

Simulating radar signals for meaningful radar receiver tests

Robert Vielhuber

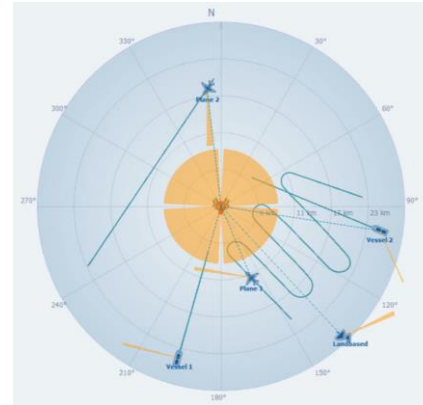
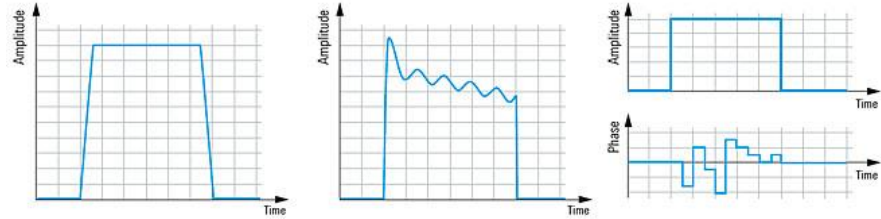
Product Manager

Signal Generators A&D

Automotive, Components

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- Import and replay legacy PDW lists
- Create complex radar scenarios
- High speed PDW streaming with R&S®SMW200A
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Building Blocks for an off-the-shelf Radar Signal Simulator

R&S®SGU100A

R&S®SGS100A


R&S®SMBV100B

R&S®SGT100A

R&S®SMW200A

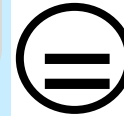
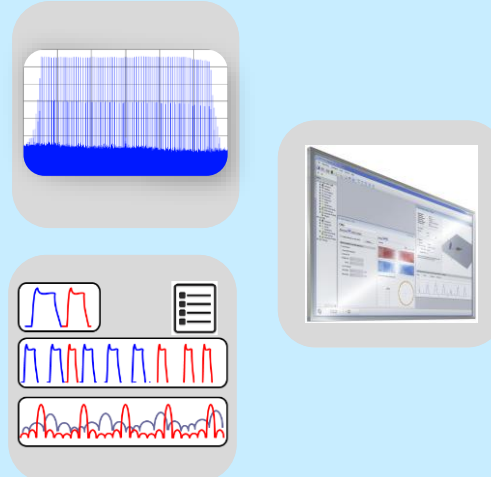
Outstanding hardware capabilities

- Up to 2 GHz internal baseband
- Dual path 20 GHz in one box
- RF frequencies up to 40 GHz
- Phase coherent signals up to 40 GHz



R&S®Pulse Sequencer software capabilities

- Generation of radar signals
- Real time sequencing
- Direction finding



Powerful radar signal simulator

- PC software
- Off-the-shelf signal generators
- Ultra flexible



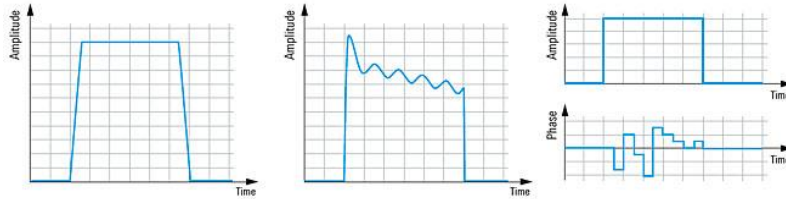
Manual radar scenario definition with Pulse Sequencer software

- Full flexibility in scenario configuration
- Single or Multi Emitters scenarios
- Moving emitters and receiver
- Good for short and medium radar scenario length
- Intuitive software GUI and fast scenario configuration



Simple modelling of special shaped pulses

- Modulated and unmodulated pulses can be defined quickly
- Linear frequency modulation, Barker coding, polyphaser codes, phase shift keying or any classical analog modulation
- Customer specific modulation formats can be added



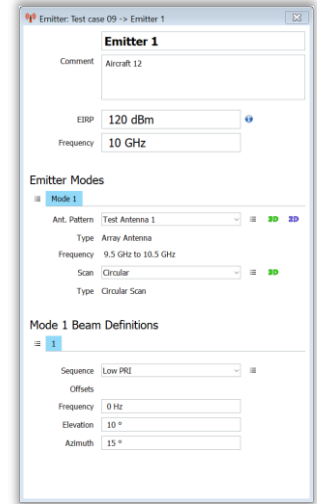
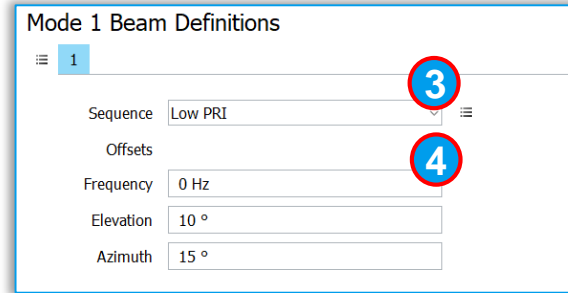
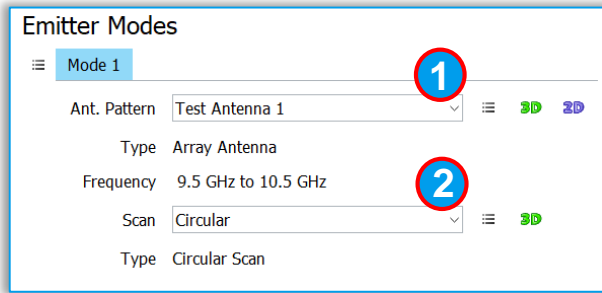
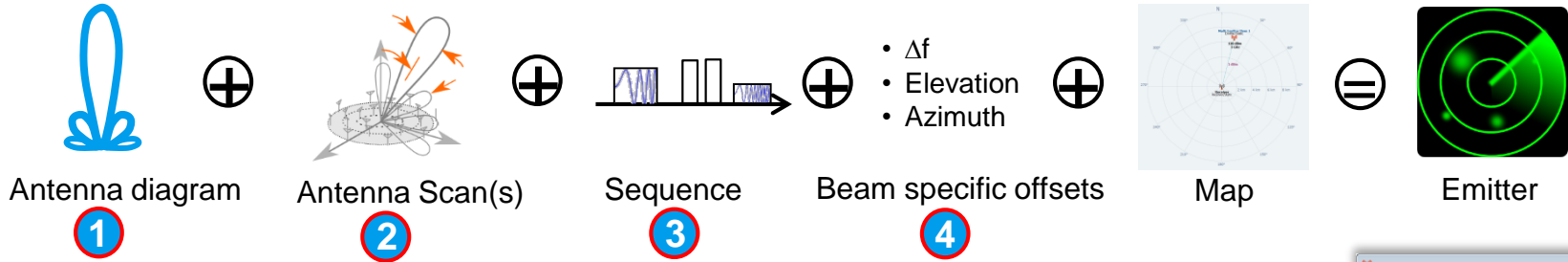
Unmodulated pulse with non-rectangular pulse envelope and with rising and falling edge

