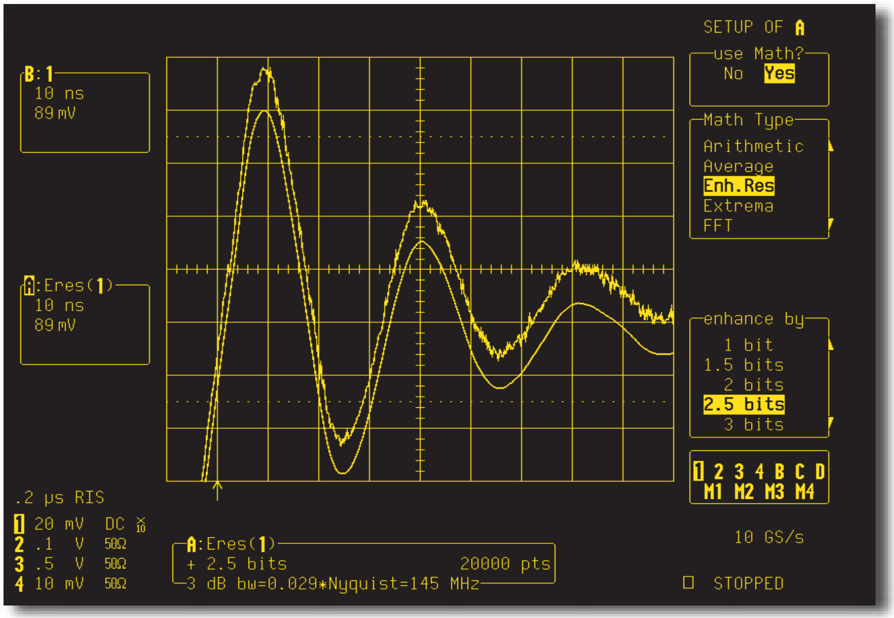
Enhanced Resolution in LeCroy Digital Oscilloscopes



Summary

The sampling rate of digital oscilloscopes – especially those with long record length – is often much higher than is actually required, considering the frequency spectrum of the signal under analysis. This oversampling can be used to your advantage, either by filtering the digitized signal in order to increase the effective resolution of the displayed trace, or to remove unwanted noise.

What is Enhanced Resolution?

Applying the Enhanced Resolution FIR (Finite Impulse Response) function is similar to smoothing the signal with a simple moving average filter, except that it is more efficient in terms of bandwidth and has better passband characteristics. New applications for this function may be found in situations where the averaging of successive traces would be useful but cannot be employed, because the signal has single-shot characteristics.

The Advantages of Enhanced Resolution

Two subtly different characteristics of the instrument are improved by the Enhanced Resolution filtering:

1. In all cases, the resolution (i.e. the ability to distinguish closely-spaced voltage levels) is improved by a fixed amount for each filter. This is a true increase in resolution which occurs whether or not the signal is noisy and whether or not it is a single-shot or a repetitive signal.

2. The signal-to-noise ratio (SNR) is improved in a manner which depends on the form of the noise in the original signal. This occurs because the Enhanced Resolution filtering decreases the bandwidth of the signal and will therefore filter out some of the noise.

Enhanced Resolution in LeCroy Scopes

LeCroy DSOs implement a set of linear-phase FIR filters, optimized to provide fast computation, excellent step response and minimum bandwidth reduction for resolution improvements of between 0.5 and 3 bits in 0.5-bit steps. Each 0.5-bit step corresponds to a bandwidth reduction by a factor of two, allowing easy control of the bandwidth/resolution trade-off. The parameters of the six filters available in these scopes are given in Table 1 on the following page.

The filters used are low pass filters, so the actual increase in SNR obtained in any particular situation will depend on the power spectral density of the noise present on the signal. The filters will give the same SNR improvement ratio as their resolution improvement ratio if white noise is present in the signal (i.e. evenly distributed across the frequency spectrum). If the noise power is biased towards high frequencies, then the SNR improvement will be better than the resolution improvement. Whereas, if the noise is mostly at lower frequencies, the improvement may not be as good as the resolution improvement. The improvement in the SNR due to the removal of coherent noise signals (for example, feed-through of clock signals) depends on whether the signal is in the passband of the filter or not. This can easily be deduced by using the Spectrum Analysis option of the digital scopes.

As an aid to choosing the appropriate filter for a given application, the Enhanced Resolution menu (see Fig. 1) indicates the -3 dB bandwidth of the current filter in two ways. It is given firstly as a percentage of the Nyquist frequency, and secondly, as the actual frequency corresponding to the time-base setting of the current waveform.

