

CHAPTER TEN: *Use Advanced Math Tools*

You have seen how to use Waverunner math tools. Now look deeper into waveform processing and apply the scope's advanced math features.

In this chapter, see how

To process extrema waveforms

To perform enhanced resolution filtering

To rescale your waveform

To do more with FFT


To use a math function

To plot parameter trends

Compute Extrema Waveforms

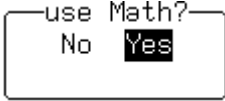
Use extrema to view a trace envelope of numerous sweeps. Your Waverunner scope repeatedly compares the maxima (roof) and minima (floor) values of new waveforms with those of already accumulated extrema records. Whenever the oscilloscope finds that a given data point of a new waveform is greater than the corresponding roof record value, or less than the floor record value, it replaces that record value with the new one. The Waverunner thus accumulates the maximum and the minimum envelope of all waveform records.

1. Press **1** to select CHANNEL 1 and display the Waverunner basic menus.


2. Press the button to 

3. Press **A** to select and set up Trace A.

3. Press the button for 

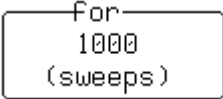
5. Press the button to select  and display the SETUP OF A menus.

6. Then press the button to select “**Extrema**” from the Math Type menu.

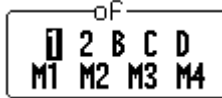
7. Press the button to select 

TIP: You can change the view of the envelope at anytime without affecting the accumulated data.

Envelope shows the entire envelope, while **Floor** and **Roof** show only the lower and upper parts of the envelope. Changing these limits will not restart the analysis.

8. Turn the upper knob to set the number of sweeps: 

9. Press the button to select the source trace:



TO DO EXTREMA

Your Waverunner scope will stop accumulating whenever the selected maximum number of sweeps is reached. You can interrupt this process by changing the trigger mode from NORMAL to STOP (by pressing the STOP button), or by turning off the function trace. A cumulation will continue when you perform the reverse action.



Reset the currently accumulated extrema waveform by either pressing CLEAR SWEEPS, or changing a parameter such as gain, offset, coupling, trigger condition, or your timebase or bandwidth limit. Waverunner displays the number of currently accumulated waveforms in the displayed trace label of the zoom trace on which the extrema function is performed. You can display roof and floor records either individually or together.

Whenever the maximum number of sweeps is reached, you can accumulate an even larger number simply by changing the value in the SETUP for menu. However, leave the other parameters unchanged, or the calculation will be restarted.

TIP: Waverunner avoids being slowed down by computing a particular math function only when that function's trace is turned on. Despite this, waveform processing can take some time when there are many data points. Cut this delay by limiting the number of data points used in the computation. Waverunner will process the entire waveform by taking every nth point — where n depends on the timebase and the desired maximum number of points. The first point taken is always the data value at the left-hand edge of the display.

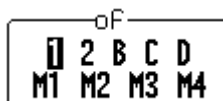


Rescale and Assign Units

This advanced math tool allows you to apply a multiplication factor (a), and additive constant (b), to your waveform. You can do it in the unit of your choice, depending on the type of application.

1. Follow the steps for setting up to do math on Trace A, B, C or D.
2. Press the button to select **Rescale** from the Math Type menu.
3. Select **a** or **b** from the next menu, below Math Type.
4. Press the button to select the mantissa, exponent, or number of digits; turn the knob to set its value.
5. If you wish, go back and select [**units**]. A new menu, called “units =” will then appear and allow you to define one of a wide range of units for your chosen value, including Amps, Celsius, Hertz, decibels, Kelvin, Ohms, Volts, and Watts.

6. Press the button to select the source trace for filtering:



TO DO AVERAGING: SUMMED VS CONTINUOUS (OPTION)

Summed Averaging is the repeated addition, with equal weight, of successive source waveform records. If a stable trigger is available, the resulting average has a random noise component lower than that of a single-shot record. Whenever the maximum number of sweeps is reached, the averaging process stops.



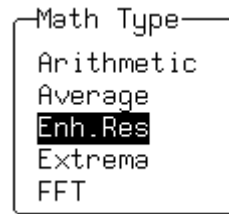
An even larger number can be accumulated simply by changing the number in the menu. However, the other parameters must be left unchanged or a new averaging calculation will be started. You can interrupt the averaging by changing the trigger mode from NORM to STOP, or by turning off the active trace. Waverunner resumes averaging when you perform the opposite action to these. Reset the accumulated average by pushing the CLEAR SWEEPS button or changing an acquisition parameter such as input gain, offset, coupling, trigger condition, timebase, or bandwidth limit. The number of current averaged waveforms of the function, or its zoom, is shown in the displayed trace label. When summed averaging is performed, the display is updated at a reduced rate — about once every 1.5 s — in order to increase the averaging speed (points and events per second).

