

# Simplifying Radar Waveform Generation using R&S Pulse Sequencer Software

## Application Note

### Products:

- R&S®SMW200A
- R&S®SMBV100A
- R&S®SGT100A

The need to properly represent the ever changing complexities of the RF environment across communications, surveillance, electronic support measures (ESM) and signal intelligence system (SIGINT) with the advances of signal complexity and bandwidth, requires an enormous test and measurement effort. Extensive field tests are often applied to verify the performance and capabilities under preferably natural but controlled conditions. This is both costly and requires a great deal of time.

RF signal environment generation using Test & Measurement equipment brings field tests into the laboratory, where a controlled, cost-effective and reproducible environment exists. The R&S®Pulse Sequencer software is a versatile tool to generate arbitrary and realistic RF signal scenarios ensuring system readiness for the real operational world.

This application note introduces the R&S®Pulse Sequencer software, explains several examples that are applicable for research, development, before operational and during life-time test in detail, and guides you through the necessary steps, to generate a self-defined, arbitrary real life RF signal environment.

### Note:

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

<https://www.rohde-schwarz.com/appnote/1MA288>

# Table of Contents

<b>1</b>	<b>Introduction</b> .....	<b>3</b>
<b>2</b>	<b>Pulse Sequencer</b> .....	<b>4</b>
2.1	Hardware and Software Requirements.....	4
2.2	Pulse Sequencer Initial Configuration.....	5
2.3	Overview and ARB Waveform Generation.....	7
2.4	Test Setup.....	9
<b>3</b>	<b>Test &amp; Measurement Examples</b> .....	<b>10</b>
<b>3.1</b>	<b>ATC Radar Beacon System and Transponder</b> .....	<b>10</b>
3.1.1	ATC Radar Beacon System Transponder Test.....	11
3.1.2	ATC Transponder Test.....	18
<b>3.2</b>	<b>Co-Existence of Radar with Other Services</b> .....	<b>18</b>
3.2.1	RF Signal Environment Generation.....	19
3.2.2	RF Environment with Emitters at Different Locations.....	27
<b>3.3</b>	<b>Radar Echo Generation in Complex RF Environment</b> .....	<b>30</b>
<b>4</b>	<b>Summary</b> .....	<b>31</b>

# 1 Introduction

The need to properly represent the ever changing complexities of the RF environment across communications, surveillance, electronic support measures (ESM) and signal intelligence system (SIGINT) with the advances of signal complexity and bandwidth, requires an enormous test and measurement effort. Extensive field tests are often applied to verify the performance and capabilities under preferably natural but controlled conditions. This is both costly and requires a great deal of time.

The real-world RF environment is often captured and stored on I/Q recorders during field tests and then replayed in the laboratory. This approach offers many advantages, but limited hard drive storage capacities and recorder bandwidth cannot map the entire environment. The RF environment may also change quickly, or several RF signals are not available, when doing the recordings.

The Rohde & Schwarz Pulse Sequencer software brings the RF signal environment from the field into the laboratory, where a controlled, cost-effective and reproducible environment applies with many variable parameters. It is a versatile tool to generate arbitrary and realistic RF signal scenarios which ensures your system to be ready for the real operational world with unlimited replay duration. It allows generating complex pulse signals by using predefined, configurable test scenarios of varying complexity and enables the simulation of signals with different emitter and receiver configurations, including antennas and scan types. The signal can be processed by the R&S test and measurement instruments to validate the representative signal test conditions.

This application note introduces the R&S®Pulse Sequencer software, explains several examples that are applicable for research, development, before operational and during life-time test in detail, and guides you through the necessary steps to generate a self-defined, arbitrary, close real-life RF signal environment.

The Pulse Sequencer software is not limited to the measurement examples described. It is available as a free download from the Rohde & Schwarz website.

<https://www.rohde-schwarz.com/software/pulse-sequencer/>

## 2 Pulse Sequencer

The R&S®Pulse Sequencer software is a stand-alone, PC based application that creates waveform files, sequence lists and complex scenarios which can be replayed by a Vector Signal Generator at RF. Waveforms generated with the software can be processed by a subset of instruments that must be equipped with the options listed under requirements.

Covered frequency ranges and I/Q modulation bandwidth depend on the capabilities of the selected Vector Signal Generator and can be as high as 40 GHz and 2 GHz I/Q modulation bandwidth using a single channel R&S®SMW200A Vector Signal Generator for example. With a frequency upconverter or multiplier the frequency range can be extended. Using additional basebands and RF sources, several GHz of I/Q modulated signals can be generated at RF.

Additional unique features, like restricted access to databases and import and export possibilities make Pulse Sequencer software a suitable tool for test and measurement applications, also in classified environments, such as research areas or pre-development.

### 2.1 Hardware and Software Requirements

The minimum configuration makes use of an R&S®SMW200A Vector Signal Generator base unit equipped with

- Baseband Generator (R&S®SMW-B10) per signal path **or** Wideband Baseband Generator (R&S®SMW-B9)
- Frequency (R&S®SMW-B1xx/B2xx)
- Baseband main module, one/two I/Q paths to RF (R&S®SMW-B13, B13T, B13XT)
- Pulse Sequencer (R&S®SMW-K300) per signal path

**or**

R&S®SMBV100A Vector Signal Generator base unit equipped with

- Baseband Generator (R&S®SMBV-B10/B51)
- Frequency (R&S®SMBV-B1xx)
- Hard Disk (removable) (R&S®SMBV-B92)
- Pulse Sequencer (R&S®SMBV-K300)

**or**

R&S®SGT100A SGMA Vector RF Source

- Baseband Generator (R&S®SGT-K510)
- Pulse Sequencing (R&S®SGT-K300)

In addition to the Rohde & Schwarz Signal Generator a standard PC or notebook should meet the following requirements:

- Microsoft®Windows 7 (or higher) operating system
- Hardware requirements of a PC for options R&S®SMW/SMBV/SGT-K300/K301 as shown in the table below.

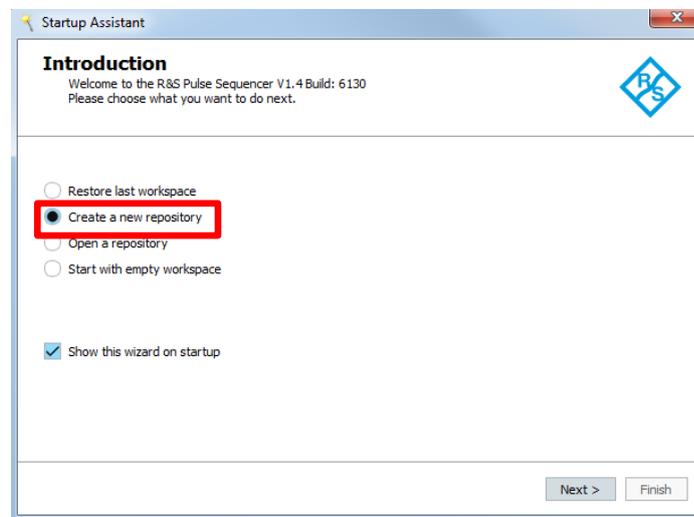
**Table 1: PC Hardware Requirements**

Hardware	Minimum requirements	Recommended hardware
AMD or Intel CPU	2x ≥ 1 GHz	8 x 2 GHz
RAM	≥ 2 GB	16 GB
Display resolution	≥ 1024x768 pixels	≥ 1024x768 pixels
Free HD space	10 GB	100 GB

## 2.2 Pulse Sequencer Initial Configuration

After installation and first start, Pulse Sequencer opens a startup assistant which supports to restore a workspace, create a new repository, open a repository or start with an empty workspace.

In case the software is started for the first time, select "create a new repository".



**Figure 1: Startup Assistant**

The startup assistant will guide you through a scenario creation. This can be a simple pulse or sequence scenario or a more complex scenario with multiple emitters, modes and antennas.

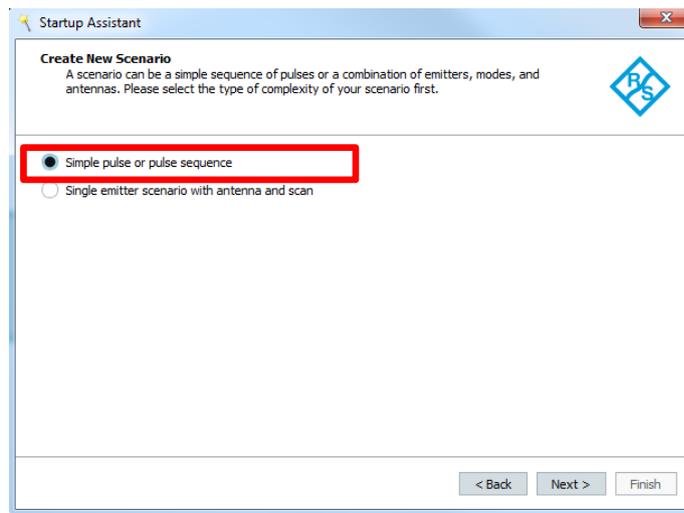


Figure 2: Startup Assistant

Initially, we create a simple pulse by clicking "Next". We insert the pulse parameters, like pulse width and select the modulation.

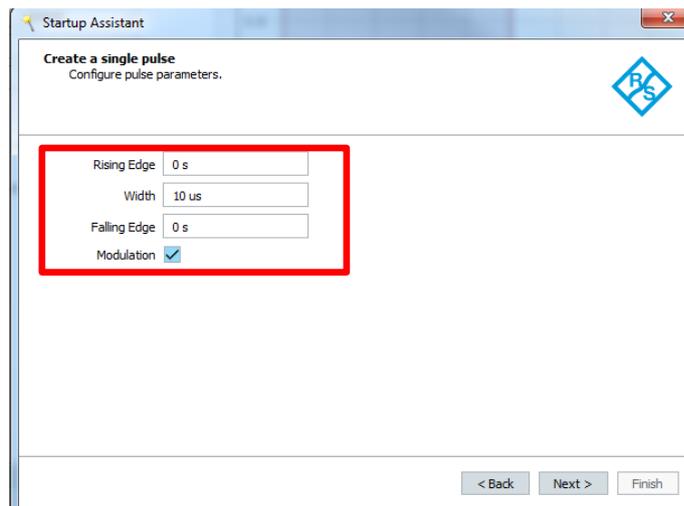


Figure 3: Startup Assistant

In the next step we define the modulation on the pulse as a frequency modulated upchirp with 5 MHz deviation (=10 MHz signal bandwidth).

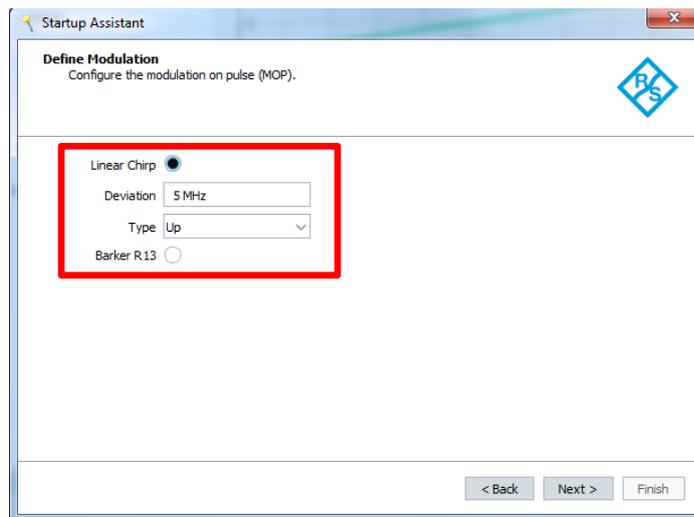


Figure 4: Startup Assistant

We define the Pulse Repetition Interval (PRI), the number of repetitions and click on with "Next" and "Finish" the startup assistant.

