Advanced Signal Analysis using the History Mode of the R&S®RTO Oscilloscope

Application Note

Products:

- R&S® RTO1002
- R&S® RTO1004
- R&S®RTO1012
- R&S®RTO1014
- R&S® RTO1022
- R&S® RTO1024
- R&S®RTO1044

Rare faults and intermittent signals are difficult to capture. The R&S®RTO Oscilloscope supports the acquisition and the detailed signal analysis of these signals by using the history mode. The history mode allows the user to look back to previous acquisitions and apply the wide set of analysis functions of the RTO. Furthermore it stores the accurate recoding time of the waveforms for subsequent analysis.

Application Note

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ROHDE&SCHWARZ

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1 Introduction

Digital oscilloscopes are indispensable for testing and debugging of electronic and system designs, due to their versatility and flexibility. The requirements for state-of-the-art oscilloscopes are a higher sample rate for a better resolution of signal details and a deeper memory for capturing longer signal sequences. A remaining challenge is the acquisition of rare, random or intermittent events. These events typically appear only for a short duration and infrequently. In order to acquire such events in sufficient detail, a high resolution and a long acquisition time is needed. Both requirements, together, mean a challenge for the size of the sample memory.

To meet this challenge, the RTO provides the history mode to look up previous waveforms, if the acquisition is stopped, regardless whether manually, by violating measurements, or by mask limits.

- The most important application of the RTO history mode is the test and debugging of electronic designs. Modern electronic designs are complex and not trivial to test, because of high signal rates in combination with small signal magnitudes and a dense design footprint. In particular, rare faults affect digital designs. The effects caused by these faults in digital circuits are for example damage, outage due to reboot, or performance degradation.
- Another application example for the RTO history mode is the analysis of rare or random events in the area of nuclear and high-energy physics, pulsed laser, and pulsed radar applications. Physical events are converted to an electrical signal, but their presence is not necessarily predictable, but they occur as a series, and it is important to capture all events with reference to a consistent time base.

Besides the two mentioned examples, which particularly benefit from its functionality, the history mode can also be useful for many other applications.

Once enabled, the history mode provides complete access to previous acquisitions. The user can apply the entire suite of RTO analysis functions for each recorded waveform. The analysis functions include zoom, cursor, search, math, protocol decoding, mask test and measurement functions.

For repetitive signals with longer idle times in between the RTO is able to capture the active signals sequences applying high timing resolution in combination with a long observation time. For this case, the RTO acquires short waveforms with the signal events and maintains with its precision time base the timing relationship between the recorded waveforms. With the history mode, the user can analyze these recorded waveforms, as well as the timing relation among the waveforms in detail.

Additionally, the RTO offers a high waveform acquisition rate of up to 1 Million acquisitions per second to ensure a high probability of signal fault detection, which in turn reduces overall measurement time [1]. For signals with an unpredictable occurrence the high acquisition rate might be insufficient for capturing all signal events. In this case, the RTO features the "Ultra-Segmentation Mode" with a minimal idle ('dead') time between consecutive acquisitions of 300ns. These two features significantly raise the confidence in the integrity of the sequences of acquired waveforms.

To gain a good understanding of the history mode and to utilize its benefits best, the next chapter of this application note describes the general internal architecture and operation of the RTO. The third chapter explains the operation of the history mode, the organization of the associated memory and the limitations of the history mode. In the fourth chapter two examples demonstrate, how the history mode is configured for specific measurement tasks and how the user benefits from this feature.

2 Digital Oscilloscope Background

2.1 Operating Principle

Figure 1 shows the block diagram of the RTO, in which arrows indicate the data-flow between different processing blocks. The entire data-path from the analog front-end to the display is divided into two different sections, each one marked with a different color code.

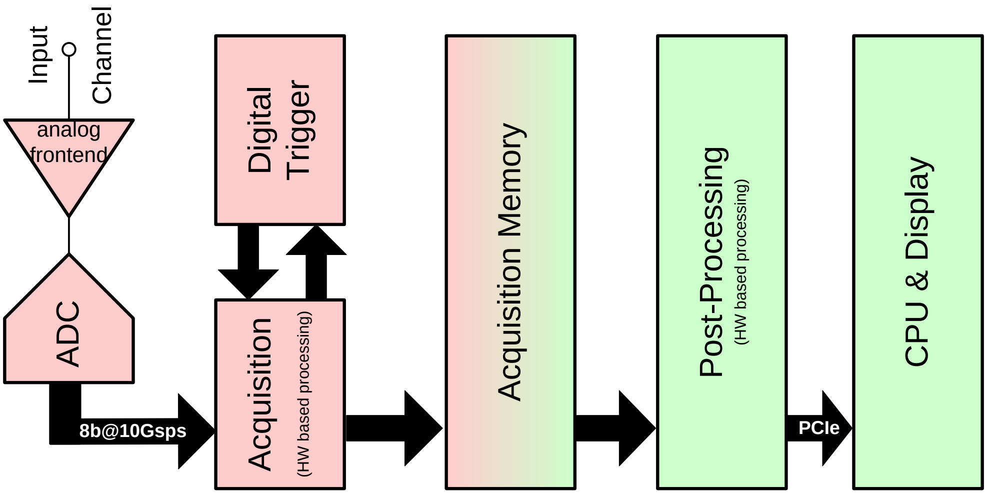

Figure 1 – R&S®RTO Oscilloscope Block Diagram

The first section is the acquisition path including the digital trigger block, marked in pink. It processes all input data in parallel before the sample data of each channel are stored in the acquisition memory. The processing steps consist of an analog pre-conditioning by the analog frontend, the sampling of the input signals with the A/D converter (ADC), and digital filtering and decimation stage in the acquisition block. At the end of the acquisition path, the samples are stored in the sample memory. In parallel to the acquisition processing, the RTO's digital trigger generates an event based on the digitized input signal. A valid trigger event controls the start of the acquisition.

The second section is the post-processing path denoted with a light green color. In this path, the RTO processes the selected analysis operations, like measurement, math, mask tests, cursor before the final display of the waveform. The acquisition memory is involved in both, the acquisition and post-processing phase, so it is marked with color grade from pink to light green.

These two sections work mutually exclusive in phases, in the following called acquisition phase and post-processing phase. A typical mode of operation is the continuous acquisition mode. During this mode, the two phases work in an alternating manner. Figure 2 shows the scheduling of this alternating operation, using the label 'acq' for acquisition phase, and 'pp' for post-processing phase. A trigger event starts the acquisition. The acquisition phase stops, once the acquisition memory has accumulated as many samples as specified by the record length. The next phase begins with the read-out of the recorded waveform from the acquisition memory to the post-processing section. Only if its processing is completed, the next acquisition phase can start again.

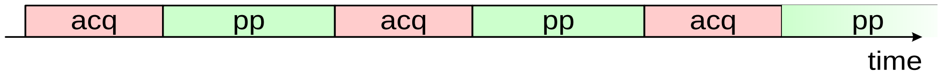

Figure 2 – Phase Scheduling of the RTO for "Continuous Acquisition" Mode

Figure 3 shows the complete RTO operation using the introduced color code. On the left-hand side, there is the acquisition block, which writes waveforms, indexed by a negative integer [1-n,0], into the acquisition memory marked by an arrow labeled with a 'W'. Right-hand side there is the post-processing block, reading the acquired waveforms out of the acquisition memory marked by an arrow labeled with an 'R'.

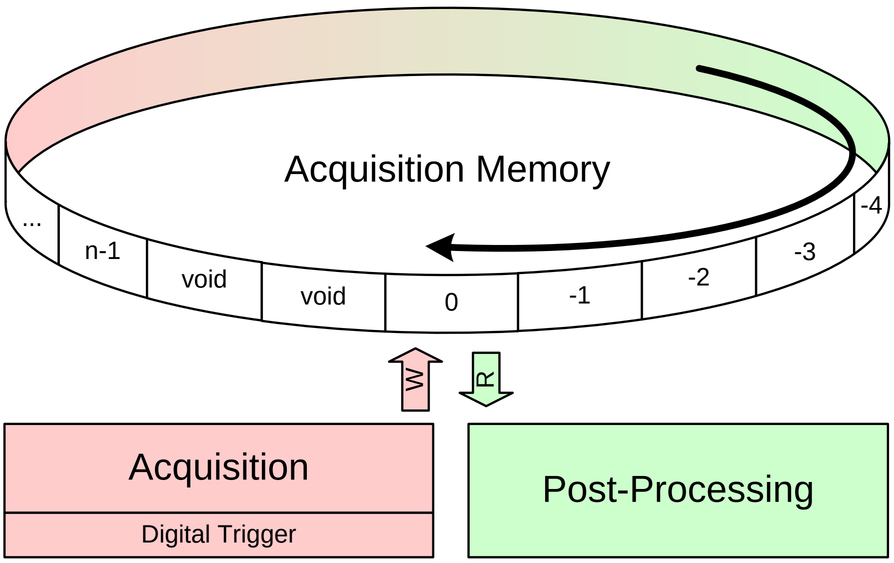

Figure 3 – Data Flow of the RTO

2.2 Memory Requirements

2.2.1 Setup Parameters

During the acquisition phase, the sample memory stores the acquired samples. The configured record length determines, how many samples are stored, and the sample rate determines how many samples per seconds are acquired. In the "Horizontal" dialog box of the RTO, both items can be configured (see Figure 4).