***Continuous Averaging** is the repeated addition, with unequal weight, of successive source waveforms. It is particularly useful for reducing noise on signals that drift very slowly in time or amplitude. The most recently acquired waveform has more weight than all the previously acquired ones: the continuous average is dominated by the statistical fluctuations of the most recently acquired waveform. The weight of ‘old’ waveforms in the continuous average gradually tends to zero (following an exponential rule) at a rate that decreases as the weight increases.*

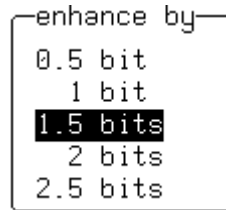
Enhance Resolution

ERES (Enhanced Resolution) filtering increases vertical resolution, allowing you to distinguish closely spaced voltage levels. Waverunner ERES is similar to smoothing the signal with a simple, moving-average filter. However, it is more efficient, both in terms of bandwidth and pass-band. Use ERES on single-shot waveforms, or where the data record is slowly repetitive — when you can't use averaging. Use it to reduce noise when your signal is noticeably noisy, but you don't need to perform noise measurements. Use it, too, when you perform high-precision voltage measurements: zooming with high vertical gain, for example.

1. Follow the steps for setting up to do math on Trace A, B, C, or D.



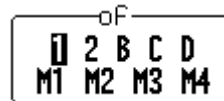
2. Then press the button to select **Enh. Res** from the Math Type menu:



3. Press the button to select 1.5 bits, for example, from

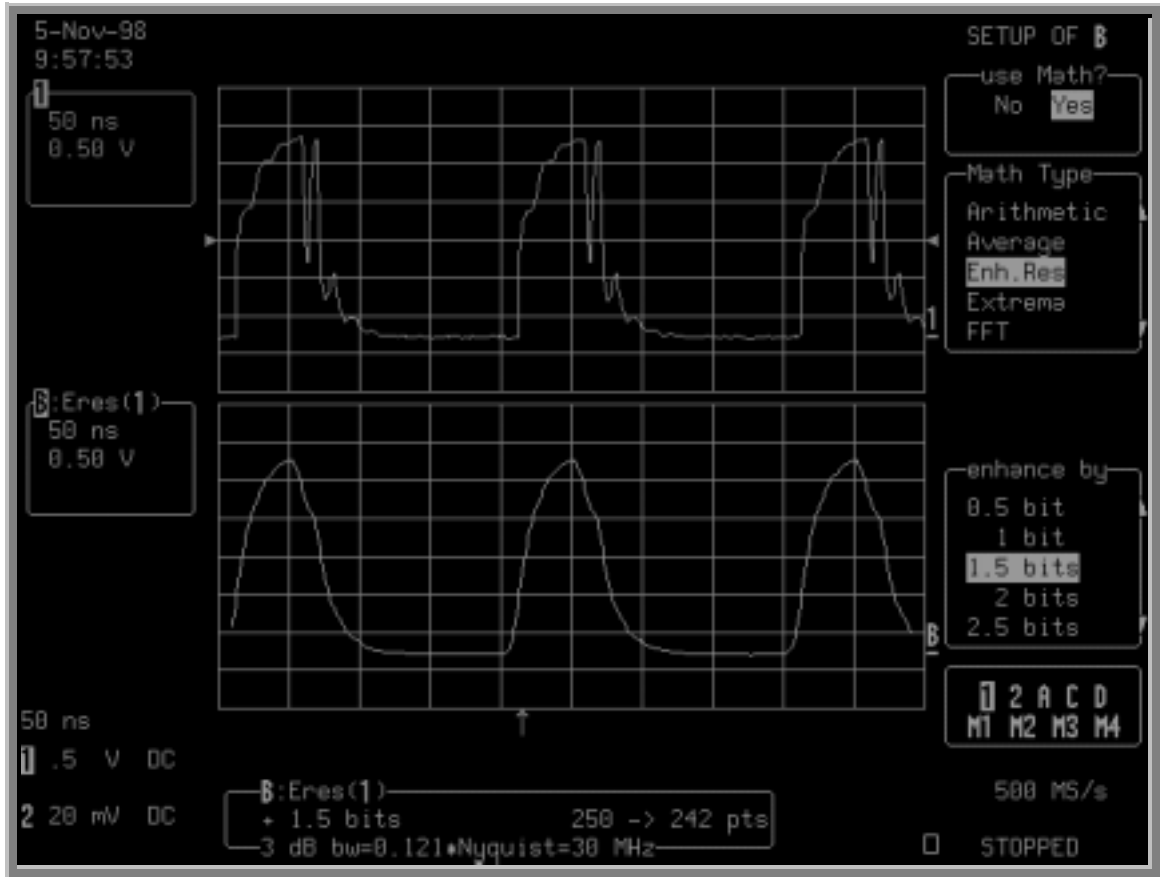
This menu allows you to choose a filter that will enhance the resolution of the displayed signal by from one to three bits, in steps of 0.5 bits.

