OSCILLOSCOPE BUYER'S GUIDE

How to choose an oscilloscope

Flyer | Version 01.00

ROHDE&SCHWARZ

Make ideas real

CONTENTS

Oscilloscopes are essential to every benchtop. Navigating through the range of available specifications, options and capabilities can be a daunting task. After all, there are many considerations: how to determine the right bandwidth for your needs, which sample rate you should choose, how to select the most appropriate trigger features, and many more.

This guide covers the most important aspects of selecting an oscilloscope and provides you with the knowledge to make the best choice for your needs.

UNDERSTANDING OSCILLOSCOPE FUNDAMENTALS

Grasping the fundamentals of oscilloscopes is crucial to choosing the one that is right for you. In this section, we explore oscilloscope basics to offer you a solid grasp of how bandwidth, sample rate and analog-to-digital converter (ADC) bits should factor into your decision-making process.

WHAT IS AN OSCILLOSCOPE?

An oscilloscope is an instrument that displays waveforms representing voltage over time. These real-time instruments capture signals as they change. They typically have a screen to display waveforms and measurements, controls to change settings, like volt per division, and input connectors for cables or probes.

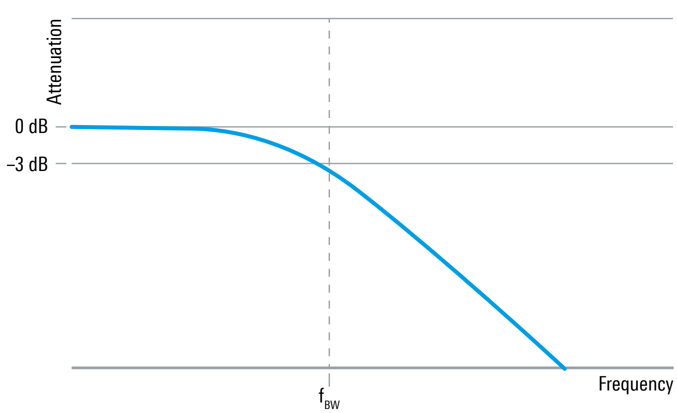
BANDWIDTH

WHAT IS BANDWIDTH?

Bandwidth is the range of frequency content an oscilloscope can measure. Oscilloscopes are one of the few wideband instruments that measure from DC (0 Hz) to their specified bandwidth. This is the most important specification when buying an oscilloscope because you cannot make accurate measurements if an oscilloscope does not have enough bandwidth.

First order bandwidth roll-off

Definition of oscilloscope bandwidth



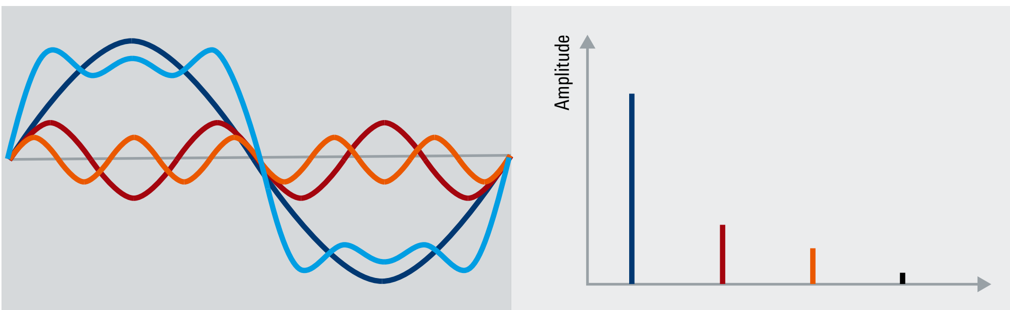
The frequency response of an oscilloscope's frontend amplifier resembles that of a lowpass filter. The shape means it passes most signal content from DC to where the attenuation drops by 3 dB. The –3 dB point is where oscilloscopes define their bandwidth and represents approximately a 30 % reduction in voltage at that frequency point.

HOW TO CHOOSE THE RIGHT BANDWIDTH

Picking a bandwidth for a specific application can be complicated when choosing an oscilloscope. For example, if you only plan to look at sine waves, all you need to do is ensure you have slightly more bandwidth than the maximum carrier frequency to account for the 3 dB attenuation. If you need to measure a 100 MHz sine wave, for instance, you might select an oscilloscope with a bandwidth of 150 MHz or more.

