RF Pulse Measurements in time and frequency domains with VSE-K6
Application Note

Products:

- R&S®RTO
- R&S®VSE-K6
- R&S®FSW
- R&S®FSV/A
- R&S®FPS

RF pulse measurements, to characterize the signal in the frequency domain, are traditionally carried out on an RF spectrum analyzer. For time related pulse parameters, oscilloscopes are widely used. However, the measurement capabilities of state of the art test and measurement equipment has evolved over time and crosses domains. With a combination of R&S®RTO digital oscilloscope and dedicated pulse analysis software R&S®VSE-K6, pulse signals can be analyzed in both domains, frequency and time.

The R&S®RTO digital oscilloscopes are unique in that they allow output of I/Q data for processing. This application note focusses on signal measurement using this instrument.

Analysis of an L-/S-band ATC RADAR utilizing the R&S®RTO2044 oscilloscope running Vector Signal Explorer Software R&S®VSE and Pulse Analysis personality R&S®VSE-K6 is followed by measurements on an X-band RADAR utilizing R&S®FSW, R&S®FPS, R&S®FSV or FSVA signal & spectrum analyzers with the same dedicated R&S®VSE-K6 software.

Note:

Please find the most up-to-date document on our homepage

http://www.rohde-schwarz.com/appnote/1MA249

Application Note
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10.2016 – 1MA249_1e

ROHDE&SCHWARZ

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- The R&S®RTO Digital Oscilloscope is referred to as RTO
- The R&S®VSE Vector Signal Explorer is referred to as VSE
- The R&S®VSE-K6 Option Pulse Analysis is referred to as VSE-K6
- The R&S®SMBV100A Vector Signal Generator is referred to as SMBV
- The R&S®SMx-K300/K301 Option Pulse Sequencer is referred to as K301
- The R&S®FSW Signal Spectrum Analyzer is referred as to FSW
- The R&S®FSV Signal Spectrum Analyzer is referred as to FSV
- The R&S®FSVA Signal Spectrum Analyzer is referred as to FSVA

1 Introduction

RADAR (**RA**dio **D**etection **A**nd **R**anging) pulse measurements are traditionally carried out on a spectrum analyzer to characterize the signal in the frequency domain. The "zero span" or IQ analysis mode of spectrum analyzers provides the possibility to analyze in the time domain, but is restricted to the analyzer's IF analysis bandwidth. Digital oscilloscopes today give the possibility to directly sample RF signals and analyze them in both domains, time and frequency, in respect to a much wider bandwidth. In addition to segmented capture, the RTO Digital Oscilloscope is unique in that it allows to output I/Q data. The availability of an IQ analysis application that also runs on the oscilloscope, significantly increases the range of a scope's possibilities in comparison to a traditional spectrum analyzer.

Strong time-domain signal features are characteristic of RADAR. It is of importance to measure the correct transmitted signal in terms of carrier frequency, rise-/fall time, pulse width, pulse repetition interval (PRI) and pulse phase information.

This application note first describes the measurement of an Air Traffic Control (ATC) RADAR signal, operating in the S-band with the RTO Digital Oscilloscope in regards to the time domain analysis and with I/Q data fed to the VSE-K6 software.

Section 2 gives a brief introduction to instruments and software used, Section 3 and 4 describe the lab application setup and usage. Section 5 and 6 document some real radar measurements with digital oscilloscopes as well as signal and spectrum analyzers and compares instrument choice.

2 Background

While signal- and spectrum analyzers can reach up to very high carrier frequencies (86 GHz in case of the R&S®FSW85), they may be restricted by processing bandwidth for some types of RADAR. A modern digital oscilloscope have a different set of limitations, mostly it is the acquisition time based on amplitude resolution and the amount of sampling memory.

Choosing the right instrument in combination with a dedicated pulse analysis software is the main theme of this paper. With just the standalone RTO2044 digital oscilloscope, you already can get a wealth of information needed for the pulse analysis on IF stages as well as the RF output of eg. an S-band ATC RADAR.

For our ATC example memory depth was of special importance as the signal just appeared every 4.5 s and the measurement instrument was to acquire as much information as possible in the relevant frequency range up to 2.8 GHz.

This section is divided into information about the RTO, the VSE-K6 and the parameters of the ATC RADAR.

2.1 RTO configuration

For this application note an RTO2044 is equipped with a memory of 1 GSamples which enables repetitive RADAR signals with longer idle times to be acquired and still allowing the fine time resolution expected [1].

Furthermore, for establishing exact time relations between components of the RADAR signal, the RTO was used in the HISTORY mode, which is explained in more detail as part of application note 1TD02 [2].

2.2 VSE-K6 configuration

Rohde & Schwarz Vector Signal Explorer (R&S®VSE) is a high-performance tool for various tasks in general signal analysis. The dedicated VSE-K6 pulse analysis software can either use the I/Q data stream from the RTO, or the RF waveform which it then converts into I/Q data. The RTO is the only oscilloscope on the market equipped with an interface to transfer I/Q data. Together with the RTO-K11 software option, the oscilloscope acquires the signals and outputs the corresponding I/Q data to the VSE-K6 software, with an adjustable sampling rate.

The table below shows the 2 possibilities.

RTO-VSE capture Mode			
Name	[Auto]	[I/Q]	[Waveform]
Description	Uses "I/Q" mode when possible, and "Waveform" only when required by the application (e.g. pulse measurements). The VSE-K6 [Auto] will use per default the [Waveform]	With activated I/Q Software Interface RTO-K11 the RTO performs digital I/Q demodulation and provides the corresponding I/Q data [1]; The VSE-K6 takes control of the sample rate and other scope parameters. This capability can be used for analysis of wideband RADAR and very narrow pulses [2] For data imports with small bandwidths, importing data in this format is quicker. However, the maximum record length is restricted by the RTO.	The original waveform is converted into I/Q data within the VSE software. For data imports with large bandwidths, this format is more convenient as it allows longer record lengths.[7]
RTO - Options required		R&S RTO-K11 Recommended RTO-B110 (for increase memory depth)	R&S RTO-K11. Memory options are advised.

Table 1: RTO VSE-K6 capture modes

The VSE-K6 software in combination with the RTO can analyze pulses with up to 4 GHz bandwidth and up to 199 ms record length (see table 3 below) [7].

This allows for the possibility to analyze rise time of several hundreds of picoseconds and some ms of capture time (with the equipped memory options).

The table below gives an overview of the explained two modes of IQ capture and waveform capture in terms of maximum acquired samples possible.

VSE-K6 capture length of RTO		
RTO	Max capture length (I&Q)	Max capture length (waveform)
RTO1000[1]	10 Msample/Sample rate	79 ms
RTO2000[1]	40 Msample/Sample rate (RTO-B110)	199 ms
Comment	Speed optimized, preferable for narrowband signals	Memory optimized

Table 2: VSE-K6 capture length with RTO

1 Please refer to the specification of the VSE-software for exact option requirements [7]

Another perspective of the data acquisition is the used bandwidth within the VSE-K6. In contrary to the spectrum analyzers, here the RTO needs to adjust the time reference accordingly. Changing the RF measurement bandwidth within the VSE-K6, will automatically adjust the time reference accordingly.

VSE-K6 max capture length vs measurement bandwidth (Gauss Filter)		
	bandwidth 10 MHz	bandwidth 1 GHz
RTO1000[1] (I&Q)	250 ms	2.5 ms
RTO1000[1] (waveform)	24.7 ms	24.7 ms
RTO2000[1] (I&Q)	1 s	10 ms
RTO2000[1] (waveform)	62 ms	62 ms

Table 3: VSE-K6 capture length vs. measurement bandwidth (Gauss filter)

1 Please refer to the specification of the VSE-software for exact option requirements [7]

This Application Note assumes that the user has established the connection to the VSE-K6 software first. For details please refer to [3].

2.3 Typical Air Traffic Control (ATC) RADAR parameters

Air Traffic Control (ATC) RADAR, military Air Traffic Surveillance (ATS) RADAR and Meteorological RADARs operate in S-Band frequency range, which has been defined by IEEE as all frequencies between 2 GHz to 4 GHz. Next to aviation and weather forecast, several different maritime RADARs worldwide also operate in this frequency band. The excellent meteorological and propagation characteristics make the use of this frequency band beneficial for RADAR operation. [5]

Air traffic control (ATC) S-band RADAR systems installed at airports cover the frequency range from 2.7 GHz to 3.1 GHz.

There are many different types of Air Traffic Control (ATC) RADAR deployed worldwide. Beside the frequency allocation, typical transmit power, antenna gain, maximum ranges, opening angles of the antenna in horizontal or vertical direction, pulse duration, pulse repetition frequency, duration time of a single turn of the antenna are of interest.

ATC Parameter	Typical values
Transmit Power	2 kW - 20 MW
Maximum Range	100 km - 500 km
Horizontal Antenna Opening Angle	0.4° - 2.5°
Pulse duration	< 1µs - 400µs (most ATC RADARs use double pulses, e.g. 2 x 1µs or 2 x 2µs)
Pulse period	< 1ms - 4ms
Frequency hopping	Every single pulse is transmitted at a different frequency (frequency diversity) in a distance of about 10-20 MHz
Antenna rotation time	5 revolutions/min - 15 revolutions/min
Antenna gain	25 dBi - 40 dBi

Table 4: Typical ATC RADAR parameter values

Some ATC RADARs also have different pulse waveform modes. The ASR-E for example can operate in between 2.7 GHz and 2.9 GHz with 1µs and 2x 45µs pulse duration and different antenna rotation times, e.g. 15 revolutions/min or 12 revolutions/minute [6].

2.4 Measurement Parameters

Since the RADAR is turning 360 degrees within a certain time you have to take into account the side-/main lobes of the antenna beam which the RTO will receive each time the RADAR is passing the receiving antenna. As mentioned in Table 4 you can see the revolutions per minute (rpm) also within the measurement results. In the first example the difference in time between the first measurement to the next measurement is practically the turning cycle of the RADAR dish. This time divided by 60 s reveals the rpm value.

Within this cycle an RF beam will have some dozens of pulses. The cycle time as well the internal pulses are the key parameters that needs to be measured.

You will be able to measure specific values like,

- rpm value of the turning antenna
- Antenna beam pattern (which relies also on the receive antenna pattern)
- Frequency hopping of the carrier frequency
- Pulse parameters like PRI, pulse width, rise-/fall time, overshoot and droop as shown in Figure 1
- Pulse trends.

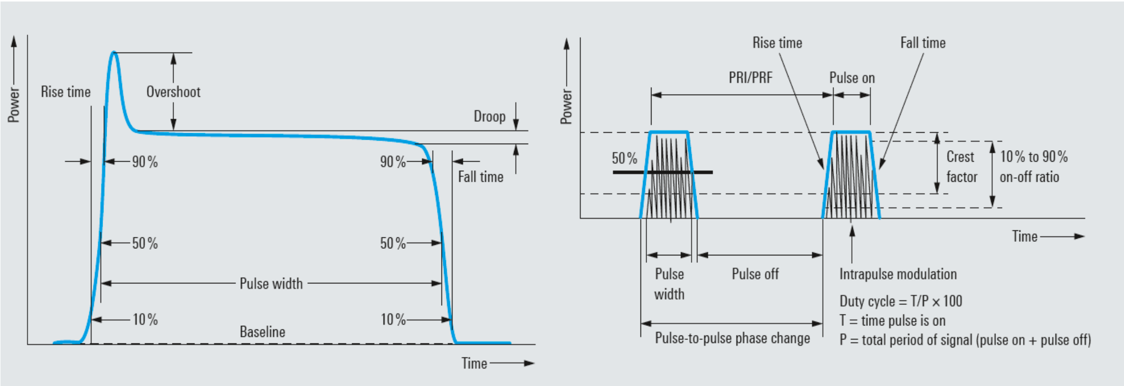


Figure 1: Pulse parameters

3 Measurement Setup for Signal Analysis with R&S®RTO

This section describes the setup for measuring an air-surveillance RADAR (ASR) signal with the RTO only.

This section uses for flexibility, a vector signal generator SMBV with the option K301 that allows an easy generation of complex pulses with an implementation of real antenna beam and scanning parameters.

Channel 1 of the RTO connects directly to the output of the vector signal generator with a 50 Ω termination.