4. Press the button to select the source trace for filtering:



Result: See illustration next page.

TIP: Depending on your sampling speed, Waverunner digital filters can affect bandwidth. If you need bandwidth at slow timebases, use Averaging with repetitive sampling.



The glitch in the waveform displayed on the top grid has been clearly eliminated by ERES: the result is the waveform on the lower grid. Trace B's label indicates this as the filtered waveform. And the information field below the grids tells you that Trace B is an ERES function of Channel 1, that the waveform has been enhanced by 1.5 bits, and that filtering has reduced the number of points from 250 to 242 (see NOTE on page131) and the bandwidth to 30 MHz.

HOW WAVERUNNER ENHANCES RESOLUTION

The Waverunner's enhanced resolution feature improves vertical resolution by a fixed amount for each filter. This real increase in resolution occurs whether or not the signal is noisy, or your signal is single-shot or repetitive. The signal-to-noise ratio (SNR) improvement you gain is dependent on the form of the noise in the original signal. The enhanced resolution filtering decreases the bandwidth of the signal, filtering out some of the noise.



PART TWO: LOOKING DEEPER

The Waverunner's constant phase FIR (Finite Impulse-Response) filters provide fast computation, excellent step response in 0.5 bit steps, and minimum bandwidth reduction for resolution improvements of between 0.5 and 3 bits. Each step corresponds to a bandwidth reduction of a factor of two, allowing easy control of the bandwidth resolution trade-off. The parameters of the six filters are given in the following table.

RESOLUTION INCREASED BY	-3 DB BANDWIDTH (\times NYQUIST)	FILTER LENGTH (SAMPLES)
0.5	0.5	2
1.0	0.241	5
1.5	0.121	10
2.0	0.058	24
2.5	0.029	51
3.0	0.016	117

With low-pass filters, the actual SNR increase obtained in any particular situation depends on the power spectral density of the noise on the signal.

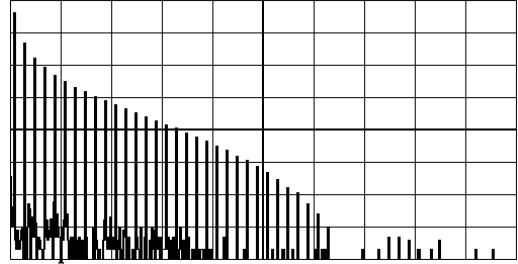
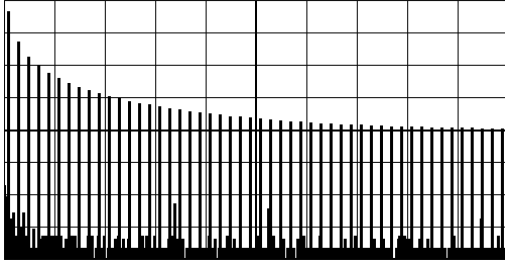
The improvement in SNR corresponds to the improvement in resolution if the noise in the signal is white — evenly distributed across the frequency spectrum.

If the noise power is biased towards high frequencies, the SNR improvement will be better than the resolution improvement.

The opposite may be true if the noise is mostly at lower frequencies. SNR improvement due to the removal of coherent noise signals — feed-through of clock signals, for example — is determined by the fall of the dominant frequency components of the signal in the passband. This is easily ascertained using spectral analysis. The filters have a precisely constant zero-phase response. This has two benefits. First, the filters do not distort the relative position of different events in the waveform, even if the events' frequency content is different. Second, because the waveforms are stored, the delay normally associated with filtering (between the input and output waveforms) can be exactly compensated during the computation of the filtered waveform.

