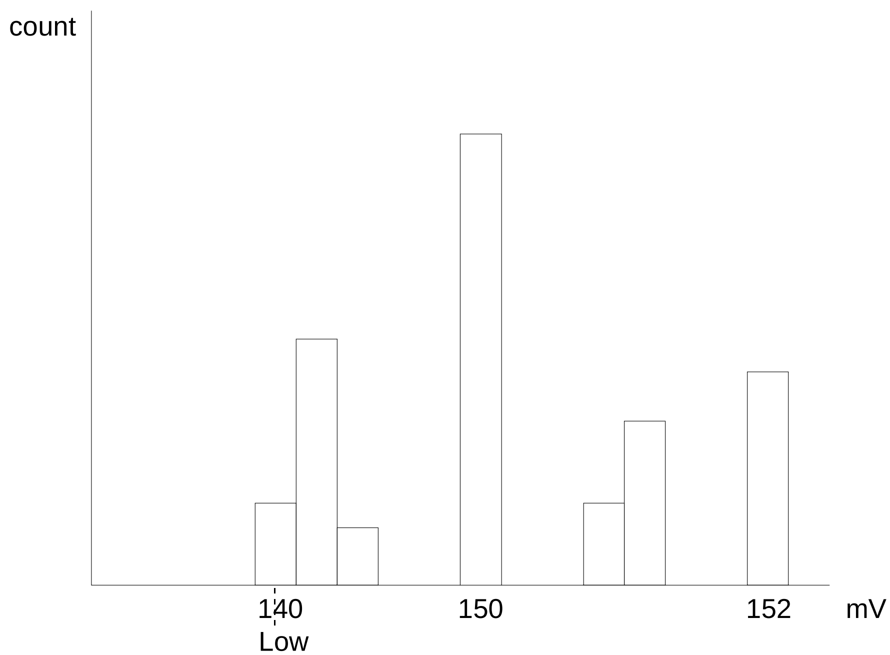
Definition

The value of the leftmost populated bin in a histogram population. It indicates the lowest parameter value in a histogram's population.

Description

The leftmost of all populated histogram bins is determined. The center value of that bin is **low**.

Example



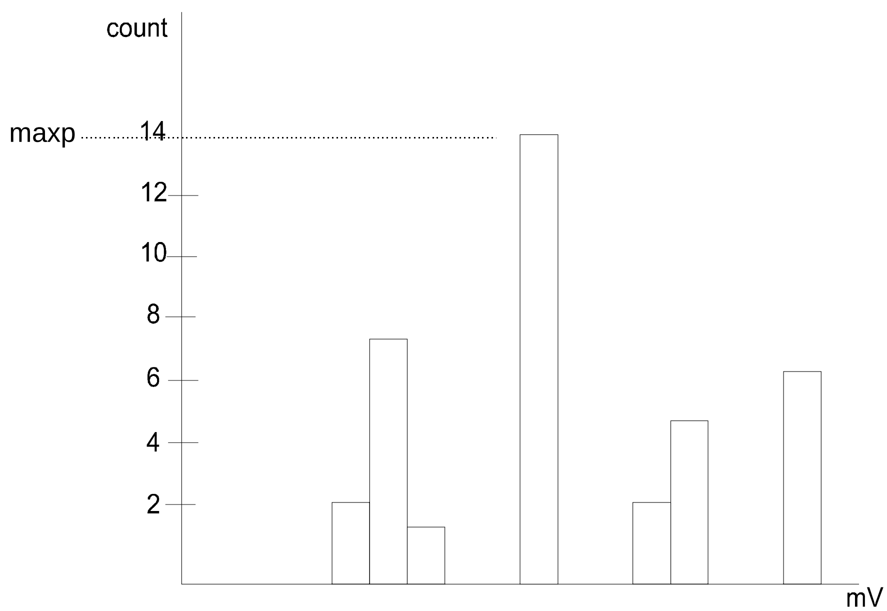
In this histogram **low** is 140 mV.

maxp Maximum Population

Definition The count (vertical value) of the highest population bin in a histogram.

Description Each bin between the parameter cursors is examined for its count. The highest count is returned as **maxp**.

