

Radar Echo Generator

Application Note

Products:

- R&S®FSW
- R&S®SMW200A
- R&S®ZVA
- R&S®RTO

Radar test systems are essential in research, development, production and maintenance of radar systems. Most radar tests are expensive to carry out in the field and have a complicated setup and operation. One of the main advantages of the Radar Echo Generator presented in this application note is its ability to generate arbitrary virtual radar echo signals in real time in the laboratory using only commercial measuring equipment. The Radar Echo Generator not only allows to reproduce the results and automate the tests, but also it significantly reduces the measurement effort and costs while providing greater utility for the existing common test equipment.

This application note presents a solution for testing the complete radar system by generating any kind of radar echo signals with arbitrary range, Doppler frequency and Radar Cross Section. The Radar Echo Generator makes it possible to perform real time tests on many applications including aerospace & defense and commercial radar systems.

Note:

Please find the most up-to-date document on our homepage
<http://www.rohde-schwarz.com/appnote/1MA283>.

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Motivation

Radar systems are used in various applications like in military, aircraft safety and navigation and automotive applications. From military to aviation and automotive radar, the main idea of using radar devices is to improve safety by detecting targets. For each of these applications an appropriate radar system has to be developed, i.e. the physical size of the radar, operating frequency, waveform, transmit power, antenna aperture and other parameters have to be chosen and optimized according to the desired application. Furthermore, these parameters have to be tested beforehand to ensure proper functionality of the radar system.

Operators are often interested in a quick overview and main functionality test, which covers the most important tasks of radar, namely target detection and tracking including range, velocity, elevation and azimuth angles. To ensure realistic measurements, the test should consider the maximum unambiguous range and the blind range of the radar. Additionally, range resolution is also essential in the system design. It gives the minimum distance between two targets at which they can be detected by the radar. Another important factor is radar accuracy which is defined as the degree of conformance between the measured value at a given time and its true value. The accuracy has to be measured from time to time, since components like power amplifiers, filters or oscillators age with time due to the use of magnetic materials and hence signal generation and detection are adversely effected.

Testing of radar systems and parameters is often performed in the field under controlled conditions, where artificial targets are deployed, detected and tracked by the radar. The radar performance is then determined by comparing the acquired data from the radar with GPS (Global Positioning System) coordinates. However, field test using towed targets or corner reflectors can be complex, time consuming and expensive and thus not preferred by radar manufacturers. On the other hand, simple and quick tests performed in the laboratory needs much less effort, are more flexible, improve the time-to-market and hence are more attractive. Yet, we need to ensure a correct functioning of the entire radar system under real conditions in the laboratory. This is why, the complete system has to be tested including the RF-Frontend, transmission and reception and the entire signal processing chain. The Rohde & Schwarz Radar Echo Generator offers the manufacturers the possibility to test their radar system design more efficiently with less costs. Moreover, Rohde & Schwarz Radar Echo Generator can be used in several different applications.

The Rohde & Schwarz Radar Echo Generator application uses commercial off-the-shelf measurement instruments, such as Rohde & Schwarz Vector Signal Generator R&S®SMW200A and Rohde & Schwarz Signal and Spectrum Analyzer R&S®FSW. The spectrum analyzer captures the RF transmitted radar signal from the Radar Under Test. After generating the baseband signal, the spectrum analyzer transfers the signal to the signal generator. The signal is then manipulated by introducing delay, radial velocity, and attenuation before RF conversion and retransmitting back to the Radar Under Test. The system does not need to know which kind of radar waveform was transmitted. Instead it acts similar to Digital Radio Frequency Memory build out measurement equipment. Although these devices may be used in other signal analysis and signal generation application, when used together as in this case, they build up a Radar Echo Generator, where radar tests can be mapped efficiently from the field to the laboratory.

1 Radar Echo Generation

Testing of radar systems with real targets can be a complex task, including expensive and non-reproducible field test, or involving special designed hardware. A better and novel approach is to use standard test and measurement equipment, for example by combining the Rohde & Schwarz Vector Signal Generator R&S®SMW200A and Rohde & Schwarz Signal and Spectrum Analyzer R&S®FSW, forming the Radar Echo Generator.

This chapter focuses on the functionality of the Rohde & Schwarz Radar Echo Generator R&S®SMW-K78 application. More specifically, it explains how the Radar Echo Generator receives, manipulates and retransmits radar waveforms to the Radar Under Test. We first introduce the basics of radar measurements, and then move on to explain in detail the system setup and configuration of the Radar Echo Generator.

1.1 Basics of Radar Measurements

Radar technology is based on the transmission of electromagnetic waves through space propagating with speed of light c_0 . Once the wavefront hits an obstacle, a portion of the wave is reflected back and an echo is received by the radar. In the following analysis, we assume that the radar and the target are located in the far field, i.e. the term planar wavefront holds, and we use this information to give the radar equation.

1.1.1 Radar Equation and Range-Velocity Measurement

The radar equation is used to configure the Radar Echo Generator as illustrated in section 1.5.1. The radar equation depends on different parameters that can be adjusted to produce a given received power. In this section, we give a short overview about these parameters and how they influence the received power.

The radar transmits a waveform with power P_T which reaches the target of cross-section σ known as Radar Cross Section RCS at distance R from the transmitter. The impinging signal is scattered by the target and is dependent on the material, dimension, shape and orientation of the object. The radar absorbs back some of the scattered energy and has now the received power [1]

$$P_R = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R^4 L}$$

with G_T and G_R are the gain of the transmitting and receiving antennas respectively, and L is the total system loss. The radar equation allows us to extract information about the target object from one echo or a sequence of echoes including range, velocity, azimuth and elevation angles, size, shape and polarization. The most important parameters considered by radar tests are range, velocity and direction.

In the white paper [2] different methods have been introduced in detail for measuring these parameters. The application note [3] provides an overview of the most important radar measurements. For other radar measurements, such as coexistence tests, it is referred to [4].

1.1.2 Minimum Detectable Signal

The minimum detectable signal (MDS) corresponds to the minimum signal power required to detect a radar echo signal, i.e. only echoes with received power higher than the MDS can be detected. That's why, it is important to include the MDS measurement in the radar tests, which can be measured using the Radar Echo Generator as it will be explained in section 2.3. In this section, we give a short introduction about the theoretical background of the MDS for a receiver in general.

In receiver systems, we are often interested in the signal-noise-ratio (SNR) rather than the signal power due to the presence of noise. The SNR measures the signal quality and is given by the ratio of signal power to the noise power. The most known noise source is thermal noise caused by the random motion of electrons at a temperature T_0 . The noise power in this case is

$$P_N = KBT_0$$

with K the Boltzmann's constant and B the noise bandwidth. Each device at the receiver side introduces some gain G to the received signal and adds to it some unintentional noise represented by the noise factor F . The noise power at the output of the device is larger than at its input, and becomes now

$$P_N = GFKBT_0$$

where the noise factor can be also expressed as the ratio of input SNR to output SNR

$$F = \frac{(SNR)_{in}}{(SNR)_{out}}$$

The noise factor also determines the minimum signal level at the receiver input, which is required to detect a signal. After substitutions, we obtain the minimum signal level

$$(P_R)_{min} = KTB F (SNR_{out})_{min}$$

where $(SNR_{out})_{min}$ represents the minimum required SNR at the receiver output prior to processing to detect a signal.

1.1.3 Dynamic Range

Another important performance criterion in radar tests is the dynamic range, which gives the range of the signal levels that the radar shall detect. From the radar equation, the received power depends on the Radar Cross Section of the target and the distance of this target from the radar. Closer targets with high RCS are expected to have high power compared to a target with smaller RCS located very far away from the radar. Thus, the power ratio between strong and weak signals may reach up to 90 dB or more, which may degrade the performance of the analog-to-digital converter (ADC) at the receiver if the ADC is not designed properly. For this reason, it is important to include the dynamic range measurement in the radar tests.

The dynamic range (DR) is defined as the ratio between the maximum and minimum possible received power at the receiver

$$DR = (P_R)_{max}[dB] - (P_R)_{min}[dB]$$

1.2 System Overview

The Radar Echo Generator (REG) consists of one R&S®FSW Signal and Spectrum Analyzer and one R&S®SMW200A Vector Signal Generator. The spectrum analyzer is used for down-conversion and digitization of the radar signal transmitted from the Radar Under Test (RUT). It captures the waveform seamlessly and streams the in-phase and quadrature components (I/Q) continuously to the signal generator. The generator is used for signal manipulation and retransmission. An inbuilt REG block in the transmission path manipulates the I/Q data. It simulates the range by introducing delay, the velocity by adding Doppler frequency, and the RCS by attenuating the signal. Finally, the R&S®SMW200A converts the baseband digital signal into a RF analog signal prior retransmission to the RUT. [Figure 1](#) illustrates the components of REG.

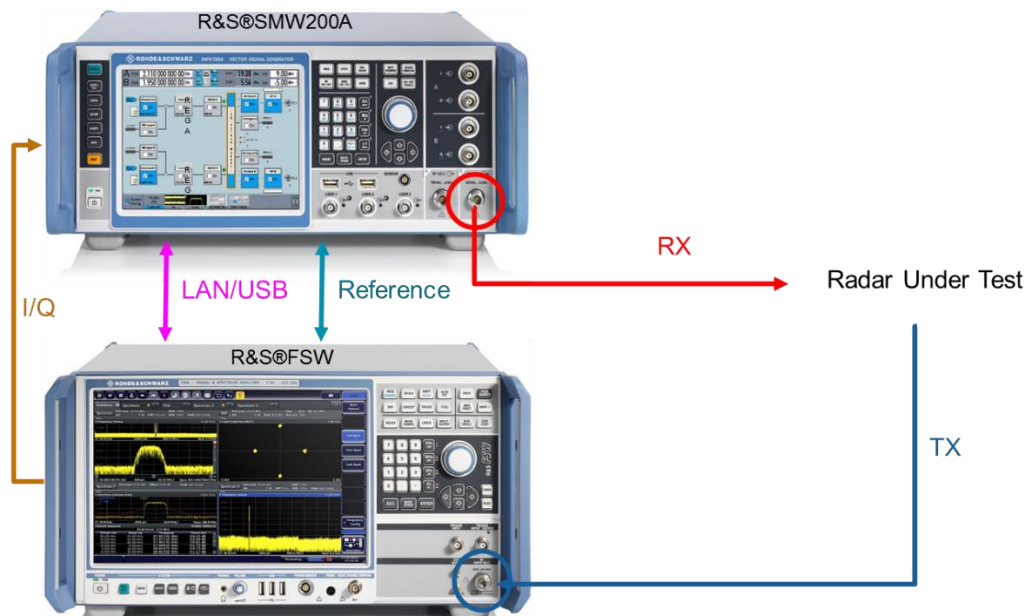


Figure 1 Radar Echo Generator System Overview

[Table 1](#) - [Table 3](#) below show the hardware requirements for the REG operating in frequency bands up to 40 GHz with an instantaneous signal bandwidth of up to 160 MHz. The R&S®SMW-K78 is a software application that adds functionality to generate a single or multiple radar echo signals for radar tests.

R&S®SMW200A
1x R&S®SMW200A Vector Signal Generator
1x Baseband Generator (R&S®SMW-B10)
1x B13 Signal routing and baseband main module, one I/Q path to RF, retrofit in <i>factory only</i> (hardware option) or 1x B13T Signal routing and baseband main module, two I/Q path to RF, retrofit in <i>factory only</i> (hardware option)
1x Frequency (R&S®SMW-B1xx)
1x Fading Simulator (R&S®SMW-B14)
1x Radar Echo Generator (R&S®SMW-K78)

Table 1 Requirements on SMW for generating up to 6 radar echo signals

R&S®FSW
1x R&S®FSW Signal and Spectrum Analyzer
1x R&S®FSW-B17 Digital Baseband Interface
1x R&S®FSW-B160 160 MHz Analysis Bandwidth or any of the options R&S®FSW-B80/-B320/-B500

Table 2 Requirements on FSW

Additional Equipment and cables
One R&S®SMU-Z6 cable for connecting the digital I/Q interfaces of the R&S®SMW and R&S®FSW
Two BNC cables for feeding the external reference frequency and the trigger signal
USB or LAN cable to remotely connect the R&S®SMW and R&S®FSW
Two RF cables (conducted test)
One TX antenna and one RX antenna (OTA test) with corresponding cables
External attenuator to protect the input stage of the R&S®FSW (optional)
Circulator for decoupling the radar transmit and receive signals (conducted test)

Table 3 Cable requirements

1.3 System Setup

The Radar Echo Generation option is the result of combining the R&S®FSW Signal and Spectrum Analyzer and the R&S®SMW200A Vector Signal Generator. It offers three ways to connect these devices: Conducted test, over-the-air (OTA) test or custom test by loading waveforms to the arbitrary generator. In this section, we will consider the first two test methods.

1.3.1 Common Connections

In conducted test and OTA test, we have a common connection setup to ensure that the communication between the R&S®SMW200A and R&S®FSW is working properly. See also [Figure 2](#).

- The power cables of R&S®SMW200A and R&S®FSW have to be connected
- Connect the R&S®FSW 10 MHz Reference Output (REF OUTPUT 10 MHz 10 dBm) to the R&S®SMW200A Reference INPUT (REF IN) using a BNC cable
- Connect the R&S®FSW Digital Baseband Output to the R&S®SMW200A Coder Input (DIG I/Q INOUT) using the R&S®SMU-Z6 cable
- Optional LAN or USB connection for remote control of the analyzer from the R&S®SMW200A
- Optional trigger BNC cable (R&S®SMW200A User 1 Input) to trigger the signal generator for user defined actions

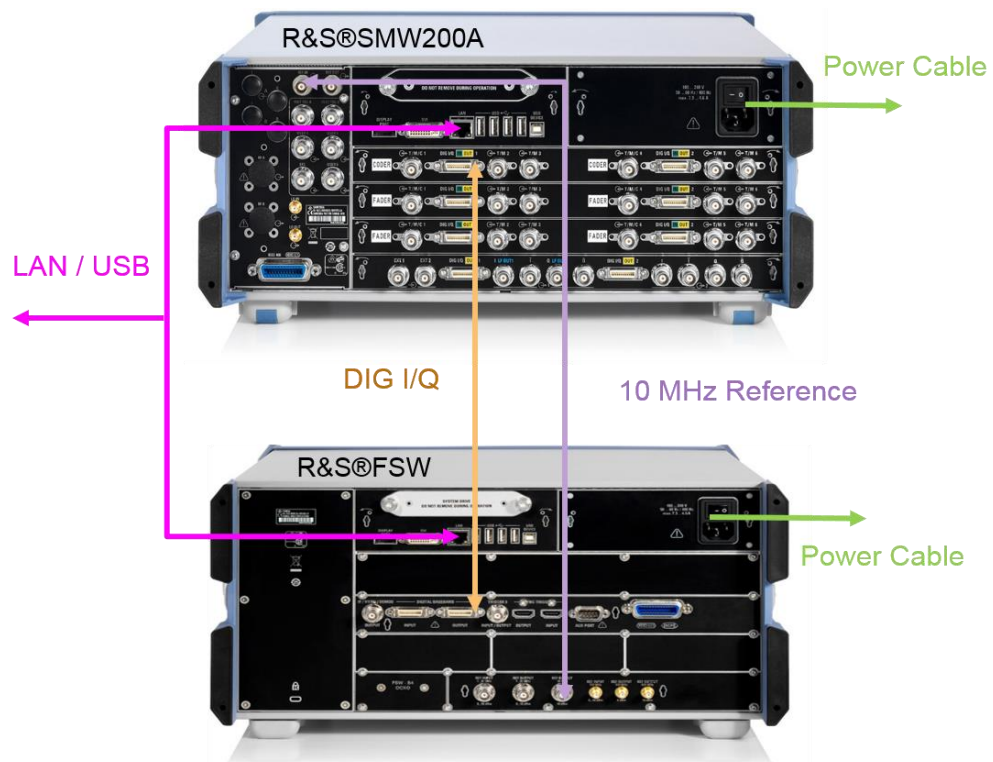


Figure 2 Connecting the SMW and FSW

1.3.2 Conducted Test

In the conducted setup, the RUT and the measuring equipment are connected via RF cables.

