

Testing FPGA-Based Hardware Emulators with Slow I/Q Signals

Application Note

Products:

- | R&S® SMU200A
- | R&S® AMU200A
- | R&S® SMBV100A
- | R&S® SMJ100A
- | R&S® EX-IQ-BOX

During the design process of chipsets or modules, FPGA-based hardware emulators are utilized to perform early tests with real test and measurement instruments. These hardware emulators usually run at artificially reduced speed, but apart from that function like the finished design.

In this application note we explain how to test FPGA-based hardware emulators using Rohde & Schwarz vector signal generators for creating suitable real-time test signals at reduced sample rates. We further explain how to correctly adapt AWGN signal generation and fading simulation for “slow I/Q”.

Table of Contents

1	Introductory Note	3
2	Introduction	3
3	Background	5
4	Test Setup.....	8
5	Signal Generator Settings	9
5.1	Baseband Signal	9
5.2	AWGN Signal	9
5.3	Fading Simulation	11
5.3.1	Adjusting Path Delays	11
5.3.2	Adjusting Doppler Shifts	13
5.4	Digital I/Q Output Settings.....	15
5.5	HARQ Feedback	15
6	Abbreviations	16
7	References.....	16
8	Ordering Information	16

1 Introductory Note

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

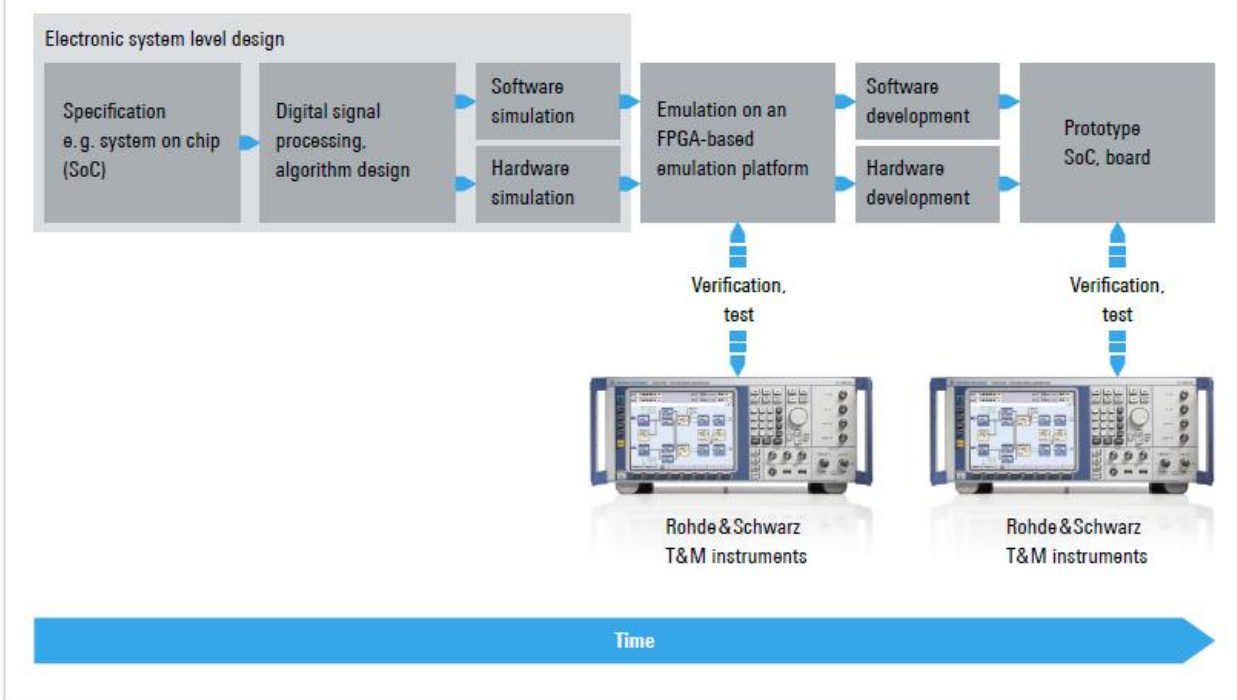
- The R&S[®] SMU200A vector signal generator is referred to as SMU.
- The R&S[®] SMBV100A vector signal generator is referred to as SMBV.
- The R&S[®] SMJ100A vector signal generator is referred to as SMJ.
- The R&S[®] AMU200A baseband signal generator and fading simulator is referred to as AMU.
- The R&S[®] EX-IQ-BOX digital interface module is referred to as EX-IQ-BOX.