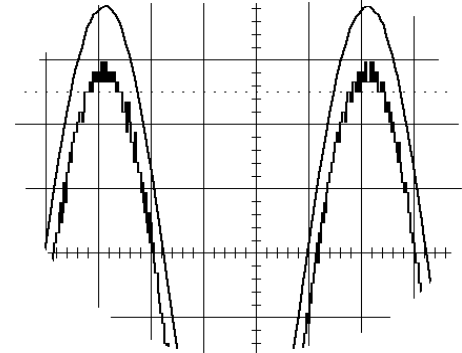
The filters have been given exact unity gain at low frequency. Enhanced resolution should therefore not cause overflow if the source data is not overflowed. If part of the source trace were to overflow, filtering would be allowed, but the results in the vicinity of the overflowed data — the filter impulse response length — would be incorrect. This is because in some circumstances an overflow may be a spike of only one or two samples, and the energy in this spike may not be enough to significantly affect the results. It would then be undesirable to disallow the whole trace.

The examples on the following page illustrate how you might use the Waverunner's enhanced resolution function.

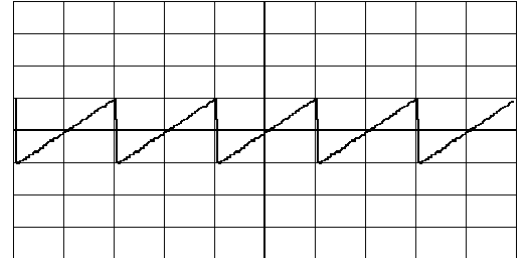
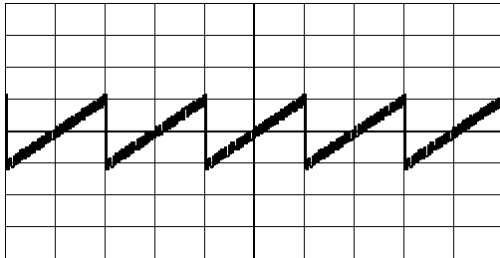


In low-pass filtering: The spectrum of a square signal before (above left) and after (above right) enhanced resolution processing. The result clearly illustrates how the filter rejects high-frequency components from the signal. The higher the bit enhancement, the lower the resulting bandwidth.

To increase vertical resolution: In the example at right, the lower (“inner”) trace has been significantly enhanced by a three-bit enhanced resolution function.



To reduce noise: The example below shows enhanced resolution of a noisy signal. The original trace (below left) has been processed by a two-bit enhanced resolution filter. The result (below right) shows a “smooth” trace, where most of the noise has been eliminated.



NOTE: Enhanced resolution can only improve the resolution of a trace; it cannot improve the accuracy or linearity of the original quantization. The pass-band will cause signal attenuation for signals near the cut-off frequency. The highest frequencies passed may be slightly attenuated. Perform the filtering on finite record lengths. Data will be lost at the start and end of the waveform; the trace will be slightly shorter after filtering. The number of samples lost is exactly equal to the length of the impulse response of the filter used — between two and 117 samples. Normally this loss — just 0.2% of a 50 000 point trace — is not noticed. However, you might filter a record so short there would be no data output. In that case, however, the Waverunner would not allow you to use the ERES feature.

Do More with FFT

In Part One (Chapter 5, “Use Math Tools”) we looked at how to use Fast Fourier Transform (FFT) to display and measure signals in the frequency domain. Now see how to use the optional FFT Average feature, and how to set up an FFT span to improve resolution. Valuable hints on how to get even more from this tool are also given here.

DO FFT AVERAGE

1. Follow the steps for setting up to do math on Trace A, B, C, or D.
2. Press the button to select **FFT AVG** from the Math Type menu.
3. Press the button to select an FFT function to average. Select **Power Spect**, for example, and you can define a function as the power average of FFT spectra, computed by another FFT function.

CLEAR
SWEEPS

4. Press  to reset FFT average and show the number of currently accumulated waveforms in the displayed trace field of the math trace or its zoom.

When FFT or FFT Averaging is used, the memory status field beneath the grid shows the parameters of the waveform descriptor.

C:PS(AVGP(B))
Power Spectrum 10000 -> 2500 pts

DO ADDITIONAL PROCESSING

You can perform other math and waveform processing functions, such as averaging or arithmetic, before doing FFT. For example: if a stable trigger were available you could perform time-domain averaging to reduce random noise in the signal.

TIP: To increase the FFT frequency range — the Nyquist frequency — raise the effective sampling frequency by increasing the maximum number of points or using a faster time base.

To increase the FFT frequency resolution, increase the length of the time-domain waveform record by using a slower timebase.

USE CURSORS WITH FFT

Move the absolute time cursor into the frequency domain to read the amplitude and frequency of a data point. Do this by moving it beyond the right-hand edge of a time-domain waveform. Then move the relative time cursors into the frequency domain to simultaneously indicate the frequency difference and the amplitude difference between two points on each frequency-domain trace. Use the absolute voltage cursor to read the

absolute value of a point in a spectrum in the appropriate units. And adjust the relative Voltage cursors to indicate the difference between two levels on each trace.