3.1 Connection Setup RTO

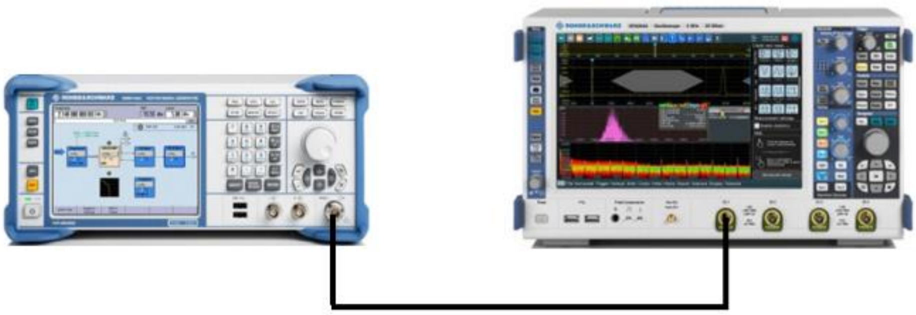


Figure 2: Lab Setup for Scope

The SMBV is transmitting the following parameters,

- References are not locked.
- Frequency 2.8 GHz, no hopping applied.
- Level: -11 dBm in power which equals (at 50 Ohm) to 63.02 mV
- ASR-9 signal generated with SMBV-K301 with the following parameters,
  - Transmission period: every 4.8 sec which resembles a 12.5 rpm turning Antenna.
  - Antenna beam pattern: Standard cosecant pattern with HPBW 1.4 deg
  - Pulse sequence parameters as seen in Table 5

ASR-9 simulated pulse sequence parameters		
Pulse type	I	II
Pulse width	1 us	1 us
Rise time	100 ns	100 ns
Fall time	100 ns	100 ns
PRI	757 us	1 ms
Number of pulses	8	10

Table 5: Simulated pulse parameters

3.2 Analysis Setup

This section describes the configuration of the RTO in order to analyze certain pulse parameters. The figures are labeled with red circle numbers 1, while the detailed step-by-step procedure is described with numbers below. Note that for most of the function within the RTO there are keys or menu bar functions. Quoted button/tabs functions are in brackets **[and bold]**, the steps are defined in red circles on the graphical user interface of the application.

There are four different procedures described in the next subsections, how to measure

- the signal and antenna beam pattern,
- possible frequency hopping, carrier frequency and rpm of transmitting RADAR signal,
- the number of pulses within a transmitting RADAR signal and distribution of PRIs,
- and the pulse properties.

This section describes the guidelines in nine steps from the initial measurement setup (preset) to the first analysis results.

3.2.1 Analysis setup: RADAR Signal Capture

1. From Reset Press the **[Ch1Wfm1]** window.

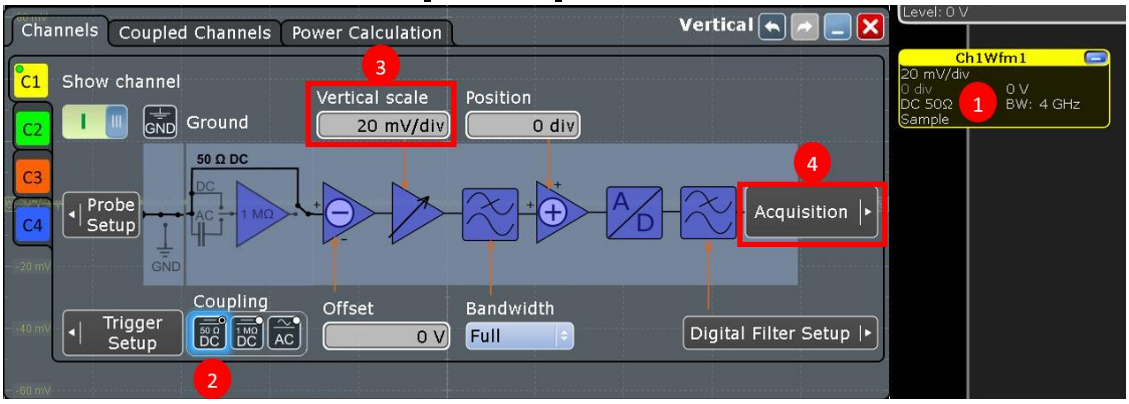


Figure 3: Channel configuration

2. Click on the **[50 Ohm DC Coupling]**
3. Align **[Vertical scale]** to the expected signal strength (here 20 mV/div)
4. Press **[Acquisition]**, another window opens
5. Choose the **[Setup]** tab
6. Disable **[Auto adjustment]**
7. Set the **[Sample rate]** at least twice the main frequency component (in this example the carrier frequency is 2.8 GHz so 5.6 GSa/s would meet the requirement
8. Set the **[Acquisition time]** to at max possible without changing the sample rate.

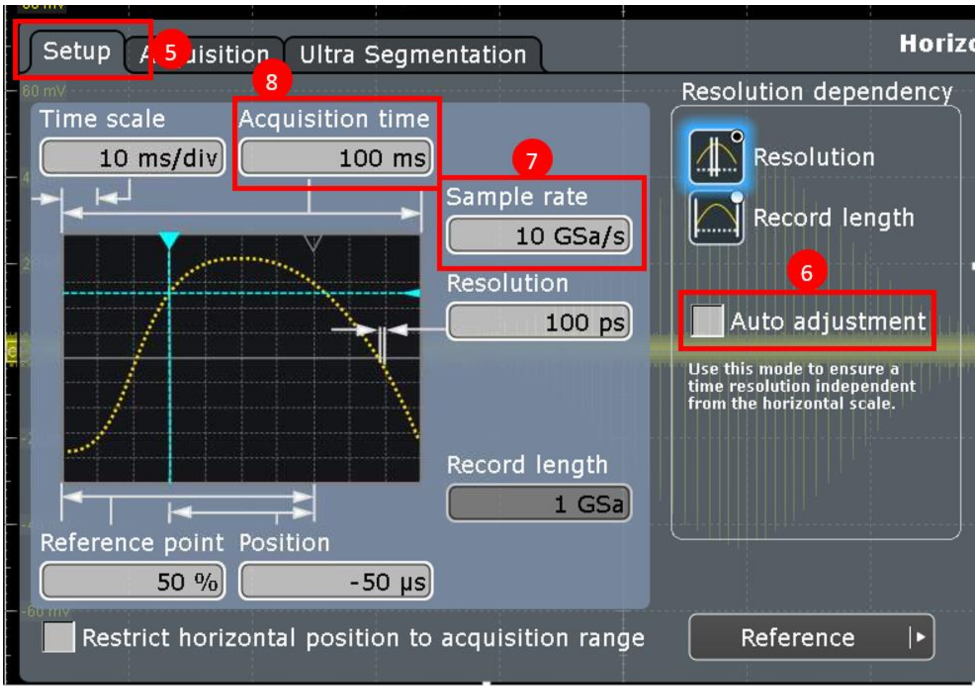


Figure 4: Acquisition configuration

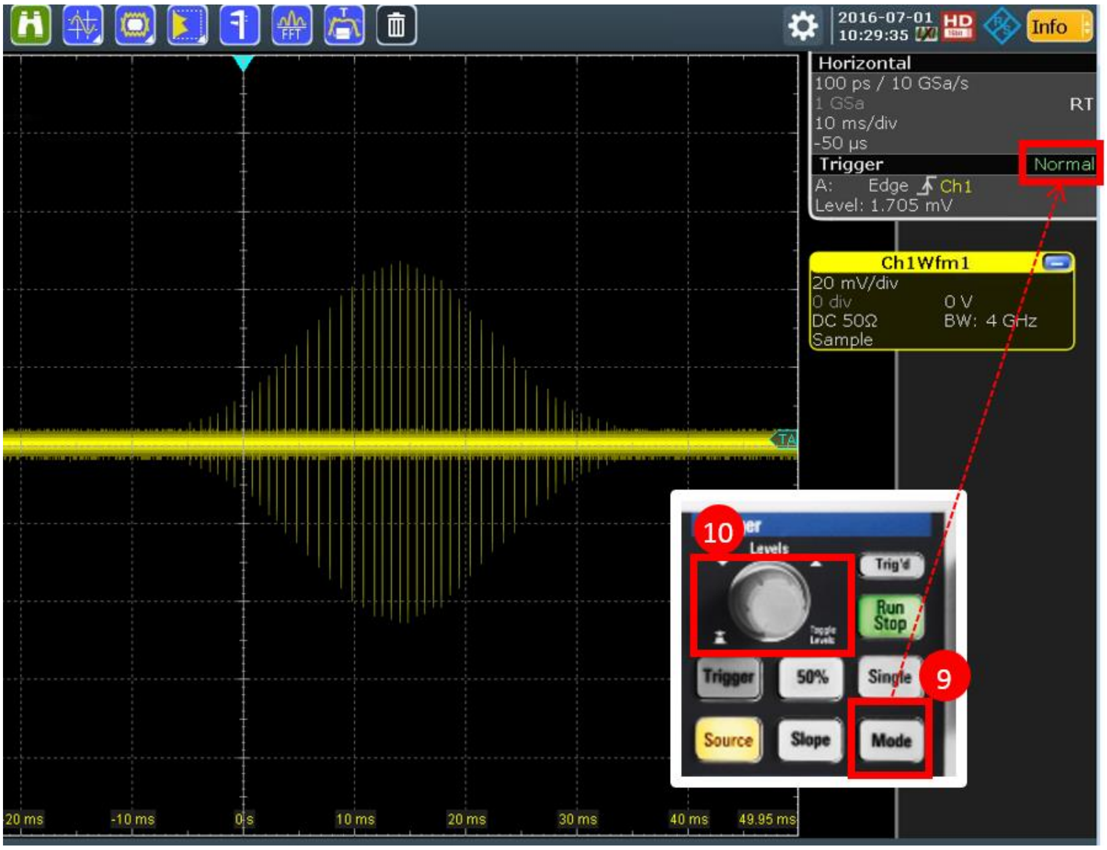


Figure 5: Signal capture from preset

9. Press **[Mode]** to change the trigger mode to **[Normal]**. You should see the signal with its carrier frequency.

10. When changing the **[Tigger Level]** you can decide which levels of the turning antenna are to be acquired.

3.2.2 Analysis setup: Frequency Properties

This section describes the measurement setup for the analysis of the

- carrier frequency of the acquired pulses within 5 ms,
- power of the carrier frequency of a selected pulse,
- scanning rpm of the turning antenna.

The measurements are based on the previous settings (see 3.2.1 Analysis setup: RADAR Signal)

1. Click on **[Horizontal]** and change the acquisition time to 5 ms (see Figure 6: Frequency view) so you can see some pulses.

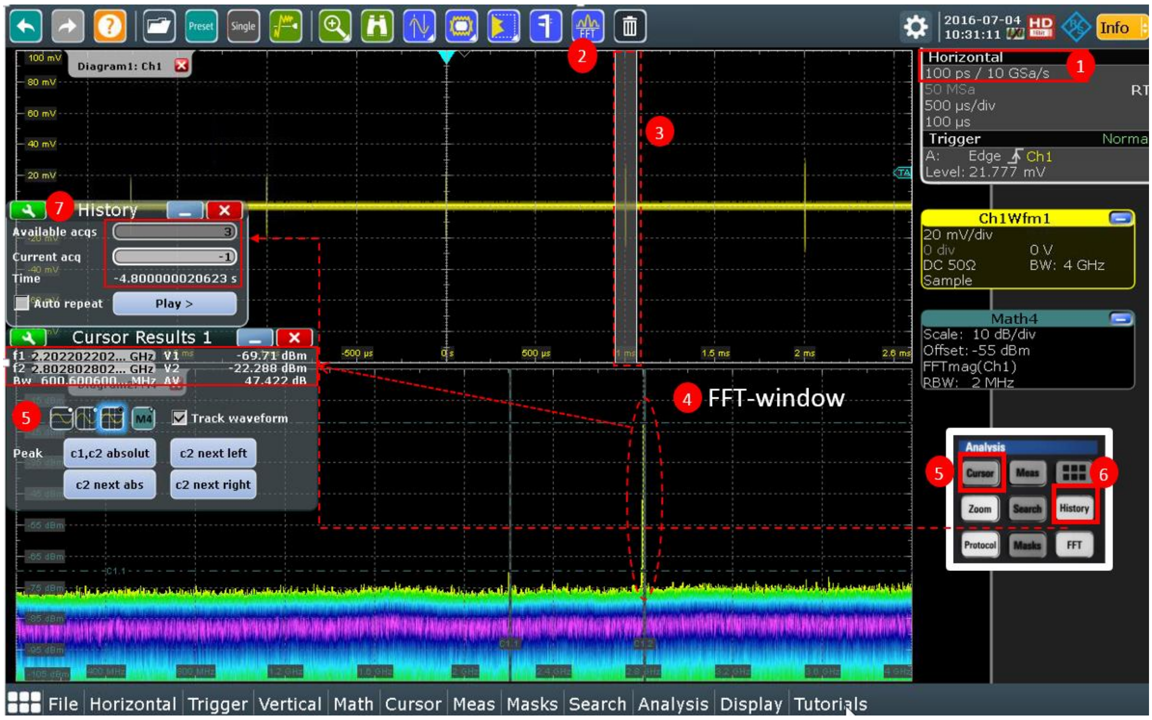


Figure 6: Frequency view

2. Click on the **[FFT Icon]** in the Icon bar.
3. Draw a square among the pulse of interest using the touch screen. Please note that you can move the square at any time to another pulse if interest.
4. The FFT diagram Window appears after drawing the square. The FFT applies "Math4" waveform, as named **[M4]** in the figure above. In the screen you can verify the carrier frequency and harmonics.
5. In order to measure the carrier frequency you can add a **[Curser]** and drag them to the point of interest. In the "Cursor Results 1" window you can verify the main carrier at f2: 2.802 GHz with -22.288 dBm (the reference clock are not locked). Note that the curser shows the [Hz/dBm] information from the position you selected.
6. In order to measure the antenna turning speed, set the **[History]** mode. The history mode is explained in detail in [1].
7. Verify the time between the available acquisitions, by toggling the **[Current acq]** from 0 to -2. In here you can see that the time between acquisition 0 and -1 is -4.8 s which corresponds to 12.5 rpm (60 s/4.8 s) of the antenna.

