SELECTING YOUR NEXT OSCILLOSCOPE

Why deep memory matters

White paper | Version 01.00

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CONTENTS

ROHDE & SCHWARZ PRODUCTS

- R&S®MXO 4 Series oscilloscopes
- R&S®MXO 5 Series oscilloscopes
- R&S®RTA4000 Series oscilloscopes
- R&S®RTB2000 Series oscilloscopes
- R&S®RTM3000 Series oscilloscopes
- R&S®RTO6 Series oscilloscopes
- R&S®RTP Series oscilloscopes

1 OVERVIEW

Oscilloscope users consistently rate bandwidth, sample rate and memory depth as the three most important specifications. This application note will focus on oscilloscope selection considerations associated with acquisition memory. Selecting an oscilloscope with deep memory can save a significant amount of time during troubleshooting and debugging.

It is helpful to assess the goodness and quality of oscilloscope memory depth, versus just looking at a single figure. Understanding memory depth attributes and benefits ensures that the selected oscilloscope matches the desired needs and applications.

This document provides:

- A description of how oscilloscope acquisition memory is defined
- Insight into the relationship between memory and other oscilloscope parameters
- Examples where deep memory provides value

2 ACQUISITION MEMORY DEFINITION

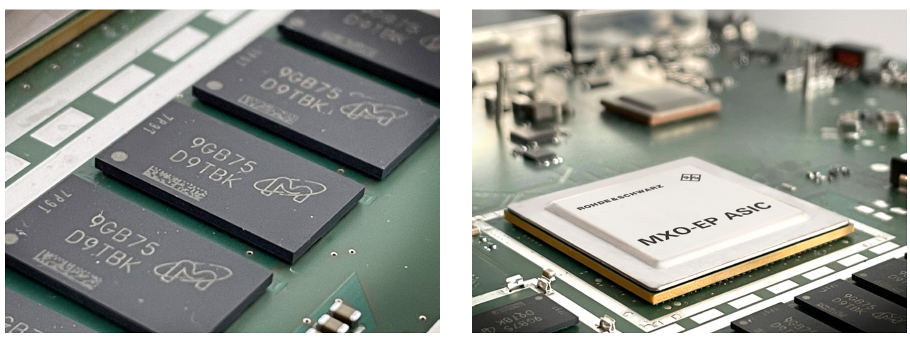
Acquisition memory – also referred to as memory (M) or record length (RL) – describes the number of samples that can be stored with each oscilloscope acquisition. The unit for specifying acquisition memory is the sample, typically referred to as a point (i.e. Mpoints) to avoid confusing sample rate (Msample/s) and memory depth (Msample). Memory depth equals the instrument's sample rate times the amount of time captured.

$$\textit{Acquisition memory} = (\textit{Sample rate}) \times (\textit{Time captured})$$

An oscilloscope that acquires a record length of 1 Msample in a single acquisition on one channel has acquisition memory of 1 Mpoints. If multiple channels each acquire 1 Mpoints of memory at the same time, the record length is still defined as 1 Mpoints. If a sample point comes from an 8-bit ADC or has 16 times more vertical information from a 12-bit ADC, it is still a single memory point.

Fig. 1: R&S®MXO 4 and R&S®MXO 5 Series oscilloscopes include MXO-EP (extreme performance) ASIC technology to maintain a fast deep memory update rate

The 28 nm CMOS ASIC powering the industry's fastest deep memory update rate contains 36 million gates and can process 200 Gbit/s.



2.1 Is more better?

If all other attributes are equal, an oscilloscope with more memory depth will always be more valuable than an oscilloscope with less acquisition memory. However, more memory also comes with a tradeoff when the additional memory is utilized. Oscilloscopes are processing-intensive instruments. As more memory is utilized, the processing requirements increase, slowing down overall oscilloscope operation. Ideally, an oscilloscope would offer an infinite amount of acquisition memory, but only use just the amount needed and no more for a specific application to keep the oscilloscope as responsive as possible.

In practice, most users do not know how much memory their current oscilloscope has and tend to figure out how to creatively debug and test using whatever memory is available. When a team selects a new oscilloscope, they often buy more memory as an insurance policy for potential future needs. After the transition, they wonder how they ever got along with a smaller amount.

Standard or pay option?

