WHITE PAPER

Using a Digital Oscilloscope for Signal Analysis Including A Practical Example of PLL Characterization

December 5, 2011

Dr. Michael Lauterbach
Wayne Swirnow

Summary

The oscilloscope has been a primary tool for electronic design engineers since the invention of that instrument, many years ago. The first decades of oscilloscopes were "analog" in nature.

Their fundamental technology was the front end amplifier, sweep generator and—most particularly— the phosphor which was used to coat the screen of a CRT. That phosphor served as a memory element that briefly held the shape of the signal on the CRT for the viewer. The value of the scope was in its ability to trigger many times per second and overlay the phosphorescent images on the screen. Information concerning the waveshape of the signal was transferred via viewing the signal (sometimes using a hood to eliminate light sources and at other times using a camera). The analysis was done in the brain of the human who viewed the information and extracted insights from the waveshape.

Back in the early 1980's the analog oscilloscope began to give way to a new type of instrument for capturing and measuring signals called the digital oscilloscope. The digital scope sometimes called the DSO (Digital Storage Oscilloscope) offered the user the ability to capture a waveform by converting the analog data to digital numbers, then displaying the data points on the CRT screen. Because all the data was now stored in memory there were several advantages to this technology with regard to viewing and analyzing the waveform. Engineers who were looking at single shot or low repetition rate events found that the DSO provided a way to capture, store and view a very brightly displayed waveform regardless of how slow the repetition rate was. Also, the DSO did not suffer from the waveform decay or blooming display issues which were problematic with analog storage oscilloscopes. The DSO's digital format gave the engineer the ability dive further into analysis of the waveform than earlier "viewing technologies." New tools to perform waveform measurements automatically like pulse parameters removed subjectivity and variability caused by the engineer "reading the screen" and increased measurement accuracy. There were feature sets like pre and post trigger display, multiple zoom capability, and waveform analysis such as averaging, basic math and FFT which the basic analog scope simply could not do. These tools made waveform analysis available to every engineer without the need to use standalone digitizer cards and write software for analyzing the data.

Some applications are still best suited to use of oscilloscopes that can quickly trigger and present a view of the signal—using a time constant that allows many signals to be overlaid on the screen simultaneously. The fastest analog storage scopes could trigger up to 1,000,000 times per second and draw each individual signal on the screen in real time, with a variable decay rate for the phosphorescence. But the market for such scopes has ended, primarily because design/test engineers can no longer extract sufficient information from a signal by viewing it. In many applications, "viewing tools" are becoming a dead end. They take the engineer a short distance in the right direction, but give no way to get where he really needs to go. As an example, an engineer might be tasked with verifying the performance of a 133 MHz clock used to transfer data to/from a micro-processor. One key question is whether the clock meets certain test standards for cycle-to-cycle jitter. Imagine an engineer trying to visually observe 133 million cycles of the waveform per second on the screen and trying to decide "by eyeball" if the clock meets the spec. Impossible. Actually, if there is a gross error in the clock it could be obvious the signal does NOT meet the test standard, but in the more normal case it isn't clear from observing a long, complex waveshape whether the circuit is working properly (or not).

So here is the conundrum. How does a digital oscilloscope, which can capture a large amount of highly accurate data—which contains the answer the user needs—display that data in a way that extracts the desired content concerning a complex signal structure. If the information is that the signal "passes" a certain test standard, the scope could simply display a text message. But if the circuit is not working properly, how can the myriad information available in the scope be displayed in a way that gives insight to the user? This brings us to the concept of "WaveShape Analysis" which is the ability of an oscilloscope to represent complex data using a format which is NOT the usual voltage versus time waveform. The new view of the data should allow the engineer to "discern by viewing" and "confirm by measuring" using the new view of the data—just like he did in the "old days" by viewing the raw signal shape and putting cursors on it to make a measurement. This type of analysis is based on being able to view waveforms in the time, frequency, statistical and parameter modulation domains. Only by using this broad range of views can the oscilloscope user gather a complete understanding of the circuit/device performance. WaveShape Analysis involves the ability to use powerful math functions to transform signals from one domain to the other. All of this processing has to be easily accessible, understandable, and lightning fast, otherwise it will not be used. Modern digital oscilloscope have finally matured to the point where they can enable engineers to quickly acquire, measure, analyze and present to the user in simple to view formats vast amounts of data. The scope can extract "information" from "raw data."