3.2.3 Analysis Setup: PRI properties

This section describes the configuration setup for analysis of

- pulses, where the carrier frequency is filtered out, within 20 ms of acquisition time
- pulse repetition interval (PRI) distribution of the transmitted pulses.

This analysis is based on the data which has been captured as described previously. It applies the **[Math]** functionality build in the RTO to filter out the carrier frequency. This, in fact is an AM demodulation to acquire the pulse envelope from the carrier frequency, which is the better procedure than using the "envelope" waveform arithmetic as described in the manual of the RTO.

1. Click **[Horizontal]** and change the acquisition time to 20 ms see Figure 4: Acquisition configuration step 8.

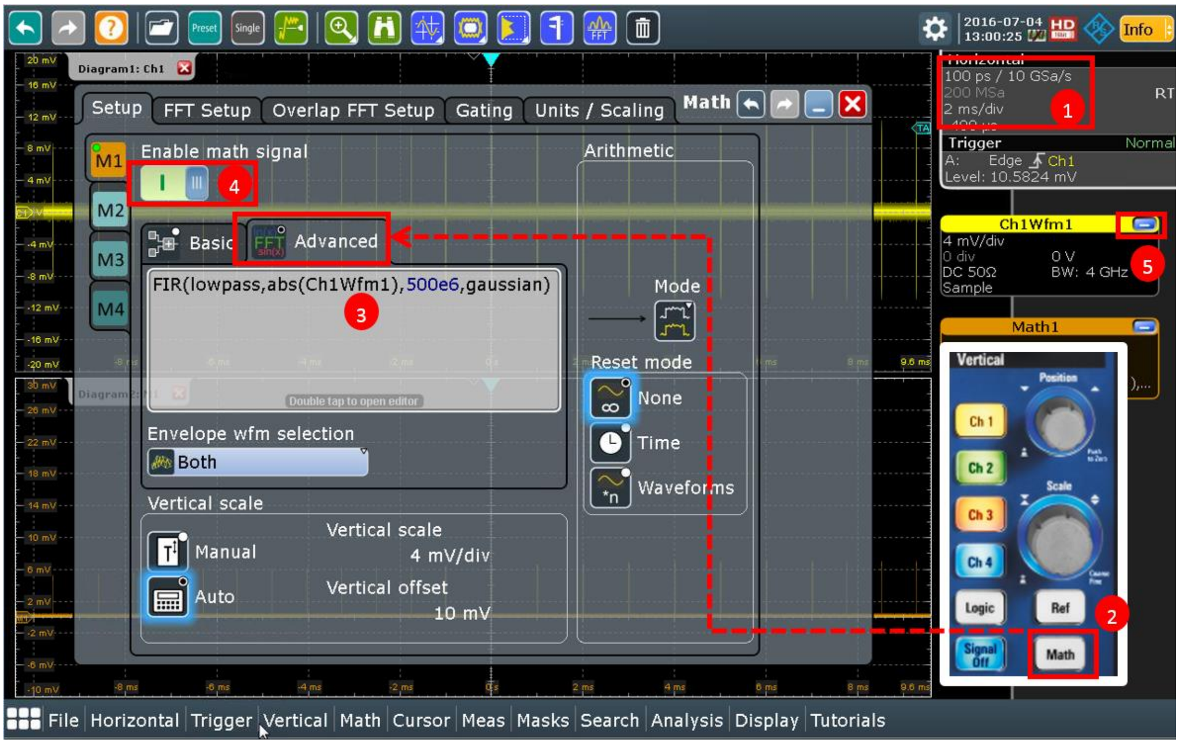


Figure 7: Advanced Math configuration

2. Press (2x) **[Math]** on the keypad and select the **[FFT Advanced]** tab.
3. Click on the editor area. The **[Formula Editor]** opens, (see Figure 8: FormulaEditor on next page)

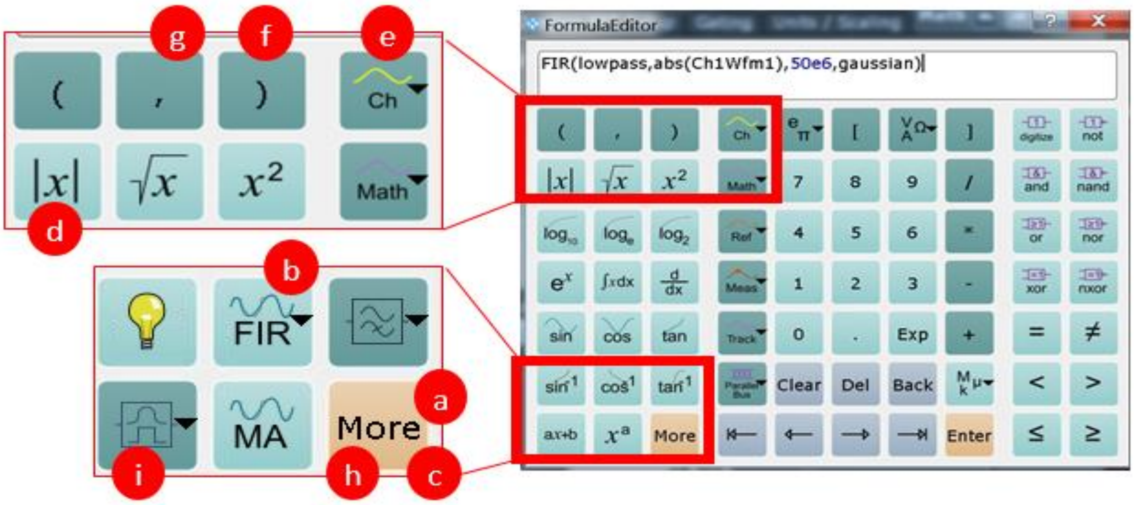


Figure 8: FormulaEditor

a) click on **[MORE]** to get more menus

b) click on **[FIR]** and select **[Lowpass]**

c) click 2 x **[More]**, to

d) click on **[|x|]**

e) click on **[Ch]** select **[Ch1Wfm1]**

f) close the bracket **[ )]**

g) click in a comma **[,]**, dial in a frequency value of the lowpass filter, in here 50 MHz, click **[,]**.

h) click **[More]** then

i) click on filter shapes and chose **[Gaussian]**, select the brackets **[ )]** like in step f)

j) press **[Enter]** and close the **[FormulaEditor]**

4. Enable the math signal. It will take another acquisition time to display the new **[Math1]** signal

5. Minimize the **[Ch1Wfm1]**, so you have in the main display only the pulses.

One possibility to measure PRI is by using the cursers. In contrast to this manual measurement, there is a possibility of automatic PRI measurement, which also allows statistical analysis. The RTO has a "distribution option" where you can for example create a histogram of the PRIs. To do this analysis press **[MEAS]** and follow the instructions below.

6. Press **[MEAS]**

7. Verify the **[Setup]** tab

Figure 9: Measurement configuration

8. as **[Source]** chose **[M1]** which refers to the Math1 waveform
9. at **[Amp/Time]** chose the **[Period]**, optional are other measurements
10. switch on **[State]**
11. select the second tab **[Long Term/Track]**
12. disable **[Continuous auto scale]**
13. set the **[Meas scale]** according to the expected values (in here 1 ms/div and offset 3 ms]
14. use **[Number of bins]**=1000 and enable the **[Histogram]**

In Figure 10 you can see the two diagrams. The top diagram shows the RADAR signal pulses without the carrier frequency. The lower diagram reveals the distribution of the pulse PRIs within the acquisition duration.

One can clearly see that the 50 ms acquisition duration captured at approximately 40 pulses with two different PRIs (in this measurement 1 ms and 757 us)

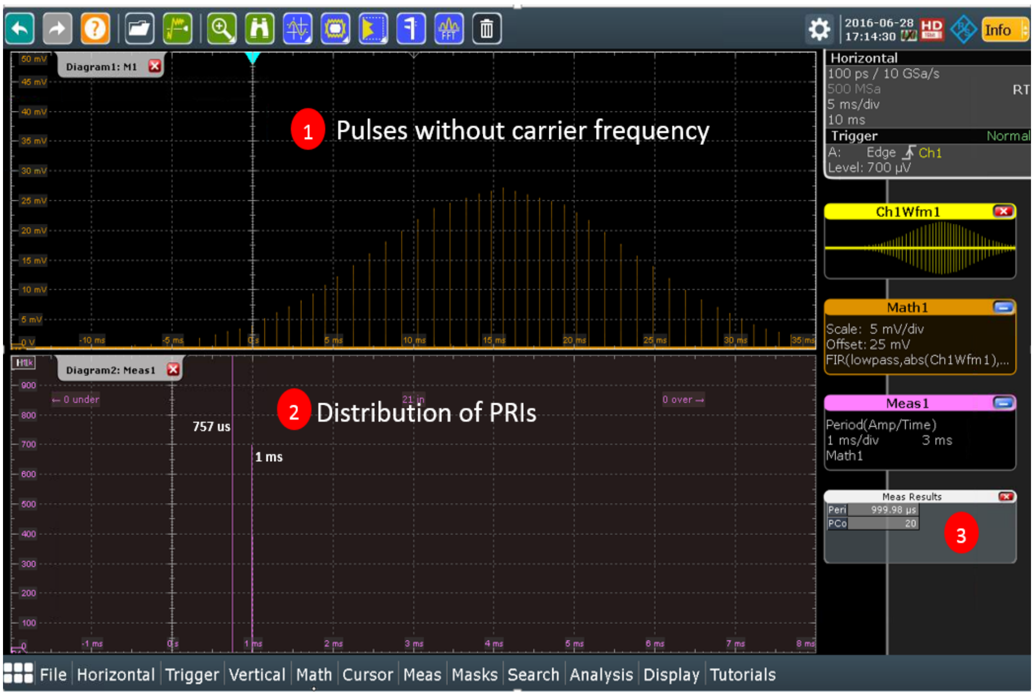
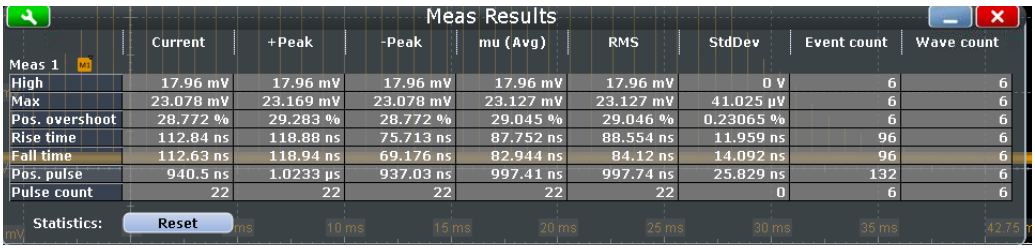


Figure 10: Distribution of PRIs

You can add also a statistical measurement (as seen in Figure 11 to the acquired pulses as like rise-/fall time, pulse length and linearity, by clicking [Meas Results] at (3), adding more measurement properties (see Figure 9) and enabling the **[Statistics]**



Meas Results

Meas 1	Current	+Peak	-Peak	mu (Avg)	RMS	StdDev	Event count	Wave count
High	17.96 mV	17.96 mV	17.96 mV	17.96 mV	17.96 mV	0 V	6	6
Max	23.078 mV	23.169 mV	23.078 mV	23.127 mV	23.127 mV	41.025 µV	6	6
Pos. overshoot	28.772 %	29.283 %	28.772 %	29.045 %	29.046 %	0.23065 %	6	6
Rise time	112.84 ns	118.88 ns	75.713 ns	87.752 ns	88.554 ns	11.959 ns	96	6
Fall time	112.63 ns	118.94 ns	69.176 ns	82.944 ns	84.12 ns	14.092 ns	96	6
Pos. pulse	940.5 ns	1.0233 µs	937.03 ns	997.41 ns	997.74 ns	25.829 ns	132	6
Pulse count	22	22	22	22	22	0	6	6

Statistics: Reset

Figure 11: Statistical measurement view

3.2.4 Analysis Setup: Pulse width list

This section describes the steps to get a list view of the captured pulses within an acquisition. It relies on the setup seen from Figure 10. The outcome will be a table with the pulse width of each acquired pulse that can be exported into a *.csv file.

1. Click on the **[Search]** button, the **[Setup]** window opens,
2. Select the **[M4]** (=Math4) trace, which is the "filtered" trace from prior section.

Figure 12: Search configuration

3. Select **[Width]** from the search criteria.
4. On the "Detailed Search Parameter Group", select **[Width]** tab, leave polarity as default positive.
5. Select the **[Longer]** from the **[Range]** and type in the minimum pulse width to look for, in this example it is "longer than 750 ns".
6. Select the **[Trigger]** level accordingly
7. Set control to **[Enable]**

8. On the **[Noise Reject]** tab uncheck the **[Noise reject]** in the **[Search tab]**. Close the window. After a couple of seconds the table will be populated.