Overshoot, droop and ripple in an unmodulated non-rectangular pulse

I/Q modulated pulse (MOP)

- Simplify the creation of radar signals with intuitive pulse definition
- Perfect for applications where precise pulse modelling is required

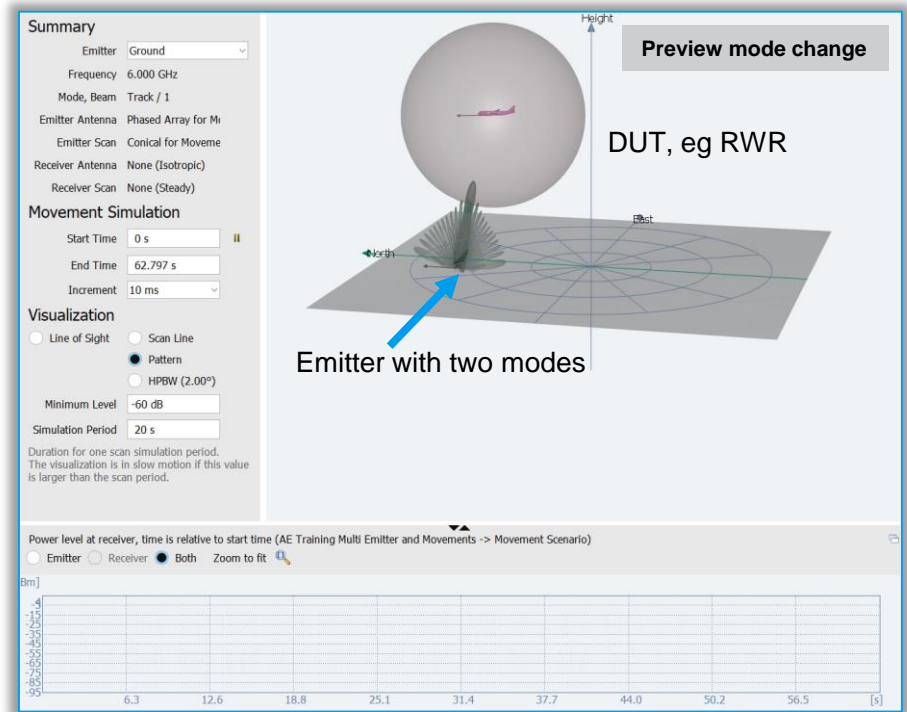
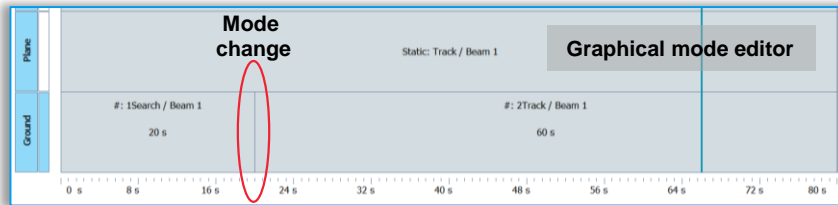
Simple modelling of emitters



- Quick and easy modelling of emitters
- Supports antenna diagrams, scans and map for localized emitters/receiver

Mode changes – simple operation and powerful preview

- Mode change: Switch emitter parameters over time
 - Antenna patterns and scans
 - Offset frequency
 - Sequences (PRI, pulse width etc.)
- Application: search and track mode
 - Graphical mode editor allows fast and easy setup of modes and changes

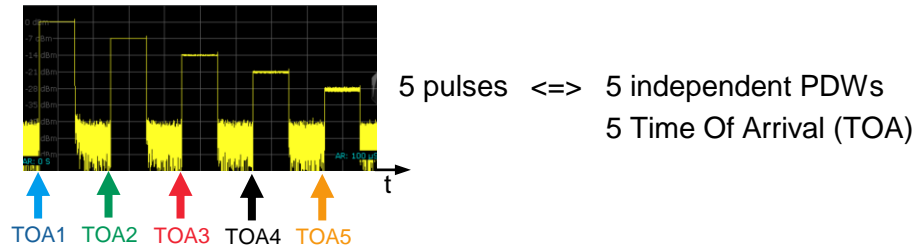


→ Graphical previews bring great confidence in scenario creation and save test setup time

PDW import in Pulse Sequencer Software and replay with R&S®SMW200A

What is a Pulse Descriptor Word?

- A Pulse Descriptor Word (PDW) is a set of parameters which fully describes a pulse
- It is THE language of radar systems and components
- It is used for exchange of pulse definitions from one system component to another
- Often used to store recorded radar scenarios
- No open industry standard, formats are often customer specific



Radar receiver test using legacy PDW lists

■ Task:

Test the radar receiver with radar signals described in PDW lists

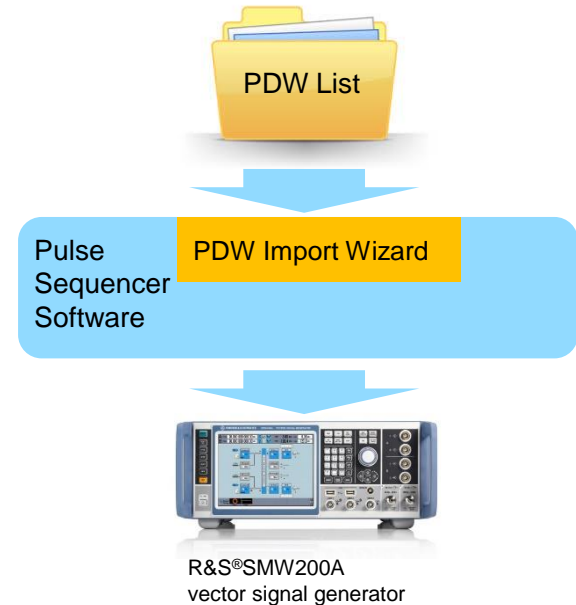
■ Initial situation:

- Large number of recorded or manually created PDW lists exist
- Legacy PDW files often have different formats
- Need a mechanism to convert stored PDWs back into a real radar RF signal

■ Solution: PDW List Import into Pulse Sequencer Software

- Highest flexibility -> import can be easily customized by the user, import all kind of formats
- No re-formatting of legacy PDW lists
- Generate signals with complex modulations on pulse from PDWs

→ Perfect for design verification and tests of radar receivers



PDW Import and Interleaving in Pulse Sequencer Software

Customer PDW lists

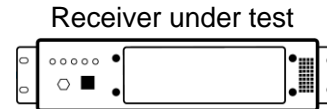
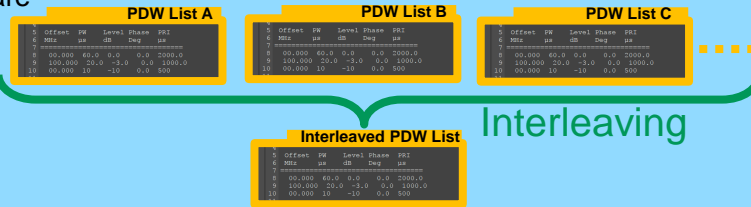
5	Offset	PW	Level	Phase	PRI
6	MHz	µs	dB	Deg	µs
8	00.000	60.0	0.0	0.0	2000.0
9	100.000	20.0	-3.0	0.0	1000.0
10	00.000	10	-10	0.0	500

PDW import template to map customer format to R&S format

11					
12	1	: RFOFFSET	MHz	#	Frequency offset
13	2	: WIDTH	us	#	Pulse width
14	3	: LEVELOFFSET	dB	#	Level attenuation
15	4	: PHASE	Deg	#	Phase
16	5	: PRI	us	#	PRI
17					

Pulse Sequencer Software

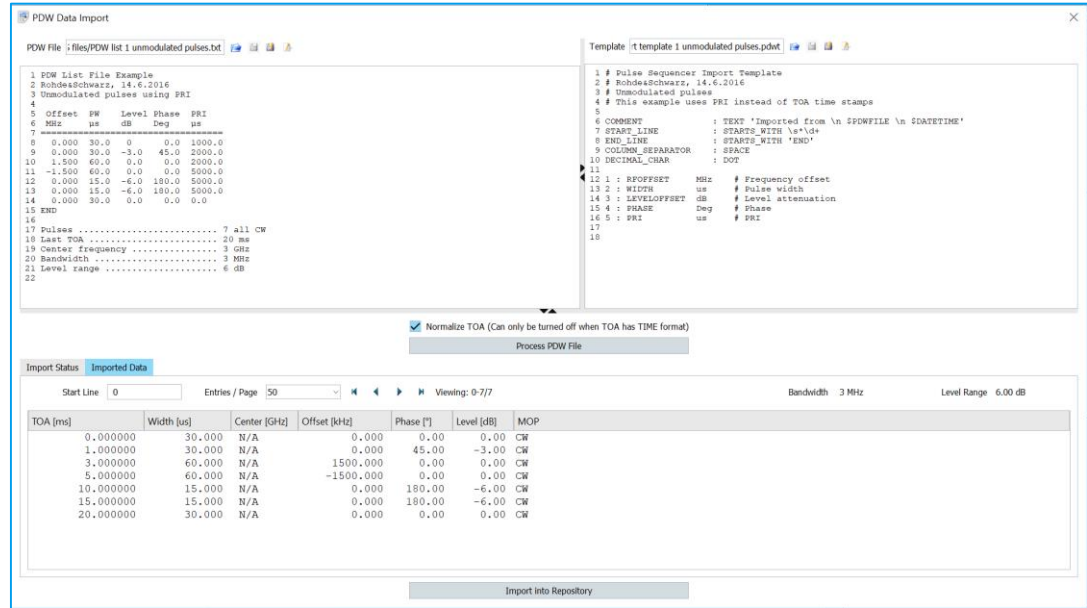
PDW Import Wizard



→ Simple and fast generation of radar test signals using interleaved PDW lists

The PDW Import Dialog

- Part of Pulse Sequencer software
- Three steps to import and replay customer PDWs
 1. Prepare import template for customer PDW list
 2. Process and import customer PDW list
 3. Generate signals on signal generator



The PDW List File

- Prepared by the customer before running the wizard
- Customer specific text file
- Single rows per PDW
- Maximum file size of 1GB results in app. 60 Mio PDWs

The screenshot shows the 'PDW Data Import' application. The top-left pane displays the contents of a text file named 'files/PDW list 1 unmodulated pulses.txt'. The file contains a list of PDW parameters and a summary of the pulses. The top-right pane shows a template for the PDW file, with fields for pulse sequence, start/end lines, and various parameters like offset, width, level, and phase. The bottom section of the interface shows the 'Import Status' and a table of the imported data.

```
1 PDW List File Example
2 Rohde&Schwarz, 14.6.2016
3 Unmodulated pulses using PRI
4
5 Offset PW Level Phase PRI
6 MHz us dB Deg us
7 -----
8 0.000 30.0 0 0.0 1000.0
9 0.000 30.0 -3.0 45.0 2000.0
10 1.500 60.0 0.0 0.0 2000.0
11 -1.500 60.0 0.0 0.0 5000.0
12 0.000 15.0 -6.0 180.0 5000.0
13 0.000 15.0 -6.0 180.0 5000.0
14 0.000 30.0 0.0 0.0 0.0
15 END
16
17 Pulses ..... 7 all CW
18 Last TOA ..... 20 ms
19 Center Frequency ..... 3 GHz
20 Bandwidth ..... 3 MHz
21 Level range ..... 6 dB
22
```

TOA [ms]	Width [us]	Center [GHz]	Offset [kHz]	Phase [°]	Level [dB]	MOP
0.000000	30.000	N/A	0.000	0.00	0.00	CW
1.000000	30.000	N/A	0.000	45.00	-3.00	CW
3.000000	60.000	N/A	1500.000	0.00	0.00	CW
5.000000	60.000	N/A	-1500.000	0.00	0.00	CW
10.000000	15.000	N/A	0.000	180.00	-6.00	CW
15.000000	15.000	N/A	0.000	180.00	-6.00	CW
20.000000	30.000	N/A	0.000	0.00	0.00	CW