Sine wave and harmonics

Estimated bandwidth based on sine waves



Fundamental (first harmonic)
Third harmonic
Fifth harmonic
Fourier square wave (first – fifth harmonic)

More complex waveforms (e.g. digital signals) have many factors that need to be taken into consideration. A rule of thumb for digital or other complex signals is to pick a bandwidth that is three to five times faster than the fastest clock or data signal. If you are measuring a memory bus with a data rate of 133 MHz, for instance, the bandwidth should be at least 400 MHz. However, this assumes that a digital signal's rise time correlates with the data rate.

$$\frac{0.35}{t_{rise}} = \frac{0.35}{600\ ps} = 583\ MHz$$

The rise and falling edges in digital signals tend to have more frequency content than the fundamental frequency. The equation 0.35 over rise time provides a rough estimate of the bandwidth in the signal. Consider the previous bus example. If the signal has a 600 ps rise time and plug that into the above equation, we can see that there is frequency content up to 583 MHz. That value falls within the three to five times the data rate guideline.

OTHER BANDWIDTH CONSIDERATIONS

Most oscilloscopes have upgradeable bandwidth options. There are limits to upgradeability, of course, but there could be a path forward if you find the bandwidth is too limited.

Too much bandwidth can affect your measurement. In general, more bandwidth in a measurement also means more broadband noise. Fortunately, many oscilloscopes offer filters to reduce frontend bandwidth. All Rohde & Schwarz oscilloscopes have a 20 MHz filter for power supply measurements. In addition, models like the MXO 4 series and the R&S®RTO6 have a high definition (HD) mode to trade bandwidth for ADC resolution to enable high accuracy on low bandwidth measurements.

SAMPLE RATE

WHAT IS SAMPLE RATE?

The analog-to-digital converter (ADC) in an oscilloscope digitizes the analog signal. The rate it digitizes is called the sample rate. Manufacturers specify the sample rate in sample per second. The R&S®RTC1000 oscilloscope (300 MHz model) has a sample rate of 2 Gsample/s, for instance.

HOW TO CHOOSE THE RIGHT SAMPLE RATE

At a minimum, an oscilloscope's sample rate should be least 2.5 times higher than the bandwidth. If an oscilloscope has 1.5 GHz bandwidth, for example, the sample rate should be higher than 3.75 Gsample/s. In general, most oscilloscopes meet this minimum requirement. However, an oscilloscope might interleave multiple channels to achieve the fastest sample rate.

Acquisition system (source: R&S®RTC1000 specifications)		
Maximum real-time sampling rate		2 × 1 Gsample/s or 1 × 2 Gsample/s
Memory depth per channel		2 × 1 Msample or 1 × 2 Msample
Acquisition modes	refresh	first sample in decimation interval
	peak detect	largest and smallest sample in decimation interval (1 ns detection)
	high resolution	average value of all samples in decimation interval (up to 16 bit)
	envelope	envelope of acquired waveforms
	average	average over a series of acquired waveforms
	filter	lowpass, adjustable
	smooth	
Number of averaged waveforms		2 to 1024
Waveform acquisition rate	dot display, single channel, max. waveform rate	up to 10 000 waveforms/s

The R&S®RTC1000 oscilloscope (300 MHz model) samples at 2 Gsample/s on a single-channel but only 1 Gsample/s when both channels are enabled. Fortunately, even at this reduced sample rate, the R&S®RTC1000 still samples the analog bandwidth by a factor of over 2.5. In general, a higher sample rate is better.

OTHER SAMPLE RATE CONSIDERATIONS

Oscilloscopes have different acquisition modes, such as peak detect or high resolution. These modes allow the ADC to continue running at its maximum sampling rate but reduce the amount of data points stored in memory. They also make higher sample rates useful for applications with relatively slow signals.

ADC BITS

WHAT ARE ADC BITS?

An oscilloscope's analog-to-digital converter (ADC) outputs binary values. Like any ADC, the number of bits making up the binary values determines the resolution. For example, an 8 bit ADC outputs 256 unique values or voltage levels. While a 10 bit ADC outputs 1024 unique values and a 12 bit ADC outputs 4096 voltage levels.

