Application Note

5G FR1 DOWNLINK MIMO PHASE COHERENT SIGNAL ANALYSIS

Products:

- ► R&S®RTP
- ► R&S®RTO
- ► R&S®VSE
- ► R&S®NRQ6
- ► R&S®SMW200A

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http://www.rohde-schwarz.com/appnote/GFM343

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Contents

1 Overview

5G New Radio (NR) FR1 MIMO or beamforming downlink signal analysis especially the phase measurement of each MIMO layer and the determination of the phase difference between the MIMO layers are essential for the 5G base station product design.

In this application note, it describes two test solutions from R&S® to cope with the 5G FR1 downlink MIMO signal analysis challenges either using R&S®RTP/RTO oscilloscope or R&S®NRQ6 frequency selective power sensor as RF frontend to capture the signal and together with R&S®VSE as post-processing tool for the IQ analysis.

The aim of this application note is to walk the user through the necessary steps on both test solutions to enable the 5G FR1 downlink MIMO signal analysis.

The entire application note is organized with following structure:

Chapter 2 gives a high level introduction of both test solutions

Chapter 3 outlines the test solution with oscilloscope R&S®RTP/RTO as RF frontend that includes its environment setup as well as the related settings in R&S®VSE

Chapter 4 describes the test solution with R&S®NRQ6 as RF frontend

Appendix A lists the parameters of the applied example 5G FR1 downlink 2x2 MIMO signal

Appendix B gives a guide on how the example signal is generated on a vector signal generator R&S®SMW200A

Appendix C provides the informative content about 5G NR antenna port

Throughout the whole application note, the following abbreviations are used for Rohde & Schwarz test equipments:

► R&S®RTP High-Performance Oscilloscope is referred to as RTP

► R&S®RTO Oscilloscope is referred to as RTO

► R&S®RTP/R&S®RTO-K11 I/Q software interface is referred to as RTP/RTO-K11

► R&S®VSE Vector Signal Explorer is referred to as VSE

► R&S®VSE-K144 5G NR Uplink and Downlink Measurement Application is referred to as VSE-K144

► R&S®VSE-K146 5G NR MIMO Measurement Application is referred to as VSE-K146

► R&S®VSE-K544 User defined frequency response correction by SnP file is referred to as VSE-K544

► R&S®NRQ6 Frequency Selective Power Sensor is referred to as NRQ6

► R&S®NRQ6-K1 IQ Data Interface is referred to as NRQ6-K1

► R&S®NRQ6-K3 Phase Coherent Measurements is referred to as NRQ6-K3

► R&S®SMW200A Vector Signal Generator is referred to as SMW200A

It is assumed that the reader has certain pre-knowledge of 5G NR physical layer. In case a refreshment is needed, please refer to the R&S® 5G eBook [1] for further reading.

2 Introduction

5G NR, state of the art mobile radio access technology, largely enhances the mobile broadband communication (eMBB), enables the Ultra-Low Latency Communication (URLLC) and massive IoT (mIoT) connectivities to serve the vertical industries.

Massive Multiple-Input Multiple Output (MIMO) antenna system and beamforming are no doubt few of the compelling technologies facilitated by 5G NR. They are the key enablers and foundational components of 5G deployment for improving end-user experience, network capacity and coverage that contribute to the high spectral efficiency in the end.

It is essential for the participants of the 5G network infrastructure eco-system, meaning chipset vendors, R&D, productions as well as the services to ensure the specification conformed and high performance of the MIMO or beamforming system before the product launch and commercial deployment. Market driven test solutions of 5G MIMO signal analysis are asked. Rohde & Schwarz®, active player in the test and measurement business field of mobile telecommunications over years, offers the test solutions based on this market needs.

In Fig. 2-1 shows a general concept for 5G FR1 downlink MIMO signal analysis based on MIMO conducted test mode. Meaning all the MIMO layers are connected to the used RF frontend per RF cables directly. In this application note, two test solutions from R&S® product family are described. As RF frontend, either RTP/RTO or NRQ6 with required software options can be utilized to capture the MIMO signal. Both solutions facilitate the VSE with option K144 and K146 as a post-processing tool to demodulate and decode the baseband IQ signal. Thanks to the multi-channel capability of the RF frontend as well as MIMO measurement featured by VSE-K146, simultaneous phase coherent measurement of the MIMO layers becomes true. Furthermore, the phase difference between any two of the MIMO layers can be determined easily and effectively.

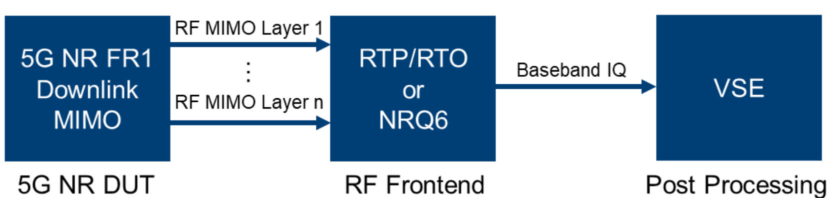


Fig. 2-1: Block diagram of 5G NR FR1 downlink MIMO signal analysis test concept

Table 2-1 summarizes the entire measurement items out of VSE-K144 and K146 personality.

Measurement	Description
EVM vs. Carrier	Error Vector Magnitude (EVM) of the subcarriers within the channel bandwidth
EVM vs. Symbol	Error Vector Magnitude (EVM) of the OFDM symbols
EVM vs. RB	Error Vector Magnitude (EVM) of the PDSCH resource block
Freq Error vs. Symbol	Frequency error of each symbol
Power Spectrum	Power density of captured signal in capture buffer
Flatness vs. Carrier	Relative power offset caused by the transmit channel for each subcarrier
CCDF	Complementary Cumulative Distribution Function (CCDF) is the probability of an amplitude exceeding the mean power measured over the entire captured signal
Constellation	A diagram indicates the quality of the modulation of the signal
Allocation Summary	Tabular representation of various parameters of the measured resource allocations
Bitstream	Demodulated data stream for the data allocations
Channel Decoder	Shows the characteristics of various channels in a specific subframe
Result Summary	Shows all relevant measurement results in numerical form, combined in one table
EVM vs. Symb x Carrier	EVM for each carrier in each symbol
Power vs. Symb x Carrier	Power for each carrier in each symbol
Alloc ID vs. Symb x Carrier	Graphical representation of the allocation type of each subcarrier in each symbol of the captured signal
RS Phase	Shows the phase of the carriers occupied by various reference signals (PDSCH, PDCCH etc.) on different antenna ports (AP).
RS Phase Diff	Shows the phase difference of different antenna ports (AP) relative to a reference antenna port defined in VSE
Beamforming Summary	Shows the phase characteristics for each allocation used by the UE-specific reference signals (PDSCH, CORESET, CSI-RS etc.) in numerical form

Table 2-1: R&S®VSE-K144 / K146 5G NR measurements

VSE performs not only the signal analysis, but also takes care of the remote controlling of the connected RF frontend. In short, VSE is the only GUI that the user needs to interact with.

For sake of simplicity, a 5G FR1 downlink MIMO 2x2 signal is considered as an example signal in this application note. The details of the signal parameters can be found in Appendix A.

The solutions described in this application note are however not limited to two MIMO layers. By adding more RF frontend capacity, it can be extended to maximum eight MIMO layers from the VSE perspective.

3 Test Solution with Oscilloscope RTP/RTO

3.1 Setup

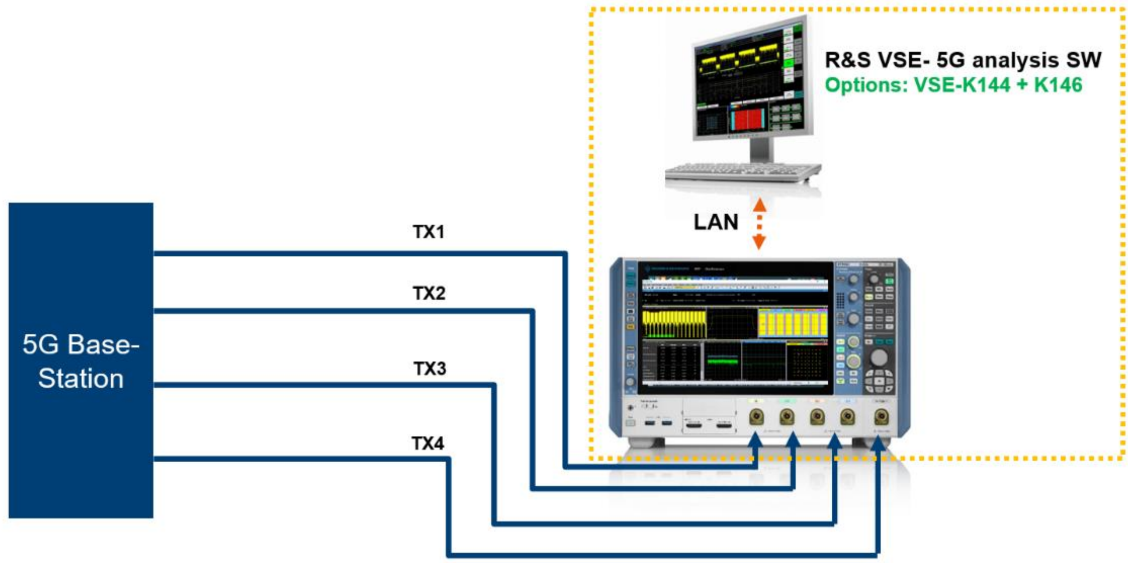


Fig. 3-1: 5G FR1 MIMO signal analysis with RTP/RTO and VSE

Fig. 3-1 illustrates the entire setup of the test solution with RTP/RTO as RF frontend. The DUT, e.g. 5G base station, feeds the downlink MIMO signals to RTP/RTO. With the help of RTP/RTO-K11 option, the RF signals are down-converted and down sampled. The generated IQ data are then stored in the memory and later on transferred to VSE for analysis. The controlling part of the RTP/RTO is integrated in the VSE tool. Therefore, VSE serves as both controller and analyzer.

An RTP/RTO is a multichannel oscilloscope with maximum support of four channels. Due to this hardware capacity, phase coherent measurement can be performed with up to four MIMO data streams simultaneously based on one single RTP/RTO together with VSE.

3.2 Calibration and Frequency Response Correction

In order to achieve the best possible measurement performance, the fixtures, e.g. RF cables, connectors, connected between the DUT and RF frontend (either RTP/RTO or NRQ6) have to be calibrated with respect to their amplitude and phase characteristics in frequency domain beforehand. With proper calibration or frequency response correction (FRC), the imperfection of the frequency response on the measurement results can be eliminated. The FRC feature in VSE requires VSE-K544 option.

One of the ideal instrument to conduct such calibration is the Vector Network Analyzer (VNA). See [2] to understand the basics of the calibration using VNA.

Based on the 2-ports cable calibration result out of VNA, an S-Parameter Touchstone file (*.s2p) is generated. The created Touchstone file can then be imported in the VSE as user defined frequency response correction to be applied to each MIMO layer individually.

In VSE main menu, goto Meas **Setup > User Correction** (Fig. 3-2)

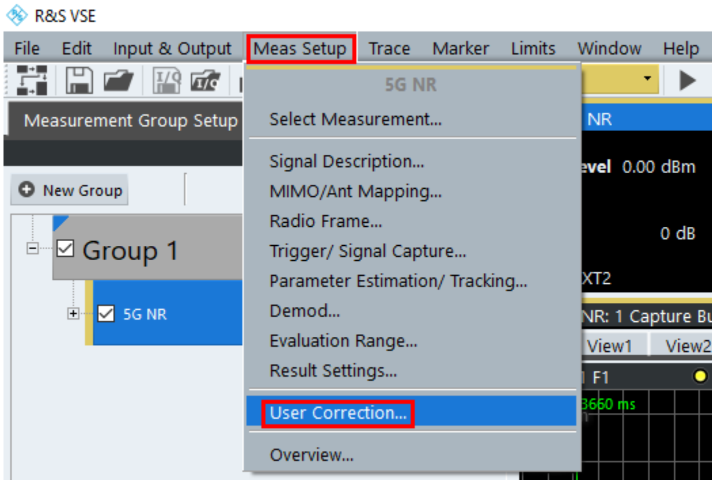


Fig. 3-2: Menu to access to user correction

1. As shown in Fig. 3-3, select "**Channel**". This allows the multiple input sources to apply the FRC separately.
2. Select each MIMO layer source and **add the Touchstone file** of the connected RF components individually
3. **Turn on** the Frequency Response Correction

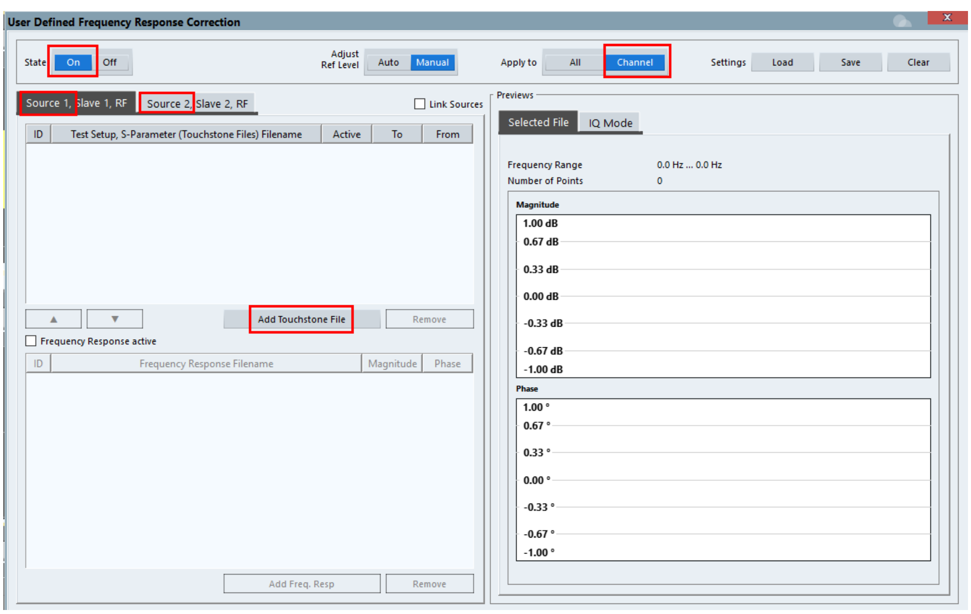


Fig. 3-3: Enter and enable the Touchstone file

Fig. 3-4 shows an example of a loaded Touchstone file with graphical representation of magnitude and phase compensation value over the calibrated frequency range.