2 Introduction

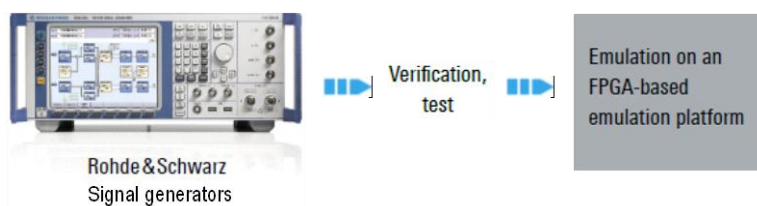
Modern mobile radio standards such as LTE or LTE-Advanced are significantly more complex than 2nd generation standards such as GSM. Not only are the physical transmission methods different – OFDM and MIMO instead of single-carrier GMSK modulation, for example – the entire preprocessing stage for user data is much more demanding. This is a particular challenge in the development of RF and baseband modules. Accordingly, more emphasis is placed today on design verification at the various stages of the process.

For example, any 3GPP FDD/LTE chipset or module design starts with a complete specification of the required attributes. Based on this specification, the design is modeled using algorithm design and simulation tools. During software simulation, the design of the chip is verified against the 3GPP FDD/LTE standard. This is done using stimuli and channel models, and using software models of ideal reference receivers. Then the design is split into the software and hardware components that need to be developed, and the hardware and software is co-simulated. If the simulation is satisfactory, development typically continues with FPGA-based hardware emulators. These usually run at an artificially reduced speed, but apart from that function just like the finished design. This makes it possible to perform initial tests using real test and measurement instruments relatively early in the design process. Iterative verification using software simulation and real test and measurement instruments leads to the first prototype of a chipset or module. The chipset or module is again verified with test and measurement instruments before it is integrated into a more complex design such as a mobile phone or a base station.

Typical design flow



In this application note we focus on testing FPGA-based hardware emulators which run at reduced speed. We explain how to configure Rohde & Schwarz vector signal generators for creating suitable real-time test signals at reduced sample rates and how to correctly adapt AWGN signal generation and fading simulation.

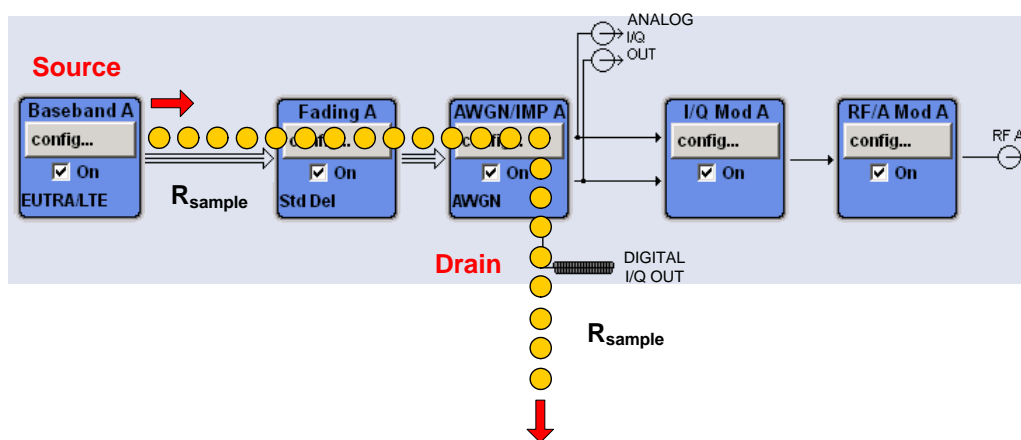


3 Background

Rohde & Schwarz vector signal generators offer ARB-based as well as real-time signal generation. When testing hardware emulators using the internal ARB generator, the playback of waveforms (which are generated/recorded at original speed or obtained from simulation) can be slowed-down easily. When testing is carried out using the internal real-time baseband generator, the data generation can be slowed-down as easily by reducing the sample rate. In both cases, if fading simulation and/or AWGN is applied to the baseband signal, the situation becomes more advanced. Fading simulator and AWGN settings need to be adapted to the “slowed-down” state. How to do this is explained in detail in section 5.