The maximum sample rate equals the sample rate of the ADC, which is 10 Gsample/s for the RTO. The standard size of the waveform memory of the RTO is 20 Msample per channel. Memory options for the RTO are available to upgrade to a deeper waveform memory. 50 and 100 Msample per channel are available with the RTO-B101 and the RTO-B102 options.

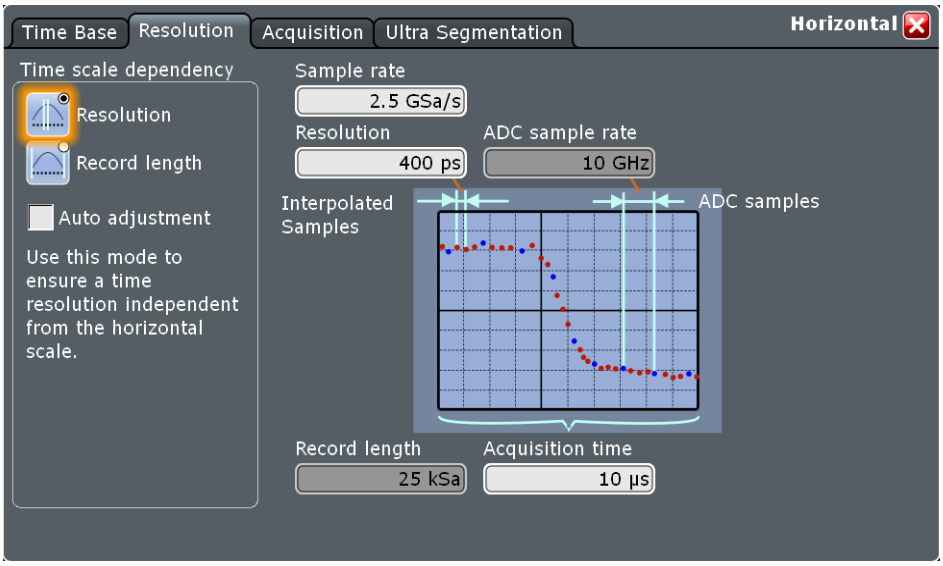

Figure 4 – Horizontal / Resolution Dialog Box

2.2.2 Memory Requirement for a Pulse Sequence Example

The example below highlights the memory requirements for the pulsed signal (see Figure 7) as introduced in chapter 1. The number of samples during an observation period depends on the selected sample rate, the number of pulses to be recorded and the pulse repetition rate. Equation (2-1) shows the corresponding calculation. Realistic and reasonable parameters to investigate the required sample memory are listed in Table 1 in the column marked with “Example”. The required size of the sample memory would be 2 Gsamples. This exceeds the size of the sample memory for typical real time oscilloscopes presently on the market. In chapter 3.4 this example will be reviewed applying the history mode to show its benefits.

$$S_M = \frac{R_S \cdot N_P}{R_P} \qquad (2\text{-}1)$$

Table 1

	Example	
S_M	2 GSa	Required sample memory
R_S	10 GSa/s	Sample rate / samples per second
N_P	20	Number of pulses
R_P	100 s^{-1}	Average pulse repetition rate / pulses per second

2.3 Acquisition and Trigger Control

Analysis of the specific signals as mentioned above requires configuration of the acquisition and the trigger control.

The RTO provides powerful trigger functions, which enables the acquisition to be more selective. The user has to specify the decisive trigger condition. However this can be difficult, as conditions to isolate dedicated signal events are not always known. With the support of the mask and measurement functions, the user has to detail the expected result and the RTO stops the acquisition in case of a violation of them. Then the data is available for examination and the user can create a suitable trigger condition.

An acquisition phase starts with arming of the digital trigger system. The RTO provides a comprehensive list of trigger types like Edge, Glitch, Width, Runt, Window, Timeout, Interval, Slew Rate, Data2Clock, State, Pattern, Serial Pattern, near field communication trigger and TV trigger. If the user chooses the right trigger type and configures all trigger settings correctly, various incidents in analog, digital, and logic signals can be detected. In chapter 4.3 an example of a specific trigger type will be demonstrated.

If the trigger mode is set to "auto mode" and the trigger condition is not met for a certain period of time an internal trigger event is created to enforce a signal display. For rare faults and sporadic signals it is important to trigger solely on their occurrence and choosing the "normal mode" sustains to acquire just the sporadic signals. In this case, and if the trigger is missing for a certain period of time, a window will pop up to display the elapsed time since the last trigger event.

3 RTO History Mode

The RTO's history mode mitigates the inherent contradiction between sample rate and observation time.

Typically, a digital real-time oscilloscope acquires not just one long waveform. Instead multiple waveforms, triggered by a dedicated trigger condition are stored in multiple records in the acquisition memory. The associated memory organization is explained in detail in chapter 3.2.

3.1 Operational Description

The RTO's history mode enables the user to access previously recorded waveforms stored in records in the acquisition memory. This history mode can only be used if the acquisition sequence has been stopped. The user may replay the waveforms from the last acquisition just for viewing, or he may apply analysis functions out of the RTO toolset for each record. These analysis functions include measurement, math, mask test, cursor and display operations.

The post-processed data are displayed either as graphical waveforms or as numerical values. With respect to the phase scheduling, introduced in Figure 2, the history mode successively schedules individual post-processing phases, whereas the continuous acquisition mode alternatingly schedules acquisition phase and post processing phase.

The “History” result dialog box (see Figure 5) contains controls for the access and display of acquired waveforms. The “History” menu is invoked by pressing the “History” key on the front panel, or from the menu bar "Display" > "Show history". Once activated, a continuously running acquisition stops immediately.

The most recent acquired waveform is indexed as zero, which is also the initial displayed waveform. Older records are indexed backwards in a descending order. When changing the sequence number manually in the input box labeled with “Current acq”, the RTO post-processes and displays the waveform with the selected sequence number accordingly. Instead of displaying waveforms individually, the user can replay all acquired waveforms, by pressing the “Play” button. In the preference dialog box of the history, the user can specifically select the range of records, which will be processed and displayed (see Figure 6). It is possible to set the replay time per acquisition. Changing this setting to smaller values is useful to reduce the analysis time, if the RTO has acquired a huge number of waveforms and the user applies these to an automated mask or measurement function. Regardless of the manual setting of the replay display of the waveforms, the absolute or relative time of recording is shown in the history preference dialog box.

Figure 5 – History Result Dialog Box

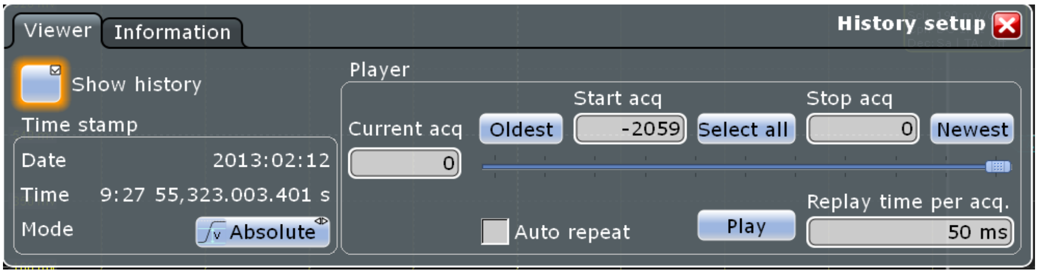

Figure 6 – History Setup Dialog Box

An important prerequisite for the history mode is to stop a running acquisition, when the RTO is in the continuous acquisition mode. There are several ways to stop the acquisition either manually by pressing the HISTORY, "RUN CONT" or "RUN Nx SINGLE" key at the front panel or by configuration of a "Stop on Violation" condition in the mask or measurement function. Chapter 4.3 shows an example of such a configuration.

3.2 Memory Organization

The acquisition memory and its organization is of great importance for the history mode-and its segmentation is very useful for storing of the acquisition data. This can be demonstrated on basis of the application example of a pulsed signal (see chapter 1 and 2.2). In the top row of Figure 7 a pulse train of such a pulsed signal is shown. Because of its fast rise-time, it requires a high resolution, and a large observation time due to the pulse distance, which is typically in the µs range. The example of the pulse train shows five pulses with a similar, but not equal, outline and not equidistant time spacing. The time axis is discontinuous to indicate an arbitrary, but large time in-between the pulses, compared to the pulse width.

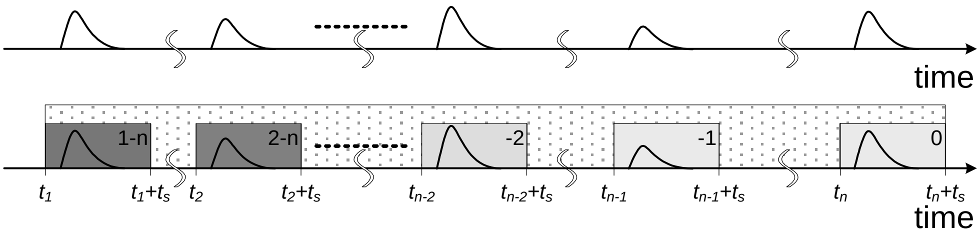

Figure 7 – Acquisition of a Pulse Train with Single or Multiple Acquisitions

The bottom row of Figure 7 displays the same signal as the top row. In case of a single acquisition, the RTO would record these pulses with the time interval $[t_1,t_n+t_s]$. A stippled frame around the pulses indicates the acquisition time interval in this case.