ACCURACY, RESOLUTION AND SENSITIVITY

While an ADC's resolution affects an oscilloscope's measurement accuracy, it is not the only aspect to consider.

Accuracy is defined here as the difference between the expected measurement and the actual value. In other words, it is the uncertainty of a measurement. Resolution is the smallest change that a measurement system can represent. In an oscilloscope, the ADC's bit width is the main factor in resolution. Finally, sensitivity is the smallest detectable change. At first, this definition may sound the same as resolution, and individual elements of an acquisition system may have very high sensitivity. However, the overall sensitivity is the combination of accuracy and resolution.

FURTHER CONSIDERATIONS

Not all oscilloscopes operate at full bit width all of the time, which is why you should carefully review the specifications to understand any limitations. Fortunately, all Rohde & Schwarz oscilloscopes use their full bit width at all times.

Additionally, some Rohde & Schwarz oscilloscope models can increase their effective bit width with a feature called high definition (HD) mode. This mode trades bandwidth for higher resolution measurements. For example, the MXO 4 series offers a 12 bit ADC which can effectively increase up to 18 bit.

USING ADVANCED OSCILLOSCOPE FEATURES

Maximizing your oscilloscope's potential hinges on harnessing its advanced features. This section will guide you through triggering, memory depth, fast segmentation and history mode, as well as waveform update rate, to help you effectively select and utilize these features.

TRIGGERING

WHAT IS A TRIGGER?

In oscilloscopes, the trigger system monitors the signal(s) under test for specific events. When it detects these user-selectable criteria, it creates a trigger action. The most common trigger type is the edge-level trigger, and the most common action is to update the screen with the event at the center.

Trigger systems can identify many other events, such as pulse widths, runt voltages, logic levels and serial protocol packets. They also have several tools to filter out noise, qualify valid events and trigger other instruments.

HOW TO CHOOSE THE RIGHT TRIGGER FEATURES

A full-featured trigger system can significantly reduce debugging time and make it possible to characterize very complex signals. The first thing to consider is the types of triggers an oscilloscope supports. Then, you can look at its other capabilities, such as adjustable hysteresis and sequence triggering.

Adjustable hysteresis means that the trigger can tolerate more noise on a waveform or focus on a specific event on an edge. For example, oscilloscopes with precise digital trigger systems can trigger on events smaller than 0.0001 of a vertical division. Sequence triggering, sometimes called A ▷ B triggering, allows you to create a two-stage trigger condition. You can qualify a particular pulse width only after the falling edge of an enable signal.

FURTHER CONSIDERATIONS

When evaluating an oscilloscope's trigger system, paying careful attention to its specifications is essential. Some oscilloscope trigger systems may only be full bandwidth on the edge trigger. The other trigger types may be relatively slow compared to the oscilloscope's bandwidth.

Oscilloscopes like the MXO 4 series and R&S®RTO6 utilize a digital trigger system. Instead of relying on an analog circuit to identify events, a custom ASIC watches the digital samples from the ADC in real-time to detect trigger events. This unique trigger method provides the most precise triggering capability. A significant advantage to such a system is that all trigger types are full bandwidth. For example, a digital trigger's glitch detection is as fast as a single sample period of the ADC. Another benefit is the incredible voltage sensitivity.

MEMORY DEPTH

WHAT IS MEMORY DEPTH?

The ADC stores its samples in a memory buffer. Because ADCs tend to sample in the gigabit range, this memory must be close to the ADC and very fast. The number of stored acquisition samples is called the memory depth. For example, if a channel has a 10 Mpoints buffer, it stores up to 10 million sample during each acquisition.

$$\frac{1}{5\ Gsample/s} \times 10\ Mpoints = 100\ ms$$

There is a direct correlation between how fast an oscilloscope samples, how much memory it has and how much time it can capture. The timebase setting determines the minimum time an oscilloscope requires to capture a signal. The acquisition system balances memory depth and sample rate to maximize the sample rate for a given timebase setting. The more memory available, the slower (longer) the timebase setting can be while maintaining a high sample rate.