Figure 13: Search result list

3.2.5 Analysis Setup: Pulse properties

This section describes the analysis setup within a shorter acquisition time and with a much more reliable trigger, namely the width trigger. The width trigger detects positive and/or negative pulses of a pulse width (duration) inside or outside of a defined time limit. With the known off-time of the radar pulse, the RTO makes sure to acquire every pulse the radar sends. An "Edge" trigger might trigger on a pulse midamble due to a sudden change of amplitude as well. To understand the width trigger see Figure 14.

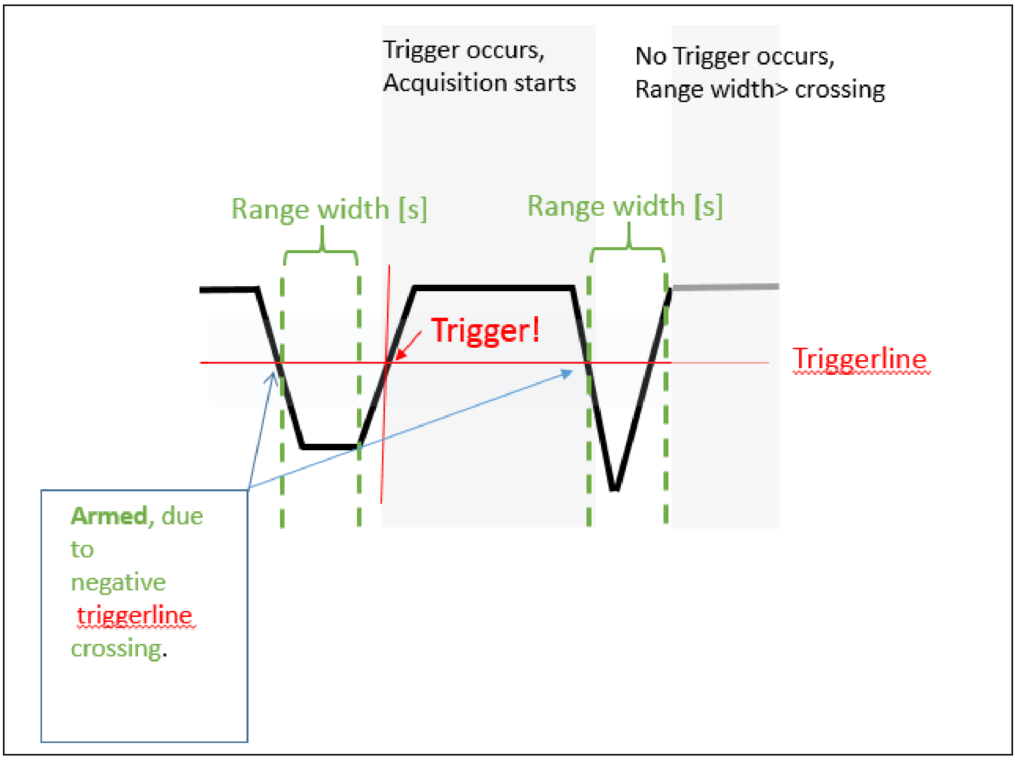


Figure 14: Width trigger schematic

With the history mode [1] you can verify and observe each pulse within the capture time in regards to the,

- pulse properties of fall-/rise time, the pulse-/ width, -overshoot and magnitude.

Note that the **[Math1]** waveform from section 3.2.3 is being used to analyze the pulses.

1. Click on **[Horizontal]** pane and decrease the **[Acquisition time]** to 2 us (see Figure 4 of section 3.2.1 Step 8)
2. Click on the **[Trigger]**, the **[Trigger/Setup]** window opens,

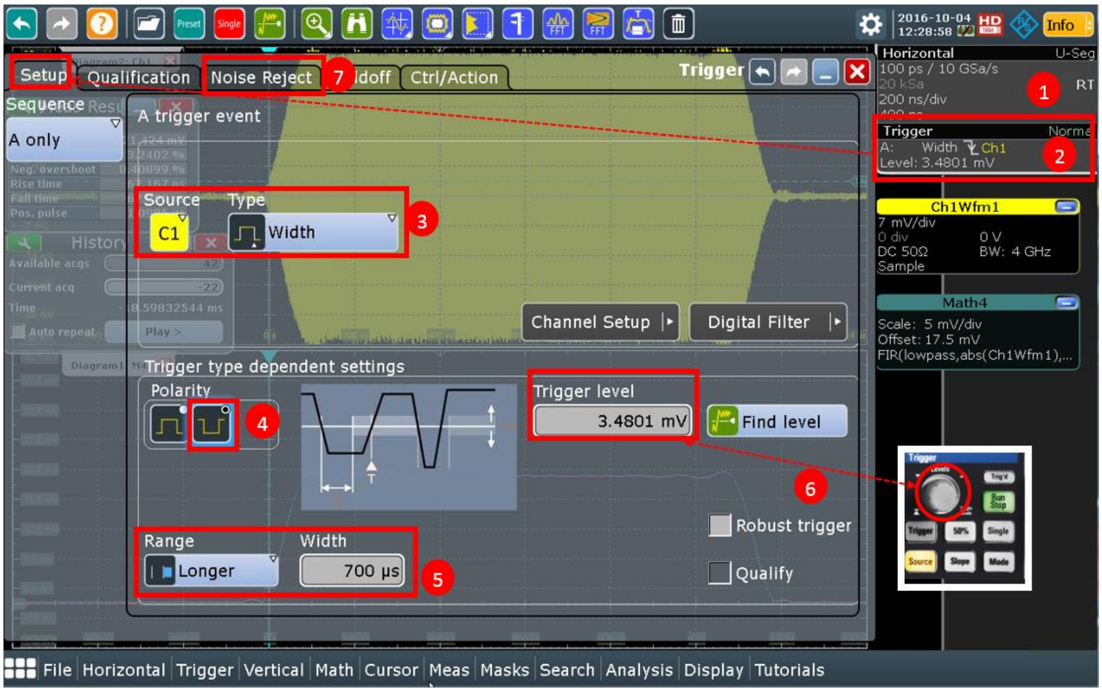


Figure 15: RTO Width trigger settings

3. Select **[Type]** to **[Width]** and keep the source your measurement channel signal, here **[C1]**.
4. Change the polarity to negative.
5. Select the Range to **[Longer]**, since Figure 10 reveals that the min PRI is 753 us, select the **[Width]** to 700 us.
6. Select the **[Trigger Level]** to be above noise level.
7. Click on Tab **[Noise Reject]** and select there **[Manual]** only.
8. Click on the [Horizontal] and select the [Ultra Segmentation] tab
9. Match **[Enable ultra segmentation]**
10. Match **[Acquire maximum]** for maximum pulse acquisition within the beam.

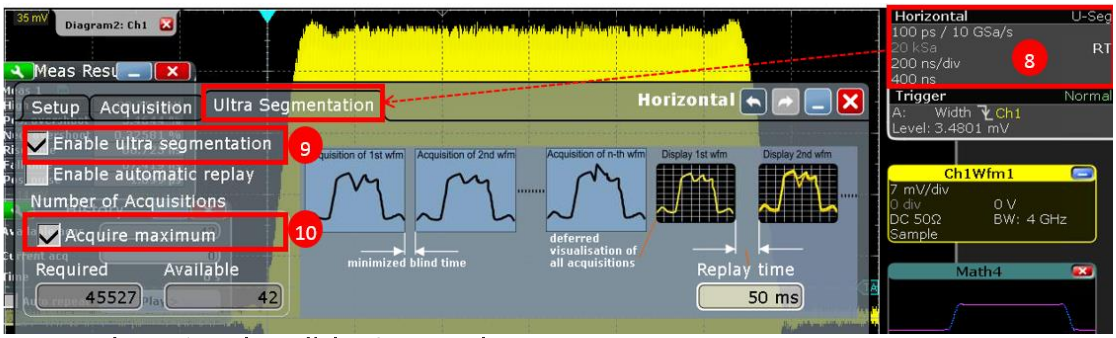


Figure 16: Horizontal/Ultra Segmentation

11. Click on **[Meas]** and select the measurements according to your needs (Figure 9: Measurement configuration step 9)

Figure 17: RTO Single pulse analysis

12. Click on **[History]** so that the acquired pulses are in the acquisition memory. Once clicked, the acquisition is stopped.

13. Now you can toggle/navigate among the acquired pulses and analyze each of them separately. This example shows 42 acquisitions and the -22th is analyzed by rotating the navigation wheel.

14. The measurement result is drawn in volts. In our example the "high" pulse value is 21.42 mV (-20.37 dBm), which is the power of the pulse width, not the peak value. The conversion can be done quickly via the application R&S dB Calculator (download at [9]).

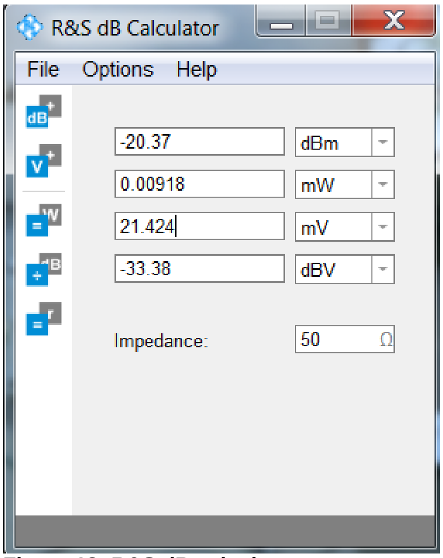


Figure 18: R&S dB calculator

3.2.6 Analysis Setup: Modulation on Pulse

This section describes the analysis setup based on 3.2.2 Analysis setup: Frequency Properties with the addition of a modulation on pulse. The modulation is a 150 MHz upchirp within a 1 us pulse width and a PRI of 10 us. This example is verified in Figure 19 below.

The pictures shows in 3 diagram areas the following information

[Diagram 1:Ch1]: One pulse captured with a FFT gate. The FFT gate is the time window from which the FFT is calculated. See detailed view Figure 21

[Diagram2: M4]: is the FFT spectrum view on which the cursers are applied showing the approx. bandwidth of the chirp, namely 149 MHz

[Diagram3: SG4]: is the spectrogram over time and frequency showing the modulation on the chirp for approx. 14 pulses. The colors have been adjusted beforehand to resemble the monochrome radar display colors. The spectrogram fills from bottom to top, which means the "current pulse" in time is at the bottom and the "oldest pulse" acquisition is on top. The frequency starts from lower RF frequency to upper which is namely the upchirp.

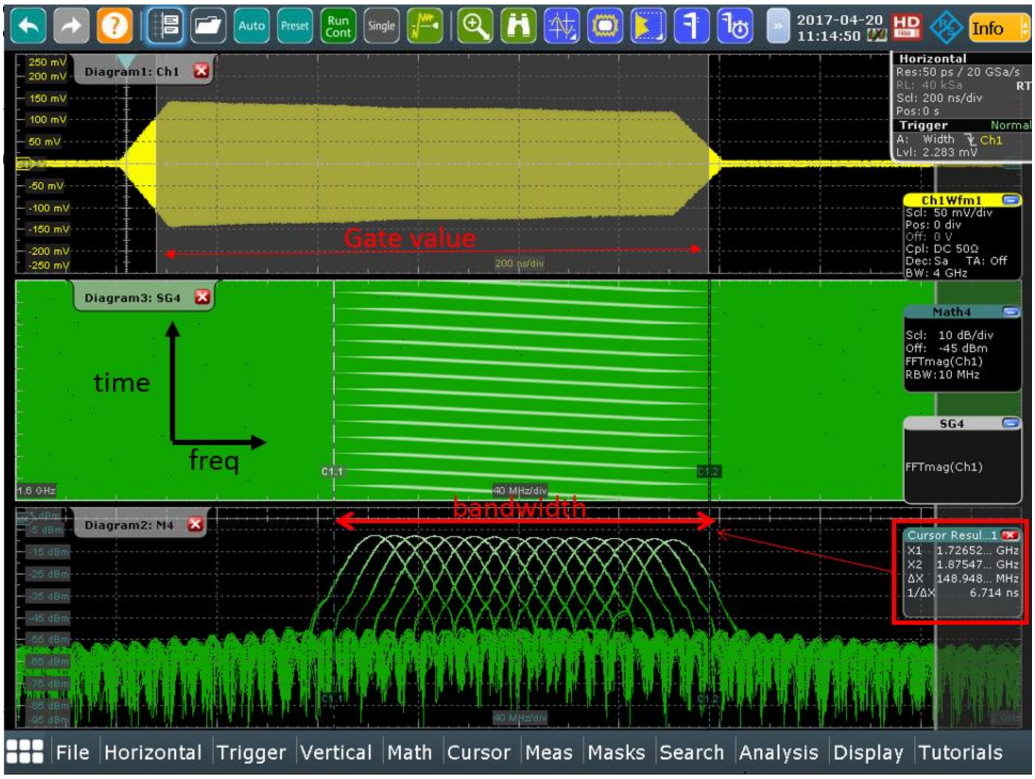


Figure 19: Modulation on pulse

In order to use **[FFT Gating]** use the **[Math]** setup as like mentioned in section 3.2.2 steps 1 to 3.

