Comparing USB Oscilloscopes to Benchtop Instruments

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Introduction

Standalone benchtop test equipment has typically been the mainstay for the engineering test lab. Often, test benches are crowded with cables and box-shaped equipment fitted with a display and knobs. The traditional oscilloscope initially granted real-time signal analysis in the time domain with the cathode-ray oscilloscope (CRO). Eventually, solid-state technology allowed for triggering and stable representations of waveforms for analysis. This quickly shifted to a fully digital microprocessor-based oscilloscope that leveraged analog-to-digital conversion to convert the measured analog signal into digital data for the later digital signal processing (DSP) blocks and memory to capture and analyze the waveforms.

With the proliferation of standardized high-speed digital interfaces such as PCIe, USB, SerDes, and ethernet, the processing and viewing of the high-speed signals on circuit boards could now be accomplished with custom test equipment designed to communicate via these standard interfaces with off-the-shelf desktop computers and laptops. This paradigm shift in test equipment has lowered the barriers for the design and development of electronic devices. Now, USB-based test equipment often functions on par (or better) than their standalone benchtop counterparts. Some have the added capability of including multiple instruments over a single platform - a feature that is almost always a costly endeavor for most benchtop oscilloscopes with add-ons. This article examines and compares the USB oscilloscope to the benchtop oscilloscope by assessing the practical aspects of each with parameters such as cost, size, and base performance.

What is a Benchtop Oscilloscope?

The benchtop oscilloscope takes a signal from a high-speed circuit and processes it using front-end signal conditioning or gain control circuitry with variable gain amplifiers, attenuators, buffers, and trigger filters. The oscilloscope then digitizes it with ADCs, processes the data with DSP blocks, stores it in memory, and displays it on its native screen (***Figure 1***).

A proprietary user interface (UI) allows the tester to navigate between different modes and signal adjustments seamlessly. These oscilloscopes can be sampling oscilloscopes optimized for resolution and dynamic range to analyze repetitive signals or real-time scopes with optimized sampling rates and bandwidth for real-time capture of signals. Some benchtop oscilloscopes use ASICs to accomplish the triggering of specific events. These oscilloscopes can range dramatically in cost and capabilities with prices that exceed the half-million-dollar mark. The high-end models are intended to offer complex analysis capabilities, for instance, in signal integrity applications with high-speed circuits with eye diagrams, histograms, and jitter analysis.

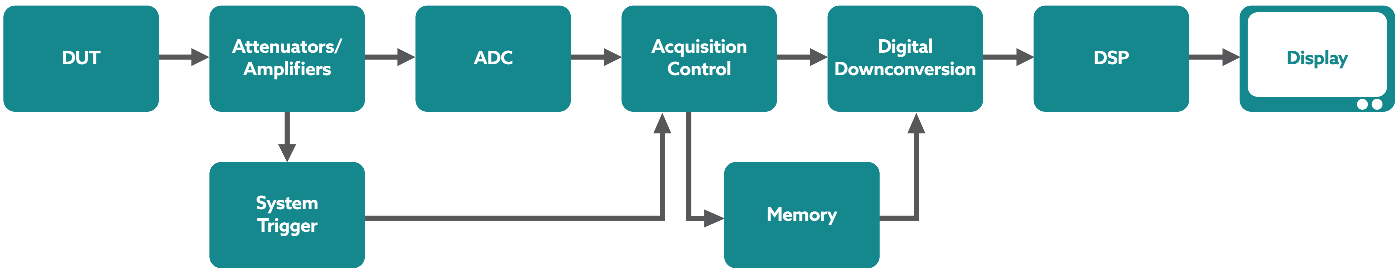

Figure 1: Block diagram of digital storage oscilloscope.

The Test Equipment Market

The electronic test and measurement market is more than an eleven billion dollar market. Like many industries, a handful of vendors remained the major contenders in the test equipment market, keeping in-house expertise, IP, and manufacturing to maintain a level of exclusivity in the market. Alongside this development of standalone test equipment came the PXI-based test instrumentation that found a niche in automated test equipment (ATE) applications where communication between slots and response time were key. However, the burgeoning USB-based test equipment market directly competes with benchtop and portable test equipment. Much of the processing and software capabilities can be handled by a decent programmable hardware fabric. The options that are missing are the knobs, display, and somewhat intuitive UI. This may well be the only option for the inexorable engineer who cannot compromise on tactile control. In most cases, the financial burden of these components often leaves companies hard-pressed to find an alternative.

What is a Usb Oscilloscope and How Can it be Built?

Instead of reassembling a waveform onto a native front-panel display that can be adjusted via knobs and buttons, the USB oscilloscope leverages the display of the external PC. It uses the high-speed USB interface to control and communicate with the test instrument. The inner workings of these oscilloscopes vary. Some USB oscilloscopes will leverage embedded processors with built-in ADCs to achieve the desired system performance, while others might be built around a high-performance FPGA. There are some major fundamental differences between these two technologies.