In general, more memory is better. However, some oscilloscopes do not maximize the use of their deep memory or become extremely slow when operating with deeper memory enabled.

HOW TO CHOOSE THE RIGHT MEMORY DEPTH

Unlike the other key oscilloscope specifications, there are no simple guidelines for memory depth. However, if you know you need to capture a certain amount of time, you can determine the minimum memory depth you need. For example, to capture 10 cycles of a 100 MHz clock signal, you would need to capture at least 100 ns. At 1 Gsample/s, the ADC samples every nanosecond. So you would need a memory depth of 100 sample.

FURTHER CONSIDERATIONS

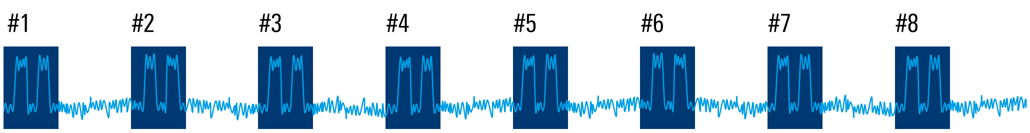
A consideration for shallow versus deep memory is how the oscilloscope processes its acquisition memory. For example, MXO 4 series, R&S®RTO6 and R&S®RTP oscilloscopes have custom ASICs to help manage deep memory operations. This ASIC keeps the oscilloscope responsive while zooming in/out of waveforms and minimizes the trigger re-arm time during acquisition.

Fast segmentation and history mode

Other considerations are modes or features that use memory other than simple acquisitions. For example, the fast-segmentation feature and history mode on Rohde & Schwarz oscilloscopes use deep memory in valuable ways.

Acquisition using segmented memory

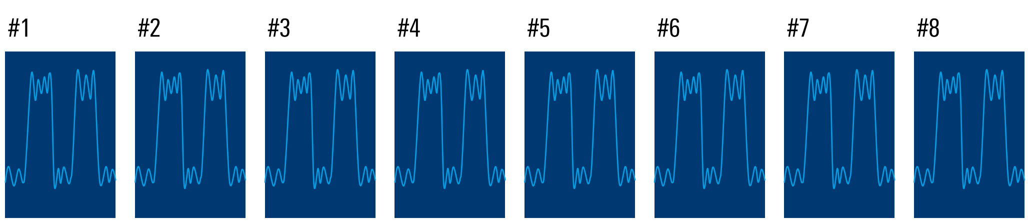
With fast segmentation, the acquisition system divides the memory into small but equal chunks or segments. These chunks are then filled as fast as the trigger system can re-arm itself. The memory controller waits until it fills all segments before transferring the acquisition data to the CPU. A fast segmentation mode has the benefit of re-arming the trigger system as fast as possible and maximizing the use of deep memory. It is beneficial for signals that have a bursting nature.



Acquisition of signal segments with activity

Analysis of each segment using the history function

History mode is another novel way to use deep memory. The memory controller divides the total available memory into chunks or segments, like in fast segmentation mode. However, in history mode, the controller fills the segments as a ring buffer with the oscilloscope processing each segment like in normal operation. The difference with history mode is that when you stop the oscilloscope, you can dial back in time to previous acquisitions. The advantage of this feature is that it gives you time to hit the stop button after seeing an anomaly on the screen.



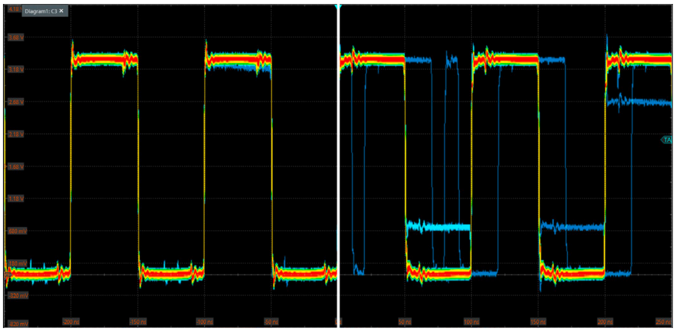
Display and analysis of each signal element

WAVEFORM UPDATE RATE

WHAT IS A WAVEFORM UPDATE RATE?

