Generation of modern radar scenarios using vector signal generators and Pulse Descriptor Words

Rainer Lenz, Alois Ascher, Steffen Heuel

Rohde & Schwarz GmbH & Co. KG
Muehldorfstr. 15, 81671 Munich, GERMANY
email: rainer.lenz at rohde-schwarz.com

Abstract: *Besides many different radars such as navigation or surveillance radars, ships and aircrafts also have early warning equipment on board. The purpose is to identify and classify radar signals in presence of many other radar signals and finally determine the threat level of it.*
This paper presents an intuitive and powerful method how to generate complex radar environments based on previously stored radar signals. The data can originate from live recordings of real world scenarios or from software simulation. This enables conclusive tests of radar receivers and radar early warning equipment on functionality and performance in the lab. This reduces field testing, saves time and improves reliability and repeatability of the equipment.

1. Introduction

Modern radar environments can be quite complex as radars follow the same trend as telecommunication equipment that is more and more software defined. The same is true for the most modern radar systems that are often multi-functional. This means that they use several modes depending on the radar task. Each radar mode uses different radar signals. Radars use low PRI for long-range surveillance whereas they use unmodulated, narrow pulses for near range detection. In order to minimize the probability of interception of the radar's transmit signal, most advanced I/Q modulated radar waveforms are used. Typically, I/Q modulated pulses with longer pulse duration or concatenated FMCW waveforms are chosen. Radars profit from using modulated waveforms as range resolution depends only on signal bandwidth, processing gain is high while lower transmit power levels can be used [1]. Modern early warning receiver equipment needs to identify radar signals not only in artificial anechoic environments but also in highly populated electromagnetic spectra such as in maritime environments with many navigation radars present. Typical early warning receivers need to operate in a peak pulse load of up to some million pulses per second. In addition, modern early warning equipment needs to follow the trend from pure analog evaluation of pulsed radar signal envelopes to the analysis of the complex samples.

2. Generation of radar scenarios

Replay of stored emitter scenarios with an RF source is an essential test step during the R&D phase of radar warning receivers in the lab or for operational testing of radar equipment prior to a mission. Using a vector signal generator for signal replay allows generating any kind of modulation format and therefore is a good alternative to dedicated radar simulators that can only produce traditional pulsed signals without I/Q modulation. With vector signal generators, modern radar waveforms can be generated and receivers can be tested with challenging radar scenarios. During verification phase of the equipment under test, many different radar scenarios are needed. One can manually define new scenarios or re-use stored legacy scenarios. Storing radar scenarios as Pulse Descriptor Words (PDWs) is a good mechanism to

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reduce memory needs. PDWs only describe the signal characteristics such as pulse duration, carrier frequency, pulse start time, pulse top power level or used modulation on pulse (MOP). Pulse breaks are achieved by assigning a timestamp to a PDW.

Typically, radar engineers have several possibilities to generate radar scenarios. The following concepts are generally used:

- **Manual generation of radar scenarios by simulation software together with a vector signal generator**
  A typical vector signal generator with additional software like the R&S Pulse Sequencer Software or any other simulation software is a good solution for simulation and generation of radar scenarios. Users can define emitters manually in the software, calculate the resulting radar signal for each emitter and upload it to the vector signal generator [2]. Once signals are defined in a software, users often do not want to touch the simulator any more but only want to regenerate the signals e.g. for verification or qualification tests.

- **Replay of recorded and stored I/Q signals**
  Scenarios can originate from live recordings in real world environments. File sizes for long scenarios could easily be in the order of several GBytes for long scenarios if stored as classical ARB waveforms. However, if exact representation of the signals is essential, this is a good test method.

- **Streaming of Pulse Descriptor Words (PDWs) to a vector signal generator [3]**
  A vector signal generator can take on the role of a powerful and flexible signal generation source for the realistic and agile radar scenarios in highly integrated radar scenario simulators. A solution for reproducing the radar scenario is to stream the stored PDWs to a signal source. As an alternative, radar engineers can simulate the scenario and stream the PDWs directly to a signal source without previously storing the PDWs. This is a good solution for mission preparation or for operational tests if ultra-long radar scenarios with high pulse density are needed.

