Simulating Fading with R&S® Vector Signal Generators

Application Note

Products:

- R&S®SMW200A
- R&S®SMU200A
- R&S®AMU200A

During wireless transmission over the air a signal is subject to fading. Since fading can strongly influence the communication, devices such as mobile phones must be tested under real-world conditions to verify their performance. The Rohde & Schwarz vector signal generators R&S®SMW200A, R&S®SMU200A and R&S®AMU200A make it possible to perform such tests. Their integrated real-time fading simulators reproduce well-defined and repeatable real-world test scenarios to bring reality into your laboratory. A multitude of standard-compliant, preconfigured fading scenarios make the configuration as easy as possible.

This application note gives a brief introduction to fading and explains how to use the fading simulators in custom applications.

Application Note

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ROHDE&SCHWARZ

Table of Contents

1 Introductory Note

The following abbreviations are used in this application note for Rohde & Schwarz products:

- The R&S®SMW200A vector signal generator is referred to as SMW
- The R&S®SMU200A vector signal generator is referred to as SMU
- The R&S®AMU200A baseband signal generator and fading simulator is referred to as AMU

2 Overview

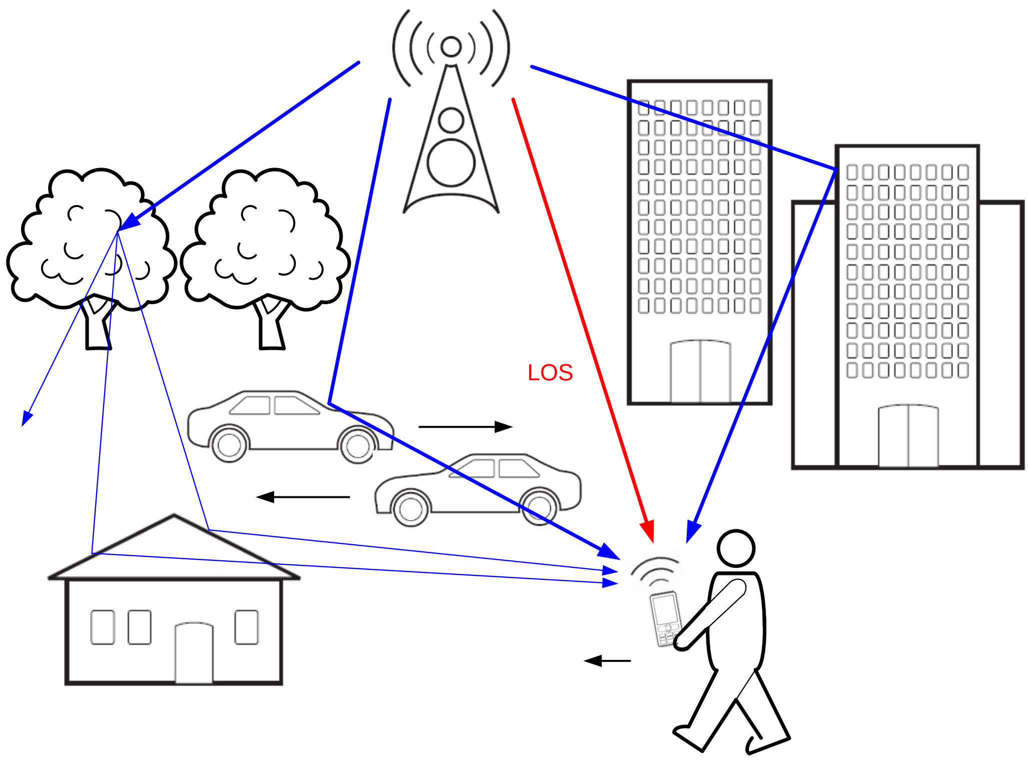
The quality of wireless communication between a transmitter and a receiver depends on the radio channel characteristics. The radio channel is susceptible to noise, interference, and fading (path loss, shadowing and multipath propagation). For this reason wireless devices such as mobile phones for example must be tested under real-world conditions to verify their performance. Test and measurement equipment from Rohde & Schwarz make it possible to perform such tests in a time-saving and cost-efficient manner. A fading simulator reproduces well-defined and repeatable real-world test scenarios in the laboratory.

This application note gives a brief introduction to fading and explains how to use the integrated real-time fading simulators of Rohde & Schwarz vector signal generators in fading applications.
This application note starts with a brief and illustrative introduction to fading (section 3). Section 4 introduces the Rohde & Schwarz vector signal generators capable of internal fading simulation and depicts some important features and characteristics. Section 5 provides support and information for users who use the fading simulators in custom (non-standardized) applications. How to measure a faded RF signal with power sensors and spectrum analyzers is explained in section 6. Section 7 presents the dynamic scenario simulation feature of the Rohde & Schwarz vector signal generators for testing aerospace and defense radio sets. This application note closes with a summary (section 8).

3 Introduction to Fading

3.1 What Is Fading?

Fading happens during wireless transmission of a signal from a transmitter to a (moving) receiver. There are different ways how a signal can experience fading – for example by shadowing or multipath propagation.
Shadowing is caused by objects such as hills or building blocks that obstruct the signal path between the transmitter and the receiver ("blocking"). The resulting amplitude change seen by the receiver is slow as it moves through the terrain. This kind of fading is thus called slow fading and is modeled using a lognormal fading profile.
Multipath propagation is primarily present in urban environments where the transmitted signal can be reflected or scattered from diverse objects such as buildings or moving vehicles. The transmitted signal therefore arrives at a receiver not only via the direct line of sight (LOS) but via multiple propagation paths. Along each path, the signal can experience a different time delay, attenuation, phase shift or Doppler frequency shift (caused by motion of transmitter, receiver and/or reflectors). At the receiver, these signal echoes interfere either constructively or destructively, which results in fast fluctuations of the received signal amplitude. This kind of fading is thus called fast fading and is modeled using e.g. Rayleigh or Rician fading profiles.



3.2 Fading Can Cause Problems…

Fading can impair the performance of a communications system, since it strongly influences the signal-to-noise ratio of the transmission channel. While the signal power at the receiver can drop severely due to fading, the noise power remains the same. As a result, the poor signal-to-noise ratio leads to an increase of bit error rates. Extreme drops in the signal-to-noise ratio may even cause a temporary failure of communications.
In addition to signal loss, multipath fading can introduce inter-symbol interference. Inter-symbol interference occurs when a signal echo transmitting a given symbol arrives at the receiver simultaneously with a different delayed signal echo transmitting a previous symbol. The symbols, transmitted adjacent in time, then interfere with each other.

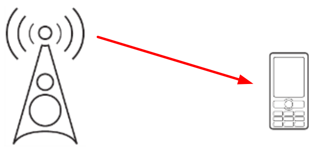
Because fading can greatly impair the performance of a communication link, it is important to test receivers under fading conditions during design and conformance test stages. This requires well-known and repeatable test conditions which can be provided by fading simulators generating realistically faded test signals in the lab.

3.3 Basic Fading Profiles

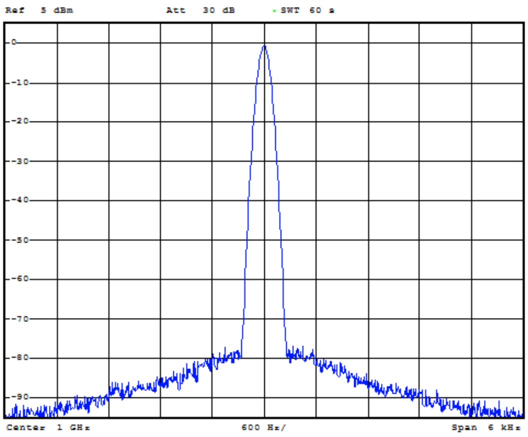
This section gives a brief overview of basic fading profiles used in simulators to model fading conditions. In the following subsections the RF spectrum of a sine waveform and the vector diagram of a QPSK waveform are shown to illustrate the effect of fading simulation on these input waveforms.

3.3.1 Static Path

A static path is basically an unfaded signal. The signal amplitude is constant. No Doppler shift is present.



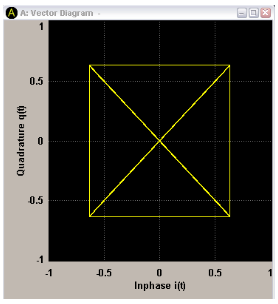
The RF spectrum of the faded sine waveform looks identical to the RF spectrum of an unfaded sine waveform:



Static path

CW spectrum. The peak is at the center RF frequency.

The vector diagram of the faded QPSK waveform looks identical to the vector diagram of an unfaded QPSK waveform:



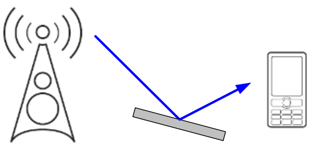
Static path

Static vector diagram.

The static path profile can be used to simulate the original LOS signal.

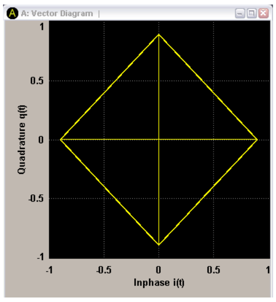
3.3.2 Constant Phase

The phase of the transmitted signal is rotated, e.g. by 180° to simulate reflection off a flat metallic surface. The signal amplitude is constant. No Doppler shift is present.



The RF spectrum of the faded sine waveform looks identical to the RF spectrum of an unfaded sine waveform (see static path).

The vector diagram of the faded QPSK waveform looks like this:



Constant phase

Static vector diagram but rotated by 45° in this example.

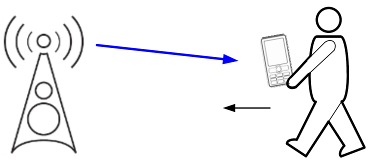
The constant phase profile can be used to simulate reflection off an obstacle. Depending on the reflecting material the signal echo undergoes a certain phase shift. The constant phase value can be set in the channel simulator.

3.3.3 Pure Doppler

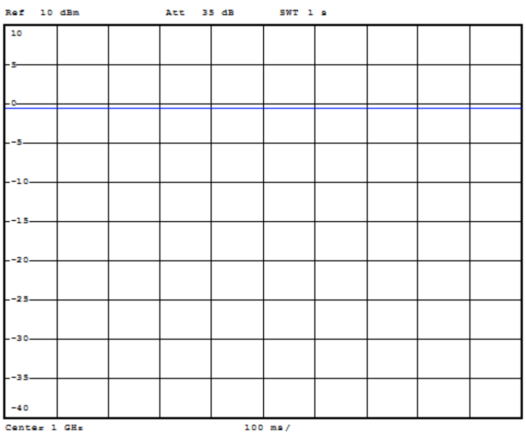
The transmitted signal is shifted in frequency to simulate a relative speed between transmitter and receiver. The signal amplitude is constant. A constant Doppler shift is present according to the following formula:

$$f_D = \frac{v_{rel}}{c} \cdot f_{RF}$$

where v_{rel} is the relative speed between transmitter and receiver, c is the speed of light, and f_{RF} is the original carrier frequency of the transmitted signal.



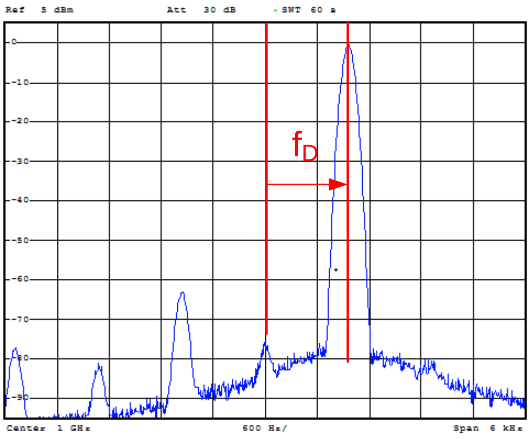
The signal amplitude plotted versus time looks like this:



Pure Doppler

The signal amplitude is constant over time.

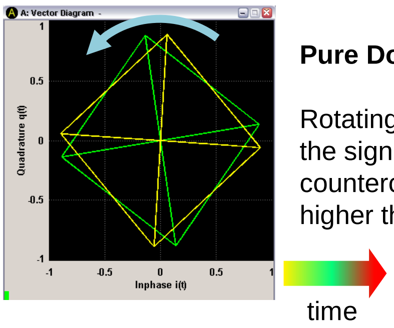
The RF spectrum of the faded sine waveform looks like this:



Pure Doppler

Doppler spectrum. The peak is shifted with respect to the center RF frequency.

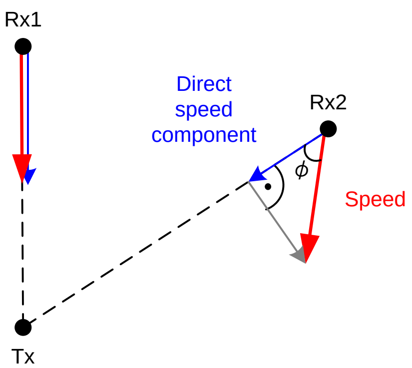
The vector diagram (snapshots) of the faded QPSK waveform looks like this:



Pure Doppler

Rotating vector diagram. The rotation direction depends on the sign of the Doppler shift (a positive Doppler shift causes a counterclockwise rotation). The higher the Doppler shift, the higher the rotation speed.

The pure Doppler profile can be used to simulate a constant frequency shift caused by the Doppler effect. A constant Doppler shift occurs if the receiver and transmitter are directly approaching or distancing each other with a constant speed. Positive Doppler shifts occur if the movement of the receiver is towards the transmitter, negative Doppler shifts occur if the movement is away from the transmitter. The constant Doppler shift value can be set in the channel simulator.