In the acquisition path, a delay line retards the signal relative to the trigger event, which is generated by a digital oscilloscope from the same signal. The digital oscilloscope trigger starts the acquisition shortly before the beginning of the pulse for a predefined acquisition time t_s. Gray-color-graded frames around the five, displayed pulses indicate the acquisition time $[t_k,t_k+t_s]$ with $k \in [1,n]$. Here it is assumed that n-times multiples of the acquisition time t_s is much smaller than the observation time, as discussed in chapter 2.2. As a result, the RTO does not record the vast periods of inactivity. Now it becomes obvious that the total number of waveform samples is reduced. This can save a lot of memory space and result in a very efficient usage of the acquisition memory.

For further illustration of this advantage, the numerical example of Table 1 is used with an assumed pulse width of less than 100 ns. Using an acquisition time t_s of 100 ns and keeping the same parameters (R_S = 10 Gsample/s, N_P = 20,R_P = 100 s^{-1}), the total amount of required memory space turns out to be 20 ksample. In this chosen example, this results in a significant improvement of a factor of 200.000 (2 Gsample/ 20 ksample).

The records are logically arranged as if they were stored in a ring buffer, while physically mapped to a linear addressable DRAM memory. Figure 8 shows in the top row the pulsed signal. As already discussed, the individual pulses are sampled for an acquisition time t_s, which, multiplied with the sample rate plus a minor overhead, determines the corresponding memory requirement of a waveform.

The ring buffer is shown in Figure 8 with the recorded waveforms indexed from 0 to 1-n with 0 as the most recent recorded waveform and 1-n as the oldest one. The memory organization associates each waveform with a small block of overhead (OVH) and a time stamp for the record. In chapter 3.4, the maximal possible number of records, called history depth, will be discussed. With the addition of a time stamp, the exact timing relation among the recorded waveforms is maintained. Unused records out of the previous acquisitions are voided and not accessible. If the memory demand of an acquisition exceeds the history depth, the most recent record overwrites the oldest one (1-n).

When the RTO enters the history mode, the actual, displayed waveform is the most recent acquired one, and the user can select the display sequence for the recorded waveforms as indicated in the bottom row of Figure 8.

3.3 Determining the Fidelity of Signal Acquisition

This chapter will introduce the observation time with the associated fault detection probability, and a mode with minimized blind time. Based on the introduction it will explain why these topics are important for the history mode.

3.3.1 Evaluating the Blind Time

In order to use the history mode effectively, it is important to understand the fidelity of the acquired data. The concept of the alternating phase of acquisition and post-processing was already introduced, but the user should be aware that during the post-processing phase the oscilloscope is not able to acquire data, it is blind. This is a general characteristic of a digital oscilloscope, not RTO-specific. In case of interest, an application note [1] provides more details on the impact of blind time of the measurement and a derivation for the probability of signal fault detection.

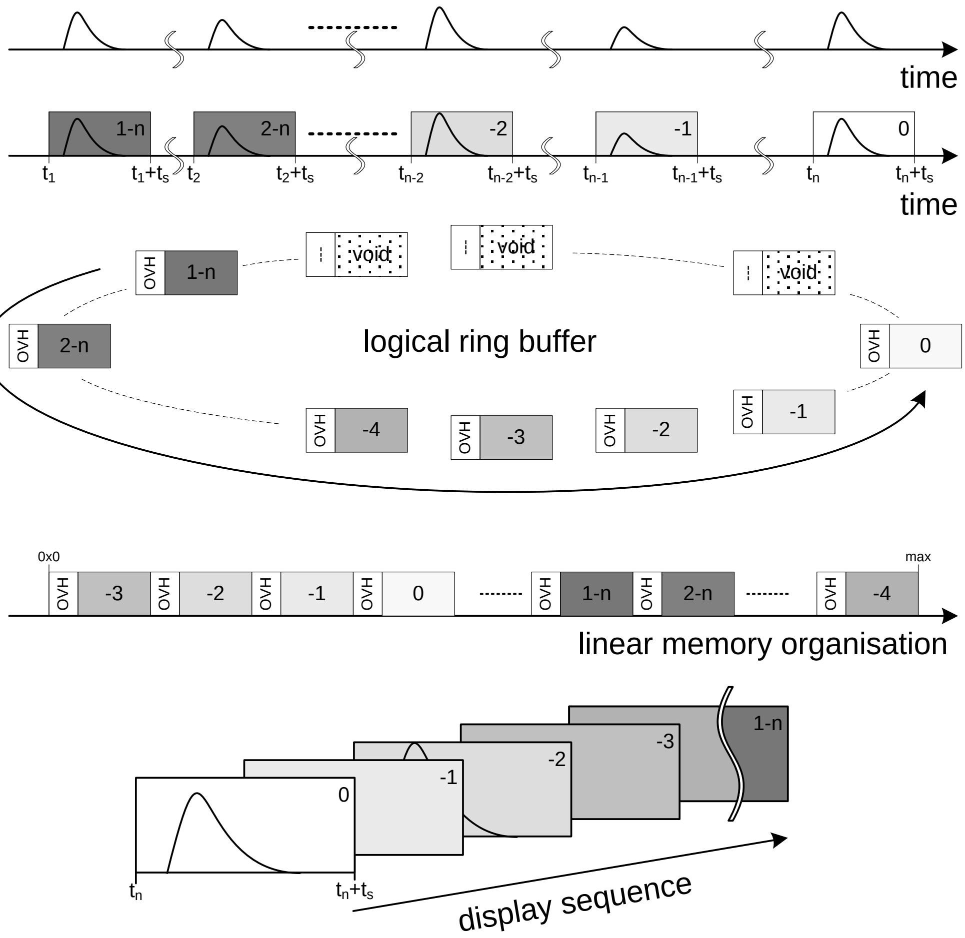

Figure 8 – Acquisition Memory Organization

The blind time of an oscilloscope consists of fixed and variable portions of time (see Figure 9). The individual oscilloscope architecture determines the fixed part t_{fb}. The variable part t_{vb} depends on the time required for post-processing, particularly record length, the number of active channels, the selected post-processing functions, and the display rendering of the waveforms.

In Figure 9 the continuous acquisition mode is shown. After the trigger event at time t_1 caused by a pulse (1-n), the RTO starts the acquisition for the acquisition time t_s. Once the RTO has finished this acquisition, it requires a fixed time of t_{fb} to continue with the post-processing phase. During this phase, it works on the acquisition data for a time of t_{vb}. After a time of $t_1+t_s+t_{fb}+t_{vb}$, the RTO is ready to accept the next trigger event and waits for it.

Using the concept of blind and acquisition time the application note analyzes the probability of detecting a random fault in the acquired signal. In this application note, Figure 10 displays the probability of signal fault detection over time as a function of the acquisition rate. The user will notice that a high acquisition rate is imperative for high confidence in the acquired data. The RTO offers with 1 M waveforms per second a high acquisition rate to ensure this high confidence. For the RTO, the user can check the waveform acquisition rate by enabling the Performance result box (see Figure 11). To enable this box the user has to select the "Display > Performance" menu entry.

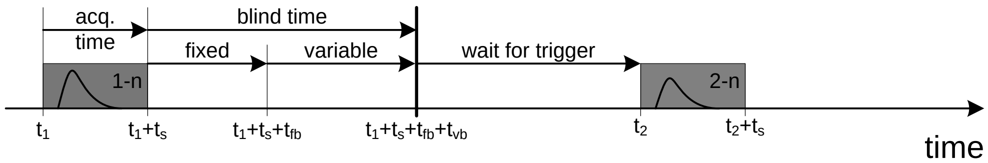

Figure 9 – Acquisition and Post-Processing Cycle of a Digital Oscilloscope

It is worth mentioning two effects may prevent the RTO from reaching this high acquisition rate. First, if the record length is high, the associated acquisition time will reduce the acquisition rate. Second, if the RTO trigger is setup in normal mode, and if the rate of trigger events is slower than the maximum acquisition rate, this will, of course, reduce the acquisition rate.

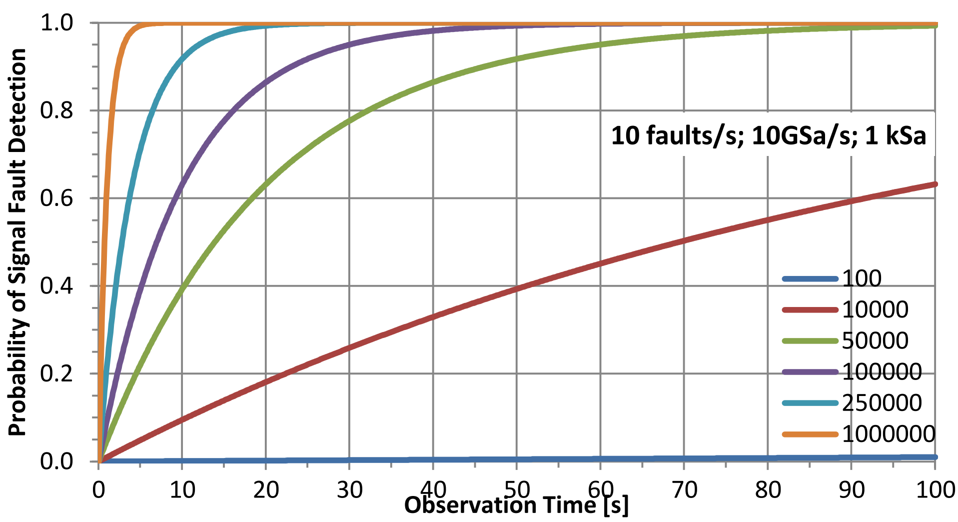

Figure 10 – Fault Detection Probability

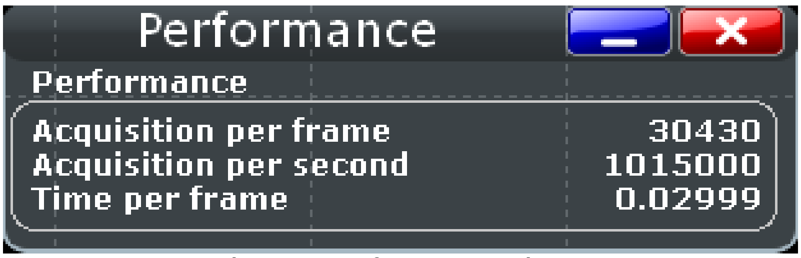

Figure 11 – Performance Result Box

3.3.2 The Ultra-Segmentation Mode

The previous section focused on the importance of the waveform acquisition rate under the assumption of a randomly distributed fault. This is a valid assumption for some applications; however, other applications like the pulsed signal will not necessarily benefit from a high acquisition rate. For these signals, it is required to capture possibly all of the pulses not just some. If the RTO is able to trigger on the signal of interest, it is more important to reduce the blind time to be able to record the next pulse.