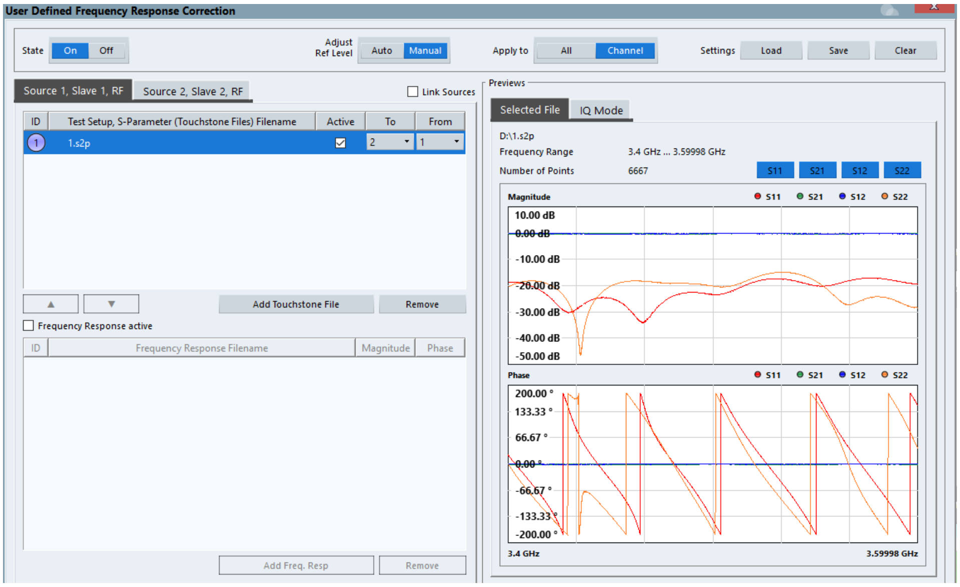


Fig. 3-4: Example of loaded Touchstone file

As long as the FRC is enabled, an indicator "**FRCORR**" in the status window of VSE as shown in Fig. 3-5 is given.

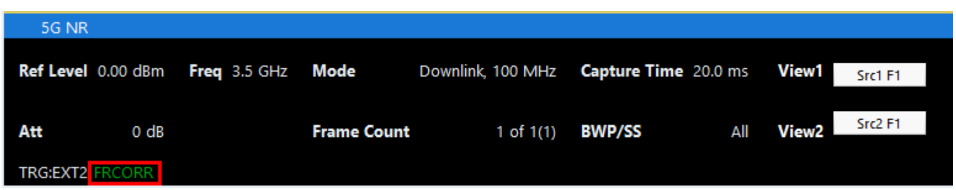


Fig. 3-5: Indication of frequency correction

Alternative to Touchstone file, a so called frequency response (FRES) file (*.fres) can be loaded for FRC as well. Please refer to Chapter 4.5 of [3] for details.

3.3 Required Software Options

3.3.1 RTP/RTO with RTP-K11 / RTO-K11 Option

RTP/RTO is time domain instrument of R&S® oscilloscope family [4].

RTP-K11 or RTO-K11 is a software option of RTP/RTO that enables the oscilloscope to be run under I/Q operation mode. This option allows the RTP/RTO to acquire digitally modulated signals and export the captured I/Q data with an adjustable sampling rate for the post processing tool, like MATLAB, LabView or VSE.

3.3.2 VSE with VSE-K144 and VSE-K146

VSE [5] is a high performance analysis software for various analysis tasks and can handle inputs from various instruments, e.g. RTP/RTO, NRQ6 etc.

For the 5G FR1 phase coherent MIMO signal analysis, minimum requirement of the VSE version should be greater than 1.70.

VSE-K144 is a firmware application running in the VSE environment that measures 5G NR signal measurement application on downlink direction for single layer.

VSE-K146 is the VSE application on top of the VSE-K144 that enables up to 8x8 true MIMO measurements for 5G downlink signal. It demodulates and decodes each MIMO layer and phase difference between the different antenna ports can be measured. A summary of the beamforming showing the phase characteristics for each allocation used by the UE-specific reference signals (PDSCH, CORESET, CSI-RS etc.) is presented by this option as well.

3.4 Measurements with VSE

3.4.1 Create the Test Environment in VSE

Before the MIMO measurements can be started in VSE, following test environments need to be setup beforehand:

1. Create the instrument (RTP/RTO) (3.4.1.1)
2. Setup the instrument (3.4.1.2)
3. Load 5G NR Channel in the measurement group and map the created instrument to the channel (3.4.1.3)
4. Enter the frequency response correction (3.4.1.4)
5. Specify the carrier frequency and set the trigger (3.4.1.5)

3.4.1.1 Create the Instrument Control for RTP/RTO in VSE

Proceed the following steps to create the instrument in VSE

1. Select tap "Instruments" and click on "New Instrument" to add a new instrument
2. Enter a name for instrument identity, e.g. RTP. See Fig. 3-7
3. Enter the IP address of the connected instrument in the "IP Address" field. Alternatively, the domain name of the instrument is also accepted in this configuration field. See Fig. 3-7. The way of how to locally check the computer name and IP address on RTP is shown in Fig. 3-6
4. Press "Connect". See Fig. 3-7. VSE is now going to create a remote connection to RTP/RTO

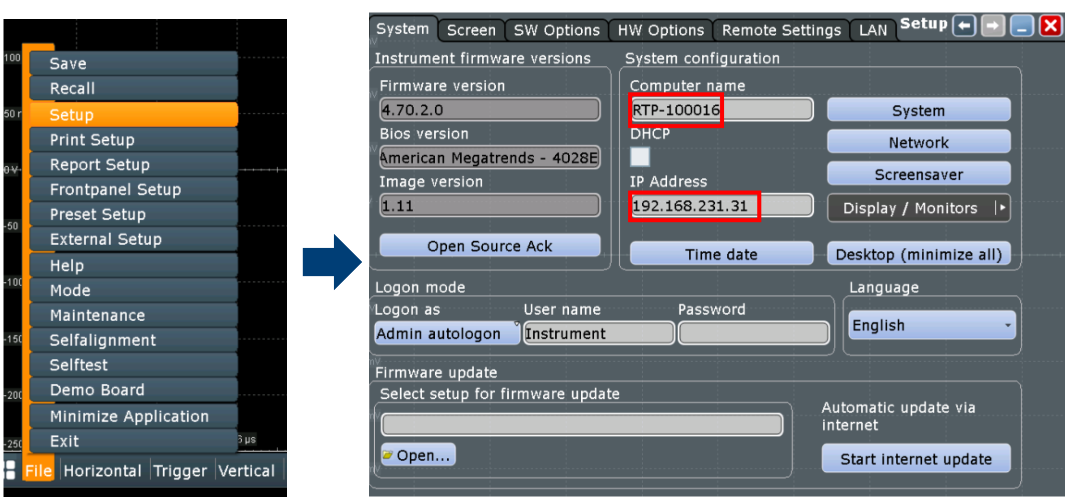


Fig. 3-6: Check computer name and IP address of RTP locally

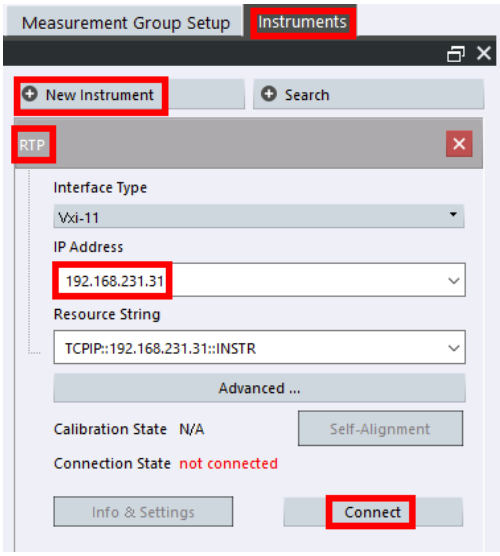


Fig. 3-7: Create a new instrument, e.g. RTP

5. As long as the connection to the instrument is established, the connection state of the instrument is changed to "connected". See Fig. 3-8.

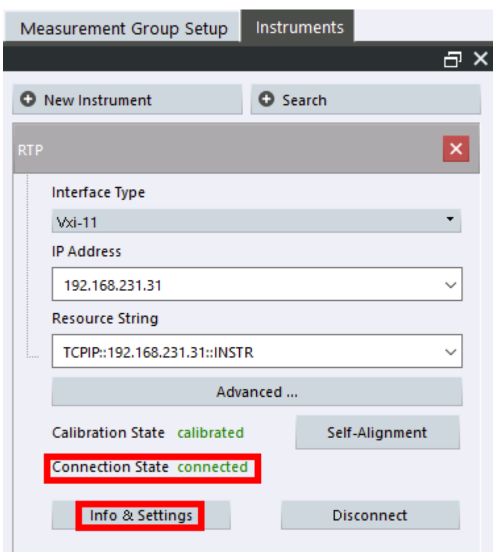


Fig. 3-8: Check status and setup the instrument

6. Press "Info & Settings" (see Fig. 3-8) to configure the instrument. Details are explained in Chapter 3.4.1.2

3.4.1.2 Setup the Instrument

1. Goto "General" tab, enable the VISA lock state is recommended. See Fig. 3-9.

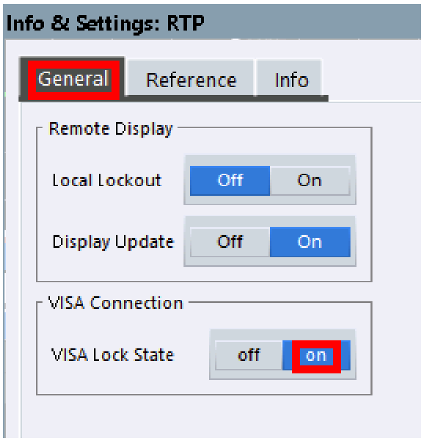


Fig. 3-9: General settings of RTP/RTO

2. Goto "Reference" tab, ensure the "Internal Reference" is selected. See Fig. 3-10,

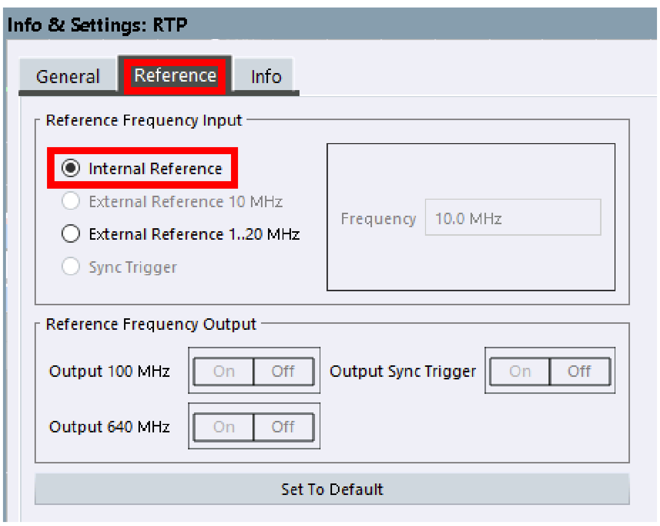


Fig. 3-10: Reference setting of RTP/RTO

3.4.1.3 Load 5G NR Channel and Source Mapping

Goto "Measurement Group Setup" and add there "5G NR" as the new channel. See Fig. 3-11.

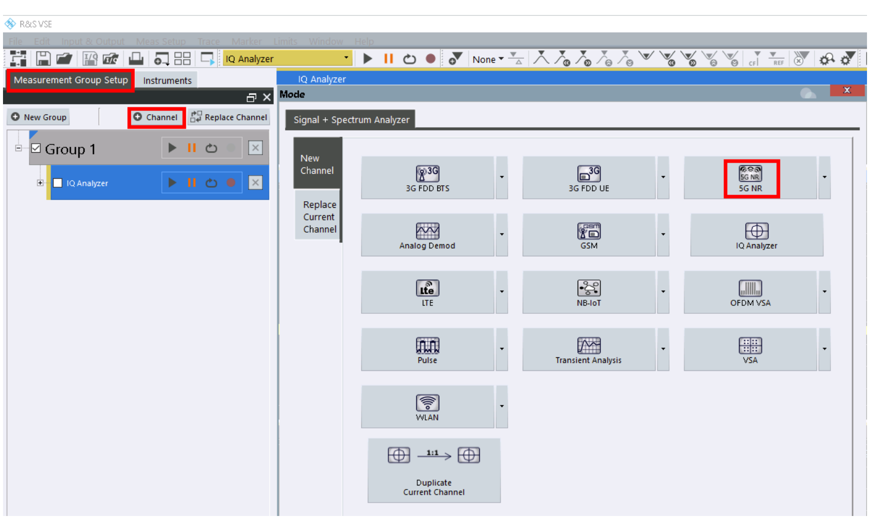


Fig. 3-11: Load 5G NR channel in a measurement group

As per default setting in VSE, a single input source is configured. Since we test here 2x2 MIMO, 2 input sources need to be enabled. The following steps shows how to add multiple sources.