In the following we focus on real-time signal generation and present some fundamental conditions and related thoughts on a basic level. Advanced users may skip this part and continue reading in section 4.

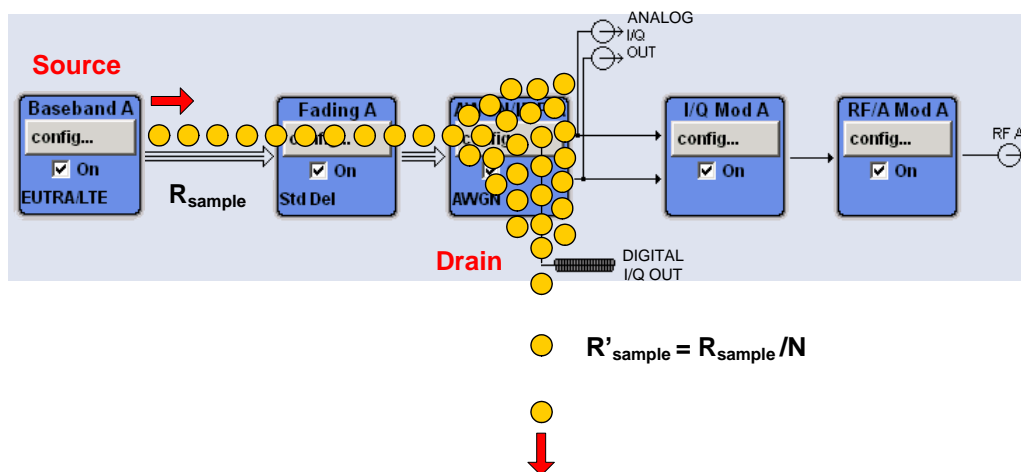
In the baseband generator under conventional operating conditions, the data is generated (continuously) at a certain sample rate, R_{sample} . Fading simulation and AWGN can be optionally applied to the signal in the instrument’s digital domain. The digital data can then be output via the instrument’s digital interface or converted to analog signals and upconverted to the RF domain. No matter how the data is output from the signal generator – digitally¹, analog or as RF signal – it is output at the sample rate R_{sample} as shown in the following figure.



A consequence of this fact is that the sample rate needs to be reduced at the baseband signal source when hardware emulators shall be tested at reduced speed. This means that also the fading simulator and AWGN settings need to be adapted.

¹ Resampling is possible for the digital output, but we disregard resampling at this point for didactic reasons.

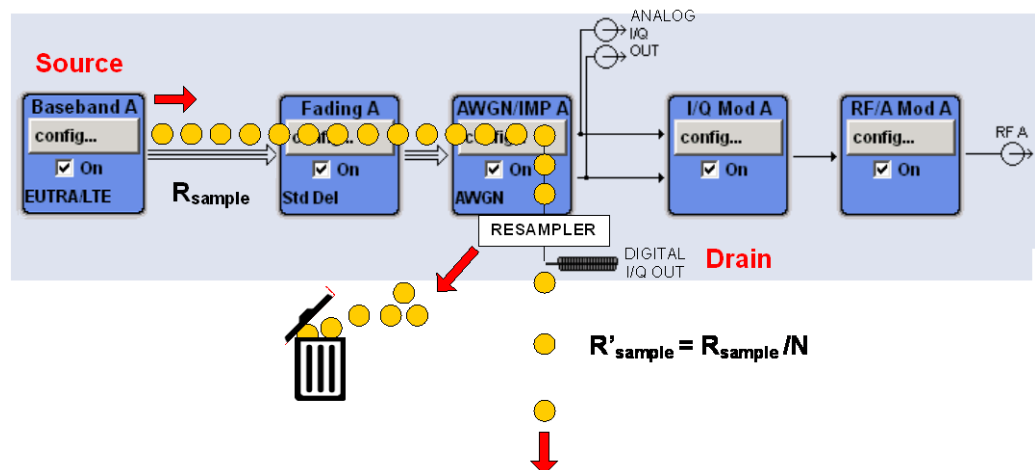
From a hypothetical point of view, let's assume the data would be generated in the baseband at R_{sample} but output at a smaller sample rate $R'_{sample} = R_{sample} / N$. On the one hand, this would avoid having to adjust the fading simulator and AWGN settings, since both units could keep running at original speed. But on the other hand, this would generate an unsolvable overflow situation, since the baseband would deliver the data faster than it could be output. Buffers would be needed to temporarily store the data. However, since a real-time baseband generator supplies data continuously, the overflow situation would reoccur as the buffer size is always limited. This hypothetical situation is shown in the following figure.



