The Impact of Digital Oscilloscope Blind Time on Your Measurements

Application Note

Products:

- R&S®RTO1012
- R&S®RTO1014
- R&S®RTO1022
- R&S®RTO1024

All digital oscilloscopes are temporarily blind. During this blind time the user will miss critical signal events at his device under test. Thus, it is necessary to understand the impact of blind time to the measurement.

This application note explains the background of blind time and points out why a high acquisition rate is important. It furthermore explains the R&S RTO oscilloscope capabilities and how they help for faster debugging, measurement and analysis.

Application Note

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ROHDE&SCHWARZ

Table of Contents

1 What is blind time?

Some people might remember the first digital oscilloscopes introduced in the early eighties. They represented a great technology revolution, but also a paradigm shift for the users. The use of digital technology offered the advantages of waveform post-processing and permanent data storage, but this came at the cost of slow display update rates. Over time digital oscilloscopes have made tremendous improvements and have nearly displaced analog oscilloscopes.

But how much can you really trust the digital oscilloscope's display of your measurement signal? Are you aware that your oscilloscope is blind most of the time? And how does this affect your ability to debug signal faults in your complex design?

1.1 The architecture of a digital oscilloscope

A basic understanding of the digital oscilloscope architecture is required to understand the source of blind time. The typical building blocks of a digital oscilloscope are shown in Figure 1.

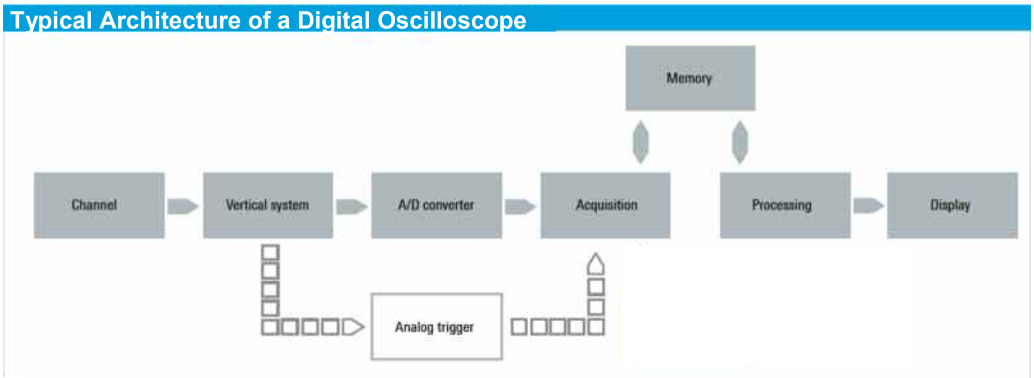

Figure 1: Typical block diagram of a digital oscilloscope

The measurement signal enters the oscilloscope at the channel input and is conditioned by attenuators or amplifiers in the vertical system. The analog-to-digital converter (ADC) samples the signal at regular time intervals and converts the respective signal amplitudes into discrete digital values called "sample points". The acquisition block performs processing functions such as filtering and sample decimation. The output data are stored in the acquisition memory as "waveform samples". The number of samples in the waveform record is defined by the user settable "record length".

Depending on the user's requirements, further post-processing can be performed on these waveform samples. Post-processing tasks include arithmetic functions like averaging, math operations like FIR filtering, automatic measurements like rise or fall times, and analysis functions like histograms or mask testing. Other post-processing examples include protocol decoding, jitter analysis, and vector signal analysis.

For a digital oscilloscope there is principally no limitation on the processing steps performed on the waveform samples. Depending on the oscilloscope's architecture, these post-processing functions are executed in software via the instrument's host processor or in hardware with dedicated ASICs or FPGAs. The final results are then presented to the user on the oscilloscope's display.

Once this cycle from signal sampling to waveform display is completed, the oscilloscope is ready to acquire a new waveform.

1.2 Blind time - a characteristic of digital oscilloscopes

Users of analog oscilloscopes are used to seeing nearly all signal details on the screen. The glow of screen's phosphor provides a natural persistence that is used to quickly detect signal faults.

While analog oscilloscopes just need to reset the horizontal system for the next electron beam sweep, digital oscilloscopes spend most of the acquisition cycle post-processing the waveform samples [1]. During this processing time the digital oscilloscope is blind and cannot monitor the measurement signal. Therefore only snapshots of the measurement signal are possible with digital oscilloscopes. Although many digital oscilloscope users are not aware of the fact that the oscilloscope is blind most of the time, this characteristic has a significant impact on the amount of detected and finally displayed signal details.

Definition of acquisition cycle, acquisition rate and blind time ratio

Figure 2 shows an example of a waveform acquisition cycle. The acquisition cycle consists of an active acquisition time and a blind time period. During the active acquisition time the oscilloscope acquires the defined number of waveform samples and writes them to the acquisition memory. The blind time of an acquisition consist of fixed and variable portions of time. The fixed parts are determined by the individual instrument architecture. The variable part depends on the time required for processing and is a function of the number of waveform samples (record length and number of active channels) and the number of selected post-processing functions (e.g. interpolation, math functions, measurements, and analysis). In a final step within the blind time period a graphic engine prepares the waveform samples for the display and the oscilloscope rearms its trigger in preparation for a new acquisition.

