R&S®NRQ6
Phase Coherent Measurements
Application Sheet

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Version 04

ROHDE&SCHWARZ
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1 Your task

This application sheet describes the cabling and configuration of two frequency selective power sensors, R&S NRQ6, to perform complex phase coherent measurements on 5G-NR/LTE/MCCW/CW signals with bandwidths ≤ 100 MHz.

The procedure described here can be applied to other signal models and more than two R&S NRQ6.

2 Possible solution

The application sheet illustrates a two-step measurement procedure, where the system is first calibrated and then used to perform synchronous phase coherent measurements based on a sender/receiver relationship between two R&S NRQ6.

Given that the two R&S NRQ6 are equipped with the appropriate software options, an R&S NRQ6 is set as receiver to be triggered by a sender R&S NRQ6. The sender R&S NRQ6 is synchronized by external reference to a signal source.

The sender is configured to forward its local oscillator signal (LO) and its clock signal (CLK) to the receiver. The receiver is instructed to use these external LO and CLK signals as internal signals. The receiver is configured to have an external trigger source, as it receives its trigger event from the sender, which can have any trigger source.

Because the sender starts its triggered measurement before the receiver does, the receiver performs deferred measurements in relation to the sender. To eliminate the resulting group delay in the receiver measurements, a calibration step is carried out. The saved calibration data is used in the measurement step to compensate the occurring group delay in the receiver measurements and to measure the relative phase difference existing between the complex measurements of the sender and receiver.

This application can be used, for example, to calibrate multiple active antenna modules for beamforming by measuring the relative phase error between a calibration port and each antenna port.

3 How to cable and configure the R&S NRQ6

Prerequisites

To use the I/Q data interface feature and the phase coherent measurement feature of the R&S NRQ6, the power sensor must be equipped with the I/Q data interface and phase coherent measurements options. You can purchase these add-ons at any time as supplementary options. If necessary, contact R&S sales.

Given that both R&S NRQ6 sensors are equipped with the I/Q data interface and phase coherent measurements options, two separate measurement steps are performed:

- Calibration step
- Measurement step

3.1 Calibration step

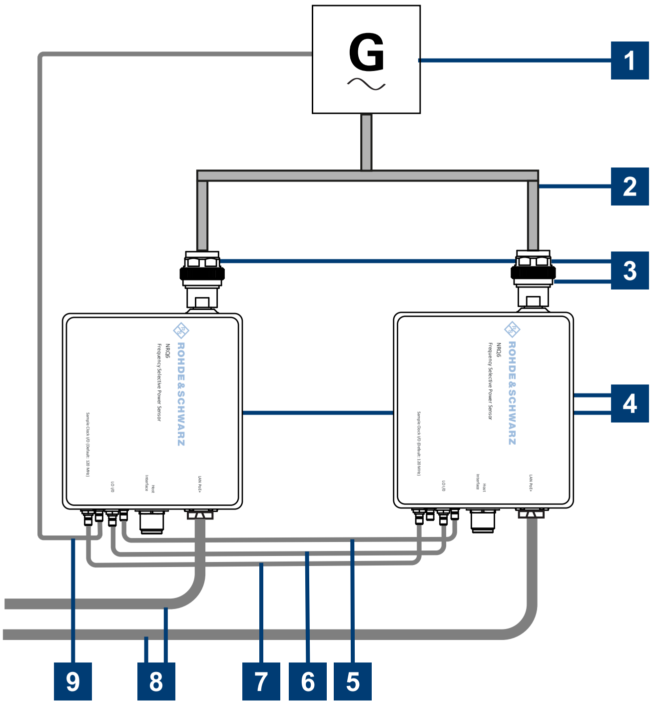

Figure 3-1: Calibrating the system

1 = Signal generator (signal source)
2 = Power splitter
3 = RF connector
4 = R&S NRQ6
5 = Trigger connection
6 = Local oscillator connection
7 = Sampling clock connection
8 = LAN connection to controlling host and power supply
9 = External reference fed into the reference clock of the sender R&S NRQ6

To calibrate the system accurately, proceed as follows:

1. Use a highly symmetrical power splitter to split the source signal of the generator into the two R&S NRQ6.
2. Connect the reference output of the signal generator to the reference input of the sender R&S NRQ6 using a standard coaxial cable with appropriate adaptor.