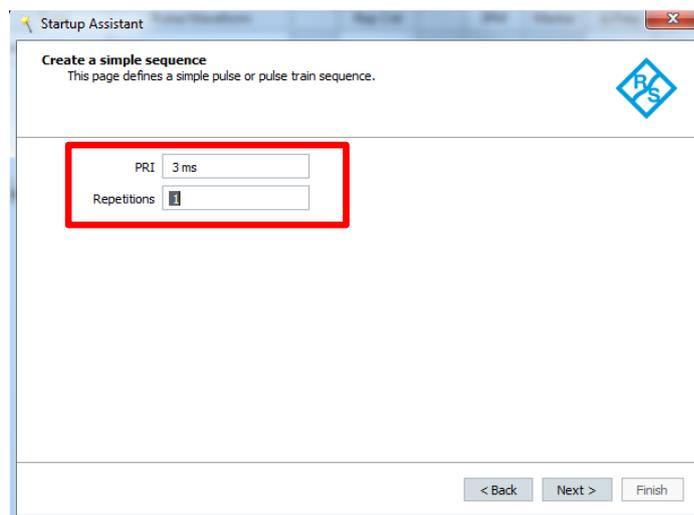
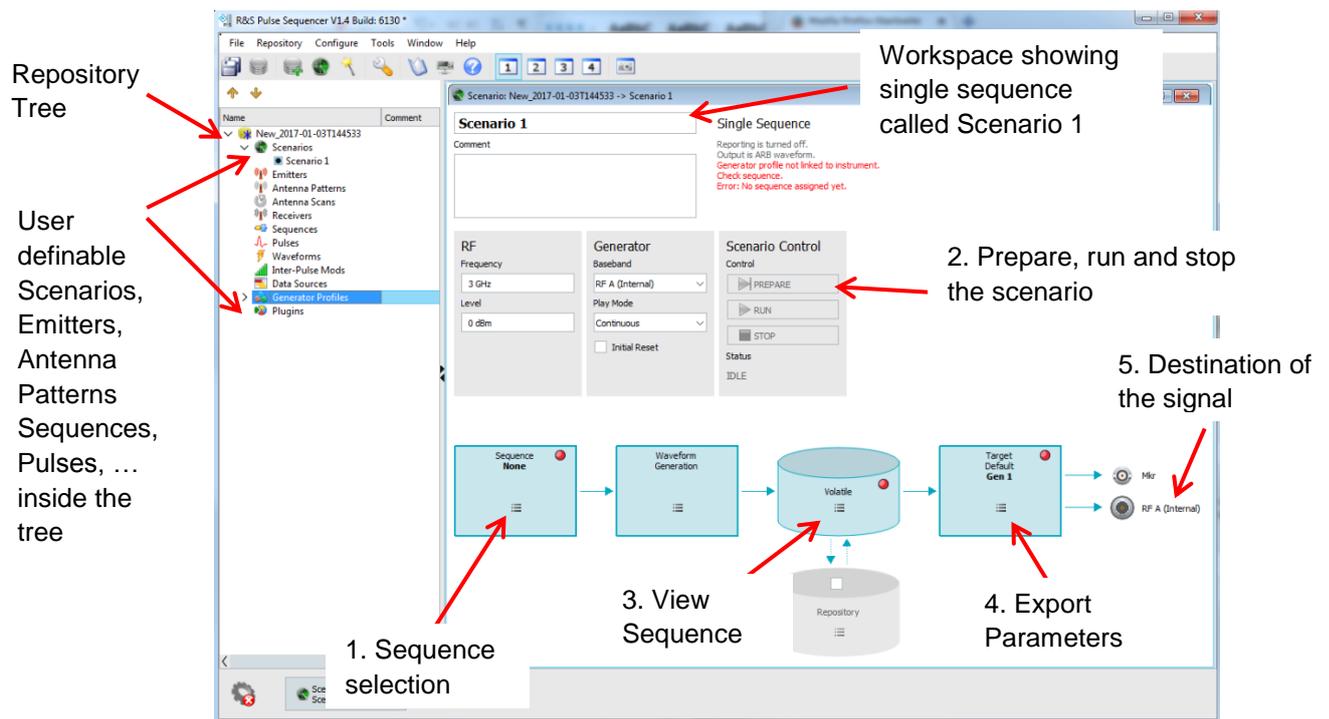


Figure 5: Startup Assistant

This will open the main workspace of the R&S Pulse Sequencer and show the sequence, ready to generate the waveform file and copy to the hard drive or vector signal generator, Figure 6.

## 2.3 Overview and ARB Waveform Generation

The default workspace for the scenario created in the previous chapter is shown below. Clicking on Scenario 1 in the repository tree leads to the screen shown in Figure 6.



**Figure 6: Screen after running the Startup Assistant**

The repository tree on the left side holds the user definable

- Scenarios
- Emitters
- Antenna Patterns
- Antenna Scans
- Receivers
- Sequences
- Pulses
- Waveforms
- Inter-Pulse Modulations
- Data Sources
- Generator Profiles and
- Plugins.

Each module holds user defined content. The "Scenario 1" depicted in Figure 6 for example is built out of "Sequence 1", which in turn is built out of "Pulse 1". Due to this modular approach, the user is able to generate arbitrary building blocks to rebuild the scenario of interest.

Chapter 3 of this application note goes into detail and explains the setup of several examples, such as for example the "Mode-S Response" or "Co-Existence" or "Interference Test". It should be mentioned, that the Pulse Sequencer software is not limited to these examples due to its modular structure.

Following the five steps shown in Figure 6 you can export to file to a memory stick or transmit the generated ARB waveform (\*.wv) to the signal generated for replay over the local Ethernet network.

After setting the Frequency and Reference Level,

1. Select the Sequence: Sequence 1,
2. Press: "Calculate + Upload" to process the scenario,
3. Verify the sequence: Volatile > View,
4. Edit the export parameters: Target > File
5. Save the waveform.

## 2.4 Test Setup

An example test setup consisting out of R&S®SMW200A Vector Signal Generator, a PC, a power amplifier and a broadband antenna (e.g. R&S®HF907, covering the frequency spectrum from 0.8 GHz to 18 GHz) as shown below.

This setup allows to stimulate the RF of a system under test over-the-air. The signals are for example transferred over the local Ethernet or a USB stick from the PC to the Vector Signal Generator.



Figure 7: R&S®SMW200A Vector Signal Generator and Pulse Sequencer

The setup in Figure 8 shows another example, where the 2-channel Vector Signal Generator is connected by RF cable to a device under test (DUT) to stimulate the RF. The user interface (UI), demonstrates the flexibility to have different signals routed to



Figure 8: R&S®SMW200A Vector Signal Generator and Pulse Sequencer

the same RF receiver to perform testing such as blocking, selectivity, and intermodulation testing as needed.

## 3 Test & Measurement Examples

This chapter explains the Pulse Sequencer software in more detail, based on typical test and measurement examples. It should be mentioned, that the capability of the Pulse Sequencer software is not limited to these examples. One can imagine many different tests and scenarios using this software.

The "ATC Radar Beacon System and Transponder" example is more a guideline how to generate a scenario using Pulse Sequencer software and explains also different modules in the repository tree of the software.

### 3.1 ATC Radar Beacon System and Transponder

An Air Traffic Control (ATC) transponder is a unit inside an aircraft which generates a response, when interrogated by the ATC Radar Beacon System (RBS). Several different codes (modes) are available, such as Mode A, Mode C or the newer Mode S.

The Mode S (Mode Selective) is a standard and mandatory for aircrafts at many airports. While the primary surveillance radar operates active and processes radar echo returns, the secondary surveillance radar actively pings an aircraft to broadcast its individual transponder address (identity), altitude and additional information.

Compared to the processor Mode 3/A, which is able to handle 4096 different codes, Mode S is able to handle more than 16 million different codes. Different pulse sequences enable a Mode S base-station to request information from all airplanes (all-call interrogations) or certain airplanes only (discrete interrogations).

A typical discrete Mode -S uplink interrogation code is drawn in Figure 9 below. Two pulses P1 and P2 with the same amplitude activate the Mode S transponder to retrieve the P6 impulse with the data block. Within P6, an intrapulse modulation with differential phase shift keying (DPSK) is used and holds either 56 or 112 bits. P5 is the Mode S side lobe suppression pulse, which is transmitted from the control beam. The power control of P5 pulse is important, as it should not overwhelm the sync phase of the P6 pulse in order for the receiver to read the subsequent information [1]. This signal is transmitted at the uplink frequency of 1030 MHz.

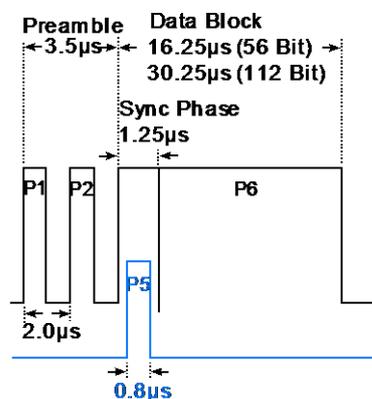


Figure 9: Discrete Mode S Uplink Interrogation

A Mode S reply is transmitted by the ATC transponder at 1090 MHz and begins with a four pulse preamble, followed by the data block using a pulse-position modulation (PPM), as this is less susceptible against interference or extreme temperature variability. If there is a falling edge pulse within the 1µs data interval (clock), a logical one is interpreted; a rising edge contributes with a logical zero.

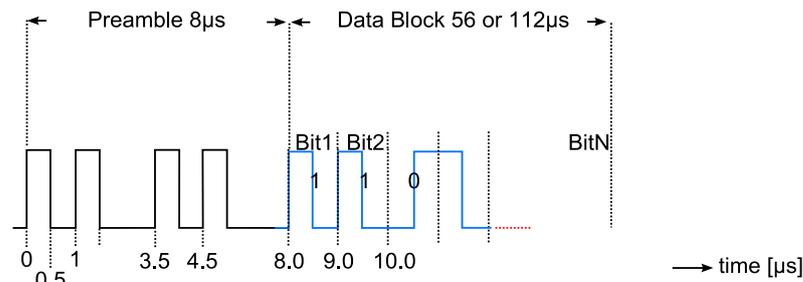


Figure 10: Mode S Downlink waveform

### 3.1.1 ATC Radar Beacon System Transponder Test

The performance and operation of an ATCRBS concerning the reception and processing of the Mode S response waveform is tested. Therefore a Mode S downlink response is generated using the R&S Pulse Sequencer software and is transmitted using the R&S®SMW200A Vector Signal Generator.

