Keysight Technologies
Understanding the Differences Between Oscilloscopes and Digitizers for Wideband Signal Acquisitions

White Paper
Most of us remember the first time we used an oscilloscope. With one look at the large display, we could tell immediately what was happening to our waveforms. From the earliest days, oscilloscopes have been a primary tool for quick visualization of time variant waveforms, and over the years, they’ve been optimized for benchtop usability. Wideband digitizers are related to modern oscilloscopes since both utilize analog to digital converters (ADC) for waveform acquisition. Although there are many similarities between oscilloscopes and wideband digitizers, it’s important to understand they have different targeted applications and their architectures and features have been optimized for those applications.

Some test equipment suppliers will promote a scope as a wideband digitizer, or vice versa, and this may cause confusion when trying to select the right product for your application. The differences between digitizers and scopes may seem subtle, but the wrong selection can cause headaches down the line. Knowing the architecture, applications and trade-offs will help you choose the right solution for your application. Keysight Technologies, Inc. offers extensive experience and a broad selection of oscilloscopes and wideband digitizers, one of which will be the ideal fit for your measurement challenge.
Overview

Scope and digitizer history and evolving features

For several decades, oscilloscopes have been and they continue to be the best tool to visualize time variant waveforms on a large display. Usability features such as triggering, signal probing and configurable range settings quickly became popular. As ADC technologies evolved, they were incorporated into Digital Sampling Oscilloscopes (DSO). For waveform visualization, 8-bit ADC resolution was found to be sufficient, while extending ADC update rates and bandwidths into the hundreds of GHz has become extremely important as evolving commercial and military technologies demanded signal visualization over wider bandwidths. High speed digital test, emerging serial protocols, advanced radar systems, and communications all need extremely wide bandwidths. Hardware embedded reconstruction filters and signal correction processing was incorporated to improve visualization and accuracy.

Though oscilloscopes are most commonly offered in LXI formats for benchtop or rack-mount applications, modular PXIe and AXIe versions are beginning to appear on the market. Scope technology, migrated to modular formats, retain many typical scope features, packaged in a smaller footprint, which utilize fast PCIe interfaces to maintain high display refresh rates.

In contrast to scopes, wideband digitizers target applications where the high resolution and dynamic range are required, and in many cases, the results are displayed in the frequency domain. Digitizers normally return ADC data to controllers for software processing via fast multi-lane PCIe buses. New generations of high-speed and high-resolution ADC technologies provide excellent resolution and dynamic range into the tens of GHz, as well as direct acquisition of high-resolution wideband waveforms. Much of the analysis is done in application software and displayed at the controller, so there's no need for embedded displays, making digitizers good choice for ATE systems and high density multi-channel implementations.

This historical backdrop helps us understand the sometimes subtle differences seen in modern day scopes and digitizers and their targeted applications. The following sections discuss key attributes for wideband waveform acquisitions with a short description of implementation differences between scopes and wideband digitizers. These are not hard-fast rules and there are many overlaps. However, a thorough understanding of these attributes will help with selection of your next waveform acquisition solution.
ADC resolution and dynamic range

Scopes and digitizers both rely on an analog to digital converter (ADC) for waveform acquisition, and the ADC resolution is a primary factor for dynamic range performance. The ADC samples input voltages and generates a binary representation of the voltage level, and in the process, creates quantization noise. In an ideal ADC, the quantization noise is represented by the equation:

\[
\text{SQNR}_{\text{dB}} = 6.02 \times B + 1.761 \quad (\text{dB})^1
\]

\( B = \# \text{quantization bits} \quad [1] \)

SQNR is the signal to quantization noise ratio\(^1\). Quantization noise occurs when sampled voltages do not lie precisely at the center of each quantization bin. This creates a small error which over large acquisition durations appears as broadband noise. Equation 1 shows each bit (B) of the ADC improves the dynamic range by 6.02 dB, so naturally a higher ADC resolution improves the overall dynamic range. However, there are additional sources of noise to consider: ADC differential and integral nonlinearities, thermal and shot noise, input signal distortion as well as sample aperture jitter and ADC sample clock noise all act to degrade SQNR performance.

A better figure of merit for digitizer and scope noise performance is the effective number of bits (ENOB) as defined by IEEE 1057. For a waveform digitizing system, if quantization noise and all other noise sources are considered you can re-write equation 1 as:

\[
\text{ENOB} = \left( \frac{\text{SNR}_{\text{dB}} - 1.76}{6.02} \right)
\]

Equation 2 provides a relatively simple method to measure ENOB by digitizing a high quality sinusoidal signal and calculating the overall signal to noise ratio. It’s a good figure of merit since it accurately reflects broadband noise as it will appear in either the frequency or time domain for a single shot measurement.

Oscilloscopes often use 8-bit ADC’s for acquisitions over extremely large bandwidths. For example, current ADC technologies support sampling rates up to 160 GS/sec with 8-bit resolution. However, some oscilloscopes also may implement high resolution modes of operation to improve the ADC resolution by using oversampling and digital averaging. With an N-tap boxcar-averaging filter, the effective resolution may be improved by 1 bit for every 2 taps implemented. The boxcar filter is a moving average of adjacent waveform points, and can increase the effective resolution at the expense of reducing the effective sample rate and resulting bandwidth.

\[
\text{Resolution enhancement achieved (bits)} = \log_2(N) \quad N = \# \text{of taps} \quad [3]
\]

\[
\text{Resulting Bandwidth after boxcar averaging} = 0.4428 \frac{F_s}{N} \quad [4]
\]

---

1. Equation 1 is valid for full scale signals and noise components evenly distributed and measured across 1st Nyquist Zone.
For example, the Keysight M9243A is a PXI version of Keysight InfiniiVision X-Series oscilloscopes with an ADC sample rate of 2.5 GS/sec and an 8-bit ADC. It also supports a high-resolution operating mode to improve resolution through the use of an on-board 16 tap FIR filter, up to 12-bits with a corresponding reduction of bandwidth by factor of 16 (from 1 GHz to approximately 69 MHz).