Specifically for this case the RTO implements the Ultra-Segmentation mode. With reference to Figure 9, it appears that the blind time consists of two parts, which are not in the same range (t_{fb}≈0.3 µs, min t_{vb}≈0.9 µs [2]). The dominant part is the variable blind time t_{vb}, which the post-processing phase contributes. Scheduling only consecutively acquisition phases will leave out the variable part of the blind time (see Figure 9). Consequently, there is no display update of the acquired waveforms in the Ultra-Segmentation mode. After the sequence of acquisitions is finished, the history mode function is used to access and display the previously acquired waveforms.

In Figure 12 the Ultra-Segmentation mode shows the advantage of the omitted variable blind time. After a trigger event at time t_1 and acquisition of a pulse (1-n) it samples for an acquisition time t_s, afterwards the RTO needs only a fixed blind time of t_{fb}, before the next trigger can occur and the RTO acquires the next signal.

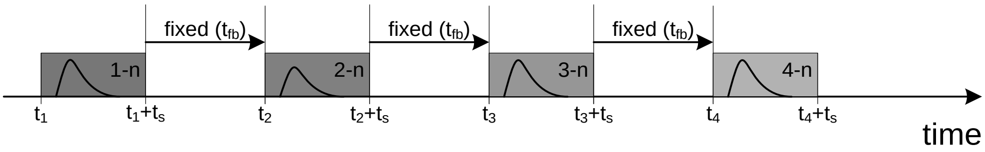

Figure 12 – Ultra-Segmentation Cycle of a Digital Oscilloscope

The Ultra-Segmentation is invoked by pressing the "HORIZONTAL" key on the front panel and selecting the "Ultra Segmentation" tab. This brings up the dialog box, which allows the user to enable this mode and to specify the number of waveforms to be acquired (see Figure 13).

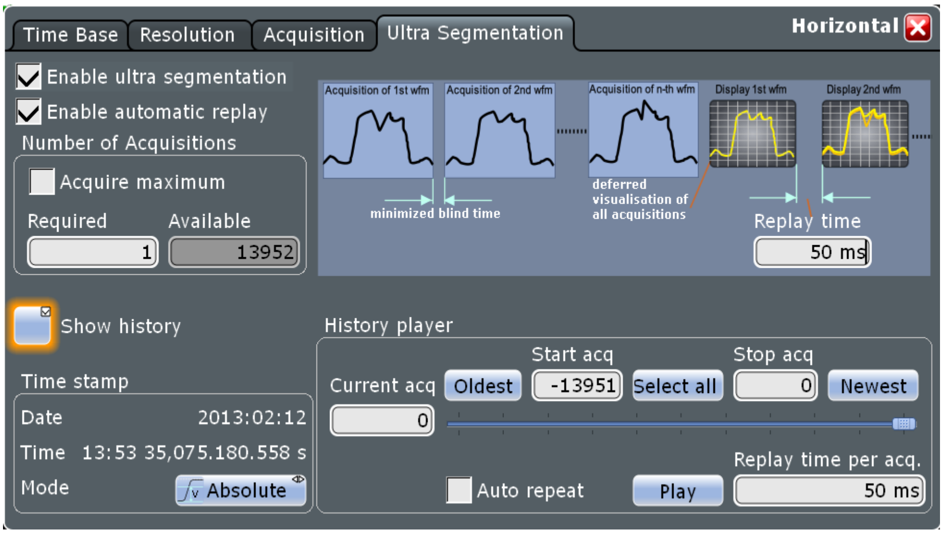

Figure 13 – Dialog Box for Ultra-Segmentation

Once the series of acquisitions using the Ultra-Segmentation Mode is complete, the user has the option to start the history mode including the automatic replay by selecting the "Show history" button in the dialog box. Another way would be pressing the "HISTORY" key on the front panel. The user can now apply the functions as already described in chapter 3.1.

3.4 Limitations of the History Mode

Some limitations apply to the use of history mode. First, the read access to the acquisition memory is only possible if the acquisition is stopped as aforementioned. Starting a new acquisition will void the acquired waveform data. This happens if the user presses the RUN key on the front panel or sends a similar remote command. Second, adding an input channel or changing the time scale will void the data in the acquisition memory, even if the acquisition is stopped.

There are also two separate acquisition modes in which the history mode is not available, the “equivalent time” sampling mode and the roll-mode. Due to the specific use of the waveform memory in these modes, the captured data is not accessible by the history mode.

For the acquisition memory, there is a limitation on the maximum number of acquired waveform records, which can be stored. This limit is called history depth. The user can approximately calculate it as follows:

$$H = \frac{S_M}{R_L + 1000} - 1 \qquad (3\text{-}1)$$

Table 2	
H	History depth per channel
S_M	available sample memory per channel (20 / 50 / 100 Msample[1])
R_L	Record Length, typically 5 ksample

Depending on configured decimation mode, waveform arithmetic modes or active math signals, the history depth might be smaller. If an input channel is unused, the active channel allocates the sample memory of the inactive channel. For example, a four channel RTO with 20 Msample per channel, will have 80 Msample of sample memory available for one channel if the other channels are inactive.

[1] RTO-B101 option supports 50 Msample per channel, RTO-B102 100 Msample per channel

4 Application Examples

Prior to the introduction of the application examples, it is worthwhile to review the configuration of the RTO and consider a strategy to maximize the benefits of the history mode.

4.1 Configuration Scheme for the Time Base

The most important constraint is the choice of a suitable sampling rate, which is compliant with the Nyquist-Shannon sampling theorem [3]. Generally, the sample rate should be more than twice the highest frequency component in the signal spectrum. For pulsed RF signals, the user should take harmonics of the carrier frequency and the modulation bandwidth into account.

After the sample rate is determined, the user should decide on acquisition time or record length. All three numbers can be configured in the HORIZONTAL dialog box (see Figure 4), but they are related, because sample rate multiplied by acquisition time yields the record length. For the pulsed signal, the maximum pulse length constrains the minimum acquisition time.

For a digital signal, the required acquisition time might be not as easy to determine as in the case of a pulsed signal. A good choice strongly depends on the content of the signal. The symbol length might be a good choice, for example for a UART protocol, it would be 10 bits, which comprise a data byte plus stop bits.

The last item to consider is the observation time. Pulsed signals require the user to think about the number of pulses to record. In any case, the user should investigate, whether his memory requirement exceeds the available history depth of the RTO in use, based on the calculation given in chapter 3.4.

4.2 Pulsed Radar Signals

After this theoretical preparation, a detailed investigation of a pulsed radar signal is presented .This example demonstrates several RTO features, including the analysis in the frequency domain across several recorded waveforms and the associated mask testing, as well as measurements in the time domain. Additionally it will show case the superior, short blind time of the RTO, in particular, when the RTO is in Ultra-Segmentation mode. This ensures that all required data is captured, so that the user has a high confidence in the acquisition. Again it should be emphasized that Ultra-Segmentation and history mode are two different things, but the waveforms captured during Ultra-Segmentation mode can only be accessed by using the history mode.

To maintain the focus on RTO-specific features, this application note makes some assumptions to simplify the setup. Instead of measuring real world signals and in order to ensure flexibility, a vector signal generator SMBV100A [2] from Rohde & Schwarz generates the signal, and allows an easy generation of a complex pulse train. Channel 1 of the RTO connects directly to the output of the vector signal generator with a 50 Ω termination. The nominal carrier frequency of the signals is selected to be at 400 MHz, which is not a typical radar band, but a real-world radar signal is usually subjected to a RF-down-conversion into a comparable IF band. The RTO can directly capture and measure the 400 MHz signal.

The radar signal consists of a sequence of three different pulse types with 21 pulses in total. Figure 15 shows these captured pulses, grouped in one acquisition and frequently referred as a pulse train. This pulse train repeats every 100 ms and is closely related to a real world example. The chirp pulse parameters are explained in Figure 14. The first pulse type, marked with 'Type 1', occurs only once, and it is characterized by a (Δf) 2 MHz ramp-down LFM chirp with a 8 µs pulse width. It has also an offset of 2 MHz to the nominal carrier frequency. With the given horizontal scale of 500 µs/div it is hardly visible, because of low amplitude and close spacing to the adjacent pulse. The following pulses are from a second pulse type, marked with 'Type 2', with a 3.5 MHz ramp-up LFM chirp at the nominal carrier frequency and a 5 µs pulse width, repeated ten times with a pulse repetition of 80 µs. Finally, ten pulses of a third pulse type are recorded, which have a pulse repetition of 800 µs, marked with 'Type 3'. These pulses show also a 3.5 MHz ramp-down LFM chirp at the nominal carrier frequency but a 13 µs pulse width. All three types have different amplitude levels.