The waveform update rate is sometimes called the trigger rate. It is how fast the oscilloscope can acquire waveforms between trigger events. In general, the quicker an oscilloscope re-arms and re-triggers, the less dead time between acquisitions.

Dead time is the time between acquisitions when the oscilloscope cannot capture a waveform. The lower the dead time, the faster the trigger rate, and the more likely an oscilloscope can capture infrequent events like a transient pulse.



Typical update rate (left) compared with the R&S®RTO6 update rate (right)

Some Rohde & Schwarz oscilloscopes have a custom ASIC that enables ultra-fast waveform update rates. For example, the R&S®RTO6 can acquire up to 1 million waveforms/s. And the MXO 4 series can acquire up to 4.5 million waveforms/s.

FURTHER CONSIDERATIONS

Different measurements, acquisition modes and memory depths can affect the waveform update rate. Some oscilloscope manufacturers may specify their maximum update rate (or minimum dead time) only when special modes are enabled. Therefore, when looking at this specification, it is essential to understand under what conditions the fastest rate applies.

ADDITIONAL OSCILLOSCOPE CONSIDERATIONS

Choosing the right oscilloscope involves more than understanding its basic and advanced features. In this section, we will explore additional considerations such as probes, integrated instruments, form factor and remote control. By the end, you will be equipped to make an informed decision.

PROBES

WHAT ARE OSCILLOSCOPE PROBES?

Before you can measure a signal, you have to get it into an oscilloscope. Sometimes, you can use BNC (or SMA) cables to connect directly from a device under test into the oscilloscope's front panel. But in most cases, you need to use a probe.

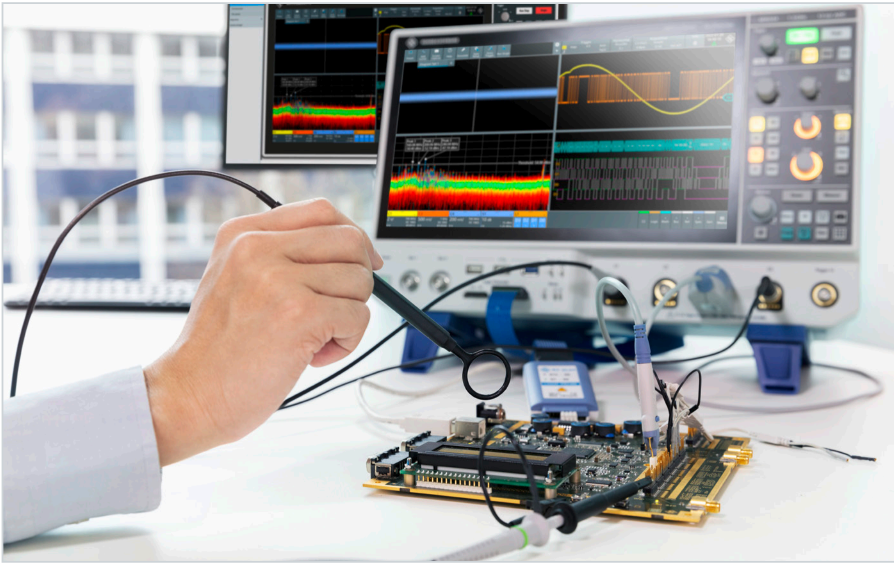
HOW TO CHOOSE THE RIGHT PROBES

Passive voltage probe

The most common probe type is the passive voltage probe. These inexpensive probes are suitable for general purpose applications. Probes with different attenuation factors offer either higher-voltage or low-loading of a signal.

Passive probes that come with an oscilloscope are generally rated at or slightly higher than the oscilloscope's bandwidth. Most passive probes do not exceed 500 MHz or 700 MHz of bandwidth. An active voltage probe is necessary for probing signals with more than 700 MHz of bandwidth.

Active voltage probes use an amplifier circuit that offers higher bandwidth and lower circuit loading than passive probes. They come in single-ended, differential and modular form factors. As their name implies, these probes require power for operation.



The right setup with the right probes

Some probes measure quantities other than voltage. For example, hall-effect sensor current probes non-intrusively measure the current through a wire. Another example is near-field probes that measure electromagnetic fields emitted from components, wires and PCBs.