#### 3.1.1.1 Test Setup

For Signal Generation the vector signal generator R&S®SMW200A is used. This signal generator offers up to 8 baseband sources. Each R&S®SMW200 can be configured with a single RF source of up to 40 GHz or up to two 20 GHz RF sources in a single instrument.

The RF output is connected to the radar under test (RUT), either using an RF cable or transmitting the signal using a power amplifier and an antenna, such as the R&S®HL223 Antenna, ranging from 200 MHz to 1.3 GHz. The Pulse Sequencer Software generates the desired signals, which are transferred to the vector signal generator via Ethernet connection or USB Stick.

#### 3.1.1.2 Pulse Sequencer Setup

Launch the Pulse Sequencer and import the Mode-S archive ("Mode-S.psarch"), which comes with this application note available on the Rohde & Schwarz website <https://www.rohde-schwarz.com/appnote/1MA288>.

This example shows the downlink signal of the Mode-S interrogation as depicted in Figure 10.

- File > Import Repository Archive
- Select the "Mode-S.psarch" file from your download folder

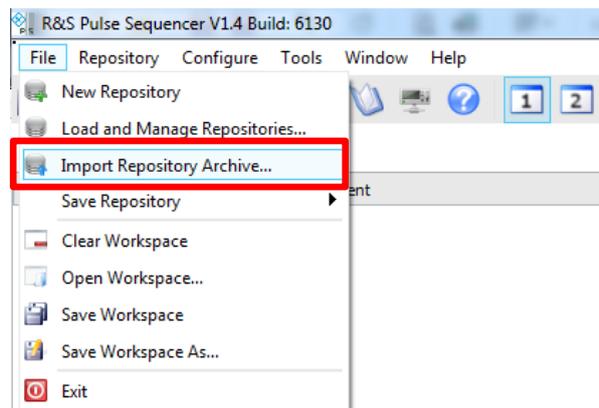


Figure 11

**i Load the File into your repository**

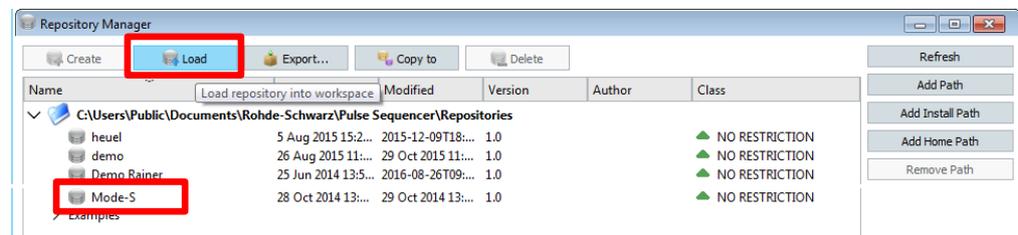


Figure 12

The Mode-S repository holds a simple pulse of 0.5  $\mu$ s with from which the preamble is built and a data block with 56 bits of 56  $\mu$ s length using pulse power modulation. The encoded data can be arbitrarily set.

At this position one can already generate the waveform file and save or replay using the vector signal generator.

- Note: You can also save your repository and protect it with a password in order to make it limited to a specific and control number of other users.

After the import of the archive, the Mode S repository tree is shown on the left side of the screen.

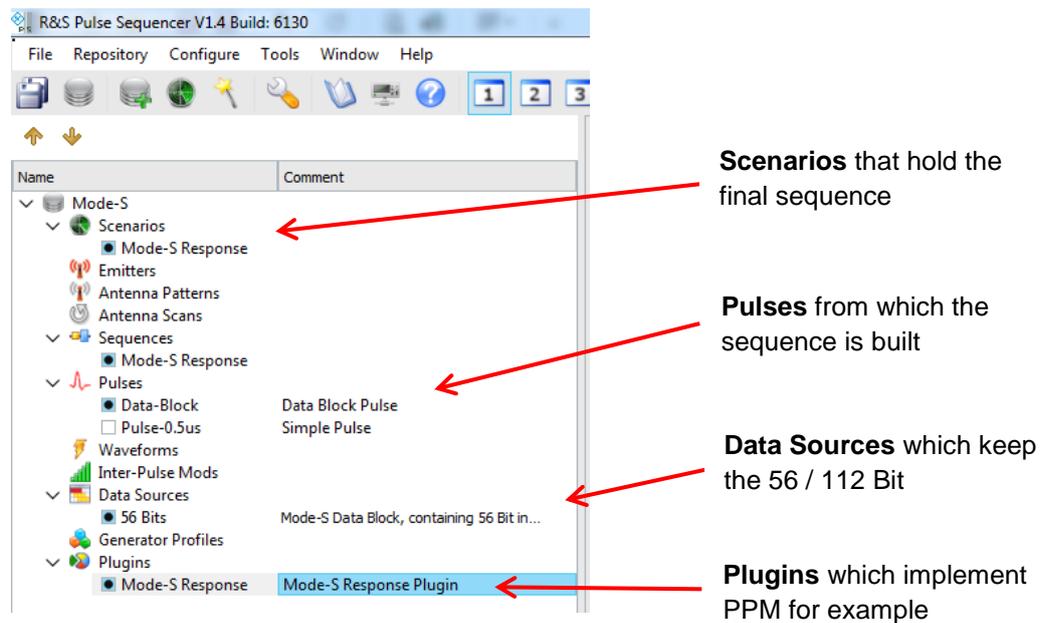


Figure 13: Repository tree

To understand the setup in detail, the building process of this Mode S response signal scenario is explained.

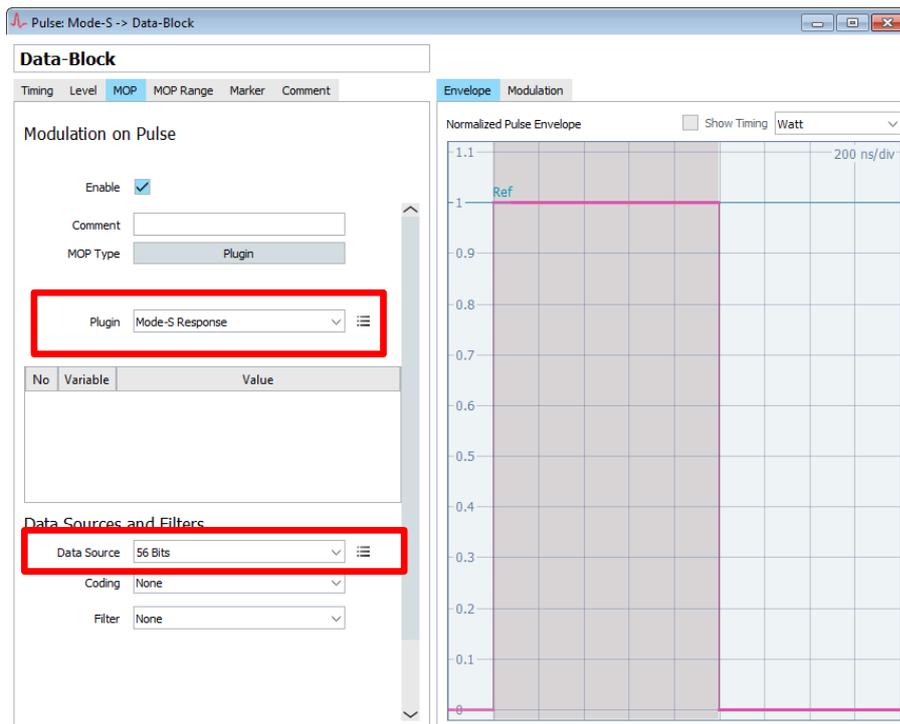
### Pulses

By double clicking on

- Pulses > Data-Block,

you can open the properties. All pulse parameters, like Timing, Level, Modulation On Pulse (MOP) can be changed accordingly to the pulse form. The configuration also allows marker settings at different positions.

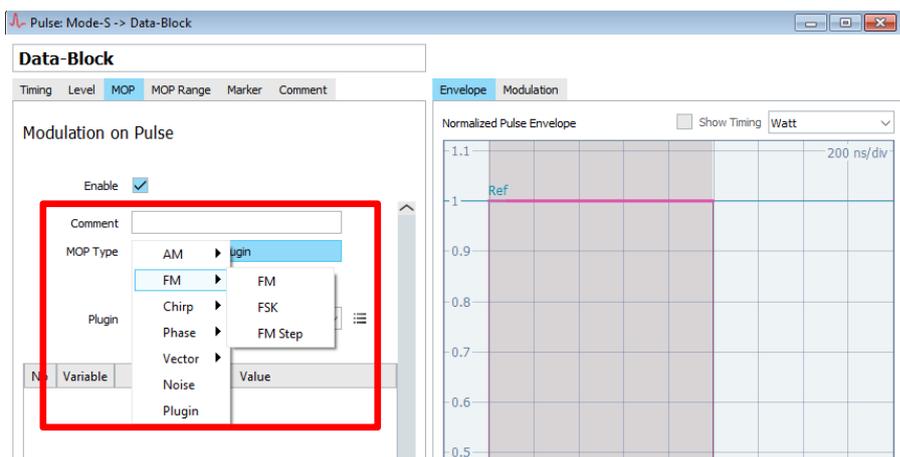
Envelope, I/Q data, frequency or phase over time of the pulse signal can be depicted, accordingly to the settings.



**Figure 14: Definition of a Pulse with Mode-S PPM and Payload as response (downlink from the aircraft to the ground station)**

In this setup the Mode-S Modulation plugin and the defined Data Source with the 56 Bits are selected, Figure 14.

For other applications you can also choose from a variety of implemented modulation schemes, like Frequency Modulation (FM), Frequency Shift Keying (FSK), Stepped Frequency Modulation (FM Step) or different phase codes, Figure 15.



**Figure 15: Modulations On Pulse (MOP)**

This concludes the definition of the "data pulse". Now the "sequence" is configured by double clicking on the "Mode-S Response" Sequence.

## Sequences

The sequence is rebuilt accordingly to the reply waveform shown in Figure 10. After a double pulse with 0.5  $\mu\text{s}$  duration and a Pulse Repetition Interval (PRI) of 1  $\mu\text{s}$ , a delay of 2  $\mu\text{s}$  follows. The same double pulse is repeated until the data block is transmitted starting from 8  $\mu\text{s}$  on.

Describe the sequence by appending or deleting new items

Select a specific signal type, e.g. pulse, wave, loop, filler, overlay, subsequence

**Sequence Description Table:**

No	Nesting	Type	Pulse/Waveform	Rep Cnt	IPM	Marker	$\Delta$ Freq	$\Delta$ Level	Phase	PRI	Delay
1	< >	Loop		2							
2	< >	Pulse	Pulse-0.5us	2		1,2,3,4...	0 Hz	0 dB	0°	1 us	0 s
3	< >	Filler									

**Block Diagram:**

```

    graph LR
      1((1: Loop 2x)) --> 2((2: Pulse Pulse-0.5u... 2x 1.0 us PRI))
      2 --> 3((3: Filler Blank Duration 1.5 us))
      3 --> 4((4: Filler Blank Duration 1.0 us))
      4 --> 5((5: Pulse Data-Block 56 x 1.0 us PRI))
  
```

**Annotations:**

- Select from the defined pulses, waveforms ...**: Points to the 'Pulse/Waveform' column in the table.
- Signal sequence is shown in the block diagram**: Points to the block diagram below the table.
- Set parameters like PRI, Phase, Delay ...**: Points to the 'PRI' and 'Delay' columns in the table.