- Connect the RUT RF transmitter to the R&S®FSW Signal and Spectrum Analyzer RF Input
- ▶ *NOTE: Use a proper attenuator to limit the input power to maximum of +30 dBm.*

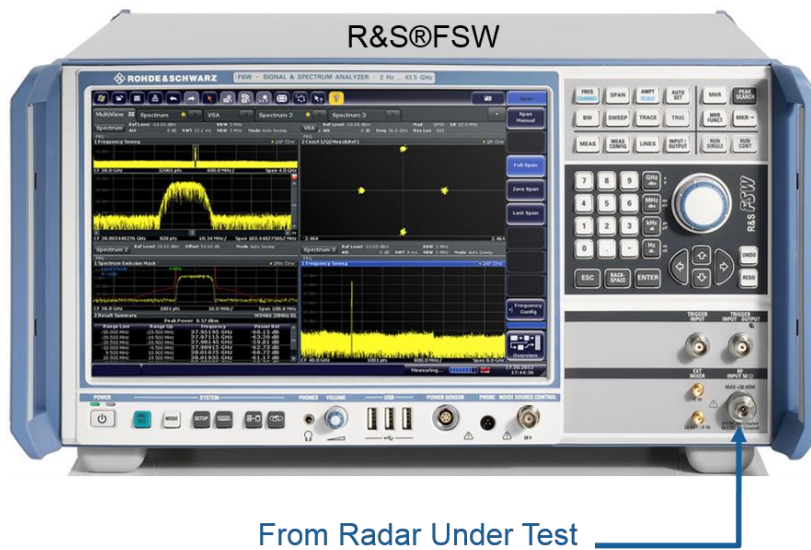


Figure 3 Interface between RUT transmit signal and FSW

- Connect the RUT RF receiver to the R&S®SMW200A Vector Signal Generator RF Output

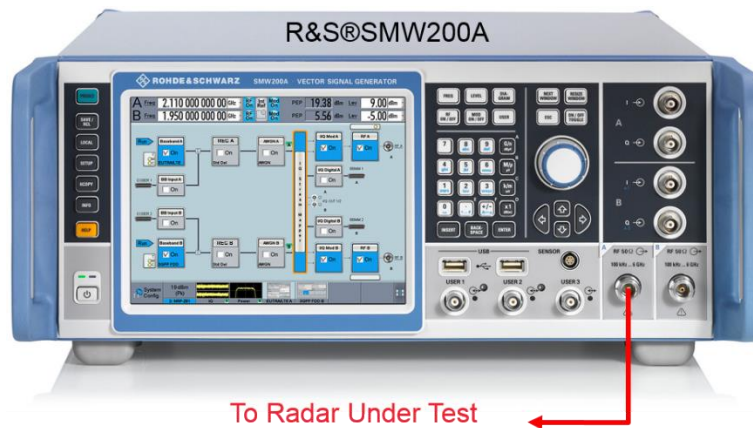


Figure 4 Interface between RUT receive signal and SMW

- To decouple the radar transmit and receive signals, a circulator from a third party can be used between the RUT and the measuring equipment. The complete figure for conducted test with all devices and connections is shown below

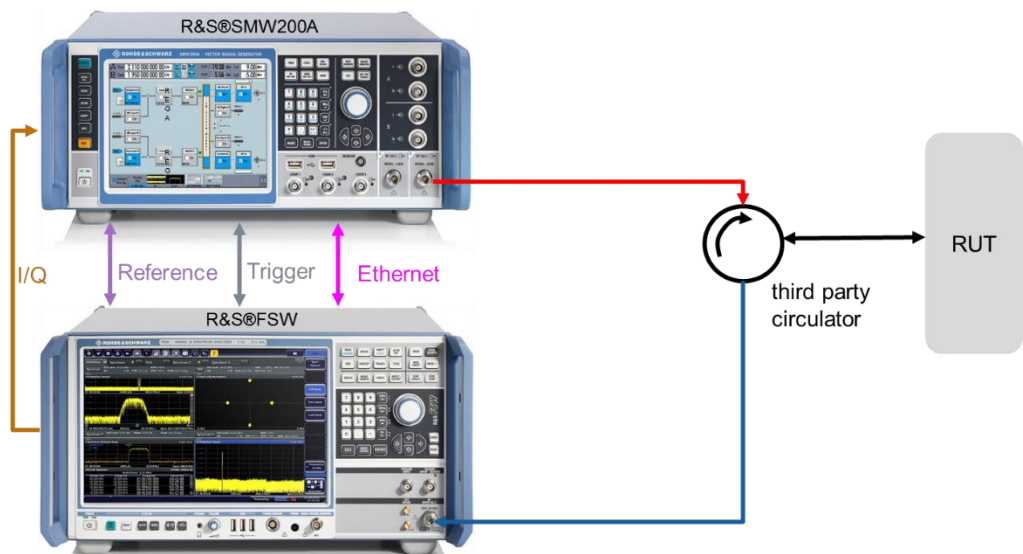


Figure 5 Setup for conducted tests

1.3.3 OTA Test

Alternatively to the conducted test, an OTA test may take place. This is especially beneficial if the RUT and REG are located several meters away from each other or the radar antenna shall not be detached.

To transmit and receive the radar signal, both the RUT and REG are equipped with transmit and receive antennas. We refer to the distance between RUT and REG as OTA Range Offset.

Below, we can see the complete figure for OTA test with all devices and required connections. Basically, it is the same as the conducted test, however the connections between RUT and the measuring equipment is not via cable anymore, but over the air using antennas. Note that we have to add the losses of the cables between the device and the antenna to the total system loss.

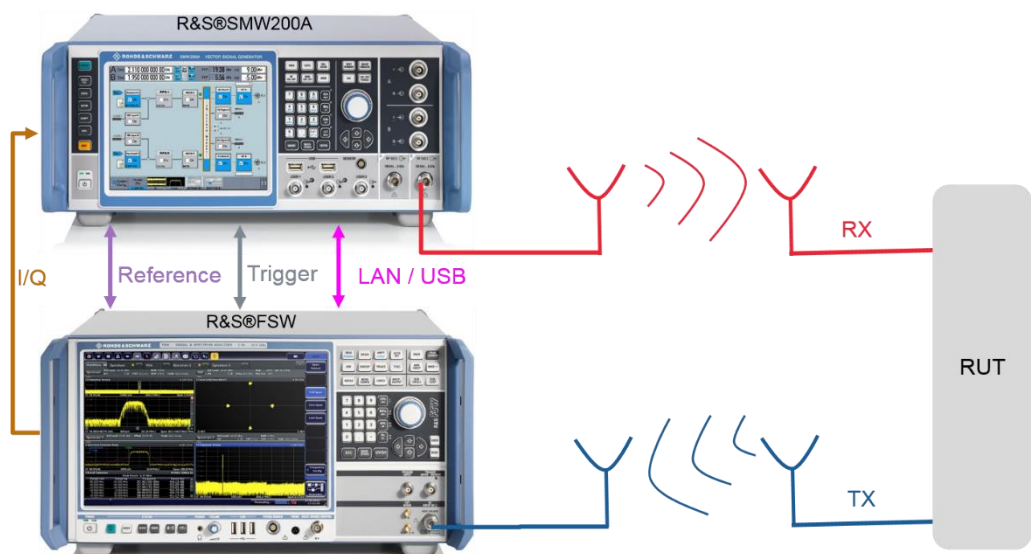


Figure 6 Setup for OTA tests

1.3.4 General Recommendation

Please note some general recommendations that may be considered during measurement setup for achieving better results:

- Use short cables
- Connect all required cables between the REG block and RUT, such as reference frequency, data, trigger and RF signals
- Use a proper attenuator to limit the input power level
- Configure the “System Configuration” settings, in particular the signal routing from the BB IN block to the REG block

1.4 System Settings

In this section, we will explain how to choose the appropriate settings for the measuring equipment for both conducted and OTA Tests.

The measuring equipment operates up to 40 GHz and all radar signals with a signal bandwidth of up to 160 MHz can be tested. For demonstration purposes, we consider a RUT operating at 9.375 GHz.

1.4.1 Signal Generator Settings

Generally, the R&S®SMW200A is able to process more than a single RF channel at the same time. In the following, we illustrate the R&S®SMW200A settings using Channel A.

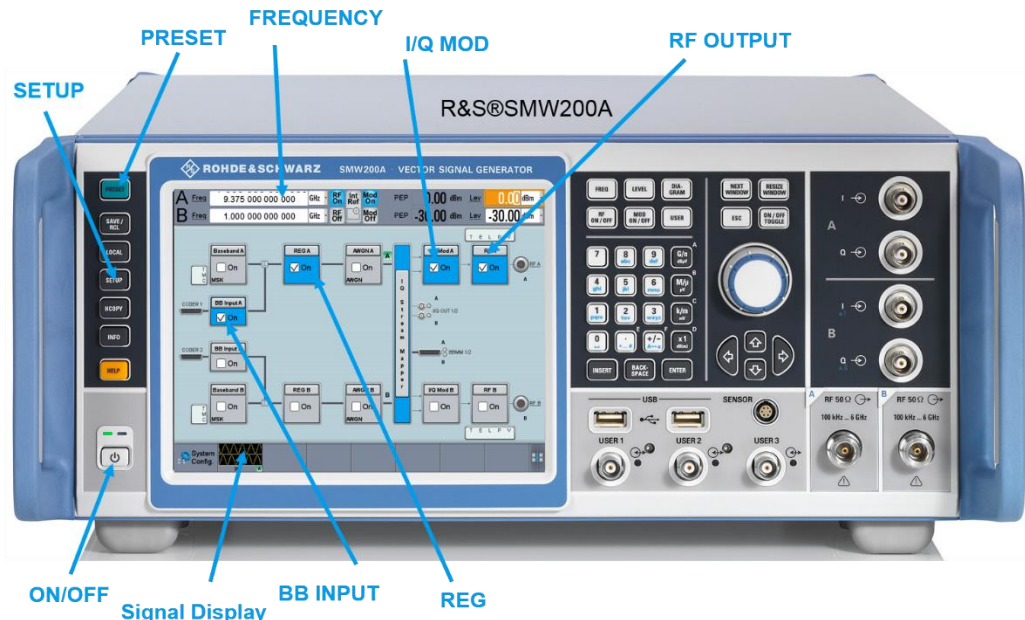


Figure 7 Overview of the SMW buttons

- Switch on the Vector Signal Generator R&S®SMW200A by pushing the ON/OFF button in the down left corner
- Preset R&S®SMW200A by pressing PRESET
- Select the RF frequency to the desired value (in our demonstration we set frequency to 9.375 GHz)
- Check for an external 10 MHz reference signal by pressing the SETUP button. Choose Reference Freq / LO Coupling, set Source → External, and External Reference Frequency → 10 MHz (Figure 8)

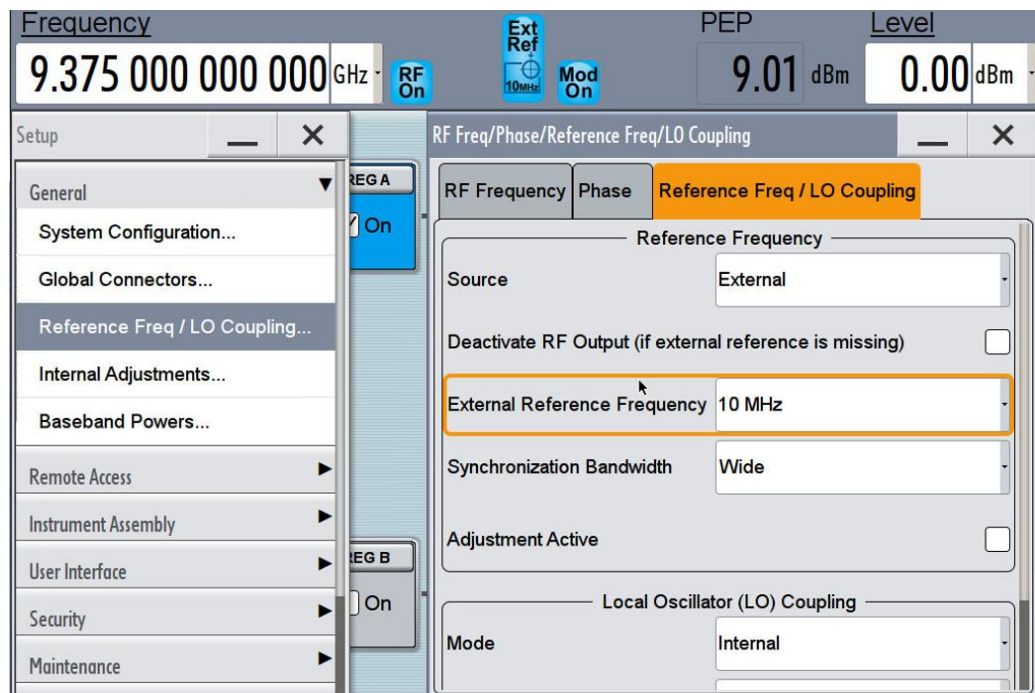


Figure 8 Setting the reference frequency to external 10 MHz

Enable the Radar Echo Generator Figure 9 in the R&S®SMW200A,

- Go to SETUP → System Configuration → Fading / Baseband Configuration → Mode and choose Radar Echo Generation.
- Press APPLY and OK

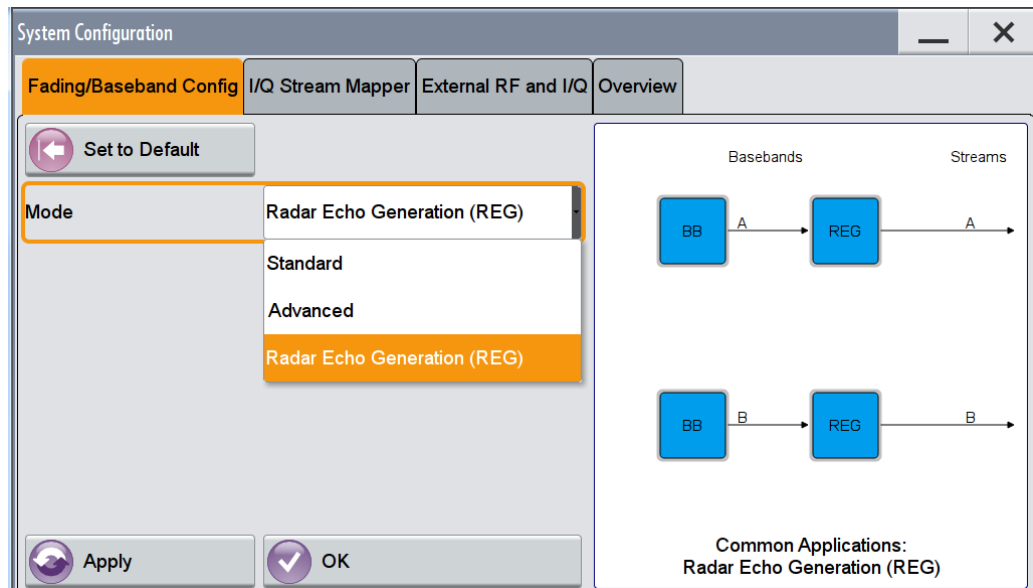


Figure 9 System Configuration

The Digital IQ, frequency and level settings of the R&S®FSW can be fully remote controlled by the R&S®SMW200A signal generator. Ensure that the R&S®FSW Signal and Spectrum Analyser is switched on and all cables are connected to the R&S®SMW as described above.