NOTE: *The following FFT-related error messages may appear at the top of the screen:*

“Incompatible input record type” – *FFT Average done on a function not defined as FFT.*

“Horizontal units don’t match” – *FFT of a frequency-domain waveform is not available.*

“FFT source data zero filled” – *If there are invalid data points in the source waveform (at the beginning or at the end of the record), these are replaced by zeros before FFT processing.*

“FFT source data over/underflow” – *The source waveform data has been clipped in amplitude, either in the acquisition — gain too high or inappropriate offset — or in previous processing. The resulting FFT contains harmonic components that would not be present in the unclipped waveform. The settings that define the acquisition or processing should be changed indirectly by means of another function or expansion. One of the definitions should be changed to eliminate the over/underflow condition.*

“Circular computation” – *A function definition is circular (i.e., the function is its own source).*



PART TWO: LOOKING DEEPER

TO SET UP FFT SPAN AND RESOLUTION



To set up an FFT correctly, start with the frequency resolution, or Δf . This is the spacing of samples in the frequency domain display. Set the Δf by inputting the time duration of the time domain signal to the FFT.

If an acquisition channel (Channel 1, 2, or 3 or 4) is the source, then the waveform duration is the capture time: the TIME/DIV setting multiplied by 10. If the source waveform is a zoom trace, the frequency resolution is the reciprocal of the displayed waveform's duration. The relationship between capture time and frequency resolution is illustrated below (Fig. 1).

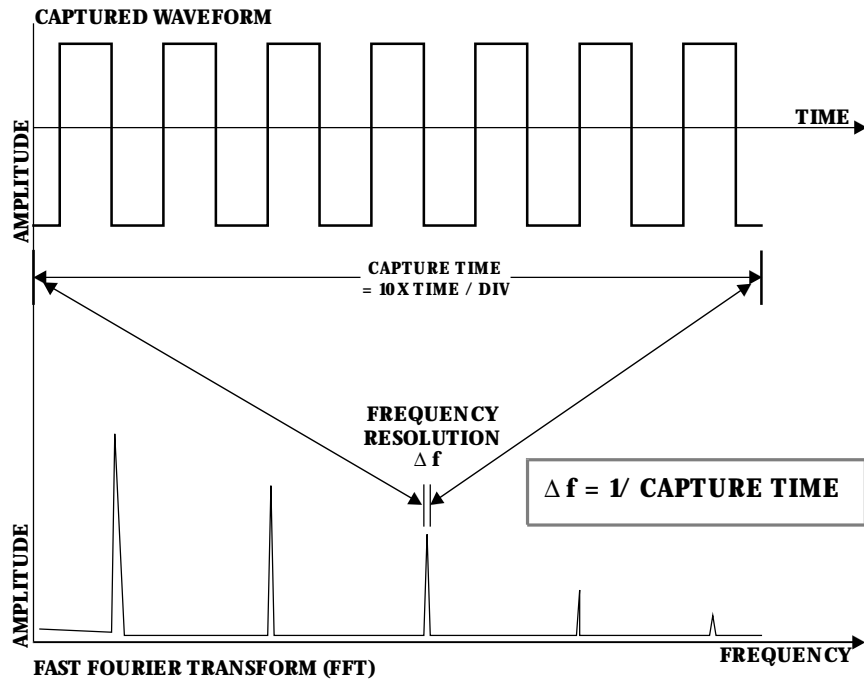


Figure 1. Capture time determines the frequency resolution Δ .

The frequency span of the FFT is called the Nyquist frequency, and is related to the sampling frequency of the time domain waveform. If the math memory size is identical to the number of samples in the acquired waveform, then the span will be half the sampling frequency. But if this “max points for math” number is less than the number of points, the waveform and the FFT span will be decimated. The relationship between the FFT span and the sampling rate ($1/\Delta T$) is illustrated on the next page (Fig. 2).