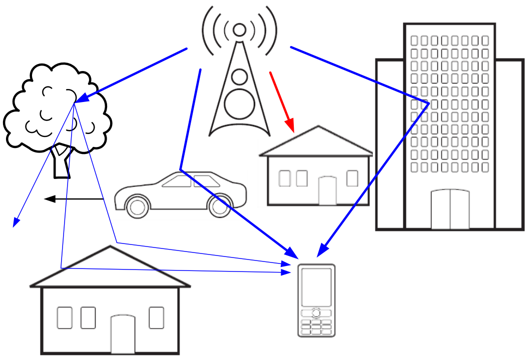
$$f_{D,\max} = \frac{v}{c} \cdot f_{RF}$$

$$f_D = \frac{v}{c} \cdot f_{RF} \cdot \cos\varphi = \frac{v_{direct}}{c} \cdot f_{RF}$$

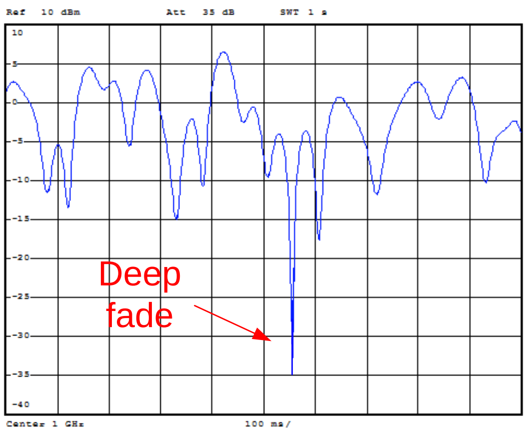
If the receiver is directly approaching the transmitter with a velocity *v* (see Rx1 in above figure), the resulting Doppler shift will be positive and equal to $f_{D,max}$. At the point where the receiver passes the transmitter, the Doppler shift is changing sign and is then equal to $-f_{D,max}$. The situation is slightly different when the receiver is not directly approaching the transmitter but passing the transmitter at some distance (see Rx2). In this case, the Doppler shift is no longer constant. It will continuously decrease from $f_{D,max}$ to 0 while the receiver is approaching the transmitter from a large distance and increase from 0 to $-f_{D,max}$ while the receiver is distancing the transmitter by a large distance. In order for a Doppler shift to occur, there must be a velocity component in the direction of the transmitter. This "direct" speed component determines the magnitude of the Doppler shift. While the receiver is passing the transmitter, the direct speed component decreases to zero and with it the Doppler shift.

3.3.4 Rayleigh

The amplitude of the transmitted signal follows a Rayleigh distribution simulating multipath propagation without a direct line of sight. The signal amplitude varies in time. Time-varying Doppler shifts are present.



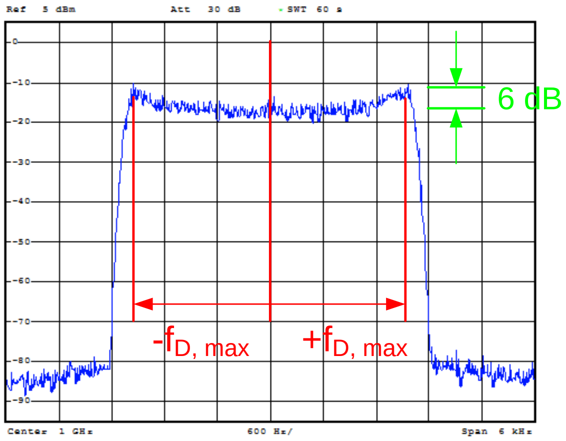
The signal amplitude plotted versus time (snapshot) looks like this:



Rayleigh

The signal amplitude varies in time. Deep fades can occur that are caused by destructive interference of the signal echoes.

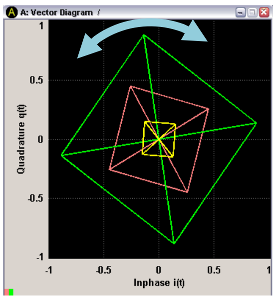
The RF spectrum of the faded sine waveform looks like this:



Rayleigh

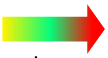
Doppler-spreaded spectrum with the classical 6 dB U-shape. The Doppler shifts vary in the range 0 to $\pm f_{D\ max}$.

The vector diagram (snapshots) of the faded QPSK waveform looks like this:



Rayleigh

Rotating and fluctuating vector diagram. The square rotates in different directions and changes its size. This depicts the time-varying Doppler shifts and the amplitude fluctuations in the signal.

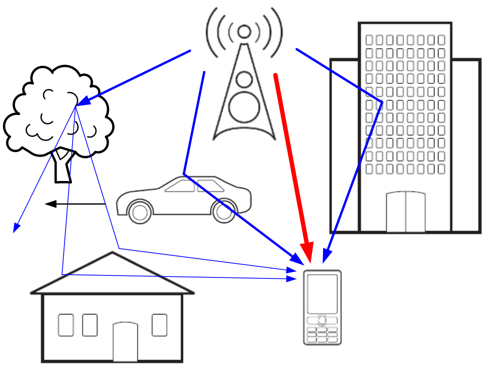


time

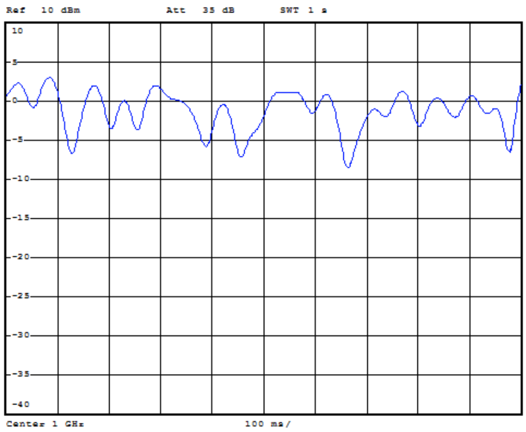
The Rayleigh profile can be used to simulate multipath propagation, e.g. in dense cities where no direct line of sight exists between the transmitter and the receiver. In such an environment multiple, potentially Doppler-shifted signal echoes reach the receiver and interfere constructively or destructively resulting in fluctuations of the amplitude. If the phases of the signal echoes are such that destructive interference occurs, the amplitude at the receiver can drop tremendously, referred to as “deep fade”. The shape of the frequency spectrum is also a consequence of multiple Doppler-shifted signal echoes superimposing at the receiver. In an urban environment, the movement of the receiver and/or the movement of obstacles (reflecting the radio signal) cause non-constant Doppler shifts. The sum of all these Doppler shifts results in a broadened frequency spectrum with a spectral bandwidth of twice the maximum Doppler frequency. The maximum Doppler shift value can be set in the channel simulator.

3.3.5 Rice

The amplitude of the transmitted signal follows a Rician distribution simulating multipath propagation with a (strong) direct line of sight. The signal amplitude varies in time. Time-varying Doppler shifts are present.



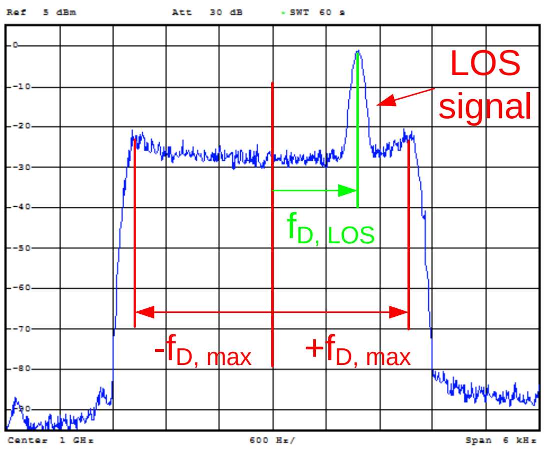
The signal amplitude plotted versus time (snapshot) looks like this:



Rice

The signal amplitude varies in time. Deep fades do not occur since the direct LOS signal strongly contributes to the received power.

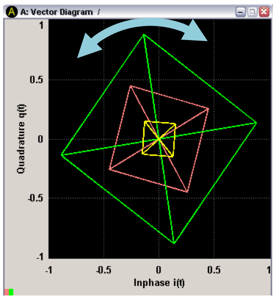
The RF spectrum of the faded sine waveform looks like this:



Rice

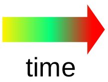
Classical Rayleigh Doppler-spreaded spectrum but with superimposed, discrete peak corresponding to the direct LOS signal. The LOS signal can also exhibit a Doppler shift.

The vector diagram (snapshots) of the faded QPSK waveform looks like this:



Rice

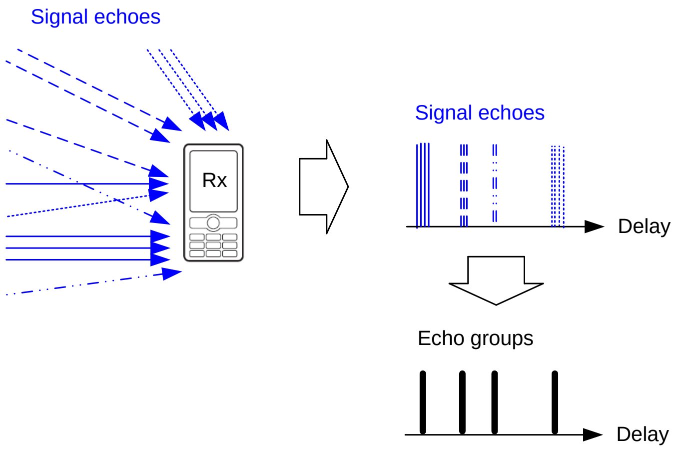
Rotating and fluctuating vector diagram similar to Rayleigh.



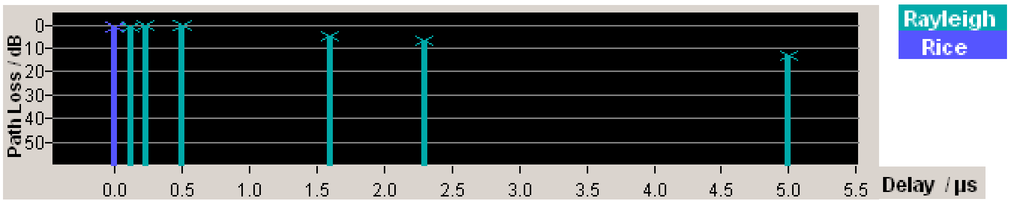
The Rice profile can be used to simulate multipath propagation in environments where a direct line of sight exists between the transmitter and the receiver. The direct LOS signal appears in the frequency spectrum as a discrete spectral line. The discrete peak can also be Doppler-shifted. Rice fading is basically a combination of Rayleigh fading and a pure Doppler component. As with Rayleigh fading, the signal echoes interfere constructively or destructively at the receiver which results in amplitude fluctuations. However, even if the echoes interfere destructively, the amplitude at the receiver does not drop as significantly, because the direct LOS signal always contributes to the received power. The power of the discrete LOS component relative to the Rayleigh component can be set in the channel simulator (in form of a power ratio). This way, the user can determine how much the discrete component predominates. The Doppler shift of the LOS signal can also be set in the channel simulator. It does not need to be the same as the maximum Doppler shift of the Rayleigh component. Both Doppler shift values, the frequency shift of the LOS signal and the maximum shift of the signal echoes can both be set in the channel simulator (in form of a frequency ratio).

3.4 Power Delay Profile

In wireless communications, the transmitted radio signal travels over many different paths to the receiver. The multiple signal echoes travel different distances and suffer different power losses. They therefore arrive at the receiver with different time delays and power levels. Some of the signal echoes will have similar delays. All echoes with similar delays can be combined to an echo group exhibiting a specific, average delay. This way, the individual signal echoes can be concentrated to various echo groups, also commonly called “taps”.



Since each tap represents the sum of multiple signal echoes (arriving at the same time at the receiver), the amplitude distribution for this tap can be, for example, Rayleigh or Rician. The average power level of a tap results from the power levels of all signal echoes contributing to this tap. Generally, the tap power decreases with increasing delay, because the signals arriving at large delays have travelled a larger path, possibly with multiple reflections, and suffered therefore from a greater path loss. The average power and delay of a tap is displayed in a power delay profile. The power delay profile includes all received taps.

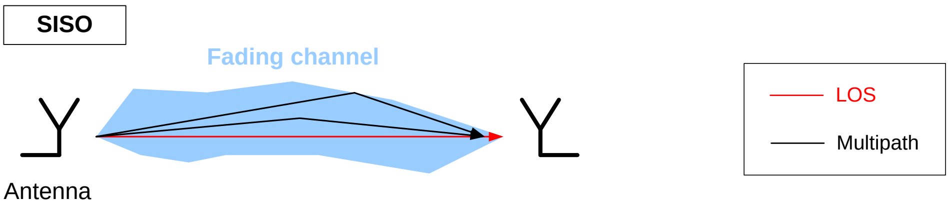


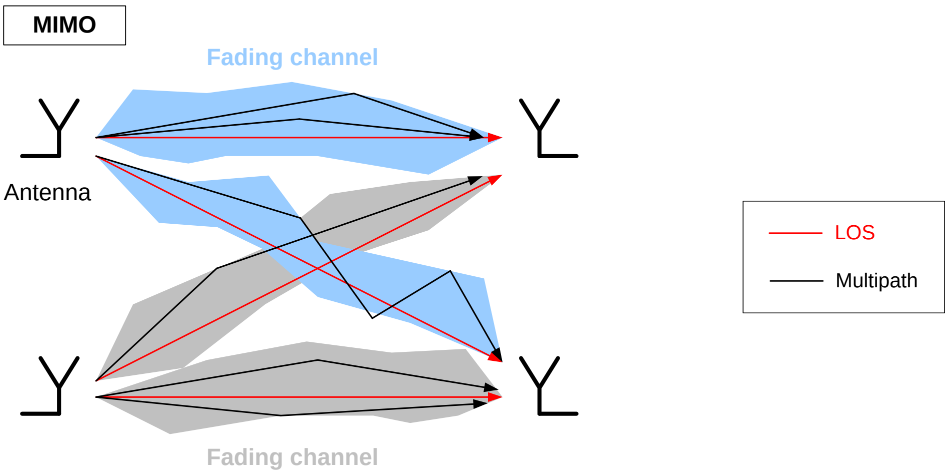
Such a power delay profile is used to model the characteristics of the fading channel. Many wireless communications standards define specific power delay profiles to be used for performance and conformance testing. In channel simulators, the power delay profile is thus the basis for fading simulation. Each tap’s delay and power loss as well as the fading profile (e.g. Rayleigh) can be set in the channel simulator.