The PDW Import Template File

- Template maps user specific PDW format into R&S format
- Benefit is that virtually any custom PDW list according to R&S ICD can be imported and played
- Template is customer specific txt file
- To prepare the template the Interface Specification (R&S website) and supplied examples can be used *



The screenshot shows the 'PDW Data Import' window with a template file 'template 1 unmodulated pulses.pdwt' open. The template contains the following text:

```

1 # Pulse Sequencer Import Template
2 # Rohde&Schwarz, 14.6.2016
3 # Unmodulated pulses
4 # This example uses PRI instead of TOA time stamps
5
6 COMMENT      : TEXT 'Imported from \n $PWDFILE \n $DATE$TIME'
7 START_LINE   : STARTS_WITH '\e*\d+'
8 END_LINE     : STARTS_WITH '*END'
9 COLUMN_SEPARATOR : SPACE
10 DECIMAL_CHAR : DOT
11
12 1 : RFOFFSET  MHz      # Frequency offset
13 2 : WIDTH    us       # Pulse width
14 3 : LEVELOFFSET dB     # Level attenuation
15 4 : PHASE    Deg      # Phase
16 5 : PRI      us       # PRI
17
18

```

Below the template, the 'Imported Data' table is visible with the following columns: TOA [ms], Width [us], Center [GHz], Offset [kHz], Phase [°], Level [dB], and MOP. The table contains 7 rows of data:

TOA [ms]	Width [us]	Center [GHz]	Offset [kHz]	Phase [°]	Level [dB]	MOP
0.000000	30.0000	N/A	0.0000	0.00	0.00	CW
1.000000	30.0000	N/A	0.0000	45.00	-3.00	CW
3.000000	60.0000	N/A	1500.0000	0.00	0.00	CW
5.000000	60.0000	N/A	-1500.0000	0.00	0.00	CW
10.000000	15.0000	N/A	0.0000	180.00	-6.00	CW
15.000000	15.0000	N/A	0.0000	180.00	-6.00	CW
20.000000	30.0000	N/A	0.0000	0.00	0.00	CW

* Examples for PDW list files and import templates are automatically installed with Pulse Sequencer SW

The PDW Import Wizard

- Transfers the PDWs from the PDW list file into Pulse Sequencer Repository
- Processes and checks the PDW list file according to the import template instructions
- Shows the processed PDWs in a plain text table

The screenshot displays the 'PDW Data Import' wizard. The top section shows the PDW list file content and the import template. The bottom section shows the 'Imported Data' table.

```
1 PDW List File Example
2 Rohde&Schwarz, 14.6.2016
3 Unmodulated pulses using PRI
4
5 Offset  PW  Level Phase  PRI
6 MHz    us  dB    Deg  us
7
8 0.000  30.0  0    0.0  1000.0
9 0.000  30.0 -3.0  45.0  2000.0
10 1.500  60.0  0.0  0.0  2000.0
11 -1.500 60.0  0.0  0.0  5000.0
12 0.000  15.0 -6.0  180.0  5000.0
13 0.000  15.0 -6.0  180.0  5000.0
14 0.000  30.0  0.0  0.0  0.0
15 END
16
17 Pulses ..... 7 all CW
18 Last TOA ..... 20 ms
19 Center Frequency ..... 3 GHz
20 Bandwidth ..... 3 MHz
21 Level range ..... 6 dB
22
```

```
1 # Pulse Sequence Import Template
2 # Rohde&Schwarz, 14.6.2016
3 # Unmodulated pulses
4 # This example uses PRI instead of TOA time stamps
5
6 COMMENT      : TEXT 'Imported from \n $DIRNAME \n $DATEIME'
7 START_LINE   : STARTS_WITH 'e'+
8 END_LINE     : STARTS_WITH 'END'
9 COLUMN_SEPARATOR : SPACE
10 DECIMAL_CHAR : DOT
11
12 1 : FPOFFSET  MHz  # Frequency offset
13 2 : WIDTH    us  # Pulse width
14 3 : LEVELOFFSET dB  # Level attenuation
15 4 : PHASE    Deg  # Phase
16 5 : PRI      us  # PRI
17
```

Normalized TOA (Can only be turned off when TOA has TIME format)

Process PDW File

Import Status: Imported Data

Start Line: 0 Entries / Page: 50 Viewing: 0-7/7 Bandwidth: 3 MHz Level Range: 6.00 dB

TOA [ms]	Width [us]	Center [GHz]	Offset [kHz]	Phase [°]	Level [dB]	MOP
0.000000	30.000	N/A	0.000	0.00	0.00	CW
1.000000	30.000	N/A	0.000	45.00	-3.00	CW
3.000000	60.000	N/A	1500.000	0.00	0.00	CW
5.000000	60.000	N/A	-1500.000	0.00	0.00	CW
10.000000	15.000	N/A	0.000	180.00	-6.00	CW
15.000000	15.000	N/A	0.000	180.00	-6.00	CW
20.000000	30.000	N/A	0.000	0.00	0.00	CW