Example



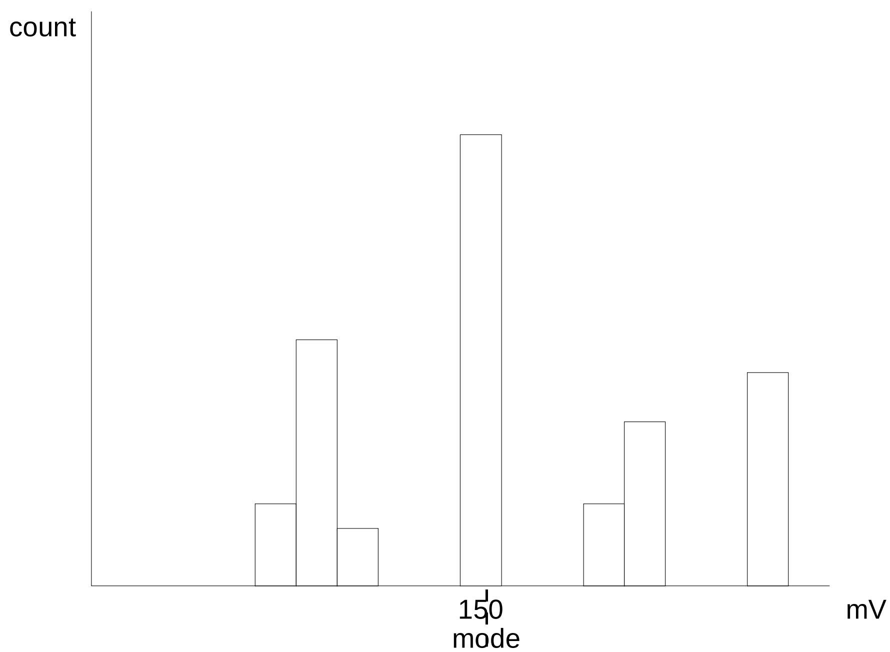
In this example, **maxp** is 14.

mode **Mode**

Definition The value of the highest population bin in a histogram.

Description Each bin between the parameter cursors is examined for its population count. The leftmost bin with the highest count found is selected. Its center value is returned as **mode**.

Example



In this example **mode** is 150 mV.

pctl — Percentile

Definition

Computes the horizontal data value that separates the data in a histogram, so that the population on the left is a specified percentage 'xx' of the total population. When the threshold is set to 50%, **pctl** is the same as **hmedian**.

Description

The total population of the histogram is determined. Scanning from left to right, the population of each bin is summed until a bin that causes the sum to equal or exceed 'xx'% of the population value is encountered. A ratio of the number of counts needed for 'xx'% population/total bin population is then determined for the bin. The horizontal value of the bin at that ratio point of its range is found, and returned as **pctl**.

Example

The total population of a histogram is 100. The histogram range is divided into 20 bins and 'xx' is set to 25%. The population sum at the sixth bin from the left is 22. The population of the seventh is 9 and its sub-range is 6.1–6.4 V. The ratio of counts needed for 25% population to total bin population is:

3 counts needed / 9 counts = 1/3.

The value for **pctl** is:

6.1 volts + .33 * (6.4 – 6.1) volts = 6.2 volts.

Parameter Settings

Selection of the **pctl** parameter in the "**CHANGE PARAM**" menu group causes the "**MORE pctl SETUP**" menu to appear. Pressing the correponding menu button displays a threshold setting menu. And with the associated knob the user can set the percentage value to between 1% and 100% of the total population.

pks Peaks

Definition The number of peaks in a histogram.

Description The instrument analyzes histogram data to identify peaks from background noise and histogram binning artifacts such as small gaps.

Peak identification is a three-step process:

1) The mean height of the histogram is calculated for all populated bins. A threshold (T1) is calculated from this mean where:

   T1= mean + 2 sqrt(mean).