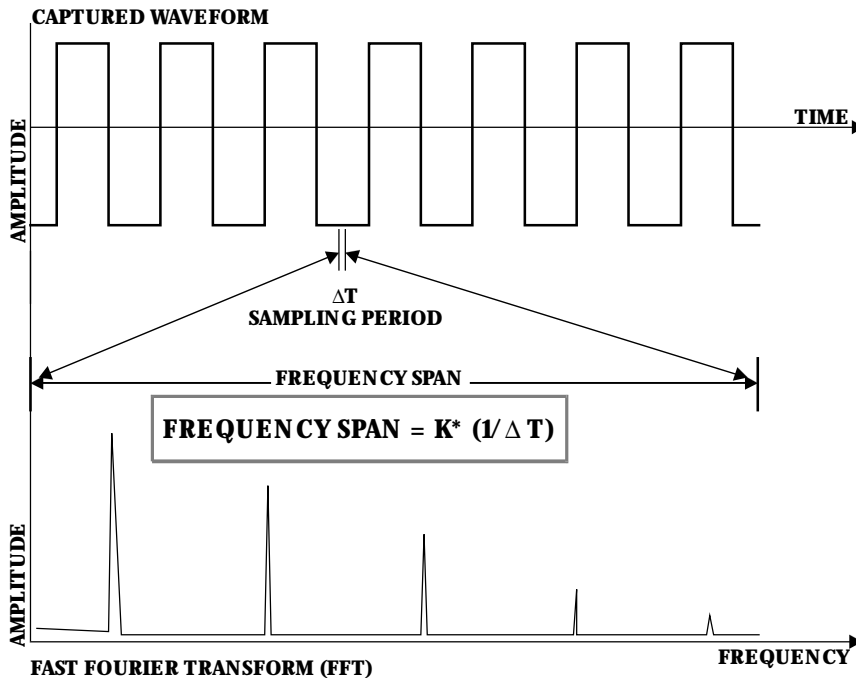


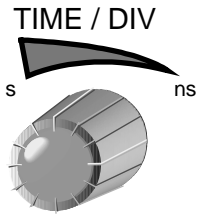
Figure 2. The span of the FFT is related to the sampling rate ($1/\Delta T$).

The Waverunner automatically adjusts the span, and the FFT transform size, to account for the “max points for math” you enter, as well as the display scaling. The scope may also adjust the length of the displayed trace. You can read the span in the displayed trace label for the trace with FFT, with the horizontal calibration in Hz/div. It is also displayed as the Nyquist frequency in the information field that appears at the bottom of the screen when you set up for FFT.

SET FFT SPAN


1. To obtain the FFT span you want, first make sure that your sampling rate is more than twice the span desired. Control the sampling rate, then set the acquisition memory length. You could further adjust the sampling rate by limiting the number of points. For example, to analyze a continuous periodic waveform, you may wish to have a span of 10 MHz and frequency resolution of 10 kHz. That frequency resolution would require a capture time of 100 μ s. You would therefore set the time per division to 10 μ s to obtain the necessary Δf of 10 kHz. You would need an effective sampling rate of greater than 20 MS/s in order to obtain the required 10 MHz span. On a Waverunner scope with a sampling rate of 500 MS/s and a 50 000-sample default memory length, you would use a 10 μ s time/div setting to first give a 250 MHz span.

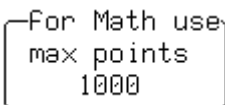
PART TWO: LOOKING DEEPER

2. Turn  and set time per division to 10 μ s.

TIP: Of the two methods proposed in Step 3 below, the second is preferable because it maintains a high input sampling rate and reduces the risk of aliasing the captured data.

Then, to obtain the 10 MHz span, reduce the sampling rate in either of two ways:

3. Press  and decrease the number of samples by setting the “record up to” menu to 2500 in a sampling rate of 25 MS/s.

Alternatively, use  to limit the number of points to 2500. Choosing this method would leave the sampling rate at 500 MS/s but decimate the waveform data before the FFT to reduce the effective sampling rate to 25 MS/s. This would in turn give a span of 12.5 MHz, the closest achievable span to > 10 MHz.

A sampling rate of 25 MS/s would result in a full-scale range of 12.5 MHz (1.25 MHz per division). To maintain a display scale factor of 1, 2, or 5, your Waverunner scope would decimate the acquired waveform and calculate the FFT using a 2000-point transform. This would result in a scale factor of 2 MHz/Div. The display would be truncated at 6.25 divisions to retain the original 12.5 MHz span.