The Keysight M9703B is an AXIe high-resolution wideband digitizer. It uses a 12-bit ADC that supports either 8 channels at 1.6 GS/sec or 4 channels at 3.2 GS/sec (using channel interleaving). Data returned from the ADC has an ENOB reflective of the intrinsic ADC 12-bit resolution, combined with channel and ADC clock noise characteristics.

Figure 5 shows relative ENOB performance of Keysight’s M9703B digitizer as compared to the Keysight 9000 Infiniium series of oscilloscopes. The ENOB over frequency represents the performance of the whole system, not just the ADC. It’s common for scopes to provide extremely wide bandwidth while digitizers provide higher ENOB’s over lower bandwidths. The latest Keysight series of oscilloscopes support real time bandwidths as high as 63 GHz.

Figure 5. Typical ENOB of the Keysight M9703B digitizer vs. a Keysight Infiniium 9000 series oscilloscope. Digitizers commonly offer highest resolution over lower bandwidths while oscilloscopes support widest bandwidths.
Input bandwidth and ADC sample rate

ADCs sample voltage at an instant in time and convert it to a binary representation. Sampling theory states that if a series of ADC samples occur at equally spaced intervals, an input waveform can be sampled and then fully reconstructed for frequencies up to ½ the ADC sampling frequency. This is the basis for the Nyquist sampling theorem, with which most of us are familiar. For a sampling system, the Nyquist frequency $F_N$ is equal to ½ the sample frequency $f_s$. It is important to remember that signal energy above the Nyquist frequency will mix with the ADC sample rate and products will fold back on top of the signals of interest at baseband, preventing an accurate acquisition (aliasing). This must be avoided. Both oscilloscopes and digitizers include some sort of input bandwidth limiting.

Nyquist Sampling Theorem

For a limited bandwidth signal with a maximum frequency $F_{max}$, the equally-spaced sampling frequency $f_s$ must be greater than twice the maximum frequency $F_{max}$ in order to have the signal be uniquely reconstructed without aliasing.

Input filter responses provide either Gaussian and maximally-flat responses, as shown in Figure 6. To achieve sufficient input signal attenuation at the Nyquist frequency, the filter -3 dB bandwidth ($F_{BW}$) is selected based on the filter style. For Gaussian input filters the ADC sample frequency $F_s$ is typically 4 times $F_{BW}$ ($F_{BW} = F_s/4$) and for maximally flat filters $F_s$ is chosen at least 2.5 to 3 times $F_{BW}$ ($F_{BW} = F_s/2.5$ to $F_s/3$). This provides sufficient attenuation above the Nyquist frequency to prevent significant alias products from appearing when running at maximum ADC rates. However, most digitizers and oscilloscopes support a lower ADC sample rate by using decimation methods (discarding sample points to achieve a lower effective sample rate), which results in a lower Nyquist frequency $F_{N\text{eff}}$. To prevent aliasing products, the user must ensure there is no signal energy above the effective Nyquist frequency. This is true for both digitizers and oscilloscopes.
The style of filter and its input bandwidth also impact signal measurements at higher frequencies and should be considered carefully when selecting a scope or digitizer. In general, for low bandwidth oscilloscopes (less than 1 or 2 GHz) Gaussian input filter input stages are commonly used, while higher bandwidth scopes commonly use a maximally flat response. Higher bandwidth scopes are usually pushing ADC capabilities as high as possible, and a maximally flat response optimizes usable bandwidth, while still meeting the Nyquist sampling criteria. A simple method to determine a scope’s filter response is to check the data sheet and note the $F_{BW}$ bandwidth and the rise-time (10%–90%). Calculate the $F_{BW} \times RT$ product and compare:

\[
BW \times RT = 0.35 \quad \text{Gaussian response} \quad \quad [5]
\]
\[
BW \times RT > 0.35 \quad \text{Maximally flat response} \quad \quad [6]
\]

Selecting a scope or digitizer with the correct input filter response and bandwidth depends on your application needs. A couple of general rules for selection of bandwidth and response types is shown in Table 1.

### Table 1. Guidelines for selecting scope or digitizer input bandwidth and filter type.

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Scope/Digitizer 3 dB Bandwidth Selection Guide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog signal</td>
<td>Select bandwidth $F_{BW} = 3 \times$ highest frequency to be measured</td>
</tr>
<tr>
<td>Digital signal</td>
<td>Select bandwidth $F_{BW} = 5 \times$ highest clock rate to be measured</td>
</tr>
</tbody>
</table>

**Rise time**

1. Determine maximum signal frequency ($F_{max}$)
   - $0.5 / \text{signal rise time (10\%-90\%)}$ or $0.4 / \text{signal rise time (20\%-80\%)}$

2. Determine oscilloscope response type
   - Gaussian
   - Maximally-flat

3. Determine bandwidth depending on required accuracy
   - 20%: $1.0 \times F_{max}$
   - 10%: $1.3 \times F_{max}$
   - 3%: $1.9 \times F_{max}$

---

1. From Keysight Application note 5988-8008EN: Understanding Oscilloscope Frequency Response and Its Effect on Rise-Time Accuracy
Digitizers are commonly used in ATE applications where the system designer may want more flexibility in input filter selection. In some cases, the system designer may even need to extend the signal input bandwidth above the Nyquist frequency to capture signals at frequencies above the 1st Nyquist zone. This is a mode called undersampling. For example, the M9203A and M9703B wideband digitizers, under certain conditions, provide an input filter $F_{BW}$ bandwidth of 2.0 GHz with an ADC sample rate $F_s = 1.6$ GS/sec. Although this seems to contradict our previous discussion on the need for alias filtering, you can see with careful input filter design it’s possible to acquire waveforms at frequencies in the 2nd or 3rd Nyquist zones as shown Figure 7.