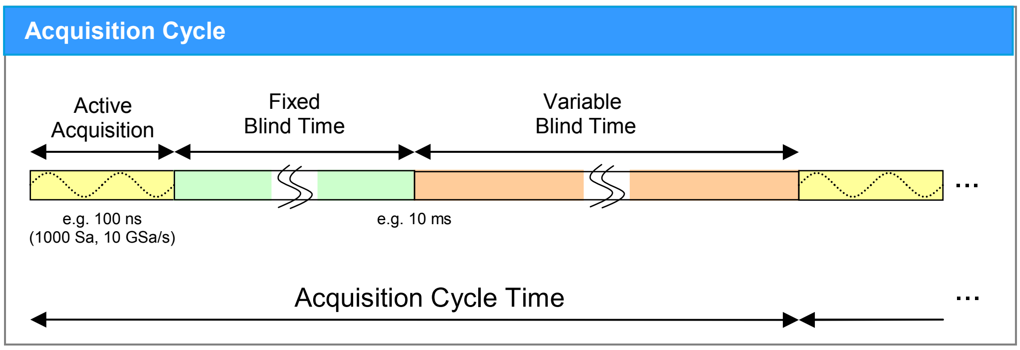

Figure 2: Acquisition and analysis cycle of a digital oscilloscope

The ratio of the active acquisition time to the blind time is an important characteristic of a digital oscilloscope. It can be defined either as the blind time ratio or the waveform acquisition rate.

Equation 1: $$blind\_time\_ratio = \frac{blind\_time}{acquisition\_cycle\_time}$$

Equation 2: $$acquisition\_rate = \frac{1}{acquisition\_cycle\_time}$$

For example, if the active acquisition time is 100 ns and the blind time is 10 ms then the overall acquisition cycle is 10.0001 ms. This results in a blind time ratio of 99.999% and a waveform acquisition rate of less than 100 waveforms per second.

High amount of data - the challenge of processing power

A natural reaction to the discussion so far could be to say "Let's build a faster digital oscilloscope with improved processing power and pipelined architecture".
However, such a solution would require massive processing capabilities. For example, a digital oscilloscope with a 10 Gsample/s 8-bit ADC produces 80 Gbits of continuous data that must be processed and displayed every second. In addition, DSP filtering, arithmetic operations, analysis functions and measurements are often applied to the waveform samples which require additional processing power. Real-time processing with no blind time is currently not feasible for a digital oscilloscope in a laboratory environment. Nevertheless, the need for the shortest possible blind time still remains a valid requirement, as engineers do not want to miss critical signal details and require high number of acquired waveforms for reliable analysis results.

Measurement of the blind time of my oscilloscope

There are various ways to evaluate the actual waveform acquisition rate, and the corresponding blind time of a digital oscilloscope. Since the waveform acquisition rate can vary with instrument setup, the evaluation must be performed for the current measurement conditions.

Some oscilloscopes offer an acquisition counter, others have a direct acquisition rate performance display. Another possibility is to monitor the trigger out of the oscilloscope. Every rising edge represents a new acquisition.

Just be careful to ensure that the signal source contains available trigger events that occur more frequently than the expected waveform acquisition rate. Otherwise, the measurement results will not show the true oscilloscope performance.

2 What is the impact of blind time?

As section 1 provides some background information on the existence of blind time, the natural question then is: How does blind time affect the oscilloscope measurements? The oscilloscope user expects high confidence and trust in the displayed signals. This includes expectations of accurate timing and amplitude representation, as well as a completely monitored signal behavior over time.

2.1 Invisible signal faults

In a typical test scenario the user performs a series of measurements in an attempt to determine the source of faulty system behavior. Another scenario could be that the user tries to prove fault-free operation over many signal periods. A good approach for these kind of applications is to use a standard trigger event such as "edge" and enable the "persistence" mode to monitor signal changes over time, Figure 4. This mode can be utilized to highlight rare signal events with different brightness and, or different color. Once the user knows the shape of the signal fault he can restart the acquisition with an appropriate trigger condition such as a glitch width or runt amplitude. This 2-step approach, however, is only possible with repetitive signal behavior. Debugging an unknown single event is not possible.

Figure 3, on the other hand, shows that signal events occurring during the blind time will not be captured and, therefore, will not be displayed. They remain invisible for the user. The only chance to detect these kind of faults is if the faulty signal behavior repeats over time. With a long observation times the probability increases that the faulty signal behavior will then coincide with the oscilloscopes' active acquisition time.

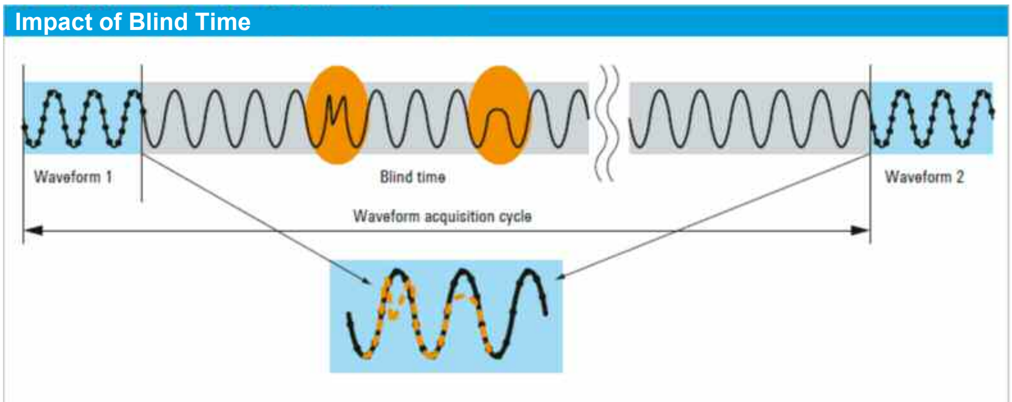

Figure 3: Signal events occurring during the oscilloscopes blind time remain invisible for the user