All oscilloscopes have a defined amount of base acquisition memory that comes standard with the oscilloscope purchase. Historically, oscilloscope manufacturers produced different versions of hardware, each with a specific amount of total acquisition memory. In the early 2000s, manufacturers found it more economical to create a single hardware platform with the deepest memory that would be used. Instruments come standard with a portion of this acquisition memory enabled, then via a software license, users can enable more of the available acquisition memory. Many users also liked having a lower initial purchase price with less memory, but with the flexibility to license more memory as their needs evolved. Oscilloscope manufacturers may have a specification that references the base memory or might communicate a memory depth specification associated with a larger acquisition memory depth that is enabled with a for-pay option. Without looking at a data sheet, it is often difficult to determine if a manufacturer's memory value is the base memory value included with the instrument, or if the memory value is a maximum value associated with an additional for-pay option.

3 MEMORY DEPTH IS NOT A STATIC VALUE

Have you ever purchased a product for a couple of banner specifications and then found out they were mutually exclusive? Not all oscilloscope manufacturers specify acquisition memory depth in the same way. Oscilloscope manufacturers typically provide a banner specification for memory depth, but this depth might not be available based on different oscilloscope settings. Most oscilloscope architectures have tradeoffs between memory depth and other oscilloscope settings. Let's take a look at a few common ones.

3.1 Number of channels

Internal to the oscilloscope architecture, there is a memory controller and some fixed amount of acquisition memory – typically, a fast in slow out (FISO) DDR memory architecture. The total available DDR memory in the system will be a much higher amount since it is shared across channels, reference waveforms and other functionality.

Fig. 2: Many oscilloscopes have a tradeoff between the number of channels that are enabled and the maximum memory available per channel

Many oscilloscope architectures provide a maximum memory specification that applies when up to half of the analog channels are turned on, but drops by a factor of two when analog channels that share the same processing and storage path are simultaneously enabled. For example, an oscilloscope may have memory depth of 4 Mpoints when only channel 1 is enabled, but when channel 2 is additionally turned on, the memory depth per channel drops to 2 Mpoints.

For many oscilloscopes, the memory architecture is shared across both analog and digital channels. Digital channel samples consume less sample space as they are only 1 bit. However, digital channels are typically turned on in granularity of 8 or 16 channels at a time, so overall memory consumption can be high. For example, an oscilloscope that starts with 4 Mpoints of acquisition memory on a single channel drops to 2 Mpoints memory when two channels are enabled, and drops again to 1 Mpoints memory depth when MSO logic channels are turned on.

3.2 Single versus run mode

Depending on the oscilloscope architecture, the maximum memory depth specification may be different if the oscilloscope is running repetitively or if a single acquisition is taken. The maximum depth applies definitively to a single-shot acquisition. However, it might be half the value when the oscilloscope is running repetitively. Oscilloscopes with faster throughput architectures have two acquisition engines running sequentially and storing to acquisition memory sequentially. In run mode, they each have access to half of the memory, while in single mode – since the update rate is not important –, just one engine is running and has access to twice the amount of storage space. On other oscilloscopes, the memory depth is identical in single versus run mode. It depends on the oscilloscope architecture and the decisions that were made when designing the oscilloscope.

For the above example of an oscilloscope with 4 Mpoints of memory with one channel, this value drops to 2 Mpoints with two channels and 1 Mpoints with digital additionally added. The oscilloscope drops to 512 kpoints when in run mode.

4 DEEP MEMORY

4.1 How much is deep?

The definition of deep memory varies from manufacturer to manufacturer and has changed over time. Early digital oscilloscope acquisition memory was measured in hundreds of points and evolved to kpoints in the 1990s. Today's oscilloscopes have acquisition memory depth typically in the tens to hundreds of Mpoints. Manufacturers will claim to have deep memory even though a competitor may offer up to 100 times more acquisition memory depth. This is particularly the case for oscilloscopes that have been on the market for a long period of time: When they were new, their memory depth was considered deep, but relative to current competitors, the memory depth is small. Many types of embedded hardware testing can benefit from oscilloscope deep memory.

4.2 Application examples

Need to capture long time

The boot time of a power supply is a classic example of something that occurs in "human" time. Power sequencing takes tens of milliseconds. While turning voltage rails on/off does not require higher bandwidths and high-speed serial buses, other system components have signals that require higher bandwidth analysis in parallel with power sequencing events. For this, deep memory is extremely beneficial to capture sufficient time with sufficient bandwidth.

Root cause and symptom are separated in time

Sometimes the source of a problem is greatly distanced in time from a symptom that is observable. Having deep memory enables teams to isolate the symptom, then track back to the root cause.