2) A second threshold is determined based on all populated bins under T1 in height, where:

   T2 = mean + 2 * sigma,

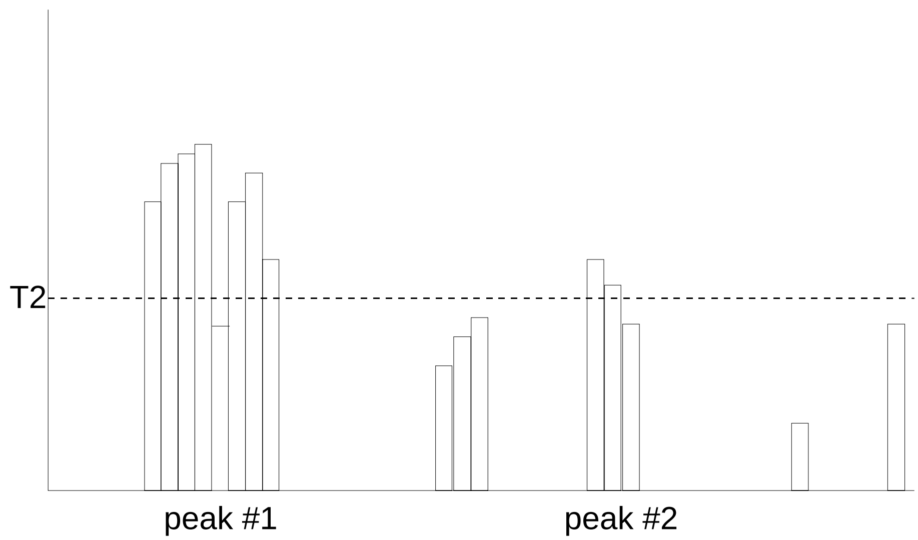
   and where sigma is the standard deviation of all populated bins under T1.

3) Once T2 is defined, the histogram distribution is scanned from left to right. Any bin that crosses above T2 signifies the existence of a peak. Scanning continues to the right until one bin or more crosses below T2. However, if the bin(s) cross below T2 for less than a hundreth of the histogram range, they are ignored, and scanning continues in search of a peak(s) that crosses under T2 for more than a hundreth of the histogram range. Scanning goes on over the remainder of the range to identify additional peaks. Additional peaks within a fiftieth of the range of the populated part of a bin from a previous peak are ignored.

Note: If the number of bins is set too high a histogram may have many small gaps. This increases sigma and thereby T2, and in extreme cases can prevent determination of a peak, even if one appears to be present to the eye.

Example

The example below shows that two peaks have been identified. The peak with the highest population is peak #1.



range

Range

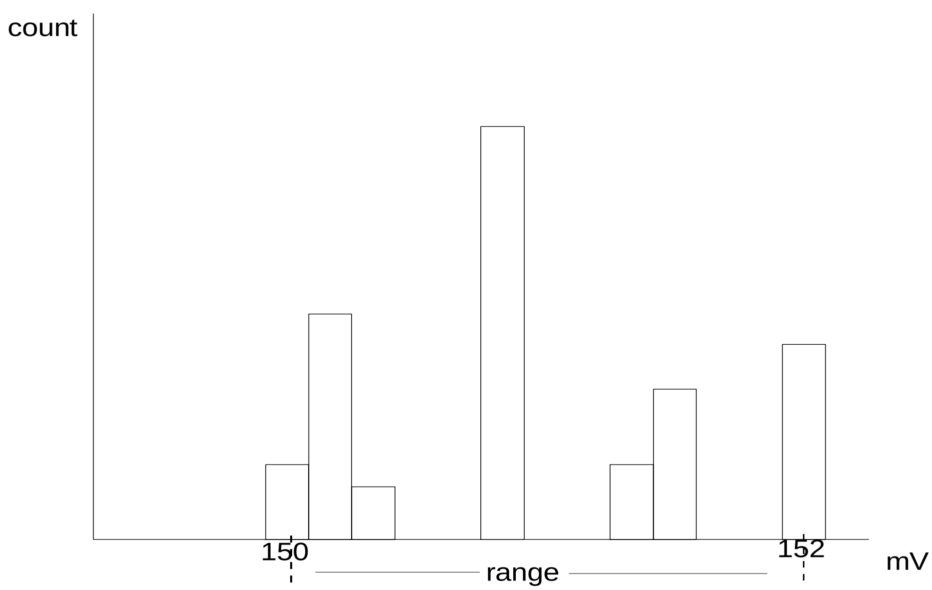
Definition

Computes the difference between the value of the rightmost and that of the leftmost populated bin.

Description

The rightmost and leftmost populated bins are identified. The difference in value between the two is returned as the **range**.