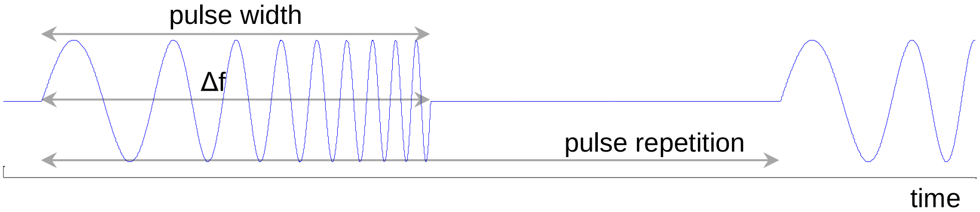

Figure 14 – Chirp Parameter

Based on the signal parameters as described above, the time base is set to a resolution of 400 ps to meet the Nyquist criteria taking all the harmonics of the carrier into account. With a record length of 12.5 Msample and a continuous acquisition, 5 ms are stored per waveform, so that the RTO displays a complete pulse train. The acquisition rate is low, because this pulse train occurs only ten times per second due to the 100 ms interval.

A comprehensive analysis will cover multiple pulse trains, as it is insufficient to analyze just a single one. Therefore the total observation time is expanded to 3 s in a next step. With 100 ms repetition rate and a required resolution of 400 ps, it is clear that the history mode is required for this analysis. In order to maximize the detection capability, meaning minimized blind time, the Ultra-Segmentation is enabled. With the apriori knowledge of the pulse train this seems not logical, but recoding unknown pulse trains with unknown pulse repetition times, this is an important feature. The time base is kept to 400 ps resolution with 50 ksample record length, which results in a 20 µs acquisition time for 600 pulse trains. Without the use of the history mode, the memory requirement would definitely exceed the available sample memory.

For the validation of the setup, it is important to ensure that all signal details are captured. Therefore, the initial part of the RTO investigation is the analysis of the time stamps. A MATLAB® scripts in this application note (see p. 28) retrieves the relative time stamps of the individual, captured waveforms. A further analysis of the timestamps (for details see Appendix B p. 29) retrieved with the MATLAB® script shows, that all pulses are properly captured.

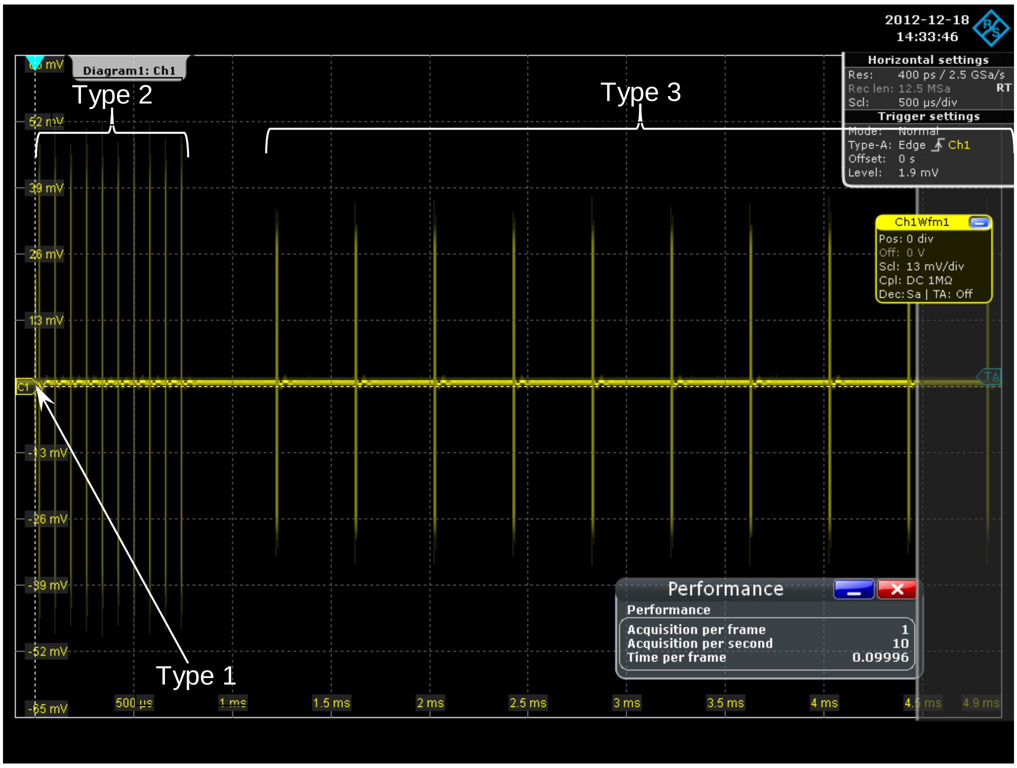

Figure 15 – Pulse Train

In Figure 16 the timestamps of 21 recorded pulses are displayed in a 5 ms interval with the described spacing followed by a 95 ms period of inactivity, which isn't shown for better visibility. Secondly, the time difference between the first and the second pulse, 20.29846 µs, is rather small. Since the acquisition time (t_s) is 20 µs, the time difference between acquisition number -34 and -33 reduced by the acquisition time is just 298 ns (see p. 29), which equals the minimized blind time (t_{fb}). Capturing pulses so close together in separate acquisitions is very challenging for a digital oscilloscope!

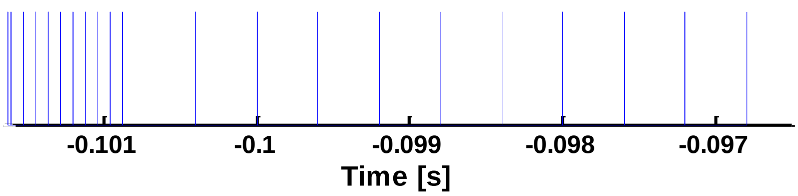

Figure 16 – Recorded Timestamps

The second step is the verification of the individual pulses. To analyze the parameter of interest the user may enable the measurement function for burst-length and amplitude; furthermore, the user can easily study other parameters of interest in the frequency domain, like the chirp bandwidth. To do so, the user configures the MATH function FFT of the RTO, with a center frequency of 400 MHz and a span of 12.5 MHz and applies the measurement function "signal bandwidth" to the spectrum. In order to obtain best results, the signal is plotted as a frame average using a Hamming window. This window type is recommended in the user manual [4] for sinusoidal signals. To ensure that the spectrum of 3.5 MHz around a carrier frequency of 400 MHz is met for all waveforms the user can add a mask to check this behavior for all pulses.

This setup is shown in Figure 17, and the measurement results for burst width and signal bandwidth matches the described configuration. To check these parameters now for all waveforms, the user simply presses the PLAY button of the History result box, and the history mode will access all waveforms in the memory for measurement.

As a result, the pulse type two and three show intended simulated deviation. For the pulse type one the mask test in the frequency domain shows an intended shift of the center frequency of 2 MHz (see Figure 18). Also the reduced signal bandwidth of 2 MHz is measured.

In summary, high timing resolution as well as a long observation time are key for the analysis of pulsed signals in time and frequency domain. The RTO efficiently support these requirements, where the history mode and the full set of test and measurement functions are available, like in the standard continuous acquisition mode or "RUN Nx SINGLE" mode.