In the SMW screen, click on the REG block then choose System Configuration and move to the tab “External RF and I/Q” as depicted in Figure 10. A table is opened with the corresponding available interfaces. In our demonstration for example, the interface CODER 1 is used for connecting the FSW to the SMW.

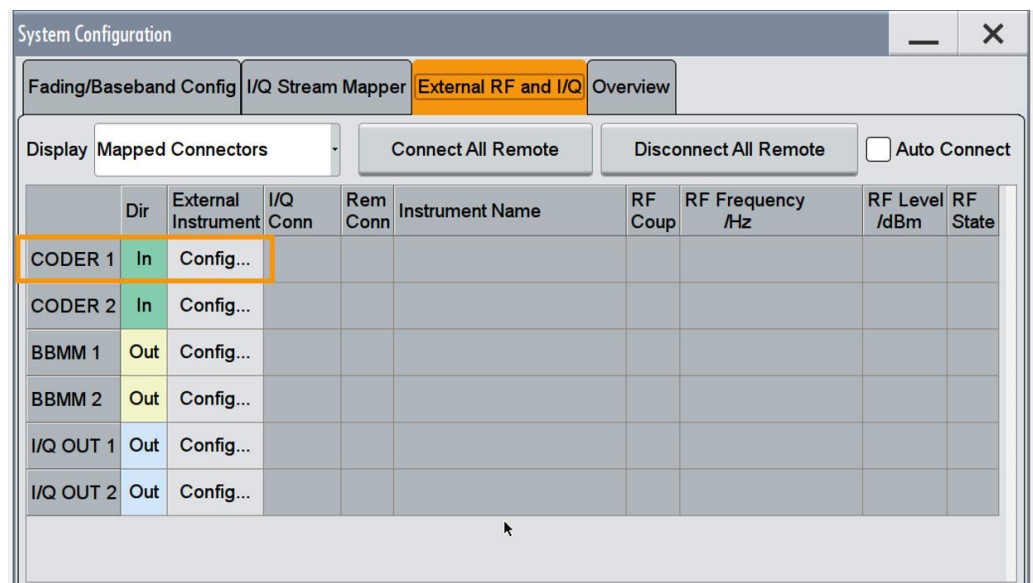


Figure 10 Configuring the remote access of FSW from SMW

After clicking on “CONFIG”, a new window is opened for external instrument configuration (Figure 11). By clicking on SCAN, the SMW scans the network for all instruments connected to it. Choose the appropriate one from the button “External Instrument”, then click on Apply and Connect. If the remote connection was successful, you can see a blue circle and the name of the FSW detected in the tab “External RF and I/Q” as illustrated in Figure 12.

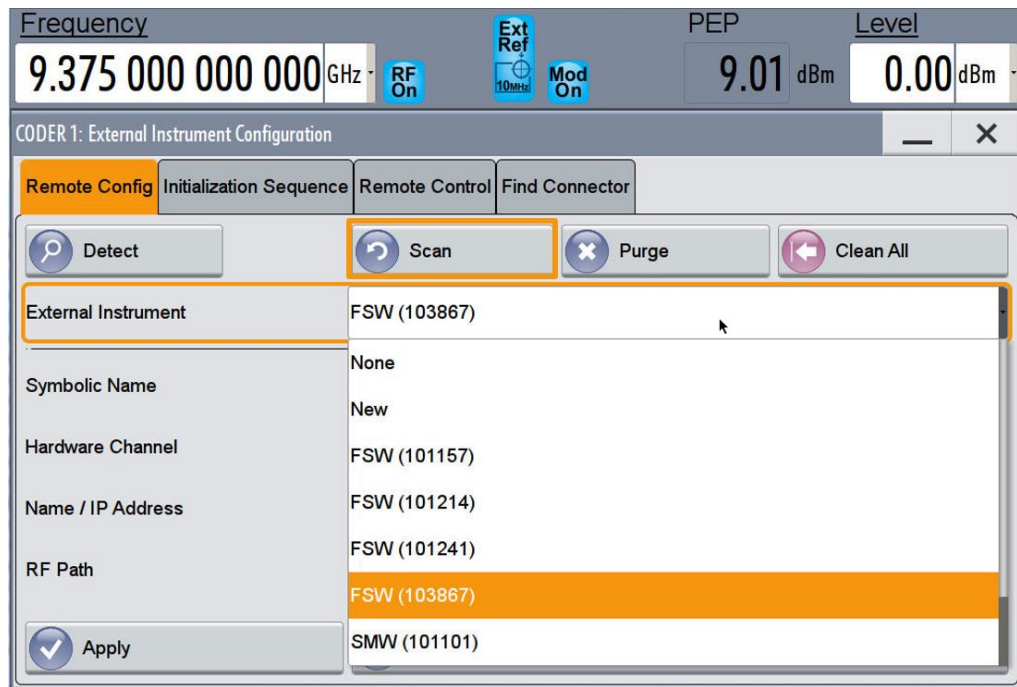


Figure 11 Choose the corresponding FSW connected to the SMW

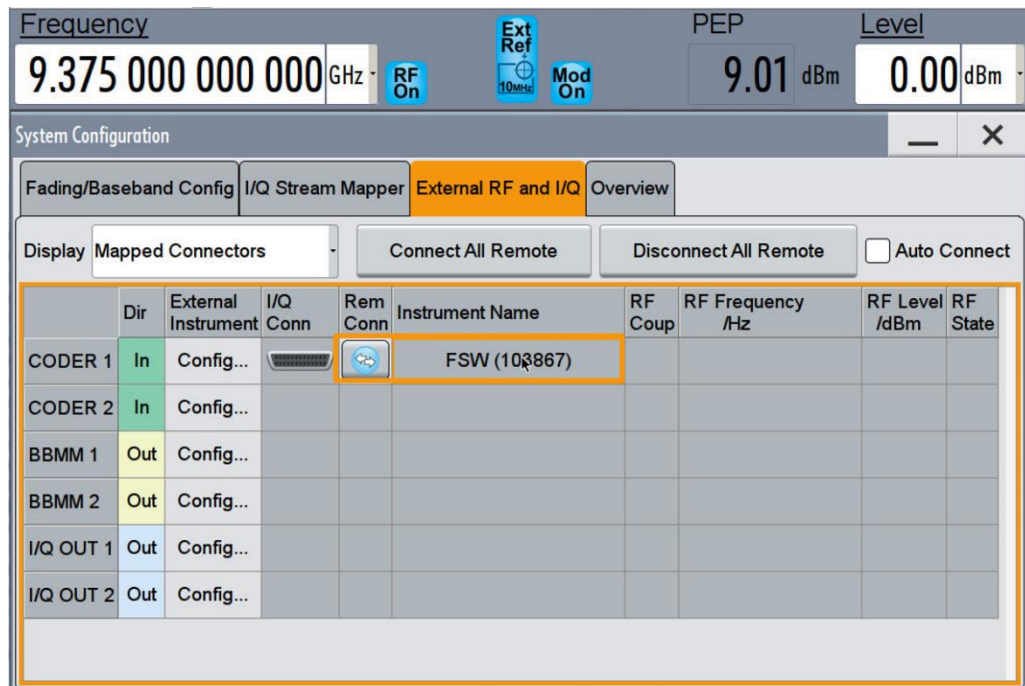


Figure 12 Confirmation of the Remote Connect

The remote control of the FSW from the SMW allows the user to control the FSW settings from the SMW. For example, the sample rate, carrier frequency and reference signal level can be adjusted directly in the SMW. Please see section 1.5 for more information.

- Note that this procedure has to be done every time the equipment is booted. To avoid this activate the option "Auto Connect" on the upper right side of Figure 12.

1.5 Configuration of the Radar Echo Generator

The REG block was already introduced in the previous sections. In this section, the configuration of the Radar Echo Generator is considered, i.e. how to manipulate the radar signal by introducing delay, radial velocity and RCS.

The Radar Echo Generator settings are grouped into several tabs. The "Radar Setup" tab comprises the settings of the setup, such as the settings for conducted or OTA test.

The "Simulation Setup" tab is used for calibration purposes.

In the "Object Configuration" tab, static or moving objects can be defined.

The last tab "Object Preview" visualizes the defined targets in a two dimensional plot. Below, we elaborate the configuration of these tabs.

1.5.1 Radar Setup

In the Radar Setup tab shown in Figure 13, we have the option to choose between conducted test and OTA test, and adjust the corresponding parameters.

- Enable the Radar Echo Generator

- In the Test Setup field, choose either Conducted Test or OTA Test. On the right half side of the screen, we can set values for P_T , G_T , G_R and system loss
- ▶ For OTA Test, we can choose values for the additional antennas required. The OTA Range Offset must be also configured
- Choose an appropriate external attenuator if required in the field “Ext. Attenuator”
- In the field Radar Rx power setting, we have the option to choose between “Radar Equation” and “Manual”, i.e. the leveling of the echoes is done either manually or by using the radar equation
- Press the button “Set Ref. Level on Analyzer”. In this case, the external attenuator and Radar TX power set the maximum input power on FSW for manual echo leveling, i.e. the leveling in this case depends only on these two parameters. If "Radar Equation" is chosen, the leveling of the FSW is determined by the radar equation as in section 1.1.1, i.e. the power level is updated automatically if the parameters of the radar equation change

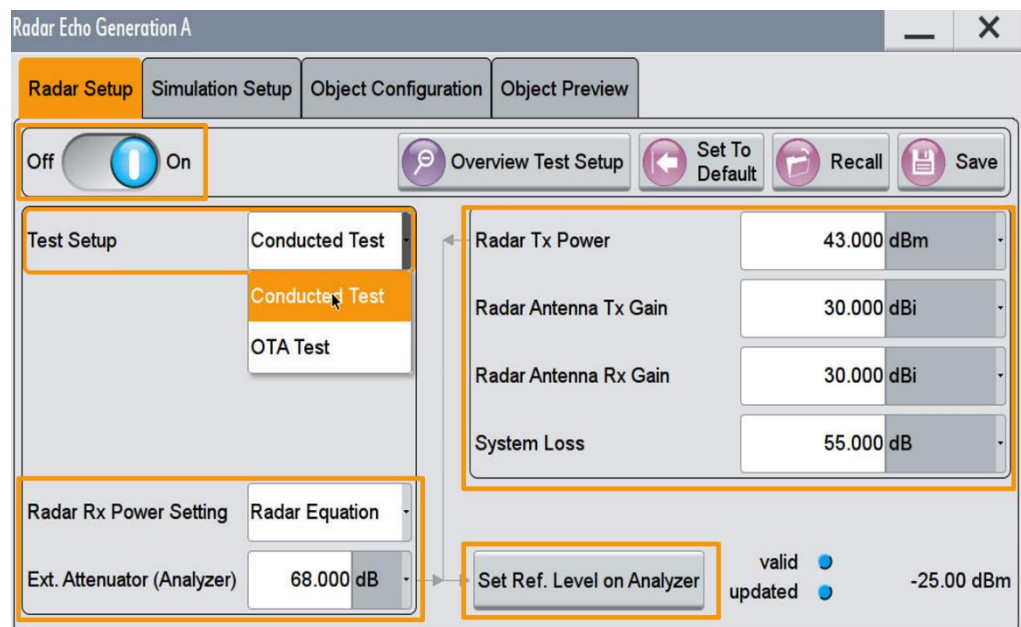


Figure 13 Radar Setup window

- ▶ Please note: Blue LEDs on the GUI display that the value has been remotely set to the FSW.

1.5.2 Simulation Setup

The Simulation Setup tab shown in Figure 14 allows the user to determine how the system latency is estimated. The value of the system latency corresponds to the processing time of the REG. Please check, in this case, if the R&S@FSW and R&S@SMW200A are connected properly as described in section 1.3. The latency can be estimated e.g. manually by setting the option System Latency Calibration to “Manual”. In this case, the blind zone value is set manually.

The blind zone is determined by the processing time in the Radar Echo Generator from the input of the FSW to the RF output at the SMW. In our setup, a system latency of 11.11 μ s was measured corresponding to approximately 0.9 NM (Nautical Mile). Note that this value is not fixed, but is determined by the configuration of the R&S@SMW200A.

In case of manual calibration, the system latency can be measured for example by deactivating the REG block in the SMW. The radar considers only the internal delay of the system setup, and shows the estimated value on the radar display in range. For future release, latency calibration will be estimated automatically.

Another way to calibrate the Radar Echo Generator is via delay measurement using an oscilloscope, as explained in section 1.6 in detail.

The simulation Setup tab provides additional two options for remote control of the FSW from the SMW:

The button “Set Frequency on Analyzer” for example allows the SMW to set the desired frequency directly on the analyzer as indicated in the field “Dedicated Frequency”. In our case, the dedicated frequency is 9.375 GHz.

Another button “Adjust dedicated level” sets the power level value on the SMW to the corresponding value, for which the RUT receives the Radar RX power as it is calculated with the Radar Equation. In other words, after adding the loss between SMW and RUT to the power level at the RF output of the SMW, we should obtain the same received power as computed by the radar equation.