Import into Repository

→ Ready for further processing in Pulse Sequencer software

How to import legacy PDW lists in Pulse Sequencer Software

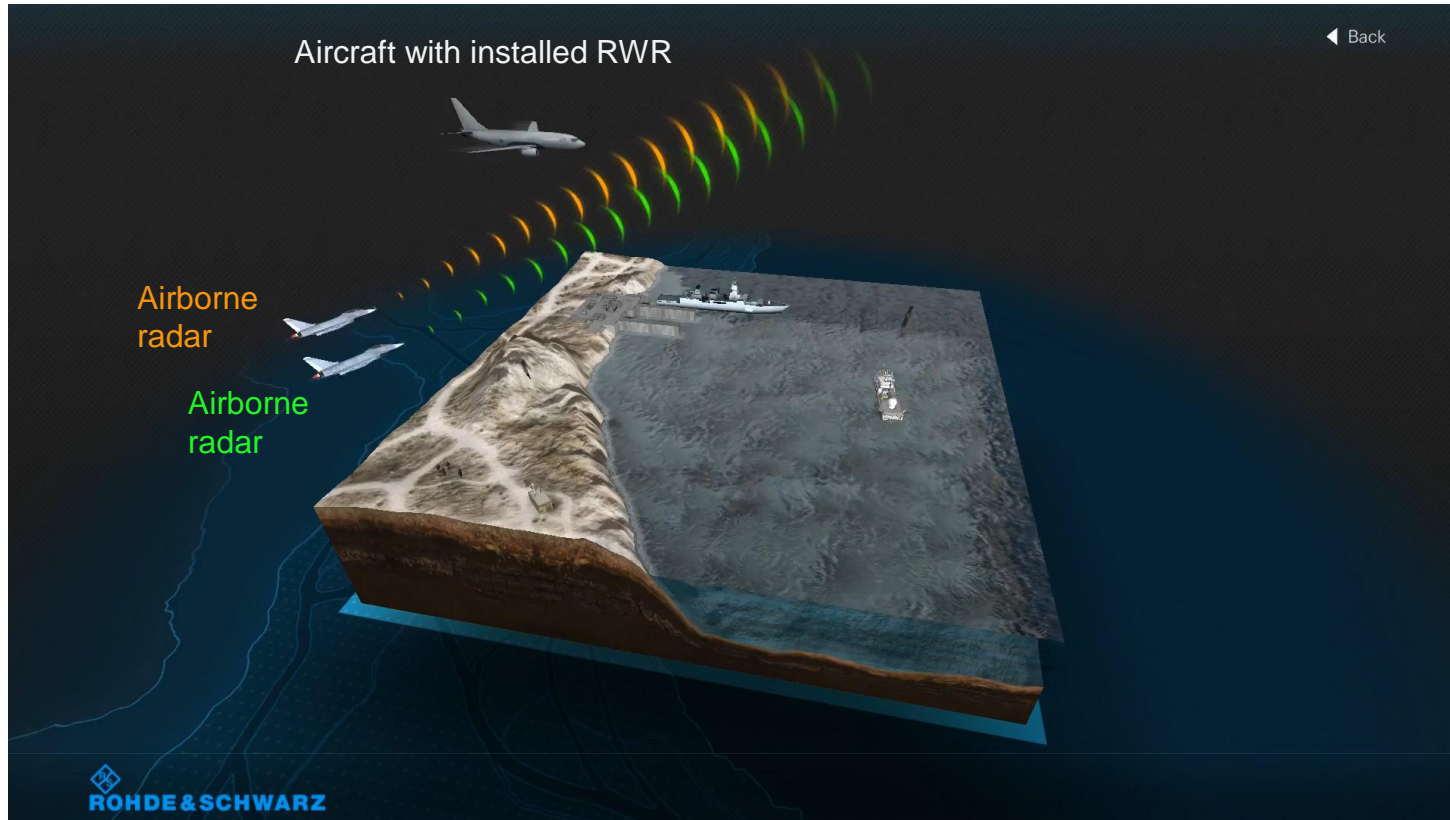
A short example

The screenshot displays the R&S Pulse Sequencer V1.9 software interface. The main window is titled "Scenario: PDW Import for webinar -> PDW list import". The interface is divided into several sections:

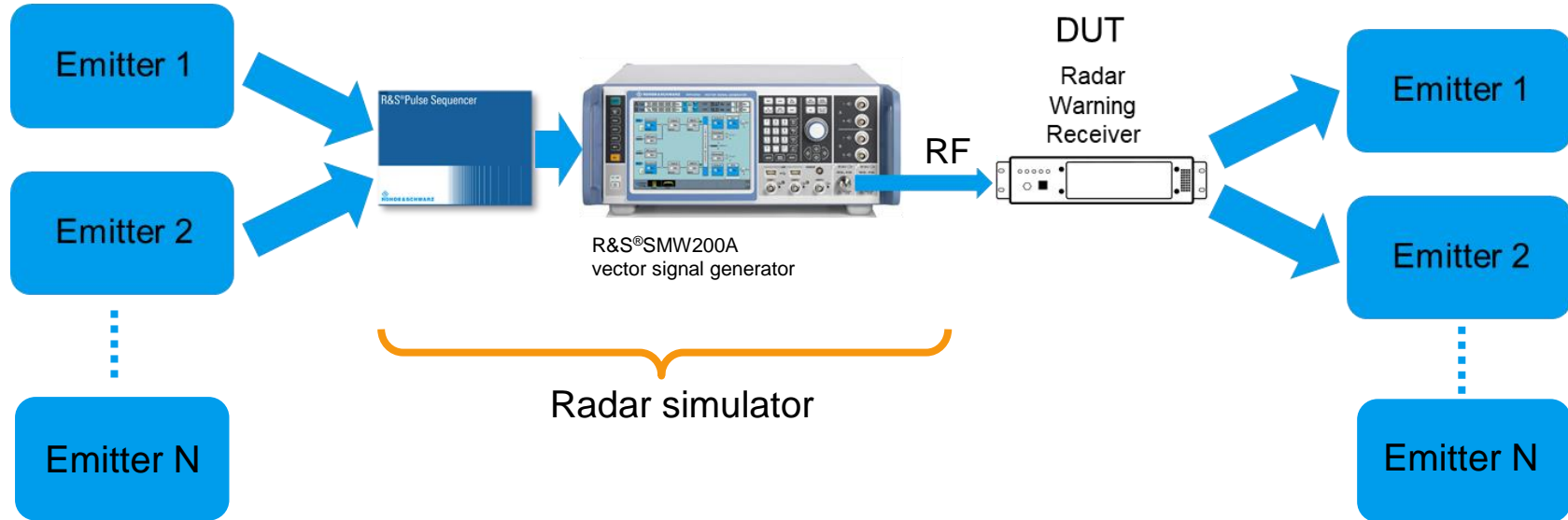
- Left Panel (Repositories):** A tree view showing the project structure. Under "Scenarios", "PDW list import" is selected. Other categories include "Emitters", "Antenna Patterns", "Antenna Scans", "Receivers", "Sequences", "Pulses", "Waveforms & Imported Signals", "Generator Profiles", and "Plugins".
- Scenario Configuration:**
 - PDW list import:** A text field containing "PDW list Scenario for Webinar 2019".
 - PDW List (Collection):** A section for managing the collection of PDW lists.
 - Controls:** Includes a "PREPARE" button, "RUN" and "STOP" buttons, and a "Status" indicator set to "IDLE".
 - Generator:** Shows "Play Mode" set to "Continuous".
 - PDW Lists:** Includes an "Interleaving" checkbox.
- Block Diagram:** A flow diagram at the bottom showing the data flow:
 - A "PDW Lists" block (with an "Edit" button) feeds into a "Signal Generation" block.
 - The "Signal Generation" block is connected to a "Repository" (represented by a cylinder icon).
 - The "Signal Generation" block also feeds into a "DefaultIvSetup" block (with "Config" and "Assign" buttons).