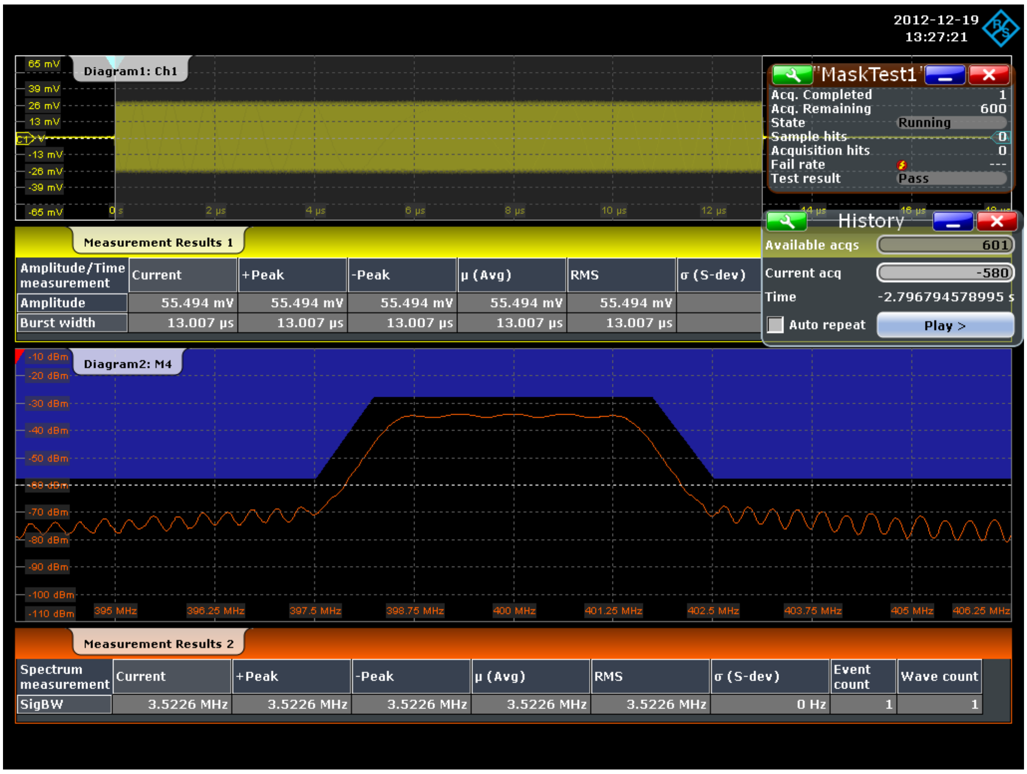

Figure 17 – Radar Pulse Type 3

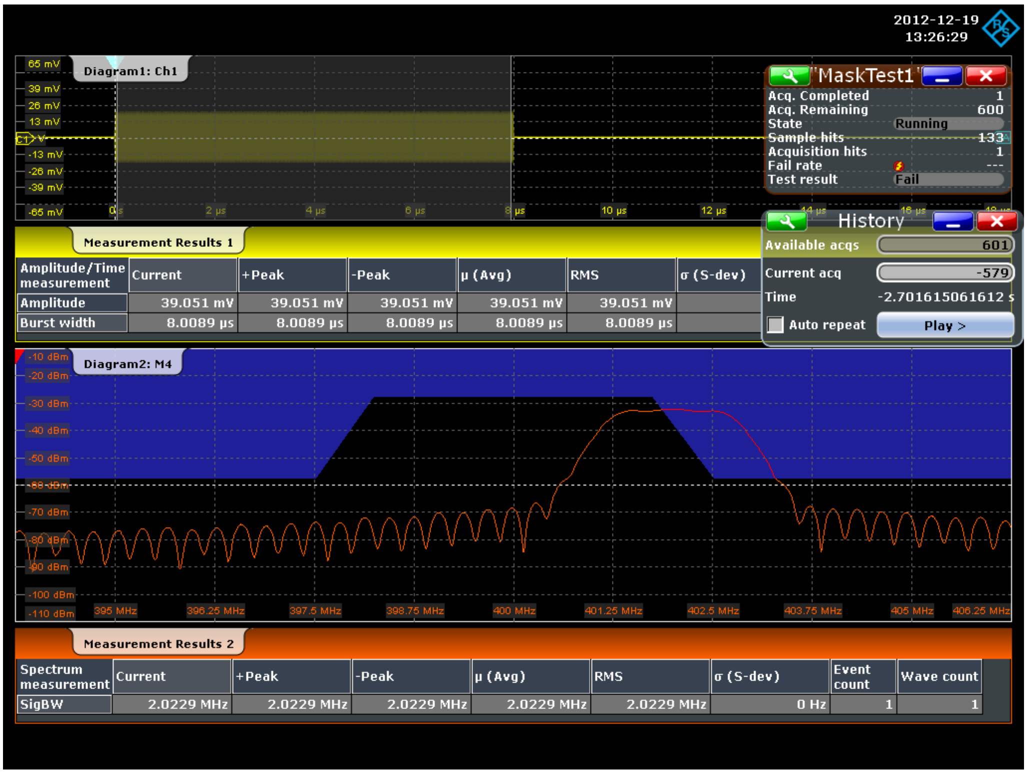

Figure 18 – Radar Pulse Type 1

4.3 Debug of Intermittent Faults

The second application example as described in chapter 1 is debugging of a digital circuit to find intermittent faults. Particularly the mask and trigger features of the RTO turn out to be useful for this application and this chapter will discuss the features in more detail. As a test setup, the RTO connects to the RTO demo board. On the board there is a 10 MHz TTL signal asserting a PRBS signal, which an active probe (RT-ZS30) captures for analysis with the RTO. This PRBS signals exhibits random signal anomalies.

For a targeted search of a so far unknown problem of the demo board signal using the RTO, the user may take a three-step approach. To localize the issue in a first step, the RTO plots the digital signal of the design in an eye diagram using the display persistence. Anomalies in the eye pattern will lead to the second step. The observed anomalies are unspecific, and provide just an indication (Figure 19). For convenience, the AUTOSET key will configure the scope, and setting the trigger to a double edge trigger will display the eye. Clearly visible in the eye pattern is a runt for low and high level of the digital signal. But there are some spurs in the middle, which will be in the focus of the next step.

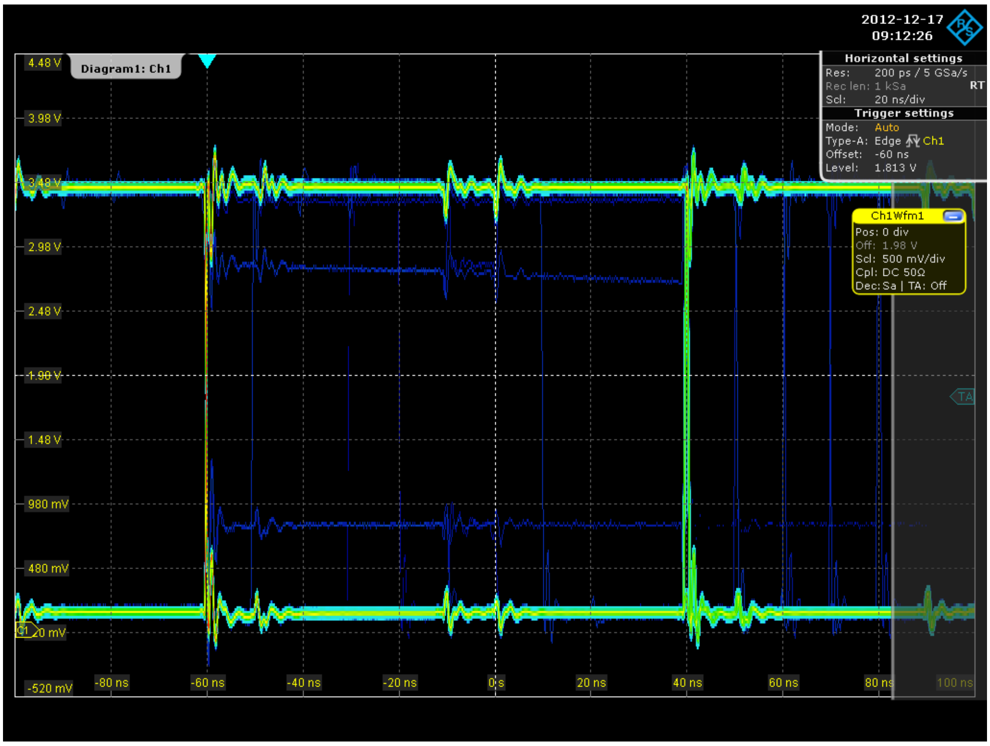

Figure 19 – Eye Pattern with Persistence

As a second step, the user specifies the desired tolerances by defining a mask, based on either an interface standard or by design considerations. In this example, it is simply a mask with a rectangular shape based on the design knowledge of TTL signals. The mask menu is invoked for example with the "MASK" key on the face plate, and lets the user specify a mask. In this case an inner mask is defined in the range of [5,95] ns and [0.45,3.05] V. When this mask is applied, the RTO captures specific violations (see Figure 20) and reports the statistics in the signal icon.

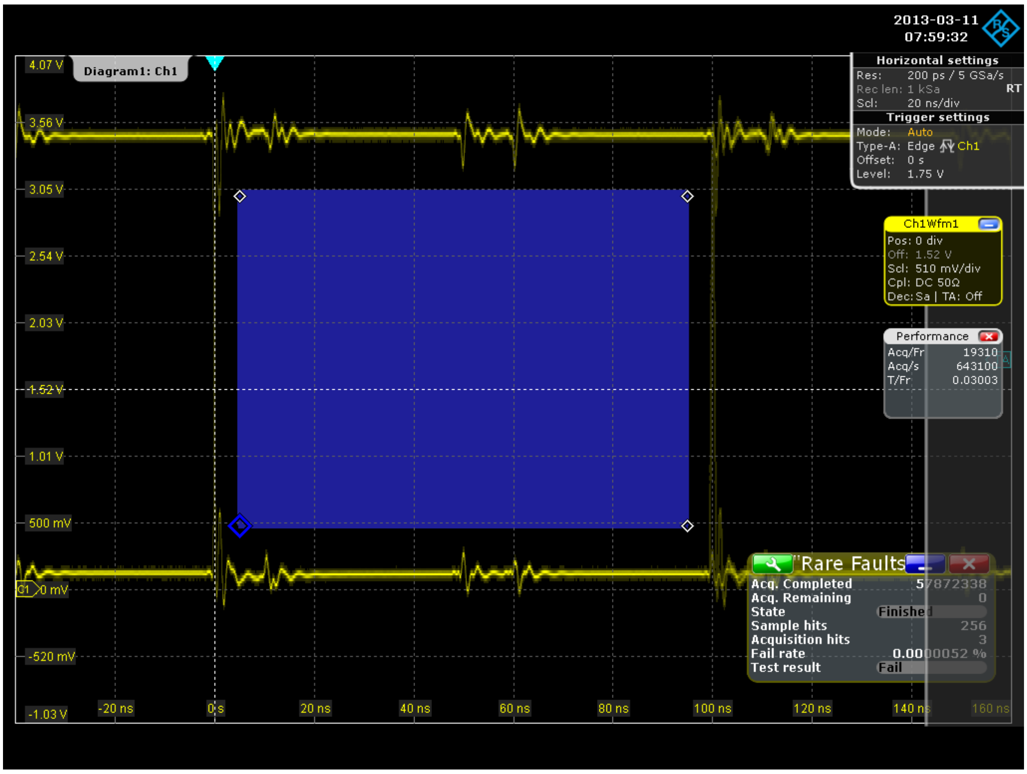

Figure 20 – Applied MASK Test (cont.)