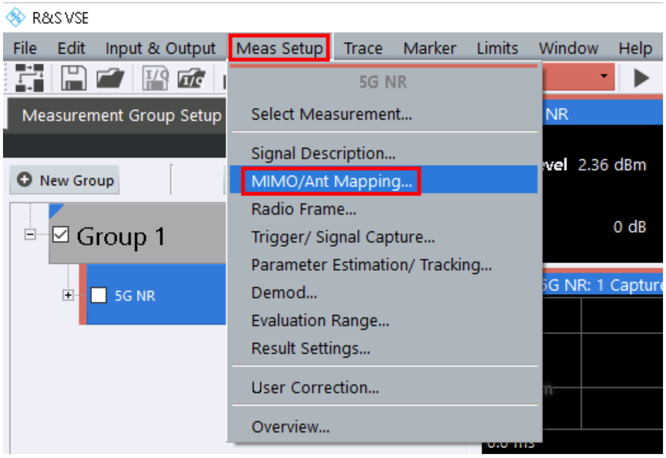


Fig. 3-12: Enter MIMO/Antenna Mapping to enable MIMO scenario

1. In VSE menu bar, goto Meas Setup > MIMO/Ant Mapping. See Fig. 3-12.
2. In the opened configuration window (see Fig. 3-13), enter the number of MIMO layers in the field "Number of Input Sources". For example, "2" for 2x2 MIMO case.
3. Ensure the input source type is set to "instrument"
4. Select "MIMO" and "Conducted" as measurement setup
5. The antenna port to physical port mapping is automatically carried out, i.e. Config 1 corresponds to MIMO layer 1 with PDSCH Antenna Port configured as 1000, and Config 2 for MIMO layer 2 with PDSCH Antenna Port configured as 1001. See Appendix C or [1] for more information about the antenna ports.
6. In the simultaneous signal capture setup section, ensure that the input source (physical connection) matches the configuration mentioned in the step 5. In our example here, RTP Channel 1 is physically connected to MIMO layer1 which is mapped to Config 1, so as the mapping from Channel 2 to Config 2.

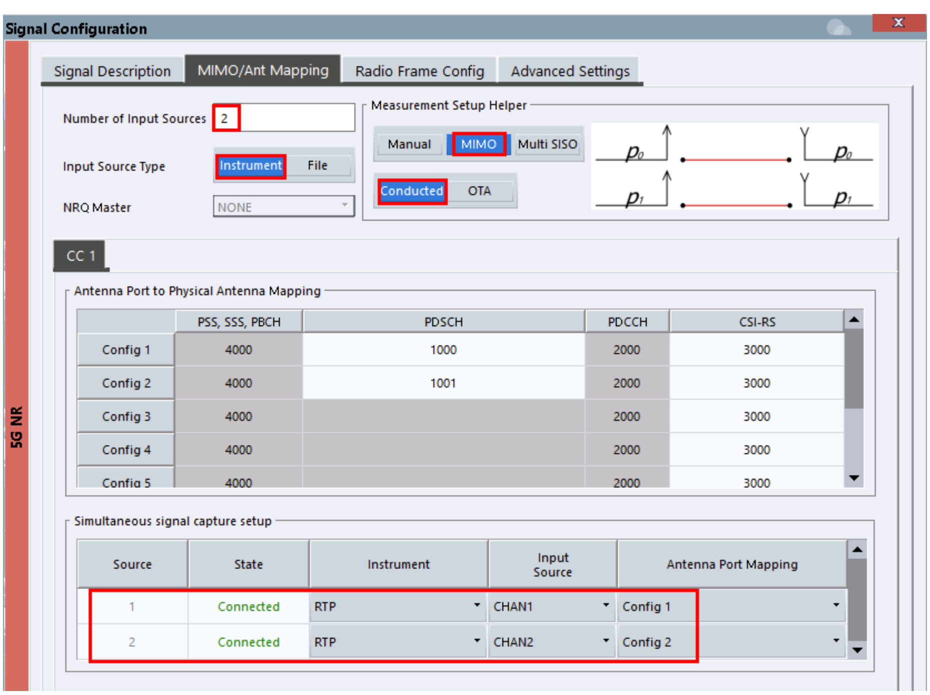


Fig. 3-13: MIMO setup and antenna port (AP) to physical antenna mapping with RTP/RTO

7. After the above steps are completed, close the window will save the settings automatically. In the "Measurement Group Setup" tab, the applied instrument, its configured number of sources from the previous step, and its physical input source assignments is shown in Fig. 3-14. Double check if these assignments reflect the physical connections.

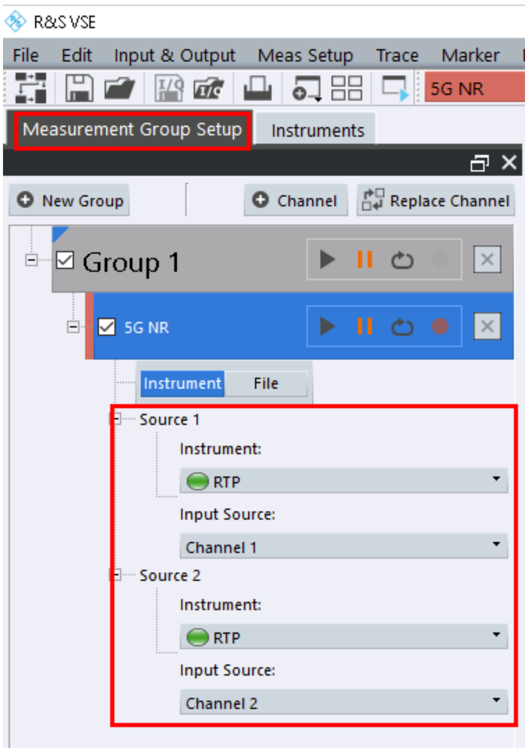


Fig. 3-14: Instrument and input source mapping

3.4.1.4 Enter Frequency Response Correction Values

See chapter 3.2

3.4.1.5 Specify the Carrier Frequency and Set the Trigger

1. Set the carrier center frequency. For example, enter 3.5 GHz as center frequency for FR1. See Fig. 3-15

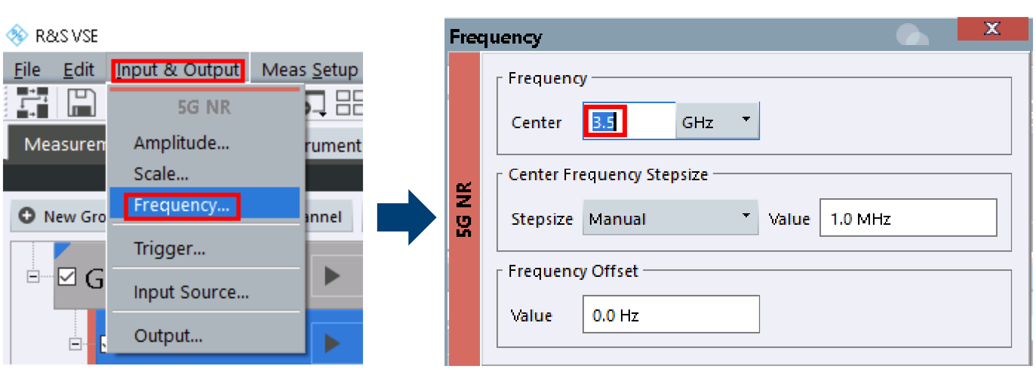


Fig. 3-15: Enter carrier center frequency

2. Set "External Trigger 1" as source trigger. See Fig. 3-16.

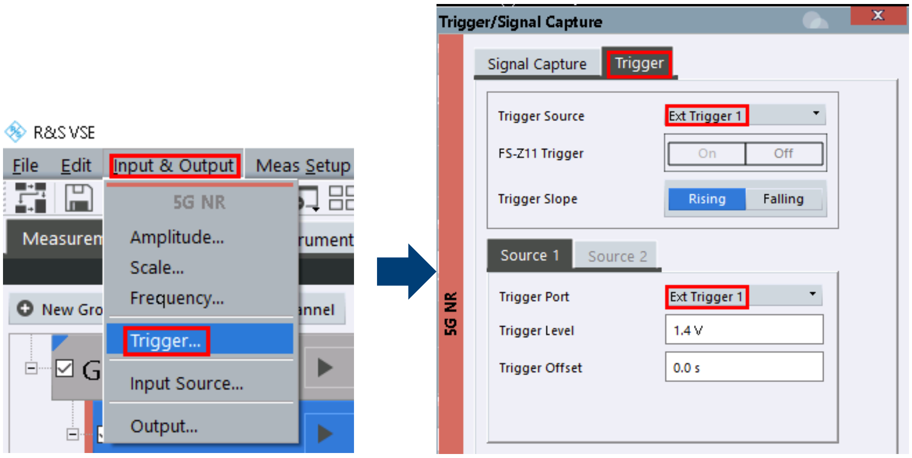


Fig. 3-16: Set trigger for RTP/RTO

3.4.2 VSE Signal Configuration

This section describes the necessary settings on VSE for 5G MIMO testing.

Example 5G FR1 2x2 MIMO signal parameters can be referred in Appendix A.

3.4.2.1 Signal Parameter Settings

3.4.2.1.1 Signal Description

To access to the signal description as shown in Fig. 3-17, enter VSE main menu: Meas Setup > Signal Description

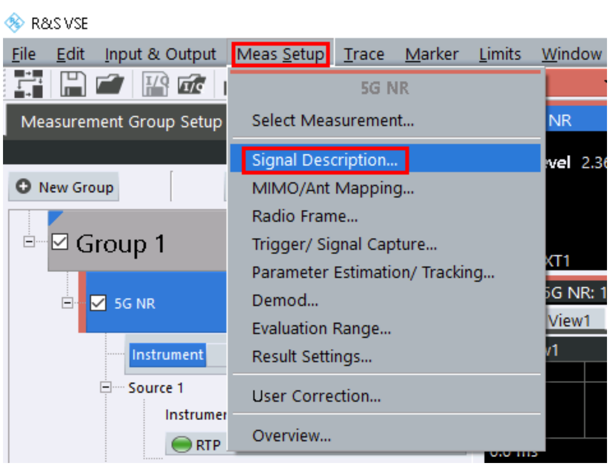


Fig. 3-17: Access to signal description

Main parameters settings are listed in Table 3-1

Field	Value	Remark
Mode	Downlink	
Deploy Frequency Range	3 GHz < f <= 6 GHz	DUT dependent
Channel Bandwidth	100 MHz	DUT dependent
Synchronization	Auto	
Auto Detection Cell ID	Off	
Cell ID	0	The Cell ID should match the one configured on DUT

Table 3-1 Main parameter settings of signal description

Fig. 3-18 shows the signal description configuration page in VSE.

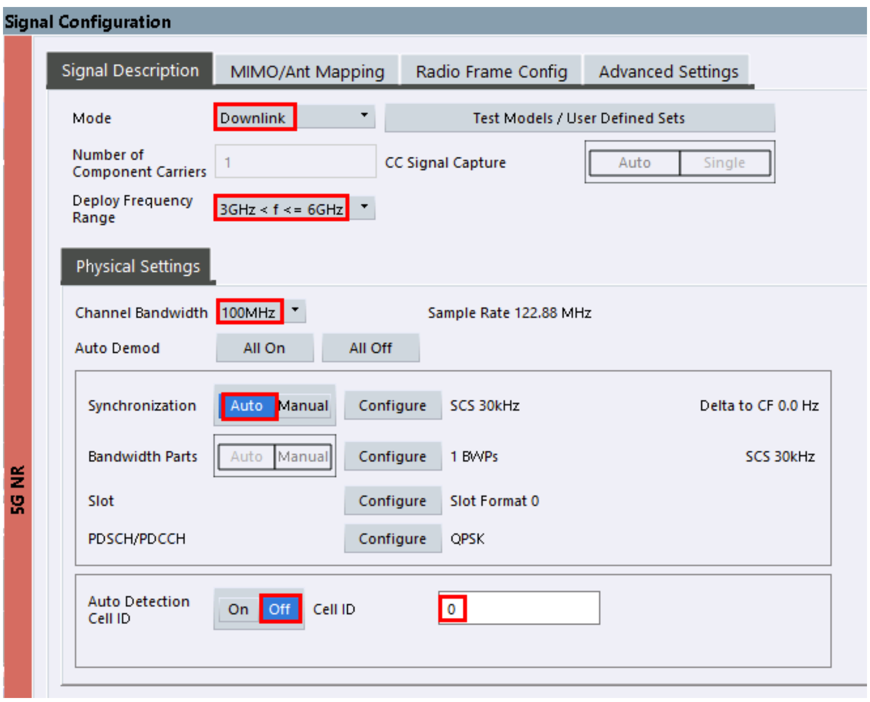


Fig. 3-18: Signal description

3.4.2.1.2 Radio Frame

In VSE main menu, enter Meas Setup > Radio Frame

Following four configuration sections need to be went through.

1. Synchronization
2. BWP Config
3. Slot Config
4. PDSCH/PDCCH Config

Synchronization

Table 3-2 gives a brief summary of major parameter settings for synchronization radio frame

Field	Value	Remark
Detection	Auto	
Offset rel to	TxBW	Shall match the signal configuration on the DUT

Table 3-2 Main parameter settings of synchronization radio frame

Fig. 3-19 shows the synchronization configuration page in VSE.

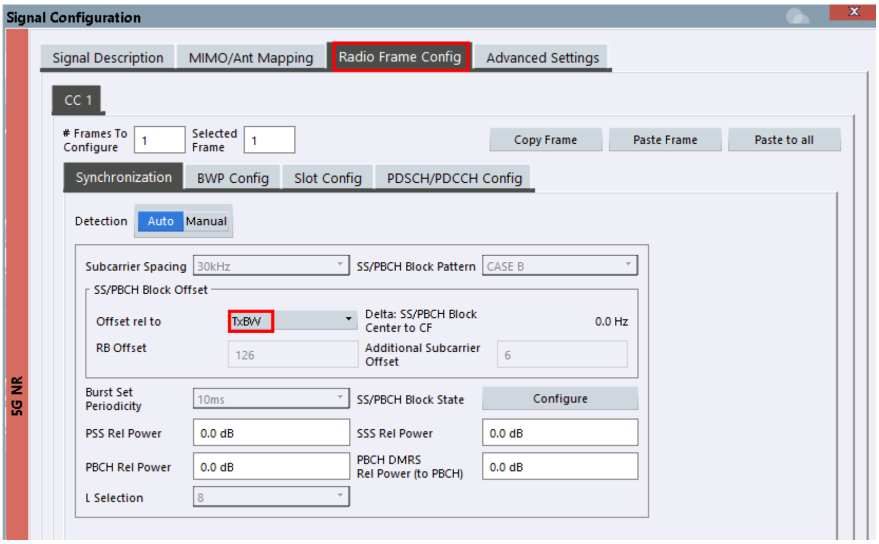


Fig. 3-19: Radio frame configuration - Synchronization

BWP Configuration

Table 3-3 gives a summary of one BWP configuration

Field	Value	Remark
Subcarrier Spacing	30 kHz	
#RBs	273	Maximum number of Resource Blocks
RB Offset	0	

Table 3-3 Main parameter settings of synchronization radio frame

Fig. 3-20 shows the BWP configuration page in VSE.