A look at the basic difference between an FPGA and an embedded processor

Embedded CPUs can accomplish data parallelism, while FPGAs can do both data and pipeline parallelism. GPU and CPU architectures follow the single-instruction, multiple-data execution model (SIMD) or single-instruction, multiple-data execution threads (SIMT) execution models, where an instruction fetch cannot occur at the same time as a data operation (e.g., decode, execute). Because of this, tasks in the instruction set are performed sequentially. Identical tasks are executed with each processing element (PE) per clock cycle; data must then be partitioned and distributed to the PEs in parallel. On the other hand, FPGAs can perform all of these different tasks in the fetch-execute cycle concurrently. Instead of performing identical tasks within the same clock cycle, an FPGA (or SoC/ASIC) can take data with different timestamps in parallel and process it accordingly through an instruction pipeline.

How this difference applies to implementing a USB oscilloscope

Standard embedded processors such as an ARM Cortex or x86 are often the go-to architecture for employing the data processing and functions necessary in oscilloscopes. On the manufacturing side, using microcontrollers and general-purpose CPUs keeps the cost of the instrument down where the cores are designed to process as much data as possible from the ADCs and use glue logic to interface with peripheral devices. However, to achieve a vertical resolution and sampling rate to adequately discern the slight changes in modern high-speed signals, 8-bit and beyond ADCs that operate at high sampling rates are required.

Today's cutting-edge ADCs operate at up to a 32-bit resolution with a sampling rate of up to 64 giga-samples per second (GSPS). Most MCUs are not equipped to process the multi-lane serial data links found at the output of ADCs and DACs (e.g., JESD204B, JESD204C, serial LVDS, etc.) The bottlenecks of general-purpose embedded processors make it difficult to capture and process the sheer amount of data coming in from multiple channels from the ADC. Most CPUs would likely dedicate most, if not all, their resources to capture the incoming data stream. Oscilloscopes require the near-real-time viewing of waveforms. Even the skew and delays that occur due to the internal routing and the supply voltage and temperature variations of the FPGA cannot be ignored. However, FPGAs have the processing capabilities and pipeline parallelism to take data from the high-speed ADC and process it while also running schemes and techniques (e.g., PLL, DLL, dynamic clock edge selection, etc.) in the background to ensure the data is being extracted and processed accurately.

The inherent flexibility of an FPGA-based USB oscilloscope allows for introducing multiple instruments to support more complex test setups. Digilent oscilloscopes build upon the basic functional blocks of the oscilloscope and the agility of powerful reprogrammable platforms (e.g., FPGA, ASIC) by doubling as logic analyzers, signal generators, programmable power supplies, voltmeters, and spectrum analyzers.

A High-Level Comparison Between a Benchtop and USB Oscilloscope

As previously mentioned, the major differentiating factor between benchtop and USB oscilloscopes is cost. Size is another major factor. USB-powered oscilloscopes can be carried and plugged into practically any computer via the USB interface. This simple play-and-play capability opens doors for portable test and analysis. A USB will require the use of an external PC and display. Benchtop oscilloscopes are self-contained without the need for additional devices. This can be a double-edged sword, as it is very difficult to add critical features for further analysis, such as additional instruments on top of the base model.

Newer iterations of these USB oscilloscopes (i.e., ADP3450) can run Linux in a stand-alone mode where tests can be run, stored, and driven on a display directly on the device. This sidesteps the potential bottleneck of USB data transfer and enables the user to develop scripts with a language-of-choice (e.g., Python) for custom, automated tests in manufacturing environments. This way, engineers do not have to build custom boards for different products - they can simply change the code. This feature can also be accomplished with the PC; it is just faster on the equipment itself.

Transferring data from a benchtop oscilloscope is not straightforward. Many engineers will often resort to clunky methods with a thumb drive or use the native RS-232 or GPIB interface to connect to a desktop computer (laptops likely cannot interface with these). For a USB-based oscilloscope, this is fairly straightforward. Data can be transferred readily to a portable device via USB for data storage for further analysis, sharing, and presentation. A USB can easily use an external keyboard and mouse for simpler control and user operation as far as tactile feedback is concerned. The USB oscilloscope can be more portable than benchtop equipment as field service engineers are likely already carrying a laptop.