Need to solve complex problems

Deep memory in an oscilloscope can unravel problems faster. Electromagnetic interference (EMI), crosstalk/cross-coupling and related issues can plague many different parts of a design. Often, the device impacted is operating at full speed, but the source of the problem is occurring in milliseconds or seconds.

Serial buses

Low-speed serial buses such as I^2C, SPI, RS-232, CAN or LIN are often used as the control elements for digital designs. In many cases, because these are the source of change or action on the system, they are used to troubleshoot and understand system behavior. While protocol triggers can help, visibility across many bursts or packets of data is often required to gain insight. Two commonly used methods to view multiple bursts, i.e. reducing sample rate on the oscilloscope or viewing multiple packets with segmented memory, have tradeoffs. Reducing sample rate to capture more time runs the risk of undersampling the serial bus and not being able to trigger or decode correctly. Using segmented memory eliminates the ability to see between trigger events and often limits analysis capabilities since the oscilloscope may only be able to analyze packets in a given segment, but not across segments.

When further analysis is needed

Several applications require users to collect as much information as possible, then analyze this data after collecting it. This "swallow and wallow" approach can involve further analysis using oscilloscope tools and analysis applications, or might require offloading the instrument's capture using MATLAB® or a Python script.

5 MEMORY, SAMPLE RATE AND BANDWIDTH RELATIONSHIP

Many users think of memory depth, sample rate and bandwidth as independent specifications with a constant value. However, in reality they are closely related.

Acquisition memory = (Sample rate) × (Time captured)

5.1 Capture more time at a specified sample rate

$$\text{Time captured} = \frac{\text{Acquisition memory}}{\text{Sample rate}}$$

Fig. 3: More memory means an oscilloscope can capture more time at a given sample rate

Many users want to capture a specific amount of time or as much time as they can. For a given sample rate, having more memory allows the user to capture longer periods of time. This benefit is obvious and appreciated. Additional memory depth allows the user to retain a needed sample rate or even a faster-than-needed sample rate. This provides some degree of confidence while also ensuring greater flexibility when acquiring a combination of slow and fast signals.

5.2 Retain needed sample rate when more time is captured

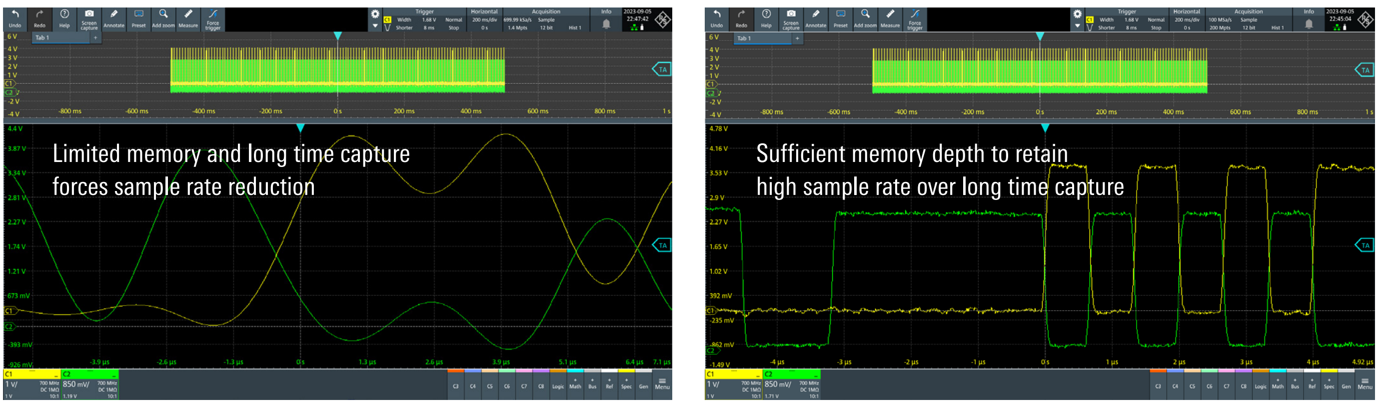
$$\text{Sample rate} = \frac{\text{Time captured}}{\text{Acquisition memory}}$$

When a user changes the oscilloscope timebase to a slower setting to capture more time, the capture rate remains constant until a maximum memory depth is reached. Beyond this point, when more time is captured, the instrument must reduce its sample rate. Turning the timebase to capture even more time further reduces the sample rate.