3.5 Fading and MIMO

While the performance of a single input, single output (SISO) system with only one transmit and one receive antenna is degraded by the fading process, multiple input, multiple output (MIMO) systems relies on statistically independent fading in the multiple transmission paths to increase signal diversity.

Fading is an essential component in MIMO systems, since sufficiently different – i.e. in the best case, uncorrelated – fading channels are required to distinguish the data streams coming from the different transmit antennas. Uncorrelated fading channels are, however, only a best-case scenario. Due to the (close) placement of the antennas, the different fading channels are not fully uncorrelated under real operating conditions.



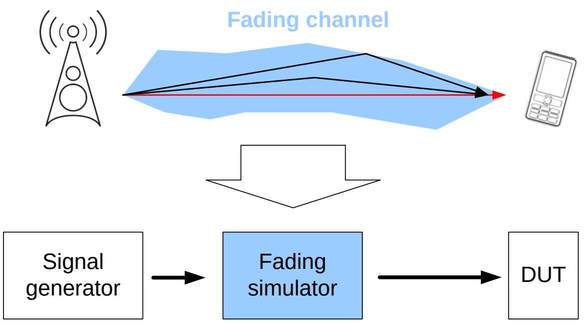


MIMO systems need to be tested under multi-path fading conditions. As MIMO is implemented in all modern communications systems for increasing data throughput, fading simulators must be able to provide realistic MIMO fading scenarios. In addition, it is essential to simulate a variable degree of correlation between the fading channels. Only by correlating the individual channels with each other a realistic channel simulation can be provided for MIMO testing.

4 Fading Simulation

4.1 Why Fading Simulation?

In real life, the radio signal is subject to a multitude of effects such as multipath propagation, attenuation and shadowing, Doppler shift, etc. a receiver must be able to cope with these conditions. Testing under real-world propagation conditions is therefore important during R&D and conformance test phases to ensure proper performance of the product in later everyday use.
A common approach is to use a radio channel simulator for these tests. Such a simulator emulates the propagation conditions of a real radio channel in a laboratory environment.



Fading simulation offers the following benefits:

- Real world effects can be modeled in a controlled way, which allows testing the receiver under well-defined and controlled conditions.
- The simulated fading conditions are reproducible. This allows repeating a measurement any time under the exact same conditions.
- Comprehensive testing under various environmental conditions can be performed in the laboratory. The propagation conditions occurring for example indoors, in dense cities, suburban and rural areas, or in high-speed trains can be emulated without the need to travel to these locations and to transport the equipment.
- For this reason, the time and cost saving can be substantial compared to field test.
- The complexity of the fading scenario is scalable from simple scenarios with e.g. just one Doppler path up to complex scenarios with e.g. strong multipath propagation and time-varying delays. This allows stressing the receiver gradually, which is especially helpful in the early stages of the development process.

The benefits of fading simulation are obvious. This is why fading simulators are widely used for testing performance and conformance of products. Such instruments allow for a shorter development time and thus contribute to a shorter time-to-market for new products.

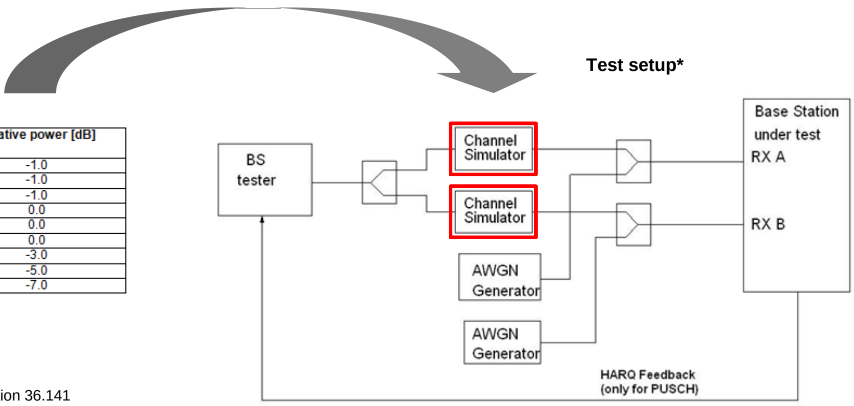
4.2 Application Area of Fading Simulation

Fading simulation is relevant during the whole development process of a product - including design, integration, validation, and conformance test stages.

For example, all modern mobile communications standards stipulate conformance tests under fading conditions. The specified fading scenarios take power delay profiles as a basis to model e.g. pedestrian, vehicle and even high-speed mobility in rural, urban and indoor environments. The specified power delay profiles are reproduced using a channel simulator.

Power delay profile parameters*

Excess tap delay [ns]	Relative power [dB]
0	-1.0
50	-1.0
120	-1.0
200	0.0
230	0.0
500	0.0
1600	-3.0
2300	-5.0
5000	-7.0



* from 3GPP test specification 36.141

For example, the 3GPP standards for WCDMA and LTE include a whole series of test cases that require channel simulation.

Examples for test cases that require channel simulation
3GPP TS 36.141
8.2.1 Performance requirements of PUSCH in multipath fading propagation conditions
8.2.2 Performance requirements for UL timing adjustment
8.2.3 Performance requirements for HARQ-ACK multiplexed on PUSCH
8.2.4 Performance requirements for High Speed Train conditions
8.3.1 ACK missed detection for single user PUCCH format 1a
8.3.2 CQI missed detection for PUCCH format 2
8.3.3 ACK missed detection for multi user PUCCH format 1a
8.4.1 PRACH false alarm probability and missed detection

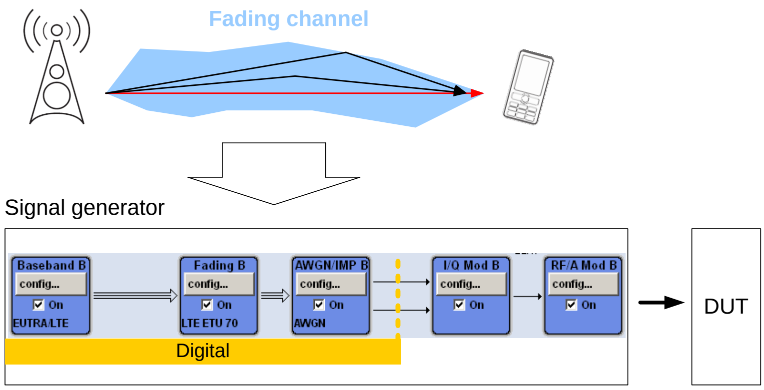
Examples for test cases that require channel simulation
3GPP TS 25.141
8.3.1 Demodulation of DCH in multipath fading conditions: Multipath fading case 1
8.3.2 Demodulation of DCH in multipath fading conditions: Multipath fading case 2
8.3.3 Demodulation of DCH in multipath fading conditions: Multipath fading case 3
8.3.4 Demodulation of DCH in multipath fading conditions: Multipath fading case 4
8.4 Demodulation of DCH in moving propagation conditions
8.5 Demodulation of DCH in birth/death propagation conditions
8.8.2 RACH preamble detection in multipath fading case 3
8.8.4 Demodulation of RACH message in multipath fading case 3
8.9.2 CPCH access preamble and collision detection, preamble detection in multipath fading case 3
8.9.4 Demodulation of CPCH message in multipath fading case 3

But fading simulation is not limited to mobile communication networks. Another area where fading simulation is relevant is in military radio systems, e.g. in systems based on software-defined radios. Especially airborne radios are subject to extreme conditions. Long distances between transmitter and receiver introduce considerable signal delays and path attenuations. The high speeds of (supersonic) aircrafts create significant Doppler shifts in the received signal. Simulation of these effects is used to test the performance of military radios with the objective of optimizing the design and verifying the compliance to the system specifications.

4.3 Rohde & Schwarz Real-Time Fading Simulators

The Rohde & Schwarz vector signal generators SMW, SMU, and the baseband signal generator AMU offer integrated real-time fading simulation to bring reality to your lab.

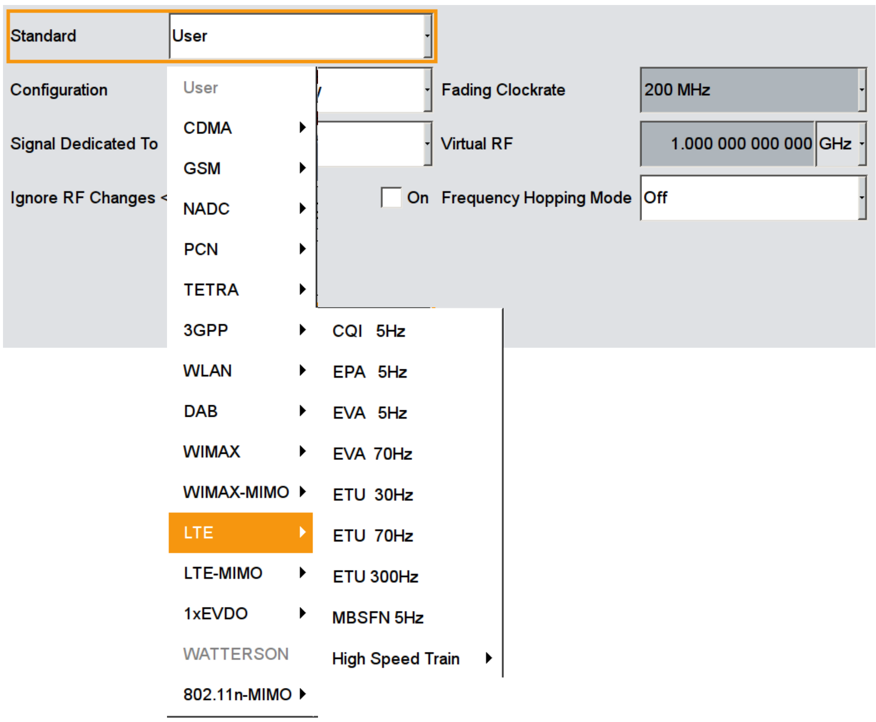
These signal generators provide test signals for all main communication and radio standards such as LTE, HSPA+, GSM/EDGE, WLAN, etc. The standard-compliant signals are generated in the digital baseband of the instrument. The internal channel simulators then add fading according to user- or standard-defined specifications. In addition, the internal AWGN generator can superimpose noise on the faded signals with settable signal to noise ratio. Note that fading and AWGN are applied to the original baseband data in the digital stage. The whole channel simulation process happens digitally. Finally, the digital signals are up-converted to the RF.



The user can choose from various preconfigured fading scenarios that are in accordance with test scenarios stipulated in communications standards. The provided scenarios emulate stationary as well as dynamic propagation conditions (e.g. birth/death or high-speed train scenarios). The user can also select preconfigured MIMO fading scenarios specified for LTE (EPA, EVA, ETU profiles) or WLAN 802.11n (Modell A to F). All fading parameters including the correlation between the MIMO fading channels are automatically configured in accordance with the selected scenario.

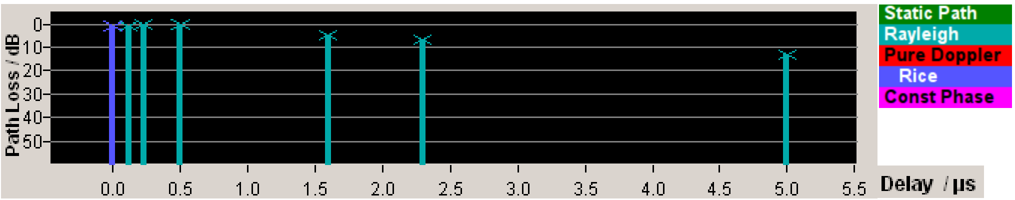
Preconfigured fading scenarios are available for the following standards: 3GPP WCDMA, LTE, LTE MIMO, WiMAX™, WiMAX™ MIMO, WLAN, WLAN MIMO, DAB, GSM, CDMA, TETRA, 1xEVDO, NADC, PCN. The Watterson channel model for simulating high-frequency ionospheric channels is also supported.

Preconfigured fading scenarios



Besides the preconfigured scenarios, the user can always configure custom fading scenarios to meet specific test needs. Each fading path can be individually delayed and attenuated. For each fading path, a fading profile such as Rayleigh, Rician, pure Doppler or Gauss can be selected. In addition, lognormal fading (slow fading) can be superimposed onto these fast fading profiles (see section 5.3).

A display of the power delay profile shows graphically the simulated fading paths with their respective delay and attenuation.



4.3.1 Instrument Overview

The SMW offers up to eight baseband sources and channel simulation of up to 16 fading channels in one instrument. This means that 4x4 MIMO fading is supported within in a single SMW[1]. MIMO fading for 8x2 including channel correlations can also be simulated using a single SMW.

SMW

Fading simulation options		
SMW		
Option	**Name**	**Remark**
R&S®SMW-B14	Fading Simulator	One, two, or four fading simulators can be installed in one SMW.
R&S®SMW -K71	Dynamic Fading	Support of dynamically changing power delay profiles (3GPP birth-death, moving propagation, high-speed train)
R&S®SMW -K72	Extended Statistic Functions	Support of special fading profiles for the DAB and WiMAX™ standards.