- **Import and load lists of recorded PDWs and replay with a vector signal generator**
  Often radar engineers want to import and replay existing PDW lists with a signal source. Stored signals can originate from live recordings of real-world scenarios or from scenarios generated by simulation software before.

This paper will propose a convenient and simple method how radar engineers can import and load lists of recorded PDWs into a vector signal generator and replay them.

3. A typical and representative radar scenario

Typically, many different operating radars can be found close to the coast. Nearly every ship carries at least one S- or X-band navigation radar. All radars are active all the time. Figure 1 shows a representative simulation of such a scenario. The level traces of the figure below are typical for radars with circular scan. Over time, several antenna turns are visible. As the navigation radars are very often of the same kind or brand, all radar signals are quite similar, mostly using very similar signal parameters such as pulse width or PRI. They operate in S-band and or in X–band. These bands are used for navigation purpose. The example scenario shown below has a total length of 16 seconds. This can lead to a file size of several GBytes when storing it as an I/Q waveform file and depends on the used sample rate and number of Bits. Using Pulse Descriptor Words to describe the scenario considerably reduces the file size as sampling the pulse breaks between the pulses can be avoided. For this example, it roughly leads to a file size of only a few MBytes. This clearly shows the benefit of storing scenarios as lists containing Pulse Descriptor Words. For real life recordings or much longer scenarios, this benefit will further increase.

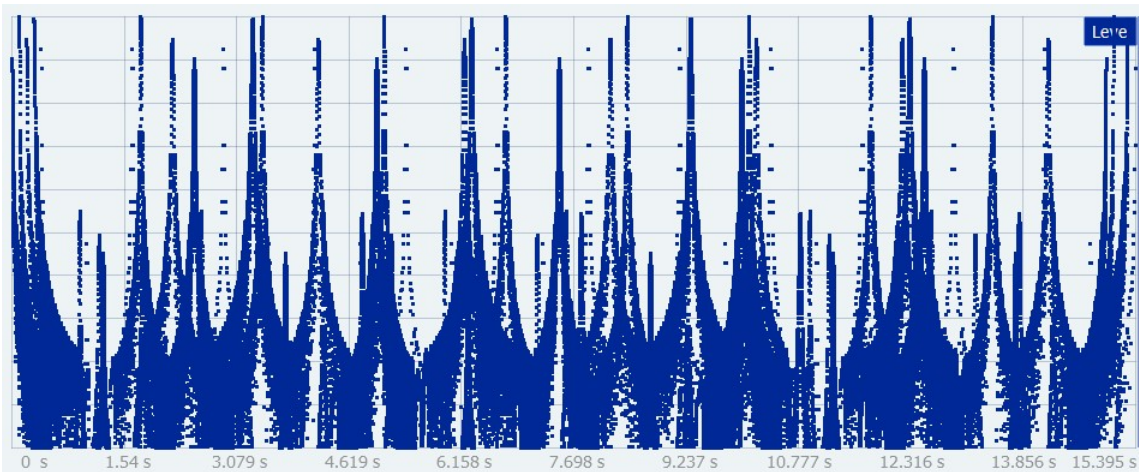

Figure 1: Simulated radar scenario from many active navigation radars as seen by a receiver with omnidirectional antenna pattern. The trace shows the characteristic level variation over time at a receiver input due to circularly scanning navigation radar antennas.

4. Proposed mechanism for generation of radar scenarios from recorded PDWs

To minimize the memory requirements of the signal files, the received radar signals are stored as lists of PDWs. The PDWs describe all pulse parameters such as pulse duration, pulse top power level and carrier frequency together with a timestamp defining the pulse start time.
The PDWs can also contain information about the modulation on pulse (MOP) used. The PDW lists can contain PDWs originating form a single emitter or from multi emitter scenarios such as the navigation radar scenario described above [5].
The following figure shows a novel and innovative mechanism for import and replay of previously recorded signals using a piece of software and a vector signal generator.

