Resolution rises to become banner spec for oscilloscopes

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Since its invention in the 1980s, the digital oscilloscope represented a more modern approach to the visualization of waveforms compared with the analog instruments it replaced. Analog oscilloscopes displayed waveforms directly, but digital oscilloscopes use high-speed analog-to-digital converters (ADCs) to sample the analog input signal and convert the signal amplitude at each sampled point into digital values. The digital amplitude values are subsequently reconstructed to represent the input signal for display.

Why did oscilloscope makers abandon the simplicity of analog for the complexity of digital processing? The one-word answer is flexibility. Once the analog input signal is converted into digital form, it’s ripe for post-processing and analysis that analog instruments could never accomplish. Signal parameters including frequency, amplitude, period, rise/fall times, peak-to-peak voltages, phase differences, slew rates, and many others can be measured and displayed in real time. Not only that, but large amounts of digital memory enable modern oscilloscopes to save, manipulate, and recreate real-world waveforms.

The digital revolution in oscilloscopes brought new and different ways to evaluate the instruments. Heading the list of banner specifications is bandwidth, or the frequency range over which the oscilloscope makes reliably accurate measurements. An oscilloscope’s sampling rate tells you how many samples per second the ADC can acquire and store in memory. Faster sampling rates mean that the instrument can display, and base its measurements on, finer detail when acquiring high-speed signals. A third banner specification, record length, indicates how many waveform points an oscilloscope can acquire for a single waveform record.

Resolution: The new banner spec

Yet, one key specification has been consistently overlooked in the digital age: ADC resolution. The ADC’s resolution determines the fidelity with which it digitizes and reproduces signals on-screen. The oscilloscope parameter most improved by ADCs with greater resolution is the instrument’s vertical precision.

Early digital oscilloscopes were equipped with 6-bit ADCs. ADCs have resolution of 2^n bits, which, in the case of the 6-bit ADC translates into 2^6 bits, or 64 vertical quantization levels. Soon thereafter, oscilloscopes with 8-bit ADCs delivered 2^8 bits of resolution, which means 256 vertical quantization levels and a 4X improvement in vertical precision. But since then, all oscilloscopes have employed 8-bit ADCs. Yes, sampling rates have risen, which enables faster real-time signal acquisition. But the vertical resolution and precision have not fundamentally changed.

8-bit compromises

There are some techniques oscilloscope makers use to increase vertical resolution in 8-bit oscilloscopes, one being averaging of the values of each sampling point from multiple acquisitions. This averages out uncorrelated noise, yielding higher effective vertical precision. However, this approach only works with repetitive waveforms, rendering it semi-useful at best.

A more broadly applicable means of boosting vertical precision is known as “enhanced-resolution” or “high-resolution” mode. This technique involves filtering that uses adjacent acquisition samples to mathematically generate a display with higher vertical resolution. But this technique forces a bandwidth trade-off against the extra vertical resolution. The end result is a reduction of the -3dB bandwidth.

HD4096 technology

Eschewing these techniques, Teledyne LeCroy has redesigned the underlying hardware architecture in its oscilloscopes to achieve 12-bit resolution and 4096 levels of vertical quantization. In its HD4096 High Definition technology, Teledyne LeCroy combines high-sample-rate 12-bit ADCs with high signal-to-noise ratio amplifiers and low-noise system architecture to deliver 16 times more vertical resolution than any 8-bit oscilloscope.

HD4096 High Definition technology is available in a new family of oscilloscopes called High Definition Oscilloscopes or HDOs. The HDOs natively achieve high resolution, resulting in clean, sharp waveforms that present far greater signal detail. The increased vertical resolution not only provides a better-looking waveform display, but also much more accurate measurements. Because HD4096 technology achieves true 12-bit resolution through hardware improvements and not through averaging or filtering, users of the HDO oscilloscopes may capture and display signals at the instrument's full sampling rate (which, in the case of the HDOs, is up to 2.5 Gsamples/s at bandwidths up to 1 GHz).

HD4096 technology represents a new approach to oscilloscope design that required rethinking of the instruments' signal-acquisition system. The theoretical dynamic range of an 8-bit oscilloscope is approximately 48 dB (6 dB/bit); for a 12-bit oscilloscope, it's approximately 72 dB. However, in actual practice, the front-end amplifiers and signal paths in the best 8-bit oscilloscopes only reach a signal-to-noise (SNR) ratio in the range of -35 to -40 dB. Simply swapping out an 8-bit ADC and replacing it with a 12-bit device alone would not change that SNR. But the use of new, lower-noise technology in the front-end amplifiers and signal paths, HD4096 technology achieves a 15-dB improvement in SNR over 8-bit architectures to reach an SNR of -55 dB.

To achieve the lower noise in the HDO oscilloscopes, Teledyne LeCroy has designed a custom IC for the front end. But that isn't the only consideration to maximize signal fidelity. Particular care has been taken in power supply design to minimize that perennial source of noise. In addition, routing of critical signal paths within the instruments is done so that as little system noise as possible is coupled into them. Crosstalk is further reduced by using one ADC per channel rather than sharing one ADC chip across two channels.

Another area of improvement in the HDO oscilloscopes is DC gain accuracy. The HDOs include a DC reference circuit that is as stable over temperature variations and operating conditions as possible. This ensures the best possible DC measurement accuracy. The key in this regard was designing for low temperature drift, achieved through careful application of resistors with low temperature coefficients and by paying close attention to components in the DC amplifier chain. Not only do the HDOs provide low drift and high accuracy, but they also deliver a high offset range.

Thanks to the development of HD4096 technology, vertical display and measurement precision in digital oscilloscopes has taken a huge leap forward. It's also paved the way for resolution to take its rightful place in the pantheon of banner specifications for oscilloscopes in years to come.