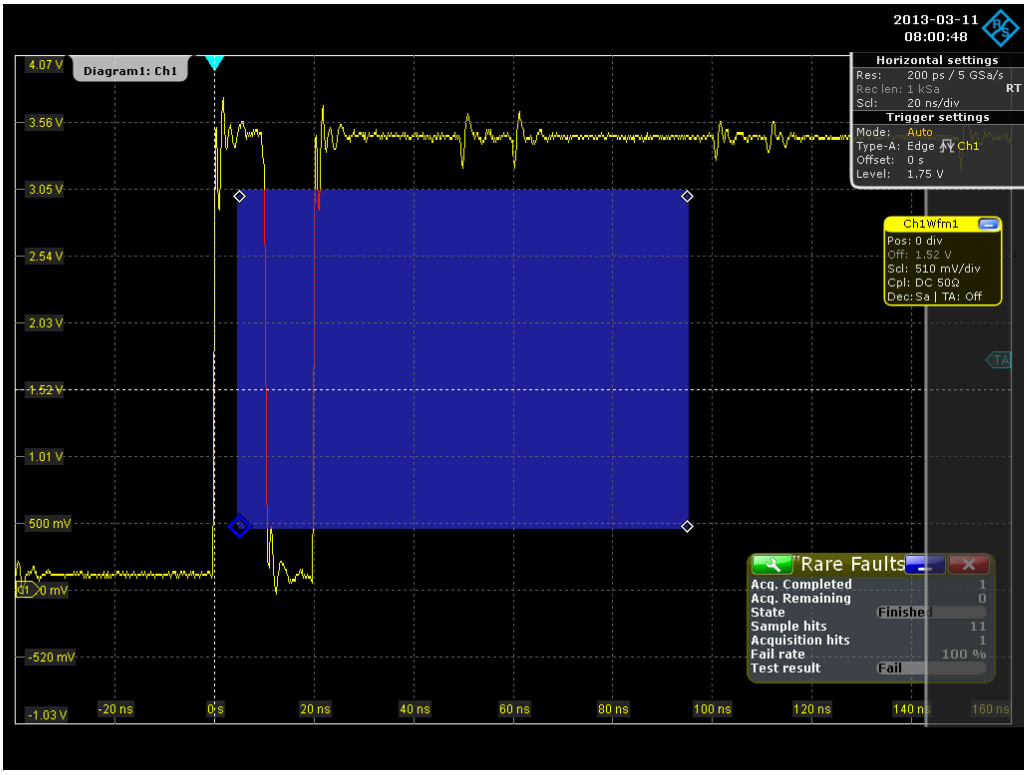

Figure 21 – Applied MASK Test (stop on fail)

In Figure 21, the RTO stopped the acquisition of the signal, because a mask violation was detected. This behavior was specified in the "Event Actions /Reset" tab of the mask menu. The captured signal trace shows a glitch of about 10 ns pulse width.

For the third step, the information gathered is used to guide the user in taking advantage of specific trigger features. In this case he will configure a GLITCH trigger with a pulse width of less than 25 ns, as he might be unsure about the pulse width variation of the glitch. In order to capture only waveforms with glitches, the trigger mode is set to "Normal" and the resolution is set to 500 ps. Following the dependencies in chapter 4.1, a record length 100 ksample is configured allowing the recording of an arbitrary number of 500 bit-periods. If a fault occurred, it is of interest what happened prior to this occurrence, so the reference point of the trigger is set to 98% of the display in the examples of Figure 22 and Figure 23.

With reference to chapter 4.1, the alerted user should check the history depth. For this configuration, a scope with a standard acquisition memory of 20 Msample per channel would support a history depth of 800 waveforms for a four channel RTO. The user may specify the number of waveforms to be recorded in the trigger control box. With the configured glitch trigger, an acquisition of a waveform will only happen if a glitch occurs.

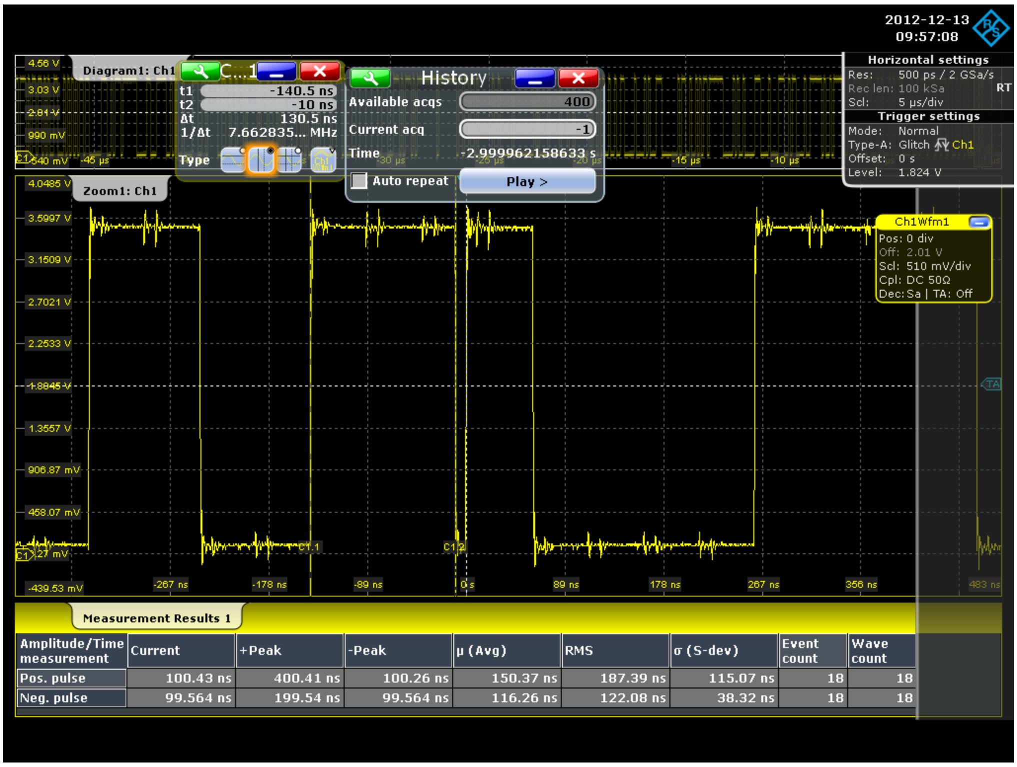

Figure 22 – Debug using the History Mode

After the acquisition is completed, the user can apply the comprehensive set of analysis functions. In this case, the RTO has sampled 500 bit-intervals per waveform (see top window Figure 22), a zoom into the time window shows the glitch and applying the cursor helps to measure its characteristics. By changing the "Current acq" field, for example with the navigation knob, the user scans through the individual waveforms. This way the RTO enables the user to analyze the cause of the glitch in the acquired data stream in detail and give him a high confidence in capturing all intermittent faults.

Besides this directed analysis, the user has also the option with the RTO to analyze the acquired data statically in the post-processing phase. For example, the measurement functions will show him the pulse width for positive and negative pulses, for all pulses in each acquired waveform and for the complete set of waveforms. Additionally the user can enable a histogram for these values, including the statistics. Once the user has configured this function, the replay of the history will complete the statistics.

In Figure 23, the RTO displays these measurement functions in the lower, two windows. It is apparent from the statistics that all 401 waveforms are counted and that the minimum glitch pulse width is 9.5 ns. This can be determined with high confidence as the RTO was setup to capture pulses up to a width of 25 ns, and the hardware can detect pulses down to a width[2] of 100 ps. The pulse width histogram shows distinct bins at 100 ns and multiple of it, weighted by the relative occurrence, for more than 50.000 pulses.

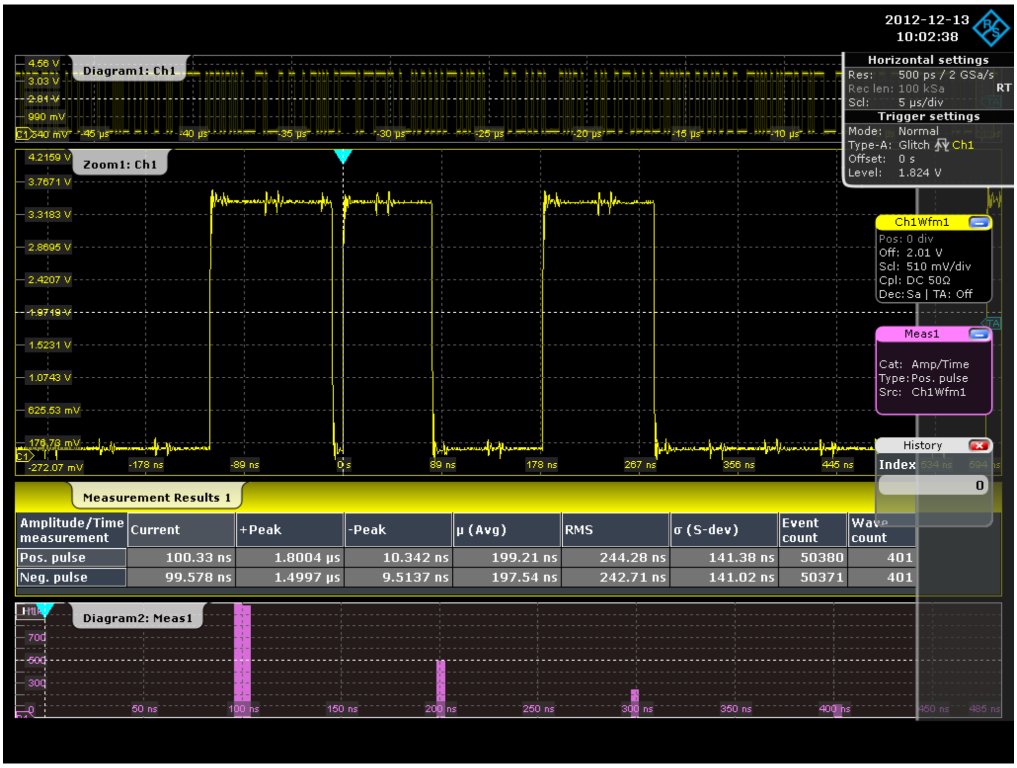

Figure 23 – Debug using the History Mode

Similar to the application example in chapter 4.2, the timestamps are downloaded, analyzed and shown in Figure 24. The time difference between glitches is displayed in red versus the number of occurrence. From this graph, it becomes clear that the glitch occurs after two and three seconds. However, for the moment, it is unclear whether the