The filters used for the Enhanced Resolution function have an exactly linear phase response. This has two desirable properties. Firstly, the filters do not distort the relative position of different events in the waveform, even if the frequency content of the events is different. Secondl
being stored, the

Resolution Enhancement [Bits]	-3dB Bandwidth [x NyQuist]	Filter Length [samples]
0.5	0.5	2
1	0.241	5
1.5	0.121	10
2	0.058	24
2.5	0.029	51
3	0.016	117

Table 1: Parameters of the Enhanced Resolution FIR Filters.

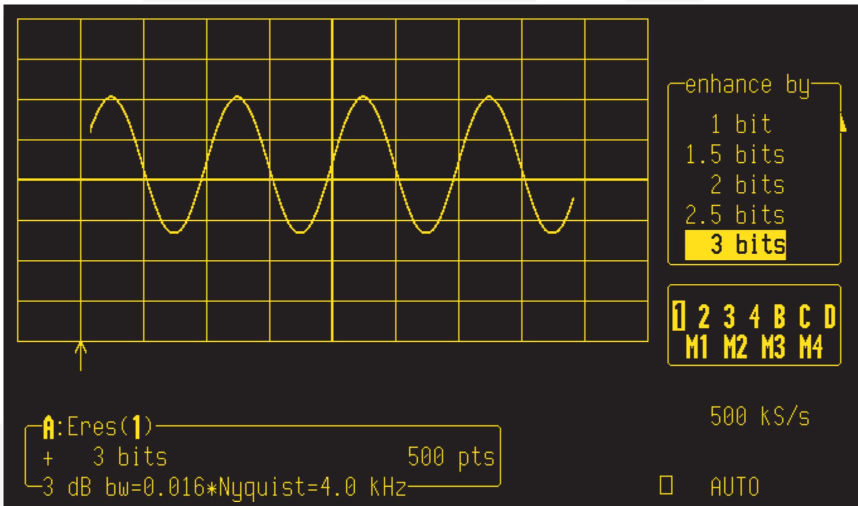


Figure 1: The enhanced resolution menu in LeCroy DSOs.

ated with filtering (between the input and output waveforms) can be exactly compensated for during the computation of the filtered waveform.

When Should Enhanced Resolution be Used?

There are two main situations for which Enhanced Resolution is especially useful. If the signal is noticeably noisy (and measurements of the noise are not required), the signal can be "cleaned up" by using the Enhanced Resolution function. Also, even if the signal is not particularly noisy, but high-precision measurements of the waveform are required (perhaps when using Expand with high vertical gain), then Enhanced Resolution will increase the resolution of the measurements.

In general, Enhanced Resolution replaces the Averaging function in situations where the data record has a single-shot or slowly repetitive nature and averaging cannot be used.

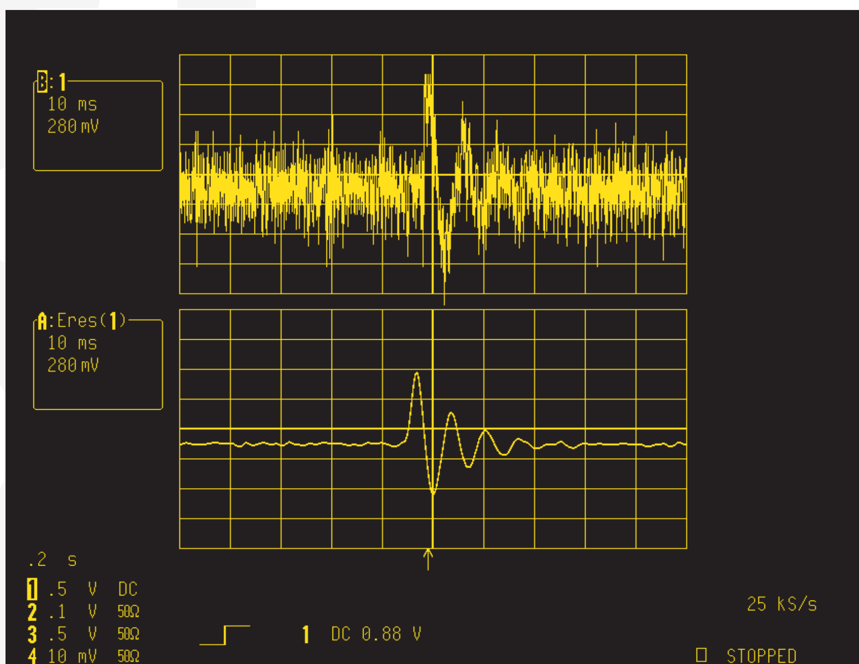
The following examples illustrate uses of the Enhanced Resolution function in these situations.