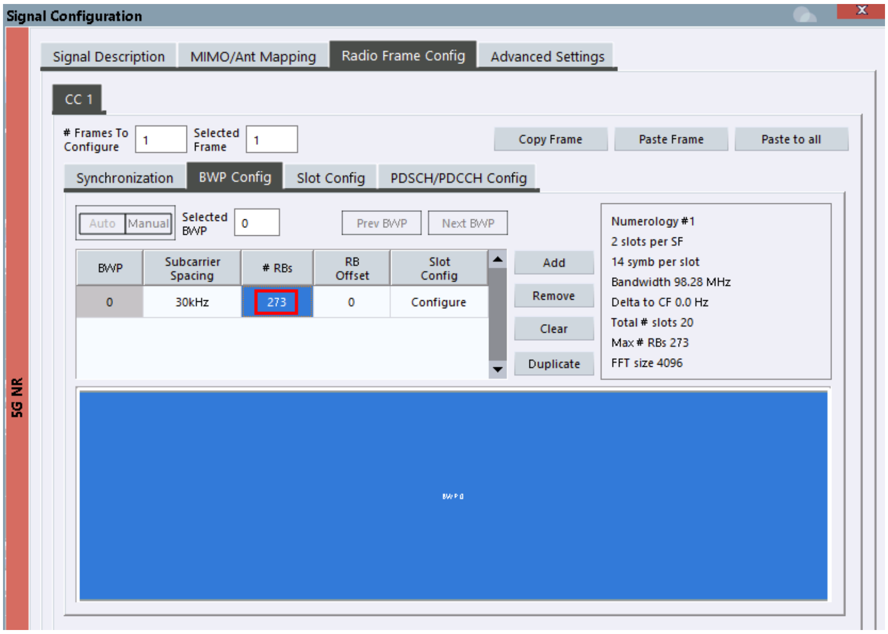


Fig. 3-20: Radio frame configuration - BWP Config

Slot Configuration

Table 3-4 gives a summary of the major parameter settings for slot configuration in the given BWP 0

Field	Value	Remark
BWP Number	0	1 BWP is configured, the numbering begins with 0
Slot Allocation	Data	Slot configured for user data transmission
Slot Format	0	Defines the usage of the OFDM symbols. "0" stands for downlink

Table 3-4 Main parameter settings of slot configuration

In Fig. 3-21, it shows the slot configuration page in VSE. Since the SCS is 30 kHz, altogether 20 slots are available in one radio frame. In our example here, all 20 slots have the same configuration. Therefore, we actually duplicate the slot configuration from 0 to the remaining 19 slots. The copy-paste operation can be performed easily and flexibly in VSE as highlighted in Fig. 3-21.

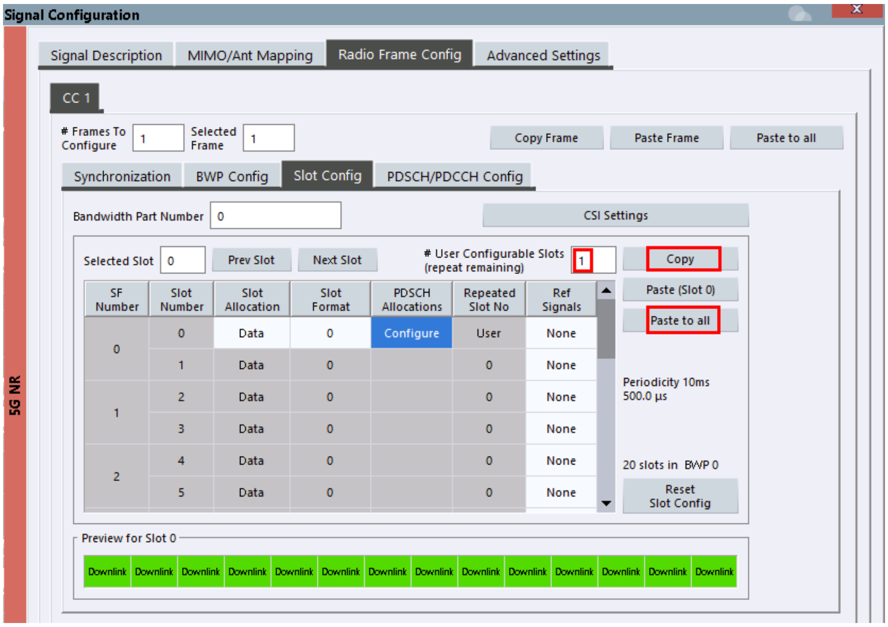


Fig. 3-21: Radio frame configuration - Slot Config

PDSCH/PDCCH Config

PDCCH(CORESET) and PDSCH can be configured individually in VSE main menu under Radio Frame Config > PDSCH/PDCCH Config section.

It includes the configuration of the modulation coding scheme of the PDSCH, the number of RBs, offset RB, number of symbol, offset symbol of PDSCH and CORESET etc. plus more additional enhanced configurations. e.g. MIMO layers/codewords.

Table 3-5 lists the resource scheduling of PDCCH(CORESET) and PDSCH. Apparently those scheduling parameters should all match the settings given at the DUT side.

Field	Value	Remark
CORESET Number of RBs	270	
CORESET Offset RB	0	
CORESET Number of Symbols	1	
CORESET Offset Symb	0	
Enh.CORESET Precoder Granularity	REG Bundle	
PDSCH Modulation	64 QAM	
PDSCH Number of RBs	273	
PDSCH Offset RB	0	
PDSCH Number of Symbols	13	
PDSCH Offset Symb	1	
Enh.PDSCH Layers/Codewords	2/1	For 2x2 MIMO

Table 3-5 Main parameter settings of PDSCH/PDCCH configuration

Fig. 3-22 shows the setting page of PDSCH/PDCCH in VSE.

Fig. 3-23 and Fig. 3-24 shows the enhanced settings for CORESET and PDSCH (setting of PDSCH DMRS) , respectively

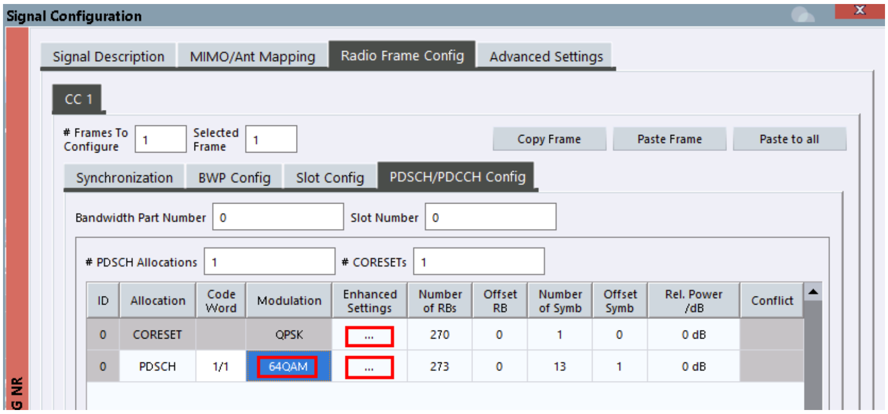


Fig. 3-22: Radio frame configuration - PDSCH/PDCCH Config

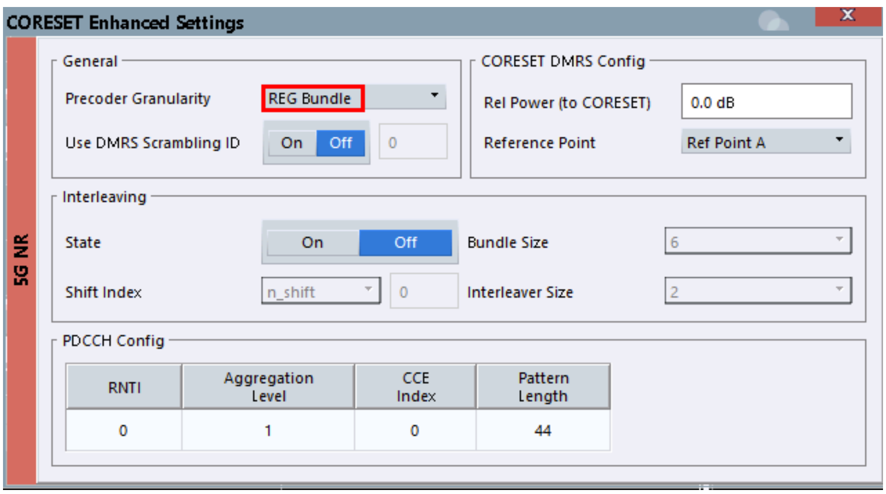


Fig. 3-23: Enhanced CORESET settings

PDSCH DMRS Config

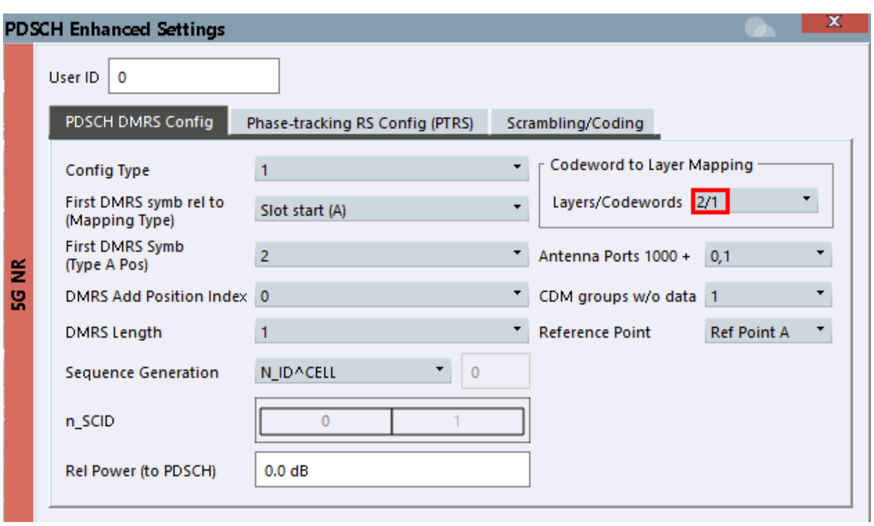


Fig. 3-24: Enhanced PDSCH settings - PDSCH DMRS Config for 2-layer MIMO

If 4-layer MIMO is under tested, then the codeword to layer mapping in DMRS settings should be set as shown in Fig. 3-25

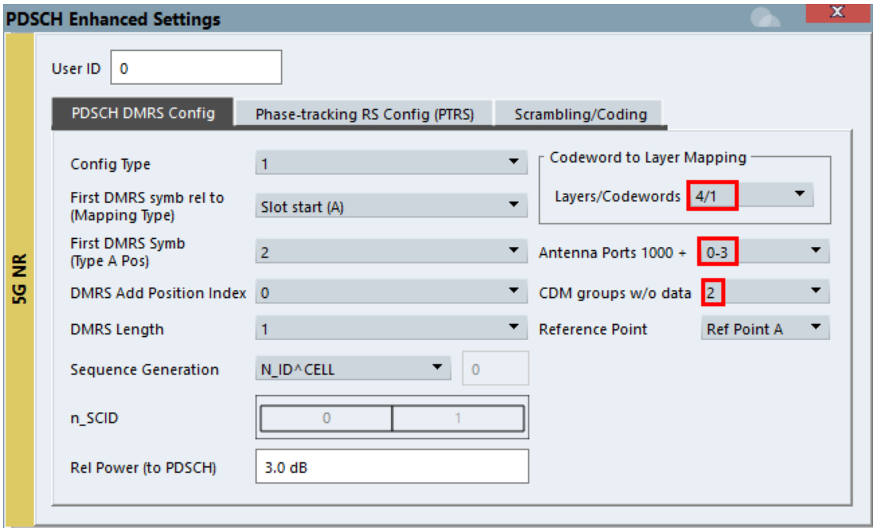


Fig. 3-25 Enhanced PDSCH settings - PDSCH DMRS Config for 4-layer MIMO

Layers/Codewords: 4/1

Antenna Ports 1000+: 0-3

CDM groups w/o data: 2

The antenna port of each MIMO layer is assigned as follows:

AP = 1000 for MIMO Layer 1

AP = 1001 for MIMO Layer 2

AP = 1002 for MIMO Layer 3

AP = 1003 for MIMO Layer 4

Phase Tracking Reference Signal (PTRS) Config

PTRS is disabled in our example signal. Thus, the PTRS is turned off in VSE setting accordingly. See Fig. 3-26.