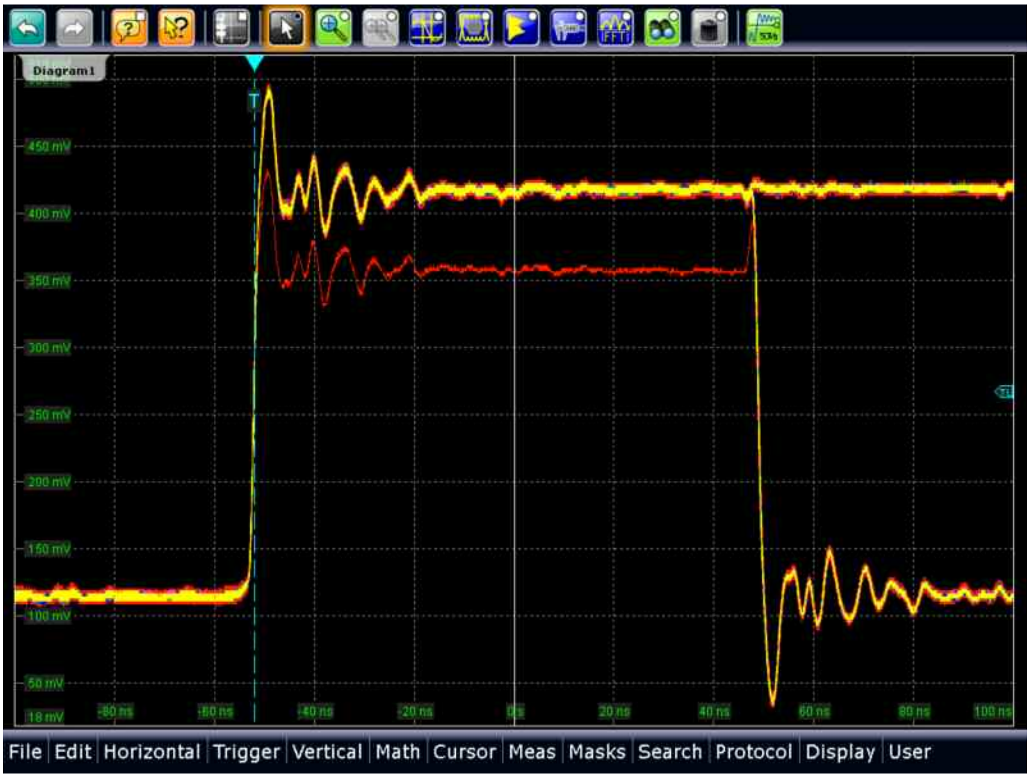

Figure 4: With the persistence view rare signal behaviors are highlighted. In this example sometimes a runt occurred.

2.2 The impact of blind time on the measurement

Digital oscilloscope user must be aware that their measurement tool only observes fractions of the signal. The following section discusses a few areas where blind time impacts the measurement results.

Instrument responsiveness

The most obvious issue with blind time is the instrument responsiveness. Oscilloscope users will often increase the time base in order to improve the probability of capturing an elusive event. It may not be obvious at this point, but increasing the time base can indeed result in a shorter blind time ratio. Unfortunately, the longer record length results in a reduced acquisition rate and a much slower waveform update rate. This can become quite frustrating when the instrument settings must be varied while in continuous run mode. After every setting change that requires a new acquisition the user must pause and wait for the result of that change to appear on the display.

Detection of rare signal faults

Blind time has the largest impact on the debugging process where rare signal events need to be found and analyzed. As previously discussed, signal faults can only be displayed when they occur within the active acquisition time of the acquisition cycle (Figure 3). For a typical digital oscilloscope the active acquisition time is much below 1%. The user therefore relies on repeating signal conditions and long wait times. Eventually, the active acquisition time of the oscilloscope will coincide with the signal anomaly. A shorter blind time supports faster detection of unknown signal behavior. A more detailed discussion on the test time impact for rare signal faults follows in section 2.3.

Confidence in analysis results

Analysis functions such as measurements, mask testing (Figure 5), histograms and FFT's require additional processing time and therefore extend the blind time of each acquisition cycle. The longer the waveform record length the worse the situation gets. Many of these analysis functions characterize the statistical behavior and worst case limits of the test signal. A longer blind time conflicts with the requirement to collect a large number of waveforms in order to achieve results with high statistical confidence. Long blind time, therefore, has a direct impact on the overall test time.

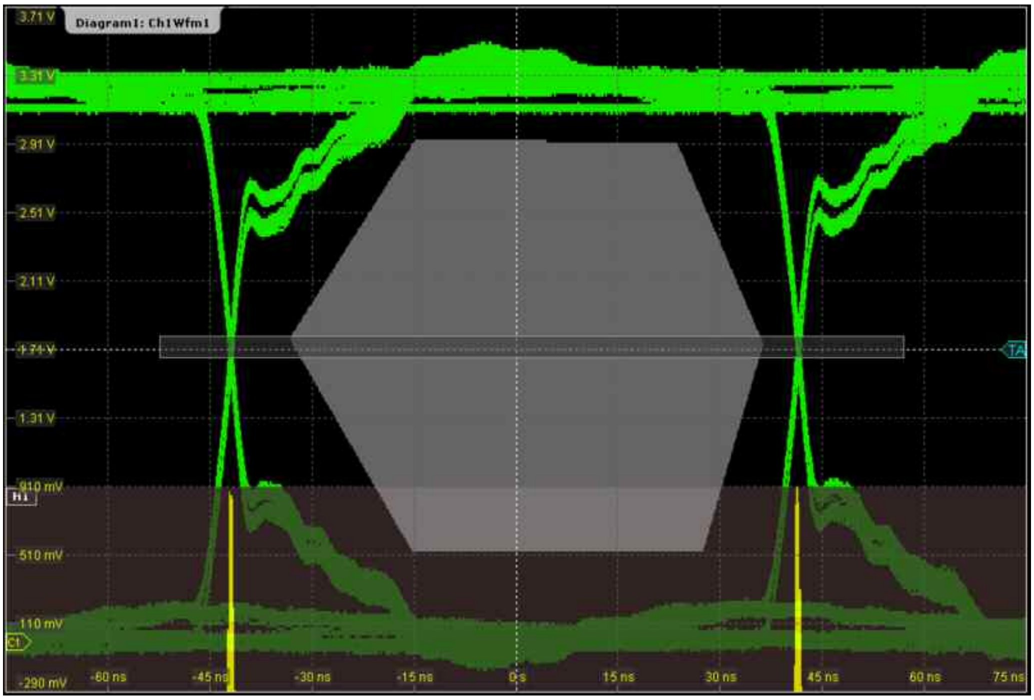

Figure 5: Mask or histogram test for verifying physical layer specifications require high number of acquired waveforms to get statistically reliable results

Reduced acquisition rate for math, cursor, and zoom functions

Other post-processing operations such as waveform arithmetic, cursor functions, and zoom windows require also additional processing time. Once these are activated the acquisition rate of the digital oscilloscope is typically reduced significantly. Given a fixed observation time, fewer signal details are included in the analysis and presented on the display.