Often, this results in a sample rate that is insufficient for the rated oscilloscope bandwidth. Signals will be undersampled and aliasing can occur. This too can be frustrating since the measurement results will not be valid. A user thinking the oscilloscope bandwidth is 1 GHz may not realize that the sample rate is only sufficient for 1 MHz bandwidth.

There is no notification from the oscilloscope that the user might have a significant measurement problem. Oscilloscopes are not designed to let users know when the sample rate is not sufficient for the rated bandwidth and undersampling and/or aliasing is occurring. The challenge of identifying such issues is more difficult on oscilloscopes that do not display the sample rate at all times on the main display. For designs that have a combination of fast and slow signals, more memory is extremely beneficial for longer time capture with a sufficient sample rate for the fast signals.

Fig. 4: More memory means the instrument can capture more time without reducing the sample rate

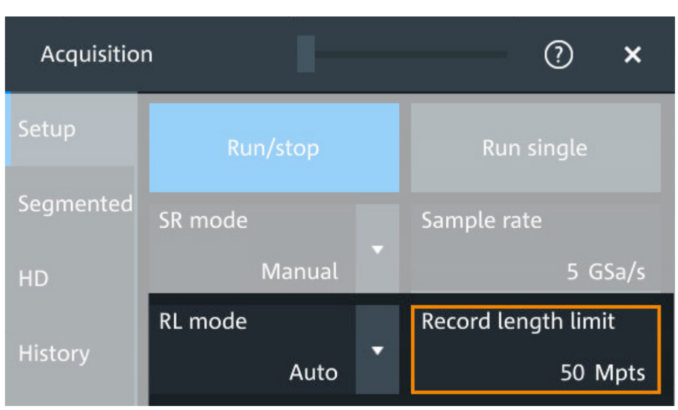


5.3 Relationship dependencies

By default, most oscilloscopes limit the amount of memory used. They do this to ensure the oscilloscope does not get sluggish when deep memory is enabled. For example, one manufacturer might have a default limit of 1.25 Mpoints memory while another has a default limit of 10 Mpoints, while both oscilloscopes have a maximum available memory that is greater than either of their default values.

Fig. 5: Record length limit setting of oscilloscopes

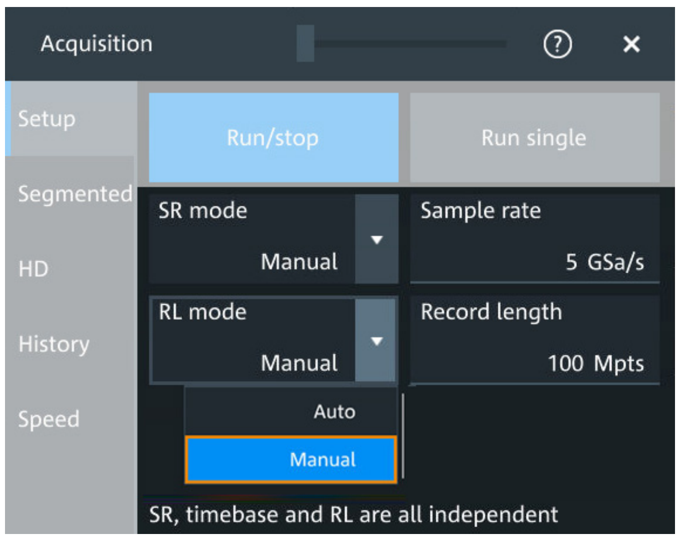
By default, this value is set to a lower value to enable the oscilloscope to achieve a faster update rate. Users can manually tell the oscilloscope to use more of the available memory by increasing this value.



Users must manually change the oscilloscope settings to allow the instrument to use more than the artificial default limit. To make this change, users might need to enter a manual acquisition setting dialog where they can control at least the sample rate. Some oscilloscopes do not allow the user to independently control the sample rate, or the oscilloscope may not allow the user to independently control the timebase, sample rate and memory depth.

This can lead to a frustrating user experience since the dependencies are not expected and there is no workaround. Oscilloscopes that allow the user to independently control all three settings are able to capture off-screen acquisition, which can be useful in some instances.

Fig. 6: The R&S®MXO 4 and R&S®MXO 5 Series allow users to set the sample rate, record length (memory) and timebase – all independent of one other



6 SEGMENTED MEMORY

Most oscilloscopes provide a segmented memory mode as a standard function or as a for-pay option. This mode provides a more effective way of capturing signals that are separated by periods when the signal is inactive. Examples include serial buses, pulse analysis and RF chirps.