Example



In this example **range** is 2 mV.

sigma Sigma

Definition The standard deviation of the data in a histogram.

Description **sigma** is calculated by the formulas:

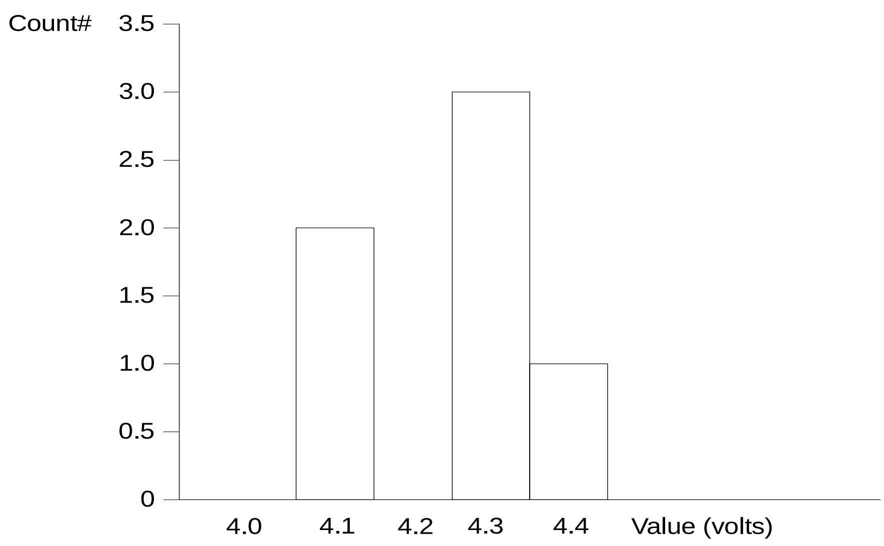
$$\text{mean} = \sum_{i=1}^{n}[\text{bin count}_i * \text{bin value}_i] \Big/ \Big(\sum_{i=1}^{n}\text{bin count}_i;$$

sigma =

$$\sqrt{\sum_{i=1}^{n}[\text{bin count}_i * (\text{bin value}_i - \text{mean})^2] \Big/ \Big(\sum_{i=1}^{n}[\text{bin count}_i] \ -1\Big)},$$

where n is the number of bins in the histogram, bin count is the count or height of a bin and bin value is the center value of the range of parameter values a bin can represent.

Example For the histogram:



mean = (2 * 4.1 + 3* 4.3 + 1 * 4.4) / 6 = 4.25

$$\text{sigma} = \sqrt{(2*(4.1 - 4.25)^2 + 3*(4.3 - 4.25)^2 + 1*(4.4 - 4.25)^2) \ / \ (6-1)} = .1225$$

totp

Total Population

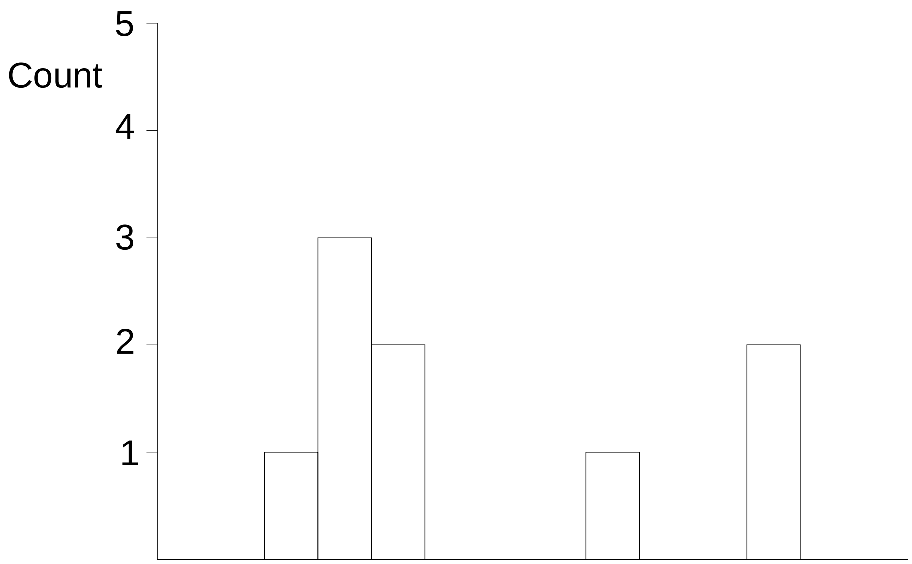
Definition

Calculates the total population of a histogram between the parameter cursors.