Filtering-Out Noise

Figure 2 shows the effect of Enhanced Resolution on a noisy signal, containing a ringing spike almost buried in noise on the upper grid. The lower grid shows the same signal after a 3-bit resolution enhancement: the spike is now clearly visible, and measurements such as frequency, amplitude or cycles can now be performed on the signal of interest.

The same signal viewed in the frequency domain shows the low-pass filtering effect of the Enhanced Resolution function. Figure 3 shows the power spectrum of the signals from Figure 2. The upper trace shows the spectrum of the unfiltered signal, while the lower trace shows the spectrum of the signal after the 3-bit resolution enhancement.

Figure 2: Noisy signal cleaned up with a 3-bit resolution enhancement.



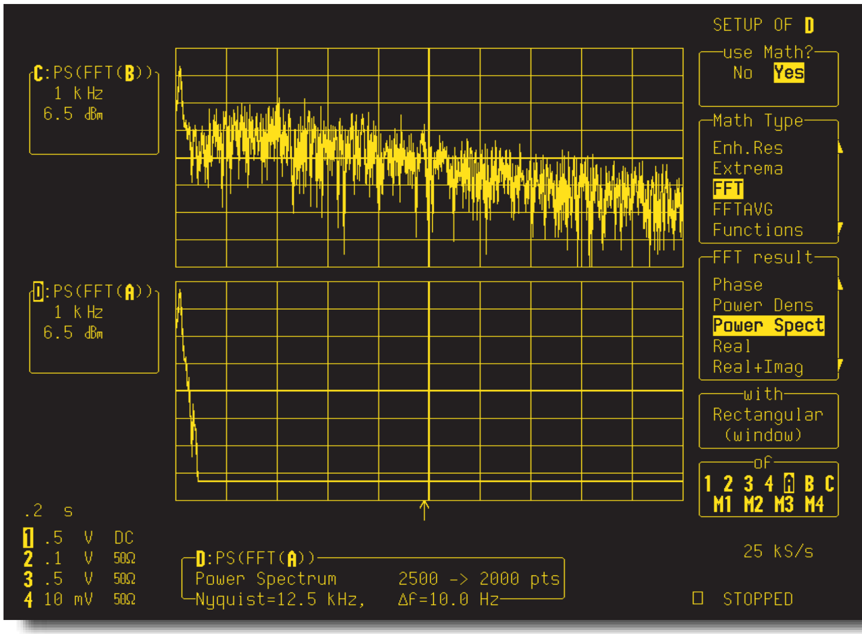


Figure 3: Frequency spectrum of signals from Figure 2. Notice the low-pass filter effect of the Enhanced Resolution function.

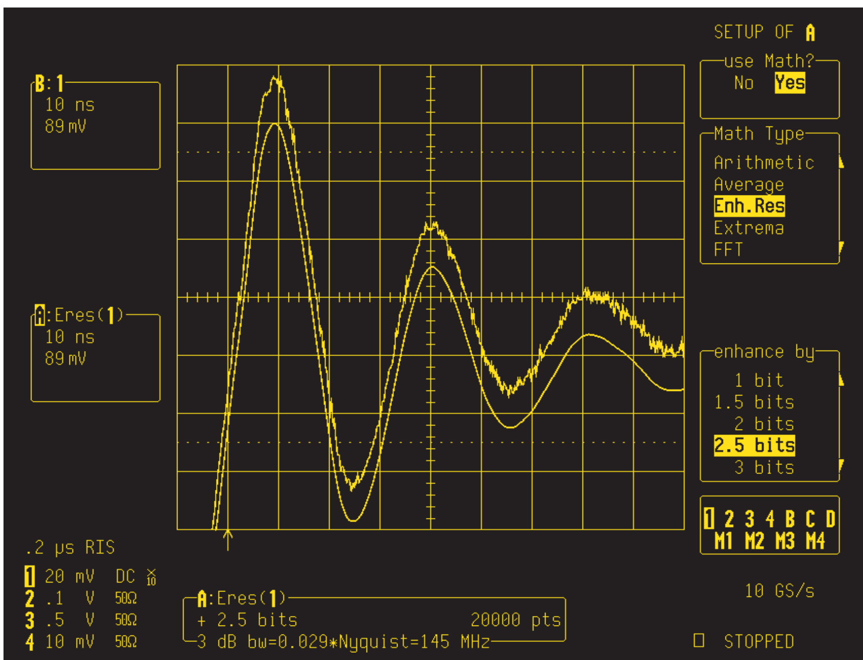


Figure 4: Resolution improvement on a RIS waveform viewed with vertical expansion.