- *Note: The I/Q interface between R&S@FSW and R&S@SMW200A is synchronized as soon as the BB INPUT is switched on*

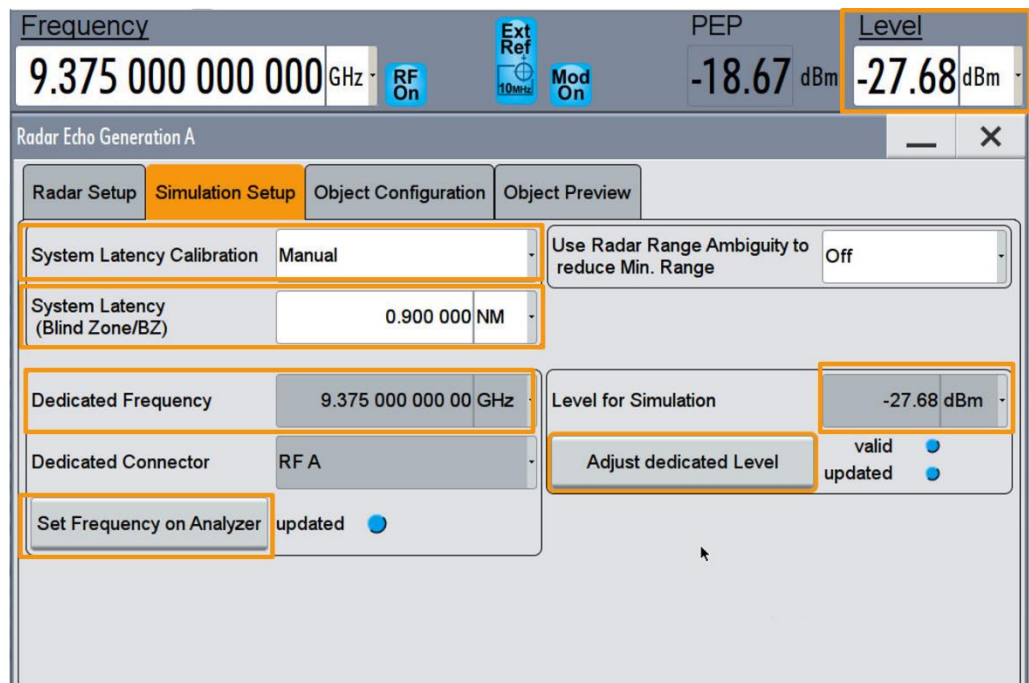


Figure 14 Simulation Setup window

1.5.3 Object Configuration

In the Object Configuration tab as depicted in [Figure 15](#), the user can configure up to 24 target objects depending on the configuration of the SMW, store their configuration into files and load these files for quick setup later.

- Add a new target object and give it a name. Select the Object Type. Three options are available: Static, Moving or Static + Moving

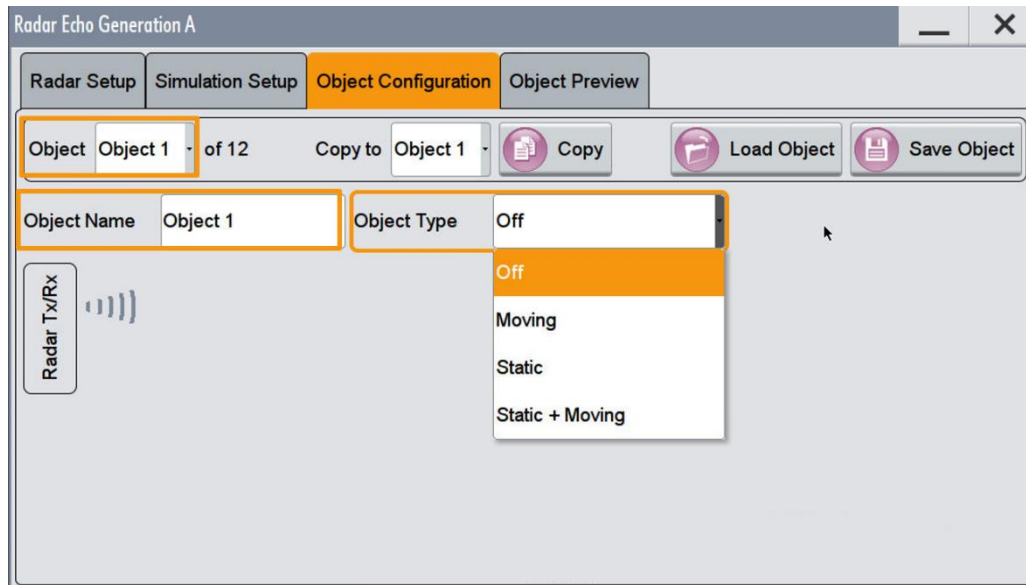


Figure 15 Creating a radar target

- *Static Object:*

Object Type → *Static*, set a possible value for the object range, for example, *Range* → 2 NM.

Additionally, a value for the object RCS can be chosen by clicking on the blue RCS circle (see [Figure 16](#))

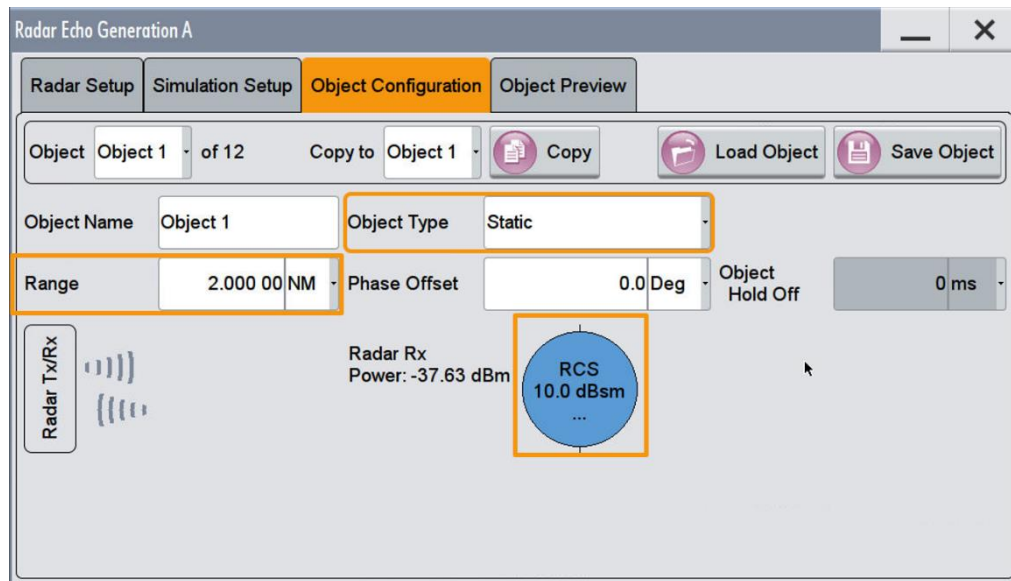


Figure 16 Creating a static target

► *Moving Object:*

Object Type → *Moving*, and set a possible value for the object start and end range, for example, *Start Range* → 6 NM and *End Range* → 2.5 NM. Moreover, we have to choose an appropriate value for the radial velocity of the object, for example 100 m/s. In this configuration, we assume that the moving object is approaching the radar.

Additionally, a value for the object RCS can be chosen by clicking on the RCS button (see Figure 17)

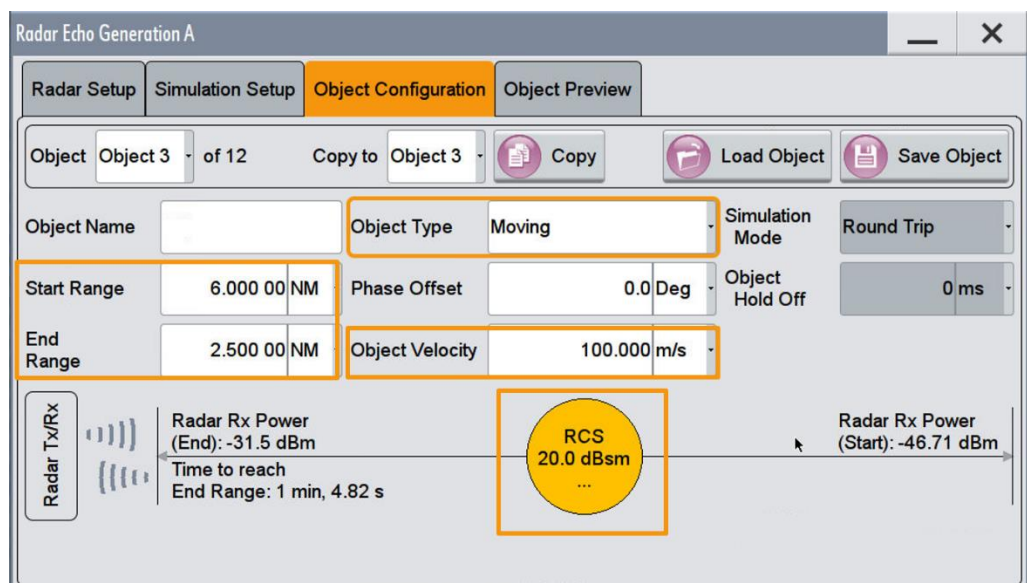


Figure 17 Creating a moving target

- To set the value of the RCS, we have the option to choose the “Swerling 0” Model. The RCS value can be given in *sm* (square meter) or *dBsm* (dB square meter)

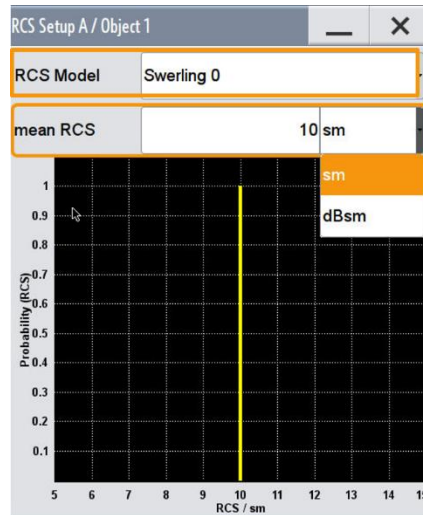


Figure 18 Choosing a value for the RCS

1.5.4 Object Preview

The last tab “Object Preview” in Figure 19 visualizes the defined targets in a two dimensional plot, where the x-axis is represented by the range and the y-axis represents either velocity or received power.

In our example, we defined three objects, two static objects at 2 NM and 2.2 NM, and one moving target in a round trip mode from 6 NM to 2.5 NM with 100 m/s radial velocity. The colors in the plot correspond to the colors in the object configuration.

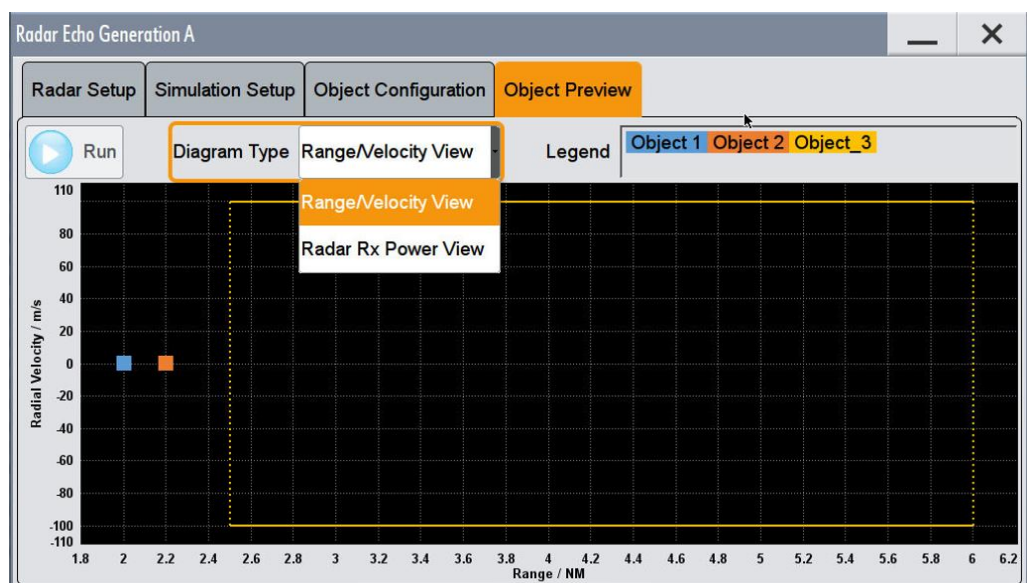


Figure 19 Object Preview Window

When all settings are setup properly, close the Radar Echo Generator tab and enable the RF.

1.5.5 REG Configuration Summary

- In the R&S®SMW200A, enable the REG (go to SETUP → System Configuration → Fading / Baseband Configuration → Mode and choose Radar Echo Generation. Press APPLY and click on OK)
- Set the R&S®SMW200A External Reference to 10 MHz external
- Configure the remote access of the R&S®FSW from the R&S®SMW200A
- Configure the taps “Radar Setup”, “Simulation Setup”, “Object Configuration” as described above
- Enable the RF
- Set the leveling and calibration according to sections [1.5.1](#) and [1.5.2](#)

1.6 System Latency Calibration

For accurate radar measurements, the delay through the instruments has to be measured.

In section [1.5.2](#), two ways were mentioned to calibrate the REG and to estimate the system latency. The first one estimates the delay using a PPI radar display by switching off the REG block, whereas the second way uses an oscilloscope to measure the time difference between the generated and processed signal. In this section, we explain the second method to estimate the signal processing delay as depicted in [Figure 20](#) in detail.

For simplicity of the setup, an internal arbitrary signal, e.g. a pulse signal, is generated in the SMW, whose output is connected to a power divider. The signal is split into two paths, one is directly fed to one of the input ports of the R&S®RTO, and the other path is connected to the FSW. The FSW performs digitization and provides the SMW with the I/Q data. The SMW transforms the baseband signal to the RF domain again and forwards the signal to the second input port of the RTO. At this stage, the RTO measures the time difference between the signals at its two input ports and estimates the minimum range that can be simulated using the Radar Echo Generator.

