ENHANCED RESOLUTION

Summary

The sampling rate available in digital oscilloscopes especially those with long waveforms capture time is often much higher than is actually required for the frequency spectrum of the signal being analyzed. This over-sampling can be used to advantage, either by filtering the digitized signal in order to increase the effective resolution of the displayed trace, or by removing unwanted noise.

I. Enhanced Resolution

The Enhanced Resolution function applies a Finite Impulse Response (FIR) filter which, 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. Applications for this function include situations where the averaging of successive traces would be useful but cannot be employed because the signal has single-shot characteristics (the signal may not be repetitive or you might not be able to set a stable trigger.

a. The Advantages of Enhanced Resolution

Two subtly different characteristics of the instrument are improved by the Enhanced Resolution (ERES) 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.

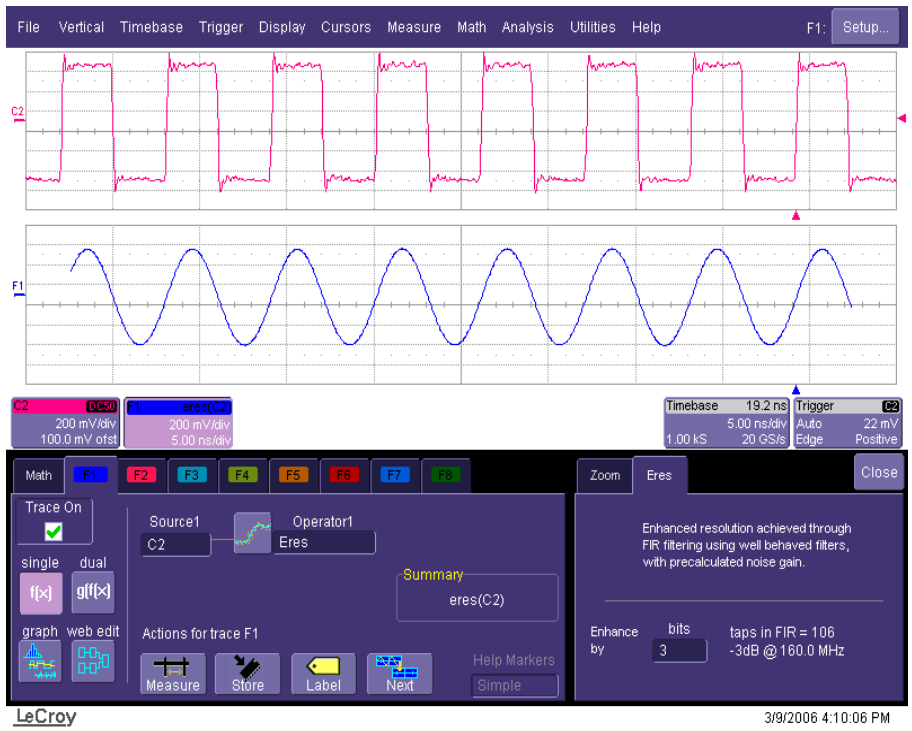

Figure 1, The ERES dialog box showing the bandwidth in the lower left corner

2. The signal-to-noise ratio (SNR) is improved in a manner that 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.

b. Enhanced Resolution in LeCroy oscilloscopes

LeCroy DSOs implement a set of linear phase finite impulse response (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 the table below.

Table 1 The Enhanced Resolution filter parameters

Resolution Enhancement [Bits]	-3 dB Bandwidth [x Nyquist]	Filter Length [samples]	Effective Dynamic Range
0.5	0.5	2	362:1
1	0.241	5	512:1
1.5	0.121	11	724:1
2	0.058	25	1024:1
2.5	0.029	52	1448:1
3	0.016	106	2048:1