2.3 Test time for capturing rare signal events

As described in section 2.1, a digital oscilloscope captures only a small portion of the test signal and, hence, misses signal details that occur during the blind time period (figure 3). Assuming the missed signal behavior repeats over time, statistics can be used to calculate the average time required to capture and visualize such signal events. In the following more details on the time required to capture rare signal events will be provided.

Calculation of statistical test time to capture rare signal events

For a given waveform acquisition time (i.e. number of samples * resolution, or 10* time scale), a given acquisition rate and a given signal event rate (e.g. repetition rate of a glitch), the probability to catch and display the signal event improves with increased measurement time according to following equation:

Equation 3: $P = 100 - 100 * (1 - GlitchRate * T)^{AcqRate * t_{measure}}$

P:	probability to catch a rare repeating signal event [%]
GlitchRate:	signal fault rate (e.g. repeating glitch) [1/s]
T:	active acquisition time or waveform display time (Record Length / sample rate, or Record Length * Resolution, or 10 * time scale per div) [s]
AcqRate:	acquisition rate [wfms / s]
$t_{measure}$:	measurement time [s]

In order to calculate the required measurement time for a certain probability, the following equation applies:

Equation 4: $t_{measure} = \dfrac{\log(1 - \frac{P}{100})}{AcqRate * \log(1 - GlitchRate * T)}$

Example of required test time to visualize a signal error

Assume a signal with an error repeating 10 times per second. The signal itself is a data signal that is displayed on the oscilloscope with a time scale of 10 ns/div. Having a display with 10 horizontal divisions an active acquisition time of 100 ns can be calculated. To ensure a high confidence level of capturing the desired signal event, a probability of 99.9% is used.

The required test time now depends on the acquisition rate of the oscilloscope. The following table shows the required test time for a few different waveform acquisition rates.

Acquisition Rate	Test Time
100 wfms /s	19 hours: 11 min : 08 s
10,000 wfms /s	11 min : 31 s
100,000 wfms /s	1 min : 09 s
1,000,000 wfms/s	7 s

Table 1: Average test time for catching repeating signal faults with a probability of 99.9% (T=100 ns, GlitchRate=10/s)

Example of probability to visualize a signal error

The following graph, Figure 6, shows the dependency of the required test time for a signal fault rate of 10 faults per seconds. With a higher acquisition rate the probability is clearly higher to catch a rare signal fault in shorter time.

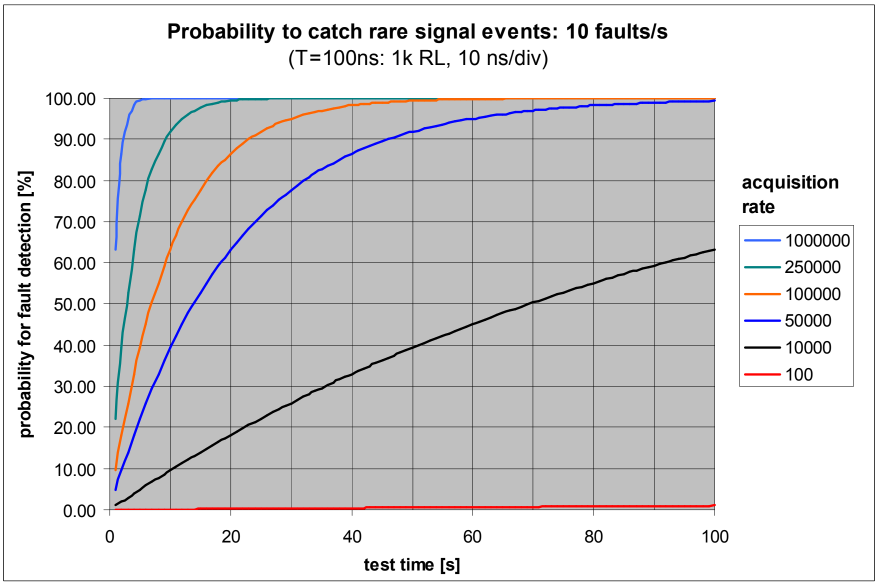

Figure 6: Probability of required test time to detect a rare signal event that occurs 10 times per second, in dependency of the oscilloscopes waveform acquisition rate

3 What are the trade-offs of current solutions to reduce blind time?

The long blind time of digital oscilloscopes limit the visibility of the test signal. Various strategies have been developed to work around this architectural issue.

3.1 "Single run" with deep memory

With a single waveform acquisition a continuous signal sequence can be captured. The post-processing happens after the "single run" is executed and, therefore, doesn't interrupt the signal sequence. The maximum active acquisition time depends on the sampling frequency and the acquisition memory size of the oscilloscope. With a typical memory size of 10 million samples and a sampling rate of 10 Gsample/s a maximum continuous recording time of 1 ms is possible. Even with deep memories like 100 Msample, a continuous observation time of only 10 ms is possible at this sample rate. In Table 2 a few more examples of the maximum capture duration as a function of the sample rate and memory size are given.