Figure 16: Sequence

## Scenarios

A sequence describes a part of a scenario. There is only information about the waveform defined. Next, we need to configure Pulse Sequencer software to generate and upload the scenario to the Vector Signal Generator. Therefore, we change to the "Scenarios" by double-clicking on "Mode-S Response", Figure 17.

**Scenario Control Panel:**

- PREPARE
- RUN
- STOP
- Status: IDLE

**Data Flow Diagram:**

```

    graph LR
      S[Sequence Mode-S Response] --> WG[Waveform Generation]
      WG --> V[(Volatile)]
      V --> T[Target Local ARB File (None)]
  
```

**Annotations:**

- Process the sequence data**: Points to the 'RUN' button in the Scenario Control panel.

Figure 17: Scenario

If a waveform has been selected as the target output, its frequency and reference level settings can be set inside the scenario. The waveform is processed by pressing "Prepare + Run", Figure 18.

- Press: Prepare and Run

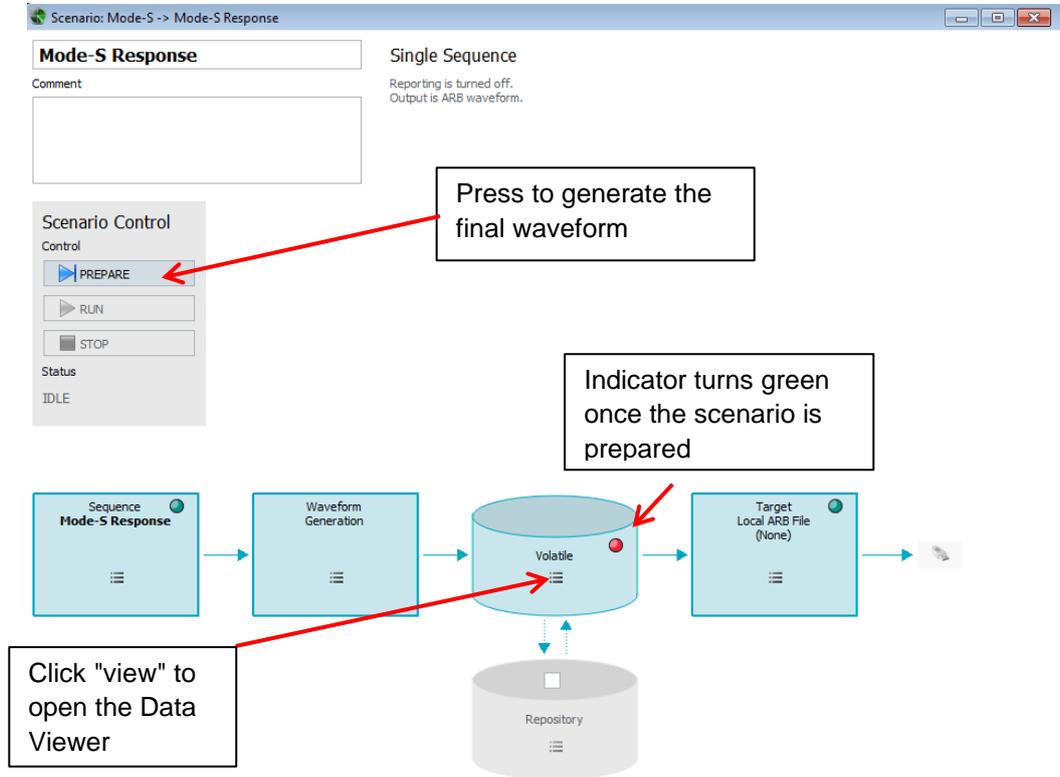


Figure 18: Generate the waveform

The generated waveform can be verified using the "Data View" by pressing

- Press: Volatile > View

The data view mode can display I/Q, magnitude, phase, frequency or power vs. time or sample. It is possible to display details of the sequence or run the sequence automatically.

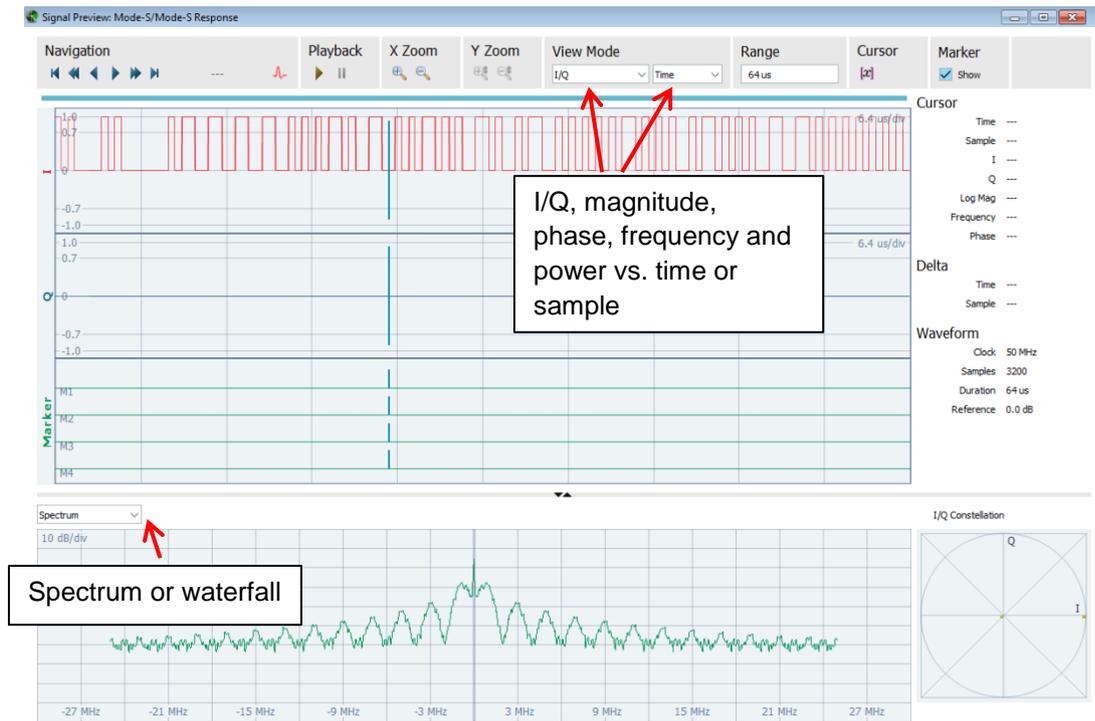


Figure 19: View the waveform of the Mode-S downlink

The sequence is now ready to be transferred either to the SMW200A Vector Signal Generator using the Local Area Network or to be exported as a file, which can then be copied to the Signal Generator.

- Press: ARB File Export > Target

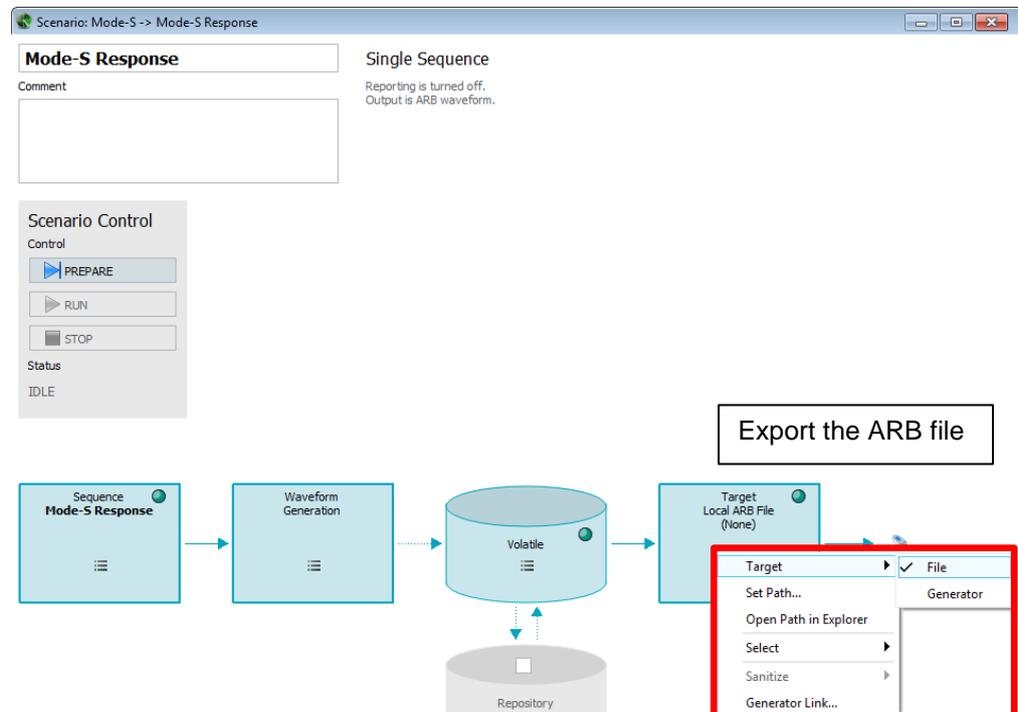


Figure 20: Export the ARB file

### 3.1.2 ATC Transponder Test

According to part 91, the document "general operating and flight rules" within the electronic code of federal regulations [2] describes in §91.413 "ATC transponder tests and inspections", the integrated ATC transponder system has to be tested and comply with the specification.

FAA Federal Aviation Regulations (FARS, 14 CFR), Appendix F - ATC Transponder Tests and Inspections [3] describes the details of the required tests concerning Radio Reply Frequency, Suppression and Receiver Sensitivity.

For the radio reply tests an R&S®FSW Spectrum Analyzer for example can be used to verify the reply frequency for to be in the range of  $1090\pm 3\text{MHz}$  (all classes), and  $1090\pm 1\text{MHz}$  respectively for other classes (e.g. 1B, 2B, 3B, Mode S, see [3] for details).

For interrogation of the transponder an R&S®SMW200A with Pulse Sequencer is used. The uplink waveform is rebuilt according to section 3.1.1, considering the different preamble and P5 pulse.

The Pulse Sequencer software is not limited to Mode S tests. Many different developed codes may be tested, such as

- Mode 1 used to sort military targets,
- Mode 2 used for identification of military aircraft missions,
- Mode 3/A to identify each aircraft inside the coverage area,
- Mode C to request the altitude of an aircraft,
- Mode 4 (used by military aircrafts for Identification Friend or Foe (IFF) or
- Mode S.

As explained in the Mode S Transponder Test earlier in this section, the desired code can be rebuilt in the Pulse Sequencer software by the user.

## 3.2 Co-Existence of Radar with Other Services

Another application which can be tested with Pulse Sequencer software is the co-existence of radar with any other service. It may happen that the ATC radar transmitter pulse interferes with the receiver of the mobile unit (e.g. LTE device).