1. Click on the tab **[FFT Setup]**

Figure 20: Math/FFT Setup

2. Chose the **[Center frequency]**, here 2.8 GHz and chose the **[Frequency span]** here 200 MHz If **[Enable math signal]** is not already at **[On]** click on it.
3. **[Enable]** spectrogram will open the **[Diagram 2]** window.
4. Switch to **[FFT Gating]** tab
5. Enable the **[Use gate]**

6. Change the gate values according to the pulse width midamble by changing the values in the **[Gate Definition]** or simply by dragging on the **[Diagram 1:Ch1]** the left and right vertical gate lines.

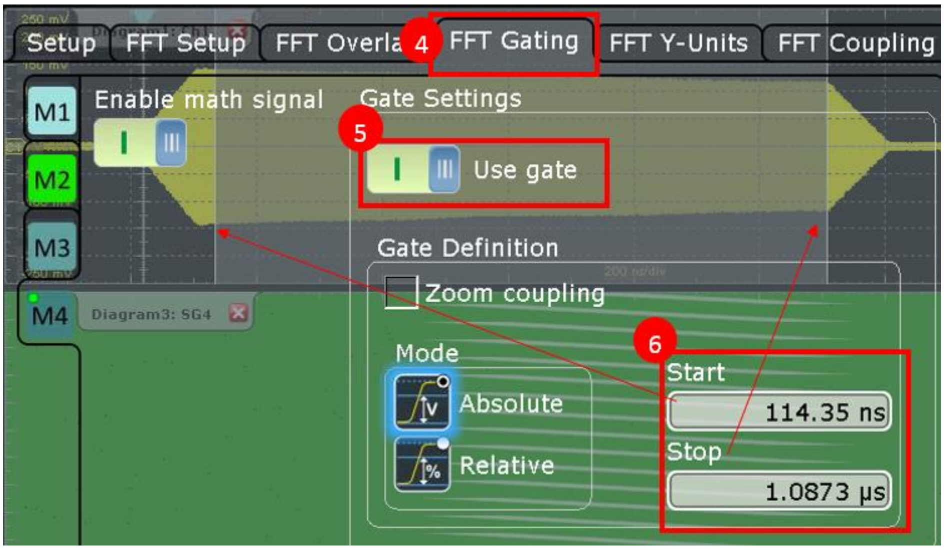


Figure 21: Math/FFT Gating

4 Measurement Setup for Signal Analysis using a combination of RTO & VSE-K6

This section describes measurements on the same signal as used in the previous section. Instead of using the RTO time domain measurement, it documents the difference when using the VSE-K6.

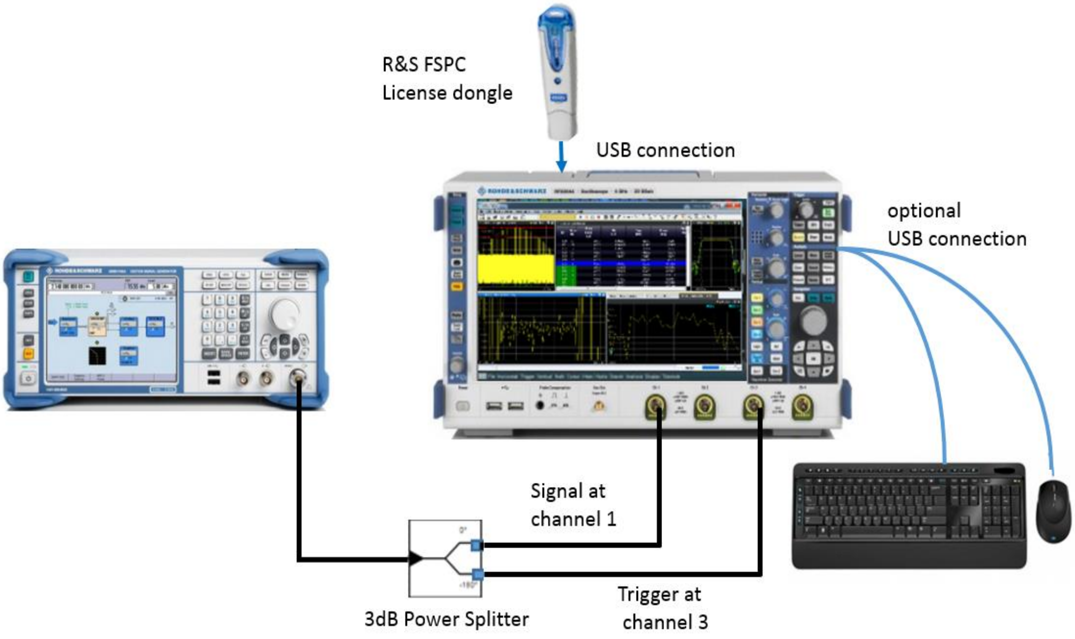


Figure 22: Lab Setup for RTO & VSE-K6

4.1 Connection Setup RTO and VSE-K6

The RTO requires a license dongle to run the VSE-K6. Furthermore, The RTO shares the memory between channel 1/2 and 3/4. For this reason and to reach the optimal performance and maximum memory you should connect the signals either to channels 1/3 or 2/4.

In the figure below the Signal Generator SMBV generates the ATC RADAR signal as shown in the previous section. This signal is split and connected to channel 1 and channel 3. Channel 3 is just used to trigger on the Voltage level.

4.2 Analysis Setup

This subsection explains the analysis windows of the pulse analysis within the VSE. For first connectivity please refer to [4] page 9-12.

4.2.1 VSE-K6

Once the RTO is switched on and the default RTO screen is shown from which you can start the VSE-K6 application.

1. Press  on the **[Analysis]** pane to open the App Cockpit.
2. Select **[R&S Apps]** from the **[App Cockpit]**.
3. Click on the VSE-K6 Icon.

Figure 23: App Cockpit tab

The VSE Software opens in the main display, while the RTO display reveals as **[Remote display]** in the background. The RTO display can from now on only be accessed via the keyboard combination Alt +Tab.

4.2.2 Analysis Setup: Configuration in VSE-K6

While the display windows of VSE-K6 are explained in detail in the user manual on pages 9-12 [4], this section describes the steps for measuring the ASR-9 RADAR signal described in 4.1 Connection Setup RTO and VSE-K6.

1. Click on **[Meas Setup]** in the menu bar.

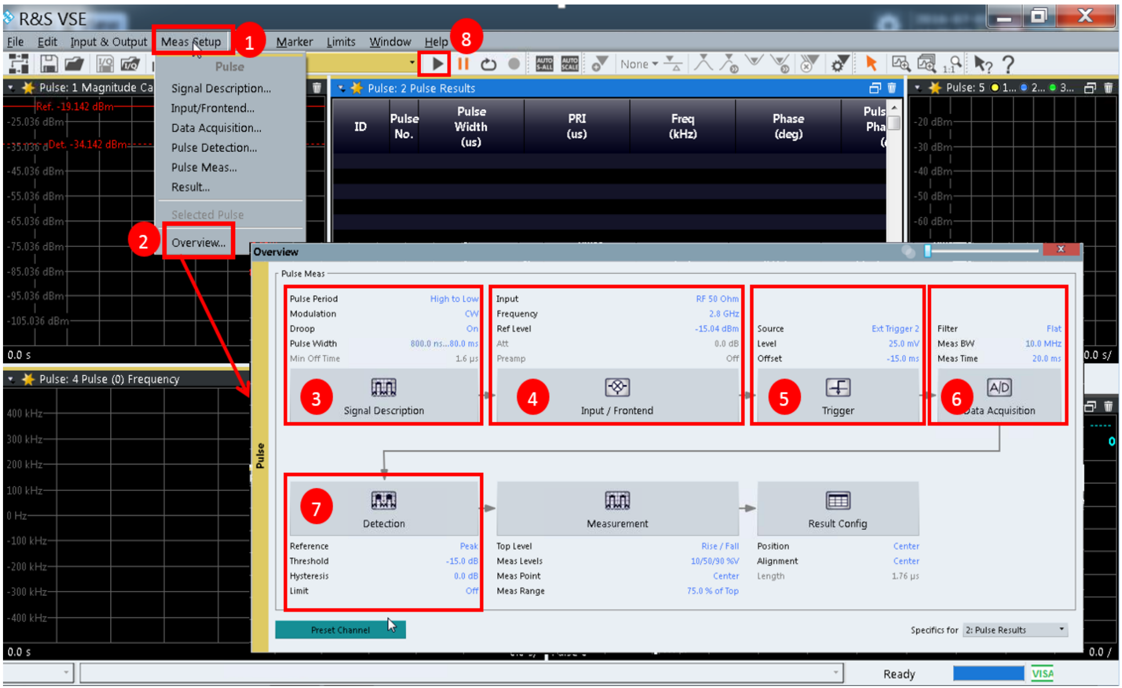


Figure 24: VSE-K6 Display

2. Navigate to **[Overview]** within the Meas Setup
3. In the **[Overview]** window you can see the values set in blue for each block. For this measurement we keep the default values within the **[Signal Description]** and close the window.
4. Click on the **[Input/Frontend]**, select the **[Frequency]** tab and enter 2.8 GHz as center frequency. Click on the **[Amplitude]** tab and enter the expected RF **[Reference level]** value (here -15 dBm). The rest of the tabs should stay in their default values. Close the **[Input/Frontend]** window.
5. Select in the **[Overview]** window the **[Trigger]** block, Set the **[Source]** to [**Ext Trigger 3]** which refers to Channel 3 of the RTO as can be seen in Figure 24. Set the **[Level]** to a proper value (here 25 mV) and the **[Offset]** to a negative value (here -15 ms). Close the window.
6. Click on the **[Data Acquisition]** block and define the **[Filter Type]** Gauss, **[Meas Bandwidth]** 10.0 MHz and **[Measurement time]** 60 ms. Close the window.
7. The **[Detection]** block defines which pulses will be demodulated and which are neglected. Select a **[Threshold]** according to the pulses that VSE-K6 shall detect.

8. Once configured press the **[play]** button which stats the acquisition. The acquisition takes several seconds. Pause the recording by pressing the **[pause]** button.

4.2.3 Analysis Setup: Measurements in VSE-K6

In this section the measurement results are explained in detail. Order the measurement windows according to your requirements. By default you will find the 5 measurement windows as shown in Figure 25 (for more details see [4]). These windows can be re-ordered and reconfigured according to your needs.

1. Click on **[Window]/[New Window]** to create additional measurement windows.

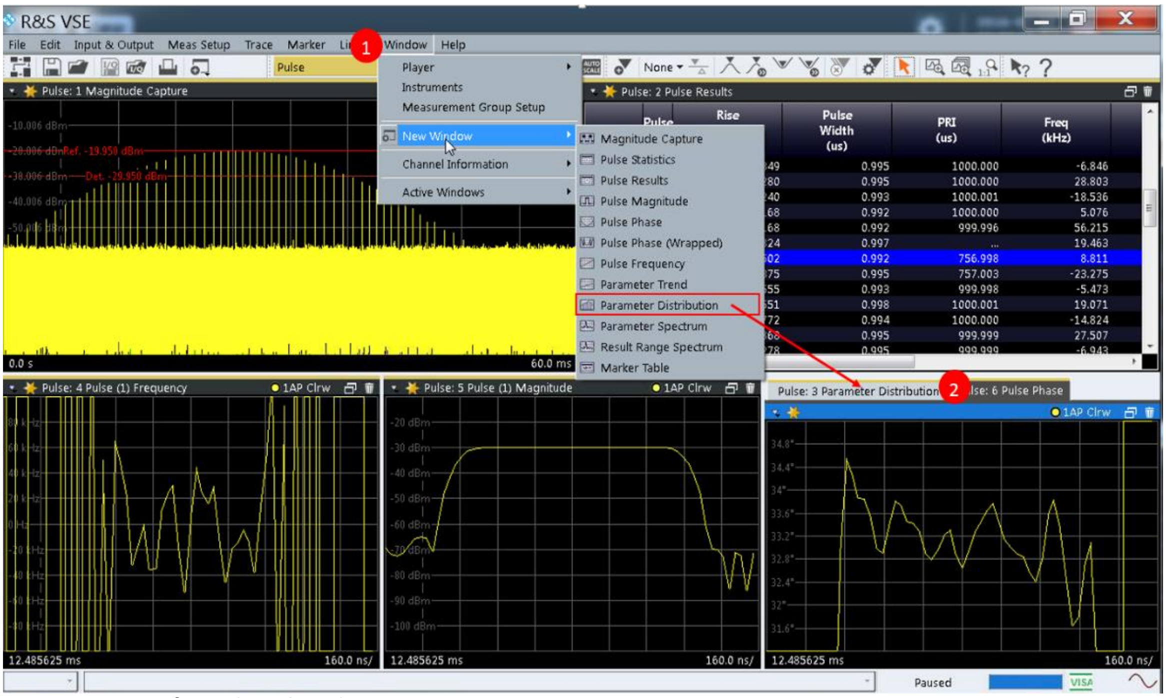


Figure 25: VSE-K6 Measurements

2. Drag the **[Parameter Distribution]** window to the desired display area.
3. Make sure the new window **[Parameter Distribution]** is highlighted (blue bar).