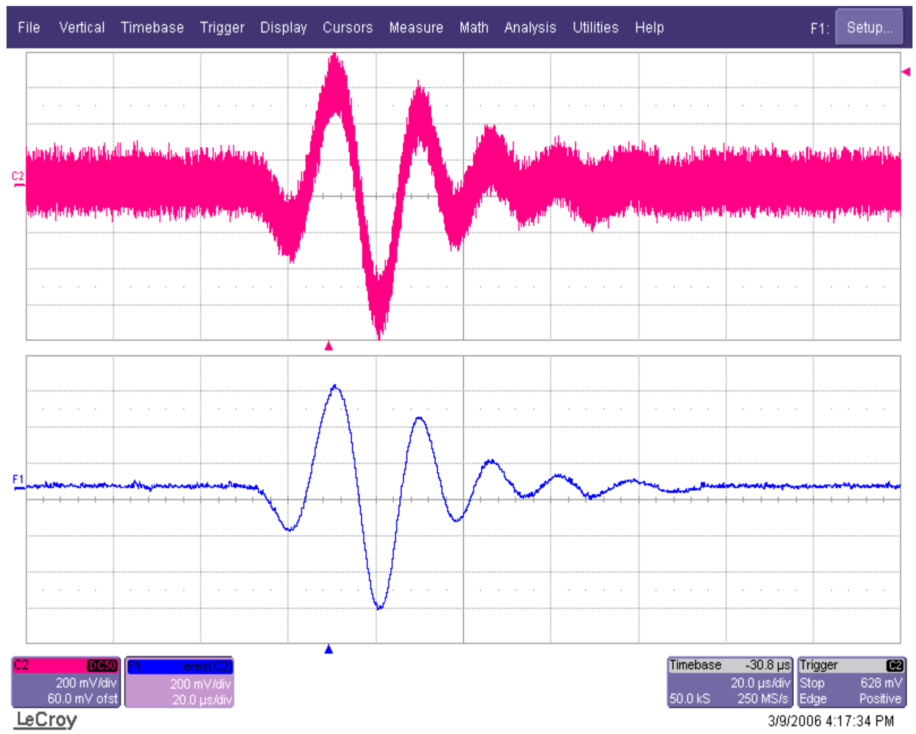

Figure 2, Noisy signal cleaned up with a 3-bit resolution enhancement.

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 the noise in the signal is white, 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. If the noise is mostly at lower frequencies, the SNR improvement may not be as much 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 or not the signal is in the passband of the filter. This can easily be deduced by using the spectrum analysis option of the digital scope.

As an aid to choosing the appropriate filter for a given application, the Enhanced Resolution dialog box (see Figure 1) indicates the -3 dB bandwidth of the ERES filter as the actual frequency corresponding to the current timebase 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. Secondly, the delay normally associated with filtering (between the input and output waveforms) can be exactly compensated for during the computation of the filtered waveform.

II. WHEN SHOULD ENHANCED RESOLUTION BE USED?

There are two main situations for which enhanced resolution is especially useful. Firstly, 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. Secondly, even if the signal is not particularly noisy, but high precision measurements of the waveform are required (perhaps when using zoom 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.

III. FILTERING-OUT NOISE

Figure 2 shows the effect of Enhanced Resolution on a noisy signal, containing a damped sinusoidal buried in noise on the upper grid. The lower grid shows the same signal after a 3-bit resolution enhancement: lower level oscillations are 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 in Figure 2. The upper pair of traces shows the input waveform and spectrum of the unfiltered signal, while the lower trace pair shows the signal and the spectrum of the signal after the 3-bit resolution enhancement. The 3.0 bit enhancement filter has a -3 dB bandwidth of 200 kHz. The filter removes energy from the signal above this frequency.

Another view of the operation of enhanced resolution can be seen in Figure 4. Here we are looking at the histograms of an acquired and a 3 bit enhanced resolution processed sine wave. The upper histogram represents the voltage amplitude of each sample in the waveform from channel 2. This is 8 bit data and when histogrammed with 2000 bins it shows, a ‘comb-like’ appearance due to the limited resolution of the 8-bit digitizer.

The lower histogram is the same waveform after enhanced resolution. Note that every bin contains data indicating there are now more that 2048 voltage levels (11 bits).

IV. IMPROVING BANDWIDTH

In many applications the loss of bandwidth may limit the usefulness of enhanced resolution. In those cases enhanced resolution is being used to improve the resolution of the waveform and not the S/N ratio. The bandwidth limitation can be rectified in two ways. If the signal is repetitive, random interleaved sampling or RIS may be used. In RIS mode the effective sample rate of the scope is increased to up to 200 GS/s for repetitive waveforms. Since the enhanced resolution bandwidth is proportional to the sampling frequency this can increase the processed bandwidth by up to 10:1.

Another commonly used technique is to apply interpolation to the acquired signal. The (Sinx)/x interpolation function increases the effective sample rate by a factor of 10:1. The optional Interpolate math function can increase the effective sampling rate by up to 50:1. In Figure 5 the upper pair of traces shows a waveform sampled at 20 GS/s. An enhanced resolution of 2 bits reduces the bandwidth to 580 MHz. By applying the (sinx)/x interpolator the effective