Capture Duration			
	10 Msample	**50 Msample**	**100 Msample**
10 Gsample/s	1 ms	5 ms	10 ms
5 Gsample/s	2 ms	10 ms	20 ms
1 Gsample/s	10 ms	50 ms	100 ms
500 Msample/s	20 ms	100 ms	200 ms
100 Msample/s	100 ms	500 ms	1,000 ms
10 Msample/s	1,000 ms	5,000 ms	10,000 ms

Table 2: Maximum Capture duration depends on sample rate and acquisition memory size

Trade-off
A reasonably long observation time to monitor a signal for unknown faulty behavior is often not possible with this approach. Even for those cases in which the faulty signal event is successfully captured, it may be very difficult, if not impossible, to identify on the display due to the enormous amount of data being presented.

3.2 Dedicated trigger events

In the 1940's the trigger system was invented in order to obtain a stable waveform display. The first trigger event for an analog oscilloscope was the "edge" event. Modern digital oscilloscopes provide a variety of trigger events to help focus the acquisition on specific signal behavior. A few examples are glitch width, runt amplitudes or rise time.

Trade-off
Dedicated trigger events can help isolate signal faults, but the challenge is to know what trigger event is required. During the debug process the specific signal fault behavior is initially unknown. Even though some oscilloscope's support a learning routine to come up with trigger suggestions, a manual interaction is required to decide whether a suggested trigger event is usable.

3.3 Special acquisition modes

To reduce blind time some oscilloscopes support special acquisition modes. In such modes the available post-processing functions are limited in order to reduce blind time and to accelerate the waveform acquisition rate. Other approaches use dedicated processing paths that bypass the standard acquisition and processing blocks and just focus on the fast display of the waveform pixels.

The goal of such special acquisition modes is to monitor the signal and highlight unusual signal behavior with special color grading (persistence mode). The higher acquisition rates of these special acquisition modes come with a price, however. Limited functionality like no access to analysis tools, limited oscilloscope control, or not being able to save the waveform data are just a few examples.

Trade-off
The use of these special acquisition modes requires a two-step approach. First, the user tries to visualize critical signal behavior. In the second step a dedicated trigger event is used to capture the critical signal event again. As a consequence the analyzed signal behavior from the second step differs from the signal behavior of the initial monitoring step.

Additionally, no or limited analysis functions are available with such fast viewing modes. Processing tasks in combination with the standard mode remain time consuming.

3.4 Faster acquisition without special mode needed

The best solution is to accelerate the acquisition and processing in such a way that the blind time in the oscilloscope's standard operating mode is reduced dramatically. The advantages of a shorter blind time are then combined with the full functionality and analysis capabilities of the oscilloscope. Most standard oscilloscopes operate with an acquisition rate below 100 waveforms/s.

Trade-off
Some oscilloscopes in the basic to mid performance, ≤ 1 GHz bandwidth class reach higher acquisition rates such as ≤ 50,000 waveforms/s at a maximum sample rate of 5 Gsample/s or ≤ 95,000 waveforms/s at a maximum sample rate of 2 Gsample/s. So far no adequate solution for faster sample rate instruments in the ≥ 1 GHz class was available.

4 The R&S®RTO oscilloscope's approach

The design of the R&S®RTO digital oscilloscope targets a minimum blind time in the standard acquisition mode. The following capture provides more details on the RTO's architecture and the associated benefits.

4.1 RTO architecture: designed for minimal blind time

The discussion in chapters 1 and 2 showed that the key contributors to the blind time are the data processing and the display preparation. Therefore the RTO architecture focuses on optimizing the processing paths and graphic controller tasks.

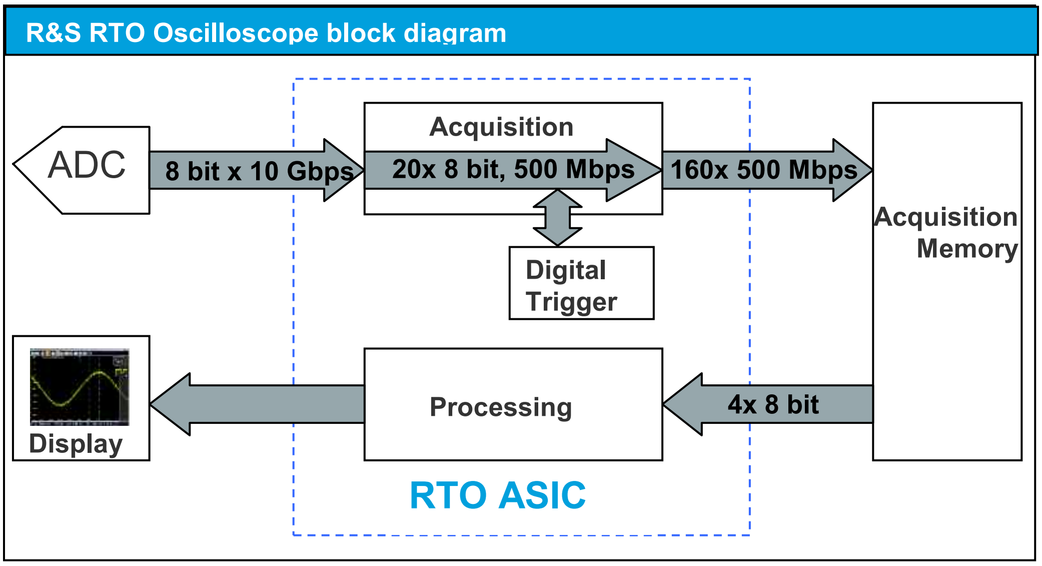

Figure 7: RTO oscilloscope architecture minimizes blind time

Figure 7 illustrates the processing paths of the R&S RTO Oscilloscope which are implemented in a dedicated ASIC. It is crucial for digital oscilloscopes that they write the samples from the ADC to the acquisition memory in real time. The difference for individual oscilloscope models then lies in the processing capabilities that can be added to this real time path.