Create Complex Radar Scenarios with Pulse Sequencer Software

Simulation of multiple moving emitters and receiver



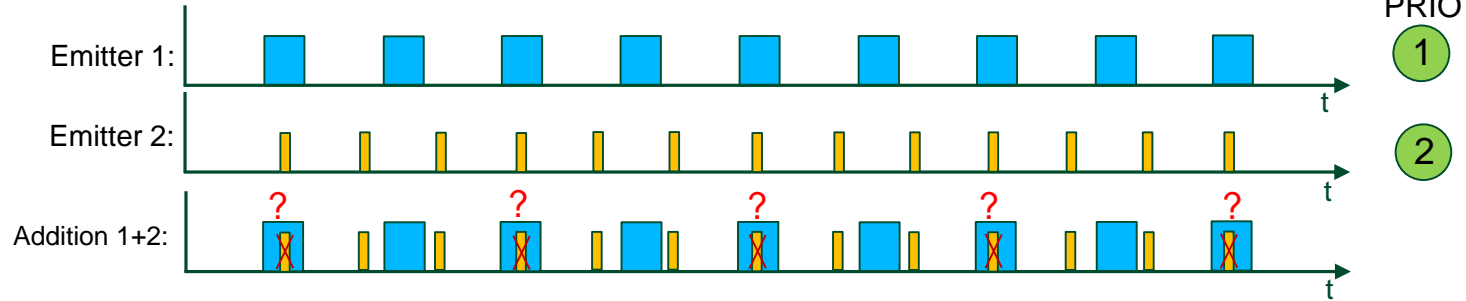
General test case for radar warning receivers



Concepts of simulation of many emitters in parallel

Challenge and solution

- **Task:** Two emitters need to be simulated and generated at the same time



- **Questions:** What will happen if two pulses occur at the same time?

- **Possible solutions:**

- Interleave pulsed signals and drop pulses if they overlap according to a priority scheme with optimized low drop rate
- Generate both pulses together (co-pulse or pulse-on-pulse scenario)

Use Case: Simulate Multi Emitters without geometric location

List emitters and prioritize them before interleaving – industry standard

Configure interleaving process

Alias Name	Emitter	Frequency	Enable	Time Offset	Prio [0=Highest]	Level Offset	Group
Emitter 0	Airborne 1	9 GHz	<input checked="" type="checkbox"/>	10 us	3	-5 dB	Group 1
Emitter 1	Airborne 2	10 GHz	<input type="checkbox"/>				
Emitter 2	Landbased 2	10 GHz	<input checked="" type="checkbox"/>	400 us	1	0 dB	Group 2
Emitter 3	Landbased 4	9 GHz	<input checked="" type="checkbox"/>	0 s	0	-20 dB	Group 2
Emitter 4	Airborne 2.1	10 GHz	<input checked="" type="checkbox"/>	0 s	4	0 dB	Group 1

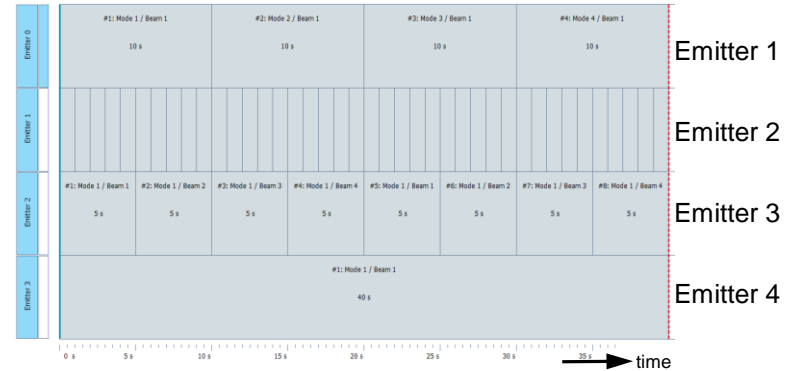
create or import

select emitters for interleaving

optimize for small pulse drop rate

Allocate emitters to groups

Four emitters, each emitter has different modes



Interleaving statistics

ID	Name	Prio	Total 1429672	Dropped 21060	Dropped % 1.473	Density (pps) 35215.3 pps
1	Emitter 0	3	990275	17401	1.757	24321.9
2	Emitter 1	2	224149	3554	1.586	5515.56
3	Emitter 2	1	212914	62	0.02912	5321.3
4	Emitter 3	0	2334	43	1.842	57.3968

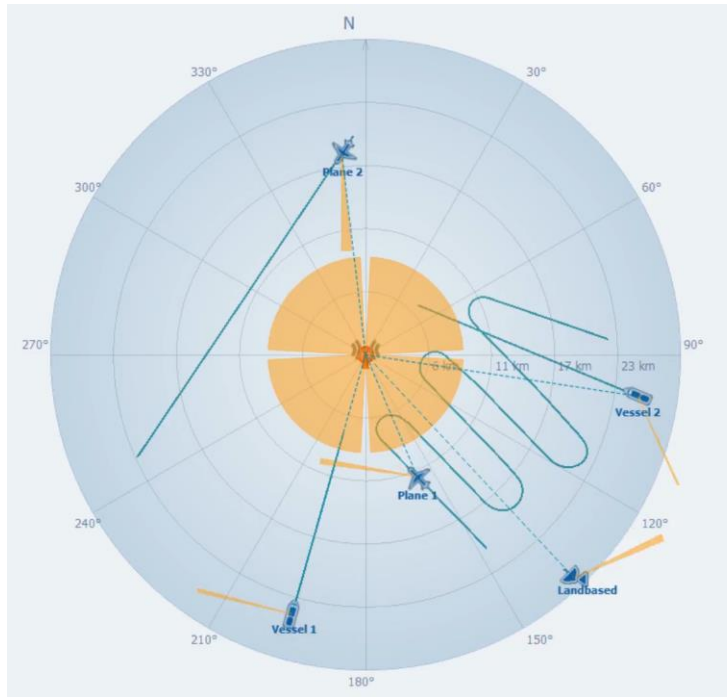
>1 Mio pulses playtime

Lowest drop rate

Pulses: 1429672, Playtime: 40 s, Interleaved: 1408612, Dropped: 21060 (1.473%), Density: 35215.3 pps