The classic oscilloscope measurement provides a view of voltage as a function of time. While this basic measurement tool has stood the test of time, today's complex signals require much greater WaveShape Analysis capabilities than simple cursor or parameter measurements in order to extract the useful information. Signals today are too complex to discern if they are correct simply by looking at the mass of data on the scope screen and it has become difficult to confirm their behavior by measuring using conventional parameters because many of these parameters cannot effectively or completely operate on long complex data sets.

Figure 1 shows a simple but powerful example of WaveShape Analysis. Often, the key characteristics of a signal are computed as pulse parameters such as frequency, duty cycle or the timing skew between two edges. Early digital scopes would simply display the latest measurement of the parameters. Several years ago oscilloscopes began displaying statistics including the high, low average and rms values of parameters. But the user gets little insight into the source of circuit faults from these numbers. They simply report if the signal meets or fails the specification. A histogram is a new view of the parameter data. It is a bar chart that shows how often each value of the parameter occurred. This new view (a re-presentation of the data) allows simple viewing and easy measurements that extract information from a complex set of raw data. The “histicon” (icon size view of a histogram) of the frequency parameter in Figure 1 shows the basic frequency is not stable—and the “bathub” shape is an immediate indication that the frequency variation is due to a sinusoidal modulation (for more information on interpreting histogram shapes, there are application notes at www.lecroy.com). The Gaussian shape of the duty cycle histogram means this parameter has a central value which is being affected by noise. The skew between channel 3 and channel 4 is a flat histogram. This indicates there is an equal chance of timing skew, over a certain range of times, between the two channels. The user gets immediate information from a straight-forward view of each distribution and furthermore can make simple measurements. The most advanced oscilloscopes have very fast data throughput that enables the display of up to eight simultaneous histicons of any parameters.

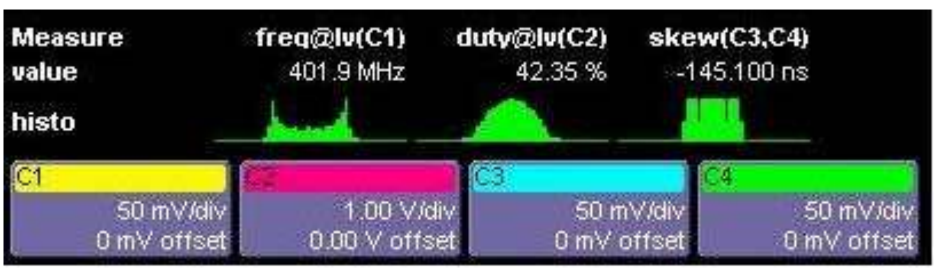

Figure 1: *Histicons (histogram icons) showing frequency modulation, noisy duty cycle and a flat distribution of timing skew.*

The ability to extract useful information from complex signals is further complicated by the length of the waveform record. A few years ago a DSO with real time or single shot sampling rate of 1GS/s was considered reasonably fast. If a 1 GS/s scope, capturing one sample per nanosecond, recorded a short simple waveform using 50 kpoints, the use of a 20 GS/s scope (20 data points per nanosecond) will require 20 times more memory, 1 Mpoint, to capture the same length signal. Of course the newer scopes with higher sampling rates capture a signal much more accurately and show more signal detail. But not only does the oscilloscope now need to have much longer record length just to cover the same time span but it also needs a high speed data path to handle this long array and be able to perform calculations on a large data file. Simply having long memory in an oscilloscope is not enough.

The challenge for T&M companies is to create a DSO with high sampling rate, long memory and very specialized hardware/software infrastructure which has been designed to acquire, move, process and extract useful information from long complex data records. This process must be fast, so the engineer is not kept waiting for the process to complete, therefore usability of the instrument stays high and the engineer stays productive. LeCroy has addressed this challenge through the invention of a new extremely fast, streaming architecture—named X-Stream technology. The new technology makes measurements 10–100 times faster than previously possible, to allow more accurate measurements, faster measurements and the ability to decrease deadtime when making measurements (thereby increasing the likelihood of being able to measure an intermittent fault). Let's look at a practical example of a moderately complex measurement—the characterization of performance of a phase locked loop.

In Figure 1 the scope user sees a statistical domain view of signal characteristics that gives insight into the waveform. A different type of WaveShape Analysis, in the time domain is shown in Figure 2.