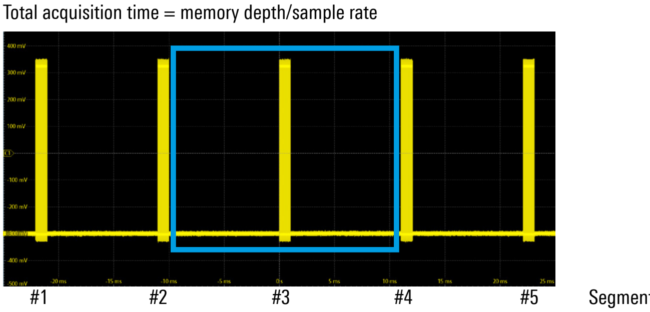
Using segmented memory, users define a trigger condition and a certain amount of memory surrounding trigger events. Each new trigger event creates a small acquisition by the oscilloscope. The period of time between trigger events when the signal is inactive is not captured and hence does not consume memory. This technique allows a single-shot capture across a longer time duration than would have been possible in a single monolithic acquisition.

Fig. 7: Segmented memory saves only a capture window around the trigger event for more efficient memory utilization in applications where a single-shot acquisition is sufficient

More memory means the instrument can have more segments, a higher sample rate or more time with each segment.

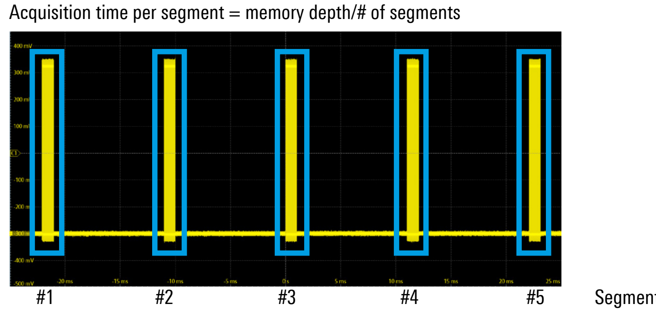
Traditional single-shot acquisition

Total acquisition time = memory depth/sample rate



Segmented memory acquisition

Acquisition time per segment = memory depth/# of segments



While segmented mode allows more efficient utilization of acquisition memory, there are tradeoffs:

- It is a single-shot acquisition and does not work well in run repetitive mode.
- Viewing the measurement results involves moving through multiple acquisition screens. Analysis across segments often has limitations or is more difficult.

Segmented mode does not compensate for shallow memory. The amount of memory available per segment equals the maximum memory divided by the number of segments. An oscilloscope with more memory depth has more powerful segmented memory since it can capture more segments, or each segment can include more time, or the overall sample rate of the oscilloscope can be higher.

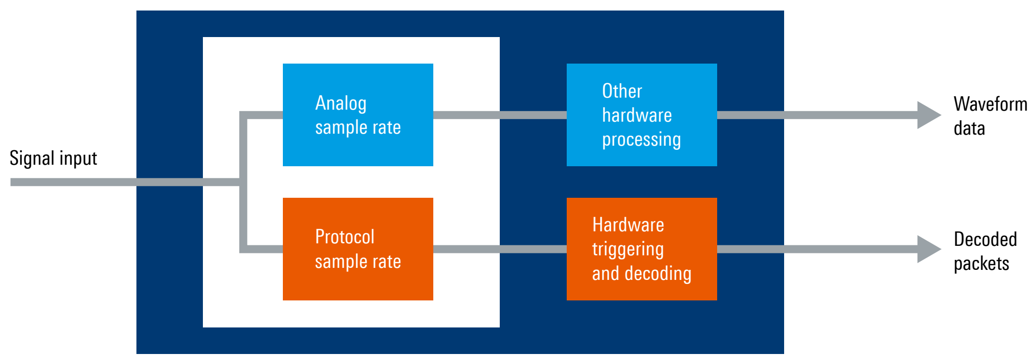
History mode is closely related to segmented mode. Segmented mode setup is handled by the user. For history mode, the oscilloscope automatically saves sequential acquisitions in the background. By pressing STOP, the user can go back and view the previous acquisitions.