3. Connect both R&S NRQ6 using standard SMA cables. Ensure that the cables used for the trigger and sample clock connection are of identical length.
   a) Trigger connection: TRIG2 -> TRIG2
   b) Sampling clock connection: CLK -> CLK
   c) Local oscillator connection: LO -> LO

After establishing the calibration setup, configure both R&S NRQ6 by entering the following SCPI commands:

SCPI commands for sender and receiver R&S NRQ6

```
*RST
# Reset the power sensor
*CLS
# Clear status subsystem
*IDN?
# Query devices' identification (optional)
SENS:ROSC:SOUR INT
# Set the source of the reference oscillator to "internal" (default setting)
SENS:ROSC:PASS OFF
# Disable clock distribution mode and the use of external clock
# (default setting)
SENS:FREQ:CONV:MIX:LO:SOUR INT
# Set the local oscillator source to "internal" (default setting)
TRIG:EXT2:IMP LOW
# Set termination resistance of the second external trigger input to "LOW"
#(= 50 ohm)
SENS:INP:ATT:AUTO OFF
# Disable the automatic setting of input attenuation (optional)
SENS:INP:ATT 0
# Set input attenuation to 0 dB (optional)
SENS:BAND:TYPE RES
# Define the bandwidth to be specified by the resolution bandwidth
SENS:BAND:VAR ON
# Enable the resampler or a continuous adjustment of the sample rate
SENS:BAND:RES:TYPE:AUTO OFF
# Disable automatic configuration of the resolution bandwidth filter type
SENS:BAND:RES:TYPE FLAT
# Set resolution bandwidth filter type to "FLAT"
SENS:BAND:RES 100e6
# Set the filter resolution bandwidth to 100 MHz
SENS:FREQ:CONV:MIX:IF:SID:AUTO OFF
# Disable automatic setting of the intermediate frequency sideband
SENS:FREQ:CONV:MIX:IF:SID RIGH
# Set used intermediate frequency sideband to the right sideband
SENS:FUNC "XTIM:VOLT:IQ"
# Set measurement mode to I/Q voltage trace mode (required option: R&S NRQ6-K1)
```

Extra SCPI commands only for sender R&S NRQ6

```
TRIG:SEND:STAT ON
# Enable the sensor to be trigger sender
TRIG:SEND:PORT EXT2
# Select "external2" (= through SMA connector) as the port where the sender
# outputs the digital trigger signal
TRIG:SOUR IMM
# Select "immediate" as the source for the trigger event
SENS:TRAC:IQ:SYNC:TYPE SEND
# Set the synchronisation for phase coherent measurements and configure
# the R&S NRQ6 as sender (required options: R&S NRQ6-K1, R&S NRQ6-K3)
SENS:FREQ:CONV:MIX:LO:OUTP ON
# Enable the output of the local oscillator signal
SENS:SAMP:CLK:OUTP ON
# Enable the output of the sampling clock signal
SENS:ROSC:SOUR REF
# Set the reference oscillator source to Reference I/O
```

Extra SCPI commands only for receiver R&S NRQ6

```
SENS:TRAC:IQ:SYNC:TYPE REC
# Set the synchronisation for phase coherent measurements and configure
# the R&S NRQ6 as receiver (required options: R&S NRQ6-K1, R&S NRQ6-K3)
SENS:FREQ:CONV:MIX:LO:SOUR EXT
# Set local oscillator source to "external" for the receiver
SENS:ROSC:PASS ON
# Set an external clock signal to be used for the receiver
TRIG:SOUR EXT2
# Select "external2" (= through SMA connector) as the source for the
# trigger event
```

After configuring both R&S NRQ6 to perform phase coherent measurements based on a sender/receiver relationship, a calibration measurement is performed at the RF ports of the sender and receiver. The measurement data are obtained by entering the following SCPI commands:

SCPI commands to fetch data

In sender and receiver:

```
SENS:FREQ 3.5e9
# Set carrier frequency of applied signal to 3.5 GHz
```

First in receiver:

```
INIT:IMM
# Wait for trigger condition to be fulfilled in order to begin the measurements
# of the receiver
```

Then in sender:

```
INIT:IMM
# Start sender measurement immediately and trigger the receiver measurements
```

In sender and receiver:

```
FETC?
# Query the measurement results
```

The fetched complex IQ data of the sender and receiver, $IQ_{cal\ sender}(n)$ and $IQ_{cal\ receiver}(n)$, are saved in a calibration file. They are recalled later in each sender/receiver measurement in the measurement step, to compensate the group delay caused by the deferred triggering of the receiver R&S NRQ6. This compensation is illustrated in the following chapter.