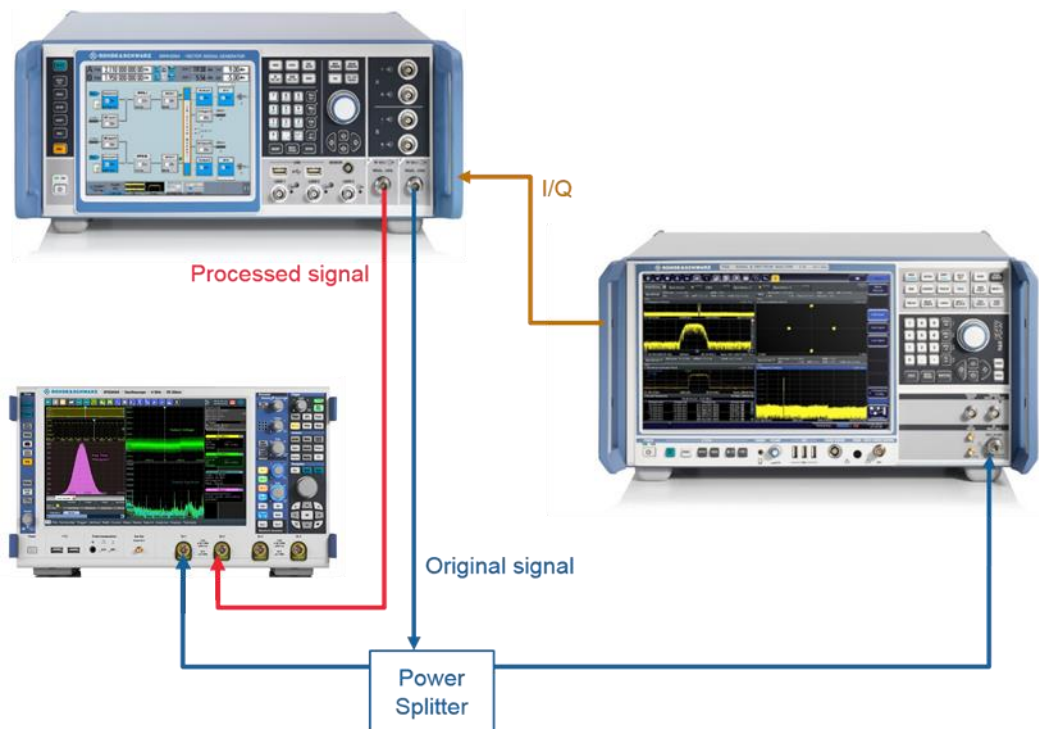


Figure 20 Signal processing delay calibration using RTO

- ▶ Configuration of the SMW and FSW should be done as described in section 1.4
- ▶ To measure the signal processing delay, the REG block in the SMW has to be deactivated. This ensures that the system delay is only due to the internal processing in the equipment
- ▶ The frequency of the signal generator and analyzer has to fit into the frequency measurement range of the oscilloscope (e.g. 1 GHz)

The RTO delay measurement functionality is used. As a measurement basis a math function is set for determining the envelope signal for both signals. The delay between the two signals is then measured automatically including statistical parameters, like mean and standard deviation of the delay.

For the measurement, use the "Measurement Tool" and draw an area around the two pulses.

The measured time delay was 12.487 μs as shown in the Figure below in this setup.

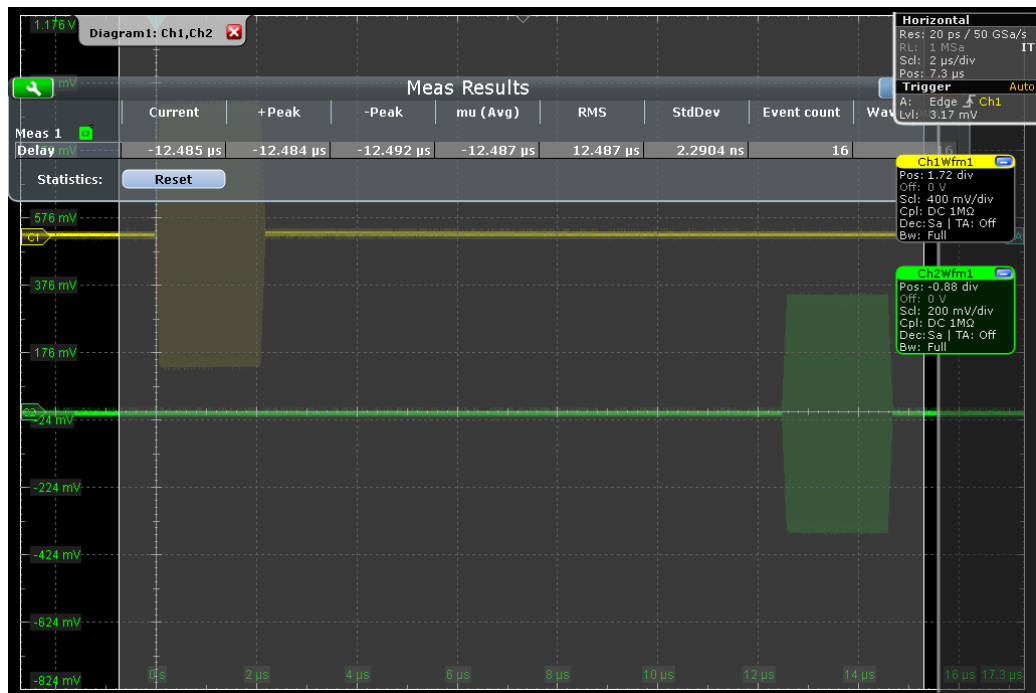


Figure 21 Internal Delay Measurement

- Please note, the I/Q interface between SMW and FSW is synchronized as soon as the BB INPUT is switched on. Due to the synchronization process it may happen that the static time delay is different from the above estimated value. It is therefore necessary to be (re)measured everytime the digital interface is switched on.

2 Radar Tests

Several radar tests can be mapped from the field to the lab. The entire radar system can be tested, including the antenna, transmitter, receiver, filter, base band signal processing and other components. In case the test setup should operate in an automated environment, all tests could be also performed automatically by using remote commands.

In this section, we apply some tests and considering several scenarios with a state of the art maritime X-Band Radar as a RUT.

We initially start with the generation of a single echo and consider both static and moving target objects individually. Subsequently, we move to the case of multiple targets. This test also investigates the scenario, where the targets may be static and/or moving. Finally, we conduct tests to measure the minimum detectable signal and the dynamic range of the RUT.

To evaluate the performance, the RUT is connected to a radar display as discussed in section 2.1.2, e.g. a PPI radar display. The PPI display has a circle shape with the radar located at its center. It shows the detected targets on the screen based on their range and velocity information. The azimuth angle 0° corresponds to the North Pole, and the South Pole corresponds to 180° .

The tests explained below are just examples. The system is not limited to these tests. Due to several available basebands in the signal generator one is for example able to perform also co-existence tests. At this point, however, it is just referred to the R&S Pulse Sequencer Software [5], which allows to generate and replay arbitrary RF environments [Figure 22](#).



Figure 22 Pulse Sequencer to generate arbitrary RF environments

The radar performance is measured and evaluated based on ADC data and displayed on a PPI radar display. The ADC data is captured and displayed using MATLAB®. [Figure 23](#) shows an example of PPI radar display without displaying any targets.

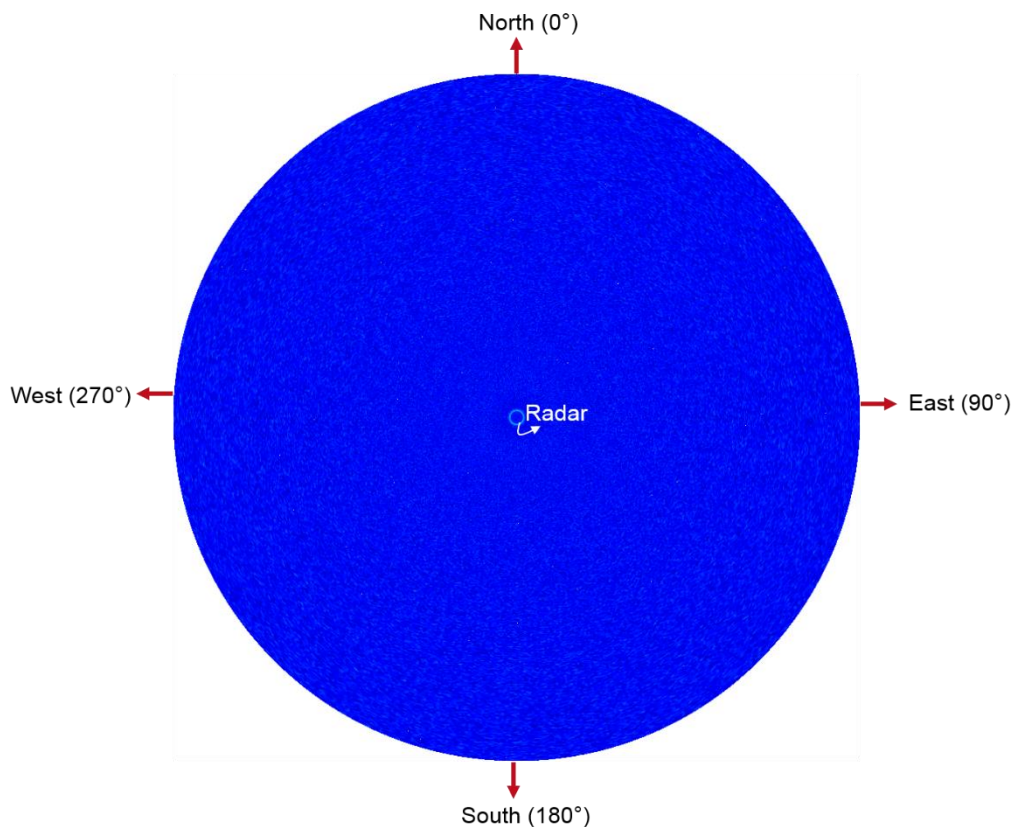


Figure 23 PPI radar display

2.1 Single Echo Generation

In the single echo generation test, we consider a single target object to be detected. This target may be either a static or moving object. Both cases are considered below, where we assume that a conducted test is used to connect the RUT to the Radar Echo Generator setup.

2.1.1 Static target

For the single static target scenario, we set the range to 2 NM and RCS to 20 dBsm. As discussed in section 1.5, in the Radar Setup tab, we select Conducted Test, and in the Object Configuration tab, we choose Object Type → Static, set the Range → 2 NM and RCS → 20 dBsm. In the Simulation Setup tab, we set the value for the system latency of the Radar Echo Generator accordingly.

Object Configuration

- Object Type: Static
- Range: 2 NM
- RCS: 20 dBsm

The PPI radar display in [Figure 24](#) shows the static target as a circle around the radar with radius given by the estimated range. The radar is located at the center of the circle. The estimated range is 2 NM confirming that the radar estimated the range of the target exactly. The circle shape means that the target is measured under every azimuth angle.

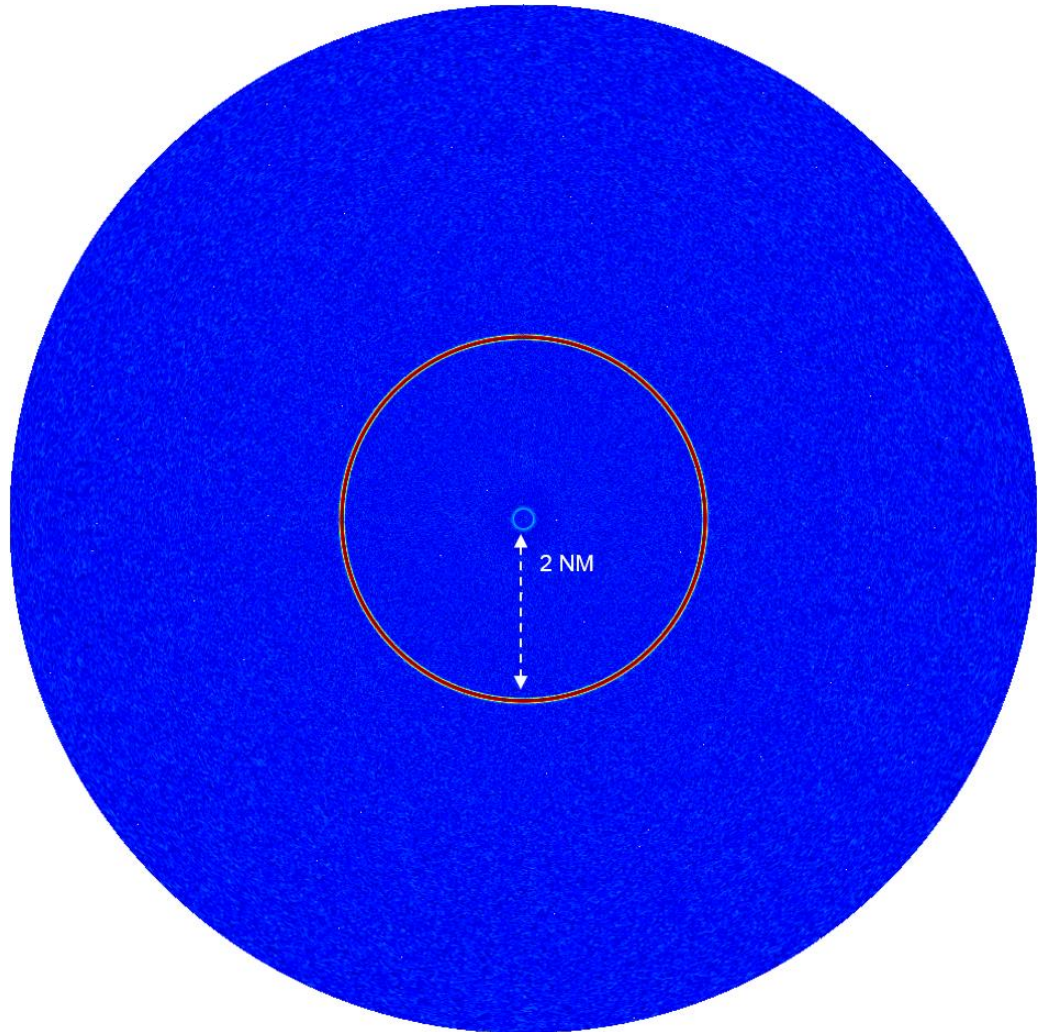


Figure 24 PPI for a static target without "Azimuth Simulation"

2.1.2 Azimuth Angle

The direction of the target is not defined yet, and the PPI display shows a circle around the radar position, indicating that the target is at all angles as shown in the figure above.

One option to solve this problem is to use an OTA radar setup, where the angle is determined by the appropriately choosing the direction of transmit and receive antenna patterns.

Another way is to use Pulse Modulation (PM) of the SMW at the RF output by varying the width and offset of its individual pulses. This is for example beneficial in a conducted radar test. The RF output signal is now only transmitted during the active state of the pulse modulator, otherwise no power is transmitted. The offset of the PM determines the angle of the target, while the width is related to the size of the target to be displayed on the radar display. Besides pulse width and pulse offset, we have to define the pulse period. Here, we have two possibilities: Either the pulse period is set manually by choosing “Auto” in the Trigger Mode or it is determined directly from the radar trigger signal by selecting “Ext Single” in the Trigger Mode. The trigger signal has to be supplied by RUT.