Again, the consequence is the same as prior to this hypothetical thought: The only way to achieve a lowered sample rate at the output of the instrument is to reduce the sample rate at the data source, i.e. the real-time baseband generator needs to be slowed down.

Finally, we want to mention a potential pitfall. When testing hardware emulators usually the digital output of the instrument is utilized. Here, the user can set an output sample rate. The data from the baseband generated at R_{sample} are resampled to the sample rate set by the user. What happens if the user sets a lower sample rate $R'_{sample} = R_{sample} / N$? In this case down-sampling takes place, i.e. the number of samples per time period is reduced. More clearly, samples are dropped as illustrated in the figure below. This is however not what is needed for testing hardware emulators. The data rate shall be slowed down keeping all samples; it shall not be reduced by dropping samples. Down-sampling is thus no suitable method to reduce the sample rate at the digital output for this particular application.

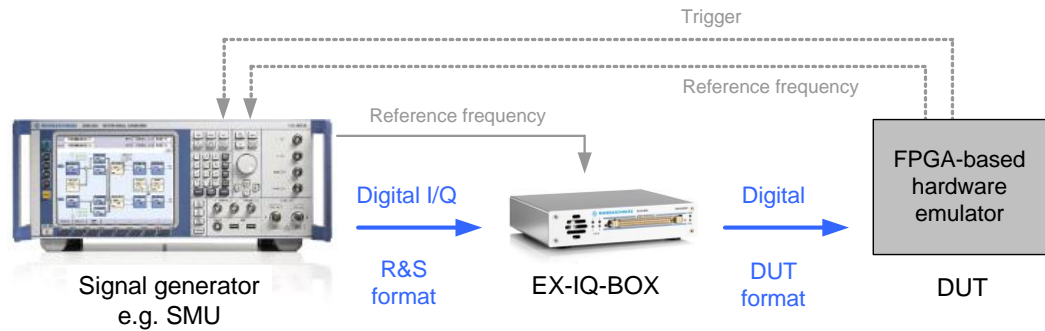
To emphasize that the sample rate really needs to be slowed down in speed (rather than being reduced by resampling), we talk about "slow I/Q" signal generation.



Note that slowing down data generation in the baseband source affects the signal bandwidth (wanted effect) while resampling leaves the signal bandwidth unchanged.

4 Test Setup

On the generation side, a typical setup for testing hardware emulators looks like this:



A Rohde & Schwarz vector signal generator – e.g. the SMU, SMBV, SMJ, or AMU – provides the slow I/Q data via its digital output. The EX-IQ-BOX converts the digital data from the Rohde & Schwarz specific format to a DUT-specific format. The EX-IQ-BOX is controlled via the DigIConf software from a PC (not shown). Please refer to references [1, 2, 3] for information on the EX-IQ-BOX.

The DUT can be for example a FPGA emulating a LTE UE chip or an eNodeB baseband unit (BBU). Also emulators of base station remote radio heads (RRH) can be tested via the CPRI interface of the Ex-IQ-BOX.

The vector signal generators named above can provide standard compliant test signals for all modern communication standards as well as AWGN signals. The SMU and the AMU can also provide real-time fading simulation. Real-time HARQ feedback for closed loop 3GPP FDD/LTE base station testing is supported by the SMU, SMJ, and AMU.

5 Signal Generator Settings

In the following sections, we use the following sample rate values as an example:

- The standard sample rate is $R_{standard} = 30.72$ MHz corresponding to a LTE signal of 20 MHz bandwidth.
- The desired slow I/Q sample rate is $R_{sample} = 240$ kHz.
- According to the formula $R_{sample} = R_{standard} / N$, is $N = 128$.

N can be regarded as a slowdown factor. It is the ratio of the original data rate to the slowed down data rate: $N = R_{standard} / R_{sample}$

5.1 Baseband Signal

The data generation is slowed down by setting the sample rate, i.e. the parameter “Sample Rate Variation”, to the desired slow I/Q sample rate.²

$$\text{Sample Rate Variation} = R_{sample} \text{ (slow IQ)}$$

For example, the sample rate is set to 240 kHz.