Description

The count for all populated bins between the parameter cursors is summed.

Example



The total population of this histogram is 9.

xapk X Coordinate of xx'th Peak

Definition

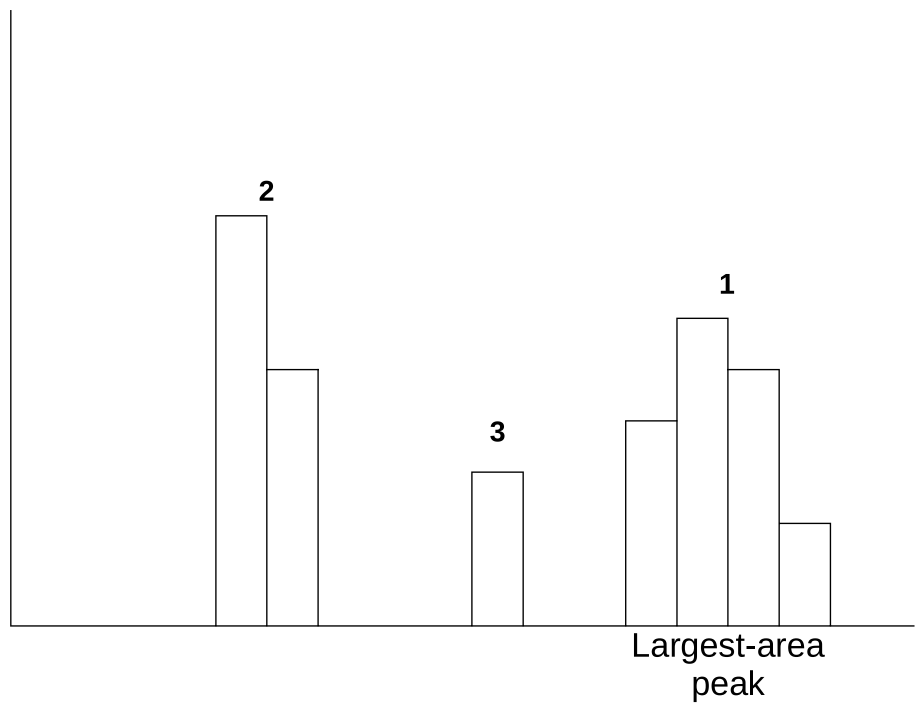
Returns the value of the xx'th peak that is the largest by area in a histogram.

Description

First the peaks in a histogram are determined and ranked in order of total area (for a discussion on how peaks are identified see the description for the **pks** parameter). The center of the n'th ranked peak (the point where the area to the left is equal to the area to the right), where n is selected by the user, is then returned as **xapk**.

Example

The rightmost peak is the largest, and thus the first-ranked, in area (1). The leftmost peak, although higher, is ranked second by area (2). The lowest peak is also the smallest in area (3).



Visualizing Trends

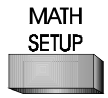
The Trend waveform processing function enables the creation of graphs of successive waveform parameter measurement values. It provides useful visual information on waveform parameter variation. And, used together with other scope features, it allows the graphing of certain parameters against others.

To Configure a Trend:

1. ***Select and configure a custom parameter, which will be used to perform the measurement that is to be trended. This can be done by either:***
   - ***choosing "Custom" mode from the "MEASURE" "Parameters" menu group as for histograms (see page 1–3 of the present manual and the CURSORS/MEASURE & Parameters chapter of the oscilloscope Operator's Manual), or***
   - ***accessing the same menu group using the "PARAMETER SETUP" menu from the "TREND…" group (see following pages).***