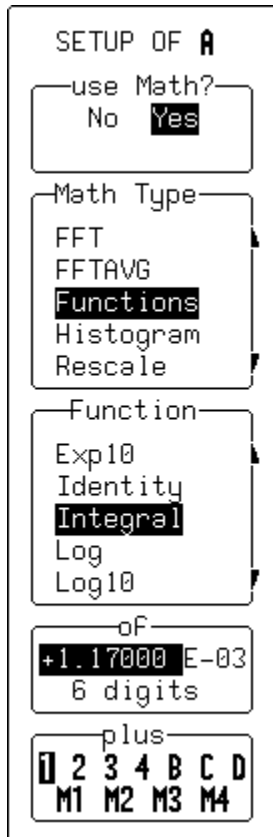
FFT WINDOW FILTER PARAMETERS				
Window Type	Highest Side Lobe (dB)	Scallop Loss (dB)	ENBW (bins)	Coherent Gain (dB)
Rectangular	-13	3.92	1.0	0.0
von Hann	-32	1.42	1.5	-6.02
Hamming	-43	1.78	1.37	-5.35
Flat Top	-44	0.01	2.96	-11.05
Blackman-Harris	-67	1.13	1.71	-7.53

Use an Advanced Math Function

These functions allow you to automatically carry out complex computations on your signal. See Chapter 5, “Use Math Tools,” for the full range of standard and optional math functions. To choose and use a function:

1. Follow the steps for setting up to do math on Trace A, B, C, or D.
2. Then use these menus to choose and use an advanced math function.

NOTE: Waverunner computes square root on the absolute value of the waveform. For logarithmic and exponential functions, it uses the input signal's numerical value without units.



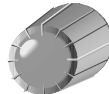
To select to do math.



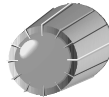
To select **Functions**.



To select **Integral**, for example.



To set the signal offset to compensate for any DC offset in the signal.




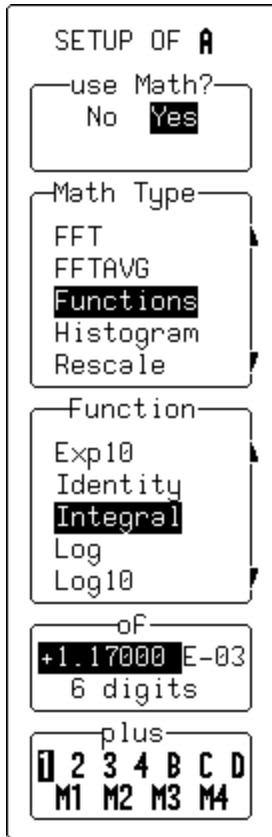
To select the source waveform.

NOTE: When you use Integral, your source signal can be offset by an additive constant in the range -10^6 to $+10^6$ times the vertical unit of the signal.

Resample to Deskew

Deskew whenever you need to compensate for different lengths of cables, probes or anything else that causes timing mismatches between signals. Resample a signal on one channel and adjust it in time relative to a signal on another.

1. Display the signals on two different channels.
2. Press  to make a zoom of the channel whose signal you wish to adjust in time.



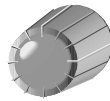
3. Use these menus to deskew the signal.



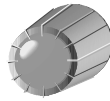
To select to do math.



To select **Resample**.



To adjust with the knob, in the range ± 2000 ns, the signal on Trace A, and compensate for the timing differences between it and the other signal.

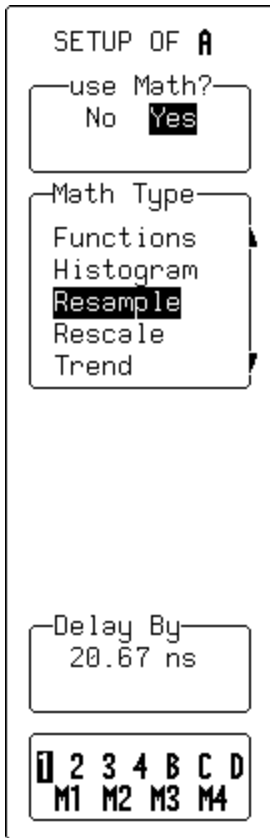


To select the channel whose signal you wish to adjust.

Plot Trends

Plot a line graph of a parameter's evolution over time using the optional Trend feature (EMM Option). And eliminate the need to make and record a large number of individual measurements. When you set up the trend plot, Waverunner will generate it automatically as the scope takes data, making the measurements and plotting the values for you. The graph's vertical axis will be the value of the parameter, and its horizontal axis the order in which the values were captured. In this way you can graphically display up to 20 000 individual parameter measurements on each trace, using any of more than 100 available parameters as the trend source. You can also cross-plot two trends on an X-Y display and see the functional relationships between the two parameters.

1. Set up a custom parameter for the trend. See the next chapter, "Analyze with Parameters."
2. Follow the steps for setting up to do math on Trace A, B, C, or D.



3. Use these and the menus on the next page to create your trend graph.



To select for math.



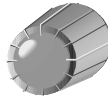
To select **Trend**.



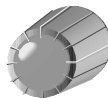
To select parameters and further configure the trend (see next page).