Air Traffic Control (ATC) radar, military Air Traffic Surveillance (ATS) radar and meteorological radar operate in S-Band frequency range, which has been defined by IEEE as all frequencies between 2 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. And not just for radar. These frequencies are of special interest also for wireless communications. In fact, 4G communications systems such as UMTS long-term evolution (LTE) make use of these frequencies as well.

Application Note 1MA211 "Co-Existence Test of LTE and Radar Systems" explains test scenarios and setups in detail, but does mainly consider mobile communication signals and replays a captured radar signal only [4].

In addition to application note 1MA211, other radar signals are considered in this application note. These radar signals are built using the Pulse Sequencer and transmitted towards another radar unit. The publication IEC 62388:2013 Norm on "Maritime navigation and radiocommunication equipment and systems - Shipborne radar - Performance requirements, methods of testing and required test results" for example performs this test when certifying a maritime radar.

In addition the radar signals may be disturbed by other signals, intentionally or not. For example, in Europe, there was an incident where several planes vanished from the radar screen in mid-2014 [5] during friendly war game exercises. Radar should therefore be tested also against other RF signals.

The Co-Existence test is explained using Pulse Sequencer. The measurement setup is the same as shown in Figure 7 and Figure 8. The scenario setup is different and depends on the user needs. An example is given below.

### 3.2.1 RF Signal Environment Generation

In this example the transmit signal of an ATC radar is defined in Pulse Sequencer Software. The technical parameters of ATC radar are given in Table 2. The robustness of this signal in co-existence with a communication signal should be validated. Therefore the radar signal is defined in the Pulse Sequencer.

Table 2: Exemplary ATC Radar Signal Parameters

Parameter	Value
Frequency Range	2.70 - 2.90 GHz
Frequency List	2.70, 2.72, 2.80, 2.82 GHz
Bandwidth	10 MHz
Peak Output Power	60 dBm
Pulse Width	4x1 us, 2x60 us
Pulse Compression	Uncompressed and Non Linear Freq. Modulation (NLFM)
Rise time (10% / 90%)	100 ns
Fall time (10% / 90%)	100 ns
Pulse Repetition Time	56 μs, 66 μs and 1.4 ms, 1.45 ms
Droop	< 4%
Azimuth Resolution	1.5°
Scan Rate	12 rpm

Initially, a new repository is created. This repository is filled with the different ATC radar pulses, sequence, antenna scan and pattern, before this is combined to a scenario and replayed using the vector signal generator.

## Repository

A new repository "Co-Existence" is setup.

- File > New Repository > "Co-Existence"
- Set the desired security level and set the role of the users, if necessary.

Security level information is assigned to each repository, where "Level 0" is the lowest level that means no restrictions and "Level 4" is the highest one. Elements belonging to a repository with higher security level cannot be copied to a repository with lower one.

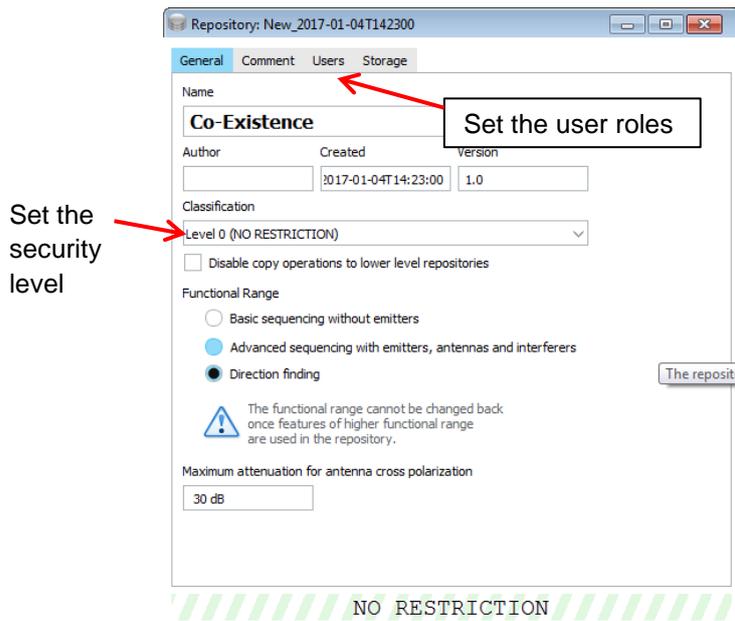


Figure 21: Repository Settings

## Pulses

In this section each pulse according to

Table 2 is defined in Pulse Sequencer software. The radar makes use of two different pulse types, one is uncompressed, another one is compressed with an NLFM.

### Uncompressed Pulse

The uncompressed pulse is defined according to Table 2.

- Add: Pulse
- Set Name, Timing and Level

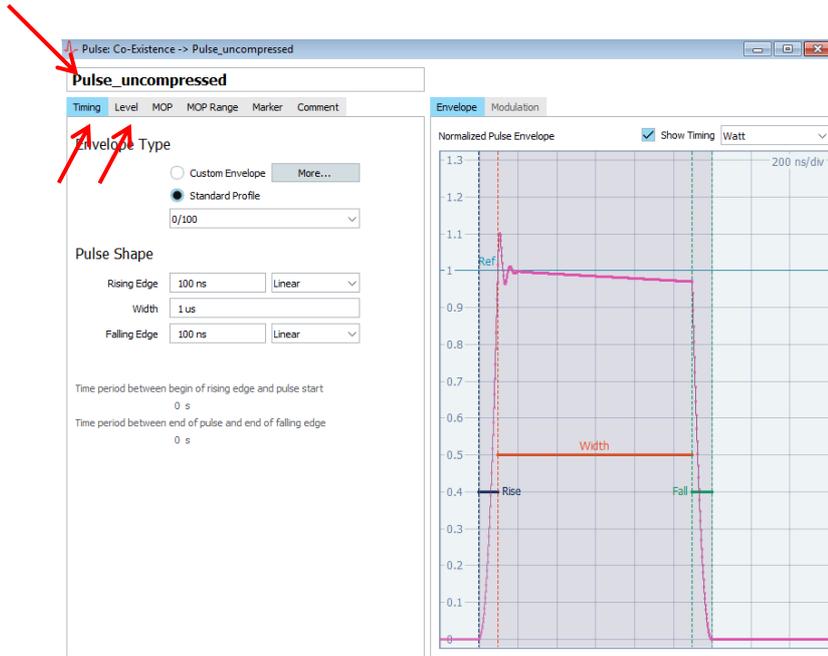


Figure 22

It is also possible to define a custom envelope instead of predefined profiles. In this case, the power levels are defined with 3% droop, 5% overshoot and 3% ripple (50 Hz).

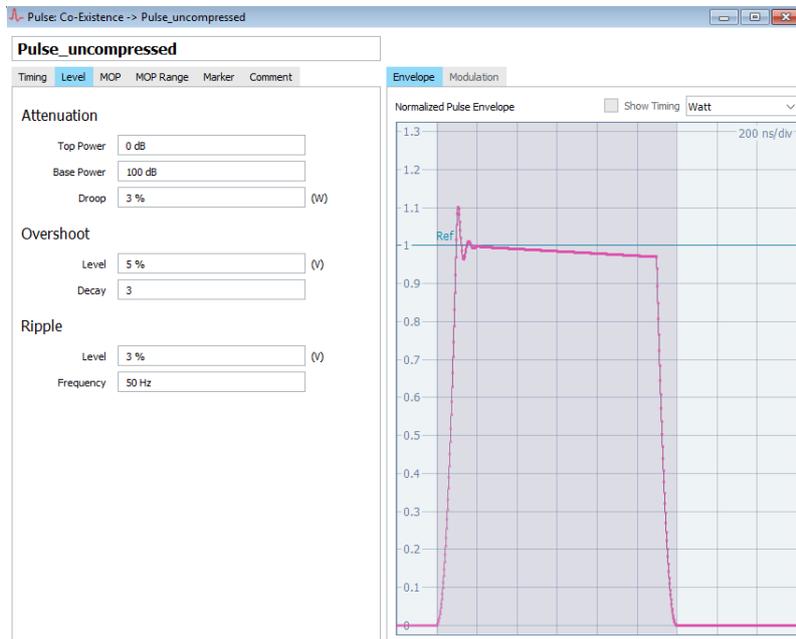


Figure 23: Level Settings

Now the non-linear FM pulse is defined according to Table 2.

**Non-linear FM Pulse**

- Add: Pulse
- Set Name, Timing; Level and Modulation On Pulse (MOP)

The MOP is a Non-linear Frequency Modulation (NLFM). This modulation is used, as it favors lower side lobe levels of the compressed pulse, which can be achieved without amplitude weighting.

Therefore "equation" is selected in the MOP. We want our chirp to be about +- 5 MHz wide from the carrier frequency in order to get the non-linear portion at the beginning and end. The Pulse Sequencer runs the variable  $t = 0..1$ . In the formula it needs to be rescaled from  $-0.5 .. 0.5$  and scaled to the entire duration  $T$ . It also has to be taken care of extremely high values (infinity) inside the formula. Therefore the square root is limited to become close to zero only by subtracting 0.99, Figure 24.

Formula:  $((t/T)-0.5)*(9E6*(1/\sqrt{1-0.99*((t/T)-0.5)^2}))$

The screenshot shows the 'Non-linear FM Pulse' configuration window. The 'Modulation on Pulse' section is highlighted with a red box. Inside this box, the 'MOP Type' is set to 'Equation', and the 'Equation' field contains the formula:  $((t/T)-0.5)*(9E6*(1/\sqrt{1-0.99*((t/T)-0.5)^2}))$ . A red box also highlights the 'Update Preview' button. Two callout boxes on the left have red arrows pointing to the 'Equation' selection and the 'Update Preview' button, with the text 'Select Chirp > Equation' and 'Insert Equation and "Update Preview"'. On the right, there is a 'Modulation' plot showing a linear frequency sweep from -5 MHz to 5 MHz over 10 microseconds, and a constellation diagram showing a circular path in the I-Q plane.

Figure 24: Non Linear Frequency Modulation Pulse

**Sequences**

The ATC radar transmits the different radar signals in an alternating way. Four uncompressed pulses with a certain PRI are transmitted, followed by 2 non-linear pulses. The sequence then repeats with a frequency offset.