[1] The SMW has two RF outputs and additionally supports external RF outputs for 4x4 MIMO RF signal generation. See reference [6] for details.

Fading simulation options		
SMW		
Option	**Name**	**Remark**
R&S®SMW -K74	MIMO Fading/Routing	Support of MIMO fading including simulation of channel correlations; up to 16 fading channels

The SMU and AMU offer up to two baseband sources and channel simulation of up to four fading channels in one instrument. This means that 2x2 MIMO fading is supported within in a single SMU / AMU. MIMO fading for 4x2 or 2x4 (including channel correlations) can be simulated by connecting two instruments [4].

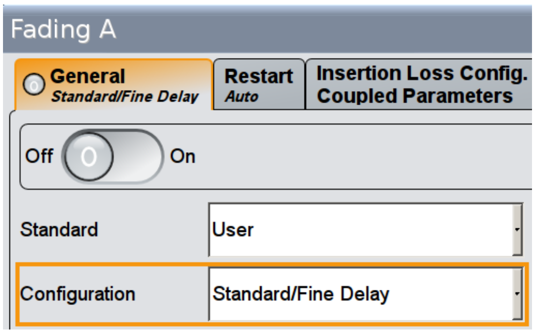
SMU

AMU

Fading simulation options		
SMU / AMU		
Option	**Name**	**Remark**
R&S®xMU-B14	Fading Simulator	First fading simulator
R&S®xMU-B15	Fading Simulator Extension	Second fading simulator
R&S®xMU-K71	Dynamic Fading and Enhanced Resolution	Support of dynamically changing power delay profiles (3GPP birth-death, moving propagation, high-speed train); enhanced resolution for tap delays
R&S®xMU-K72	Extended Statistic Functions	Support of special fading profiles for the DAB and WiMAX™ standards.
R&S®xMU-K74	MIMO Fading	Support of MIMO fading including simulation of channel correlations; up to 4 fading channels
R&S®xMU-K77	Dynamic Scenario Simulation	Support of ship to ship, tower to aircraft and user-defined scenario simulation.

4.3.2 Feature Overview

4.3.2.1 Fading Configurations



The signal generators offer different fading configurations which can be divided into three groups:

- Stationary power delay profiles. A characteristic of these fading configurations is that the number of configured taps and the configured delays remain constant over time. (For the SMU and AMU these fading configurations additionally differ in terms of the number of taps, the delay resolution and the available RF bandwidth.)
- Dynamic power delay profiles. These dynamic fading configurations are in line with test cases defined in digital standards (e.g. 3GPP, LTE). The delays vary over time.
- Kinetic scenario simulation. This fading configuration presents a different approach tailored to aerospace and defense applications. Multipath propagation and thereby power delay profiles do not apply for this concept. Instead the movement of a receiver on a specified trajectory with respect to a stationary or moving transmitter is simulated. The resulting path attenuation and Doppler shift of the LOS signal is modeled.

Fading configuration overview	
Stationary power delay profiles	
Configuration name	**Description**
Standard/fine delay (SMW only)	Simulation of up to 20 fading taps. The delay resolution is 5 ns for the standard delay taps and 2.5 ps for the fine delay taps.[2] The RF bandwidth is 160 MHz.[3]
Standard delay (SMU/AMU only)	Simulation of up to 20 fading taps[4]. The delay resolution is 10 ns. The RF bandwidth is 80 MHz.
Fine delay 30 MHz (SMU/AMU only)	Simulation of up to 12 fading taps[4]. The delay resolution is 0.01 ns. The RF bandwidth is limited to 30 MHz.
Fine delay 50 MHz (SMU/AMU only)	Simulation of up to 8 fading taps[4]. The delay resolution is 0.01 ns. The RF bandwidth is limited to 50 MHz.
Dynamic power delay profiles	
Configuration name	**Description**
Birth/death propagation	Simulation of 2 fading taps appearing (birth) and disappearing (death) at different delays to simulate appearing and disappearing signals.
Moving propagation	Simulation of 2 fading taps – one having a constant delay and the other having a dynamically changing delay, e.g. for simulating a moving receiver.
Two-channel interferer	Simulation of 2 fading taps. The reference tap has a constant delay. The moving tap either has a dynamically changing delay (sliding mode) or it's delay switches between two alternating values (hopping mode).
High-speed train	Simulation of a very rapidly moving receiver passing a transmitter.
Kinetic scenario simulation	
Configuration name	**Description**
Scenario simulation (SMU/AMU only – for now)	Ship to ship: Simulation of signal transmission from one ship to another ship, each moving straight-line with definable direction. Tower to aircraft: Simulation of signal transmission from a tower to an aircraft. The aircraft takes off, flies a circuit and lands again. The take-off, landing and circuit characteristics are customizable. User-defined: Simulation of signal transmission from a (moving) transmitter to a (moving) receiver. The trajectories of transmitter and receiver are customizable via file import. In all cases, the path attenuation and the Doppler shift of the LOS signal is simulated.[5] The RF bandwidth is limited to 50 MHz.

2 Provided the fading clock rate is 200 MHz.

3 Please see reference [1] for details on bandwidth limitations. For some scenarios the RF bandwidth is limited to 80 MHz.

4 It is possible to double the number of taps. Please see reference [2] for details and prerequisites.

5 Please see reference [2] for details and prerequisites.

4.3.2.2 Fading Profiles

The following fading profiles are supported:

The special fading profiles Gauss 1 and 2 (each is sum of two Gaussian distributions) and Gauss DAB (Gaussian distribution, shifted in frequency) are in line with the DAB standard. The profiles WiMAX™ Doppler (rounded Doppler PSG model) and WiMAX™ Rice (WiMAX™ Doppler plus pure Doppler) are in line with the WiMAX™ standard. Please refer to reference [8] for additional information.

4.3.2.3 Periodicity of Fading Process

Fading is a randomly time-varying event. The SMW, SMU, and AMU implement this phenomenon as a random process calculated in real-time. The benefit of real-time fading is that, in contrast to pre-calculated fading, the random fading process does not repeat after a certain, rather short time, e.g. after a period of 30 minutes. Characteristic to real-time fading is that the random process is only limited by the implemented algorithm. The periodicity of the algorithm is specified for the SMW as greater than one year, which means that the random fading process would repeat after one year of uninterrupted runtime under the worst-case condition of maximum receiver speed. If the fading process is not calculated for full receiver speed, this time period becomes even longer. The fading process is therefore indeed perfectly random for measurements with normal test durations.

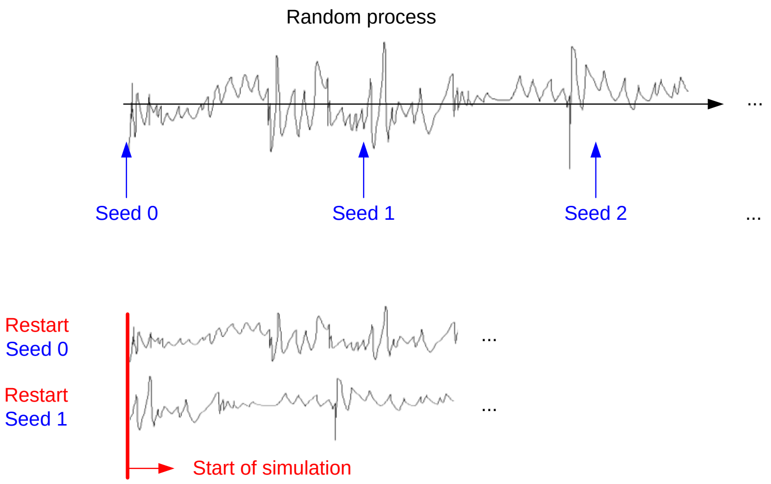
4.3.2.4 Reproducibility of Fading Process

Although the fading process itself is random, the exact same random process is reproduced by the SMW, SMU, and AMU at each start of the fading simulation. This is important to assure repeatable test conditions.

A restart of the fading process can be triggered either

- automatically, for example when the baseband generators restart after a change in the settings,
- manually via the GUI,
- or externally via an external signal.

Perfectly reproducible fading conditions are however just one important point to be considered. Another important point is the manipulation of the fading process. The SMW, SMU, and AMU allow to set a start seed value. This makes it possible to define a start “position” within the random process which is used for the simulation. In applications, where different random processes are required for testing – either from test to test or from instrument to instrument – the seed value can be used to create different, uncorrelated fading conditions. (Please see section 5.2 for more details.)



4.3.2.5 Fading Simulator Input / Output

Signal sources for fading simulation can be

- the internal baseband generators of the instrument.
- an external digital baseband signal, fed in via the digital I/Q input interface of the instrument.
- an external analog baseband signal, fed in via the analog I/Q input connectors of the instrument (SMU and AMU only).

The faded signal can be output as

- RF signal at the RF connector of the instrument.
- digital baseband signal at the digital I/Q output interface of the instrument.
- analog baseband signal at the analog I/Q output connectors of the instrument.

For MIMO fading where multiple inputs and/or outputs are required, the number of available in-/outputs of the instrument needs to be taken into account [1], [2], [3].

Overview of inputs / outputs						
Maximum values						
	Internal		**Digital I/Q**		**Analog I/Q**	
Instrument	**Baseband**	**RF**	**In**	**Out**	**In** (for fading simul., not for I/Q mod.)[6]	**Out**
SMW	8	2 + 2 external RFs	4 (config.)	2 + 4 (config.)	0	2
SMU	2	2	1	1	1	1
AMU	2	0	2	2	2	2

The SMW offers up to four configurable digital I/Q connectors that can be configured either as input or as output.

4.3.2.6 Fading Simulator Remote Control

In general, all instrument settings of the SMW, SMU, and AMU can be set remotely using SCPI commands. Remote control of the instruments is possible via Ethernet LAN (TCP/IP) and GPIB (IEC/IEEE). The SMW supports also USB. It is thus possible to configure all fading related parameters from an automated test program.

[6] There are two types of analog I/Q inputs: inputs that route to the fading simulator and inputs that directly route to the I/Q modulator (no fading simulation possible when using these inputs).

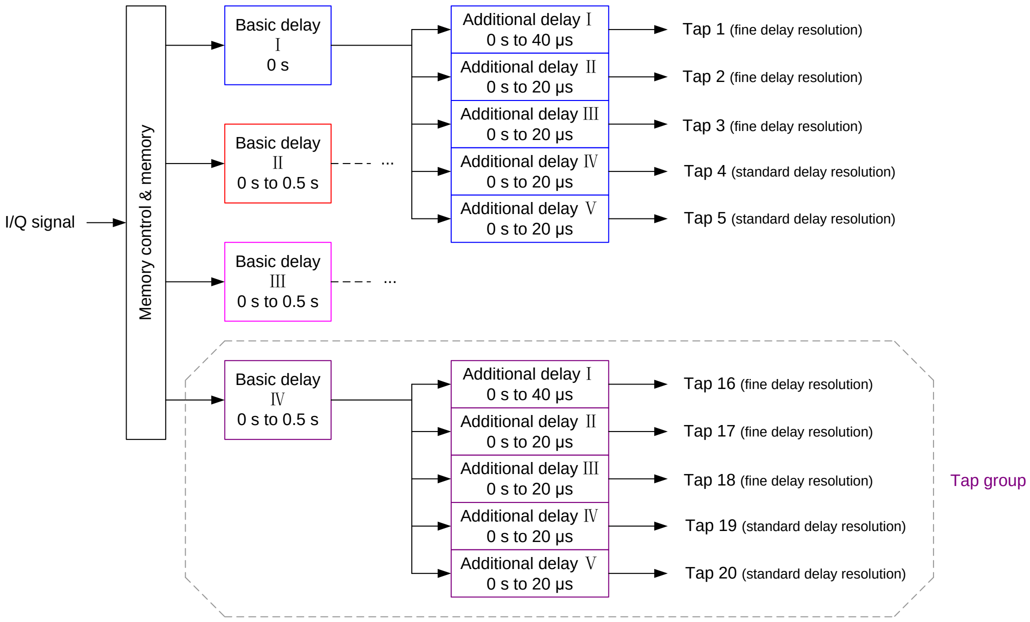
5 Using R&S Fading Simulators in User-Specific Applications

In this section we describe how to configure the fading simulator of the SMW / SMU / AMU. In case you are not using one of the preconfigured fading scenarios, the presented information and explanations will help you to set up fading scenarios according to your needs.

5.1 How to Set Delays

5.1.1 SMW

One, two or four fading simulators can be installed in one SMW. Per fading simulator a total of 20 fading taps are available. The 20 fading taps are subdivided into four tap groups. Each group consists of five taps. The first three taps offer a fine delay resolution of 2.5 ps.[7] The last two taps offer the standard delay resolution of 5.0 ns.[7] A schematic of the hardware implementation is shown in the following figure.



Each tap group has a basic delay. For the first group the basic delay is zero. The delay of a single tap is composed of the group's basic delay and an additional delay, which is specific to this single tap.

[7] at a fading clock rate of 200 MHz

The simulator hardware entails the concept of basic and additional delay. Both values can be configured by the user in the "Path Table". The resulting delay, i.e. the sum of the basic and additional delay, is displayed for each tap.