3.2 Measurement step

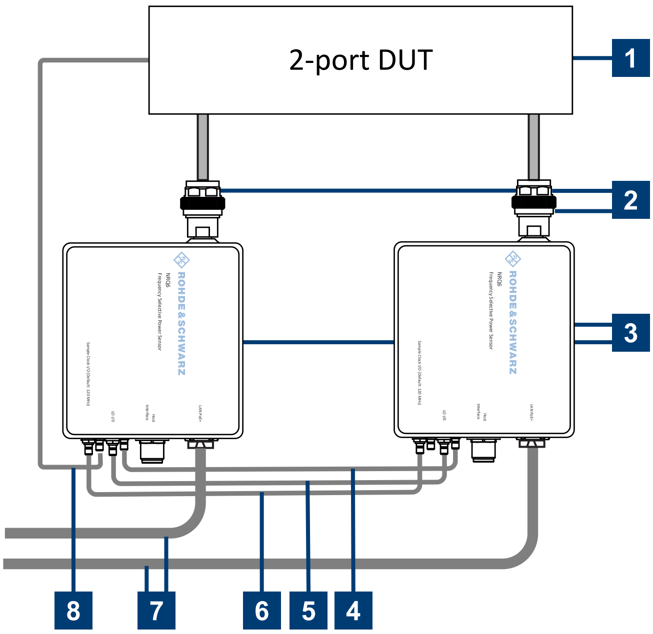

Figure 3-2: Measuring the phase difference

1 = 2-port DUT (signal source)
2 = RF connector
3 = R&S NRQ6
4 = Trigger connection
5 = Local oscillator connection
6 = Sampling clock connection
7 = LAN connection to controlling host and power supply
8 = External reference fed into the reference clock of the sender R&S NRQ6

To perform phase coherent measurements on two different channels, proceed as follows:

1. Use a 2-port DUT as a signal source for both R&S NRQ6.
2. Connect the reference output of the signal source to the reference input of the sender R&S NRQ6 using a standard coaxial cable with appropriate adaptor.

3. Connect both R&S NRQ6 using the same SMA cables as in the Calibration step.

First, both R&S NRQ6 are initialized and configured using the previously mentioned SCPI commands, expect SCPI commands to fetch data.

To perform synchronous phase coherent measurements by the two R&S NRQ6, the SCPI commands to fetch data are applied to both power sensors to deliver the fetched IQ data, $IQ_{sender}(n)$ and $IQ_{receiver}(n)$. These data must be calibrated using the saved calibration data, $IQ_{cal\ sender}(n)$ and $IQ_{cal\ receiver}(n)$, from the calibration step. In fact, the calibrated phase difference between sender and receiver can be expressed over the frequency *f* as follows:

$$\varphi_{\mathrm{sender}}(f) - \varphi_{\mathrm{receiver}}(f) = \mathrm{angle}\left(\frac{\boldsymbol{\mathcal{F}FT}\left(IQ_{\mathrm{sender}}(n)\right)/\boldsymbol{\mathcal{F}FT}\left(IQ_{\mathrm{cal\ sender}}(n)\right)}{\boldsymbol{\mathcal{F}FT}\left(IQ_{\mathrm{receiver}}(n)\right)/\boldsymbol{\mathcal{F}FT}\left(IQ_{\mathrm{cal\ receiver}}(n)\right)}\right)$$

To perform further phase coherent measurements, the SCPI commands to fetch data are applied again to both power sensors, while using the same calibration data.

For source signals with predefined subcarrier frequencies, you can obtain highly accurate phase difference results by interpolating the FFT of the fetched data vectors at the predefined subcarrier frequencies of the source signal.