4. Click the **[Meas Setup]**

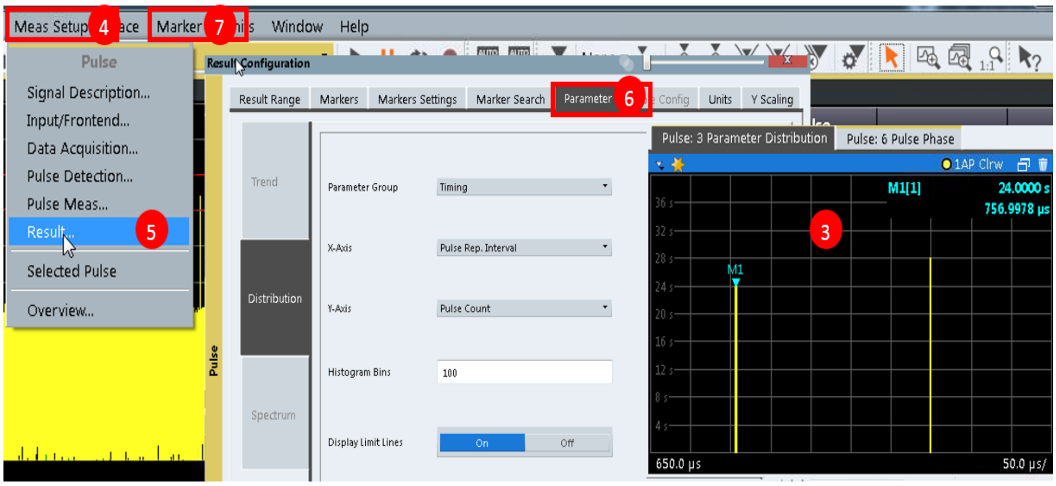


Figure 26: VSE-K6 Parameter Distribution

5. **[Chose Result…]** opens a window

6. In the parameter tab use the values as depicted in Figure 26. Close the window.

7. Add a **[Marker]** from the menu bar. The **[Parameter distribution]** windows shows the distribution of two different PRIs within the acquisition.

8. Click on the **[Pulse Results]** window and expand it. You see the acquired pulses as well as their property values.

Figure 27: VSE-K6 Result window

4.2.4 Analysis Setup: Measurements in VSE-K6 for modulation on pulse

In this section will briefly show the modulation on pulse with the VSE-K6. The pulse in this example uses a 100 MHz up-/downchirp (=triangle) modulation with a 1 us pulse width (rise/fall time of 100 ns) and a PRI of 10 us.

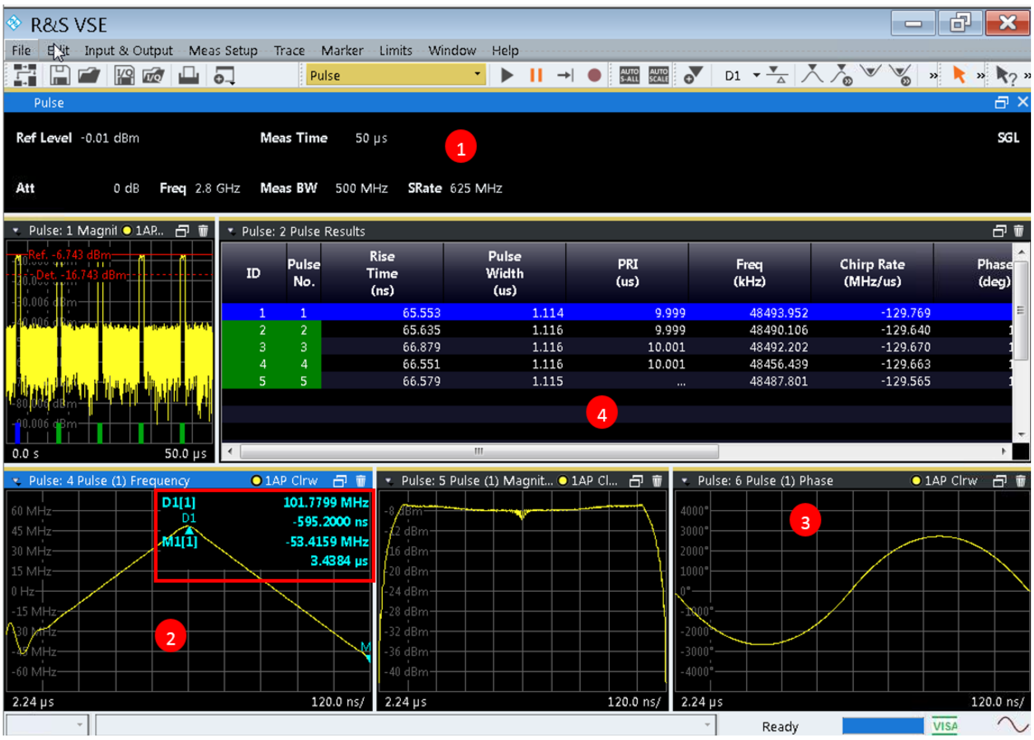


Figure 28:VSE-K6 modulation on pulse

As can see from above Figure 28 ,

1. The measurement time was adjusted to 50 us and the **[Meas BW]** to 500 MHz, although not limited, at 2.8 GHz carrier frequency.
2. One can see here the Triangle with upchirp from -50 MHz to 50 MHz within approx. 500 ns and the downchirp where the marker details are self-explanatory.
3. The pulse Phase information reveals a sine modulation.

5 RADAR Field Measurements using an RTO and VSE-K6

This section describes an ATC RADAR signal measurement performed close to Munich airport.

5.1 HW Measurement Setup

The ATC RADAR that was measured is the "ASR-South" located approximately 4 km far away from the Munich airport. The measurement equipment was setup at the observation point (small visitors outlook close to Munich airport), where the signal level was adequate without the need for an additional LNA. To receive the ATC RADAR signal the broadband R&S®HL050 Log Periodic Antenna was used. In addition a band pass filter reduces unwanted signals that can cause a trigger event from an unwanted frequency components (see Figure 30: Field test setup)

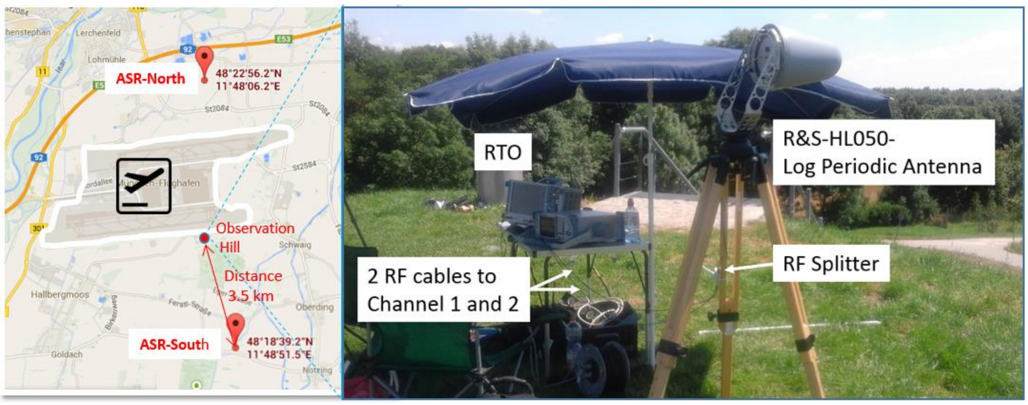


Figure 29: Location for field test

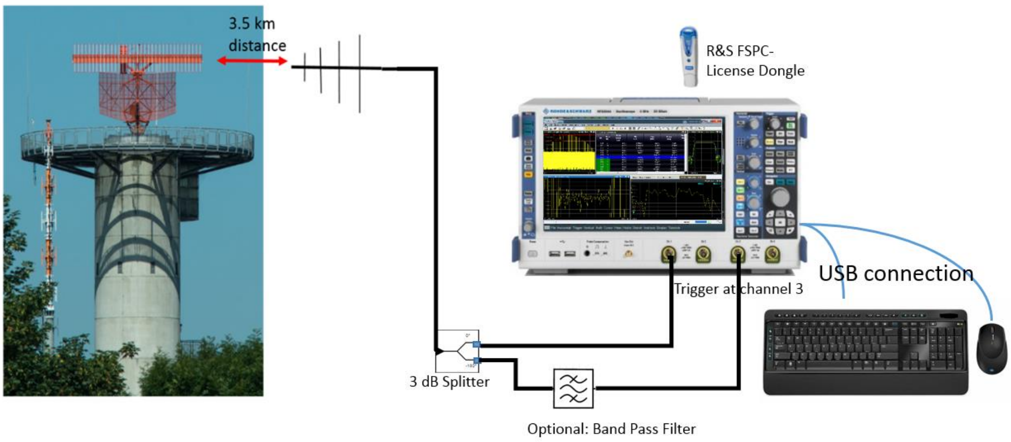


Figure 30: Field test setup

5.2 Results

This section describes the measurement results taken with the oscilloscope RTO and the VSE-K6 option as described in section 3 and section 4.

5.2.1 Oscilloscope Measurements and Analysis

1. Configure the RTO to acquire at 20 ms of data at a sample rate of 10 GSa/s. Adjust the trigger level to acquire the wanted signal. the trigger level adjustment is described in Section 3.2.1, Figure 5, step 10 in detail.

Figure 31: Scope Result

2. In this measurement the Diagram2 window shows two carriers in f1=2.82 GHz and f2= 2.88 GHz during a 50 ms acquisition at a span of 200 MHz, see Figure 31. These are the two carrier frequencies between which the RADAR is hopping.
3. Use the cursor to analyze the frequencies and levels in detail. The frequency delta between f1 and f2 is 60 MHz. Note that the power level measurement applies to the measurement taken at the moment of this specific RF beam. The following measurements are taken at different times.
4. For higher resolution the time acquisition is adjusted to 2us/div.
5. The diagram2 window, which was an FFT, is changed here to **[Math1]** as explained in section 3.2.3. One can see the pulse envelope by filtering out the carrier frequency. Adding the measurement results indicates the pulse properties per captured pulse sequence. The amplitude for the 1st pulse is ~53 mV and for the 2nd pulse ~58 mV which yields according to [9] -12.5 dBm and -11.27 dBm, see Figure 32.

6. When using the RTO history mode as explained in section 3.2.1, step 10, the first pulse shows an amplitude droop. You can move though the entire signal capture (available acquisitions) and history of the captured pulses by selecting the individual acquisition (current acquisition).

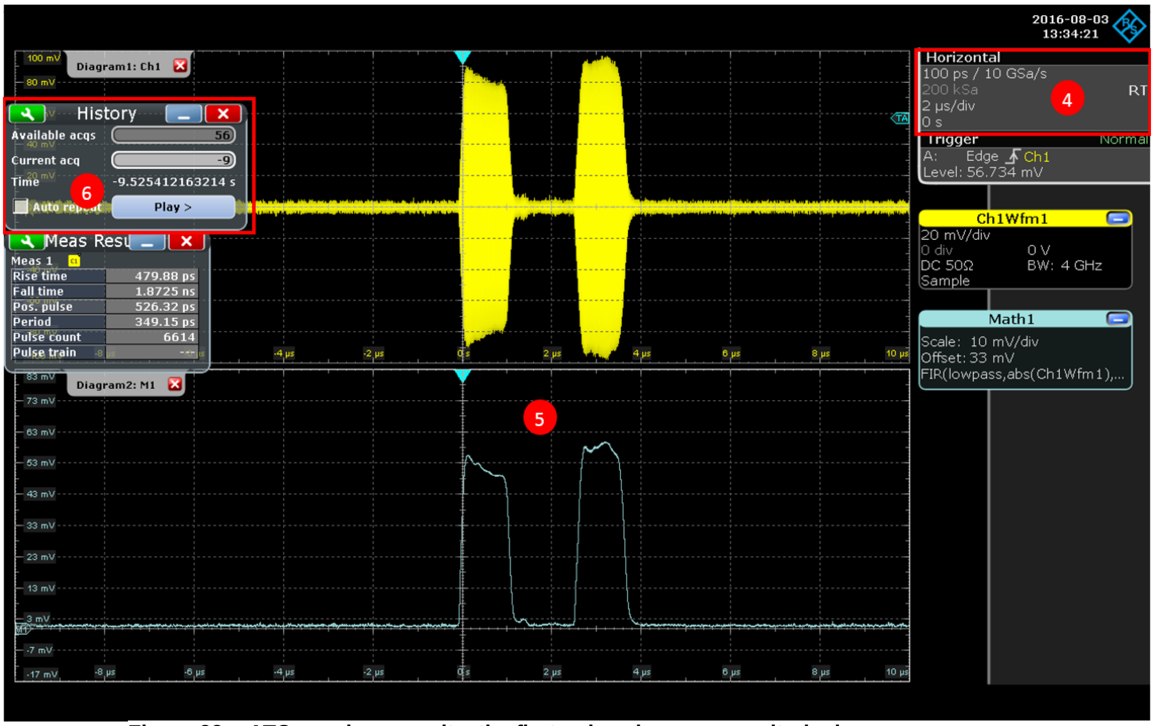


Figure 32 : ATC envelope results, the first pulse shows a magnitude droop

5.2.2 VSE-K6 Measurements and Analysis

In the VSE-K6 the main settings have to be modified in the configuration **[VSE-K6 INPUT SETTINGS]**. The measurement bandwidth has to be adjusted according to the equation: Meas BW= 2 x (fhop + 1/2 Pulse BW).