Note the sampling frequency $F_s$, which appears in this graphic as a spectral line at 1 GHz, will mix with signals in the 2nd or 3rd Nyquist zone, creating aliasing products that appear at baseband.

The same aliasing effect that we avoided earlier (and forced us to use a low frequency anti-aliasing filter) is now being used to our benefit. In order to take advantage of undersampling, all signal energy in the unwanted Nyquist zones must be eliminated, and only the signals in the Nyquist zone of interest should appear at the ADC. To support this mode of operation the system designer can include appropriate bandpass filters in the system. Since this method requires careful selection of band limiting filters it is usually up to the system designer to implement bandwidth filter circuitry.

![Figure 7. Undersampling for frequency translation from upper Nyquist zone.](image)

For applications where 2nd or 3rd Nyquist zone downconversions are desired, select a digitizer which provides appropriate input filter bandwidths and combines with external bandwidth limiting for the desired Nyquist zone. The M9203A and M9703B wideband digitizers support 2.0 GHz bandwidth with ADC sample clock rate of 1.6 GS/sec, allowing direct downconversion using undersampling.
Real-time waveform reconstruction

Oscilloscopes provide waveform reconstruction filters for improved waveform visualization and accuracy. From our previous discussion we know the ADC sample rate may be as little as 2.5 times higher than the scope bandwidth. This means at input signal frequencies approaching the scope’s upper bandwidth may be represented by as few as 2.5 samples. If the ADC waveform data is displayed with no waveform reconstruction, the observer would see a confusing cluster of points on the display as shown in Figure 8a. In this case, a 1 GHz sinewave is sampled with an ADC running at 2.5 GS/sec. With a single shot measurement, you can see it’s difficult to visualize the original signal. In Figure 8b you can see the dramatic effect of the waveform reconstruction. This feature works equally well on fast rise-time edges as shown in Figures 8c and 8d.

![Figure 8. Sampled waveform data plotted with and without waveform reconstruction.](image)

All DSO scopes include some sort of waveform reconstruction since time domain waveform visualization is so important for users. Waveform reconstruction is enabled when timebase settings result in a limited number of points available for display. For example, the Keysight M924xA PXiE oscilloscopes automatically enable waveform reconstruction for settings resulting in less than 1000 display points. The waveform reconstruction is accomplished by first passing the waveform data through a sinx/x filter to provide smoothing and then upsampling the results to a higher date rate resulting in more data points to be plotted. The best oscilloscopes provide hardware accelerated reconstruction to support extremely fast display refresh rates.

Digitizers typically do not provide on-board waveform reconstruction. For most digitizer applications, the waveform analysis is done using PC based application software providing frequency domain visualization and/or time domain waveform reconstruction in software if it is needed.
Real-time DSP corrections to minimize phase and magnitude errors

Input anti-aliasing filters introduce phase and magnitude roll-off near the $F_{BW}$ frequency. Sharp anti-aliasing filters, such as maximally-flat types, require a high-order filter which creates phase roll-off near the 3 dB frequency, which in turn can induce ringing in displayed waveforms with extremely fast rise times. Once the signal has been digitized, an on-board multi-tap FIR filter can be used to correct for phase and magnitude errors introduced by the input anti-aliasing filter. On-board DSP based filters are very fast and provide real-time allowing processing of sampled data real-time\(^1\). It’s very common to provide DSP based corrections in oscilloscopes.

Wideband digitizers also may also support corrections using on-board hardware based DSP, though this depends on the digitizer and target application. For example, in some ATE applications, the system designer will implement a system level calibration and correction process using application software. In those cases, the input characteristics are unique to the whole system - including front-end switching and signal conditioning. It would not be practical or necessary to provide digitizer level hardware embedded FIR filter for corrections.

Figure 9. Oscilloscopes provide real-time corrections for improved magnitude and phase response.

---

\(^1\) Keysight AN 5989-1145EN Advantages and Disadvantages of Using DSP Filtering on Oscilloscope Waveforms.
Another hardware based feature often available on digitizers is real-time digital downconversion (DDC). Digital downconversion works directly on ADC data providing frequency translation and decimation sometimes called tune and zoom. In DSP hardware the ADC data is first translated to 0 Hz using a quadrature mixer (tune) then filtered and decimated (zoom). The block diagram shown in Figure 10 illustrates this basic concept. Since this feature is implemented in hardware it can operate on acquired data real-time. Note that the DDC produces complex IQ data allowing center frequency translation down to 0 Hz and then filtering and data decimation to remove unwanted frequency components and reduce data size for the required bandwidth.

![Image of block diagram](image)

Figure 10. Infinite display persistence with high update rates allow capturing unexpected events and glitches.

DDC is extremely valuable when analyzing a small slice of spectrum within a wideband acquisition. Although Nyquist criteria requires the initial sampling to occur at an ADC sample frequency \( f_s > 2 f_{\text{MAX}} \) for the wideband acquisition, once the waveform is digitized the DDC provides sample rate decimation appropriate for smaller zoomed band of frequency. For example, if you’re only interested in 20 MHz centered at 600 MHz, the initial acquisition occurs at a rate to satisfy Nyquist requirements (approximately 1.6 GHz). However, once the waveform is digitized the DDC tune and zoom will translate the 20 MHz band centered at 600 MHz to 0 Hz and then decimate the effective rate to 20 MHz complex data (for both I and Q results).