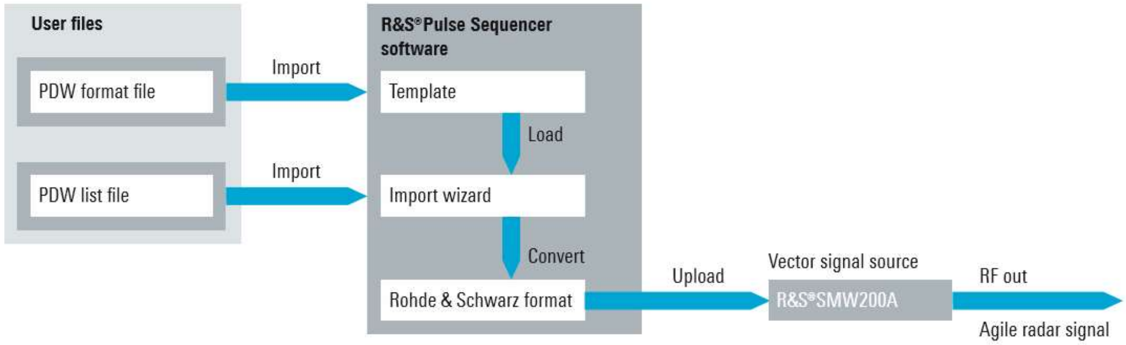

Figure 2: Workflow for import of PDWs in software (R&S Pulse Sequencer software) and replay with a vector signal generator. The user has to import the PDW list and a PDW format description file in the software. The user can easily modify example PDW format files to meet his specific format requirements. The software is therefore not limited to specific known formats, but can be tailored to the required PDW formats. [5]

Users can create PDW format files, which describe the specific formats of the PDW lists, to provide their specific format to the software. The PDW format files enable radar engineers to import their PDW lists directly without spending valuable time reformatting them. Secondly, the software is generic and no proprietary customer formats must be hard compiled into the code of the software. So no one needs to disclose his proprietary PDW format.

The software maps the imported PDW lists into the Rohde & Schwarz format as specified by the PDW format files and uploads them to the vector signal generator. The baseband hardware of the signal generator interprets the uploaded files of the converted PDW lists and generates the defined radar signals.

The PDW format file (template) describes the overall format structure of the user's PDW list and contains pulse information such as the time, frequency and MOP format. The following figure shows the content of the PDW format file.

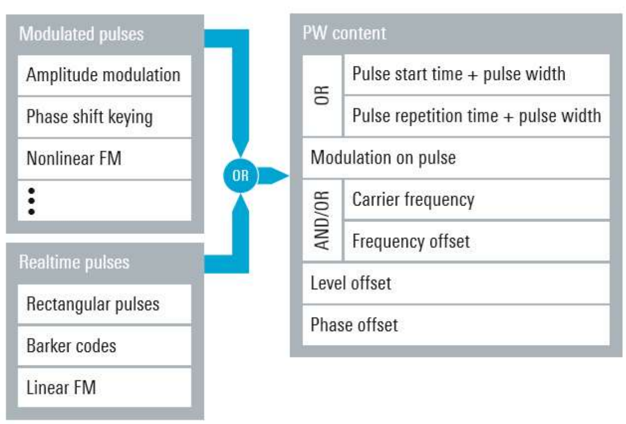

Figure 3: Main content of the PDW format file

The time format can either be given as an absolute or relative timestamp. The timestamp defines the start time of a pulse. Optionally, only the pulse repetition time together with the pulse width can be provided instead of the timestamp. The frequency can be given as an absolute frequency value (carrier frequency), as a frequency offset relative to any carrier frequency, or as a combination of both. The PDW format file can also contain information specifying the pulse level offset and pulse start phase. The following figure shows an example template file.

```
# PDW Import Template Example

COMMENT          : LINE 2
START_LINE       : STARTS_WITH \s*\d+
END_LINE         : EOF
COLUMN_SEPARATOR : SPACE
DECIMAL_CHAR     : DOT

1 : TOA          TIME
    'hh:mm:ss.zzzzzzzzz'
2 : MOP          TEXT     # Modulation Type
    'Chirp' : LFM
    'None'  : CW
3 : WIDTH        US       # Pulse Width
4 : LEVELOFFSET DB        # Power Level
5 : PHASE        DEG      # Phase
6 : CHRATE       KHZ/US   # Chirp Rate
7 : RFOFFSET     MHZ      # Frequency Offset
```