In general, active probes from one oscilloscope manufacturer may not be compatible with another. However, some manufacturers do offer adapters for other vendors' probes. (If planning to use one of these adapters, verify the probe is compatible with the adapter.)

Choose from a wide selection of compatible probes: Rohde & Schwarz offers a wide variety of passive, active and non-voltage probes with multiple form factors.

FURTHER CONSIDERATIONS

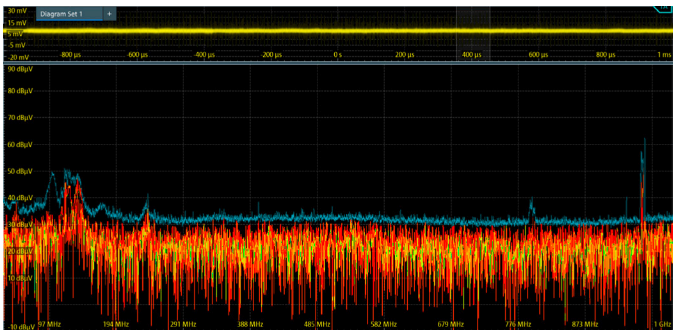
Oscilloscopes with lower bandwidths, generally less than 200 MHz, only support a passive probe interface. In other words, they only have a BNC connector on the front. On the other hand, an oscilloscope with more than 200 MHz may have an active probe interface that supports both passive and active probes.

INTEGRATED INSTRUMENTS

Oscilloscopes have grown beyond just a measurement tool for waveforms. When choosing an oscilloscope, consider the other instruments integrated into them. Here are some additional capabilities to consider.

SPECTRUM ANALYSIS (FFT) WITH OSCILLOSCOPES

A fast Fourier transform (FFT) converts time domain waveforms into a frequency domain plot. The oscilloscope display shows frequency and magnitude (instead of time and amplitude). Unlike traditional spectrum analyzers, oscilloscopes with spectrum analysis capability can measure down to DC (0 Hz).



FFT analysis with the MXO 4 series

FFTs may be implemented as a simple math function with limited controls or hardware-accelerated with spectrum-analyzer-like controls. In addition, the R&S®RTO6 offers a unique zone trigger that allows you to drop a box where a spur might (or should not) occur to limit screen updates to a frequency of interest.

ARBITRARY WAVEFORM GENERATOR

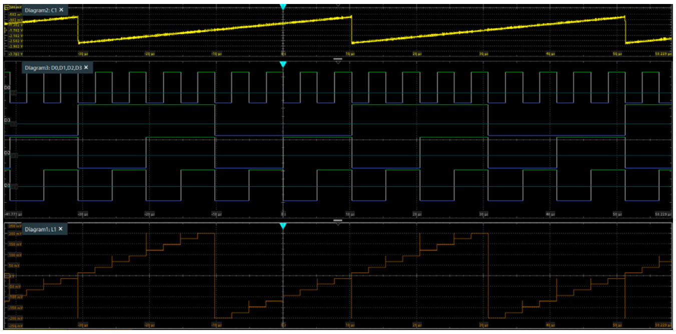
A built-in arbitrary waveform generator outputs functions like sine, triangle and square waves with modulations like AM, FM, FSK and PWM. Having a generator built into the oscilloscope can save space on your bench. In addition, many oscilloscopes can use the generator to create a signal to go into a circuit, while an analog channel measures the output. For example, the R&S®MXO4-K36 frequency response analysis (FRA) option creates Bode plots of a power supply's control loop response (CLR) and power supply rejection ratio (PSRR).

Frequency response analysis with the MXO 4 series

Most Rohde & Schwarz oscilloscopes offer an arbitrary waveform generator option as a software option or plug-in hardware module.

LOGIC ANALYZER

Oscilloscopes with digital channels can capture both analog and digital waveforms. Logic channels are typically time-correlated, meaning that the oscilloscope samples them simultaneously with the analog channels. This capability results in the display showing events on both channel types locked in time.