Use Case: Simulate Multi Emitter scenarios on a map

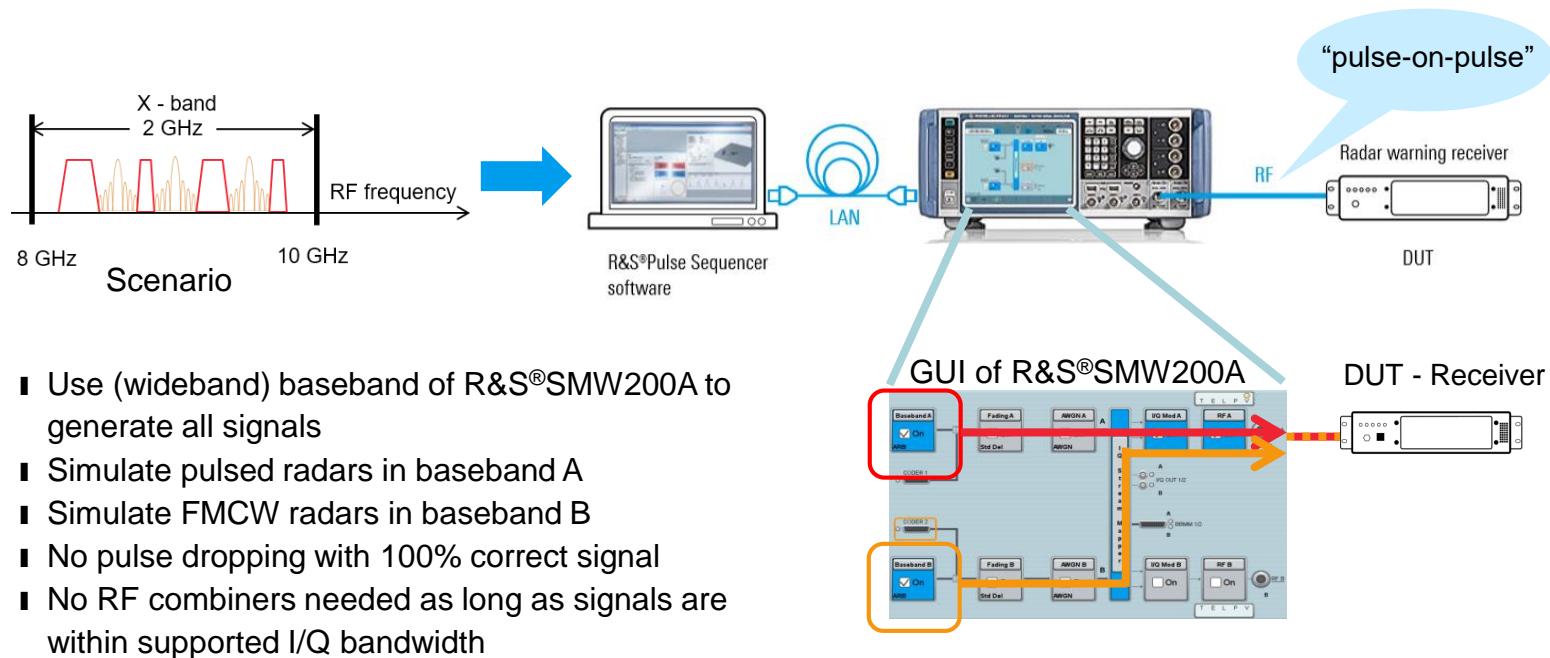
Multi emitter simulation in 3D space



- Live scenario with multiple radars
 - Two patrol aircraft with pencil beam
 - Imported real flight trajectory for patrol aircraft plane 1
 - Predefined trajectory for plane 2
 - One land based static radar
 - Several vessels with navigation radars

Solution from R&S for simulating two emitters in same radar band

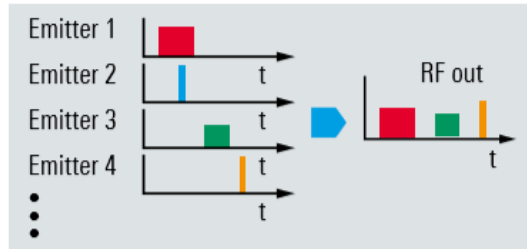
Simulate the most important radar bands with two basebands in R&S®SMW200A



- Use (wideband) baseband of R&S®SMW200A to generate all signals
- Simulate pulsed radars in baseband A
- Simulate FMCW radars in baseband B
- No pulse dropping with 100% correct signal
- No RF combiners needed as long as signals are within supported I/Q bandwidth

Solution for simulating many emitters in one radar band

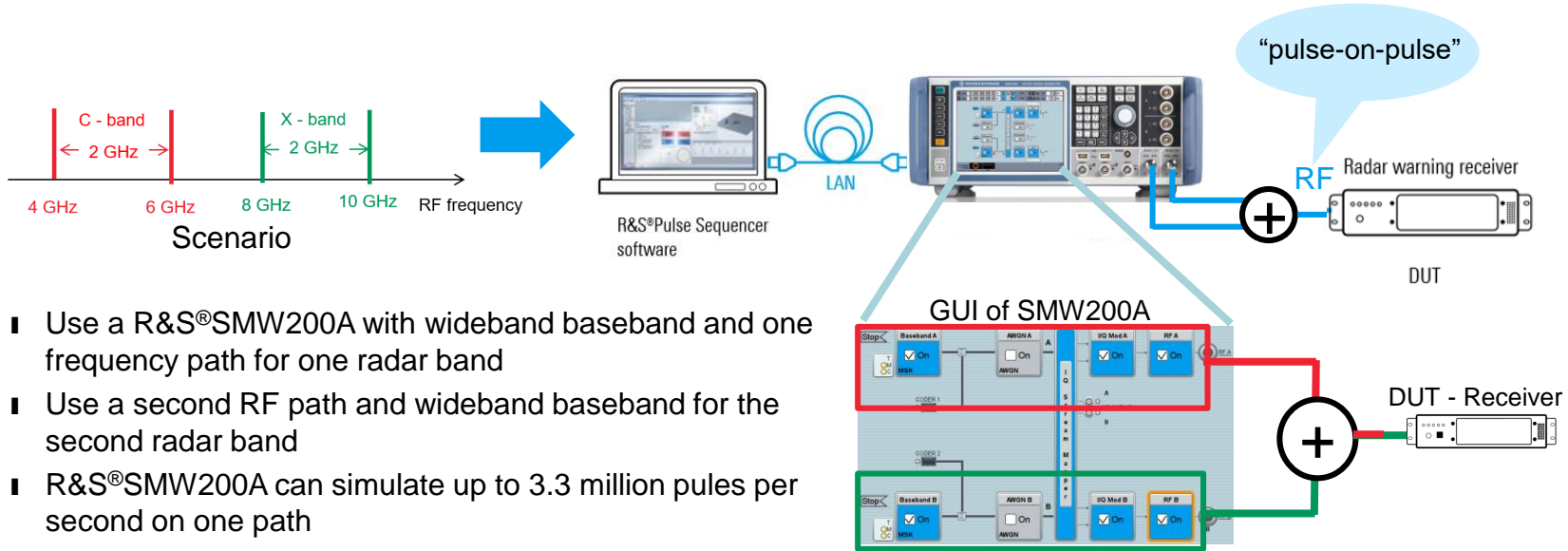
Interleave emitters with lowest drop rates