- In the RF block in the R&S@SMW200A Vector Signal Generator select Pulse Modulation, [Figure 25](#)

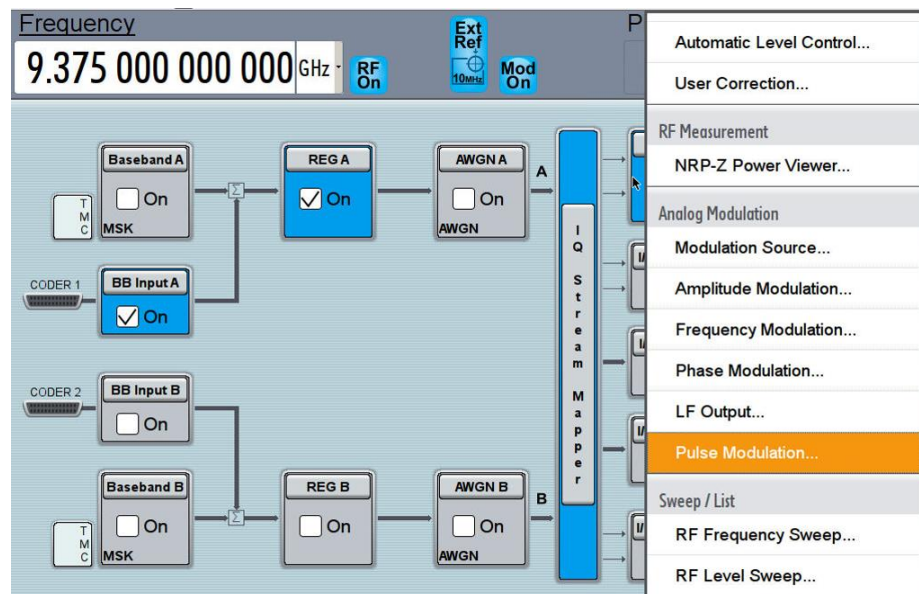


Figure 25 Select Pulse Modulation from the RF Output block

- In the Pulse Modulation tab switch on the PM by going to STATE → ON. In this tab, the user can also define the Threshold Pulse Input and set the Global Connectors for PM, [Figure 26](#)

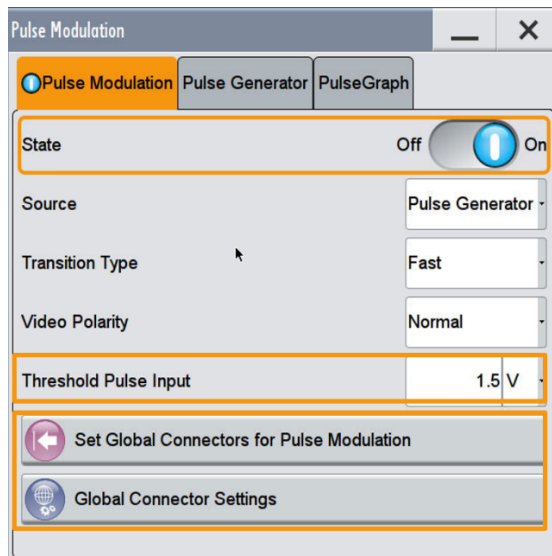


Figure 26 Turn on the Pulse Modulator

-
- The Pulse Generator tab allows the users to define the PM parameters, such as Pulse Period, Pulse Width and Pulse Delay (Offset). Additionally, we may choose between Auto or external Trigger Mode, [Figure 27](#)

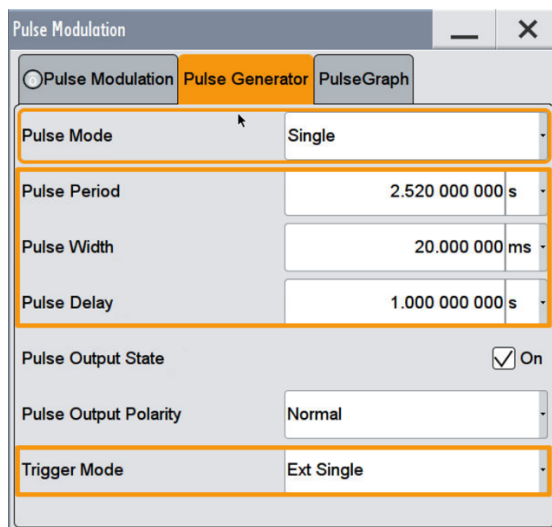


Figure 27 Choose the Pulse Modulation parameters

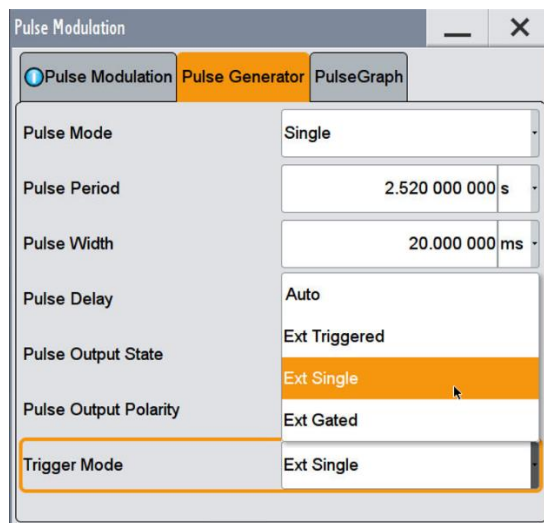


Figure 28 Option for an external triggering of the Pulse Modulator

- ▶ External Trigger Mode:
- ▶ Go to Trigger Mode → Ext Single, [Figure 28](#)
- ▶ In this case, the pulse period is directly synchronized from the radar trigger signal. Radars usually offers this option. To enable triggering from the radar reference signal, we have to assign a BNC Input to the trigger. To accomplish this, press the button "Set Global Connectors for Pulse Modulation" and then on the button "Global Connector settings".
- ▶ This will open a window on the right side of the screen. In our example, User 4 is defined to be the interface for the radar trigger signal. The trigger signal coming from the radar is connected to User 4 of the R&S®SMW Vector Signal Generator to trigger the Pulse Modulator, [Figure 29](#).
- ▶ The corresponding User 4 BNC Input is shown in [Figure 30](#). The Radar Trigger Signal has to be provided to this Input.

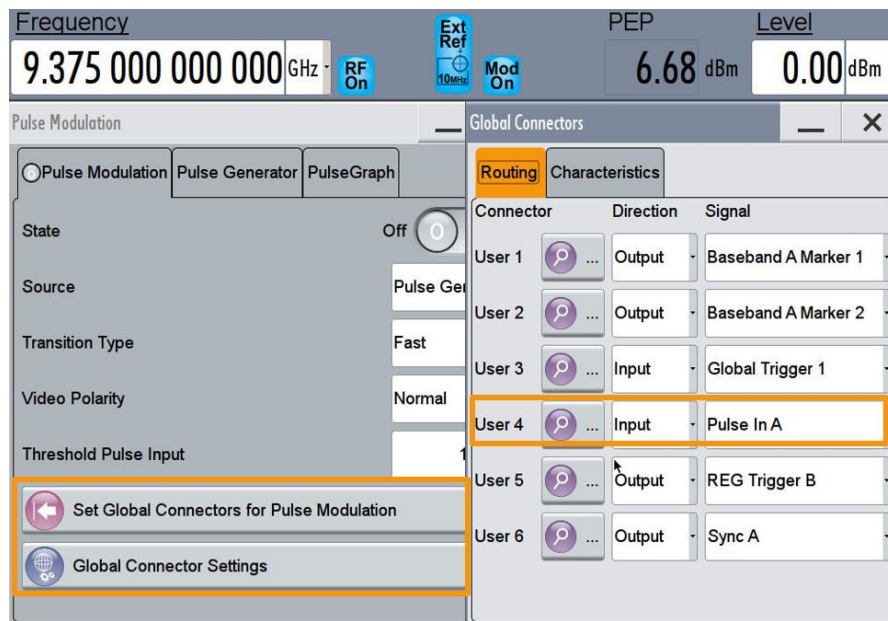


Figure 29 Choose the appropriate interface at the SMW for external triggering



Figure 30 Interface between SMW and trigger signal

Please note that in our demonstration an external trigger signal is assumed.

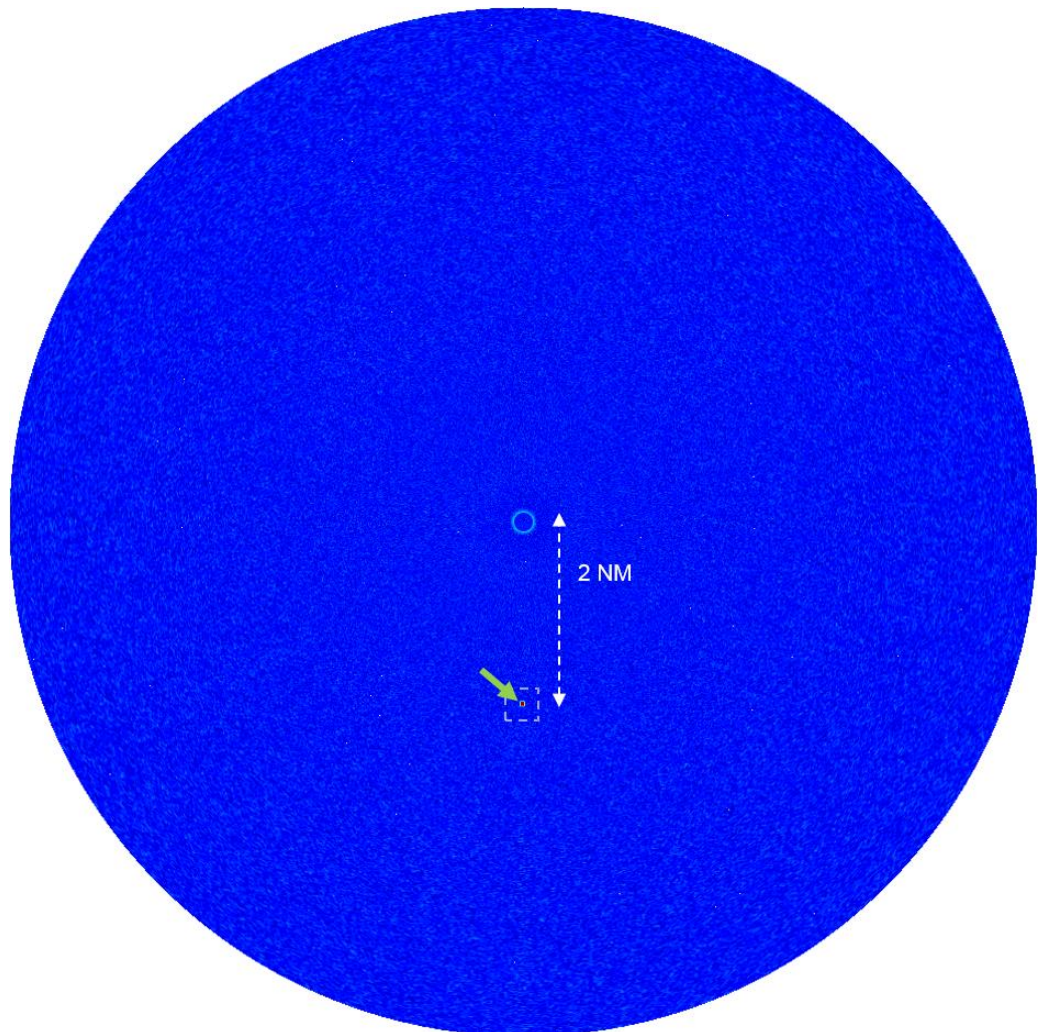


Figure 31 PPI for a static target with PM

In [Figure 31](#), after turning on the PM, the target is not a circle anymore, but is now displayed as a small arc at 180° angle.

The size of the arc is related to the pulse width of the PM. The dashed white box in the figure is drawn to indicate the position of the target, which is located in the center of the box. The green arrow is directed towards the position of the static target.

Please note that if we modify the pulse offset, the position of the target will change. [Figure 32](#) depicts the same target as before, but now we set the pulse offset to one fourth of the trigger period and the pulse width to 50 ms. The direction of the static target has changed now, and also the size of the arc is larger.

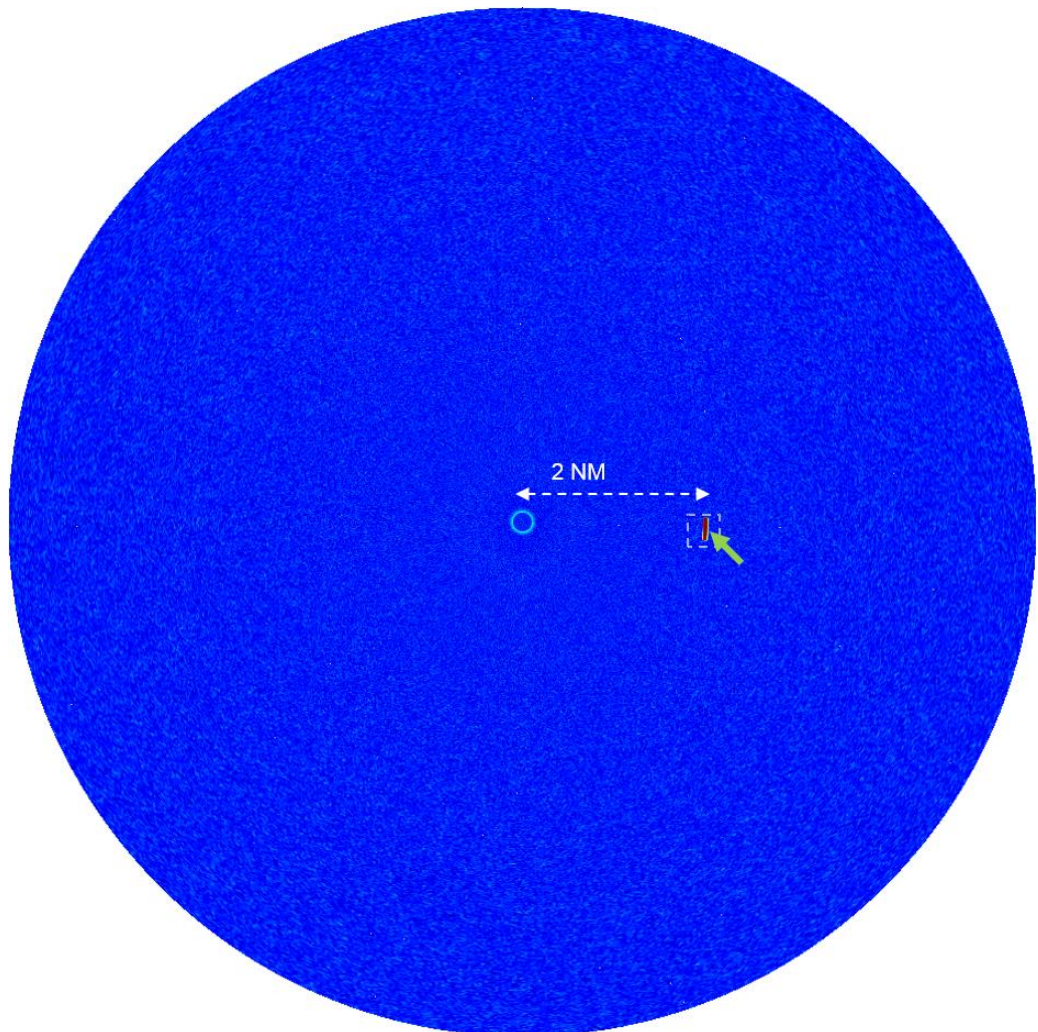


Figure 32 PPI for a static target without PM and modified pulse width and offset

2.1.3 Moving target

A moving target from 6 NM to 2.5 NM with velocity 100 m/s and RCS 20 dBsm is now considered. As discussed in section 1.5, in the Radar setup tab, we select Conducted Test, and in the Object Configuration tab, we choose Object Type → Moving, set the Start Range → 6 NM, End Range → 2.5 NM, Object Velocity → 100 m/s and RCS → 20 dBsm. In the Simulation Setup tab, we set the value for the system latency of the Radar Echo Generator accordingly.