DDC is a powerful feature with multiple advantages. First, it reduces both on-board memory and data transfer requirements. Second, the digital filtering and decimation reduces the wideband integrated noise and improves the overall SNR. Third, the resulting data record is in complex form usable directly by high end vector signal analyzer software applications. Finally, digitally translating the frequency band of interest to 0 Hz followed by digital filtering and decimating is inherently alias protected. As long as the initial ADC acquisition meets the Nyquist criteria there should be no alias products in the data record. As opposed to decimating the initial ADC sample data, the mathematically-based DDC allows bandwidth and data reduction without concern of aliasing products.

1. Keysight AN 5991-2543EN M9703A AXIe High-Speed Digitizer with Real-Time Digital Downconversion Capability
Waveform acquisition memory considerations

Waveform memory is important for acquisitions used in both time and frequency analysis. For example, consider the situation where an unknown high frequency glitch occurs during a slow power ramp-up condition. Another situation might be a challenging frequency domain measurement requiring an FFT with 10 Hz bin size which requires at least 100 mS acquisition duration. In both cases, the sample rate will need to be high to capture the high frequency events while the acquisition duration needs to be long and this can consume a lot of memory. Memory management may become an issue. For a single ADC acquisition the memory requirements are simple to determine: the acquisition duration multiplied by the acquisition rate will determine the required memory size. Available memory size depends on the product. Mid-grade scopes may have as little as 5 Ms/Ch of memory and most digitizers and some high-end scopes have up to 1 GS/ch to 4 GS/ch of memory available. Both scopes and digitizers provide various methods and features which will help reduce the on-board required memory.

Oscilloscopes commonly support infinite persistence with high waveform refresh rates. Continuous waveform acquisitions accumulate in the display memory (not waveform memory) and high waveform refresh rates reduce the chance glitch events will be missed. Once a glitch is displayed and understood the user can adjust the oscilloscope’s enhanced triggering to provide a selective acquisition for only the events of interest. This approach can limit the overall required memory depth.

![Figure 11. Infinite display persistence with high update rates allow capture of unexpected events and glitches.](image)
Both oscilloscopes and digitizers commonly support multi-segment acquisitions. The instrument can be configured for a specified number of acquisitions of a defined duration and the triggering condition can also be setup. Once the scope or digitizer is armed, subsequent triggers will initiate acquisition for one segment at a time until all of the segments are acquired. Significant memory reductions are realized in cases of multiple short burst of acquisition followed by long dead times. Multi-segment acquisitions provide waveform time-alignment within each segment, making segment to segment waveform averaging or time domain analysis simpler.

**Traditional single-shot acquisition**

Acquisition time = memory depth/sample rate

**Segmented memory acquisition**

Selectively captures more waveform data

Streaming waveform data directly to Solid State Drive (SSD) memory is another effective way to manage memory for very long or continuous acquisitions. This allows continuous, gap-free waveform acquisitions and data offloading to occur at the same time. PXle and AXle digitizers are ideal for streaming applications since they connect directly to a high-speed PCIe bus. Figure 13 shows data flow for the Keysight M9203A PXle digitizer in streaming mode. The M9203A also utilizes a DDC “tune and zoom” for frequency band selection and data reduction, allowing blocks of the spectrum up to 320 MHz wide to be continuously streamed directly to PC controller RAM or long term SSD storage.
Input ranging and setup

The actual resolution of input signal in volts-per-bit is dependent on input amplifiers, attenuators and the ADC range. To optimize voltage resolution for a given signal it is important to scale the maximum signal level to match the range of the ADC. Oscilloscopes do a very good job of input signal level conditioning using programmable input stages. The scope sensitivity can be quickly set from millivolts/division to volts/division (the division is considered the oscilloscopes displayed division with full scale having 8 divisions). In addition, oscilloscopes include many input channel usability friendly features such as programmable 50 ohm and 1 Megohm terminations, AC and DC coupling as well as bandwidth limiting. When combined with scope probes, input sensitivity can be set over a wide range - from tens of millivolts to 100's of volts per division.

Wideband digitizers may or may not support programmable input ranges. Some digitizers are optimized for ATE systems so the system designer can manage the input signal conditioning including range scaling. ATE applications commonly use front end RF switch-boxes with 50 ohm switching and routing paths. For example, the M9703B AXIe digitizer and M9203A PXI digitizers support only two ranges (1 V and 2 V) and a single 50 ohm termination. For these products, the system designer will externally adjust the levels and impedances, if necessary. Other wideband digitizers may be more flexible such as the Keysight M310xA PXIe digitizer series, which provides programmatic multi-range and termination selection. When in doubt, verify the digitizer’s input range capabilities to determine if level conditioning is required for your application.

Number of channels

Analog-only oscilloscopes commonly offer 2 to 4 channels per instrument, which fits well for many applications. Modular digitizers commonly provide many more channels depending on the format and target applications. Digitizers built upon module platforms such as PXIe or AXIe are ideal for scalable solutions supporting higher channels. Close proximity of the module slots to backplane clock and sync lines may be used for module-to-module time alignment and synchronization. This is critical for applications such as antenna calibration and beam forming, where scalable solutions requiring 100’s of channels may be easily configured.

Oscilloscopes are also available to support mixed signal configurations (MSO’s) providing time synchronous analog and digital acquisitions. MSO’s will commonly offer four analog and sixteen digital channels. Since both analog and digital acquisition blocks are engineered in the same enclosure, excellent time alignment can be achieved and interoperability is seamless. This can be a great space-efficient, mixed-signal solution providing fastest time to mix signal results.