The RTO acquisition block, for example, includes deskew capabilities, DSP filters and mathematical channel combiner functions (add, sub, inv) in the real time path. The also included decimation block even can output three waveforms based on different decimation operations (Sample, HighRes, PeakDetect, RMS) in parallel.

The key to maintaining the high data throughput is the use of massive parallel processing. The RTO's 8 bit 10 Gsample/s ADC outputs 80G bits of data that need to be processed per second. In the acquisition block these data are handled at 20 parallel paths.

The processing path between the acquisition memory and the display also consists of multiple paths (up to four). As such, very short blind times are achieved even with additional waveform processing options active (interpolation, math, etc.). The RTO performs most waveform processing and measurement functions in the dedicated RTO ASIC. Unlike software based solutions, no CPU access and related data transfer is required.

With this architecture the processing path after the acquisition memory is able to achieve data throughput rates 1/5 that of the real time path in front of the acquisition memory. This translates into a theoretical active acquisition time of 20%. Overhead in the data handling reduces this to 10% in the real instrument when operating at the maximum sample rate of 10 Gsample/s. This is a very high number for digital oscilloscopes. The next fastest solution can only provide 0.5% active acquisition time at the sample rate of 10 Gsample/s, using a special fast display mode. For the RTO no such compromises are required. Other digital oscilloscopes acquire even slower with active acquisition times rather below 0.01%.

Additionally the RTO oscilloscope includes a real-time digital trigger system. The traditional approach is to utilize a separate trigger path that is implemented with analog circuitry. In this case, the two paths (acquisition and trigger) must be carefully aligned to minimize trigger jitter. This often requires post processing techniques to reduce the trigger jitter to acceptable levels. In the RTO the acquisition and trigger paths are the same, and therefore already aligned. This enables simultaneous real-time triggering, low trigger jitter, and a high acquisition rate.

The final bottleneck for high acquisition rates within a digital oscilloscope is the graphical display of the waveforms. The RTO ASIC, therefore, also includes a dedicated graphics engine that prepares the pixel representation of the accumulated waveforms for display. In order to adapt to the high data throughput of the overall ASIC, the RTO utilizes several graphical engines in an interleaved approach.

4.2 Maximum acquisition rate of 1 Million waveforms per second

The integration of multiple high-speed processing paths, the digital trigger, graphics engine and a sophisticated memory controller into a single ASIC (Figure 7) results in the shortest blind times and highest acquisition rates. The R&S RTO oscilloscopes acquire, process and display 1 million waveforms per second while capturing a 1000 sample record length at the maximum sample rate of 10 Gsample/s.

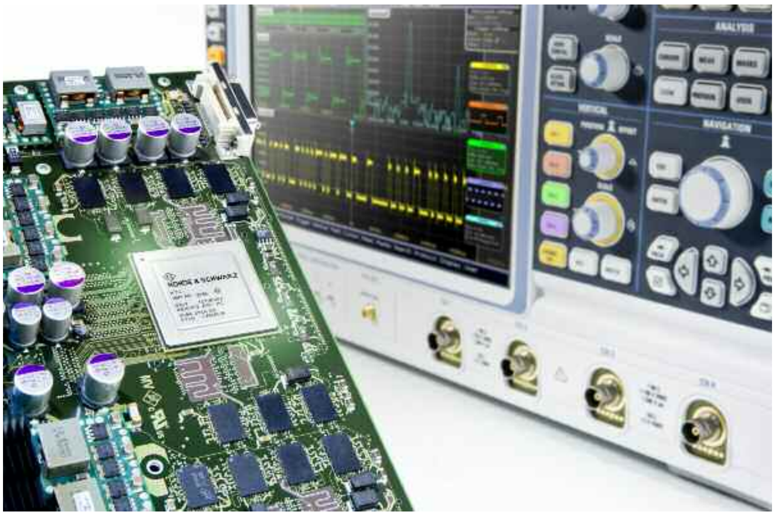

Figure 8: The RTO ASIC ensures shortest blind time with his high level of processing integration

As discussed in chapter 1.2, the acquisition rate depends on the parameter settings and the applied processing functions.
Figure 9 shows how the acquisition rate of the RTO relates to the time scaling and record length. The discussion in chapter 1.2 showed that the waveform acquisition rate decreases with longer waveform record length. This occurs because the longer active acquisition time produces a longer overall acquisition cycle. The blind time percentage, however, remains stable with the RTO for the different time scales while maintaining constant resolution.

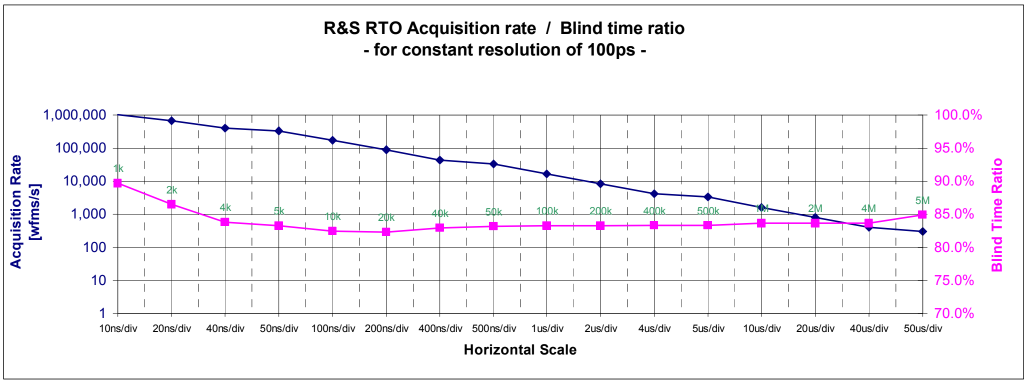

Figure 9: R&S RTO: Acquisition rate & Blind time ratio dependency for constant resolution