Basic Delay /µs	50.00
Additional Delay /µs	2.00
Resulting Delay /µs	52.00

For example, we want to configure five taps in standard delay mode with the following delays: 0.0 µs, 10 µs, 22 µs, 62 µs, 71 µs. To achieve this we need to make the following settings for basic and additional delay:

Tap group number

Tap number within group

	1 1	1 2	1 3	1 4	1 5	2 1	2 2	2 3
State	On	On	On	Off	Off	On	On	C
Profile	Rayleigh	Rayleigh	Rayleigh	Rayleigh	Rayleigh	Rayleigh	Rayleigh	Ray
Path Loss /dB	10.00	0.00	10.00	10.00	10.00	10.00	10.00	
Basic Delay /µs	0.00	0.00	0.00	0.00	0.00	62.00	62.00	
Additional Delay /µs	22.00	0.00	10.00	0.00	0.00	0.00	9.00	
Resulting Delay /µs	22.00	0.00	10.00	0.00	0.00	62.00	71.00	

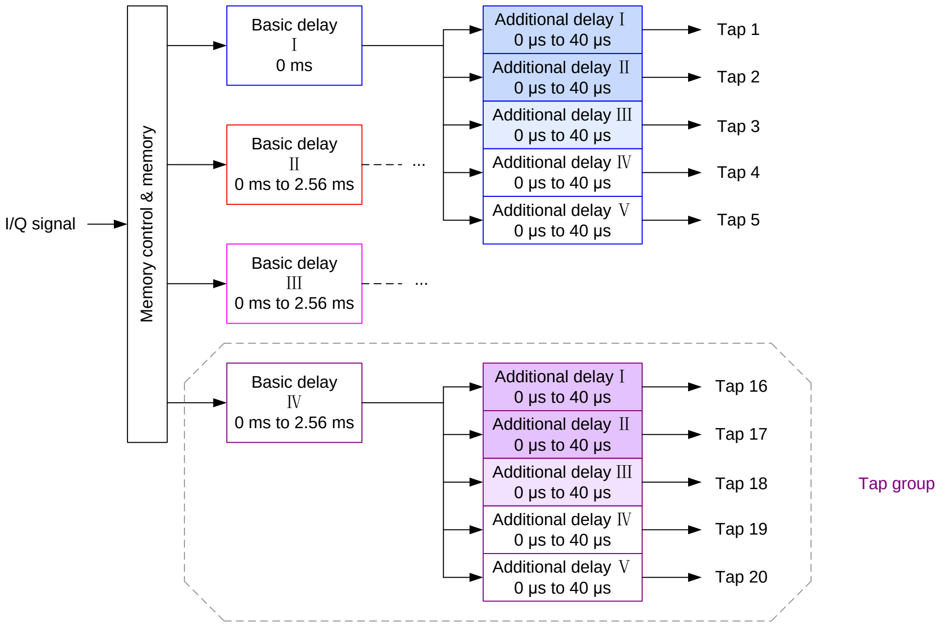
The first three taps can all be set in the first tap group. The tap with 22 µs delay however needs to be set as first tap, since the other taps in the group have a maximum additional delay of 20 µs. The fourth tap therefore needs to be set in the second tap group. The basic delay of this group is set to the wanted delay of 62 µs. The fifth tap also uses this basic delay. With an additional delay of 9 µs we obtain the wanted delay of 71 µs.

5.1.2 SMU / AMU

One or two fading simulators can be installed in one SMU / AMU. Per fading simulator up to 20 fading taps are available. The fading taps are subdivided into four tap groups. Each group consists of

- five taps in case standard delay mode is used.
- three taps in case fine delay (30 MHz) mode is used.
- two taps in case fine delay (50 MHz) mode is used.

The standard delay resolution is 10 ns and the fine delay resolution is 0.01 ns. A schematic of the hardware implementation is shown in the following figure.



Each tap group has a basic delay. For the first group the basic delay is zero. The delay of a single tap is composed of the group's basic delay and an additional delay, which is specific to this single tap.

The simulator hardware entails the concept of basic and additional delay. Both values can be configured by the user in the "Path Table". The resulting delay, i.e. the sum of the basic and additional delay, is displayed for each tap.

Basic Delay /µs	50.00
Additional Delay /µs	2.00
Resulting Delay /µs	52.00

For example, we want to configure five taps in standard delay mode with the following delays: 0.0 µs, 10 µs, 22 µs, 62 µs, 71 µs. To achieve this we need to make the following settings for basic and additional delay:

Tap group number

Tap number within group

	1 1	1 2	1 3	1 4	1 5		2 1	2 2	2 3
State	On	On	On	Off	Off		On	On	Of
Profile	Rayleigh	Rayleigh	Rayleigh	Rayleigh	Rayleigh		Rayleigh	Rayleigh	Rayl
Path Loss /dB	0.00	10.00	10.00	10.00	10.00		10.00	10.00	
Basic Delay /µs	0.00	0.00	0.00	0.00	0.00		62.00	62.00	
Additional Delay /µs	0.00	10.00	22.00	0.00	0.00		0.00	9.00	
Resulting Delay /µs	0.00	10.00	22.00	0.00	0.00		62.00	71.00	

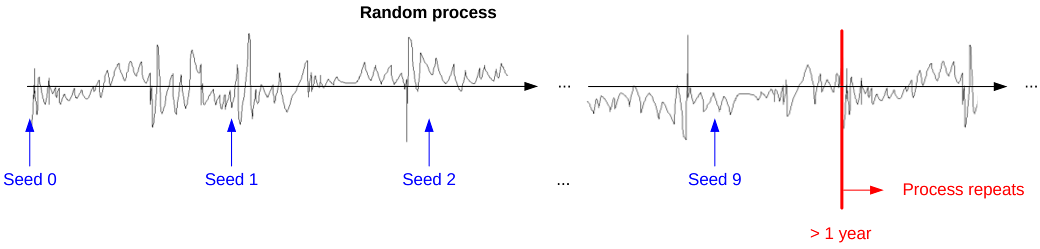
The taps with delays <40 µs can all be set in the first tap group. The fourth tap needs to be set in the second tap group. The basic delay of this group is set to the wanted delay of 62 µs. The fifth tap also uses this basic delay. With an additional delay of 9 µs we obtain the wanted delay of 71 µs.

Note that the SMU / AMU offer the “Path Delay Wizard” to support the user in configuring the delays. The user enters directly the wanted (resulting) delays and the wizard automatically arranges the taps in the “Path Table” plus it adjusts the basic and additional delays accordingly.

5.2 How to Create Different Random Fading Processes

Since fading is a randomly time-varying event, the SMW, SMU, and AMU model this phenomenon as a random process. Owing to real-time calculation, the periodicity of this process is greater than 1 year for the SMW and greater than 93 hours for the SMU and AMU. After this time period the random fading process would repeat at the earliest in case the simulator runs uninterrupted and at maximum receiver speed (worst-case).

As already mentioned in section 4.3.2.4, the SMW, SMU, and AMU allow to set a start seed value for the fading process. This makes it possible to define a start “position” within the random process. When the fading simulation starts, the fading process then begins at the specified “position”. The SMW, SMU, and AMU offer ten start seed values which are evenly distributed over the whole fading process cycle.



On the SMU and AMU, the seed value can be set as follows: in the fading menu, click on the button “Coupled Parameters”. This opens a menu where the user can select the start seed. On the SMW, the start seed can be set in the “Insertion Loss Config./Coupled Parameters” tab of the fading menu.

For example, the seed value can be used to create different, uncorrelated fading conditions from test run to test run or to de-correlate the fading processes of different instruments that otherwise run with the same fading settings.

5.3 Superimposing Lognormal Fading

Large objects such as hills, mountains or buildings that obstruct the direct signal path between transmitter and receiver cause shadowing. Compared to amplitude fluctuations at the receiver caused by multipath propagation, the amplitude variations caused by shadowing is slow. This slow fading is usually modeled using a lognormal amplitude distribution. Often fast multipath fading and slow fading coexists. For this reason, the SMW, SMU, and AMU offer the possibility to superimpose slow lognormal fading onto the fast fading profiles (e.g. Rayleigh).

Lognormal fading can be activated individually for each fading tap in the “Path Table” tab of the fading menu.

	1 1
State	On
Profile	Rayleigh
Path Loss /dB	0.00
Basic Delay /µs	0.00
Additional Delay /µs	0.00
Resulting Delay /µs	0.00
Power Ratio /dB	
Const Phase /Deg	0.0
Speed /km/h	3.000
Freq. Ratio	0.00
Res. Doppler Shift /Hz	2.78
Correlation Path	Off
Coefficient /%	100.0
Phase /Deg	0.00
Lognorm State	On
Local Constant /m	100.0
Standard Dev. /dB	5

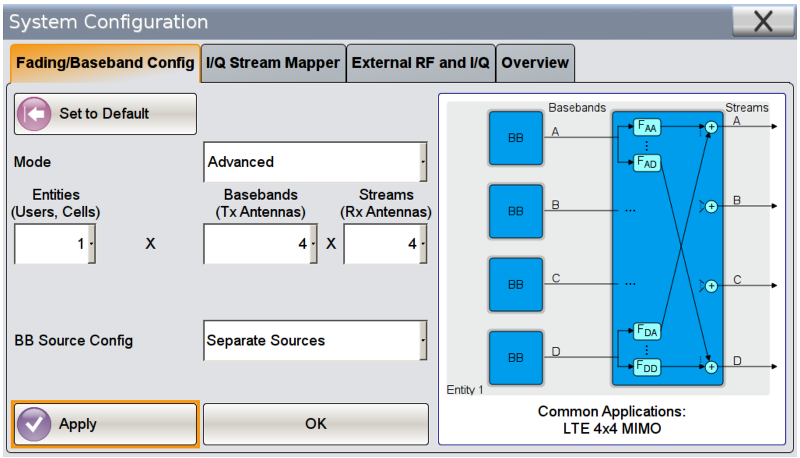
The shown example, i.e. the combination of Rayleigh fading and lognormal fading is known as Suzuki fading.

Lognormal amplitude fluctuations arise from the motion of the receiver in different environments such as urban areas, flat and open terrain, hilly or mountainous terrain, etc. The parameters relevant for lognormal fading are “Speed”, “Local Constant”, and ”Standard Dev.”. Generally, the higher the speed of the receiver is, the faster the variations in signal amplitude are. The local constant is a measure for the distance over which fading conditions do not change. In strongly structured areas, the local constant will have low values, e.g. 50 m in street canyons, whereas on wide plains with little vegetation high values, e.g. >300 m, can be expected [5]. The higher the lognormal constant is, the slower the variations in signal amplitude are. The standard deviation is a measure for the power deviation of the amplitude fluctuations, i.e. it is a measure for how strongly the amplitude varies in power over time. The higher the standard deviation is, the larger the variations in signal amplitude are.

Note that power variations induced by slow lognormal fading are not considered in the calculation of the fading insertion loss (see section 5.6). This means that the actual, averaged RF output power can deviate from the set RF level.

5.4 How to Set Up MIMO Fading Scenarios

In the SMW, the internal signal routing required for MIMO fading can be set easily from a single, intuitive menu. The following figure shows an example of 4x4 MIMO routing.



In addition, the SMW offers preconfigured settings for MIMO fading that are in accordance with test scenarios stipulated in the LTE, WiMAX™, and WLAN 802.11n standards. All parameters of the fading simulator including the correlation between the MIMO fading channels are automatically configured in accordance with the selected scenario.
The configuration of the SMW for MIMO fading scenarios is therefore straightforward. For details (e.g. on external RF outputs) and more application examples please refer to the dedicated application note “Higher Order MIMO Testing with the R&S®SMW200A Vector Signal Generator” (1GP97).

In the SMU and AMU, the internal MIMO routing can be set in a similar way. Preconfigured fading settings for MIMO are also available. For more information and details please refer to the dedicated application note “Guidelines for MIMO Test Setups – Part 2” (1GP51).

5.5 Doppler Shift, Frequency Ratio, and so on…

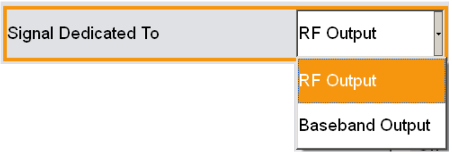
The Doppler shift is an essential component of fading, either as a pure Doppler shifted signal with and without a Rayleigh contribution (i.e. pure Doppler and Rice fading profiles) or as a key parameter for Rayleigh fading determining the spectral Doppler spread (see section 3.3).

The parameters Doppler shift $f_{D,max}$, original carrier frequency of the transmitted signal f_{RF}, relative speed between transmitter and receiver v, and speed of light c are related according to the following formula:

$$\frac{f_{D,\max}}{f_{RF}} = \frac{v}{c}$$

The parameter c is a constant.

The parameter f_{RF} is determined by the setting parameter “Signal Dedicated To” in the “General” tab of the fading menu.



- If “RF Output” is selected, the set RF frequency will be used for the calculation (not applicable for the AMU).

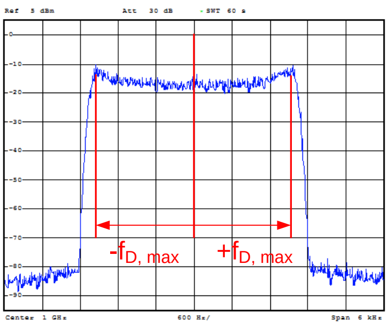
- If “Baseband Output” is selected, the frequency entered for the settings parameter “Virtual RF” will be used for the calculation. (This is needed only for special applications, e.g. for slow I/Q signal generation.)

The parameter v can be set in the “Path Table” tab of the fading menu.

Speed /km/h	3.000

(The “Speed” parameter is editable, if the table settings parameter “Keep Constant” is set to “Speed” (default setting).)

The two variable parameters f_{RF} and v determine the parameter $f_{D,max}$, and thus the Doppler spread of the Rayleigh and Rice frequency spectrums. For the Rayleigh fading profile, the maximum Doppler shift is displayed in the “Path Table” tab by the parameter “Res. Doppler Shift”.