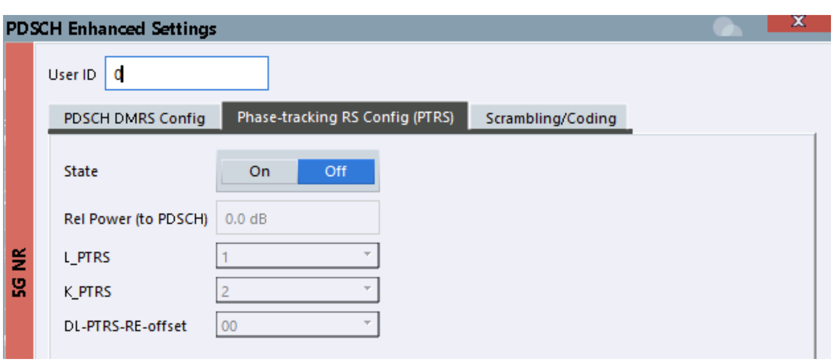


Fig. 3-26: Enhanced PDSCH settings - Phase Tracking Reference Signal (PTRS) Config

Scrambling/Coding

The configuration of scrambling and channel coding of the PDSCH is shown in Fig. 3-27

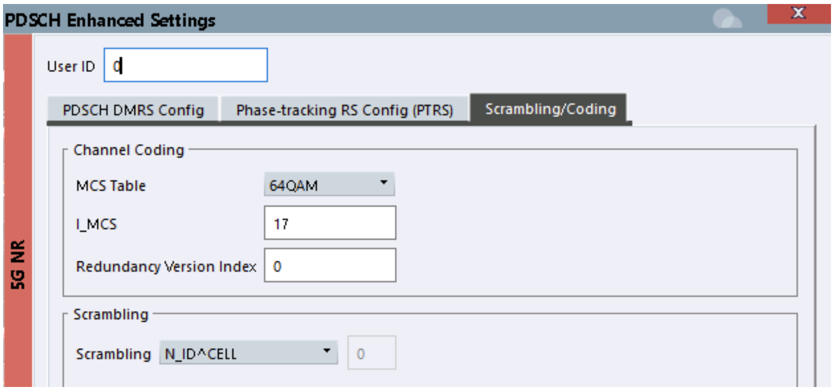


Fig. 3-27: Enhanced PDSCH settings - Scrambling and Channel Coding Config

3.4.2.1.3 Advanced Settings

Global Settings

In order to optimize the measurement results in VSE, global settings as listed in Table 3-6 need to be configured. Misconfiguration or mismatch of the settings between the VSE and DUT will lead to bad EVM values in the signal analysis.

Field	Value	Remark
Set Handling of Carrier Leakage	Ignore DC	R&S VSE removes the DC carrier from all results by ignoring the corresponding subcarriers. The DC carrier is assumed to be in the center of the channel bandwidth.
Phase Compensation	On / Off	From the base station side, it is necessary to upconvert the baseband signal to the radio frequency. The upconversion requires a frequency related phase compensation after each symbol according to 3GPP 38.211: 5.4 "Modulation and Upconversion". When "Phase Compensation" is off, the VSE assumes that the applied signal is not phase-compensated and analyzes the signal accordingly. When "Phase Compensation" is on, the VSE assumes that the applied signal is already phase-compensated for a specific frequency. This frequency is either the current center frequency ("CF"), e.g. 3.5 GHz in our example here or an arbitrary frequency ("Manual)". The setting here needs to match the settings on the DUT side, i.e. Base Station.

Table 3-6 Global advanced settings

Fig. 3-28 shows the global configuration page in VSE.

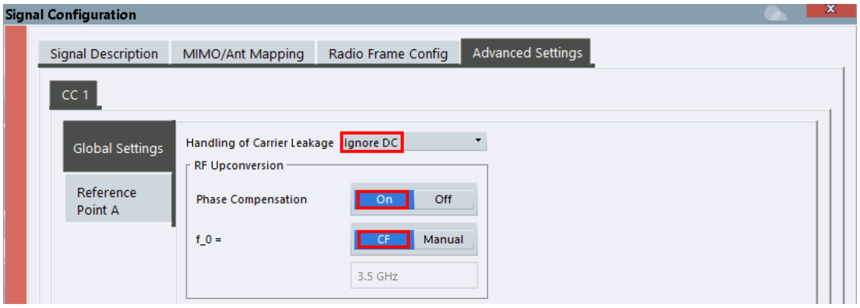


Fig. 3-28: Advance settings - Global settings

Reference Point A

Fig. 3-29 shows reference point A configuration in VSE where the user can define the location of the reference point relative to the carrier center frequency.

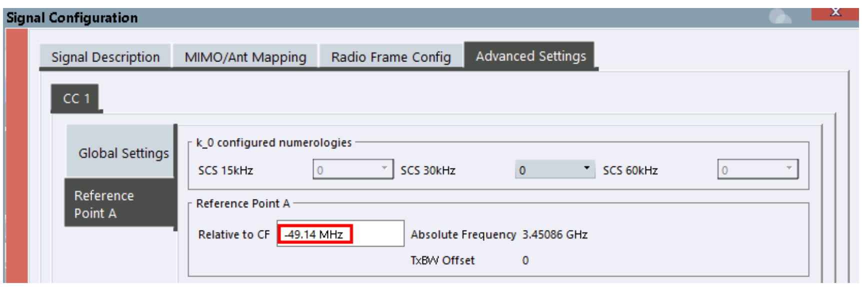


Fig. 3-29: Advance settings - Reference Point A settings

3.4.3 Add MIMO Personalities and Run Measurement

If a valid VSE-K146 option license is in place, then 5G MIMO measurement personalities are enabled. These special MIMO measurement personalities include RS Phase, RS Phase Difference measurement and Beamforming summary.

As shown in Fig. 3-30, to visualize those MIMO measurements, goto VSE menu bar, select:

Window > New Window > RS Phase

Window > New Window > RS Phase Diff

Window > New Window > Beamforming Summary

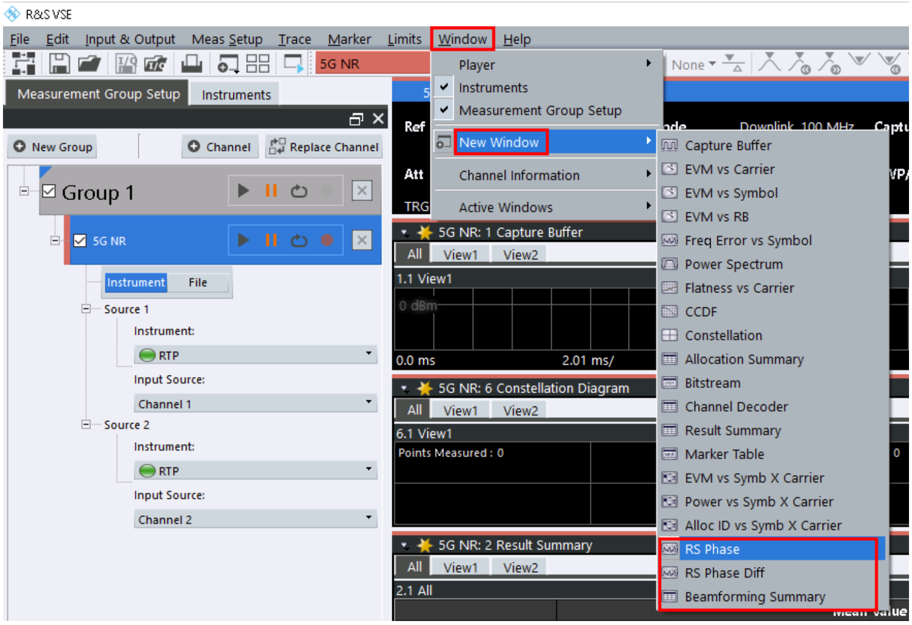


Fig. 3-30: Add VSE-K146 MIMO measurement personalities

Goto Meas Setup > Overview opens a summary of the settings as shown in Fig. 3-31.

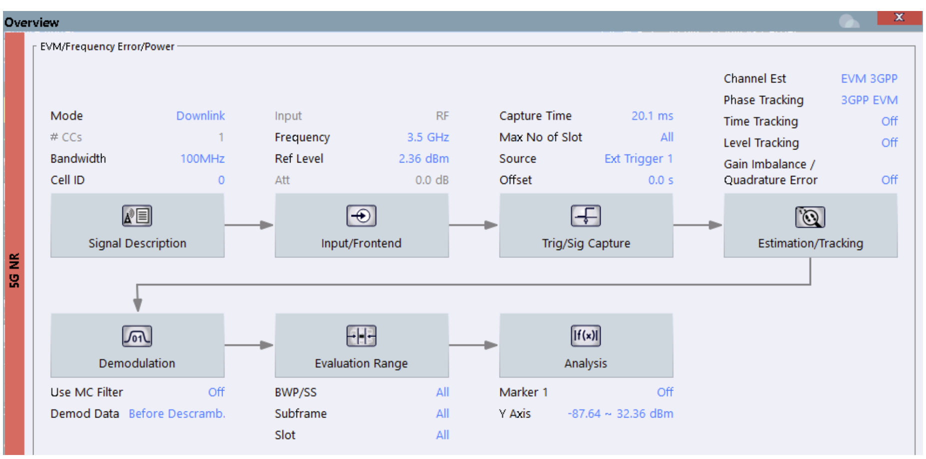


Fig. 3-31: Overview of the measurement settings

Now, the measurements can be started by pressing the capture button in the VSE function bar as indicated in Fig. 3-32.

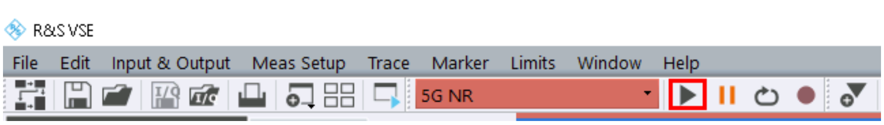


Fig. 3-32: Start the measurement

VSE delivers the measurement results as shown in Fig. 3-33.

Fig. 3-33: VSE measurements (2x2 MIMO)

Here we would like to highlight some MIMO specific measurements, namely, the RS Phase, RS Phase difference and beamforming summary.

Fig. 3-34 is the measurement result of RS Phase that shows the phase of the carriers occupied by different reference signals, e.g. PDCCH, PDSCH, SSB etc, on each MIMO layer.

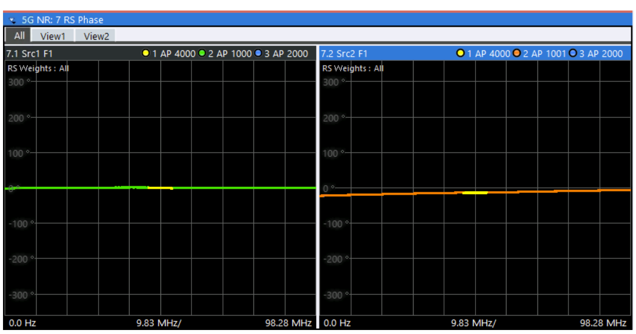


Fig. 3-34: Measurement of 5G MIMO phase

Fig. 3-35 shows the phase difference of different antenna port relative to the reference antenna port. The reference antenna port can be user defined in VSE.

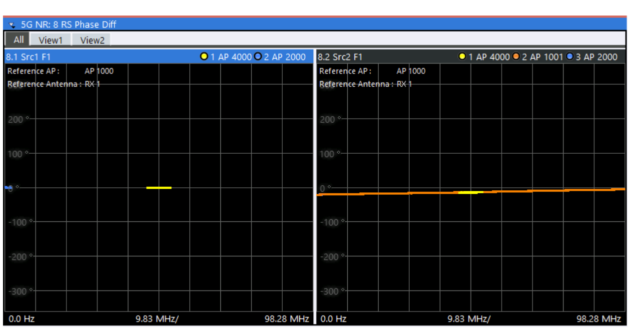
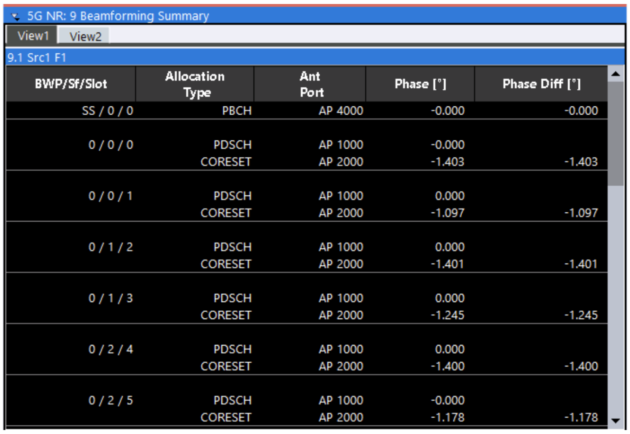


Fig. 3-35: Measurement of 5G MIMO phase difference

The beamforming summary shown in Fig. 3-36 gives an overview of the phase characteristics of each resource allocation used by the UE specific reference signals (PDSCH, CORESET etc.).



5G NR: 9 Beamforming Summary

View1 View2

9.1 Src1 F1

BWP/Sf/Slot	Allocation Type	Ant Port	Phase [°]	Phase Diff [°]
SS / 0 / 0	PBCH	AP 4000	-0.000	-0.000
0 / 0 / 0	PDSCH	AP 1000	-0.000	
	CORESET	AP 2000	-1.403	-1.403
0 / 0 / 1	PDSCH	AP 1000	0.000	
	CORESET	AP 2000	-1.097	-1.097
0 / 1 / 2	PDSCH	AP 1000	0.000	
	CORESET	AP 2000	-1.401	-1.401
0 / 1 / 3	PDSCH	AP 1000	0.000	
	CORESET	AP 2000	-1.245	-1.245
0 / 2 / 4	PDSCH	AP 1000	0.000	
	CORESET	AP 2000	-1.400	-1.400
0 / 2 / 5	PDSCH	AP 1000	-0.000	
	CORESET	AP 2000	-1.178	-1.178

Fig. 3-36: Beamforming summary

The reference antenna port can be defined through VSE's "evaluation range …" function as shown in Fig. 3-37.