7 SERIAL BUS DECODING AND MEMORY

Serial buses provide excellent points of visibility for debugging and testing. Oscilloscopes can be equipped with serial bus triggering and decoding applications that support testing at the protocol packet level. It is often very difficult to determine the correlation between deep memory and the number of packets that can be captured. For each protocol, the oscilloscope must maintain a specific sample rate for correct decoding of that protocol, and each protocol has a physical layer structure that is unique.

Fig. 8: Dual-path protocol analysis

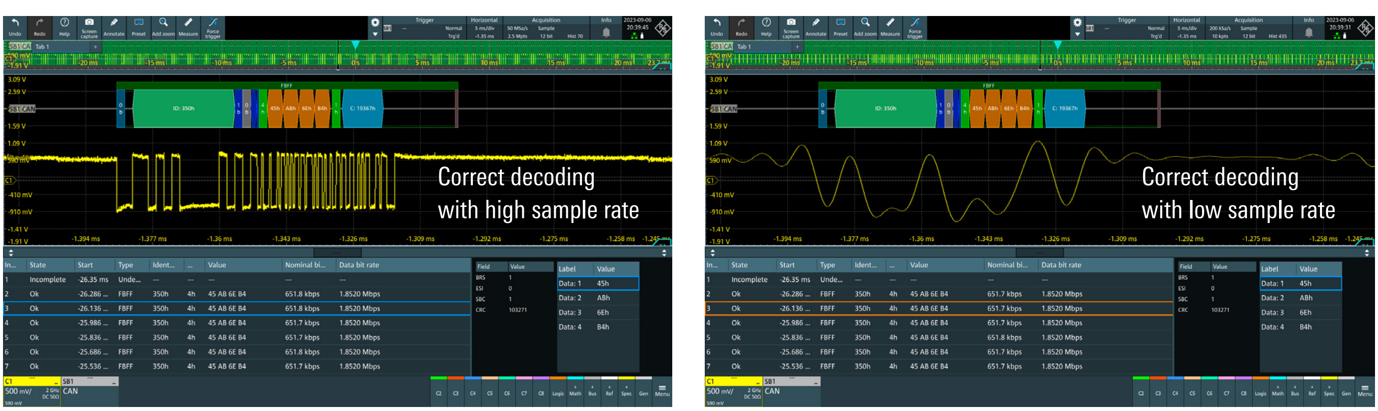
The R&S®MXO 4 and R&S®MXO 5 Series oscilloscopes are the first in the world that support dual-path protocol analysis. This innovation solves problems with oscilloscope decoding over long periods of time. A separate packet decode memory means a more responsive oscilloscope with a deterministic number of maximum packets that can be captured.



Rohde & Schwarz has introduced an innovative technique for packet decoding when long time duration capture is needed. The instrument's architecture provides two key benefits that alleviate many problems: The instrument has a dual path for protocol decoding that samples at a rate that is sufficient for popular serial buses like I^{2}C, SPI, RS-232, CAN and LIN. If the instrument has a long timebase and a lower analog sample rate, it still correctly triggers and decodes serial buses. This technique allows a large number of packets to be decoded correctly, even with a lower analog sample rate.

Fig. 9: Dual-path protocol analysis in the R&S®MXO 4 and R&S®MXO 5 Series oscilloscopes

This technique provides accurate packet triggering and packet decoding even if the original serial bus signals are severely undersampled. This allows users to capture a longer time duration with serial decoding.



8 CONCLUSION

Acquisition memory deserves its key specification status next to bandwidth and sample rate. Oscilloscopes with more acquisition memory offer greater flexibility to capture longer periods of time and retain higher sample rates with longer timebases, while providing insurance for both current and future application testing and debugging needs.

When selecting an oscilloscope, be sure to compare the relevant memory depth requirements and understand the settings associated with the demand to make equivalent comparisons. An oscilloscope's ability to quickly process more memory ensures a responsive instrument along with higher testing productivity.

Fig. 10: Rohde & Schwarz offers a portfolio of oscilloscopes that include deep standard memory

Parameter	R&S®RTM3000 Series	R&S®MXO 4 Series	R&S®MXO 5 Series	R&S®RTO6 Series
Standard memory (across four channels)	40 Mpoints	400 Mpoints	500 Mpoints	100 Mpoints
Maximum memory	80 Mpoints; 400 Mpoints segmented memory	800 Mpoints	1 Gpoints	2 Gpoints
Independent sample rate, record length and timebase		•	•	
Segmented memory	R&S®RTM-K15 option	•	•	•

Rohde & Schwarz

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