Presume that the source signal is a multicarrier signal with a center frequency of 3.5 GHz, a bandwidth of 100 MHz and a subcarrier spacing of 1 MHz. Then the frequency axis, used in the FFT interpolation, has 100 entries and is equal to:

3.5 GHz + [-50 MHz + 0.5x1 MHz, -50 MHz + 1.5x1 MHz, …, 50 MHz - 1.5x1 MHz, 50 MHz - 0.5x1 MHz]

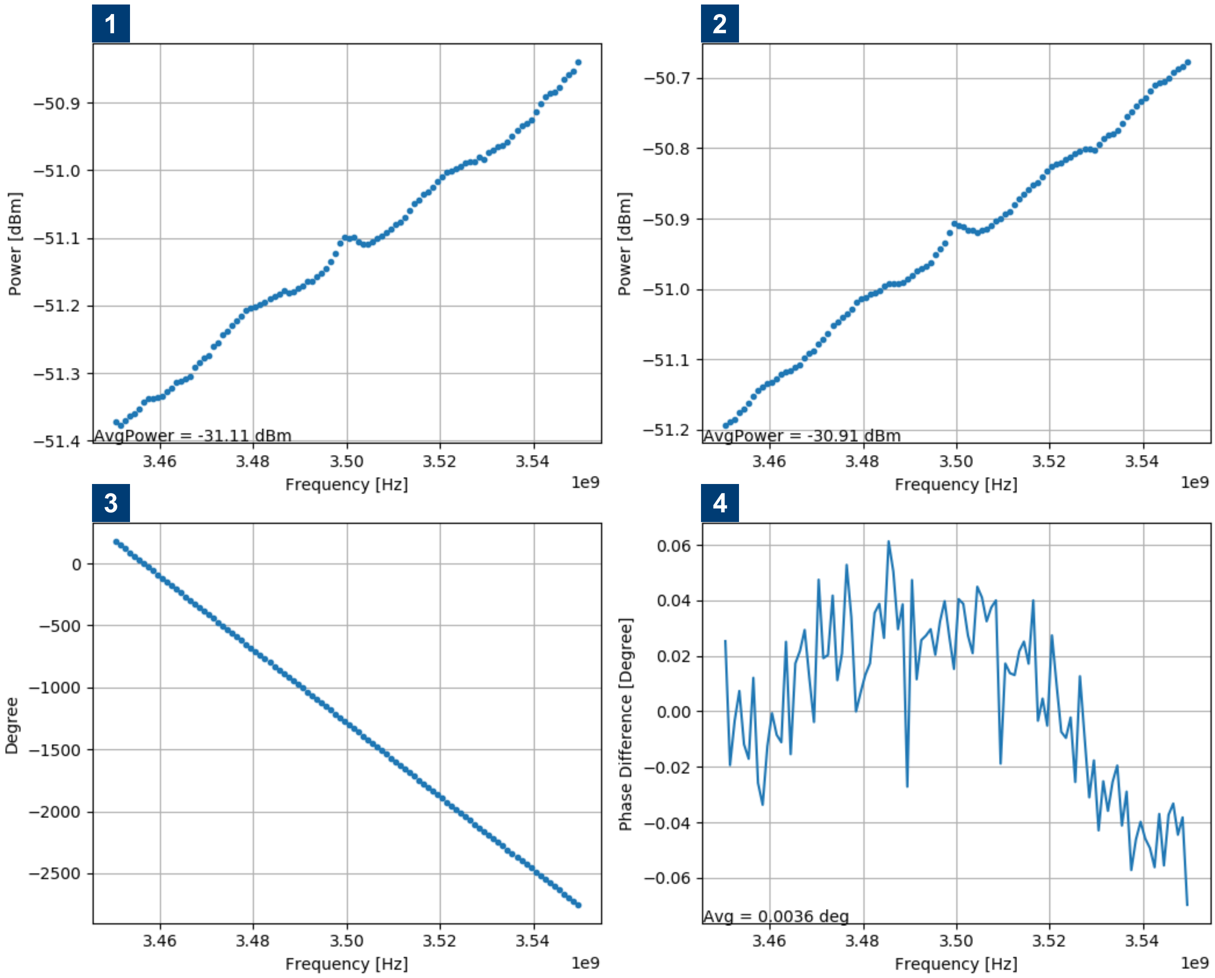

Figure 3-3: Plots of measured power and phase difference between the sender and receiver R&S NRQ6

1 = power measured by sender R&S NRQ6 (100 carriers)
2 = power measured by receiver R&S NRQ6
3 = absolute phase difference between sender and receiver
4 = relative phase difference (calibrated) between sender and receiver

For both sender and receiver R&S NRQ6, the measured power values, interpolated at the previous frequency axis, are shown in the upper two plots of Figure 3-3. The average power value is calculated in dBm and presented in the lower left corner of each plot.