Table 1: Example template file for the import of PDW lists. The template file is user specific and defines the format of the user's PDW list to import a PDW list in a user format into the software. Therefore, the user must describe his proprietary format by telling the software that e.g. column 1 specifies Time of Arrival (ToA) and time format, column 2 the used modulation type etc.

5. Proposed sequencing concept in the signal generator for replay of recorded radar scenarios stored as PDWs

After successful import, the software calculates a dedicated sequencing list that is tailored to the baseband hardware of the vector signal generator (in this case R&S SMW200A). With this concept, extensive memory use due to large waveform files can be avoided. The sequencing list holds all the signal parameters that are needed to regenerate the RF. Each set of pulse parameters is time tagged. This is very helpful for pulsed signals as no I/Q samples are needed to fill the pulse pauses. Typically, a set of pulse parameters contains information such as pulse width, modulation on pulse or any level offset to model antenna scans or frequency offsets to model frequency agility (frequency hopping). The most important MOP formats such as linear frequency modulation (up, down or triangular chirps), Barker Codes, ASK or nonlinear frequency modulation (NLFM) are supported. Unmodulated pulses, Barker coded pulses or pulses with linear frequency modulation, are generated in real-time in the vector signal generator. For these signals, a minimum PRI of 0,3 us can be achieved which leads to a maximum pulse density of more than 3 million pulses per second. For pulses that contain MOP formats such as ASK, FSK, non linear frequency modulation (NLFM), the import mechanism identifies the used modulation format as defined by the individual PDW and calculates a single waveform segment, which only includes the I/Q modulated pulse.
The format of the modulation can be defined in the PDW format file. The waveform segments are referenced in a sequencing list, which is also calculated by the software. Also in this case, pulse breaks are achieved by assigning a timestamp to each waveform segment so that no I/Q

samples are needed to fill the pulse pauses. The sequencing list references the calculated waveform segments and contains all applicable offset values and the timestamps. All offsets are applied in real-time. The waveform segments together with the sequencing list are automatically uploaded to the vector signal generator [4],[5]. After processing the imported PDWs, the resulting sequencing list can also be viewed or exported. An example is shown below. It is also possible to mix table items that define a real-time signal with table items that reference a predefined waveform segment in the ARB.

TOA	Mode	PW	Level	Frequency	Phase	MOP	Parameter
0.000 000 000 000 s	RT	20 µs	0.00 dB	–20 MHz	0.00°	LFM	2.001 MHz/µs
0.000 050 000 000 s	RT	11.535 µs	–2.00 dB	0 Hz	0.00°	BKR	R13
0.000 550 000 000 s	WV	–	0.00 dB	10 MHz	0.00°		Seg#0
0.001 050 000 000 s	WV	–	–1.00 dB	0 Hz	0.00°		Seg#1

Table 2: Example of a sequencing list with parameters for 4 pulses that define either a real-time (RT) signal or that make reference to a waveform (WV) segment

6. Conclusion

This paper presented a simple and intuitive method for replay of radar scenarios stored as PDW lists that maximizes replay time of radar scenarios with minimum memory using a vector signal generator. The stored radar signal can include any kind of pulse sequence either originating from a single emitter or from a multi emitter scenario. An import mechanism for existing Pulse Descriptor Word lists makes it easy to re-use existing legacy scenarios and use them for conclusive receiver tests in the lab. Now demanding radar scenarios can also be used during early phases of development to make sure that the radar equipment can fulfill its task reliably once employed in a mission and to reduce field-test.

References

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