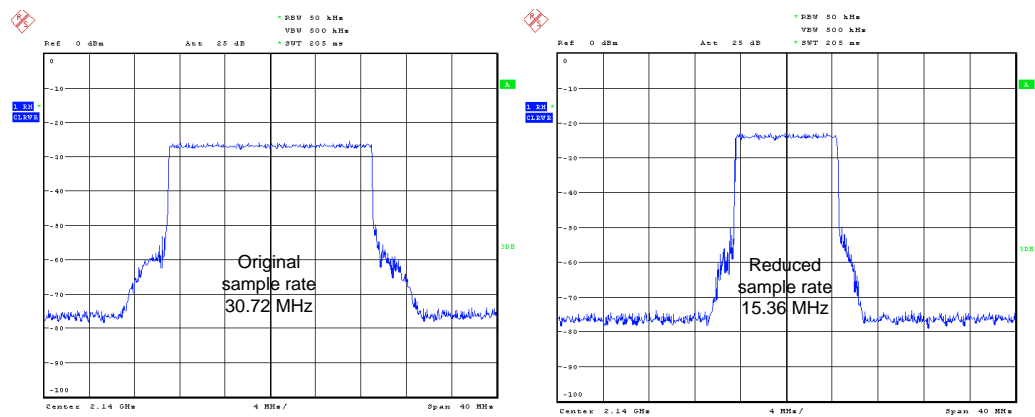


The parameter “Sample Rate Variation” is part of the “Filter/Clipping/Power Settings” menu which can be opened by clicking the “Filter/Clipping/Power” button in the main menu.

5.2 AWGN Signal

Decreasing the sample rate of the baseband signal has an effect on the bandwidth of the signal: the bandwidth narrows. For example, the bandwidth of a 20 MHz LTE signal at 30.72 MHz decreases to 10 MHz when the sample rate is reduced by a factor of 2.

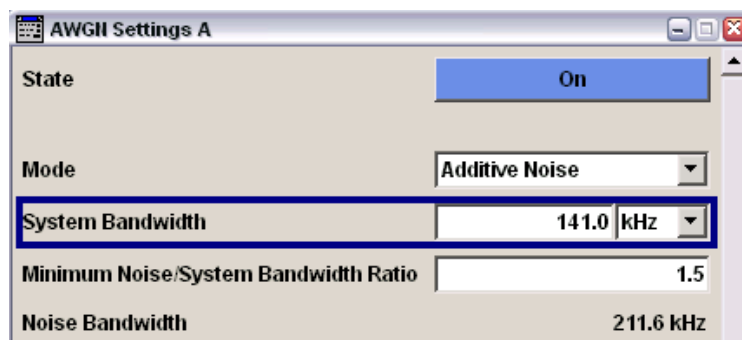
² For some digital standards the parameter is named “Chip Rate Variation”.



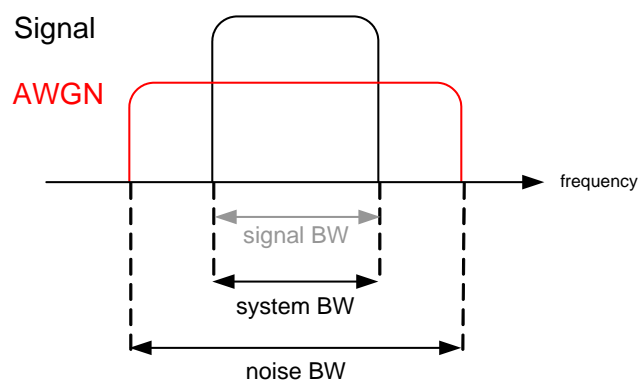
For this reason, the AWGN signal bandwidth needs to be adapted. Adjust the parameter “System Bandwidth” according to the following formula:

$$\text{System Bandwidth} = \text{Standard System Bandwidth} / N$$

For example, the occupied bandwidth of a 20 MHz LTE signal is 18.015 MHz. The AWGN system bandwidth needs thus to be set to $18.015 \text{ MHz} / 128 = 0.141 \text{ MHz}$.