The 3-bit enhancement filter has a -3 dB bandwidth of 0.016 times the Nyquist frequency, which is about 1/6 of a horizontal division. The filter removes energy from the signal above this frequency.

Improving Vertical Resolution

Enhanced Resolution can generally be used on RIS waveforms without any loss of bandwidth, because the RIS traces are usually highly oversampled with respect to the analog bandwidth of the oscilloscope. For example, at least one-bit enhancement can always be used for RIS waveforms with a time-base of 1 µs/div or faster. This is illustrated in Figure 4 where a 25 MHz damped sinewave signal is displayed without (top trace) and with (lower trace) 2.5-bit resolution enhancement. The improvement can easily be seen. In this case, the -3 dB bandwidth of the digital Enhanced Resolution filter is 145 MHz and thus has no significant distortion on the signal bandwidth of the instrument.

Conversely, RIS is very useful for increasing the sampling frequency of repetitive signals prior to Enhanced Resolution filtering, even if RIS would not be used for the normal trace. This is because the -3 dB bandwidth of the filter is increased by the greater effective sampling frequency, and more filtering (greater enhancement) can be used for a similar loss of bandwidth.

Cautionary Notes

The Enhanced Resolution function only improves the resolution of a trace. It cannot improve the accuracy or linearity of the original quantization by the 8-bit ADC.

The constraint of good temporal response for the high-resolution filters excludes the use of maximally-flat filters. Therefore, the passband will cause slight signal attenuation for signals near the cut-off frequency. One must be aware, therefore, when using these filters, that the highest frequencies passed may be slightly attenuated. The frequency response of a typical High Resolution filter (the 2-bit enhancement filter) is shown in Figure 5. The -3 dB cut-off frequency at 5.8% of the Nyquist frequency is marked.

The filtering must be performed on finite record lengths. Therefore, the discontinuity at the ends of the record cause data to be corrupted at these points. These data points are not displayed by the digital scopes, and so the trace becomes slightly shorter after filtering. The number of samples lost is exactly equal to the length of the impulse response of the filter used and thus varies between 2 and 117 samples.

Because the scopes in focus here have very long waveform memories, this loss is normally not noticed (it is only 0.2% of a 50,000 point trace, at worst). However, it is possible to ask for filtering on a record so short that there would be no data output. In this case, the DSO will not allow filtering.

Conclusion

The examples above each illustrate one feature of the Enhanced Resolution Function: noise-reduction and low-pass filtering for one, and vertical resolution improvement for the other. In many cases, however, these two features coexist, and their effects are combined on the resulting Enhanced Resolution trace in a manner which is very similar to averaging. Therefore, in single-shot applications, Enhanced Resolution can be an ideal alternative to averaging.

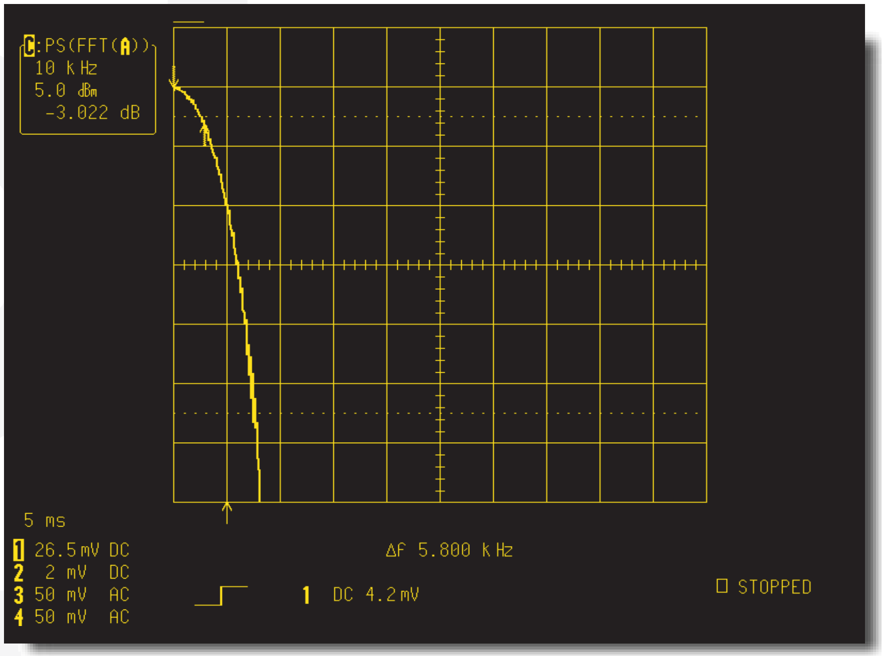


Figure 5: Frequency response of a typical FIR filter.