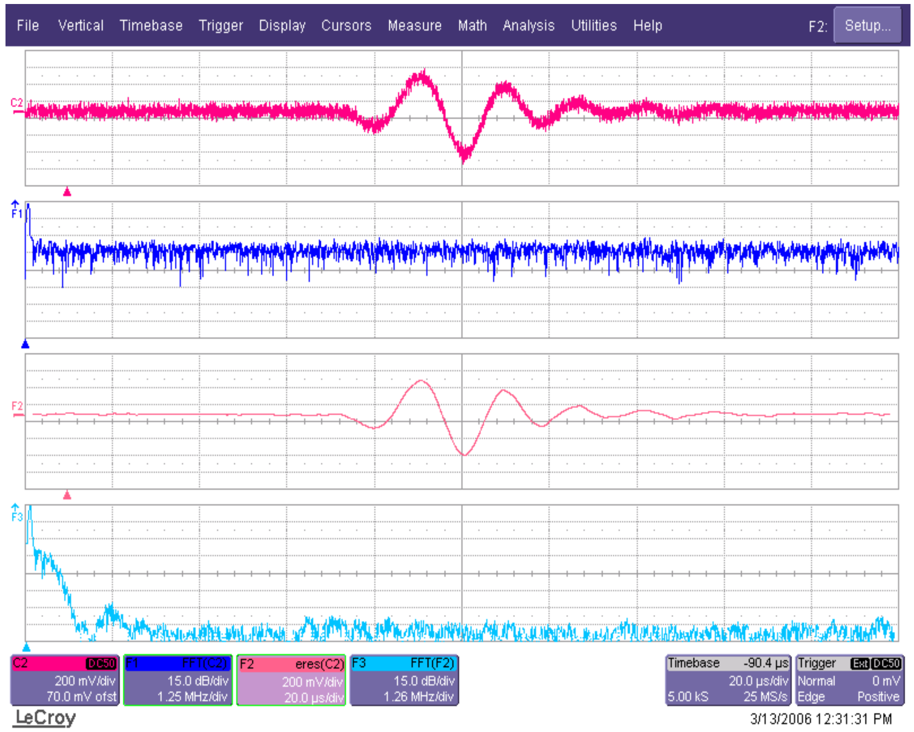

Figure 3, The frequency spectrum of the signals in Figure 2.

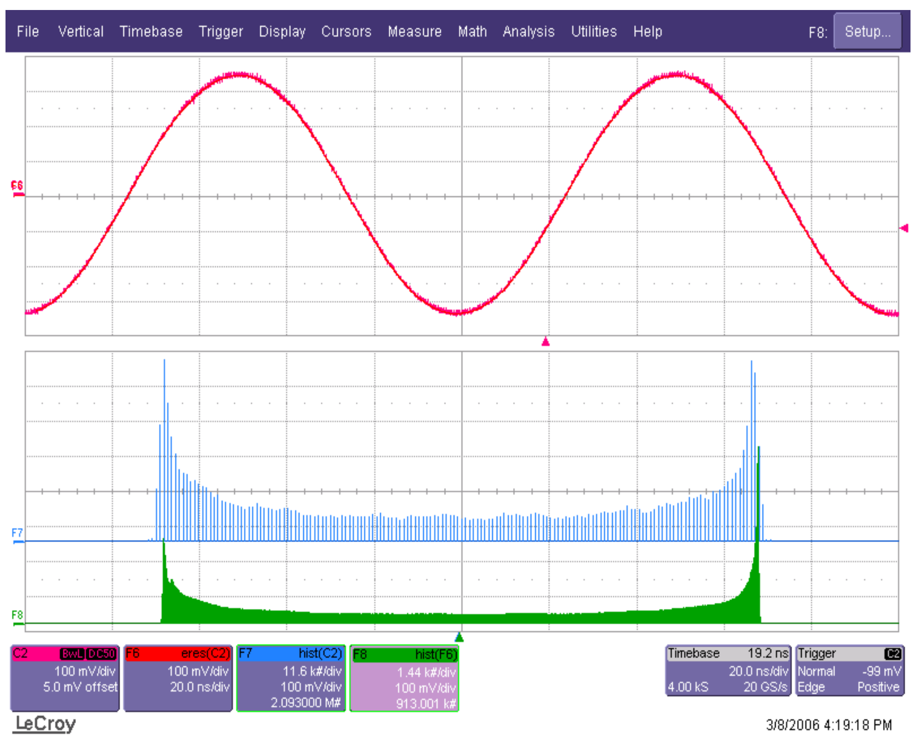

Figure 4, The effect of ERES in histograms of trace sample amplitudes

sample rate increases to 200 GS/s and the enhanced resolution bandwidth for 2-bit enhancement is now 5800 MHz.

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 3-bit enhancement filter) is shown in Figure 6. The -3 dB cut-off frequency at 80 MHz or 1.6% of the Nyquist frequency is marked.

The filtering must be performed on finite record lengths. There are discontinuities at the ends of the record because the output of the filter at these points is not defined. These data points are not displayed by the digital scope 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 106 samples(See Table 1). 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 .