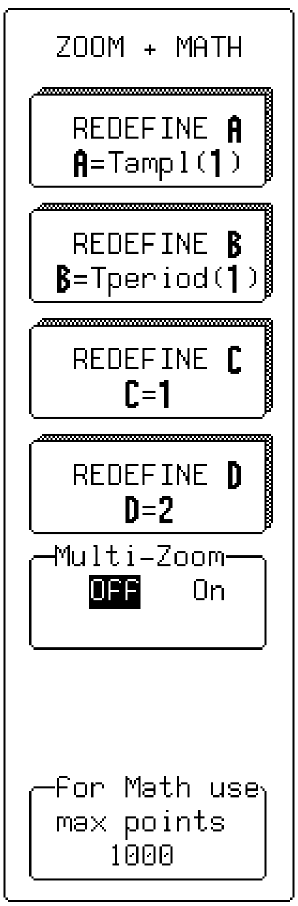
   And then selecting the desired parameter from the "CHANGE PARAM" menus that will be displayed.
2. ***Define one of the definable traces — A, B, C or D — as using Math and select "Trend" as the "Math Type" (see page 4–4).***
3. ***Select the custom parameter line to be used in the trend.***
4. ***Choose the number of values to be placed in the generated trend (page 4–5).***
5. ***Decide whether all the parameters generated from the waveform or only the average of all parameter calculations for each waveform acquisition should be placed in the trend.***
6. ***If desired, the center and height of the trend can also be configured at this stage, in the base units of the parameter being trended. However, this is not a requirement and "FIND CENTER AND HEIGHT" can be used to center the trend once the trend has been calculated.***

The Trend Configuration Menus



Press to access the ZOOM + MATH menus (*see the* MATH SETUP *Chapter of the scope* Operator's Manual *and page 1–3 of the present manual*). These allow the redefinition of each of the four traces, A, B, C and D and access their "SETUP" menus.

ZOOM + MATH



— illustrated in this example with Trace A defined as a trend of the parameter *amplitude* and Trace B as a trend of *period*. C and D are zooms of Traces 1 and 2.

REDEFINE A

Defined as the trend of the custom parameter, performed on Channel 1, **Trace A** can be set up by pressing the button corresponding to this menu.

REDEFINE B

Defined as the trend of the custom parameter, performed on Channel 1, **Trace B** can be set up by pressing the button corresponding to this menu.

REDEFINE C

Defined as a zoom of Channel 1, **Trace C** can be set up by pressing the button corresponding to this menu.

REDEFINE D

Defined as a zoom of Channel 2, **Trace D** can be set up by pressing the button corresponding to this menu.

Multi-Zoom

When "**On**", enables zoom and position controls on all traces at once.

for Math Use

To set the number of points in certain math functions, using the associated menu knob.

Note for Display of Trends:

- ***The display of defined traces is controlled by the TRACE ON/OFF buttons.***
- ***Expansion, or zooming, and positioning of traces is controlled by the horizontal and vertical ZOOM and POSITION knobs.***
- ***When Multi-zoom is on, the ZOOM and POSITION knobs are coupled and control all displayed traces at once. This is particularly useful when multiple trends of related parameters are displayed.***
- ***The button resets the multiplier for the trace expansion to '1' and the offset positioning to '0'. The button should be pressed for each reconfigured trace in order that traces can be cleanly and correctly positioned on-screen.***

SETUP OF A — allows the selected trace (here, Trace A) to be set up for trending.

use Math?

To define the trend as using math — necessary for the trend itself to be defined. Traces can be defined to use math or as zooms of other traces. As trending is a math function, “use Math?” should be set to “**Yes**”, using the corresponding menu button.

Math Type

For selecting “**Trend**”.

MORE TREND SETUP

To access more trend setup options and the final trend-dedicated menu (*next page*).

FIND CENTER AND HEIGHT

For positioning the trend automatically once it has been calculated. “FIND CENTER AND HEIGHT” places the trace appropriately, centering and scaling the trend without affecting the zoom and position settings. But ensure that these settings have been reset (*as described on the previous page*).

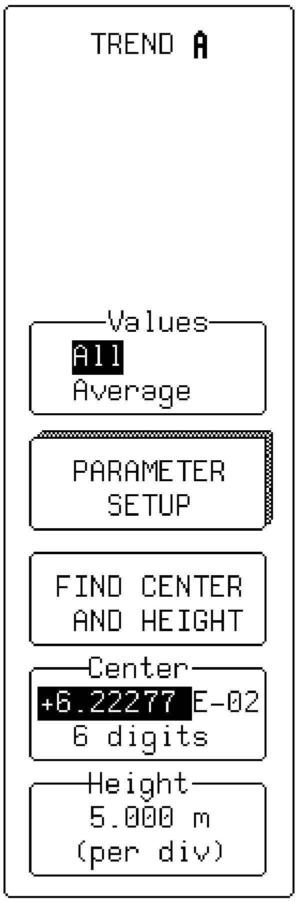
Trend of

To select the parameter for trending, using the corresponding menu button or associated knob. Any of the configured parameters, displayed on the line beneath the grid, can be chosen.