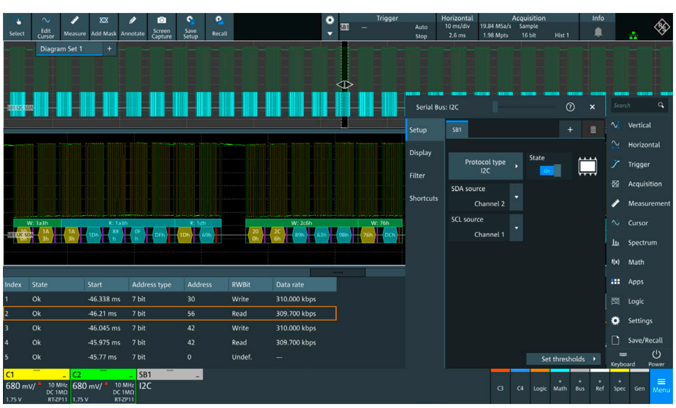


Mixed signal analysis with the R&S®RTO6

All Rohde & Schwarz oscilloscopes offer digital channels as an option. Depending on the model, either 8 or 16 channels are available.

PROTOCOL ANALYZER

Protocol analysis takes the acquired waveform (on either the analog or digital channels) and decodes it into a protocol display. For example, many microcontroller based designs feature an SPI, I²C or UART bus for communications. Using an oscilloscope's protocol analyzer features, you can trigger protocol-specific events, like the start of a packet or, in some cases, a CRC error. Once triggered, a decode display makes it easy to read bus transactions.



Serial bus analysis with the MXO 4 series: two ways of viewing protocol data

There are two ways to view the data:

- See an overlay on top of the acquired waveform (beneficial in determining if a signal integrity issue is causing a protocol problem)
- See a protocol table (lets you see a lot of protocol activity in a short period)

All Rohde & Schwarz oscilloscopes offer various decode options that can be included at the time of purchase or enabled after purchase.

FORM FACTOR (STYLE)

Oscilloscopes come in a variety of sizes. In general, the higher the bandwidth, the larger the box. Portable oscilloscopes now have as much capability as the traditional bench style.

PORTABLE OSCILLOSCOPES

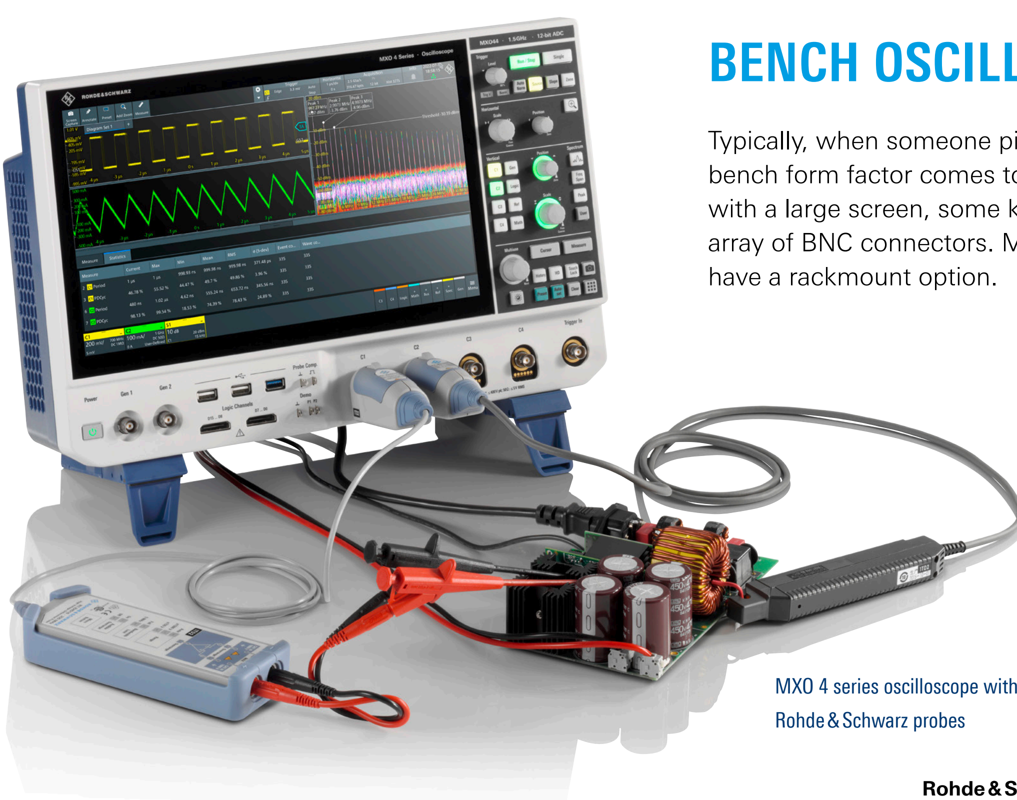
Two aspects characterize a portable or handheld oscilloscope like the R&S®Scope Rider RTH: its form factor and its battery. This oscilloscope features a touchscreen. Instead of function specific knobs, it has large push buttons and multipurpose rotary control, which you can easily use while wearing bulky gloves or when you are not directly in front of the instrument.