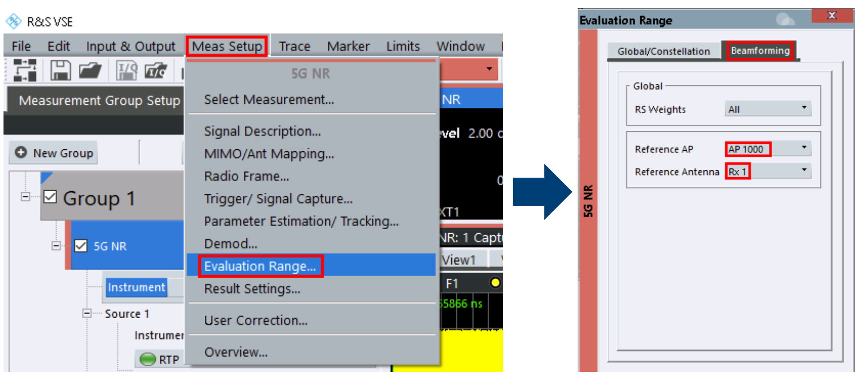


Fig. 3-37: Change reference antenna port (AP)

4 Test Solution with Frequency Selective Power Sensor NRQ6

4.1 Setup

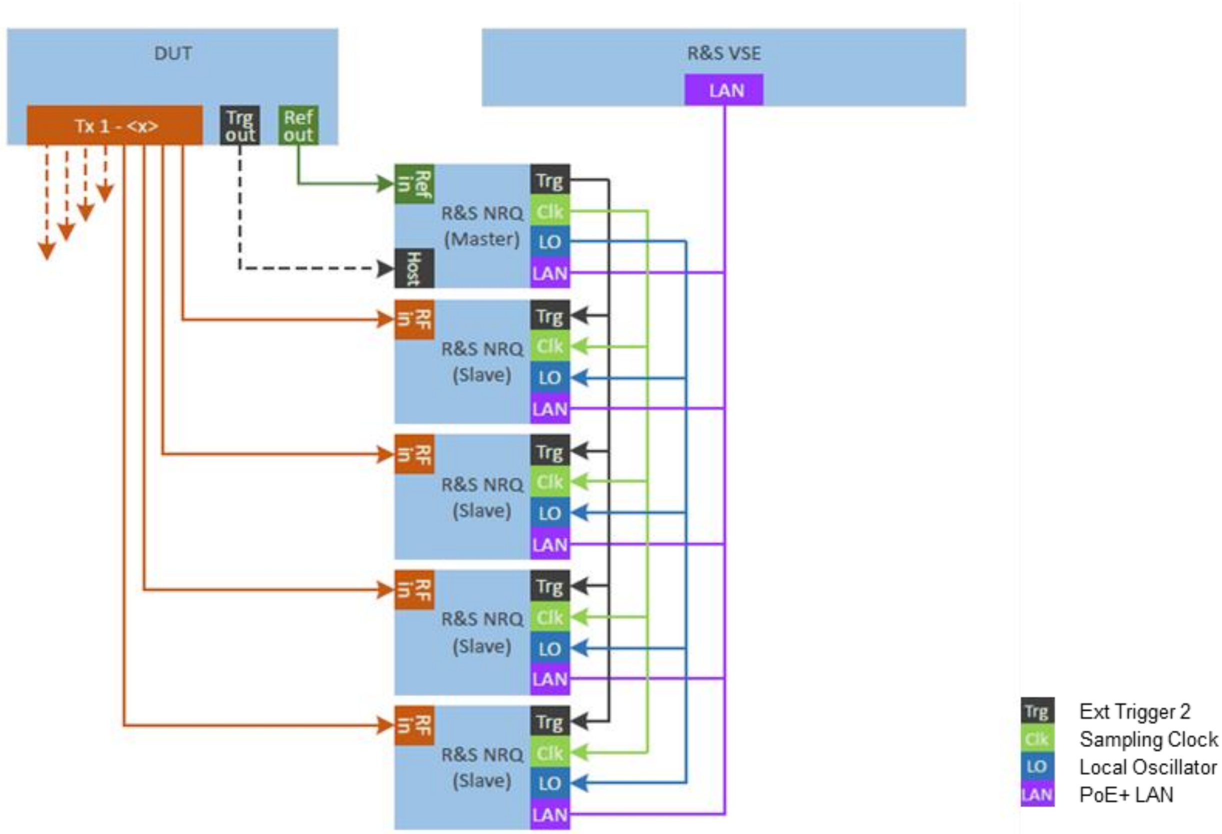


Fig. 4-1: Block diagram of test solution with NRQ6 and VSE

Fig. 4-1 shows a block diagram of test solution with NRQ6 and VSE to analyze the 5G FR1 with 4-layer MIMO signal.

The setup follows a master-slave principle. Master and slave NRQ6 are hardware identical measurement devices. The role definition is configured in the VSE, details see 4.4.1. All the NRQ6s are power supplied by Power over Ethernet (PoE+) LAN cable. A master NRQ6 is required to simultaneously trigger the slave NRQ6 units for the capturing, provide the identical clock signal and couple the LO signal to the slave NRQ6s. Multiple slave NRQ6s can be deployed in the setup. The number of the slave NRQ6 depends on the number of the MIMO layers. Each slave NRQ6 captures the data stream of one MIMO layer from DUT individually, down-converts the RF signal to baseband IQ data and then transfers them to VSE for the post processing. In this test solution, the master NRQ6 does not capture the data stream. Therefore, no RF connection is needed on master NRQ6.

It is required that the connections from the master to each slave NRQ6 are symmetrical, that means the same cable length of trigger, clock and local oscillator (LO) from master to each slave NRQ6 are expected. The phase coherent measurement is guaranteed, only if the symmetry is fulfilled.

The topology of this test solution allows the easy capacity extension to measure higher order MIMO system. Therefore, in comparison to the test solution based on RTP/RTO oscilloscope described in Chapter 3, this solution covers additionally the phase coherent measurement for MIMO layers greater than four.

4.2 Calibration and Frequency Response Correction

See 3.2

4.3 Required Software Options

4.3.1 NRQ6-K1 and NRQ6-K3

NRQ6 is a power sensor based on the principle of a measurement receiver which has a large dynamic range and can handle large variations in signal strength and deliver accurate measurement. It is an ideal cost effective and compact test equipment for 5G NR base station MIMO measurement.

To fulfill the 5G MIMO phase coherent signal analysis test purpose, software options NRQ6-K1 and NRQ6-K3 are required.

NRQ6-K1 is an essential software option on NRQ6 that enables the interface to output the IQ data from NRQ6 to VSE for the post processing.

In addition, NRQ6-K3 option is needed to deal with the phase coherent measurements between multiple power sensors.

4.3.2 VSE with VSE-K144 and VSE-K146

See 3.3.2

4.4 Measurements with VSE

4.4.1 Create the Test Environment in VSE

Before the MIMO measurements can be started in VSE, following test environments need to be setup beforehand:

1. Create the instrument (NRQ6 master and slaves) (4.4.1.1)
2. Setup the instrument (4.4.1.2)
3. Load 5G NR Channel in the measurement group and map the created instrument to the channel (4.4.1.3)
4. Enter the frequency response correction (4.4.1.4)
5. Specify the carrier frequency and set the trigger (4.4.1.5)

4.4.1.1 Create the Instrument in VSE

To measure 2x2 MIMO signal, all together three NRQ6s are required.

1 x NRQ6 works as Master

1 x NRQ6 works as first Slave to capture MIMO layer 1 signal

1 x NRQ6 works as second Slave to capture MIMO layer 2 signal

Each NRQ6 has to be defined in VSE with the following steps

1. Select tap "Instruments" and click on "New Instrument" to add a new instrument
2. Enter a name for instrument identification, e.g. Slave 1. See Fig. 4-3
3. Enter the IP address of the connected instrument in the "IP Address" field. See Fig. 4-3. Alternatively, the domain name of the NRQ6 is also accepted in this configuration field. The domain name of the NRQ6 follows the naming convention like NRQ6-<place holder>, where <place holder> is the serial number of the NRQ6. To identify the IP address of the NRQ6, easily ping the domain name on the command prompt of the control PC as shown in Fig. 4-2.

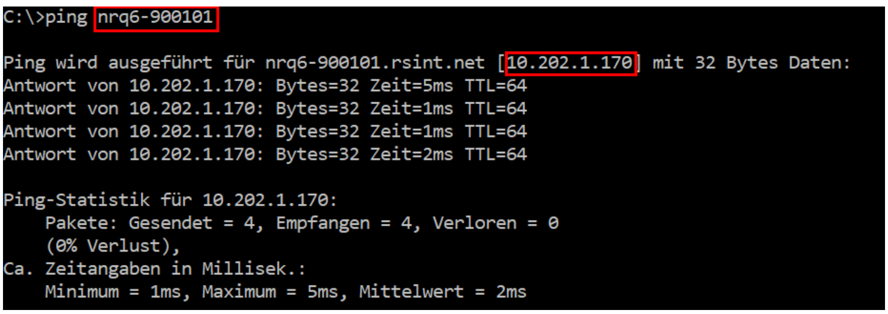


Fig. 4-2 Ping NRQ6 domain name to obtain its IP address

4. Press "Connect". See Fig. 4-3. VSE is now going to create a remote connection to NRQ6

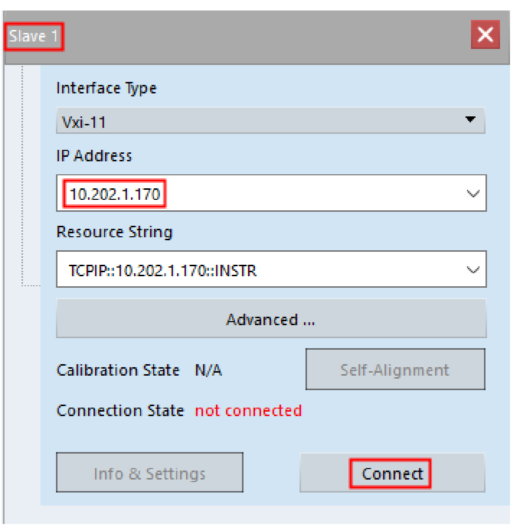


Fig. 4-3: Create a new instrument, e.g. NRQ6 slave 1

5. As long as the connection to the instrument is established, the connection state of the instrument is changed to "connected". See Fig. 4-4.

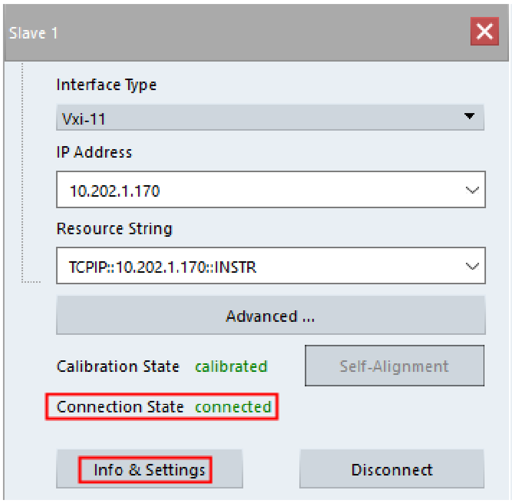


Fig. 4-4 Check NRQ6 status and setup the instrument

6. Press "Info & Settings" (see Fig. 4-4) to configure the instrument. For the settings details of master and slave NRQs, refer to Chapter 4.4.1.2.
7. Repeat step 1 to 6 until connections to all the NRQ6s are established

4.4.1.2 Setup the Instrument

Master and Slave NRQs work in different operation mode. Therefore, they have to be configured differently in VSE as described in this chapter.

4.4.1.2.1 Master NRQ6

The Master NRQ6 configurations are shown in Fig. 4-5 and Fig. 4-6

1. In tab "General" (See Fig. 4-5), proceed as following:

   Sync Mode **Master**

   Master Trigger Source[1] **Free Run, Host-Interface (Ext1) or Ext2**

   Trigger Output Port[2] **Host-Interface (Ext1) or Ext2**

   VISA Lock State[3] **On or Off**

[1] Which type of "Master Trigger Source" is chosen depends on the used input trigger source. The selection between Ext1 and Ext2 depends on the physically connected input trigger source on Master NRQ6. Details about the trigger ports on NRQ6, refer to [6].

[2] "Trigger Output Port" is the trigger port that is used by the trigger master to output a trigger signal. Note, for each NRQ6, "Trigger Output Port" has to be different from the "Master Trigger Source".

[3] It is recommended to activate "VISA Lock State". If VISA state is locked, then accessing the NRQ6 from other controlling VISA hosts is no longer possible. This prevents the settings of the NRQ6 from being altered by the other hosts.

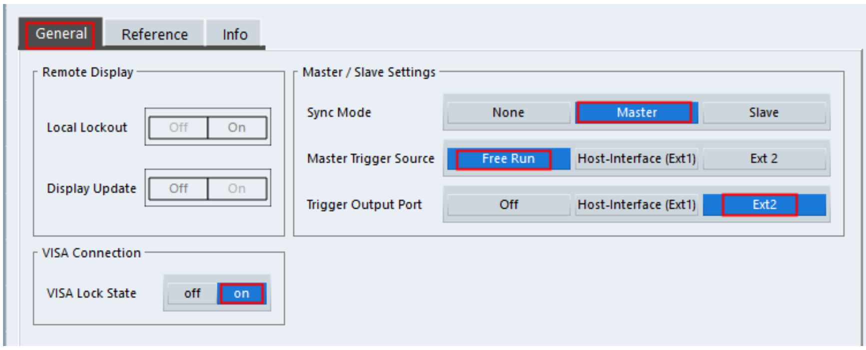


Fig. 4-5 Example of general settings for Master NRQ6,

2. In tab "Reference" (See Fig. 4-6), proceed as following:

   Reference Frequency Input **Ext.Reference e.g. Frequency 10 MHz**

   LO Source **Internal**

   LO Out **On**

   Sample CLK Source **automatically set to Internal, not configurable**

   Sample CLK Out **On**

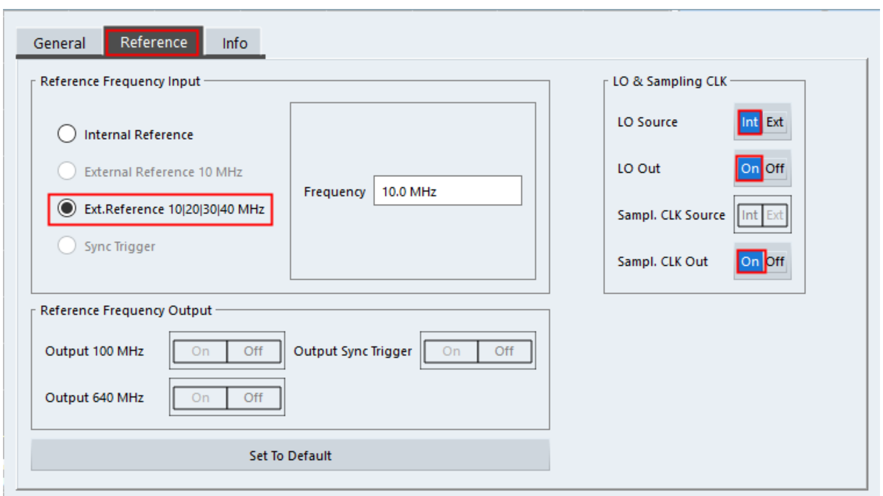


Fig. 4-6 Reference settings for Master NRQ6

4.4.1.2.2 Slave NRQ6

Configure each slave NRQ6 with the same settings as shown in Fig. 4-7 and Fig. 4-8.