Speed /km/h	3.000
Freq. Ratio	0.00
Res. Doppler Shift /Hz	2.78

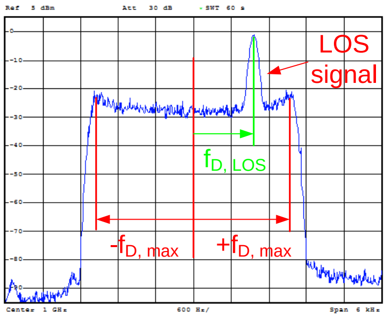
For the pure Doppler and Rice fading profiles, the user can set an additional parameter “Freq. Ratio” in the “Path Table” tab.

Freq. Ratio	1.00

This parameter determines the Doppler shift of the direct LOS signal according to the following relation:

$$f_{D,LOS} = f_{D,\max} \cdot Freq\ Ratio$$

For example, if the “Freq. Ratio” parameter is set to 0.6, the Doppler shift of the LOS signal is only 60% of the maximum Doppler shift.



Speed /km/h	3.000
Freq. Ratio	0.60
Res. Doppler Shift /Hz	1.67

Note that for the pure Doppler and Rice fading profiles, the parameter “Res. Doppler Shift” in the “Path Table” tab does not indicate the maximum Doppler shift calculated from the parameters f_{RF} and v but indicates the Doppler shift of the direct LOS signal which can be less.

5.6 Some Background Information About Leveling

Even in case of fading simulation, the RF output power is always leveled such that the user-set RF level is output in average.[8] Nevertheless, some background information on how fading simulation does influence the power parameters of the signal may be helpful. This section is meant to provide some insight.

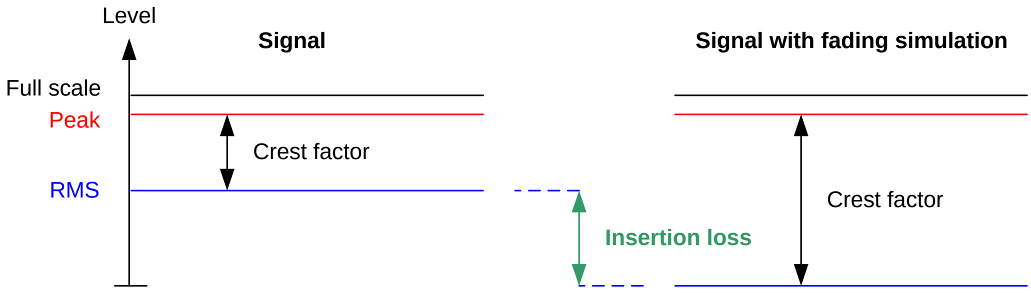
Applying fading simulation significantly increases the crest factor of the signal.

The crest factor denotes the level difference in dB between the average power and the peak envelope power (PEP). Both power values are displayed in the instrument GUI.

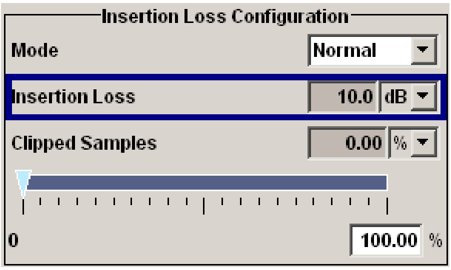
The crest factor can be determined by the following relation:
crest factor [dB] = PEP [dBm] – average power [dBm]
In this example, the crest factor is 3.25 dB. If fading simulation is applied the crest factor of the signal increases to 13.25 dB.

In the digital baseband section of the instrument, the peak level in Volt and the RMS level in Volt determine the crest factor (corresponding to PEP and average power in the RF section). The peak level is kept as close as possible to the full scale level of the baseband section (0.5 V) to maintain optimal dynamic range. An increase in the crest factor therefore results in a decrease of the signal’s RMS level.

[8] Note that the RF power set on the instrument always denotes the average level of the (faded) wanted signal without AWGN. If AWGN is applied, the specified noise level will add to the displayed RF level.



The decrease due to fading simulation is called fading insertion loss. This insertion loss can be determined by the following relation:
insertion loss [dB] = crest factor with fading [dB] – crest factor without fading [dB]
In this example, the fading insertion loss is 10.00 dB. The insertion loss is displayed in the "Insertion Loss Config./Coupled Parameters" tab of the fading menu.



In "Normal" mode the fading insertion loss is automatically set large enough, such that randomly occurring signal peaks do not exceed the internal full scale level.

Note that there are two contributions to the insertion loss displayed on the instrument:

- Insertion loss caused by fading simulation (discussed so far)
- Insertion loss caused by signal routing

For example, if the baseband source A and B are added using the "Fading" block in the GUI, the displayed insertion loss is nonzero even if there is no fading simulation running. If fading simulation is then activated, the fading insertion loss then adds to this initial routing insertion loss.

5.6.1 RF Output Power (SMW / SMU)

Independent of the insertion loss, the RF output power is always leveled such that the user-set RF level is output (in average in case of fading simulation).[9] In general, the average RF power and the PEP displayed on the instrument represent the actual signal characteristics.

[9] Note that the RF power set on the instrument always denotes the average level of the (faded) wanted signal without AWGN. If AWGN is applied, the specified noise level will add to the displayed RF level.

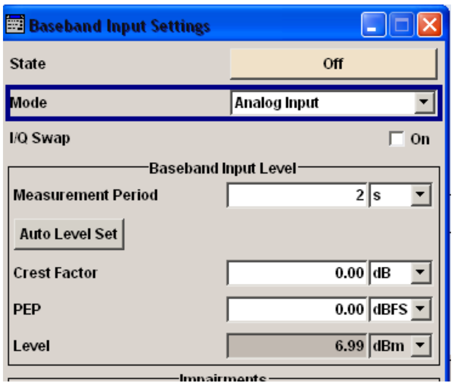
This general rule has just a few exceptions that occur very rarely. One of this rare exception appears for example, if two fading taps are configured with a “Constant phase” fading profile; the one having a phase of 0° and the other having a phase of 180°. Both taps would interfere destructively such that signal cancellation would occur. In this special case, the actual RF output power would not match the displayed user-set RF level. See reference [8] for more exceptions. In such cases, one cannot rely on the displayed value but should measure the signal power (see section 6 for details).

5.6.2 External Baseband Input

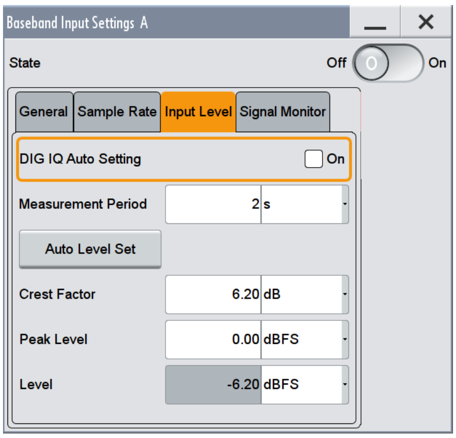
As already mention in section 4.3.2.5, an external baseband signal can be input to the SMW / SMU / AMU to apply fading simulation on this signal.

To maintain correct internal leveling, the instrument needs to know the crest factor and the peak level of the external baseband signal. If the user has knowledge about these values, it is best to enter them directly. This is done in the “Baseband Input Settings” menu (“Input Level” tab) which can be opened from the “BB Input” block. If the user has no knowledge about the crest factor and the peak level, these values can be determined automatically by an internal measurement. The measurement is started with the “Auto Level Set” button. The measurement estimates the peak and RMS level of the external input signal and calculates the crest factor. The measured values are automatically entered into the corresponding input fields. For digital baseband input (only), there is an alternative to the internal measurement. If the user enables “DIG IQ Auto Setting”, the peak and RMS level of the external input signal are received directly from the connected Rohde & Schwarz instrument which signals these values over the digital connection. The received values are automatically entered into the corresponding input fields.

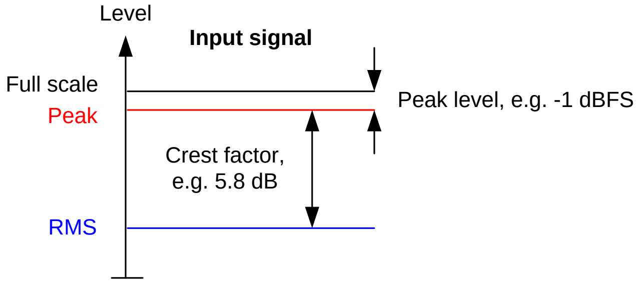
SMU / AMU



SMW



The crest factor is given in units of dB. The peak level is given in units of dBFS (dB full scale). The unit dBFS denotes the level difference in dB between the peak level and the specified maximum level for I/Q signals. For analog I/Q signals this maximum level is +0.5 V (1 V peak-to-peak) for all instruments that support analog baseband input. For example, an analog I/Q signal with a peak voltage of 0.5 V has a peak level of 0 dBFS.

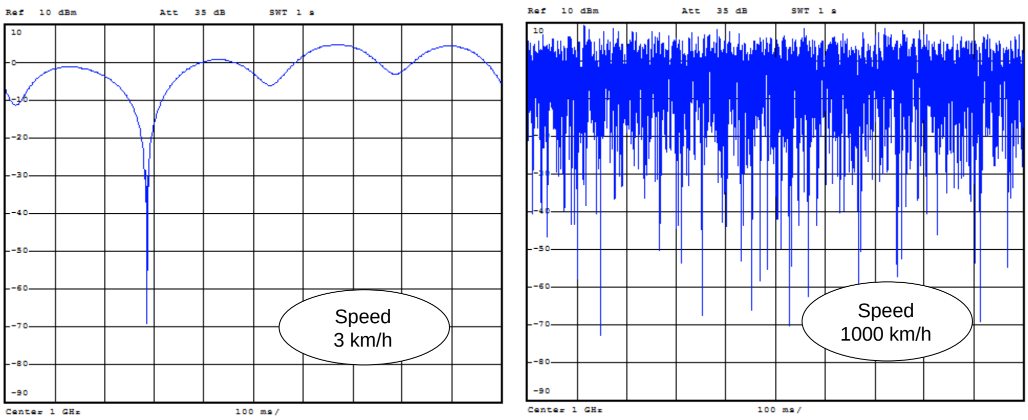

Level
Input signal
Full scale
Peak
Peak level, e.g. -1 dBFS
Crest factor,
e.g. 5.8 dB
RMS

6 How to Measure the Power of a Faded Signal

In some cases it may be useful to measure the RF output power of the signal generator, e.g. to crosscheck if the instruments settings are made correctly and if the expected RF level is really output. Fading simulation however causes strong fluctuations in the RF output power. The measured power needs therefore to be averaged over a longer period of time. In general, there is always a trade-off between measurement duration and accuracy of the measurement result. The measured power should therefore be regarded as an approximation of the average RF output power.

The question is now, how long the measurement period should be to obtain a reasonable result? Generally, the required measurement period strongly depends on the speed parameter, i.e. the relative speed between transmitter and receiver.

This parameter can be set in the “Path Table” tab of the fading menu. The faster the receiver moves through an environment (e.g. through a city canyon with buildings causing multipath conditions), the faster the changes in the received power. For illustration, the following figure shows the power fluctuations of a Rayleigh tap for a speed of 3 km/h and 1000 km/h plotted over the same time period for comparison.



If the receiver speed is very low, the RF level will fluctuate very slowly. With short measurement duration, only a momentary level will be detected. If the speed is very high, the RF level will fluctuate very fast. It is therefore possible to capture a large span of level fluctuations within the same measurement duration. As a consequence, set the speed to a high value (e.g. 1000 km/h) during the measurement to minimize the measurement time. Disable slow lognormal fading (see section 5.3).

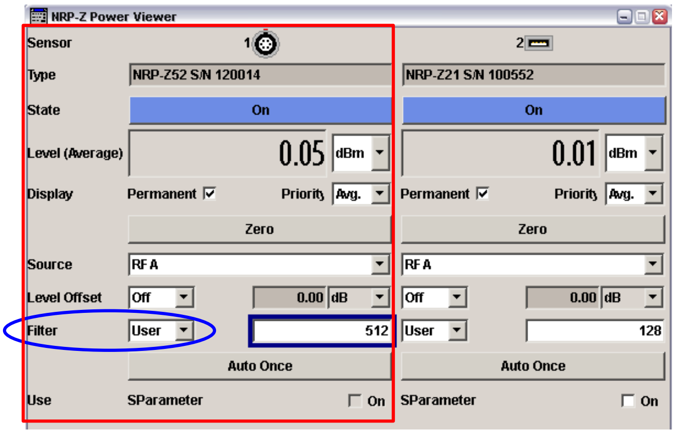
The required measurement period also strongly depends on the measuring device as described in the next sections and is best determined empirically.

6.1 Power Sensor

The RF output level can be reliably measured using a power senor of the R&S®NRP-Z family, e.g. R&S®NRP-Z51 / R&S®NRP-Z52 thermal sensors or R&S®NRP-Z11 / NRP-Z21 diode sensors. Both sensor technologies – thermal and diode – are suitable for measuring faded signals reliably. Please see reference [7] for product specifications, e.g. for the specified power measurement ranges of the sensors.