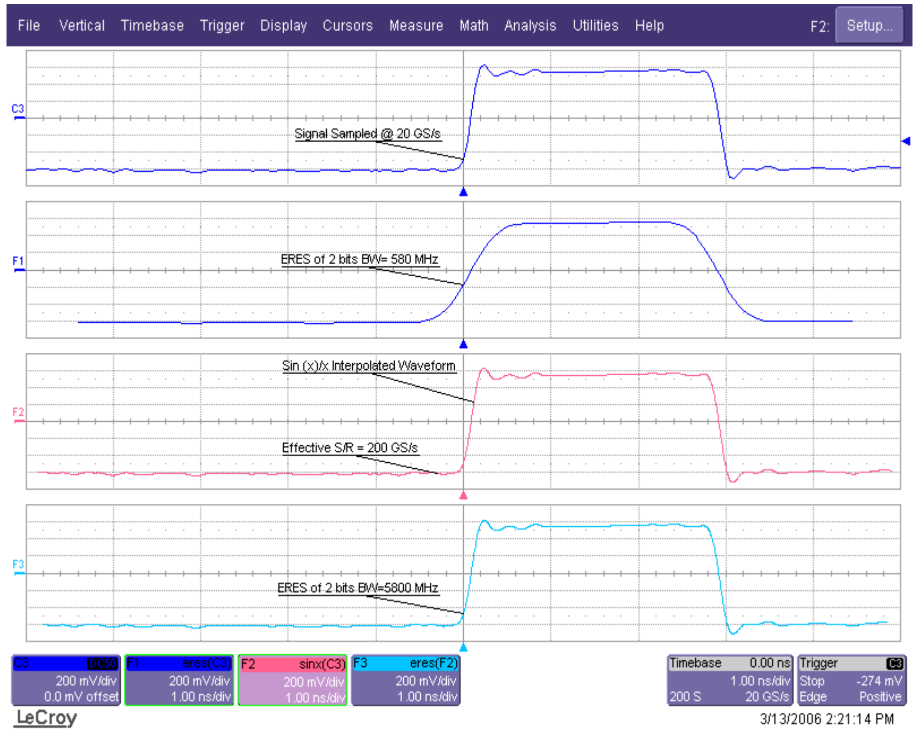

Figure 5, Using Interpolation to increase ERES bandwidth

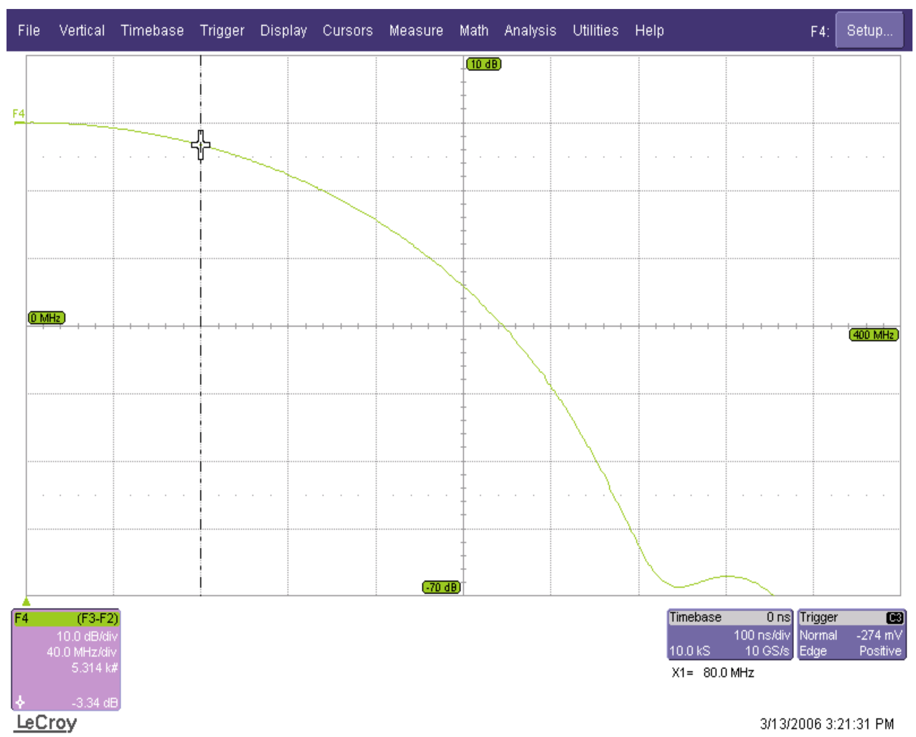

Figure 6, The frequency response of a 3 bit ERES filter

VI. CONCLUSION

The examples in sections III and IV 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.