Using up to

For selecting — using button or knob — the number of values in the trend. A maximum of 20 000 values can be chosen for any one trend. When this maximum is exceeded, the parameter results scroll off the trend.

TREND A



— this menu group appears when “MORE TREND SETUP” is selected (previous page).

Values

To select “**All**” — for every parameter calculation on each waveform to be placed in the trend. Or “**Average**” — to trend only the average of all the given values calculated on a given acquisition, and to obtain one point in the trend per acquisition. Unless this is specifically required, “All” should be selected.

PARAMETER SETUP

To access the setup menus for the selected parameter, the same menus as the “CHANGE PARAM” group.

FIND CENTER AND HEIGHT

For positioning the trend automatically once calculated. “FIND CENTER AND HEIGHT” places the trace appropriately, centering and scaling the trend without affecting the zoom and position settings. But ensure that these settings have been reset (*as described in the panel on page 4–1*).

Center

For selecting the mantissa, exponent or number of digits resolution, using the associated knob. The configuration is the value at the horizontal center line on the grid, while units are those of the parameter trended.

Height

To select — using button or knob — the vertical value of each vertical screen division. Units are those of the parameter trended.

***Note:* Press** 

after having configured the parameter in “CHANGE PARAM” to return to the menus shown this page.

Trend Calculation

Once the trend has been configured, parameter values will be calculated and trended on each subsequent acquisition. Immediately following the acquisition, its trend values will be calculated. The resulting trend is a waveform of data points that can be used the same way as any other waveform. Parameters can be calculated on it, and it can zoomed, serve as the *x* or *y* trace in an XY plot, and used in cursor measurements.

The sequence for acquiring trend data is:

1. trigger
2. waveform acquisition
3. parameter calculation(s)
4. trend update
5. trigger re-arm.

If the timebase is set in non-segmented mode, a single acquisition occurs prior to parameter calculations. However, in segment mode an acquisition for each segment occurs prior to parameter calculations. If the source of trend data is a memory, storing new data to memory effectively acts as a trigger and acquisition. Because updating the screen can take significant processing time, it occurs only once a second, minimizing trigger dead-time (under remote control the display can be turned off to maximize measurement speed).

Parameter Buffer

The oscilloscope maintains a circular parameter buffer of the last 20 000 measurements made, including values that fall outside the set trend range. If the maximum number of events to be used in a trend is a number ‘N’ less than 20 000, the trend will be continuously updated with the last ‘N’ events as new acquisitions occur. If the maximum number is greater than 20 000, the trend will be updated until the number of events is equal to ‘N’. Then, if the number of bins or the trend range is modified, the scope will use the parameter buffer values to redraw the trend with either the last ‘N’ or 20 000 values acquired — whichever is the lesser.

The parameter buffer thereby allows trends to be redisplayed using an acquired set of values and settings that produce a distribution shape with the most useful information.

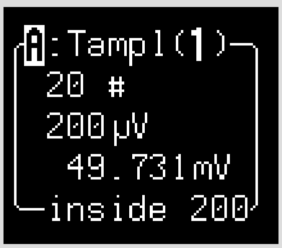
In many cases the optimal range is not readily apparent. So the scope has a powerful range-finding function. If required it will examine the values in the parameter buffer to calculate an optimal range and redisplay the trend using it. The instrument will also give a running count of the number of parameter values that fall within, below and above the range. If any fall below or above the range, the range-finder can then recalculate to include these parameter values, as long as they are still within the buffer.