The lower left plot illustrates the absolute non-calibrated phase difference between the sender and receiver R&S NRQ6. The corresponding phase slope is caused by the deferred triggering of the receiver R&S NRQ6 and is compensated after calibrating to yield the relative phase difference shown in the lower right plot of Figure 3-3. The average relative phase difference is calculated in degrees and presented in the lower left corner of the plot.

Table 3-1: Typical standard deviation of measured phase difference between both R&S NRQ6 under constant temperature and for different total average signal power values

Signal characteristics	**MCCW signal with a center frequency of 3.5 GHz, a bandwidth of 100 MHz and a subcarrier spacing of 1 MHz**		
Total average signal power	-40 dBm	-50 dBm	-60 dBm
Typical standard deviation σ of 10 consecutive phase measurement results	0.04°	0.06°	0.1°

Table 3-1 shows typical standard deviation values of the measured phase difference between the sender and receiver R&S NRQ6 under constant temperature for different total average power values of the input signal. The measured input signal is a multicarrier signal with a center frequency of 3.5 GHz, a bandwidth of 100 MHz, and a subcarrier spacing of 1 MHz.

For a decreasing total average signal power, the typical standard deviation of the measured phase difference between the R&S NRQ6 increases, since the corresponding input signal shows a deteriorating signal-to-noise ratio.

To verify the phase measurement accuracy of the R&S NRQ6, you can generate an additional constant phase/group delay between the two ports of the DUT and measure it as the relative phase difference/group delay between the complex measurements of the R&S NRQ6.

Unlike other phase coherent systems, the phase calibration, carried out for both R&S NRQ6, holds for a very long time and does not have to be repeated after each single phase measurement or after restarting the R&S NRQ6. However, a new phase calibration of both R&S NRQ6 is needed, if the cables connecting the sender and receiver R&S NRQ6 have been changed or if you want to measure a different signal type (LTE, 5G-NR, MCCW, …).

4 Increasing the number of R&S NRQ6 receivers

Based on the same concept, the phase coherent construction using a sender R&S NRQ6 and a receiver R&S NRQ6 can be extended by using many receivers R&S NRQ6, thus increasing the number of phase coherent measurement channels.

The measurement principle remains the same. The sender R&S NRQ6 is configured to forward its LO and CLK signals simultaneously to all receivers R&S NRQ6. The receivers R&S NRQ6 are instructed to use the external LO and CLK signals, coming from the sender, as internal signals. All the receivers R&S NRQ6 are triggered externally from the sender, which can have any trigger source.

For this extended setup, two different scenarios for the phase coherent measurements are possible:

- The first scenario comprises a *non-measuring* sender R&S NRQ6 and multiple measuring receivers R&S NRQ6. In fact, the sender R&S NRQ6 does not measure the input signal, but works only as a signal distributer for the multiple receivers R&S NRQ6. If there is a symmetric signal distribution from the sender to all receivers, the receivers measurements are triggered simultaneously. Therefore, no calibration step is needed for the obtained receiver measurements, because they are already synchronized and phase coherent between each other.

- The second scenario comprises a *measuring* sender R&S NRQ6 and multiple measuring receivers R&S NRQ6. In this scenario, the sender R&S NRQ6 measures the input signal and, at the same time, forwards its LO and CLK signals to the multiple receivers. Thanks to the measurement of the sender, an extra phase coherent measurement channel is available. However, a calibration step is needed for all receiver measurements to compensate the group delay caused by the deferred triggering of the receivers by the sender.