Triggering

Oscilloscopes have a long history of providing excellent triggering versatility. Over the years, user demand and competitive pressures have pushed oscilloscope vendors to optimize trigger technologies and capabilities. For example, the Keysight InfiniiVision series of scopes support dozens of triggers including edge, pulse width, pattern, Or, rise/fall time, Nth edge burst, runt, setup and hold and video to name a few. Serial protocol specific trigger events can also be detected including ARINC429, CAN, FlexRay, I2C, I2S, LIN, MIL-STD1553, SPI, UART, USB and SENT. Oscilloscope triggering is generally very extensive and flexible.
Digitizers generally support basic hardware trigger events such as external edge and/or channel level. Digitizers are commonly incorporated into ATE systems where they are combined with a source for source/measure style of testing. However, some DDC implementations include magnitude triggers generated from the zoomed center frequency allowing bandwidth selective triggering. Digitizers as well as scopes in modular PXI and AXIe formats can take advantage of mainframe trigger routing for trigger distribution.

**On-board measurements, analysis and other built-in tools:**

Scopes are optimized for usability and fast time to insight, and usually have a large variety of measurement and analysis tools built into the hardware that can be setup quickly using front panel controls. The algorithms have been thoroughly tested and stay within the box, so there is no need setup every time you need to repeat a measurement. These built-in measurement and analysis features are a big advantage for usability and consistency. In addition, by performing the analysis on-board, only the end results need to be returned to the controller. This can improve throughput in some ATE applications. Table 2 highlights the extensive optional math, FFT and serial protocol analysis tools available within the Keysight M924xA PXIe oscilloscopes.

<table>
<thead>
<tr>
<th>Math</th>
<th>Serial Analysis</th>
<th>Other Built-in’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add, subtract, multiply, divide</td>
<td>Exponential, base 10 exponential</td>
<td>DVM 3 digit</td>
</tr>
<tr>
<td>differentiate, integrate</td>
<td>Low-pass filter, high-pass filter</td>
<td>Counter – 8 digit</td>
</tr>
<tr>
<td>Enhanced FFT w/ window</td>
<td>Averaged value</td>
<td>Frequency</td>
</tr>
<tr>
<td>Ax + B</td>
<td>Smoothing,</td>
<td>Period</td>
</tr>
<tr>
<td>Squared, square root</td>
<td>Envelope, magnify, max &amp; min hold, measurement</td>
<td>Totalizer</td>
</tr>
<tr>
<td>Absolute value</td>
<td>trend chart, logic bus</td>
<td>20 MHz WaveGen</td>
</tr>
<tr>
<td>Common logarithm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural logarithm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wideband digitizers may have some limited measurement capabilities provided on-board. For example, digitizers designed for communications applications may include hardware accelerated integrated noise, ACPR and FFT measurements for improved throughput. The variety of built-in measurements in digitizers is far less than those found in scopes. Instead, digitizers rely on PC based application software for the bulk of analysis.
User interface differences - scopes vs. digitizers

User interface for setup, control and waveform visualization differ significantly between scopes and digitizers. LXI benchtop scopes provide intuitive user interfaces with large built-in LCD displays for ultimate visualization, and front panel controls for easy acquisitions and built-in measurements setup. This is consistent with the long history of providing optimized usability and fast time to insight by scopes. Waveform display panning and scaling both during and after acquisition completion is very helpful for debugging. Also, horizontally splitting the display to show a zoomed portion of the waveform is commonly supported in scopes and helps search for short anomalies within long acquisitions.

PXI scopes also bring these enhanced usability features. However instead of hardware front panel displays and controls, PXI scopes use soft front panels (SFP) as the primary user interface. PXI scope SFP’s are designed with the same focus on operator usability as the benchtop scopes, and even include making use of LCD touch screen display controls. For example, when combined with a touchscreen display the M924xA scope waveforms can be panned and zoomed with simple touch interactions. The M924xA also supports Zone Touch Triggering which allows easy setup of difficult-to-define trigger events by just drawing a box with your finger. Although the M924xA is a PXI scope, the user interface has been optimized for fast refresh rates.

![Figure 14. Bench top scopes provide large user interfaces for quick setup and easy viewing.](image)
PXI and AXIe digitizers also provide a Soft Front Panel. However, the SFP is primarily used for initial turn-on and maintenance of the digitizer module. The display update rates are not nearly as fast as oscilloscopes.

Although modular digitizers may provide some limited time and frequency domain waveform visualization, it is usually not as refined as the oscilloscope interface. The primary instrument interaction is usually via an automation environment where application software provides setup, control and results visualization for the digitizer.
#### Application software

Both digitizers and scopes are often used with PC application software and analysis tools. Waveform data may be returned to a PC environment and processed in common software environments including C#, C, VB.NET, VEE. For more complex math analysis, Matlab may be used. For high end complex modulation analysis Keysight’s 89600 VSA software provides waveform measurement and visualization in the time, frequency and modulation domains and works well with both Keysight’s digitizer and oscilloscope products.

![Image](image.png)

Figure 17. Advanced analysis software applications such as Keysight Technologies 89600 VSA software may be used with both scopes and digitizers.

Oscilloscopes are ideal for serial bus physical layer measurements due to their excellent bandwidths and on-board measurement capabilities. By combining oscilloscope acquisition capabilities with serial bus message triggering and decode, the result is an extremely valuable tool for serial bus debug and compliance test. For example, Keysight’s InfiniiVision benchtop oscilloscopes provide hardware-based triggering, decoding and message listing for many common serial protocols. Serial message frames can be checked for errors in the message fields including header, payload and CRC if present.
InfiniiVision oscilloscopes can support time aligned message decoding across different protocols. For example, automotive serial networks commonly use bridges across segments of vehicle serial networks. One branch may use the CAN protocol with a second branch using the LIN protocol. Within the vehicle these branches are connected via a bridge and operation on both sides of the bridge needs to be verified. A multi-channel scope with time aligned serial bus message decoding and time stamping is ideal for these cases.