Parameter Events Capture

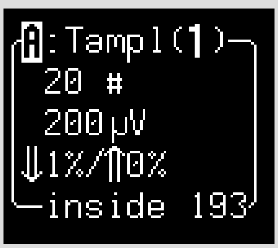
The number of events captured per waveform acquisition or display sweep depends on the parameter type. Acquisitions are initiated by the occurrence of a trigger event. Sweeps are equivalent to the waveform captured and displayed on an input channel (1, 2, 3 or 4). For non-segmented waveforms an acquisition is identical to a sweep. Whereas for segmented waveforms an acquisition occurs for each segment and a sweep is equivalent to acquisitions for all segments. Only the section of a waveform between the parameter cursors is used in the calculation of parameter values and corresponding trend events. The table provides, for each standard parameter and for a waveform section between the parameter cursors, a summary of the number of trend events captured per acquisition or sweep.

Parameters (plus others, depending on options)	**Number of Events Captured**
data	All data values in the region analyzed.
duty, freq, period, width,	Up to 49 events per acquisition.
ampl, area, base, cmean, cmedian, crms, csdev, cycles, delay, dur, first, last, maximum, mean, median, minimum, nbph, nbpw, over+, over–, phase, pkpk, points, rms, sdev, ∆dly, ∆t@lv	One event per acquisition.
f@level, f80–20%, fall, r@level, r20–80%, rise	Up to 49 events per acquisition.

Reading Trends: ***A trend is like any other waveform: its horizontal axis is in units of events, with earlier events in the leftmost part of the waveform and later events to the right. And its vertical axis is in the same units as the trended parameter. When the trend is displayed, trace labels like the ones below — for Trace*** **A** ***in these examples — appear in their customary place on-screen, identifying the trace, the math function performed and giving horizontal and vertical information…***



- **# number of events per horizontal division**
- **Units per vertical division, in units of the parameter being measured**
- **Vertical value at point in trend at cursor location when using cursors**
- **Number of events in trend that are within unzoomed horizontal display range.**



- **Percentage of values lying beyond the unzoomed vertical range when *not* in cursor measurement mode.**

Using Measurement Cursors

The parameter cursors can be used to determine the value and population of selected areas.

Figure 4.1 shows the Time cursors (Annotation ❶) positioned on the selected trend vertex, whose order number (❷) and value (❸) are also shown.

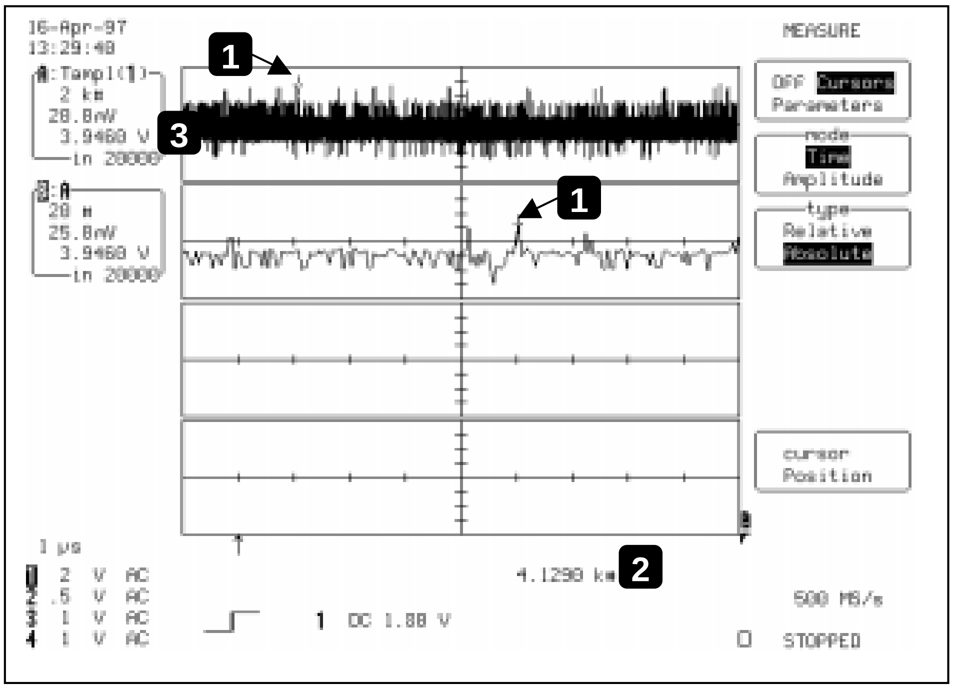


Figure 4.1

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