- Add: Sequence
- Select the Type, Pulse, Repetition Count, Delta Frequency, PRI and Delay

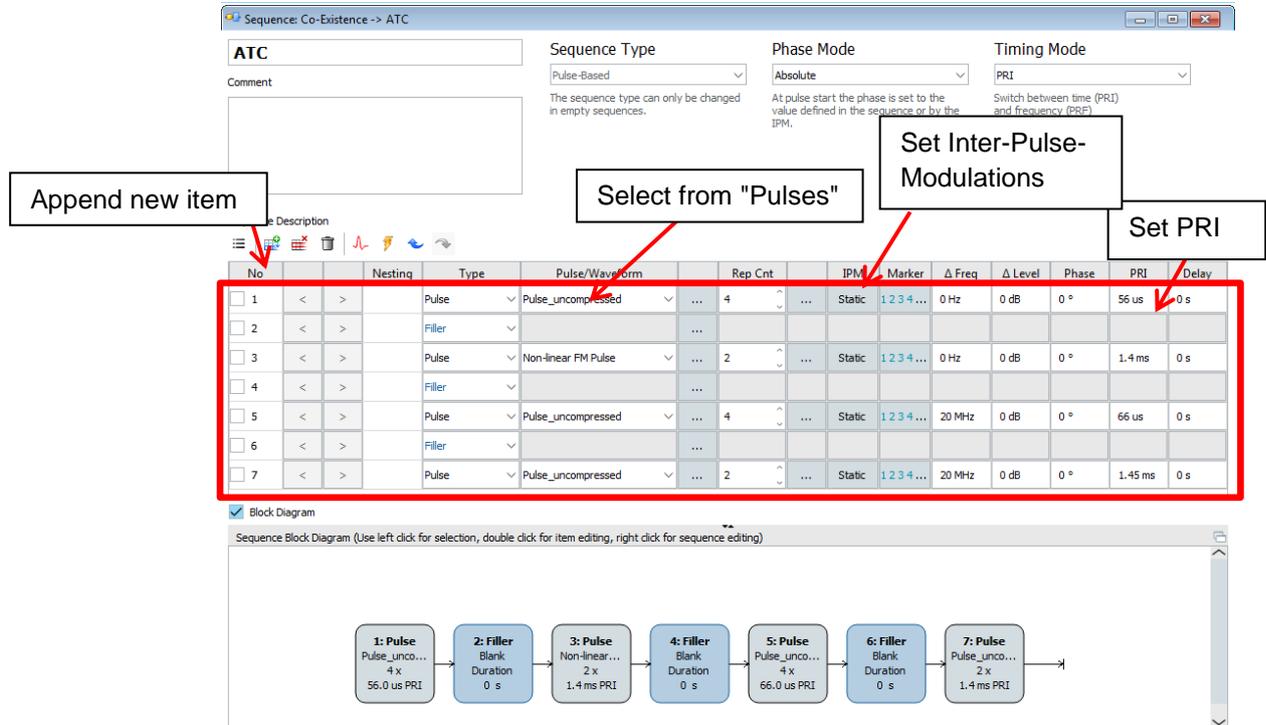


Figure 25

The waveform of the radar features a PRI jitter and frequency hopping. The PRI jitter is used to resolve ambiguous radar measurements. After the transmission of four uncompressed pulses, with a high PRI (56 μs and 66 μs) the two NLFM pulses are transmitted with a PRI of 1.4 ms and 1.45 ms. The uncompressed short pulses cover the near range up to several km, while the NLFM cover the far range of up to hundreds of km. The carrier frequency is then changed by 20 MHz. The sequence setup is shown in Figure 25.

Instead of setting a frequency offset or PRI jitter in the sequence table it is also possible to set Inter-Pulse-Modulations (IPM) according to lists, steps, random etc., Figure 26.

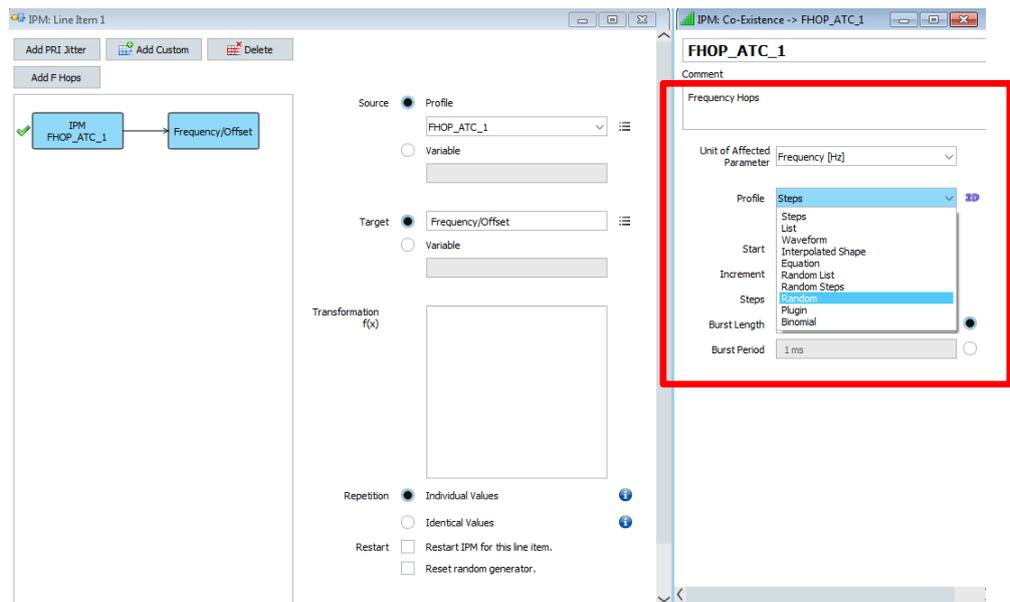


Figure 26: Inter-Pulse-Modulations

### Antenna Scans

- Add: Antenna Scan
- Select the Scan Type, Scan Rate and Direction.

The antenna scan pattern of the ATC radar is circular with a scan rate of 12 rpm. The Pulse Sequencer also allows different scan types, such as Sector, Raster, Conical, Helical, Spiral or Lobe Switching.

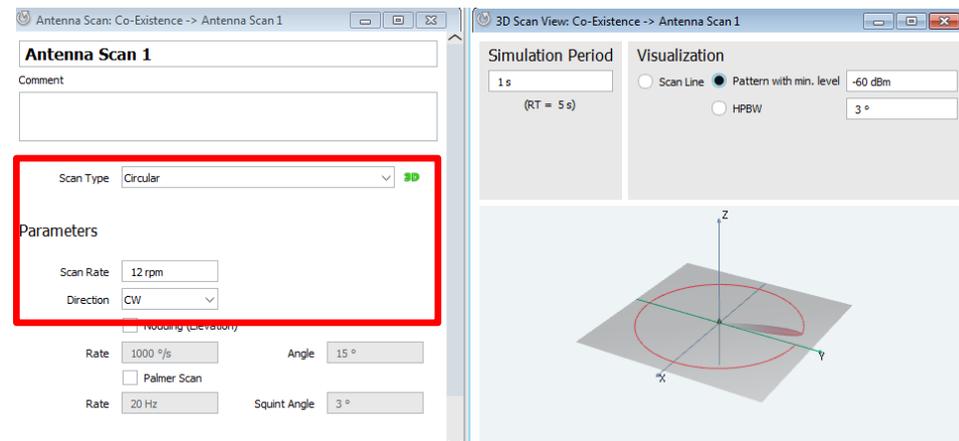


Figure 27: Antenna Scan

### Antenna Pattern

- Add: Antenna Pattern
- Select the Model, and Antenna Parameters.

The ATC radar antenna has a cosec<sup>2</sup> pattern. It is also possible to select other models, such as Dipole, Parabolic, Gaussian, Sin(x)/x, Pyramidal Horn, Planar Phased Array or import models from a file. Supported are FEKO Far Field (\*.ffe) files and \*.ant\_pat files in the Rohde & Schwarz proprietary format.

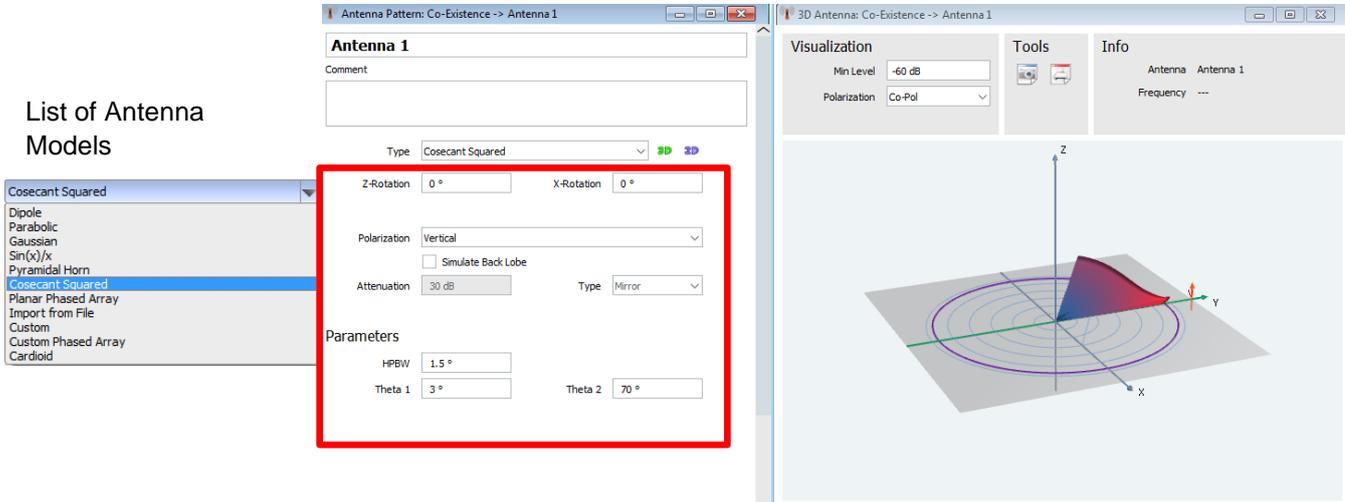


Figure 28: Antenna Pattern

## Emitter

We combine all predefined pulse and antenna parameters to an emitter.

- Add: Emitter

Set the Frequency; select the Antenna Pattern, Scan and Sequence, Figure 29.

- ▶ Note: The EIRP is only applicable for emitters used in scenarios with localization (see subchapter 3.2.2).

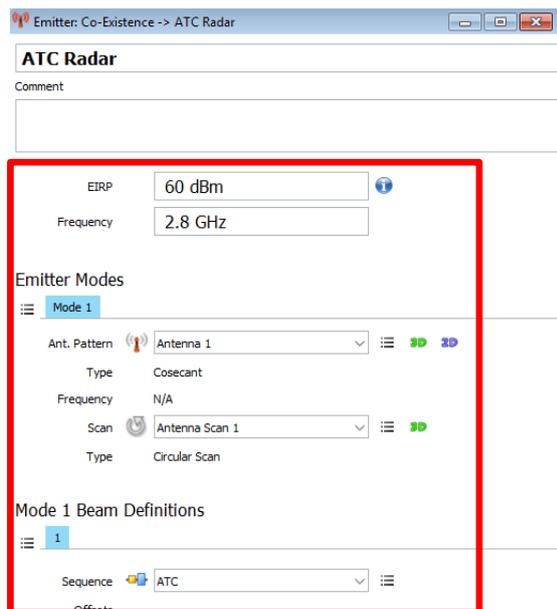


Figure 29: Emitter

## Scenario

We finalize the setup by combining the sequences and emitters to a scenario.

- Create: Scenario
- Select the Sequence and process the data by pressing "Calculate + Upload", Figure 30.