To position the trend automatically once calculated. Also centers and scales the trend without affecting zoom or position settings.



To select the parameter line to be used in the trend.



To select (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.

SETUP OF A

use Math?
No Yes

Math Type
Per.Hist
Per.Trace
Resample
Rescale
Trend

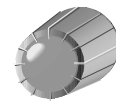
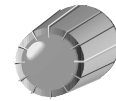
MORE
TREND SETUP

FIND CENTER
AND HEIGHT

Trend of
custom line 1
ampl(1)

using up to
1000
(values)

TIP: See the LeCroy Application Briefs (LABs) covering trend plots for help in a range of applications. Ask your LeCroy customer service center, or find these and other useful LABs at LeCroy's web site: <http://www.lecroy.com/Labs/default.asp>



RETURN



To select **All**: every parameter calculation on each waveform will be placed in the trend. Or **Average**: to trend only the average of all the given values calculated, and obtain one point in the trend, per capture.

To access the CHANGE PARAM menus and select or configure a parameter. See the next chapter, "Parameter Analysis."

To position the trend automatically once calculated. Also centers and scales the trend without affecting zoom or position settings.

To set the trend's center value.

To select the value of each vertical display division. The height per division multiplied by number of vertical display divisions (eight) determines the range of parameter values centered on the number in the "Center" menu, used to create the trend.

To return to the previous menu group.

READ TRENDS

Once the trend plot is displayed, trace labels like the ones below — for Trace A in these examples — appear in their customary place on-screen, identifying the trace and the math performed, and giving horizontal and vertical information.

```

A: Tmp1(1)
 20 #
 200 μV
 49.731mV
inside 200
    
```

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

```

A: Tmp1(1)
 20 #
 200 μV
 ↓1%/↑0%
inside 193
    
```

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

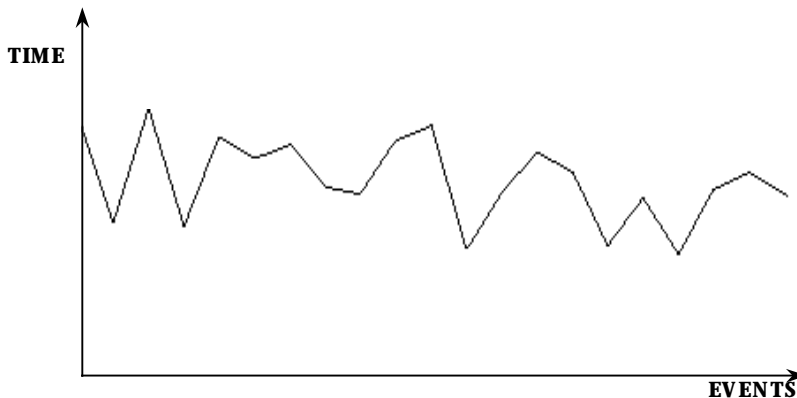


Figure 3. A trend's horizontal axis is in units of events, with the earlier events in the leftmost part of the waveform and later ones on the right. The vertical axis is in the same units as the trended parameter.

TO CALCULATE TRENDS



Once you have configured the trend, parameter values will be calculated and trended on each subsequent capture.

The trend values will be calculated immediately following the capture. The resulting trend is a waveform of data points that can be used in the same way as any other waveform. Parameters can be calculated on it, and it can be zoomed; it can serve as the x or y trace in an XY plot, or be used in cursor measurements.

The sequence for acquiring trend data is:

- 1. Trigger*
- 2. Waveform capture*
- 3. Parameter calculation(s)*
- 4. Trend update*
- 5. Trigger re-arm*

If you set the timebase in a mode other than sequence, 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 the trend data is a memory, when you save new data to memory, this acts as a trigger and acquisition. Because updating the screen can take significant processing time, the process occurs only once a second, minimizing trigger dead time (and under remote control the display can be turned off to maximize measurement speed).

The Waverunner 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. This parameter allows trends to be redisplayed using an acquired set of values and settings that produce a distribution shape with the most useful information. Once it is in buffer, you can display the trend in different scaling ranges without reacquiring data.

*In many cases the optimal range is not readily apparent. For this reason the scope has a powerful range finding function: **FIND CENTER AND HEIGHT** (see page 140). If necessary, it will examine the values in the parameter buffer to calculate an optimal range, and use it to redisplay the trend. Waverunner 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.*

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. For non-segmented waveforms a capture is the same as a sweep, whereas for segmented waveforms an acquisition occurs for each segment and a sweep is equivalent to captures 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 a summary of the number of trend events captured per acquisition or sweep for each standard parameter and for a waveform section between the parameter cursors.