The InfiniiVision family of scopes includes a large portfolio of optional serial IO software available for both debug and compliance testing. Table 3 gives a sample of the large variety of protocols supported by Keysight oscilloscopes.

Table 3. Optional serial bus analysis and compliance test software supported on Keysight InfiniiVision scopes.

<table>
<thead>
<tr>
<th>Compliance testing application software</th>
<th>Debug and analysis software</th>
</tr>
</thead>
<tbody>
<tr>
<td>BroadR-Reach, DDR, DisplayPort, Ethernet, GDDR, HDMI, HMC, HSIC, MIPI, OIF, CEI, PCI Express, SFP+ Secure Digital, Serial ATA I/II, Thunderbolt, USB, XAUI</td>
<td>ARINC 429, CAN, CXPI, FlexRay, I2C, JTAG, LIN, MIL-STD 1553, PCI Express, RS-232, SPI, SENT, UART, USB</td>
</tr>
</tbody>
</table>
On board FPGA programming

Digitizers are often used in high-end system implementations for scientific, physics or high volume manufacturing applications. In these cases, system designers may need access to on-board real time signal processing tools, and some digitizers provide access to internal FPGA’s enabling flexible hardware signal processing. Real-time data processing and manipulation routines that reside in hardware can achieve multi GS/s processing rates when embedded on a digitizer. This is useful for custom filtering, corrections and data reduction schemes as well as scientific application such as medical imaging, ultrasound, time-of-flight and Lidar ranging.

Keysight offers multiple digitizer families with an internal, user-accessible FPGA for real time processing. For example, Keysight’s M9203A PXIe digitizer and M97xx AXIe digitizers provides acquisitions up to 3.2 GHz at 12-bits, and includes access to on-board Xilinx FPGA for real time signal processing. For higher resolutions, Keysight’s M310xA family of PXIe digitizers with optional real-time FPGA programming supports up to 14-bit resolution up to 500 MS/sec. The M310xA family of digitizers also support a graphical FPGA design environment (M3602A) supporting programming with no previous FPGA experience.

![Figure 19. High end digitizers often provide on-board FPGA access for real-time waveform data processing.](image-url)
**Oscilloscope probe solutions**

When making benchtop waveform measurements on sensitive circuits, the oscilloscope connection loading must be minimized. Oscilloscope vendors provide a large portfolio of scope probing solutions including passive and active probes for both voltage and current, as well as high voltage, differential and even optical versions. These probe solutions are carefully designed to assure close match the scope inputs. Once connected, the probe becomes an extension of the scope input path.

Scope probes and probe tip hardware are optimized for operator usability and fast setups. For example, many Keysight oscilloscopes support AutoProbe intelligent interconnect. AutoProbe allowing the oscilloscope to detect the type of probe connected and automatically configures the input setting as needed.

Wideband digitizers often do not include matched probe solutions and in many cases only support a fixed 50 ohm input impedance. Digitizer target applications are most commonly for ATE and specialized system integration. In many applications, a front-end RF switch unit is integrated by the system designer providing both high frequency switching and/or signal bandwidth and level conditioning. When RF switching is involved 50 impedance paths are required, making a fixed 50 ohm termination a common choice for ATE systems.

![Figure 20. Keysight scope probing solutions include passive, active, differential, high voltage and optical.](image-url)
Summary of scope and digitizer differences

Oscilloscope and digitizers both acquire waveforms using high speed Analog to Digital Converters. However, as discussed, the architectures and feature sets of either class of products are optimized for different target applications. It is helpful to consider the general feature differences when considering your next application.