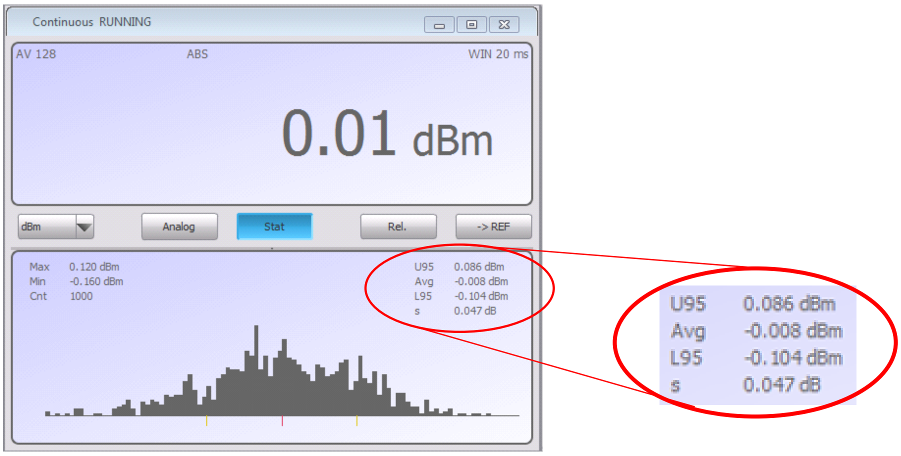
The sensor performs an averaging of the input power. The length of the sensor's averaging filter is normally automatically optimized depending on the measured input power. For measuring a faded signal, the filter length needs to be set by the user to a sufficiently large value. As a result, the averaging time and thus the measurement time increases. The measurement time is given by two times the filter length multiplied by the sensor's aperture time (see reference [7] for details). For the mentioned thermal sensor, this aperture time (i.e. sampling window) is 5 ms; for the mentioned diode sensor, it is 20 ms.

With the following example measurement we determine empirically a suitable measurement time for a simple example application:
The test signal is a single CW signal generated in the baseband of the signal generator. The RF level is set to 0 dBm. Fading simulation is not turned on yet. The measuring device is a R&S®NRP-Z51 that is directly connected to the RF output connector. At 0 dBm input power the sensor uses automatically an averaging filter length of 4. We perform a reference measurement without fading simulation. The measurement reads 0.03 dBm. (The level accuracy of the signal generator is very good but not ideal.)
Now, fading simulation is turned on. We use one Rayleigh tap and a speed of 1000 km/h. The measured power value becomes unstable due to the fluctuations in the signal. The length of the averaging filter is increased stepwise until the measured value becomes stable with the desired accuracy. For example, to achieve a stable value up to the first decimal position (0.0 dBm), we need to set the filter length to 512. This corresponds to a measurement time of 2 · 512 · 5 ms = 5.12 s. For our test application, it takes about five seconds for the measurement to complete with an accuracy of better than 0.1 dB. The measurement reads 0.0x dBm with an unstable second decimal position. It is the approximate average RF power of the faded signal.



Note that the required filter length depends on the sensor type and the applied input power.

With a second example measurement we determine a suitable measurement time for another example application:
The test signal is a LTE signal (test model 1.1) with 5 MHz RF bandwidth. The RF level is set to 0 dBm. The measuring device is a R&S®NRP-Z21 that is directly connected to the RF output connector. At 0 dBm input power the sensor uses automatically an averaging filter length of 1. The sensor is controlled and monitored using the external PC software Power Viewer Plus [9]. Fading simulation is turned on. Again, we use one Rayleigh tap and a speed of 1000 km/h. The length of the averaging filter is increased stepwise until the measured value becomes stable with the desired accuracy of better than 0.1 dB. To achieve this, we need to set the filter length to 128. The measurement time is thus 2 · 128 · 20 ms = 5.12 s. Again, it takes about five seconds for the measurement to complete.
In addition to the averaging performed by the sensor, the Power Viewer Plus software can provide an averaged value deduced from statistics. The individual sensor measurements are recorded and a measurement statistic is evaluated. In this example, the number of measurements that are used for evaluation is set to 1000. Since the individual sensor measurements still fluctuate to a certain degree (depending on the averaging set in the sensor), the measured values are distributed over a level range. The mean power value averaged over 1000 measurements reads –0.008 dBm.



The above example measurements show that both sensor types – thermal and diode – are suitable for measuring faded signals with high accuracy. Generally, a thermal sensor yields better measurement accuracy. A diode sensor offers however a greater power measurement range with lower measurement limits (see reference [7] for specifications). Whereas very high signal crest factors (> 15 dB, as can occur with fading simulation) do not influence the measurement accuracy of thermal sensors, they may slightly degrade the measurement accuracy of diode sensors. Although a very high accuracy may not be relevant for measuring faded signals, it should be nevertheless mentioned briefly how to avoid accuracy degradation for the diode sensors when measuring faded signals with very high crest factors: It is possible to shift the transition range of the three-path diode sensors to lower powers. The control command “SENSE:RANGE:AUTO:CLEVEL -10.0” can be sent to the sensor via the

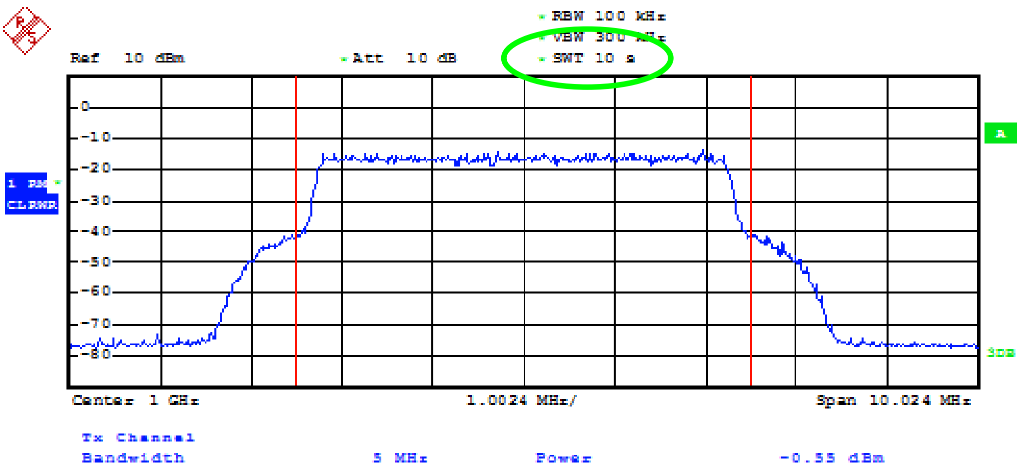
Power Viewer Plus software to reduce the transition range between the measurement paths by 10 dB. See references [9] and [10] for details. Then, even high signal peaks can no longer cause measurement errors.

Note that a power sensor is not measuring frequency-selectively but detects all incoming power within its frequency measurement range.

6.2 Spectrum Analyzer

The RF output level can also be measured using a spectrum analyzer, e.g. an R&S®FSW or R&S®FSQ signal analyzer.

With the following example measurement we determine empirically a suitable measurement time for an example application:
The test signal is a LTE signal (test model 1.1) with 5 MHz RF bandwidth. The RF level is set to 0 dBm. The measuring device is a R&S®FSQ that is connected to the RF output connector via a cable. We perform a channel power measurement with the following settings. The RMS detector is chosen as trace detector. The Tx channel bandwidth is set equal to or slightly greater than the signal bandwidth. We set it to 5 MHz. Reference level and frequency span are adjusted to fit the test signal characteristics. Fading simulation is not turned on yet. We perform a reference measurement without fading simulation. The measurement reads –0.63 dBm. (The connection cable causes some loss.) Now, fading simulation is turned on. We use one Rayleigh tap and a speed of 1000 km/h. The measured power value becomes unstable due to the fluctuations in the signal. The sweep time is increased stepwise until the measured value becomes stable with the desired accuracy of better than 0.1 dB. To achieve this, we need to set the sweep time to 10 s. The measured channel power is the approximate average RF power of the faded signal.



7 Dynamic Scenario Simulation

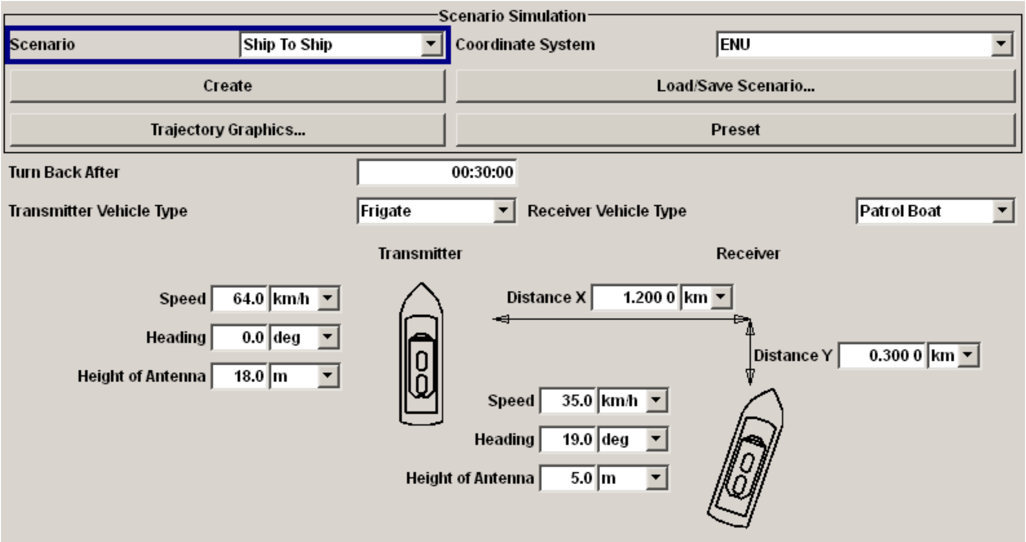
For aerospace and defense applications, the SMU /AMU offers a tailored dynamic scenario simulation option where the movement of a receiver on a specified trajectory with respect to a stationary or moving transmitter is modeled. The resulting path attenuation and Doppler shift of the LOS signal is simulated.

Users can perform reliable and repeatable tests in the laboratory. These tests can serve as preparation and/or complement to cost- and time-consuming traditional test procedures such as field and flight tests. Dynamic scenario simulation can thus help to minimize development costs and test time, which enables a faster time-to-market of A&D communication equipment.

7.1 Scenarios

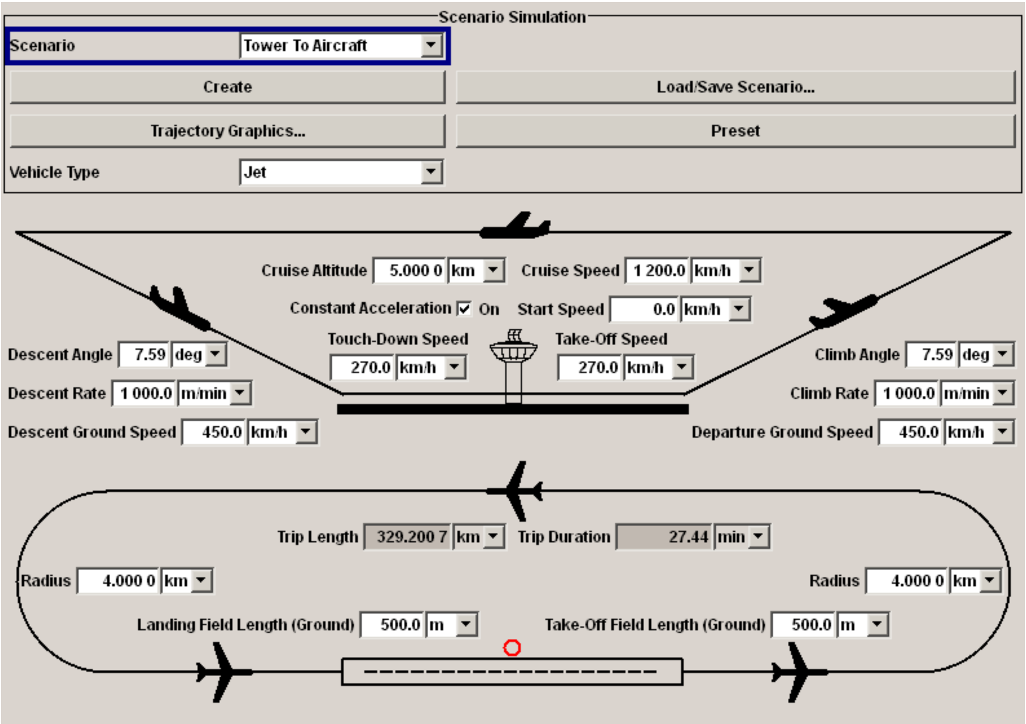
Basic ship to ship and tower to aircraft scenarios are supported. In addition, user-defined scenario simulation is possible.

Ship to ship
The radio link between two ships is simulated. Each ship is moving on a straight line with definable direction. After a specifiable time the ships turn back and return to their starting positions. The speeds of the ships can be set. The path attenuation and the Doppler shift of the LOS signal are simulated to reproduce the conditions experienced by the receiver on the ship during the trip.



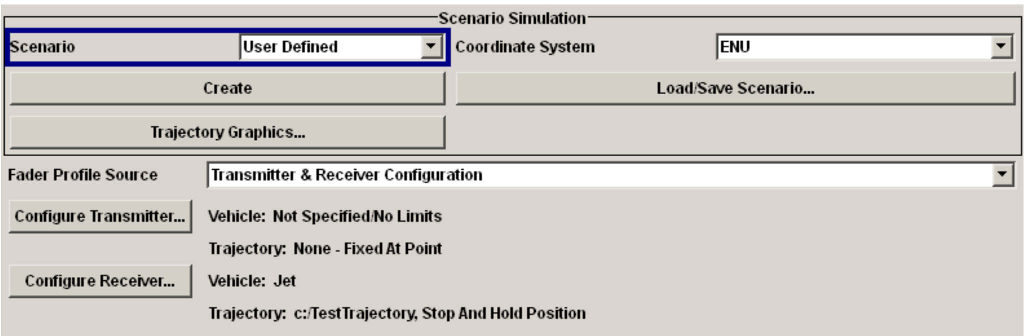
Tower to aircraft

The radio link between a tower and an aircraft is simulated. The tower is the stationary transmitter, while the aircraft is the moving receiver. The aircraft takes off, flies an aerodrome circuit and lands again. The take-off, landing and circuit characteristics are customizable. The path attenuation and the Doppler shift of the LOS signal are simulated to reproduce the conditions experienced by the receiver in the aircraft during the flight.