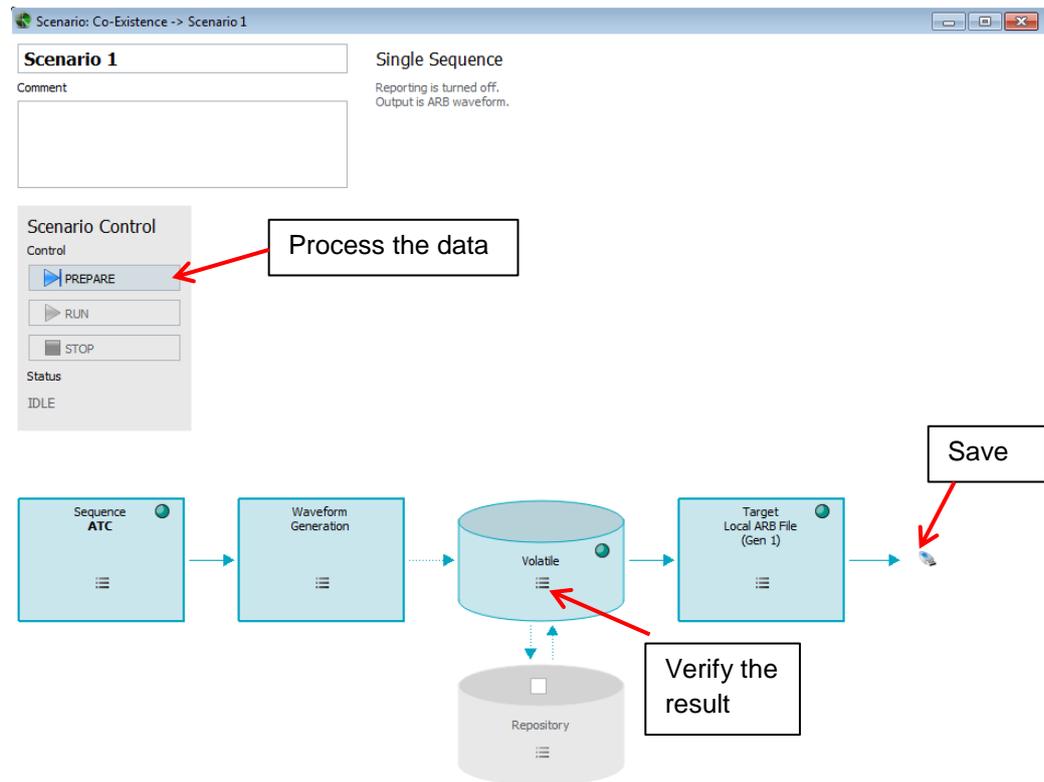


Figure 30: Scenario

The processed scenario is depicted in Figure 31. It shows the I/Q data of the first four short pulses and the non-linear frequency modulated chirp.

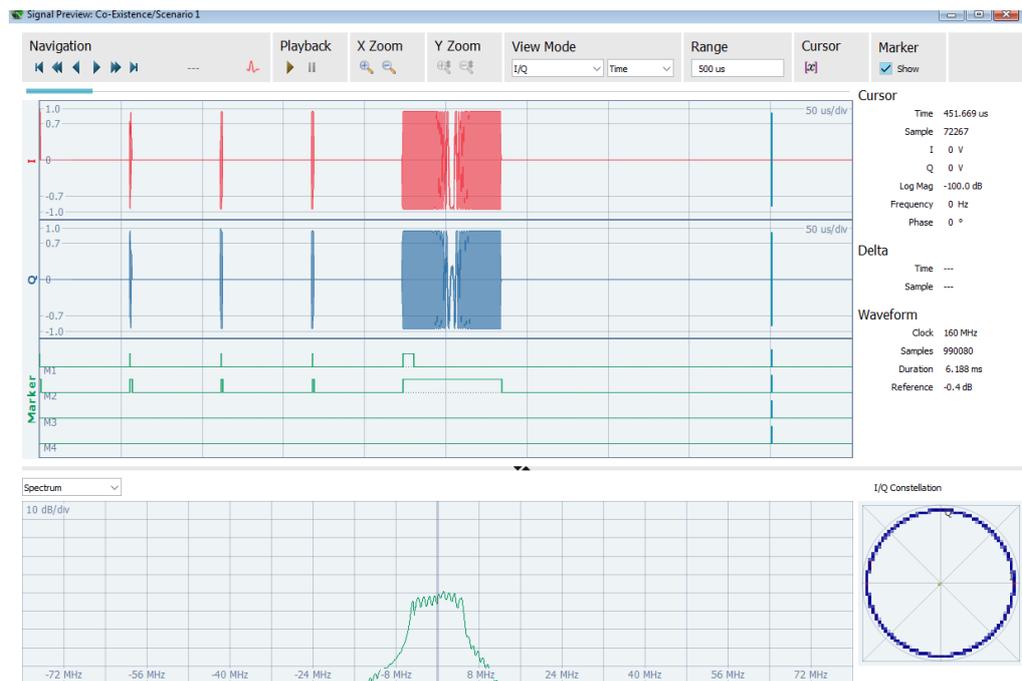


Figure 31: Scenario

This scenario is now exported as a waveform file to be used in co-existence tests of mobile networks or handsets.

### 3.2.2 RF Environment with Emitters at Different Locations

In addition to the ATC radar transmit signal and scenario setup, it is also possible to add a certain location to the ATC radar.

In this special case we are interested in the RF environment when operating two ATC radars with reference to the geographical coordinates on a map.

At Munich airport for example two ATC radars operate in northern and southern direction in a distance of 3 km and 5 km far away from the airport. We are interested in the RF environment at the airport (receiver at the airport).

We create an additional scenario, Figure 32.

- Scenario > Localized Emitters

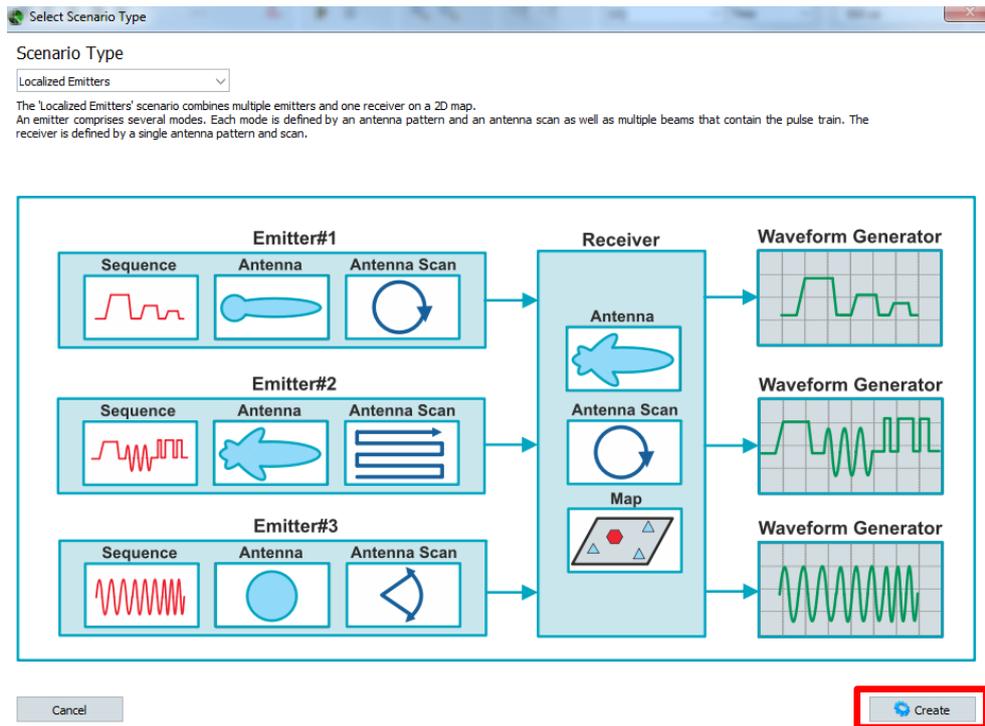


Figure 32: Localized Emitters Scenario

Create the scenario and open the 2D localizer, Figure 33, Figure 34.

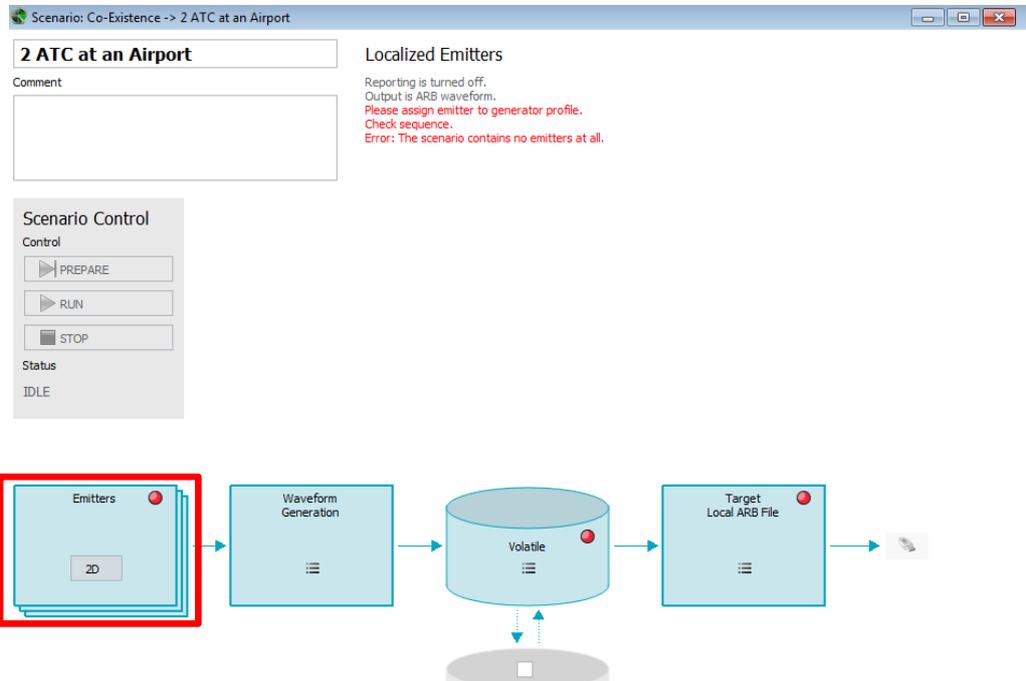


Figure 33

Right click on the 2D map to add an emitter or interferer.

Assign each ATC radar to a specific generator.