The following figure illustrates the shown setting parameters:



The noise bandwidth should be set wider than the signal bandwidth to assure that the spectrum of the noise inside the signal bandwidth is flat. This can be done by setting the parameter “Minimum Noise/System Bandwidth Ratio” to values greater than 1. The resulting noise bandwidth is then calculated and displayed according to the formula:

$$\text{Noise Bandwidth} = \text{System Bandwidth} \cdot \text{Minimum Noise/System Bandwidth Ratio}$$

The system bandwidth is the reference parameter for noise power calculation. The noise power is always calculated in relation to the system bandwidth from the set signal-to-noise ratio (SNR). This makes it easy, to set a certain noise power in a given bandwidth.

5.3 Fading Simulation

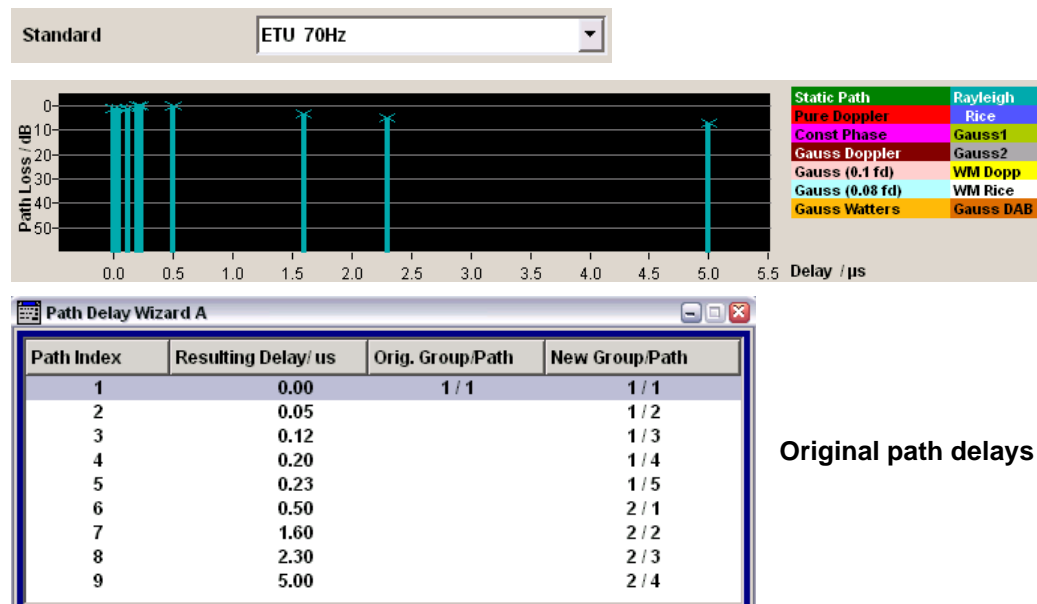
When decreasing the sample rate of the baseband signal also the fading simulation needs to be slowed down accordingly. The fading processes can be adapted to low speed by adjusting

- the path delays
- the Doppler shifts

5.3.1 Adjusting Path Delays

For example, the ETU 70 Hz fading scenario defined for LTE has nine fading taps with different delays. These delays need to be increased to slow down fading simulation to the same degree as data generation.

The original ETU 70 Hz scenario is available as predefined setting and has the following path delays:



Proceed in the following way to adjust the path delays for slow I/Q mode:

Adjust the parameter “Resulting Delay” which is the sum of the parameters “Basic Delay” and “Additional Delay” according to the following formula:

$$\text{Resulting Delay} = \text{Standard Resulting Delay} \cdot N$$

	4 1	4 2
State	On	Off
Profile	Rayleigh	Rayleigh
Path Loss /dB	5.00	0.00
Basic Delay /μs	294.40	294.40
Additional Delay /μs	0.00	0.00
Resulting Delay /μs	294.40	294.40

The easiest way to configure the “Resulting Delay” is to use the “Path Delay Wizard”, since it automatically sets the “Basic Delay” and the “Additional Delay” such that the wanted delay is achieved.