Table 4. Summary of general wideband digitizer vs scope attributes and target applications.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Wideband Digitizers</th>
<th>Oscilloscopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applications</td>
<td>Primary: ATE with some bench-top applications</td>
<td>Primary: Benchtop with some ATE applications</td>
</tr>
<tr>
<td>Time to 1st waveform insight</td>
<td>Good: Some HW/SW integration is required</td>
<td>Best: Intuitive front panel controls</td>
</tr>
<tr>
<td>Instrument enclosure format</td>
<td>Primary: Modular PXIe, AXIe format with some LXI enclosure styles available</td>
<td>Primary: Bench-top LXI enclosure with some PXI, AXI modular formats available</td>
</tr>
<tr>
<td>Instrument to PC throughput</td>
<td>Best: High speed multi-lane PCIe bus</td>
<td>Good: LAN, USB, GPIB</td>
</tr>
<tr>
<td>Initial setup and ease-of-use</td>
<td>Good: Some skill for HW/SW setup required, utility SFP</td>
<td>Best: Intuitive front panel setups and waveform visualization, full feature SFP</td>
</tr>
<tr>
<td>Resolution and dynamic range</td>
<td>Best: 12 to 16 bits</td>
<td>Good: 8 bit (hi-res 12 bits w/ limited BW)</td>
</tr>
<tr>
<td>Bandwidth (real-time)</td>
<td>Good: Up to 2.5 GHz</td>
<td>Best: Up to 63 GHz</td>
</tr>
<tr>
<td>Sample rate</td>
<td>Good: Up to 10 Gs/s</td>
<td>Best: Up to 160 Gs/s</td>
</tr>
<tr>
<td>Acquisition memory depth (record time)</td>
<td>Good: Up to 1 Gs/ch, may stream to external memory such as PC RAM or Solid State Drive</td>
<td>Good: Up to 2 Gs/ch, may use infinite persistence for glitch detection</td>
</tr>
<tr>
<td>Input alias filtering</td>
<td>Good: Sometimes flexible wideband inputs for 2nd &amp; 3rd Nyquist zone w/ undersample</td>
<td>Good: Alias protected at max sample rate, user must verify for decimated rates</td>
</tr>
<tr>
<td>Hardware based waveform reconstruction</td>
<td>None: May be done in application software if needed</td>
<td>Best: Fast waveform sinx/x reconstruction using on-board DSP</td>
</tr>
<tr>
<td>Corrections for phase and magnitude errors</td>
<td>Good: Corrections sometimes done on-board DSP or use application software</td>
<td>Best: Corrections done on-board DSP or use in application software</td>
</tr>
<tr>
<td>Embedded Digital Down Conversion (DDC)</td>
<td>Best: Commonly provided in hardware</td>
<td>None: Not provided in hardware</td>
</tr>
<tr>
<td>Number channels, channel to channel sync and extendability</td>
<td>Best: High density multi-slot mainframe with trigger system for sync</td>
<td>Good: Mixed signal products Analog/Digital MSO 4 + 40 channel support</td>
</tr>
<tr>
<td>Measurement throughput</td>
<td>Best: Using DDC combined with high speed multi-lane PCIe data IO</td>
<td>Good: Limited by data IO, although on-board measurements help</td>
</tr>
<tr>
<td>Waveform visualization update rate</td>
<td>Good: PC software and display limited</td>
<td>Best: Fast update to built-in display (LXI benchtop) or optimized SFP (PXI)</td>
</tr>
<tr>
<td>Triggering qualifiers / routing</td>
<td>Good: Limited selection of trigger qualifiers / Best: mainframe trigger routing</td>
<td>Best: Extensive selection of trigger qualifiers / Good: external cable routing</td>
</tr>
<tr>
<td>Automated measurements</td>
<td>Good: Processing is done in application software</td>
<td>Best: Both on-board and application software provided measurements</td>
</tr>
<tr>
<td>FPGA hardware processing</td>
<td>Best: On-board FPGA with programming tools</td>
<td>None</td>
</tr>
<tr>
<td>Probe</td>
<td>None: Not typically supported</td>
<td>Best: Large selection of probes</td>
</tr>
</tbody>
</table>
Applications

To help further your understanding of how wideband digitizers and oscilloscopes are used in practice, below is a list of applications and a brief description of how either are best suited for those applications. See the link in the Reference column for additional application information.

Table 5. Brief listing of how digitizers and scopes are used in common applications.

<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOCSIS 3.1 design validation test transmitter signal acquisition and modulation analysis</td>
<td>DOCSIS 3.1 requires wideband (192 MHz) acquisitions and complex modulation (4096 QAM) analysis. A high resolution wideband digitizer can achieve low MER for DVT. When combined with 89600 Vector Analysis software a 12 bit wideband digitizer such as the Keysight M9703B works well for DOCSIS 3.1 testing.</td>
<td>Application Note 5991-4301EN</td>
</tr>
<tr>
<td>Serial protocol debug and conformance testing</td>
<td>Oscilloscopes provide built-in serial protocol triggering and decode software which is ideal for both serial protocol debug and conformance testing. Serial messaging can be verified, and signal timing and level faults are easily observed.</td>
<td>Application Note 5990-8359EN, Application Note 5991-0512EN</td>
</tr>
<tr>
<td>Wideband MIMO Baseband IQ development</td>
<td>Complex MIMO based standards such as 802.11ac utilize multiple wide bandwidth channels with higher order modulation schemes (256 QAM). High dynamic range wideband digitizers are required to achieve acceptable intrinsic EVM during component development and test.</td>
<td>Application Note 5991-2263EN</td>
</tr>
<tr>
<td>Bench-top PCA debug</td>
<td>Oscilloscopes are the best choice for various bench-top signal discovery, analysis and debug tasks. Oscilloscope displays are optimized for signal visualization and probe sets allow easy signal connectivity. Usability features including advanced triggering, on-board measurement and flexible markers speed up general debug activities.</td>
<td>Application Note 5991-3958EN, Application Note 5992-2066EN, Application Note 5991-3370EN</td>
</tr>
<tr>
<td>High channel count phase coherent array calibrations</td>
<td>Modular PXI or AXIe wideband digitizers work best for high channel phase coherent measurements to improve test speed and support wideband measurements. The Keysight M9703B digitizer supports synchronization up to 40 channels, and on-board DDC tune and zoom allows selective bandwidth tuning reducing broadband noise and phase variance.</td>
<td>Application note 5991-2543EN, Solution brochure 5991-4537EN</td>
</tr>
<tr>
<td>Serial bus jitter analysis with clock recovery</td>
<td>Oscilloscopes are used for serial bus eye and jitter analysis due to high sample rates and specialized triggering systems. Infinite persistence display modes allows monitoring eye opening over long durations without consuming significant memory.</td>
<td>Application Note 5991-4000EN, Application Note 5989-0108EN</td>
</tr>
<tr>
<td>5G/MIMO channel sounding</td>
<td>Modular PXI or AXIe wideband digitizers are well suited for 5G MIMO channel sounding solutions where expandable multichannel phase coherent acquisitions are required. Digitizer on-board FPGA's may be used for real-time Channel Impulse Response (CIR) processing of multiple, phase coherent channels.</td>
<td>Solution Brochure 5992-0983EN, Application Note 5992-1064EN</td>
</tr>
<tr>
<td>5G waveform generation &amp; Analysis testbed</td>
<td>For cutting edge emerging technologies sometimes the extremely wide bandwidths that oscilloscopes provide is a must. 5G modulation bandwidths are over 2 GHz and wide bandwidth scopes can be combined with other instruments to create effective testbed for development.</td>
<td>Solution Brochure 5992-1030EN</td>
</tr>
<tr>
<td>High-energy physics advanced research</td>
<td>Modular PXI or AXIe wideband digitizers work well in Big Physics applications, particularly when synchronous stimulus/response. On-board FPGA support allows real-time data analysis when needed.</td>
<td>Application Brief 5991-0063EN, Application Note 5991-1941EN, White Paper 5991-0849EN</td>
</tr>
<tr>
<td>Analog/digital mixed signal bus debug</td>
<td>Mixed signal oscilloscopes (MSO’s) are best suited for mixed analog/digital measurements. Analog to digital time alignment is inherent with MSO scopes and built-in FFT measurements allow time correlated analog, digital, and spectral information displayed at once.</td>
<td>Application Note 5989-3702EN, Application Note 5988-7746EN, Application Note 5991-1237EN</td>
</tr>
<tr>
<td>Electronic functional test ATE systems</td>
<td>Modular digitizers work well in ATE systems where operator waveform visualization is not generally required. Oscilloscopes also may be considered when scope resolution is sufficient and built-in measurements or advanced triggering can be used.</td>
<td>Application Note 5990-4226EN, Application Note 5989-6552EN</td>
</tr>
</tbody>
</table>
Summary