Object Configuration

- Object Type: Moving
 - Start Range: 6 NM
 - End Range: 2.5 NM
 - Velocity: 100 m/s
 - RCS: 20 dBsm

The PPI radar display shows the target as a moving circle around the radar starting from 6.2 NM to 2.5 NM estimated range. The estimated range coincides very well with the initial setting of the REG confirming that the radar estimated the range and velocity of the target exactly.

To fix the angle, we enable as before the PM, set the pulse width to 10 ms and the pulse offset to half of the period of the trigger signal. Note that in our demonstration we assume external trigger signal as illustrated in section 2.1.2.

After turning on the PM, the target is not a circle anymore, but is now a small arc at 180° angle and the target object moves from 6 NM to 2.5 NM, Figure 33. The time it takes the target to reach 2.5 NM can be calculated from its velocity and the distance between the starting and end range. In the above case, it takes $T_p = 64.42$ seconds. At $t = 0$ seconds, the moving object is at 6 NM corresponding to the start range, and after $T_p/3$ the range is at 4.83 NM. Finally, the moving target reaches its destination after 64.42 seconds and has a range of 2.5 NM. The red arrow is directed towards the position of the moving target.

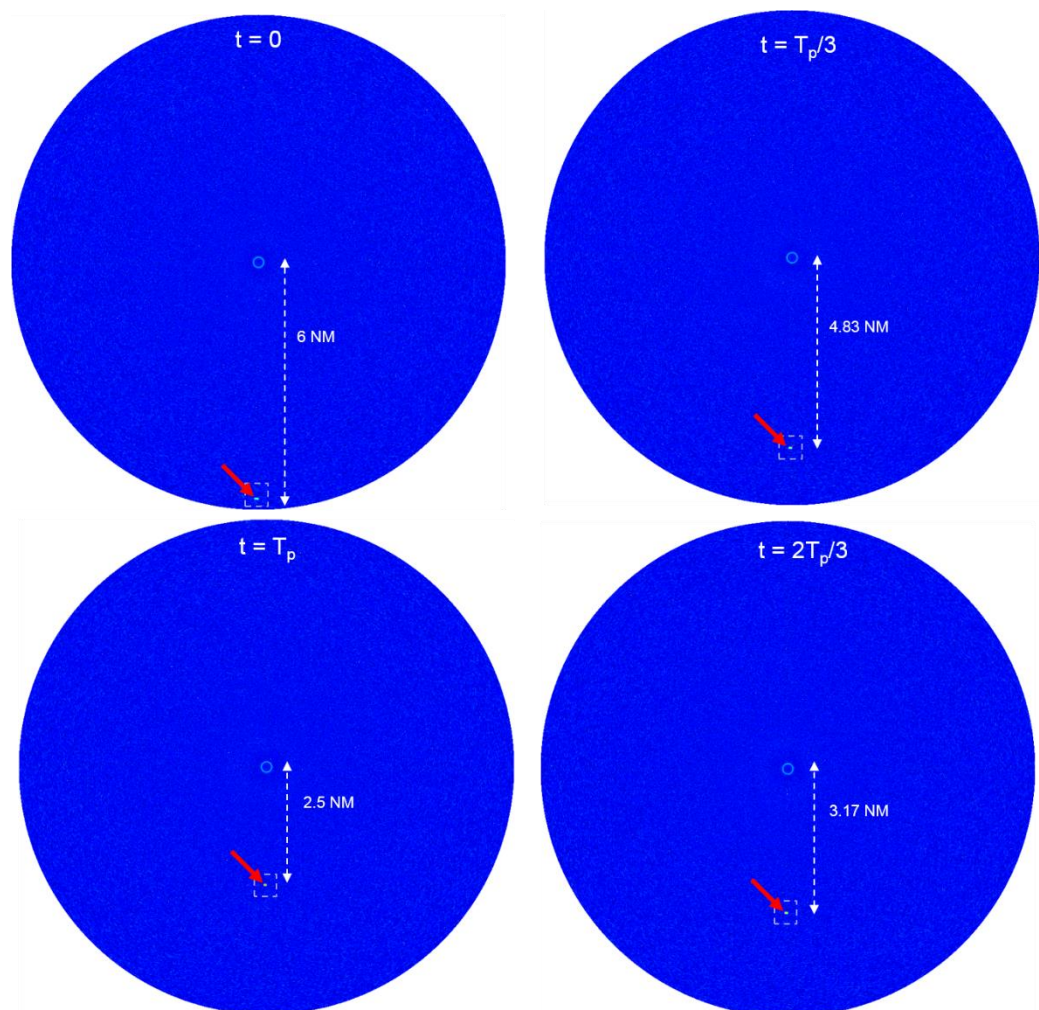


Figure 33 PPI for a moving target with PM

2.2 Multiple Echo Generation

In the multiple echo generation test, we consider multiple target objects to be detected. We consider three different scenarios. First, we study the performance of the REG with two static targets located at different positions. In the second scenario, we allow the target to move. Finally, we consider a mixture of static and moving targets to test the REG. As before, we suppose that a conducted test is used to connect the RUT with the measuring equipment.

2.2.1 Static targets

We start with two static targets located at a distance 2 NM and 2.2 NM from the radar. Both static targets have a RCS of 20 dBsm. As discussed in section 1.5, in the Radar setup tab, we select Conducted Test, and in the Object Configuration tab, we choose Object Type → Static, set the Range → 2 NM and RCS → 20 dBsm. An object name can be assigned to this target to differentiate it from other targets, for example Object Name → Object-1.

In the same tab, we create another static object with Range → 2.2 NM, RCS → 20 dBsm and Object Name → Object-2. In the Simulation Setup tab, we set the value for the system latency of the Radar Echo Generator accordingly.

Object Configuration

- Object Type / Name: Static / Object-1
Range: 2 NM
RCS: 20 dBsm
- Object Type / Name: Static / Object-2
Range: 2.2 NM
RCS: 20 dBsm

The PPI radar display shows the static targets as a circle around the radar with radius given by the estimated range of the two targets. The estimated distances are 2 NM and 2.2 NM confirming that the radar estimated the range of the targets exactly.

To fix the angle, we enable the PM at the RF output of the signal generator and set the pulse width to 10 ms and the pulse offset to half of the period of the trigger signal. Note that in our demonstration we assume external trigger signal as illustrated in section 2.1.2. In the Figure 34, the two static displayed on the PPI screen as arcs at 180° angle with the corresponding estimated range. The green arrows are directed towards the position of the two static target.

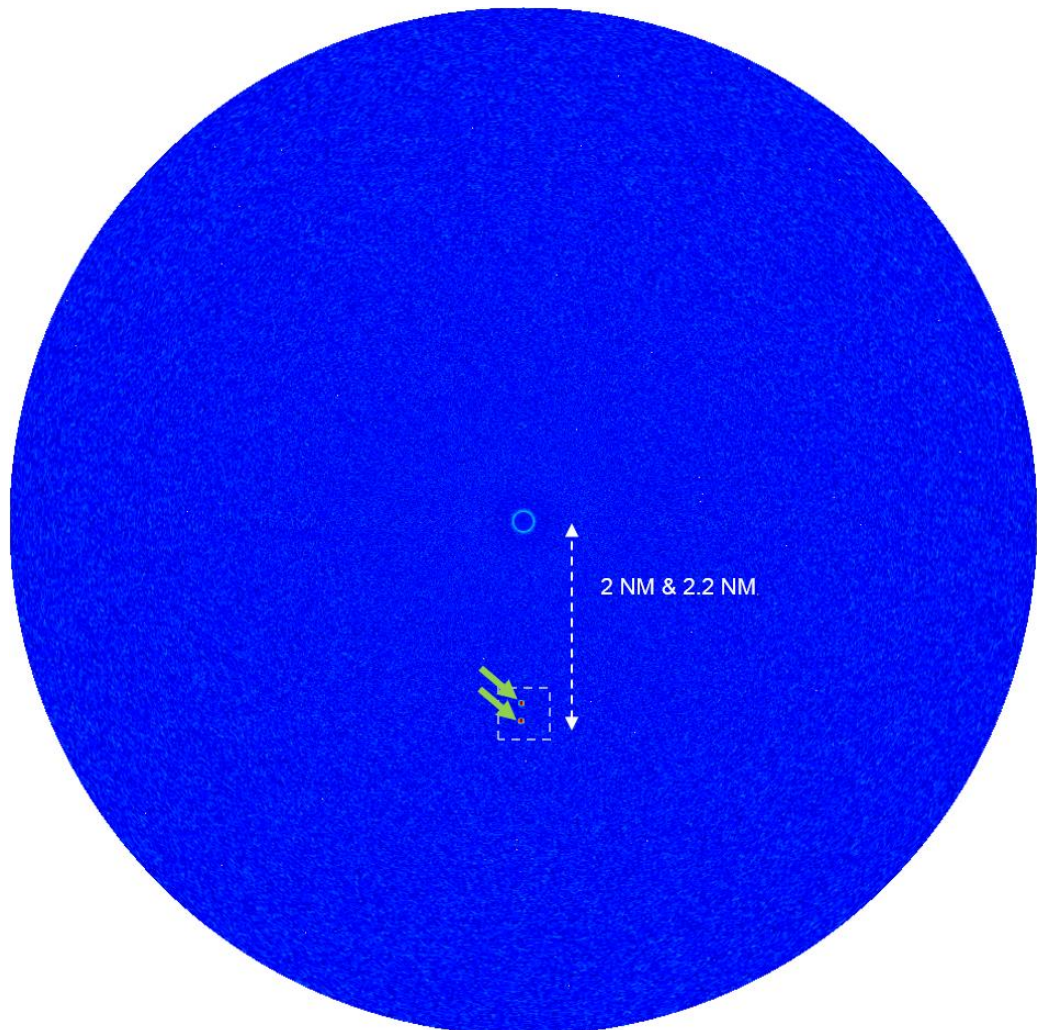


Figure 34 PPI for a two static targets with PM

2.2.2 Moving targets

In the following scenario, we simulate two moving targets approaching the radar. Both moving targets have the same RCS, but they move with different velocities. As discussed in section 1.5, in the Radar setup tab, we select Conducted Test, and in the Object Configuration tab, we choose Object Type → Moving, set the Start Range → 6 NM, End Range → 2.5 NM, Object Velocity → 100 m/s and RCS → 20 dBsm. An object name can be assigned to this target to differentiate it from other targets, for example Object Name → Object-3.

In the same tab, we create another moving object with Starting Range → 6.1 NM, End Range → 2.5 NM, Object Velocity → 50 m/s, RCS → 20 dBsm and Object Name → Object-4. In the Simulation Setup tab, we set the value for the system latency of the Radar Echo Generator accordingly.

Object Configuration

- Object Type / Name: Moving / Object-3
 - Start Range: 6 NM
 - End Range: 2.5 NM
 - Velocity: 100 m/s
 - RCS: 20 dBsm
- Object Type / Name: Moving / Object-4
 - Start Range: 6.1 NM
 - End Range: 2.5 NM
 - Velocity: 50 m/s
 - RCS: 20 dBsm

The PPI radar display shows the two targets as moving circles starting from 6 NM and 6.1 NM to 2.5 NM estimated range, and both having different radial velocities. The estimated range coincides very well with the initial setting of the REG, confirming that the radar estimated the range and velocity of the two targets exactly.

To fix the angle, we enable the PM, set the pulse width to 10 ms and the pulse offset to half of the period of the trigger signal. Note that in our demonstration we assume external trigger signal as illustrated in section [2.1.2](#).

The moving targets are shown now as two arcs shape at 180° angle, [Figure 35](#). We refer to T_p as the time needed by Object-3 to reach its end range. Clearly, the distance between the two moving objects increases compared to $t = 0$ seconds, since Object-3 is moving with a velocity twice than that of Object-4. That means, Object-3 reaches its end range at 2.5 NM, while Object-4 has covered only half of the distance. This can be inferred from the dashed white box, since its size becomes larger with time. The red arrows are directed towards the position of the two moving targets.