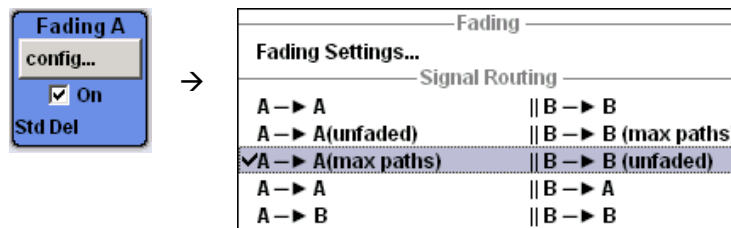
For example, the original delays increase by the slowdown factor $N = 128$ to the following values:

Path Index	Resulting Delay/ us	Orig. Group/Path	New Group/Path
1	0.00	1 / 1	1 / 1
2	6.40		1 / 2
3	15.36		1 / 3
4	25.60		1 / 4
5	29.44		1 / 5
6	64.00		2 / 1
7	204.80		3 / 1
8	294.40		4 / 1
9	640.00		6 / 1

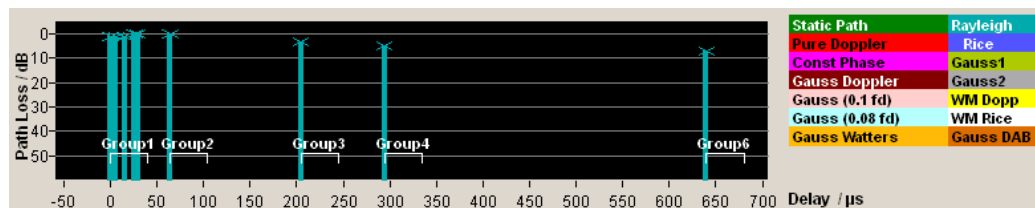
Slow I/Q path delays

Some fading scenarios, e.g. the ETU 70 Hz, have large delays between some of their fading taps. For example, taps 6, 7, 8, and 9 are largely separated. In particular the last tap has such a large delay that one fading simulator (option B14) is not sufficient any longer to reproduce the slow I/Q fading simulation. In this case a second fading simulator (option B15) is needed to enhance the number of available path groups from 4 to 8 (see reference [4] for details).³ To “combine” both fading simulators make the following selection in the “Fading” block:

³ The second fading simulator (option B15) is needed to obtain the above screenshot of the “Path Delay Wizard” showing the slow I/Q path delays for the ETU 70 Hz fading scenario.



With this setting up to 8 path groups are available which makes it possible to reproduce even fading scenarios such as the ETU 70 Hz in slow I/Q mode.



Note that the “Path Delay Wizard” configures the delay parameters only. All other settings such as the parameters “Profile” and “Path Loss” are not influenced. However, the “Path Delay Wizard” rearranges the activated taps in the path table to implement the larger delays. Therefore, after having adjusted the delays of the fading taps, adjust also the parameters “Profile” and “Path Loss” in the path table to exactly reproduce the original scenario. For example, for tap 8, change the path loss from 0 dB (default setting) to 5 dB like it is in the original fading scenario.

	3	4	4
	5	1	2
State	Off	On	Off
Profile	Rayleigh	Rayleigh	Rayleigh
Path Loss /dB	0.00	5.00	0.00
Basic Delay /μs	204.80	294.40	294.40
Additional Delay /μs	0.00	0.00	0.00
Resulting Delay /μs	204.80	294.40	294.40

5.3.2 Adjusting Doppler Shifts

In addition to adjusting the path delays, also the Doppler shifts need to be adapted.

The Doppler shift is calculated from the RF frequency and the relative speed between a transmitter and a receiver according to the following relation:

$$\frac{\text{Doppler shift}}{\text{RF frequency}} = \frac{\text{Speed}}{\text{Speed of light}}$$

For example, for the ETU 70 Hz fading scenario the stipulated Doppler shift is 70 Hz. The wanted RF frequency of the carrier signal is e.g. 2.14 GHz. To get the correct setting for the parameter “Speed” in the path table set the RF frequency to 2.14 GHz on the SMU. The speed is 35.3 km/h according to the above formula.

Speed /km/h	35.302
Freq. Ratio	0.00
Res. Doppler Shift /Hz	70.00

Proceed in the following way to adjust the Doppler shifts for slow I/Q mode. Follow the steps in the given order:

In the fading menu, set the parameter “Keep Constant” to “Speed”.

Keep Constant	Speed
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This parameter determines whether the speed or the Doppler shift is kept constant when the (virtual) RF frequency changes.

Set the parameter “Signal Dedicated To” to “Baseband Output”.