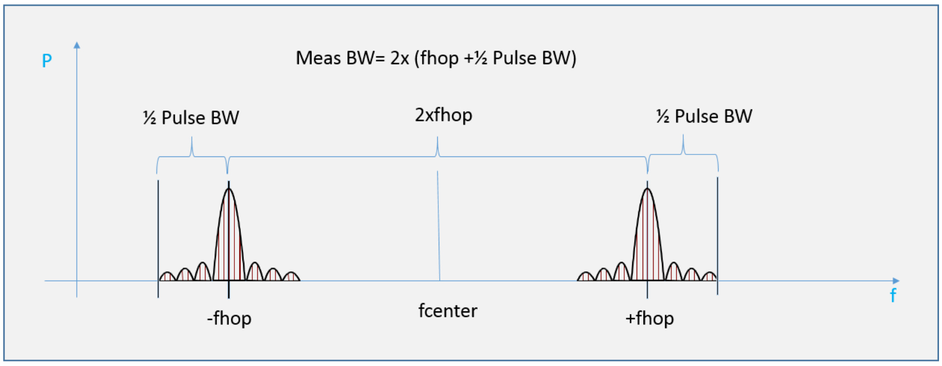


Figure 33: Measurement bandwidth calculation

Using the description from section 4.2.2 the following parameters are set in the VSE-K6:

- Center frequency: 2.85 GHz

- Measurement bandwidth: 80 MHz
- Trigger Source: External Channel 3, Trigger level 100 mV and offset -6 ms.
- Measurement time: 50 ms
- Amplitude: -10 dBm.

1. Using this configuration the **[Magnitude capture]** window displays an adequate acquisition of many pulses.

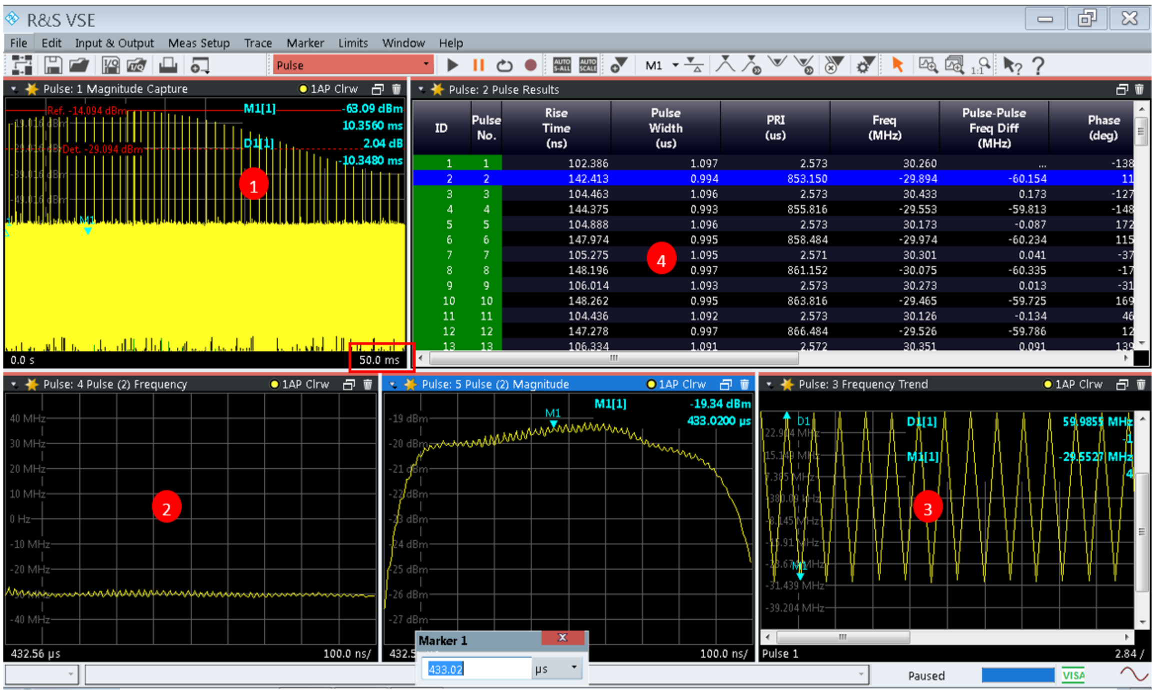


Figure 34: VSE-K6 ATC radar capture

2. The intra "Pulse Frequency" window shows that pulse number 2 with an offset of approximated -30 MHz from the center frequency (this corresponds to the RTO measurement described in section 5.2.1, where the center frequency was 2.85 GHz and two frequencies +/- 30 MHz have been measured).
3. The "Frequency Trend" window shows the frequency offset from the carrier frequency for each detected pulse. It can be seen that the RADAR hops between +30 MHz and -30 MHz frequency offset from center frequency. The delta markers shows the 60 MHz distance from 2 pulses.
4. The "Pulse Results" table shows a summary of all detected pulses with its parameters. A pulse is detected as soon as the power level reaches the detection threshold as indicated in the "Magnitude Capture" with a dashed red line. A double click on the window "Pulse Results" expands it to maximum.

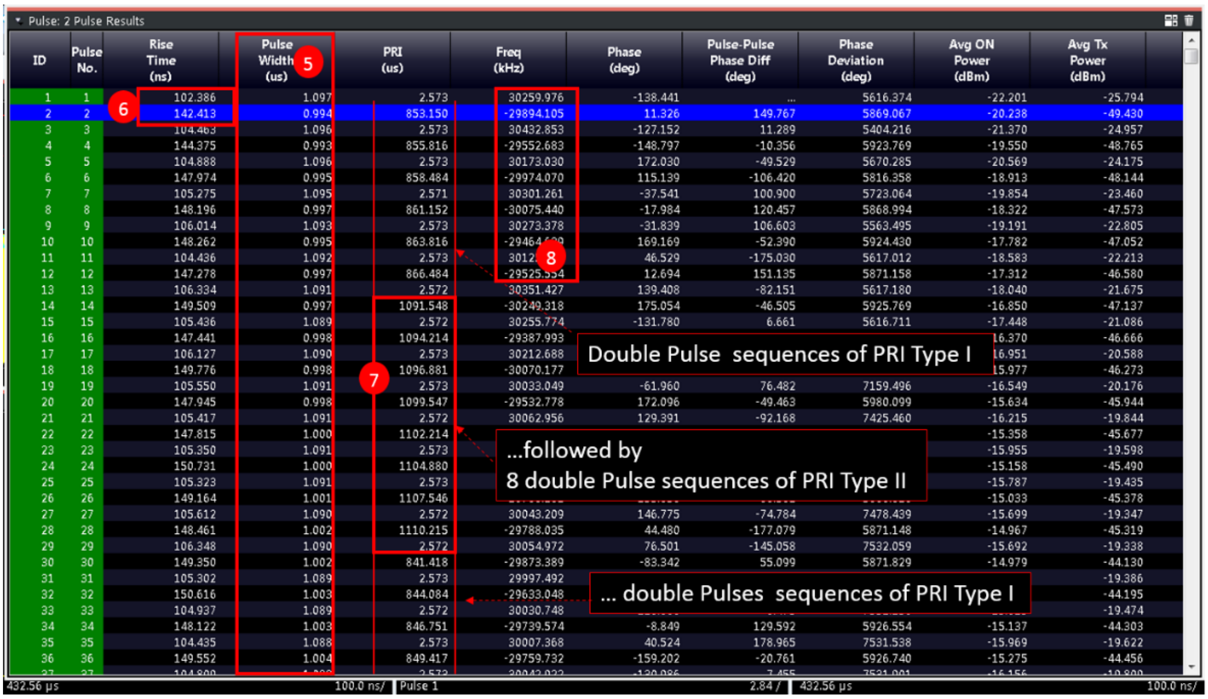


Figure 35: VSE-K6 result window

5. The pulse widths of detected pulses within the entire signal capture are 1 us +/- up to 97 ns.
6. The rise time of the odd pulses (102 ns) are different from the even pulses (142 ns). The trend of the rise times can be also shown in the trend window.
7. This RADAR is using 2 kind of double pulses of different PRI. Starting at pulse no 1 to 13 shows a double pulse sequence with constant PRI between the even to the odd pulses of 2.57 us, the even are on frequency f1 while the odd are in frequency f2. The even pulses (2, 4, 6…) are inclining the PRI by n times 2.66 us, referred here as PRI type I. As type II we refer here pulse no 14 to 29, with a PRI of approximately 1.091 ms to 1.110 ms, also with an inclining of n times 2.66 us. For a ease of understanding Figure 36 describes visually the type II double pulse sequence.

   It seems that the PRI changes linearly for every two pulses. In order to decide if it is a "staggered PRI" or simply a drift you need to collect more pulse beams. Staggered PRI is practically a means to distinguish between moving targets and stationary strong echoes. A detailed explanation can be read in the Application Note 1MA207 [11]
8. Each pulse is hopping between +/- 30 MHz with little frequency jitter.

Figure 36 describes the property of this RADAR,

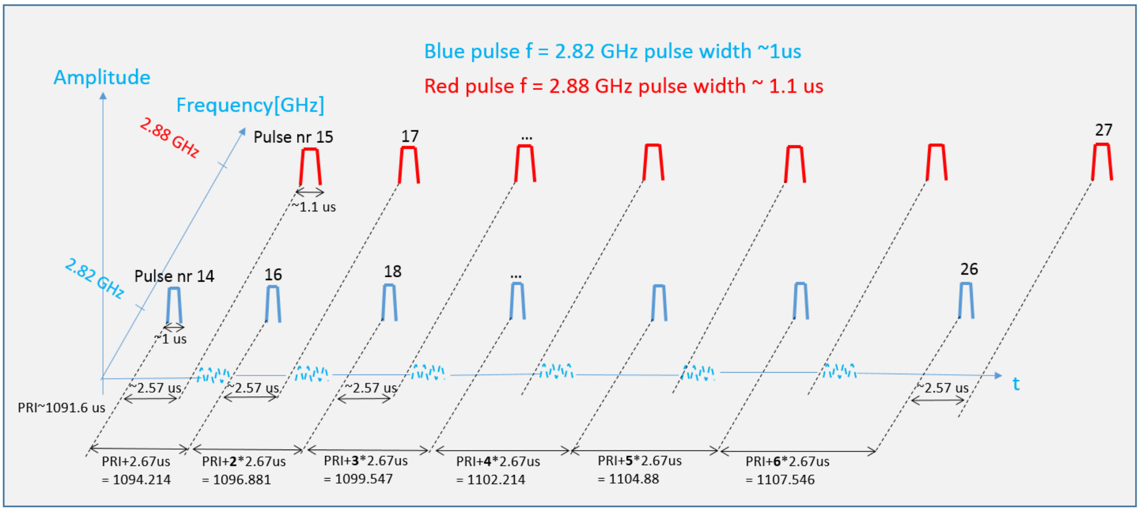


Figure 36: ATC pulse properties

6 Measurement of X-band maritime RADAR with FSx & VSE-K6

Some of the maritime RADARs operate in the frequency ranges S-,V- band, though most of them in the X-band. In most situations larger vessels are fitted with both "X" and "S" band RADARs while smaller vessels will only have an "X" band.

This section provides the setup description for measuring the X-band maritime RADAR with the help of a R&S signal spectrum analyzer in that frequency range.

6.1 Typical maritime X-band RADAR signal properties

Below is a derivation from the ITU-R M.1313 [10] recommendations for IMO (International Maritime Organization) and applies to the transmitter/receiver side of the RADAR under test (RUT).

Frequencies 8.850 GHz - 9 GHz & 9.2 GHz - 9.5 GHz		
Characteristic	**Maximum**	**Minimum**
Antenna gain [dB]	32	27
Rotation rate [rpm]	60	20
One rotation cycle [sec]	1	0.33
Peak Power [kW]	50	5
Frequency [MHz]	9445 +/- 30	9375 +/- 30
Pulse length [us]	1.2	0.03
PRF [Hz]	4000	375
PRI [ms]	2.6	0.25
Medium/Long Pulse	6	2.5
Intermediate Frequency [MHz]	60	45

Table 6: X-band RADAR property

6.2 FSx & VSE-K6 desktop option

In contrary to the RTO, where the data acquisition is from the waveform, or the RTO-K11 transfers the IQ values (see Table 1: RTO VSE-K6 capture modes), the spectrum analyzers downconverts the RF signal and transfers then the I/Q values to the VSE-K6 PC.