Plots of the first scenario with a sender and eight receivers R&S NRQ6

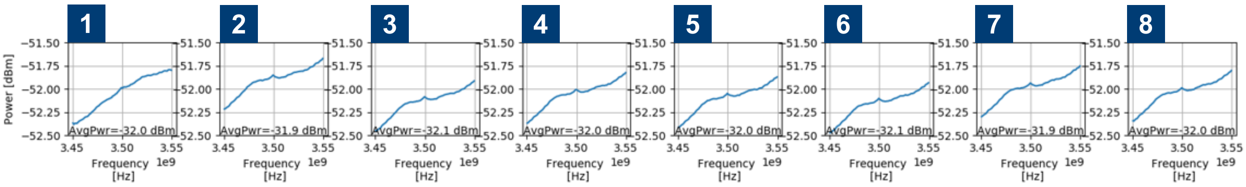

Figure 4-1: Measured power

1 = receiver 1
2 = receiver 2
... = ...
8 = receiver 8

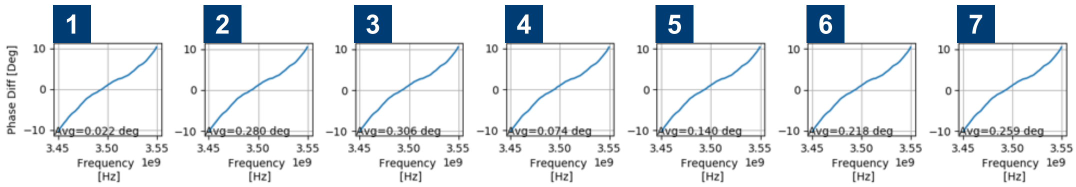

Figure 4-2: Calibrated phase difference

1 = between receivers 1 and 2
2 = between receivers 1 and 3
... = ...
7 = between receivers 1 and 8

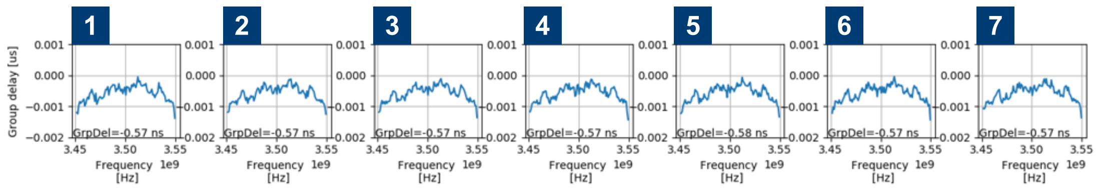

Figure 4-3: Measured group delay

1 = between receivers 1 and 2
2 = between receivers 1 and 3
... = ...
7 = between receivers 1 and 8

By applying the first scenario using a sender R&S NRQ6 and eight receivers R&S NRQ6, phase coherent measurements are made by the eight receivers R&S NRQ6. Figure 4-1 shows the measured power values in dBm at each receiver R&S NRQ6. Figure 4-2 presents the relative phase difference measured between receiver 1 and receiver 2 to 8. Figure 4-3 shows the measured group delay between receiver 1 and receiver 2 to 8.

5 Additional helpful commands

Checking the current sampling rate

```
SENS:TRAC:SRAT?
```

Specifying numeric data format

```
FORM REAL,32
#  Block data in binary form with length 32
```

Checking the number of resulting I/Q value pairs

```
SENS:TRAC:RLEN?
```

6 Learn more about the R&S NRQ6

For a detailed description of the capabilities of the R&S NRQ6, read its user manual. The user manual also explains all aspects of remote control features in details.

Also, you can always install our basic driver and tools package called R&S NRP Toolkit. Among various tools, this package supplies an optional SDK (software development kit), which contains many sample programs with full commented source code in various programming languages. These sample programs include a demonstration of the calibration step and the measurement step using two phase coherent R&S NRQ6 for the following source signals: 5G-NR, LTE, MCCW and CW. On an MS Windows PC, you find the SDK after installation under:

`C:\ProgramData\Rohde-Schwarz\NRP-Toolkit-SDK\`

The examples especially for the R&S NRQ6 are under:

`C:\ProgramData\Rohde-Schwarz\NRP-Toolkit-SDK\examples\NRQ`

Download the latest version of the R&S NRP Toolkit at:

www.rohde-schwarz.com/software/nrp_s_sn/