1. In tab "General" (See Fig. 4-7), proceed as following:

   Sync Mode **Slave**

   Trigger Output Port **Off**

   VISA Lock State **On**[4]

---

[4] The same setting as on Master NRQ6 in Chapter 4.4.1.2.1. It is recommended to activate "VISA Lock State"

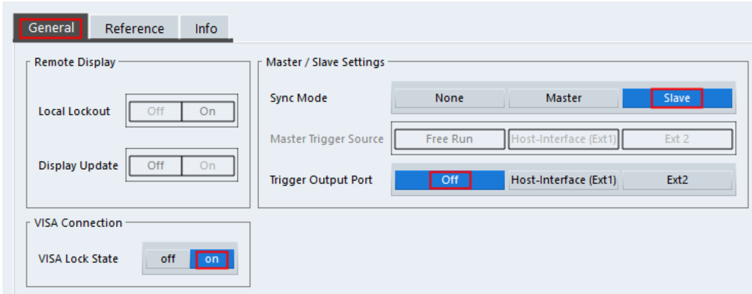


Fig. 4-7 General settings for Slave NRQ6

2. In tab "Reference" (See Fig. 4-8), proceed as following:

Reference Frequency Input **Internal Reference**

LO Source **Ext**

LO Out **automatically set to OFF, not configurable**

Sampl. CLK Source **Ext**

Sample CLK Out **automatically set to OFF, not configurable**

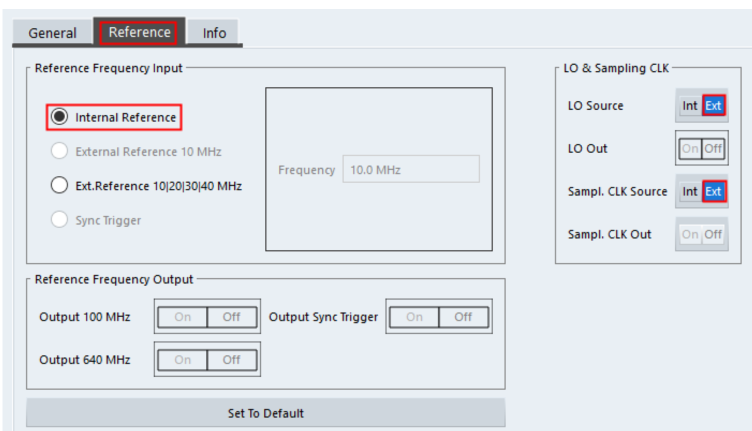


Fig. 4-8 Reference settings for Slave NRQ6

When the sample clock source is set to external, confirm the message box shown in Fig. 4-9 after ensuring that the external CLK signal delivered from the master NRQ6 is physically fed into the Sampling CLK port of the slave NRQ6.

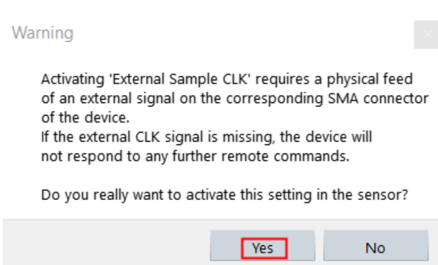


Fig. 4-9 Confirm the activating of external sample CLK

4.4.1.3 Load 5G NR Channel and Source Mapping

1. Load 5G NR channel as described in Chapter 3.4.1.3.
2. In VSE menu bar, goto Meas Setup > MIMO/Ant Mapping

3. In the opened configuration window (see Fig. 4-10), enter the number of MIMO layers in the field "Number of Input Sources". For example, "2" for MIMO 2x2
4. Ensure the input source type is set to "instrument"
5. Select instrument "Master" which is created in 4.4.1.1 as NRQ Master
6. Select "MIMO" and "Conducted" as measurement setup
7. The antenna port to physical port mapping is automatically carried out, i.e. Config 1 corresponds to MIMO layer 1 with PDSCH Antenna Port configured as 1000, and Config 2 for MIMO layer 2 with PDSCH Antenna Port configured as 1001. See Appendix C or [1] for more information about the antenna ports.
8. In the simultaneous signal capture setup section, ensure that the input source (physical connection) matches the configuration mentioned in the step 7. In our example here, Slave 1 is physically connected to MIMO layer1 which is mapped to Config 1, so as the mapping from Slave 2 to Config 2.

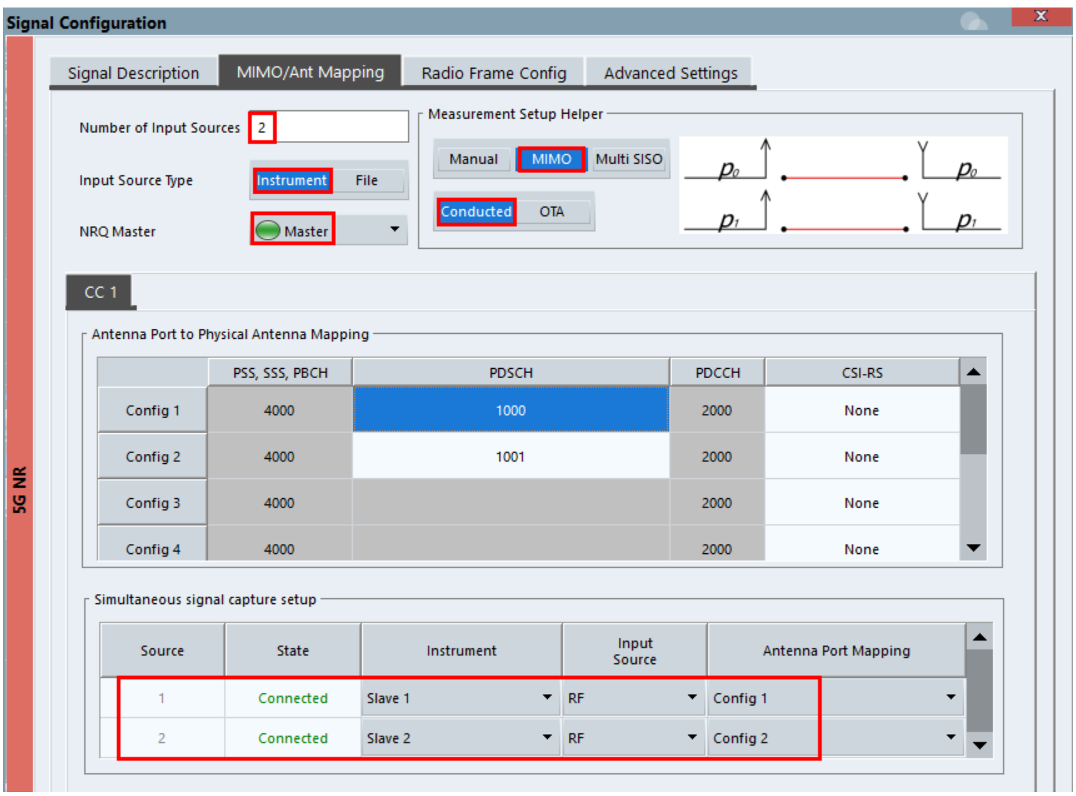


Fig. 4-10 MIMO setup and antenna port (AP) to physical antenna mapping with NRQ6

9. After the above steps are completed, close the window will save the settings automatically. In the "Measurement Group Setup" tab, the applied instrument, its associated number of source, with which the physical input source is assigned is shown in Fig. 4-11. The mappings in our example case looks like follows:

   MIMO layer 1 - Source 1 - Slave 1

   MIMO layer 2- Source 2 - Slave 2

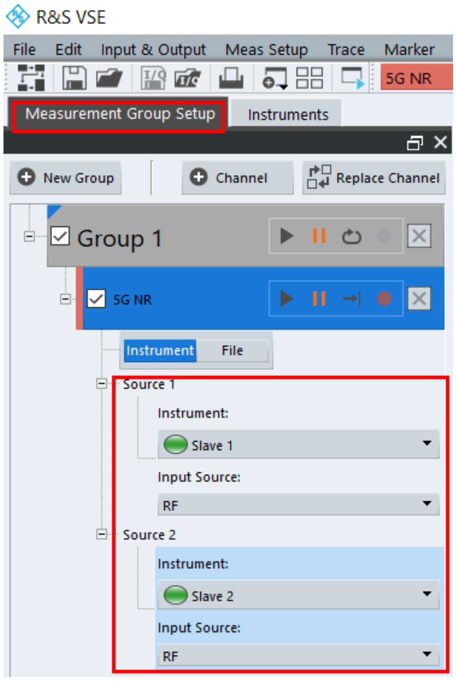


Fig. 4-11 Instrument and input source mapping with NRQ6

4.4.1.4 Enter Frequency Response Correction Values

See chapter 3.2

4.4.1.5 Specify the Carrier Frequency and Set the Trigger

1. Set carrier frequency as described in Chapter 3.4.1.5.
2. Set the trigger as follows:

   In VSE menu bar, goto Input & Output > Trigger…

   Set "External Trigger 2" as input trigger source for Slave NRQ6. See Fig. 4-12

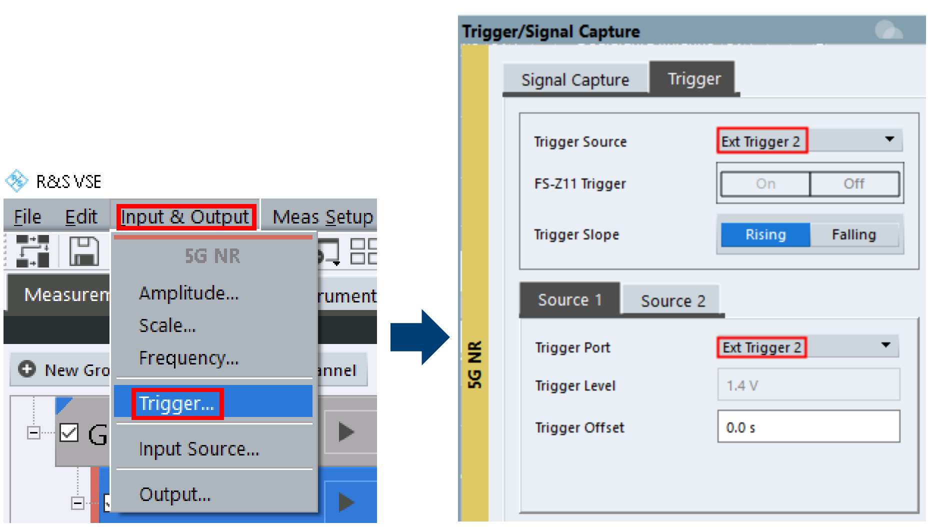


Fig. 4-12 Set trigger for NRQ6

4.4.2 VSE Signal Configuration

This part is test signal dependent. Since we use the same 2x2 MIMO signal here, all the settings can be referred to Chapter 3.4.2

4.4.3 Add MIMO Personalities and Run Measurement

Same procedure as described in Chapter 3.4.3

5 Literature

[1] "5G NR eBook," [Online]. Available: https://www.rohde-schwarz.com/5G-ebook.

[2] "White Paper - Vector Network Analyzer (VNA) Calibration: The Basics," [Online]. Available: https://docplayer.net/4805355-Vector-network-analyzer-vna-calibration-the-basics.html.

[3] R&S®VSE-K144 / -K146 3GPP 5G NR Measurement Application (Downlink) User Manual.

[4] R&S®RTP High-Performance Oscilloscope User Manual.

[5] R&S®VSE Vector Signal Explorer Base Software User Manual.

[6] R&S®NRQ6 Frequency Selective Power Sensor User Manual.