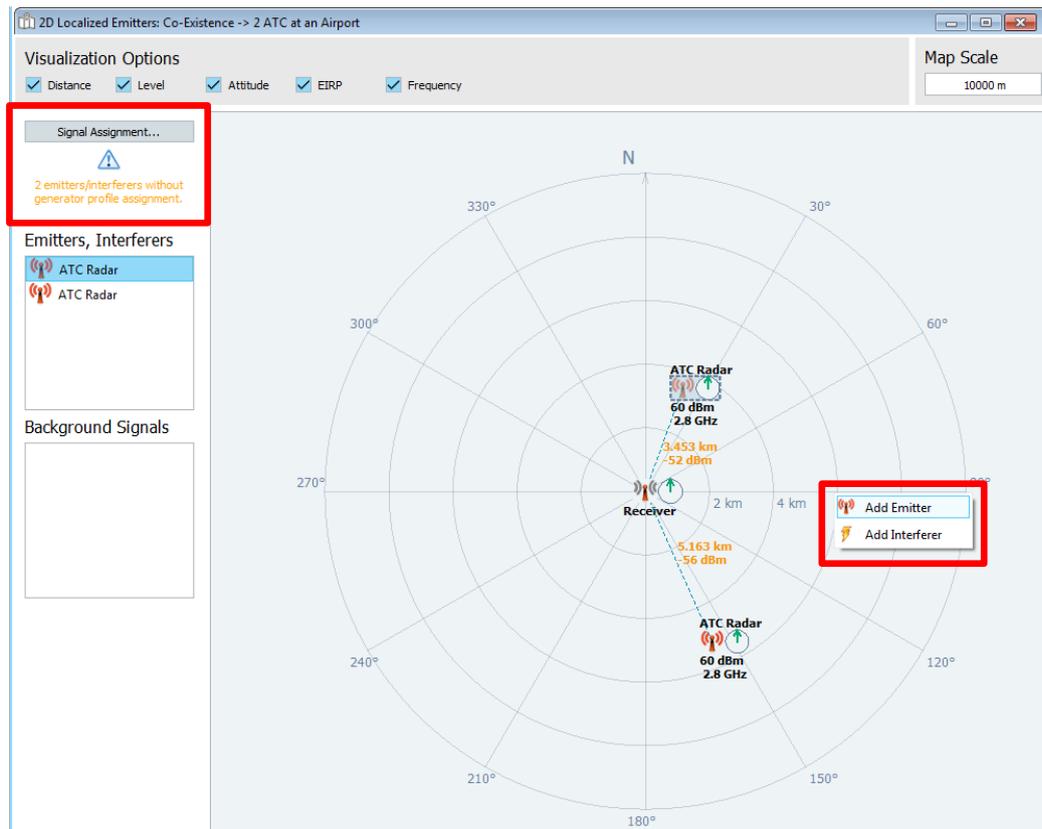


Figure 34

The ATC Radar Emitter is cloned (right click in the repository on the Emitter > ATC Radar and select "clone"). One carrier frequency of the first radar is set to 2.8 GHz, the other frequency to 2.82 GHz. Both radars are chosen in the Properties Panel (right click on an Emitter > Properties), Figure 35.

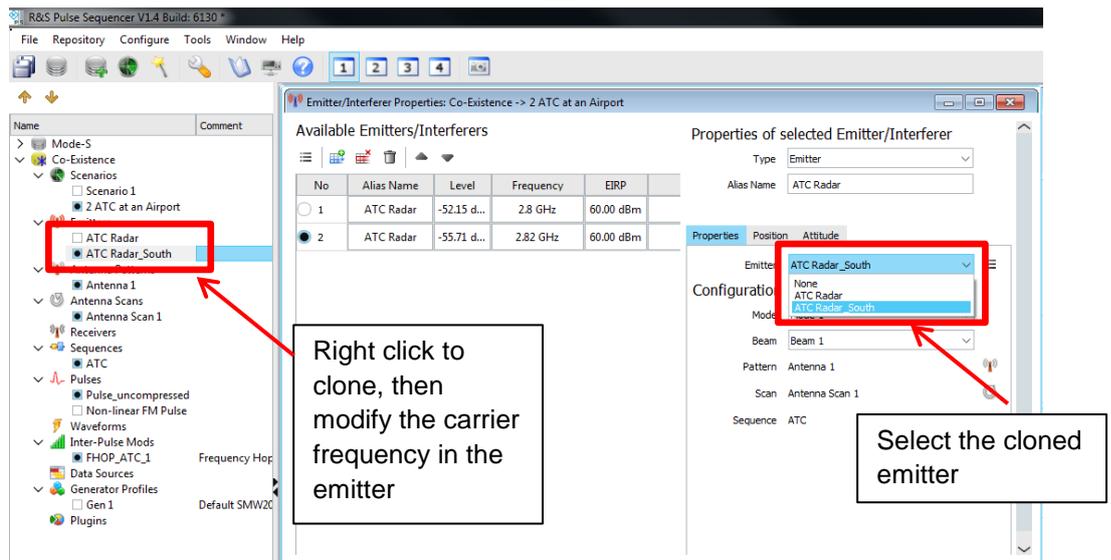


Figure 35

Process the sequence and save the ARB file.

### 3.3 Radar Echo Generation in Complex RF Environment

Radar operators are often interested in a quick overview and main functionality test of their radar system which should cover the most important tasks, namely echo detection and tracking. For this case, echos are generated at a defined range, radial velocity interval and Radar Cross Sections (RCS) using a Radar Echo Generator.

A radar echo generator working on RF signal level ensures correct functioning of the entire radar capability and builds up confidence the complete system including radar RF frontend, transmission and reception, the entire signal processing chain down to detection algorithms.

Radar echo generation uses a single baseband of the Vector Signal Generator R&S®SMW200A only. The other optionally available baseband sections can be used to replay a defined RF signal environment.

One can then:

1. Operate the radar and generate virtual radar echo signals, by capturing the original radar signal, manipulation and retransmission, and in addition simultaneously using the option R&S®SMW-K78
2. create a specific RF signal environment using the R&S®Pulse Sequencer software.

Therefore, the radar system can be tested in a user defined RF signal environment. A step-by-step description of the radar echo generation setup and operation can be found in Application Note 1MA283 [6]. The configuration of an exemplary generated moving echo signal is shown in Figure 36 below.

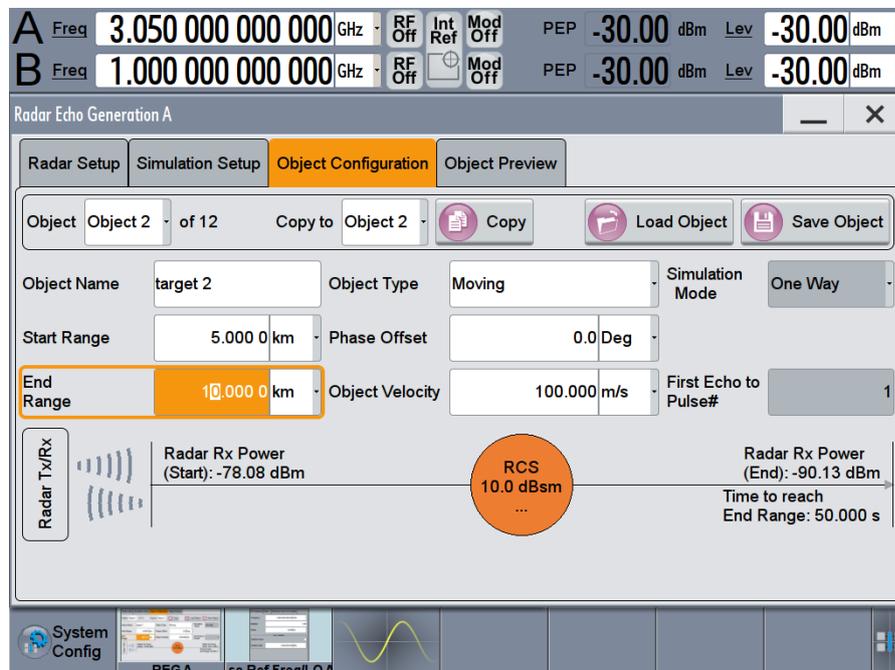


Figure 36: Generated radar echo signal, see 1MA283 [6] for further details.

## 4 Summary

Electromagnetic spectrum is a limited resource. Many services make use of the spectrum, and an increasing demand for bandwidth in mobile communications, broadcasting or surveillance systems require enormous test and measurement to ensure proper functioning, co-existence and regulation.

To test RF devices and systems in presence of other RF signals or to radio locate RF devices (for example in case of misbehavior), field tests are usually performed or I/Q data is captured and replayed in the lab. This is a costly, often time consuming, and exhausting task, for example when certain RF signals are available only sporadically making in-the-field capture difficult.

In order to rebuild arbitrary signal scenarios and to bring the field into the laboratory, Rohde & Schwarz developed the Pulse Sequencer software. R&S®Pulse Sequencer software is a stand-alone, PC based application that helps to create signals and build complex scenarios from them. The waveforms can be processed by vector signal generator instruments. Several features, like restricted access to databases and file import and export possibilities make the Pulse Sequencer a suitable tool for test and measurement applications also in classified environments, such as A&D research areas or pre-development.

In this application note, the Pulse Sequencer software was introduced, accompanied by several measurement examples. Besides the ATC transponder test, co-existence of 4G mobile networks with S-Band radar was addressed and explained in detail and further reading into radar echo generation and creation of complex RF environment pointed to additional application notes that are available.

The software is not limited to these examples. The user is able to generate self-defined pulses, waveforms, antenna patterns, emitters and much more with great flexibility and efficiency to create a very unique RF environment.

---

## References

- [1] The Mode S Beacon Radar System, The Lincoln Laboratory Journal, Vol. 2, Number 3, 1989, retrieved from [www.ll.mit.edu](http://www.ll.mit.edu), Jan 2017
- [2] Electronic Code of federal regulations, e-CFR, PART 91—GENERAL OPERATING AND FLIGHT RULES, retrieved from [www.ecfr.gov](http://www.ecfr.gov), Jan 2017
- [3] FAA Federal Aviation Regulations (FARS, 14 CFR), retrieved from [www.faa.gov](http://www.faa.gov), Jan 2017
- [4] Rohde & Schwarz Application Note 1MA211, "LTE Co-Existence Test of LTE and Radar Systems", [www.rohde-schwarz.com/appnote/1MA211](http://www.rohde-schwarz.com/appnote/1MA211), March 2014
- [5] Reuters, "Jets vanishing from Europe radar linked to war games" retrieved from <http://www.reuters.com/article/2014/06/13/us-europe-airplanes-safety-idUSKBN0EO1CW20140613>, November 2014
- [6] Rohde & Schwarz Application Note 1MA283, "Radar Echo Generator", [www.rohde-schwarz.com/appnote/1MA283](http://www.rohde-schwarz.com/appnote/1MA283), August 2016

## About Rohde & Schwarz

The Rohde & Schwarz electronics group is a leading supplier of solutions in the fields of test and measurement, broadcasting, secure communications, and radiomonitoring and radiolocation. Founded more than 80 years ago, this independent global company has an extensive sales network and is present in more than 70 countries. The company is headquartered in Munich, Germany.

## Regional contact

Europe, Africa, Middle East  
+49 89 4129 12345  
[customersupport@rohde-schwarz.com](mailto:customersupport@rohde-schwarz.com)

North America  
1 888 TEST RSA (1 888 837 87 72)  
[customer.support@rsa.rohde-schwarz.com](mailto:customer.support@rsa.rohde-schwarz.com)

Latin America  
+1 410 910 79 88  
[customersupport.la@rohde-schwarz.com](mailto:customersupport.la@rohde-schwarz.com)

Asia Pacific  
+65 65 13 04 88  
[customersupport.asia@rohde-schwarz.com](mailto:customersupport.asia@rohde-schwarz.com)

China  
+86 800 810 82 28 | +86 400 650 58 96  
[customersupport.china@rohde-schwarz.com](mailto:customersupport.china@rohde-schwarz.com)

## Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership



This application note and the supplied programs may only be used subject to the conditions of use set forth in the download area of the Rohde & Schwarz website.

R&S® is a registered trademark of Rohde & Schwarz GmbH & Co. KG; Trade names are trademarks of the owners.