Specification Comparison Between a Benchtop and USB Oscilloscope

Digilent's basic Analog Discovery 2 and advanced Analog Discovery Pro (ADP) modules offer comparable performance to popular benchtop oscilloscope alternatives. For example, the oscilloscopes are affordable ($400 for the Analog Discovery 2 and $1,295 for the ADP3450). Base models are already fitted with extra instruments without additional costs. The Analog Discovery 2 comes with a Waveform Generator, Digital Logic Analyzer, Pattern Generator, Static I/O, Spectrum Analyzer, Datalogger, Power Supplies, and Protocol Analyzer. The ADP3450 has a total of thirteen instruments with an additional Network Analyzer and Impedance Analyzer, all through Digilent's WaveForms free virtual instrument suite.

Much of the benefits of leveraging USB-based oscilloscopes are from avoiding the unforeseen costs associated with upgrades to benchtop equipment. The test and measurement market has found a unique niche in using established standards (e.g., PCIe, USB, ethernet, etc.) that allow for interoperability with standard equipment. This accessibility drives down cost significantly, shifting the market dynamics from the conventional highly proprietary technology and software development for standalone equipment to more affordable and customizable oscilloscopes built upon standard interfaces where test protocols can be customized over commonly used programming languages.

The ADP are 2- and 4-channels for the ADP3250 and ADP3450, respectively. The four channels allow the ADP3450 to have a built-in curve tracer. **Table 1** shows a comparison of the parameters between the ADP modules and a base model for a benchtop oscilloscope. As illustrated, the ADP exceeds the base model in cost, size, analog, and digital channel count and is comparable in basic performance specifications such as bandwidth. The benchtop oscilloscope exceeds the sample rate, while the ADP oscilloscopes greatly exceed the benchtop oscilloscope resolution. This allows users to capture minute differences in large amplitude signals for high dynamic range measurements such as in power integrity (PI), radar, imaging systems, and high voltage systems testing. The data buffer size of 128 mega samples in record mode allows the user to measure longer signals and, with the large sampling rate, without missing critical waveform events.

	ADP3250	ADP3450	Competitive benchtop oscilloscope
Cost	$895	$1,295	$1,543.00
Physical size	9.2" x 7.6" x 1.5"		15" x 8" x 5.6"
Analog channels	2	4	2
Digital channels	16		8 (add-on)
Bandwidth	55 MHz		50 MHz
Max Sampling Rate	0.5 GS/s per channel		1 GS/s per channel
Resolution	14-bit (16-bit with oversampling)		8-bit (12-bit with averaging)
Data buffer size	128 MS total in record mode (32,768 samples per channel in Repeated/Shift/Screen Modes)		-
Max memory depth	-		1 million points
Accuracy	±10 mV ± 0.5% (scale ≤ 200 mV/div, VinCM = 0 V) ±100 mV ± 0.5% (scale > 200 mV/div, VinCM = 0 V)		± 3% full scale (≥ 10 mV/div) ± 4% full scale (< 10 mV/div)
Trigger modes	Trigger modes: None, auto, manual (forced trigger), single Analog trigger: Edge, pulse, transition, condition, level, hysteresis, hold-off Digital trigger: Edge, level, pattern, glitch, protocol		Normal, auto, single, force
Math Functions	Addition "+", Subtraction "-", Multiplication "*", Division "/", Remainder "%" Logarithm, power, minimum, maximum, square root, sine, cos, tan, arccos, arctan, arctan2, absolute value, round, floor, ceil		Add, subtract, multiply, divide, FFT, Ax + B, Square, Absolute, Common Log, Natural Log, Exponential, Base 10 Exponential, LP Filter, HP Filter, Magnify, Measurement Trend, Chart Logic Bus (Timing or State)
Connectivity	USB 2.0 Hi-Speed, ethernet		Standard USB 2.0, LAN (GPIB option)
Instruments	Oscilloscope Waveform Generator Power Supplies Voltmeter Data Logger Logic Analyzer Pattern Generator Static I/O Spectrum Analyzer Network Analyzer Impedance Analyzer Protocol Analyzer *all instruments included		Voltmeter (included) Hardware counter (included) Function generator (add-on) Serial protocol analyzer (add-on)

***Table 1:** Comparing USB oscilloscope with a benchtop oscilloscope*

High-Performance Digilent USB Oscilloscopes for Test and Measurement

The industry's need for test and measurements with oscilloscopes is growing in importance, with high-speed digital interfaces with stringent power delivery requirements calling for rigorous time-domain analysis. More often than not, test labs turn to benchtop oscilloscopes to perform all the necessary testing in-house. These benchtop oscilloscopes, however, do not fit all testing niches. This is particularly true when cost is a serious consideration. Even though many oscilloscope vendors market an accessible entry price for their benchtop oscilloscopes, the cost exponentially increases with the myriad of "add-ons" and upgrades that are almost inevitable. Digilent's USB oscilloscopes offer superior performance than many benchtop oscilloscopes available today and do not try to outmaneuver the customer with unpredictable costs. The oscilloscopes come with free, user-friendly software to readily access the multiple instruments enabled through the oscilloscope's hardware.

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