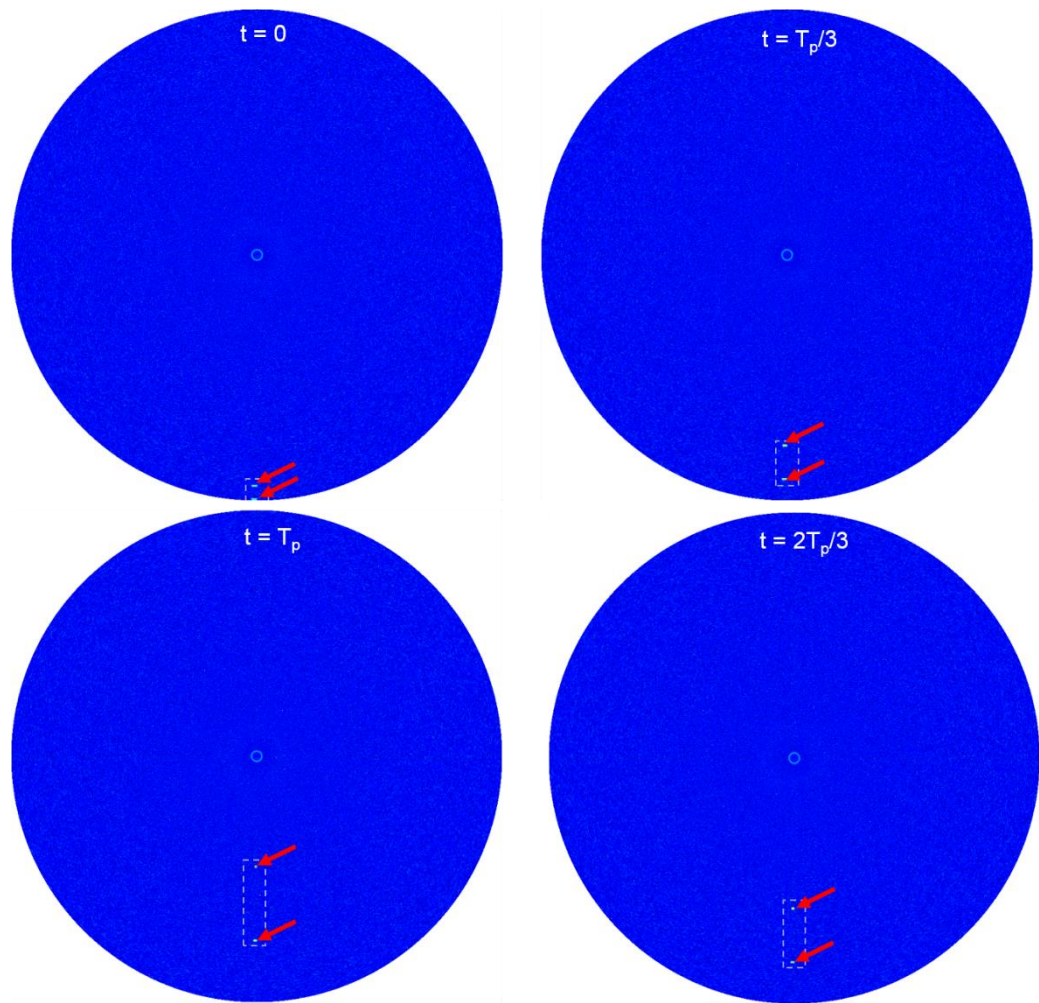


Figure 35 PPI for a two moving targets with PM

2.2.3 Static and Moving Targets

In the last scenario, we consider two static targets from section 2.2.1 and one moving target from section 2.2.2. In particular, we simulate the static targets Object-1 and Object-2, and the moving target Object-3.

Object Configuration

- Object Type / Name: Static / Object-1
Range: 2 NM
RCS: 20 dBsm
- Object Type / Name: Static / Object-2
Range: 2.2 NM
RCS: 20 dBsm

- Object Type / Name: Moving / Object-3
 - Start Range: 6 NM
 - End Range: 2.5 NM
 - Velocity: 100 m/s
 - RCS: 20 dBsm

The PPI radar display shows the static targets as circles around the radar with radius given by the estimated range of the two targets at 2 NM and 2.2 NM. The moving target is displayed also as a moving circle from 6 NM to 2.5 NM. Both results confirm that the radar estimated the range and velocity of the targets exactly. To fix the angle, we set the pulse width to 10 ms and the pulse offset to half of the period of the trigger signal. Note that in our demonstration we assume external trigger signal as illustrated in section 2.1.2.

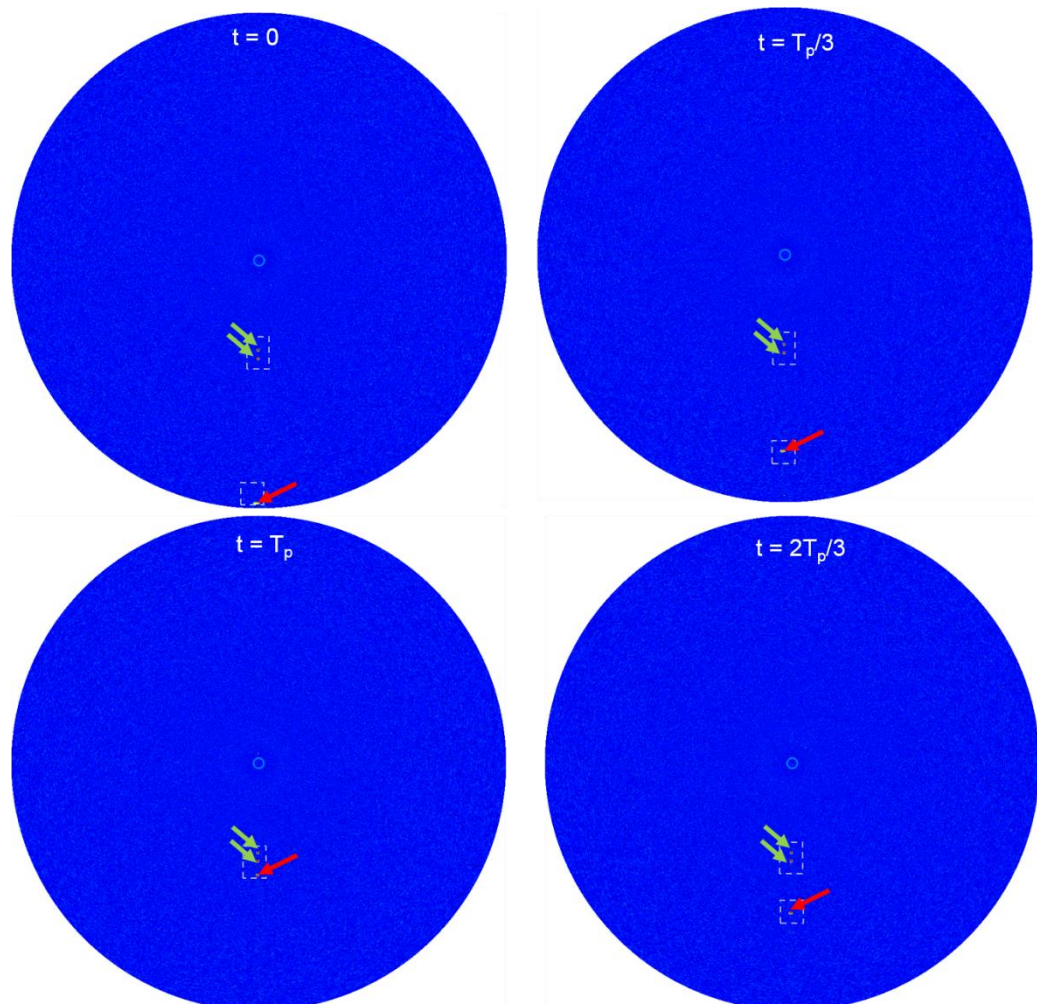


Figure 36 PPI for a two static targets and one moving target with PM

After turning on the Pulse Modulation, the static targets are displayed as small objects located at a distance 2 NM and 2.2 NM from the radar, while the moving target is now a small object moving from 6 NM to 2.5 NM, [Figure 36](#). The distance between the two static targets and the moving target decreases with time. Particularly, we see at $t = T_p$ that the distance between Object-3 and Object-2 is only 0.3 NM, and all three targets are inside a single dashed box. The green and red arrows are directed towards the position of the two static targets and the single moving target respectively.

2.3 Minimum Detectable Signal and Dynamic Range Test Cases

The minimum detectable signal test shows the minimum signal power required to detect a radar echo signal. This depends on the minimum SNR prior to detection and the system noise as well.

The output power level of the SMW Signal Generator is specified to operate from -120 dBm to $+18$ dBm (PEP) for frequencies in between $3 \text{ MHz} \leq f < 20 \text{ GHz}$. Hence, these two tests can easily be performed even in an automatic test system.

To measure the minimum detectable signal, we consider a single static target at 2 NM range. To fix the angle, we also enable the PM at the RF output of the signal generator and set the pulse width to 10 ms and the pulse offset to half of the period of the trigger signal. Furthermore, we assume external trigger signal as illustrated in section [2.1.2](#).

The system setup and REG configuration is setup as illustrated in section [1](#), and the signal power of the SMW is decreased gradually until the radar echo signal is not detected by the RUT anymore. This power corresponds to the minimum signal power required to detect a radar echo signal. Its value can be directly read from the SMW level display.

Note that we have to subtract from it any signal losses due to RF cables and connectors from the SMW to the RUT. These losses can be measured for example by using the Rohde & Schwarz Vector Network Analyzer R&S@ZVA. In our setup, a value of 65 dB attenuation was measured between the SMW and RUT.

1. Create a single static target at a range of interest
2. Decrease the signal power of SMW Level gradually. In case of a conducted test based on Radar Equation, the signal power can be changed for example by modifying the RCS of the single static target with fixed range
3. Once the radar misses the target, the minimum detectable signal level is reached

The RF output power measured by the SMW minus the cable losses to the RUT corresponds to the minimum detection threshold, which is necessary to detect the generated target.

As mentioned in the beginning, the dynamic range of a radar is an important parameter. The received power at the RUT depends on the Radar Cross Section of the target and the distance of this target from the radar. Closer targets with high RCS are expected to have high power compared to target with smaller RCS located very far from the radar. Dynamic range (DR) is defined as the difference between the maximum and minimum

possible received power at the receiver. The minimum possible power corresponds to the ADC value of zero. The maximum signal power to be detected is determined by targets having the largest ADC value.

1. Create a single target at a range of interest.
2. Increase RCS or SMW output Level gradually, until the analog input of the ADC at the radar reaches its maximum possible value
3. Read the corresponding RF output power in dB from the SMW
4. Decrease the RF Level output power of the SMW until the ADC value at the radar reaches its minimum possible value.
5. Read the corresponding RF output power in dB from the SMW
6. Compute the dynamic range in dB equal to the maximum power measured above minus the minimum detectable signal power

3 Summary

Today, radar technology plays an important role in several applications ranging from military to civilian applications. The properties of the radar to be developed, including RF frequency, waveform, power and antenna, depend on the application under consideration, and the radar parameters have to be tested beforehand to ensure proper functionality of the radar system. The Rohde & Schwarz Vector Signal Generator R&S®SMW200A and Rohde & Schwarz Signal and Spectrum Analyzer R&S®FSW make testing of radar systems possible by ensuring a proper adjustment of the radar parameters.

Another challenge in developing radar systems is that testing the radar parameters is often performed in the field under controlled conditions, where artificial targets are deployed, detected and tracked by the radar. However, field tests are not preferred in most cases, since they are very expensive and difficult to reproduce. On the contrary, simple and quick tests performed in the laboratory are cheaper and more attractive. We need to ensure a correct functioning of the entire radar system under real conditions in the laboratory though. The Rohde & Schwarz Radar Echo Generator R&S®SMW-K78 offers the manufacturers the possibility to test their complete radar system, including the RF-Frontend, transmission and reception and the entire signal processing chain more efficiently and with less costs.

The Radar Echo Generator combines the R&S®FSW Signal and Spectrum Analyzer and the R&S®SMW200A Vector Signal Generator. The spectrum analyzer is used for down-conversion and digitization of the radar signal transmitted from the Radar Under Test. The complex baseband signal of the spectrum analyzer is fed to the signal generator, which simulates the range by introducing delay, the velocity by adding Doppler frequency, and the RCS by attenuating the signal. Finally, the R&S®SMW200A converts the baseband digital signal into a RF analog signal prior to retransmission to the Radar Under Test.

The Radar Echo Generator solution has been tested and verified in different scenarios, and its performance has been evaluated by comparing the estimated values of range and velocity with actual values. Range and velocity tests were investigated for both single and multiple targets, where the targets can be static and/or moving. Additional tests were conducted to measure other important radar parameters like dynamic range and minimum detectable signal. In all tests, the estimated radar parameters match exactly the actual value simulated by the Radar Echo Generator. Hence, the Radar Echo Generator solution not only significantly reduces the measurement costs, but it can also test the entire radar system reliably and accurately.

In addition to these tests mentioned, the Vector Signal Generator can be used to generate additional interference signals on additional basebands and RF channels. For example to test radars in co-existence with LTE (Long Term Evolution) or any other interfering signals nearby.

4 Bibliography

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- [2] | R&S. 1MA239, "White Paper: Radar Waveforms for A&D and Automotive Radar," November, 2013.
- [3] | R&. 1MA127, "White Paper: Overview of Tests on Radar Systems and Components," August, 2012.
- [4] | R&S. 1MA256, "Real-Time Radar Target Generation," November, 2014.

5 Abbreviations and Symbols

Abbreviations	
ADC	Analog-to-Digital-Converter
BNC	Bayonet Neill-Concelman
DR	Dynamic Range
FSW	R&S®FSW
I/Q	Inphase/Quadrature
GPS	Global Positioning System
LAN	Local Area Network
LTE	Long Term Evolution
MATLAB	Matrix Laboratory
MDS	Minimum Detectable Signal
OTA	Over-the-Air
PM	Pulse Modulation
PPI	Plan Position Indicator
RCS	Radio Cross Section
REG	Radar Echo Generator
RF	Radio Frequency
RTO	R&S®RTO
RUT	Radar Under Test
RX	Receiver
SMW	R&S®SMW200A
SNR	Signal-to-Noise-Ratio
TX	Transmitter
USB	Universal Serial Bus

Units	
μs	Microsecond
dB	Decibel
dBm	Decibel Milliwatt
dBsm	Decibel Square Meter
GHz	Giga Hertz
m/s	Meter per second
MHz	Mega Hertz
ms	Millisecond
NM	Nautical Mile
s	Second
sm	Square Meter

Symbols	
P_T	Transmit Power
P_R	Receiver Power
G_T	Transmit Antenna Gain
G_R	Receive Antenna Gain
L	System Loss
σ	Radar Cross Section
λ	Wavelength
R	Range
K	Boltzmann's constant
F	Noise Figure
B	Bandwidth
T_0	System Temperature
c_0	Speed of Light

6 Ordering Information

Designation	Type	Order No.
Vector Signal Generator	R&S®SMW200A	1412.0000.02
Frequency Options, 100 kHz to 3 GHz	R&S®SMW-B103	1413.0004.02
Frequency Options, 100 kHz to 6 GHz	R&S®SMW-B106	1413.0104.02
Frequency Options, 100 kHz to 20 GHz	R&S®SMW-B120	1413.0404.02
Baseband generator with realtime coder and ARB (64 Msample), 120 MHz RF bandwidth	R&S®SMW-B10	1413.1200.02
Signal Routing and Baseband Main Module, one I/Q path to RF	R&S®SMW-B13	1413.2807.02
Signal Routing and Baseband Main Module, two I/Q paths to RF	R&S®SMW-B13T (alternatively to R&S®SMW-B13)	1413.3003.02
Fading Simulator	R&S®SMW-B14	1413.1500.02
Radar Echo Generator	R&S®SMW-K78	
Baseband Extension to 160 MHz RF bandwidth	R&S®SMW-K522	1413.6960.02
Signal und Spektrum Analyser 2 Hz to 8 GHz	R&S®FSW8	1312.8000K08
Signal und Spektrum Analyser 2 Hz to 16 GHz	R&S®FSW13	1312.8000K13
Signal und Spektrum Analyser 2 Hz to 26.5 GHz	R&S®FSW26	1312.8000K26
OCXO Precision Reference Frequency	R&S®FSW-B4	1313.0703.02
Digital Baseband Interface	R&S®FSW-B17	1313.0784.02
160 MHz Analysis Bandwidth	R&S®FSW-B160	1313.1668.02

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radio monitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

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Sustainable product design

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



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