Signal Dedicated To	Baseband Output
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With this setting the RF frequency used by the fading simulator to calculate the Doppler shift can be defined via the parameter “Virtual RF”.

Adjust the parameter “Virtual RF” according to the following formula:

$$\text{Virtual RF} = \text{Wanted RF frequency} / N$$

For example, the wanted RF frequency of the carrier signal is 2.14 GHz and the slowdown factor N is 128. The parameter “Virtual RF” thus needs to be set to 16.719 MHz.

Virtual RF	16.718 750 00 MHz
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As a cross check you can take a look at the path table. The parameter “Res. Doppler Shift” has changed from 70 Hz to 70 Hz / $N = 0.547$ Hz.

Speed /km/h	35.302
Freq. Ratio	0.00
Res. Doppler Shift /Hz	0.55

Note that it is not sufficient to adjust only the parameter “Res. Doppler Shift” in the path table, since this parameter influences only the Doppler shift of the direct line of sight signal. The adjustment of the Doppler shifts must be done via parameter “Virtual RF”, since this parameter influences the Doppler shifts of all multipath echoes within a (single) Rayleigh tap.

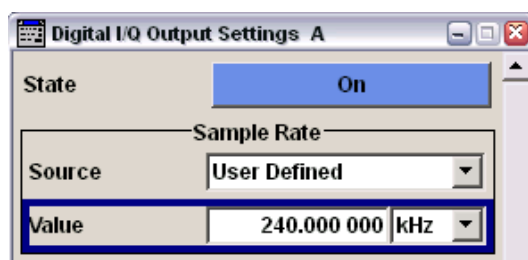
5.4 Digital I/Q Output Settings

When testing hardware emulators usually the digital output of the instrument is utilized. The I/Q data (generated at R_{sample}) can be resampled to an output sample rate that can be defined by the user.

In order not to apply any down- or up-sampling, the digital I/Q output sample rate needs to be set to the same sample rate as used in the baseband for slow I/Q signal generation.

$$\text{Sample Rate Value} = R_{sample} \text{ (slow IQ)}$$

For example, the sample rate is set to 240 kHz.



5.5 HARQ Feedback

If real-time HARQ feedback is used in the test setup (see references [5] and [6] for details), the user can set the parameter "Additional User Delay" in units of chips (3GPP FDD) or subframes (LTE). By slowing down the baseband signal these units are also "slowed down" accordingly, i.e. a LTE subframe is no longer 1 ms but takes $1 \cdot N$ milliseconds. The entered additional user delay increases therefore accordingly and does in principle not need to be adapted for slow IQ mode.



However, in some test setups some fine-adjustment may become necessary. In this case, adjust the "Additional User Delay" parameter as required.

6 Abbreviations

ARB	Arbitrary waveform generator
AWGN	Additive white Gaussian noise
BBU	Baseband unit
CPRI	Common public radio interface
DUT	Device under test
eNodeB	evolved NodeB
ETU	Extended typical urban
FPGA	Field-programmable gate array
GMSK	Gaussian minimum shift keying
GSM	Global system for mobile communication
HARQ	Hybrid automatic repeat request
I/Q	In-phase/quadrature
LTE	3GPP long term evolution
MIMO	Multiple input multiple output
OFDM	Orthogonal frequency division multiplexing
RF	Radio frequency
RRH	Remote radio head
UE	User equipment

7 References

- [1] Rohde & Schwarz, R&S®EX-IQ-BOX Digital Interface Module Operating Manual
- [2] Rohde & Schwarz, “Starting Successfully with the R&S EX-IQ-BOX” Application Note (1MA168)
- [3] Rohde & Schwarz, “CPRI RE Testing” Application Note (1GP78)
- [4] Rohde & Schwarz, Fading Simulation Manual for R&S®SMU200A and R&S®AMU200A
- [5] Rohde & Schwarz, 3GPP FDD incl. enhanced MS/BS tests, HSDPA, HSUPA, HSPA+ Digital Standard for R&S® Signal Generators Operating Manual
- [6] Rohde & Schwarz, EUTRA/LTE Digital Standard for R&S® Signal Generators Operating Manual

8 Ordering Information

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

- R&S®SMU200A vector signal generator
- R&S®AMU200A baseband signal generator and fading simulator
- R&S®SMBV100A vector signal generator
- R&S®SMJ100A vector signal generator
- R&S®EX-IQ-BOX digital interface module

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