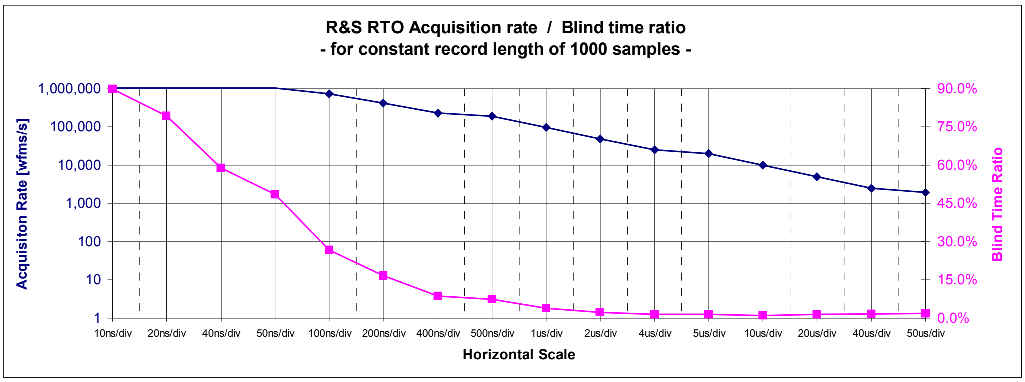

Figure 10: R&S RTO: Acquisition rate & Blind time ratio dependency for constant record length

An important point for the fast detection of rare signal faults is shown in Figure 10 and Table 3. For a constant record length the blind time percentage of the RTO oscilloscopes reduces further at slower sample rates and allows a more frequent active observation of the signal.

Application Hint

Whenever possible start with a reduced sampling rate to detect rare signal faults faster. At lower sampling rate a lower blind time percentage applies which provide a better signal coverage.

The reason for that behavior is that the same number of samples at slower timing scales corresponds to a longer active acquisition time while the processing time remains constant.

Sampling Rate	Time scale	Acquisition Rate	Blind time
10 Gsample/s	10 ns/div	1.020.000 wfms/s	90%
5 Gsample/s	20 ns/div	1.020.000 wfms/s	79%
2 Gsample/s	50 ns/div	950.000 wfms/s	52%
1 Gsample/s	100 ns/div	707.000 wfms/s	29%
100 Msample/s	1 µs/div	92.000 wfms/s	8%
10 Msample/s	10 µs/div	9.500 wfms/s	5%

Table 3: For constant record length the blind time percentage reduces at slower sampling rates: measurement examples of the RTO oscilloscope (1 channel, 1000 samples, dot mode)

4.3 Faster Results with analysis tools due to high acquisition rate

Another advantage is if high acquisition rates and short blind times can be maintained in combination with analysis functions. The more waveforms that are included in the analysis the higher the statistical confidence in the results. With a high acquisition rate the number of required waveforms is acquired faster, and the likelihood of detecting signal faults and including them in the analysis increases.

In the RTO the most important analysis functions are implemented in the ASIC. Due to the multiple processing paths the blind time is very short when these analysis functions are active. Table 4 gives an overview of the maximum acquisition rates that the RTO achieves for a few specific analysis functions. Conventional oscilloscopes reach with activated analysis tools maximum acquisition rates of 100...1000 waveforms per second.

Analysis functions	Maximum acquisition rate
none	> 1,000,000 wfms/s
Histogram	> 1,000,000 wfms/s
Mask test	> 600,000 wfms/s
Cursor measurements	> 1,000,000 wfms/s
Zoom	> 500,000 wfms/s

Table 4: Maximum acquisition rates of the RTO with analysis functions active

Figure 11 shows an example for a histogram analysis applied to the acquired waveforms. Thanks to its high acquisition rate the RTO can generate histograms based on a high waveform number in short time. This is crucial for trustworthy statistical results. During this example an acquisition rate of more than 1,000,000 waveforms per second was achieved.

Figure 12 shows another example of the RTO's high acquisition rate combined with an analysis function. The RTO achieves mask test results with high statistical confidence within seconds. In this example 6 million waveforms were captured within 10 seconds. The acquisition rate during the mask test exceeded 600,000 waveforms per second.