Both oscilloscopes and wideband digitizers use ADC technology for waveform acquisitions. Although the differences between these product classes may seem subtle, we’ve shown some significant differences in application and use model. In summary, oscilloscopes are designed for extremely wide bandwidths and are optimized to provide a large variety of usability features including large fast displays for waveform visualizations. Digitizers are designed for high dynamic range with higher resolution ADC’s, ideal for low noise floor frequency analysis. Having a good understanding of these architectures, applications and trade-offs can help you choose the right solution. Keysight offers extensive experience and broad selection of both oscilloscope and waveform digitizers, one of which will be the ideal fit for your measurement challenge. For additional information please see the Keysight website at http://www.keysight.com.

References

- Keysight AN 5989-5732EN Evaluating Oscilloscope Sample Rates vs. Sampling Fidelity
- Keysight AN 5989-5733EN Evaluating Oscilloscope Bandwidths for Your Application
- Keysight AN 5991-1617EN Evaluating High-Resolution Oscilloscopes
- Keysight AN 5989-1145EN Advantages and Disadvantages of Using DSP Filtering on Oscilloscope Waveforms
- Keysight AN 5991-2543EN M9703A AXiE High-Speed Digitizer with Real-Time Digital Downconversion Capability
- Keysight 5989-8794EN What is the difference between an equivalent time sampling oscilloscope and a real-time oscilloscope?
- Keysight 5992-1243EN Demystifying the Impact of ADCs and DACs on Test Instrument Specifications
- Keysight 5990-9923EN Minimum Required Sample Rate for a 1 GHz Bandwidth Oscilloscope
Evolving
Our unique combination of hardware, software, support, and people can help you reach your next breakthrough. We are unlocking the future of technology.

From Hewlett-Packard to Agilent to Keysight

myKeysight
www.keysight.com/find/mykeysight
A personalized view into the information most relevant to you.

Keysight Services
www.keysight.com/find/service
Our deep offering in design, test, and measurement services deploys an industry-leading array of people, processes, and tools. The result? We help you implement new technologies and engineer improved processes that lower costs.

Three-Year Warranty
www.keysight.com/find/ThreeYearWarranty
Keysight’s committed to superior product quality and lower total cost of ownership. Keysight is the only test and measurement company with three-year warranty standard on all instruments, worldwide. And, we provide a one-year warranty on many accessories, calibration devices, systems and custom products.

Keysight Assurance Plans
www.keysight.com/find/AssurancePlans
Up to ten years of protection and no budgetary surprises to ensure your instruments are operating to specification, so you can rely on accurate measurements.

Keysight Channel Partners
www.keysight.com/find/channelpartners
Get the best of both worlds: Keysight’s measurement expertise and product breadth, combined with channel partner convenience.

For more information on Keysight Technologies’ products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

Americas
Canada (877) 894 4414
Brazil 55 11 3351 7010
Mexico 001 800 254 2440
United States (800) 829 4444

Asia Pacific
Australia 1 800 629 485
China 800 810 0189
Hong Kong 800 938 693
India 1 800 11 2626
Japan 0120 (421) 345
Korea 080 769 0800
Malaysia 1 800 888 848
Singapore 1 800 375 8100
Taiwan 0800 047 866
Other AP Countries (65) 6375 8100

Europe & Middle East
Austria 0800 001122
Belgium 0800 58580
Finland 0800 523252
France 0805 980333
Germany 0800 6270999
Ireland 1800 832700
Israel 1 809 943051
Italy 800 599100
Luxembourg +32 800 58580
Netherlands 0800 233200
Russia 8800 5009286
Spain 800 000154
Sweden 0200 882255
Switzerland 0800 805353
Opt. 1 (DE)
Opt. 2 (FR)
Opt. 3 (IT)
United Kingdom 0800 0280637

For other unlisted countries:
www.keysight.com/find/contactus
(BP-2-23-17)

www.keysight.com/go/quality
Keysight Technologies, Inc.
DEKRA Certified ISO 9001:2015 Quality Management System

DEKRA Certified
ISO 9001:2015 Quality Management System

This information is subject to change without notice.
© Keysight Technologies, 2017
Published in USA, March 30, 2017
5992-2259EN
www.keysight.com