The table below shows the possible spectrum analyzers which can be used in regards to the capture length and the measurement bandwidth.

	VSE-K6 with higher frequency range Spectrum analyzers		
spectrum analyzer	Frequency up to [GHz]	Max record length I & Q [samples]	max capture time for low measurement bandwidth configuration
FSW	86	400 Ms	10 MHz/36.9 s
FSVA / FSV	40	200 Ms	10 MHz /16.77 s
FPS	40	400 Ms	10 MHz /36.9 s

Table 7: VSE-K6 capture length with FSx

[1] Please refer to the specification of the VSE-K6 data for exact option requirements [8]

This section describes the measurement on a real X-band maritime RADAR taken in the lab with an FSVA13.

6.3 HW Measurement Setup

In this setup, the RF from the RUT goes directly to FSVA13 at X-band frequency. The signal is being down-converted and the I&Q data transferred via LAN to the VSE-K6.

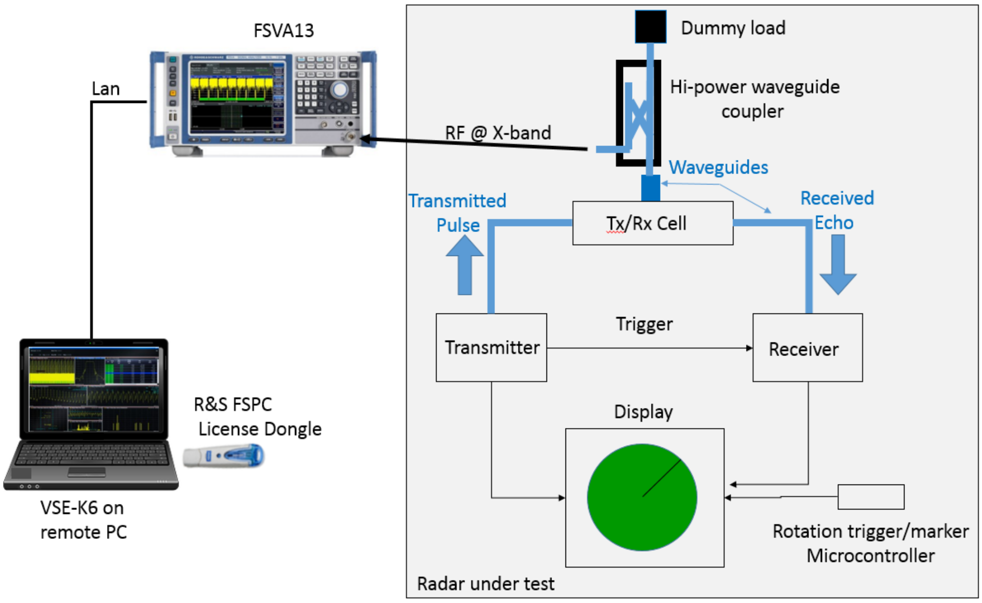


Figure 37: X-band RADAR measurement setup

6.4 Results

This section shows the VSE-K6 results in the main window in addition to the many possible statistics windows that can be added to the overview.

1. As you can see from the picture [refer] below the frequency of which this RADAR was sampled from the FSVA was at 9.38 GHz.

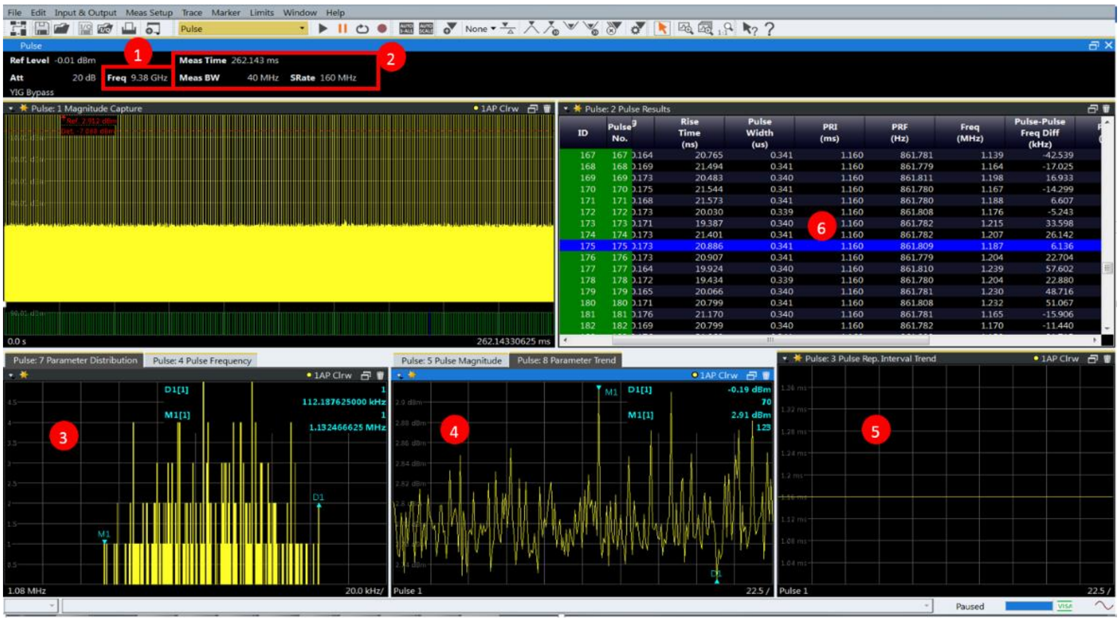


Figure 38:VSE-K6 measurement X-band radar

2. Furthermore the measurement time was set to maximum (262 ms) at highest measurement Gauss bandwidth possible (in this example it is 40 MHz, which 4 x 40 MHz the 160 MHz sampling rate).
3. You can set the **[Parameter Distribution]** window for the frequencies of all collected pulses and verify outliners. Inhere the maximal distribution among all collected pulses is 112 kHz.
4. The **[Parameter Trend]** window shows graphically the difference between the maximum pulse power and the minimal pulse power collected in this acquisition of 262 ms (in here 0.19 dB)
5. The **[Parameter Trend]** window for PRIs shows a straight line at 1.16 ms PRI for all pulses acquired. There is no staggered PRI as in the ATC RADAR.
6. A list of each pulse and its property can be seen in the **[Result window]**

7 Summary

Measuring a RADAR signal with somehow unknown pulse properties can be a challenging issue for a time domain measurement device. By combining the advantage of R&S oscilloscope hardware with the pulse measurement application software, referring to as VSE-K6, these challenges can be addressed.

In the basic configuration, RTO oscilloscopes offer 50 Msample acquisition memory per channel. Applications such as seamless acquisition of long pulse often require even deeper memory. RTO oscilloscopes' acquisition memory can be extended up to 2 Gsample. Signal processing in the ASIC ensures a smooth workflow even with deep memory.

The RTO oscilloscopes' history function ensures that previous waveforms stored in memory can always be accessed, as we have seen in this application note. A trigger timestamp allows time correlation. The user can view all saved signals and analyze the pulses with tools such as zoom, measurement, math and spectrum analysis functions.

Commercially available oscilloscopes output only the input signal sampled by the A/D converter. Prior to the actual I/Q analysis, users have to make sure that the signal is downconverted to the baseband, and then filtered and converted to the required sampling rate – steps that are error-prone and time-consuming. With the RTO oscilloscope, this process is faster and easier: The RTO-K11 I/Q software interface extracts the I/Q data from the input signal and provides this data directly to the VSE-K6.

Having the ability to verify the trend and statistical view, using the VSE-K6 adds even more perspective than only the individual pulse parameters. For example to analyze the hopping and drifting PRI of a real ATC RADAR.

The RTO digital oscilloscope offers an RF signal and pulse analysis bandwidth of up to 4 GHz. For RF frequencies of up to 85 GHz, a 2 GHz analysis bandwidth is achieved by using RTO with the FSW signal and spectrum analyzers, while a stand-alone FSW offers optional bandwidths of up to 512 MHz..

This application note presented a setup how to measure and analyze real RADARs, in lab or field conditions, and to verify its pulse properties as well as trends with the R&S RTO digital oscilloscope and the pulse analysis software VSE-K6. Furthermore the measurement results in combination with the analysis software is discussed.

8 Literature

[1] Application Note 1TD02 "Advanced Signal Analysis using the History Mode of the R&S®RTO Oscilloscope"; M. Hellwig, T. Kuhwald ;

[2] Application Note 1TD01 "How to utilize the I/Q Software Interface of the R&S®RTO Oscilloscope with MATLAB"; Rafael Ruiz; M. Hellwig;

[3] User Manual; "R&S VSE Vector Signal Explorer Base Software"

[4] User Manual; "R&S VSE-K6 Pulse Measurement Application".

[5] Application Note 1MA211; "Coexistence Test of LTE and RADAR; S. Heuel

[6] ATC-RADAR ASR-E, retrieved from http://www.RADARtutorial.eu/19.kartei/karte206.de.html, March 20, 2014 Application Note 1MA211; "Coexistence Test of LTE and RADAR; S. Heuel

[7] Datasheet; R&S VSE Vector Signal Explorer Base Software Specification ver 4.00

[8] Datasheet; R&S Pulse Measurement Application Specification VSE-K6 ver 3.00

[9] R&S dB calculator : http://www.rohde-schwarz.com/appnote/1GP77

[10] RECOMMENDATION ITU-R M.1313: https://www.itu.int

[11] Application Note 1MA240; "Pulsed RF Calculator", A. Winter; F.Schütze

[12] White paper 1MA207; "Introduction to RADAR Systems and Component Tests"; R. Minihold; D. Bues

9 Ordering Information

Designation	Type	Order No.
Vector signal explorer (VSE)		
Vector Signal Explorer Base Software	R&S®VSE	1320.7500.06
Pulse Measurement Application (requires R&S®VSE and R&S®FSPC) [1]	R&S®VSE-K6	1320.7516.06
License Dongle	R&S®FSPC	1310.0090.03
R&S®RTO 2000[2]		
Digital oscilloscope, 3 GHz, 10 Gsample/s, 50/100 Msample, 2 channels	R&S®RTO2032	1329.7002.32
Digital oscilloscope, 3 GHz, 10 Gsample/s, 50/200 Msample, 4 channels	R&S®RTO2034	1329.7002.34
Digital oscilloscope, 4 GHz, 20 Gsample/s, 50/200 Msample, 4 channels	R&S®RTO2044	1329.7002.44
Digital oscilloscope, 6 GHz, 20 Gsample/s, 50/200 Msample, 4 channels	R&S®RTO2064	1329.7002.64
RTO I/Q Software Interface	R&S®RTO-K11	1317.2975.02
RTO-OCXO 10 MHz[2]	R&S®RTO-B4	1304.8305.02
Memory Upgrade, 1 Gsample per channel	R&S®RTO-B110	1329.7090.04
Spectrum analyzers for different frequency ranges		
R&S FSW (basic instrument, 2GHz works in conjunction with RTO 2044)		
Signal and Spectrum Analyzer 2 Hz to 13.6/26/43/50/67/85 GHz	R&S®FSWxx[4]	1312.8000.xx[4]
512 MHz Analysis Bandwidth	R&S®FSW-B512	1313.4296.04
2 GHz Analysis Bandwidth[3]	R&S®FSW-B2000	1325.4750.02
Pulse Measurement (on the FSW)	R&S®FSW-K6	1313.1322.02
R&S FSV (basic instrument)		
Signal and Spectrum Analyzer 10 Hz to 4/7/13.6/30/40 GHz	R&S®FSVxx[4]	1321.3008.xx[4]
RF Preamplifier (9 kHz to 4/7 GHz) RF Preamplifier (9 kHz to 13.6/30/40 GHz)	R&S®FSV-B22 R&S®FSV-B24	1310.9600.02 1310.9616.xx[4]
160 MHz Analysis Bandwidth	R&S®FSV-B160	1311.2015.xx[4]
R&S FSVA (as described in this document)		
Signal and Spectrum Analyzer 10 Hz to 4/7/13.6/30/40 GHz	R&S®FSVAxx[4]	1321.3008.xx[4]
RF Preamplifier (9 kHz to 4/7 GHz) RF Preamplifier (9 kHz to 13.6/30/40 GHz)	R&S®FSV-B22 R&S®FSV-B24	1310.9600.02 1310.9616.xx[4]
160 MHz Analysis Bandwidth	R&S®FSV-B160	1311.2015.xx[4]

R&S FPS (basic instrument)		
Signal and Spectrum Analyzer 10 Hz to 4/7/13.6/30/40 GHz	R&S®FPS13	1319.2008.xx[4]
RF Preamplifier (9 kHz to 4/7/ RF Preamplifier (9 kHz to 13.6/30/40 GHz)	R&S®FPS-B22 R&S®FPS-B24	1321.4027.02 1321.4279.xx[4]
160 MHz Analysis Bandwidth	R&S®FPS-B160	1321.4285.xx[4]

[1] Firmware version 3.35 or higher required for use with VSE-K6.

[2] Required for use of FSW-B2000

[3] Requires an R&S RTO 2xxx series with B4.

[4] Refer please to the specification for exact ordering number of the specific frequency range.

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ISO 14001

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