The R&S®RTH has bandwidth options up to 500 MHz, a sample rate of up to 5 Gsample/s and a 10 bit ADC. In addition, it has a full-featured digital trigger system and a wide range of automated measurements. Finally, this oscilloscope has isolated inputs and comes with 4 analog channels or 2 analog channels and a hardware DMM.

R&S®Scope Rider RTH handheld oscilloscope

BENCH OSCILLOSCOPES

Typically, when someone pictures an oscilloscope, the bench form factor comes to mind. There is a front panel with a large screen, some knobs, a few buttons and an array of BNC connectors. Most bench oscilloscopes also have a rackmount option.

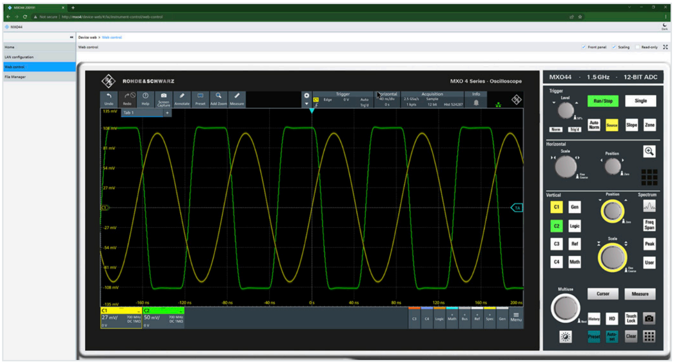


MXO 4 series oscilloscope with Rohde & Schwarz probes

REMOTE CONTROL

WHAT DOES REMOTE CONTROL MEAN?

Remote control means connecting to the instrument from a PC and controlling it as if you were sitting in front of it. In this use model, you click buttons or knobs on a virtual front panel via a web browser that mimics the instrument's front panel.



HOW TO CHOOSE THE RIGHT REMOTE ACCESS

If you need to access the oscilloscope remotely from your lab, make sure it supports remote operation. For example, the R&S®RTB2000, R&S®RTM3000, MXO 4 series, R&S®RTO6 and R&S®RTP all support a virtual front panel through a web based browser interface.

FURTHER CONSIDERATIONS

Most oscilloscopes that support GPIB require the purchase of an additional hardware option.

WHAT IS AUTOMATION (AND CONNECTIVITY)?

Automation involves controlling an instrument from a PC through a programming environment like NI's LabView™, MATLAB® or Python. These environments send commands to the oscilloscope over USB, Ethernet or GPIB.

Rear view of the R&S®RTO6 oscilloscope series.

SUMMARY

Choosing the right oscilloscope is an important decision. The most important specification to consider is the bandwidth. After that, you can consider other aspects.

Fast waveform update rates significantly reduce debugging and characterization tasks. Generally, if the waveform update is accelerated, then the oscilloscope can handle deep memory very fast as well.

When looking at triggering capabilities, consider more than just the available modes. Check whether the specifications on each of those modes match your application needs and evaluate critical factors like voltage sensitivity.

Remember, oscilloscopes now incorporate multiple test instruments. For example, if the oscilloscope has a fast and responsive FFT, it can act as a real-time spectrum analyzer; or, with protocol triggers you can use it as a logic analyzer.

Finally, there is a variety of form factors to suit a wide range of use cases – from handheld to portable to bench.

ANY QUESTIONS? NEED HELP MAKING A DECISION?

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