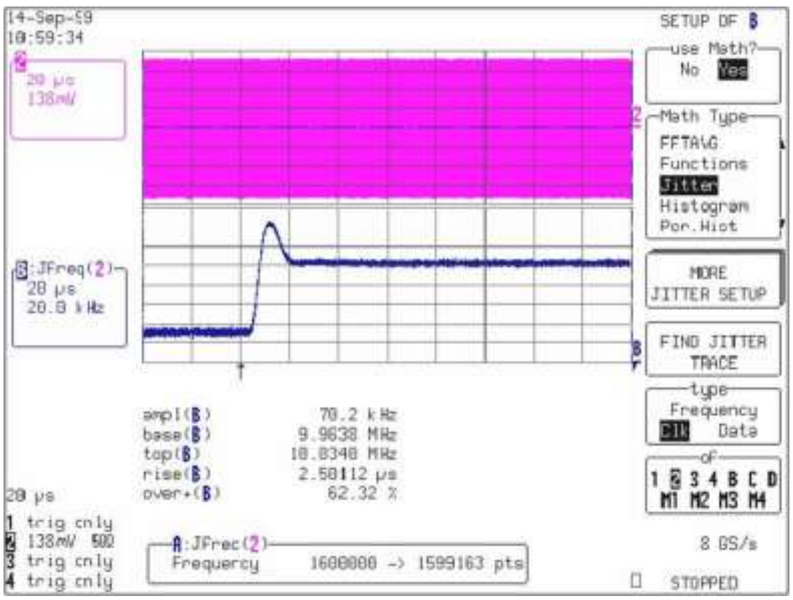

Figure 2: *The upper trace is the voltage vs. time of 100,000 cycles of a PLL. The lower trace is a track of the values of the parameter "frequency"*

The acquired waveform is 200 usec long and is sampled at 8 Gs/s— generating 1.6 million points of data. The signal in the upper half of the screen is 100,000 cycles of a phase locked loop. During the acquisition window, the PLL is "kicked" from a low frequency to a higher one. While the upper trace presents the usual voltage-vs-time oscilloscope display, the lower trace is a new presentation of the data. Every period of the PLL is measured and the lower trace tracks the PLL frequency (1/period for each of the 100,000 periods) versus time. The new view of the data shows the frequency begins at a stable, low value then there is a step which overshoots and settles to a new, higher frequency. We call this trace a "JitterTrack." It is easy to view the timing changes of a circuit with this type of trace and to make measurements such as the amplitude of the frequency shift (70.2 kHz), base/top frequencies (9.638/10.0340 MHz), rise time of the frequency step (2.50112 usec) and overshoot (62.32%).

The PLL response shown in Figure 2 is fairly simple. In general, the output phase of a PLL will respond to changes in the input phase–but only if those changes are within the bandwidth range the PLL. Input changes that occur at low frequencies are passed to the output but high frequency changes are too fast for the PLL to respond.

An engineer will often want to characterize the response curve of a PLL versus frequency. This is sometimes called the PLL loop bandwidth, or the jitter transfer function of the PLL. This brings us to a third type of view which can be used to gain insight into circuit behavior—the view in the spectral/ frequency domain.

We can measure the PLL loop bandwidth by applying an input signal that contains a step change in phase. This will allow us to measure the step response of the PLL. The PLL impulse response can obtained by differentiating the step response. The FFT of the impulse response is the frequency response of the PLL. Figure 3 shows the measurement of the frequency response of the input signal. The top trace (left side) is the input reference signal—a 66.67 MHz signal with a 2 radian step in the phase at the center of the trace. The JitterTrack (second trace on left) of TIE (Time Interval Error) actually shows the step. This is a very powerful WaveShape Analysis tool, "Parameter Modulation View" taking the large and complex data set with a phase shift in the top trace and re-presenting it in a simple to discern and measure processed trace. We have just extracted very useful information from the input signal.