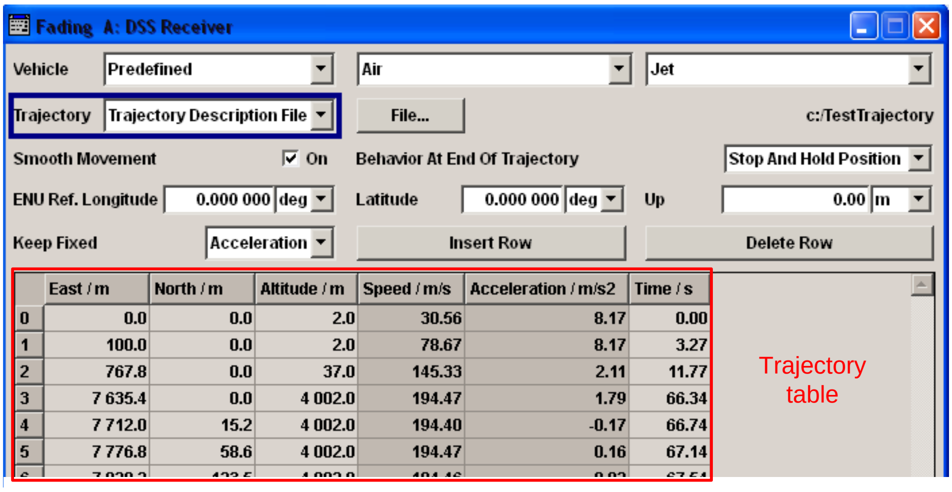


User-defined

The signal transmission from a (moving) transmitter to a (moving) receiver is simulated. The trajectories of transmitter and receiver are customizable either via direct GUI entry or via file import. The path attenuation and the Doppler shift of the LOS signal are simulated to reproduce the conditions experienced by the receiver during the trip.



The user-defined mode makes it possible to simulate more complex movements. The trajectory can be specified by the user either by entering the trajectory parameters, such as position, speed and time directly into the trajectory table or by supplying a trajectory file.



The following trajectory file formats are supported:

- Trajectory description file (R&S proprietary). The user specifies a list of waypoints and corresponding speeds.
- STK ephemeris file (AGI STK proprietary)[10]. The user can model complex mission scenarios in STK and load the resulting STK ephemeris files into the SMU / AMU.

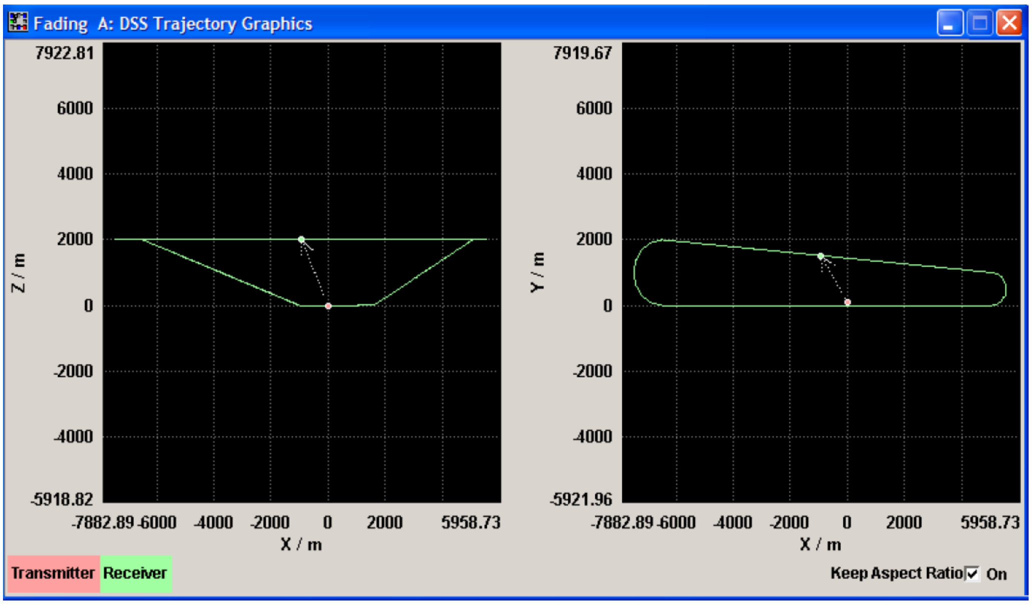
Please see reference [8] for details on the file formats.

So far, we considered the following approach: The user specifies transmitter and receiver trajectories. Based on this, the fading simulator automatically calculates the Doppler shift from the relative speed vector and the path attenuation from the transmitter-receiver-distance. A slightly different approach is to define the variations in propagation delay and path attenuation directly. The relative movement of transmitter and receiver is reflected in these specified values. To also support this approach, it is possible to load user-defined TPA files (R&S proprietary). A TPA file contains a list of time, propagation delay, and attenuation values (see reference [8] for details). The Doppler shift is automatically calculated by the fading simulator.

[10] STK is a system modeling and mission analysis application and software development kit for space, defense and intelligence engineers and analysts. STK is a product of Analytical Graphics Inc. (AGI).

7.2 Trajectory Graphics

For every scenario type, the trajectories can be visualized by the "Trajectory Graphics". Two displays – a x-z view (top view) and a x-y view (side view) – show the position of the moving receiver (and transmitter) in real-time. The direct LOS is indicated as an arrow.



7.3 High Doppler Shifts, Large Distances

Doppler shift as high as 3 kHz can be simulated. For example, at a transmitter carrier frequency of 400 MHz this corresponds to a maximum relative speed of 2250 m/s (i.e. 8100 km/h or Mach 7.5 at –50° Celcius). It is thus possible to simulate e.g. two fighter aircrafts approaching each other at supersonic speeds.

Propagation delays up to 160 µs can be simulated which correspond to a maximal transmitter-receiver distance of 48 km.[11]

[11] The maximum distance is given by multiplying the maximum propagation delay with the speed of light.

8 Summary

To test devices under real-world conditions Rohde & Schwarz offers the vector signal generators SMW, SMU and AMU with integrated real-time fading simulators. They reproduce well-defined and repeatable real-world test scenarios to bring reality into your laboratory.

The instruments provide a multitude of preconfigured fading scenarios that are in accordance with test scenarios stipulated in communication standards. The preconfigured settings make the configuration as easy and fast as possible. Even complex MIMO scenarios can be set up standard-compliant with just a few clicks. Full flexibility is however maintained. The user can always configure custom scenarios according to application needs.

For MIMO testing, the SMW supports simulation of up to 16 fading channels in a single box. 4x4 MIMO fading simulation requires thus just a single SMW which makes the SMW a truly powerful, unrivaled fading solution. The simple, compact test setup and the ease of handling make the SMW the ideal choice.

For aerospace and defense applications, the SMU /AMU offers a tailored dynamic scenario simulation feature. Long transmitter-receiver distances and high speeds corresponding to large signal delays and large Doppler shifts in the received signal can be simulated to test the performance of e.g. military radios.

9 Abbreviations

A&D	Aerospace & defense
ACPR	Adjacent channel power ratio
ARB	Arbitrary waveform generator
CW	Continuous wave
DCS	Digital cellular system
DUT	Device under test
EVM	Error vector magnitude
GPIB	General purpose interface bus
GUI	Graphical user interface
I/Q	In-phase/quadrature
LAN	Local area network
LOS	Line of sight
MIMO	Multiple input multiple output
NADC	North American digital cellular
RF	Radio frequency
RMS	Root mean square
SCPI	Standard commands for programmable instruments
USB	Universal Serial Bus

10 References

[1] Rohde & Schwarz, R&S®SMW200A Specifications (data sheet)
[2] Rohde & Schwarz, R&S®SMU200A Specifications (data sheet)
[3] Rohde & Schwarz, R&S®AMU200A Specifications (data sheet)
[4] Rohde & Schwarz Application Note, “Guidelines for MIMO Test Setups – Part 2” (1GP51)
[5] Rohde & Schwarz Application Note, “Fading Channel Simulation in DVB” (7BM05)
[6] Rohde & Schwarz Application Note, “Higher Order MIMO Testing with the R&S®SMW200A Vector Signal Generator” (1GP97)
[7] Rohde & Schwarz, R&S®NRP Power Meter and R&S®NRP-Zxx Power Sensors Specifications (data sheet)
[8] Rohde & Schwarz, Fading Simulator R&S®SMU200A and R&S®AMU200A Operating Manual
[9] Rohde & Schwarz, R&S®Power Viewer Plus Software Manual
[10] Rohde & Schwarz, R&S®NRP-Z11, R&S®NRP-Z21 Power Sensors Operating Manual

11 Ordering Information

Please visit the Rohde & Schwarz product websites at www.rohde-schwarz.com for comprehensive ordering information on the following Rohde & Schwarz signal generators:

- R&S®SMW200A vector signal generator
- R&S®SMU200A vector signal generator
- R&S®AMU200A baseband signal generator and fading simulator

SMW		
R&S®SMW200A	Vector Signal Generator	1412.0000.02
R&S®SMW-B103	Frequency option 3 GHz, 1st RF path	1413.0004.02
R&S®SMW-B106	Frequency option 6 GHz, 1st RF path	1413.0104.02
R&S®SMW-B203	Frequency option 3 GHz, 2nd RF path	1413.0804.02
R&S®SMW-B206	Frequency option 6 GHz, 2nd RF path	1413.0904.02
R&S®SMW-B90	Phase Coherence	1413.5841.02
R&S®SMW-B13	Baseband Main Module, one I/Q path to RF	1413.2807.02
R&S®SMW-B13T	Baseband Main Module, two I/Q paths to RF	1413.3003.02
R&S®SMW-B10	Baseband Generator with ARB (64 Msample) and Digital Modulation (realtime), 120 MHz RF bandwidth	1413.1200.02
R&S®SMW-K16	Differential Analog I/Q Outputs	1413.3384.02
R&S®SMW-K18	Digital Baseband Output	1413.3432.02
R&S®SMW-K511	ARB Memory Extension to 512 Msample	1413.6860.02
R&S®SMW-K512	ARB Memory Extension to 1 Gsample	1413.6919.02
R&S®SMW-K522	Baseband Extension to 160 MHz RF bandwidth	1413.6960.02
R&S®SMW-B14	Fading Simulator	1413.1500.02
R&S®SMW-K71	Dynamic Fading	1413.3532.02
R&S®SMW-K72	Enhanced Fading Models	1413.3584.02
R&S®SMW-K74	MIMO Fading/Routing	1413.3632.02
R&S®SMW-K62	Additive White Gaussian Noise (AWGN)	1413.3484.02
SMU		
R&S®SMU200A	Vector Signal Generator	1141.2005.02
R&S®SMU-B102	Frequency option 2.2 GHz, 1st RF path	1141.8503.02
R&S®SMU-B103	Frequency option 3 GHz, 1st RF path	1141.8603.02
R&S®SMU-B104	Frequency option 4 GHz, 1st RF path	1141.8603.02
R&S®SMU-B106	Frequency option 6 GHz, 1st RF path	1141.8803.02
R&S®SMU-B202	Frequency option 2.2 GHz, 2nd RF path	1141.9400.02
R&S®SMU-B203	Frequency option 3 GHz, 2nd RF path	1141.9500.02
R&S®SMU-B90	Phase Coherence	1409.8604.02
R&S®SMU-B13	Baseband Main Module	1141.8003.04
R&S®SMU-B9	Baseband Generator with ARB (128 Msamples)	1161.0866.02
R&S®SMU-B10	Baseband Generator with ARB (64 Msamples)	1141.7007.02
R&S®SMU-B11	Baseband Generator with ARB (16 Msamples)	1159.8411.02
R&S®SMU-B14	Fading Simulator	1160.1800.02
R&S®SMU-B15	Fading Simulator Extension	1160.2288.02
R&S®SMU-K71	Dynamic Fading and Enhanced Resolution	1160.9201.02

R&S®SMU-K72	Extended Statistic Functions	1408.7062.02
R&S®SMU-K74	MIMO Fading	1408.7762.02
R&S®SMU-K77	Dynamic Scenario Simulation	1408.8598.02
R&S®SMU-K62	Additive White Gaussian Noise (AWGN)	1159.8511.02
AMU		
R&S®AMU200A	Baseband Signal Generator and Fading Simulator	1402.4090.02
R&S®AMU-B13	Baseband Main Module	1402.5500.02
R&S®AMU-B9	Baseband Generator with ARB (128 Msamples)	1402.8809.02
R&S®AMU-B10	Baseband Generator with ARB (64 Msamples)	1402.5300.02
R&S®AMU-B11	Baseband Generator with ARB (16 Msamples)	1402.5400.02
R&S®AMU-B16	Differential I/Q Output	1402.5800.02
R&S®AMU-B17	Baseband I/Q Input (digital/analog)	1402.5900.02
R&S®AMU-B18	Baseband Digital I/Q Output	1402.6006.02
R&S®AMU-B14	Fading Simulator	1402.5600.02
R&S®AMU-B15	Fading Simulator Extension	1402.5700.02
R&S®AMU-K71	Dynamic Fading and Enhanced Resolution	1402.7302.02
R&S®AMU-K72	Enhanced Fading Profiles	1402.9605.02
R&S®AMU-K74	MIMO Fading	1402.9857.02
R&S®AMU-K77	Dynamic Scenario Simulation	1403.0930.02
R&S®AMU-K62	Additive White Gaussian Noise (AWGN)	1402.7202.02
R&S®AMU-Z7	Analog I/Q Combiner	1415.7006.02

About Rohde & Schwarz

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

Environmental commitment

- Energy-efficient products
- Continuous improvement in environmental sustainability
- ISO 14001-certified environmental management system

Certified Quality System
ISO 9001

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