[2] 50 ps for a RTO-1044

time difference is randomly distributed between 2 and 3 s. A second histogram in the same axis in blue shows the time difference between every second glitch. This histogram reveals that the glitches are distributed alternatingly between 2 and 3 s with a periodicity of 5 s. The second plot in Figure 24 increases the resolution of this histogram and plots the distribution relative to the mean value. The jitter distribution of the glitch becomes apparent.

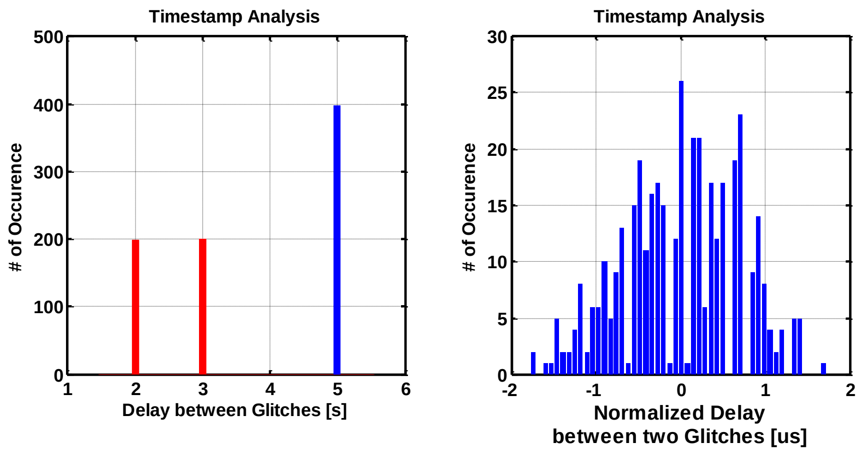

Figure 24 – Analysis of Timestamps

Looking at the overall observation time of 1000 s, the user may notice that a digital oscilloscope could not acquire such a signal in a single acquisition with the selected resolution. So the use of the history mode becomes mandatory for an in-depth analysis. The history mode is not limited to the two application examples aforementioned; the user might also use this mode for serial protocol or parallel protocol analysis in combination with the Mixed Signal Option (MSO).

5 Conclusion

The history mode of the RTO allows the user to access previous acquisitions and to apply the rich set of analysis functions of the RTO. The timing relation among these acquisitions is retained and can be used as a basis for subsequent analysis.

Moreover this mode mitigates the trade-off between a high sample rate and a long observation time. Several applications may benefit from the history mode; among others, this application note has presented the analysis of two of them.

The versatile trigger of the RTO lets the user focus on the important parts of his analysis through a selective recording. Moreover the RTO leverages the memory architecture in a very efficient manner, and provides a rich set of test and measurement functions to analyze the acquired waveforms. Furthermore, the continuous time base lets the user extend the observation time far beyond the storage capabilities of the acquisition memory. In summary, the described features make the history mode an important tool, e.g. for debugging of digital circuits and analysis of infrequent, intermittent signals or serial protocol data. Notably the history mode is a standard feature for the RTO.

6 Literature

[1] Guido Schulze, Bob Barnett, „The Impact of Digital Oscilloscope Blind Time on Your Measurements," Rohde & Schwarz GmbH & Co. KG, August 2010. [Online]. Available: http://www2.rohde-schwarz.com/file_15192/1ER02_1e.pdf.

[2] Test & Measurement, „R&S®RTO Digital Oscilloscope Specifications," Rohde & Schwarz GmbH & Co. KG, December 2012. [Online]. Available: http://cdn.rohde-schwarz.com/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/RTO_dat-sw_en.pdf.

[3] Harry Nyquist, „Certain Topics in Telegraph Transmission Theory," in *Winter Convention of the A. i. E. E.*, New York, 1928.

[4] Rohde & Schwarz GmbH & Co. KG, R&S®SMBV100A Vector Signal Generator -- Operating Manual, München, 2012.

[5] Test & Measurement, RTO Digital Oszilloscope - User Manual, München: Rohde & Schwarz GmbH & Co. KG, 2012.

Appendix

A Appendix A

A MATLAB® code example is given below, which was used to retrieve the timestamp information of the recorded waveforms from the RTO for further analysis. Examples of the analysis are discussed in the chapters 4.2 and 4.3.

```
%% ---- Establish Connection to the RTO ----
RTO = visa('ni', 'TCPIP::10.113.10.39');
RTO.Timeout = 10;
fopen(RTO);
% Query and display the connected instrument ID String
fprintf(RTO, '*IDN?'); disp(['    ID: ' fscanf(RTO)])
% Work with the RTO history mode
% - get available number of acquisitions
% - get timestamps for every acquisition
%% ---- Configure the RTO ----
% Enable history mode
fprintf(RTO, ':CHANnel:WAVeform:HISTory:STATe 1');
% Get available acquisitions and print
nofAcq = str2num(query(RTO, 'ACQuire:AVAilable?'));
fprintf('\n=======================================================\n');
fprintf('Number of available acquisitions: %i\n', nofAcq);
fprintf('=======================================================\n\n');
% create an array
timeStampRel = zeros(nofAcq,1,'double');
% Get timestamps for every acquisition and print
for idx = -(nofAcq-1):0
    fprintf(RTO, 'CHANnel:WAVeform:HISTory:CURRent %i', idx);
    fprintf(RTO, '*OPC?'); [~] = fscanf(RTO);

    fprintf(RTO, 'CHANnel:WAVeform:HISTory:TSRelative?');
    timeStampRel(nofAcq + idx) = str2double(fscanf(RTO));
    fprintf('Acquisition %i\t%9.7f\n', ...
        idx, timeStampRel(nofAcq + idx));
end
% Close connection
fclose(RTO);
% store data for further processing
save timeStamp.m timeStampRel;
```

B Appendix B

Table 3 shows a subset of retrieved timestamps of the recorded waveforms. The first column indicate the acquisition index, the second one the associated timestamp. The host based post-processing added the third column, showing the time difference between two adjacent timestamps.

Table 3

Current acq.	Relative Timestamp [s]	Time Difference [µs]
-34	-0.196799628	95179.52141
-33	-0.101620106	20.29846
-32	-0.101599808	79.99993
-31	-0.101519808	79.99977
-30	-0.101439808	79.99997
-29	-0.101359808	79.99973
-28	-0.101279808	79.99995
-27	-0.101199808	79.99975
-26	-0.101119809	79.99997
-25	-0.101039809	79.99973
-24	-0.100959809	79.99995
-23	-0.100879809	479.99913
-22	-0.10039981	399.999143
-21	-0.099999811	399.999356
-20	-0.099599811	399.999145
-19	-0.099199812	399.999356
-18	-0.098799813	399.999161
-17	-0.098399814	399.999166
-16	-0.097999814	399.999351
-15	-0.097599815	399.99915
-14	-0.097199816	399.999373
-13	-0.096799817	95179.52106
-12	-0.001620296	20.298469

Index

7 Ordering Information

Naming	Type	Order number
Digital Oscilloscopes		
600-MHz, 2 channels 10 Gsample/s, 20/40 Msample	R&S®RTO1002	1316.1000.02
600-MHz, 4 channels 10 Gsample/s, 20/40 Msample	R&S®RTO1004	1316.1000.04
1 GHz, 2 channels 10 Gsample/s, 20/40 Msample	R&S®RTO1012	1316.1000.12
1 GHz, 4 channels 10 Gsample/s, 20/80 Msample	R&S®RTO1014	1316.1000.14
2 GHz, 2 channels 10 Gsample/s, 20/40 Msample	R&S®RTO1022	1316.1000.22
2 GHz, 4 channels 10 Gsample/s, 20/80 Msample	R&S®RTO1024	1316.1000.24
4 GHz, 4 channels 20 Gsample/s, 20/80 Msample	R&S®RTO1044	1316.1000.44
Memory upgrade, 50Msample per channel	R&S®RTO-B101	1304.8428.02
Memory upgrade, 100Msample per channel	R&S®RTO-B102	1304.8438.02
Mixed Signal, 400 MHz, 5Gsample/s, 16 channels, 200 Msample/channel	R&S®RTO-B1	1304.9901.03

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