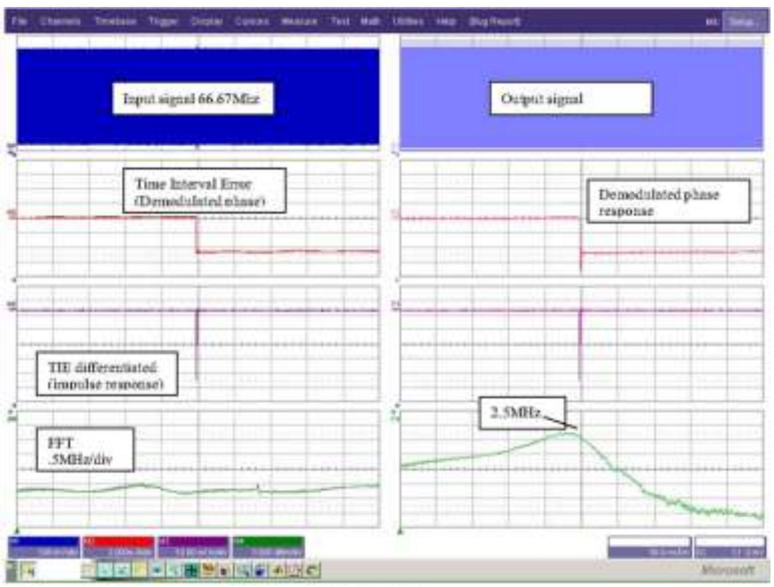

Figure 3: *Analysis of PLL response. The input of the PLL is analyzed by the four traces on the left side and the output of the PLL is characterized on the right side*

This is differentiated (third trace left) and then processed through an FFT and averaging to show the frequency response of the input in the bottom trace. This is the input excitation to the PLL and it is a spectrally flat input out to 5 MHz (to within about ± 1.5 dB).

In Figure 3 (right half) the output signal is analyzed. Going through the identical processing steps the result is the output response of the PLL. Note that it is a lowpass characteristic with an upper cutoff frequency of about 3 MHz. There is a broad peak at about 2.5 MHz, after which the response rolls off. The final step is to divide the output spectrum by the input spectrum as shown in Figure 4. As these are both logarithmically weighted, this is the normalized frequency response of the PLL.

This type of WaveShape Analysis can be extended to measure characteristics such as phase offset between the input and output waveforms. Measurements can be made for static clock frequencies or in the presence of spread spectrum modulation.

All of the WaveShape Analysis we have applied has been derived from the raw voltage vs time measurements of the input and output waveforms. But, as in many applications, the user cares less about the raw data and is more concerned with information concerning component/ circuit performance. These crucial performance characteristics can best be observed from waveform analysis in the time, frequency, statistical and parameter modulation domains. Current oscilloscopes, which include these highly integrated WaveShape Analysis tools more than pay for themselves when it comes to solving problems involving today's complex electronic circuits and devices.

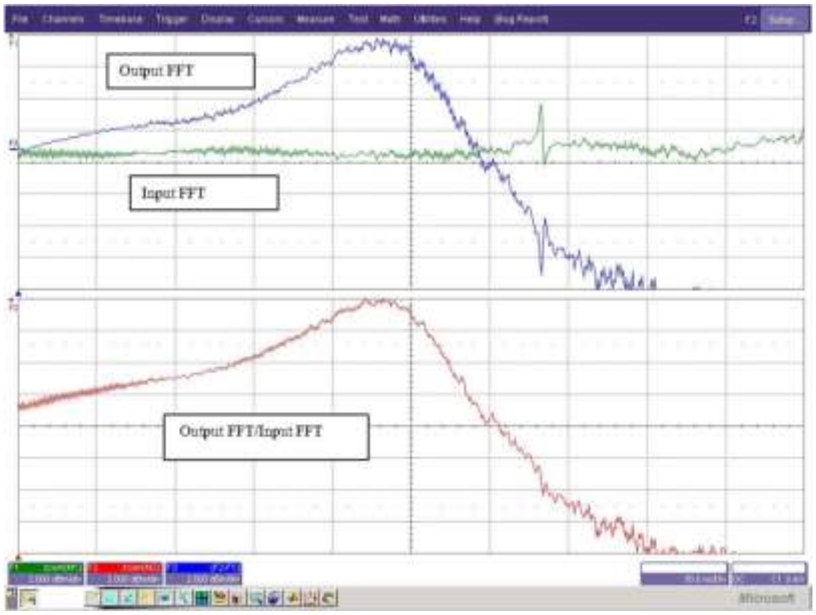

Figure 4: *Frequency response of a PLL computed by taking the difference (bottom grid) of the logarithmic output and input responses*

For more information on X-Stream technology, characterizing PLL's, and many other types of measurements, consult www.lecroy.com.