- R&S Pulse Sequencer software together with R&S®SMW200A vector signal generator
 - Simulates the radar scenarios
 - Uses a smart algorithm to interleave signals with priority scheme
 - Drops pulses in case they collide and ensures lowest drop rates
 - Up to 3.3 million pulses per second per band
- Example
 - Pulse from emitter 2 (blue pulse) is dropped as it overlaps with the pulse from emitter 1 (red pulse)

Solution for simulating emitters in two radar bands

Simulate the most important radar bands with a two path R&S®SMW200A



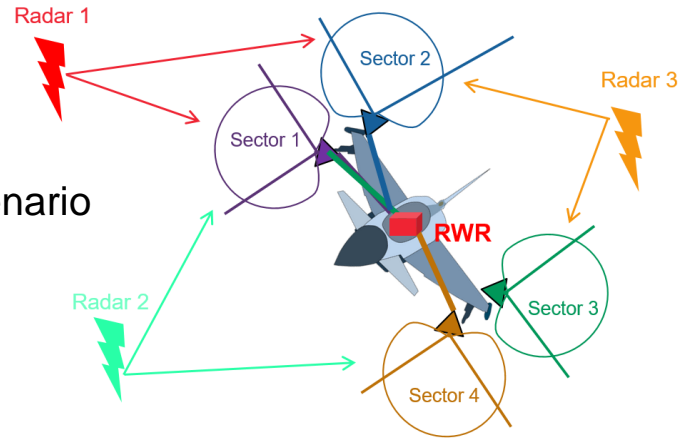
- Use a R&S®SMW200A with wideband baseband and one frequency path for one radar band
- Use a second RF path and wideband baseband for the second radar band
- R&S®SMW200A can simulate up to 3.3 million pulses per second on one path
- Up to 2 GHz instantaneous or agile I/Q modulation bandwidth for radar simulation
- Does not lose pulses

Simulation Angle of Arrival in the lab

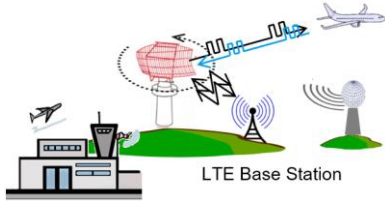


This setup

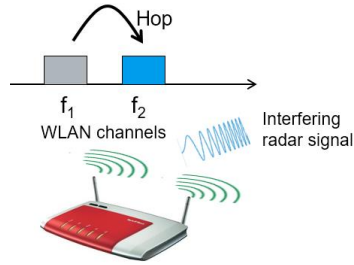
... simulates this scenario



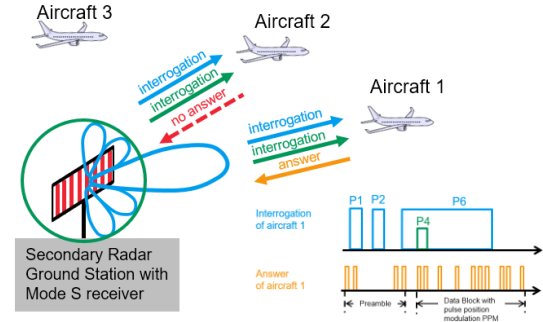
Other applications served by the R&S Pulse Sequencer software



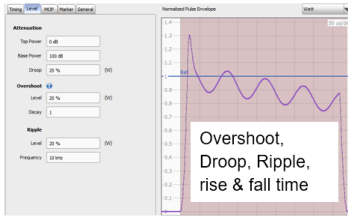
Co-existence testing of air traffic control radars with commercial base stations



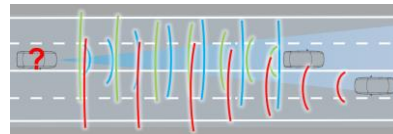
Testing DFS capability of WiFi routers



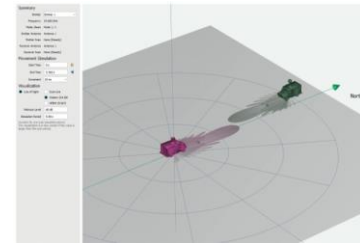
Simulation of Mode S interrogation and answer patterns for testing receivers used with secondary radar signals



Component testing with user-impaired pulsed signals or simple pulses



Simulation of automotive FMCW fast chirp sequences of interferers for testing robustness of automotive radar sensors together with AREG100A



High Speed PDW Streaming with R&S[®] SMW200A

Applications for PDW streaming

- Control the radar signal from a stream of PDWs
- Change the radar scenario during testing

Main differences of importing PDWs vs streaming PDWs

PDW import into Pulse Sequencer software

- Pulse Sequencer Software acts as radar simulator
- PDW list (scenario) exists
- Import file and generate the scenario as a whole
- PDWs can have any format

→ Perfect for quick reuse of legacy PDW lists

PDW streaming

- Customer radar simulator ready to stream PDWs
- PDWs can be generated during test
- Generate the signal pulse by pulse
- PDW lists must conform to R&S format

→ Perfect for flexible customized solutions



PDW Streaming using R&S®SMW200A vector signal generator

- Customer radar simulator calculates the scenarios and streams radar signal as PDWs to signal source
- High pulse density is achieved for radar scenarios with long playtime with classical pulses and I/Q modulated waveform segments
- Adaptive changes of signal parameters in radar simulator during playtime is possible as the signal does not need to be pre-calculated
- Good for ultra long radar scenarios



High Speed PDW Streaming with R&S®SMW200A

- The more radars there are in the scenario, the higher the pulse rate the receiver must be able to handle.
- Maximum pulse density is a key performance parameter of a Radar Warning Receiver (RWR)
- Use R&S®SMW200A vector signal generator with real-time control interface software option for PDW streaming
- PDW execution rate in R&S®SMW200A up to 2 Mpulse/s per baseband board
- Up to 4 Mpulse/s using one instrument with 2 baseband boards



Download the Pulse Sequencer software!

Resources

- Download Pulse Sequencer software from the Rohde&Schwarz homepage and try it out