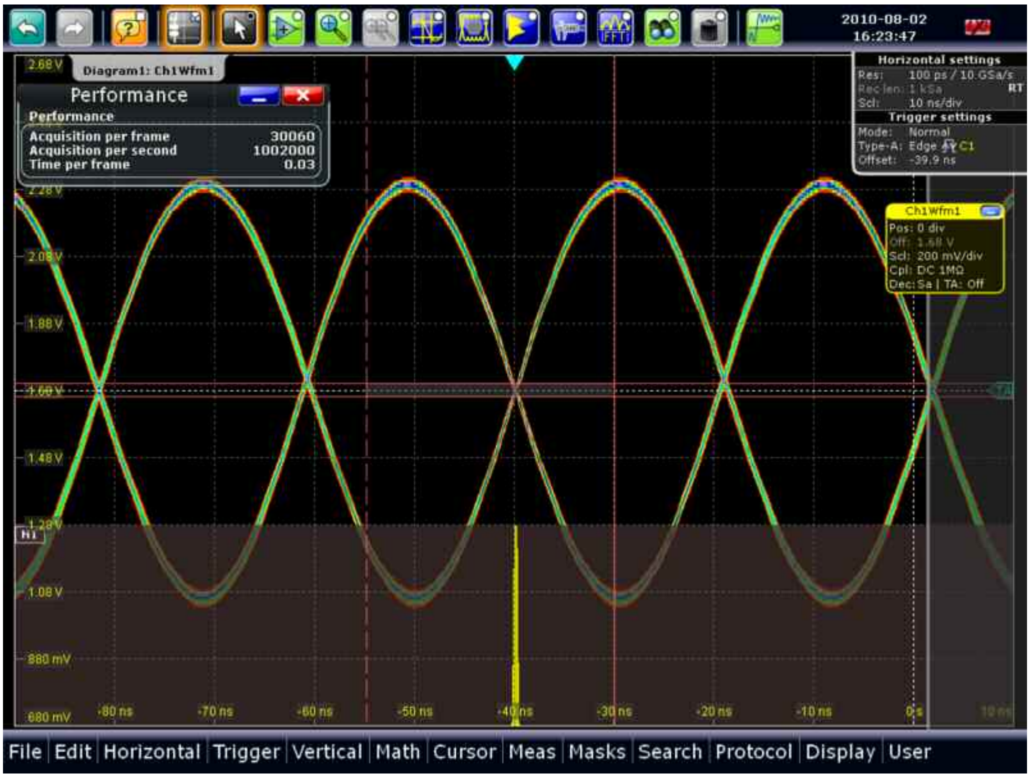

Figure 11: The high acquisition rate even with the histogram tool active enables in depth statistical analysis within short measurement time

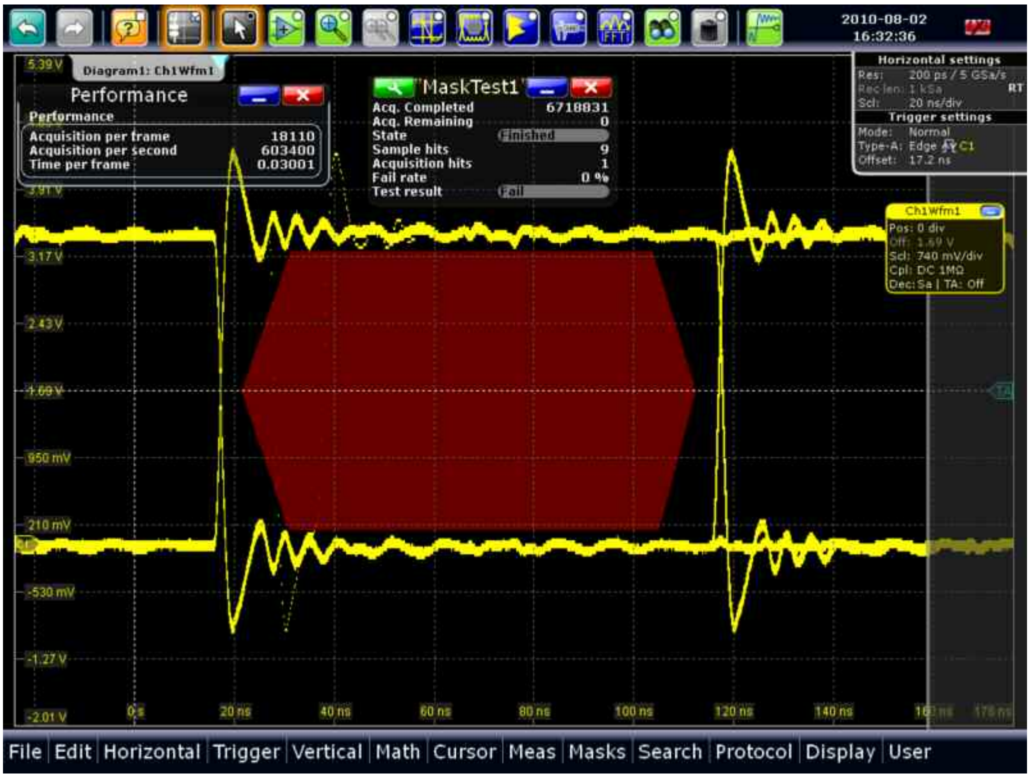

Figure 12: Fast Mask test results with high statistical confidence due to high number of waveforms: the R&S RTO executes mask test analysis with more than 600,000 waveforms per second.

5 Conclusion

All digital oscilloscopes are temporary blind which influences the confidence in the displayed signal details and the respective measurement and analysis results.

The R&S RTO oscilloscopes decrease the blind time tremendously due to their architecture and the high level of HW integration of the acquisition and processing functions.

Furthermore they offer a new level of debugging and analysis capabilities as the acquisition rate maintains high while performing measurement and analysis tasks.

The advantages of high acquisition rate and respective small blind times include:

- fast detection of rare signal faults
- good instrument responsiveness even with deep memory and analysis functions in use
- measurements results provide high statistical confidence
- decrease of overall test time for debugging and measurement tasks

These advantages combined with other outstanding features like digital trigger, high dynamic range (ENOB) and intuitive user interface make the RTO oscilloscope the tool of choice for your current and future development work.

6 Literature

[1] Hickmann, I.: Digital Oscilloscopes, Newnes, 2001
[2] R&S®RTO Digital Oscilloscope, Product Brochure
[3] R&S®RTO Digital Oscilloscope, Operation Manual

7 Additional Information

This Application Note is subject to improvements and extensions. Please visit our website in order to download new versions. Please send any comments or suggestions about this Application Note to TM-Applications@rohde-schwarz.com.

8 Ordering Information

Naming	Type	Order number
Base unit (included accessories: per channel: 500 MHz passive voltage probe (10:1), accessory pouch, Quick-start manual, CD with manual, power cord)		
Digital Oscilloscopes		
1 GHz, 10 GSample/s, 20/40 MSample, 2 channels	R&S®RTO1012	1304.6002.12
1 GHz, 10 GSample/s, 20/80 MSample, 4 channels	R&S®RTO1014	1304.6002.14
2 GHz, 10 GSample/s, 20/40 MSample, 2 channels	R&S®RTO1022	1304.6002.22
2 GHz, 10 GSample/s, 20/80 MSample, 4 channels	R&S®RTO1024	1304.6002.24

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