6 Ordering Information

6.1 R&S®RTP/RTO

Designation	Type	Order No.
Oscilloscope		
RTO Digital Oscilloscope (6 GHz BW on 2 channels, 4 GHz BW on 4 channels)	R&S®RTO2064	1329.7002.64
RTP Digital Oscilloscope (8 GHz BW on 4 channels)	R&S®RTP804	1320.5007.08
RTP Digital Oscilloscope (13 GHz BW on 2 channels, 8 GHz BW on 4 channels)	R&S®RTP134	1320.5007.13
RTP Digital Oscilloscope (16 GHz BW on 2 channels, 8 GHz BW on 4 channels)	R&S®RTP164	1320.5007.16
Required options		
I/Q Software Interface	R&S®RTO-K11	1329.7360.02
	R&S®RTP-K11	1800.6683.02
Recommended options		
Memory upgrade 1GSa per channel (HW opt)	R&S®RTO-B110	1329.7090.02
	R&S®RTP-B110	1337.9530.02

6.2 R&S®NRQ6

Designation	Type	Order No.
Frequency selective power sensor	R&S®NRQ6	1421.3509.02
I/Q data interface	R&S®NRQ6-K1	1421.4705.02
Power servoing	R&S®NRQ6-K2	1421.4740.02
Phase coherent measurements	R&S®NRQ6-K3	1421.4770.02
Accessories		
Ten-port PoE+ switch	R&S®NRP-ZAP2	3639.1902.02
USB interface cable, length: 0.75 m	R&S®NRP-ZKU	1419.0658.02
USB interface cable, length: 1.50 m	R&S®NRP-ZKU	1419.0658.03
USB interface cable, length: 3.00 m	R&S®NRP-ZKU	1419.0658.04
USB interface cable, length: 5.00 m	R&S®NRP-ZKU	1419.0658.05
Six-pole interface cable, length: 1.50 m	R&S®NRP-ZK6	1419.0664.02
Six-pole interface cable, length: 3.00 m	R&S®NRP-ZK6	1419.0664.03
Six-pole interface cable, length: 5.00 m	R&S®NRP-ZK6	1419.0664.04
USB Sensor Hub	R&S®NRP-Z5	1146.7740.02
Documentation		
Documentation of calibration values (DCV)	R&S®DCV-1	0240.2187.06
Hardcopy of DCV (in combination with R&S®DCV-1 only)	R&S®DCV-ZP	1173.6506.02
Accredited calibration for R&S®NRQ6 power sensor	R&S®NRP-ACA	1419.0812.00

6.3 R&S®VSE

Designation	Type	Order No.
Vector Signal Explorer		
Vector Signal Explorer Base Software, Basic Edition	R&S®VSE	1345.1011.06
License dongle	R&S®FSPC	1310.0002.03
Required options		
3GPP 5G-NR downlink and uplink	R&S®VSE-K144	1309.9574.03
3GPP 5G MIMO downlink (requires VSE-K144)	R&S®VSE-K146	1345.1305.02
Recommended options		
User defined frequency response correction by SnP file	R&S®VSE-K544	1309.9580.06

7 Appendix

A Example 5G FR1 Downlink 2x2 MIMO Signal Parameters

In this application note, an example 5G FR1 2x2 MIMO downlink test signal is applied with the following parameter settings given in Table 7-1 to Table 7-5.

Parameter	Value
Carrier Frequency	3.5 GHz
Duplexing	FDD
Deployment	3 GHz < f <= 7.125 GHz
Subcarrier Spacing (SCS)	30 kHz
Channel Bandwidth	100 MHz
Cell ID	0
RF Phase Compensation	ON

Table 7-1 General configuration

Parameter	Value
RB Offset	126
SC Offset	6
SS/PBCH case	Case B
L	8
Positions	1100 0000
Burst Set Periodicity	10 ms

Table 7-2: SS/PBCH Configuration

Parameter	Value
Number of DL BWPs	1
No. of Resource Blocks (RB)	273
RB Offset in TxBW	0
RB Offset to PointA	0

Table 7-3: Bandwidth Parts

Since 30 kHz Subcarrier Spacing (SCS) is configured, a radio frame contains 20 slots. For sake of simplicity, CORESET and PDSCH scheduling as listed in Table 7-4 and Table 7-5 showing the scheduling on slot 0 (the first slot). The same scheduling is then duplicated to the rest of the 19 slots.

Parameter	Value
No. of Symbols	1
Symbol Offset	0
No. of RBs	270
RB Offset	0
Precoder Granularity	REG Bundle
Use DMRS scrambling ID	OFF
Use Bitmap for Resources in Frequency Domain	OFF
CORESET ID	1
Interleaving	OFF
Search Space	Aggregation Level 1, 2, 4, 8, 16 Max.Candidates 1

Table 7-4: Scheduling CORESET

Parameter	Value
DMRS Mapping Type	A
No. of Symbols	13
Symbol Offset	1
No. of RBs	273
RB Offset	0
PDSCH Type	DCI Format 1_1
Number of Codewords	1
Scheduled by CORESET 0	OFF
Rate Match Pattern Group	None
Resource Allocation	Type 1
Modulation	64 QAM
CDM Groups w/o Data	1
Number of Layers	2
DMRS Type A Position	2
DMRS Sequence Generation	N_ID^Cell
N_SCID	0
DMRS Antenna Ports	1000, 1001

Table 7-5: Scheduling PDSCH

B Example 5G FR1 Downlink 2x2 MIMO Signal Generation

R&S®SMW200A, a high-end vector signal generator from R&S®, can be utilized to generate the signal with the parameters described in Appendix A. The generated signal can be considered as a reference signal to the real signal under test.

A step-by-step description is given here to show the entire setup procedure.

1. Press "Preset" hard-button on SMW200A's front panel
2. Define 2x2 MIMO system structure

   a) Goto **System Configuration**, see Fig. 7-1

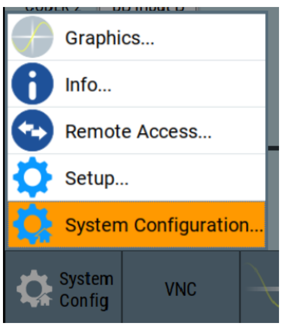


Fig. 7-1 Access to System Configuration

   b) In tab "**Fading/Baseband Config**", see Fig. 7-2

   set Mode **Advanced**

   Signal Outputs **Analog & Digital**

   Entities **1**

   Basebands (Tx Antennas) **2**

   Streams (Rx Antennas) **2**

   BB Source Config **Coupled Sources**

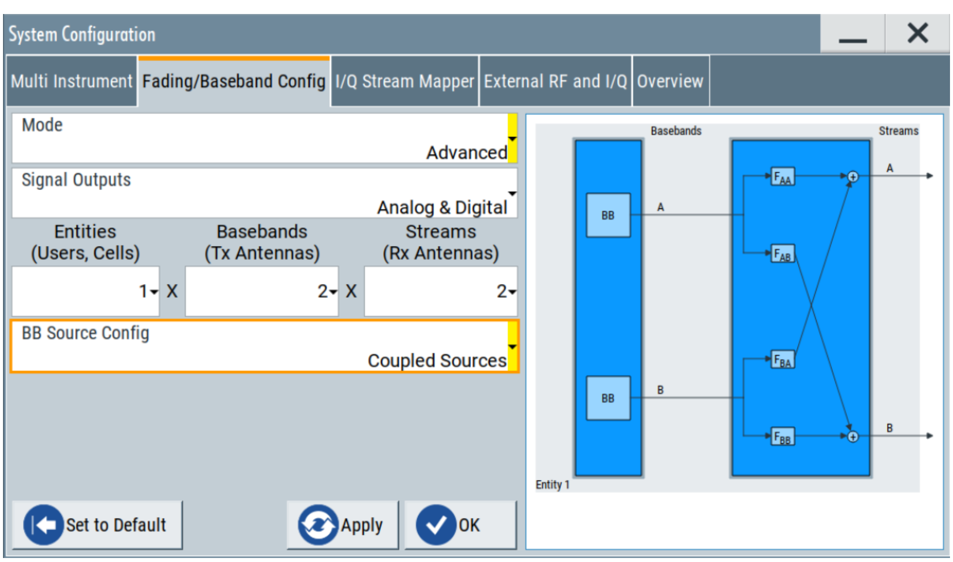


Fig. 7-2 Fading/Baseband config under system configuration

   c) Press "**Apply**" to save the settings and then press "**OK**" to exit the system configuration. The system structure as shown in Fig. 7-3 shall appear.

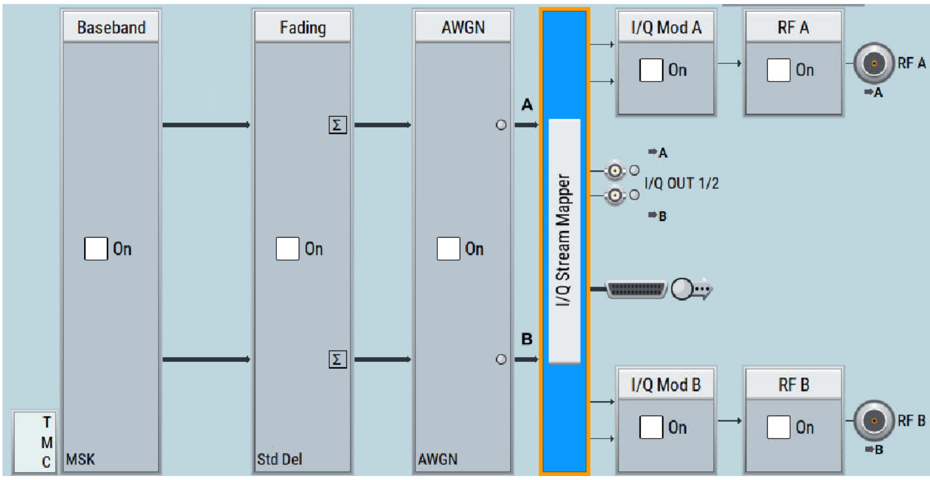


Fig. 7-3 2x2 MIMO system structure on SMW200A

3. Click on Fading module and check option "**Bypass if Fading Off**". See Fig. 7-4

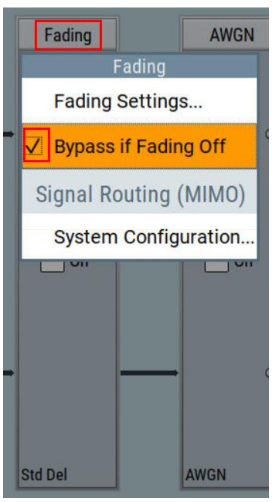


Fig. 7-4 Bypass Fading module if Fading is Off

4. In Baseband module, select "**5G NR**". See Fig. 7-5

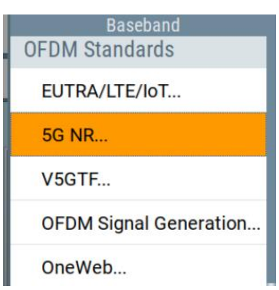


Fig. 7-5 Select 5G NR baseband

5. In 5G NR baseband module, following settings are required to be set
   a) Link Direction **Downlink**. See Fig. 7-6

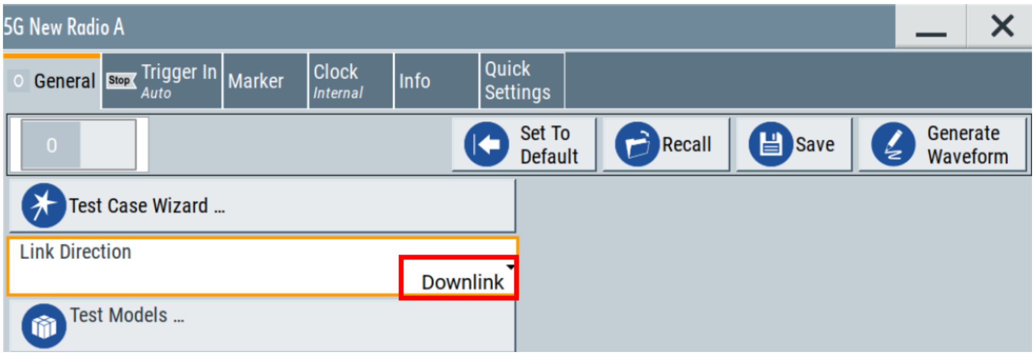


Fig. 7-6 Select link direction

b) In Node Settings, see Fig. 7-7

Deployment **3 GHz < f <= 6 GHz**

Frequency / GHz **3.5 GHz** (carrier frequency), this is required when RF Phase Compensation is enabled

RF Phase Compensation **Enabled**

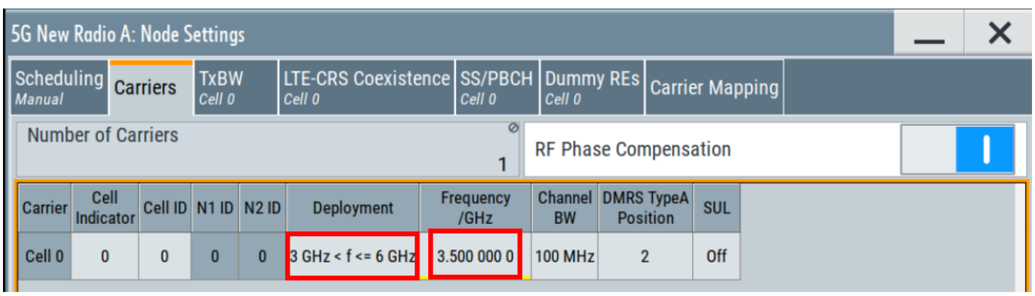


Fig. 7-7 5G NR node settings

c) In Users/BWPs settings, default settings are used

d) In Scheduling Settings,

Default CORESET scheduling and settings are kept

Default PDSCH scheduling is kept

Config PDSCH settings, click on the "**Config…**". See Fig. 7-8

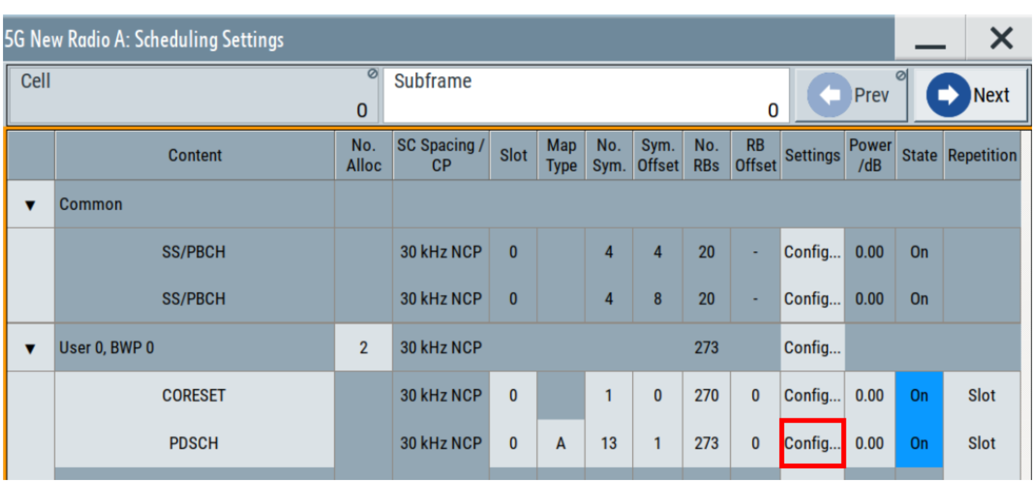


Fig. 7-8 5G NR scheduling settings

In tab "**General**", set Modulation **64 QAM**, see Fig. 7-9

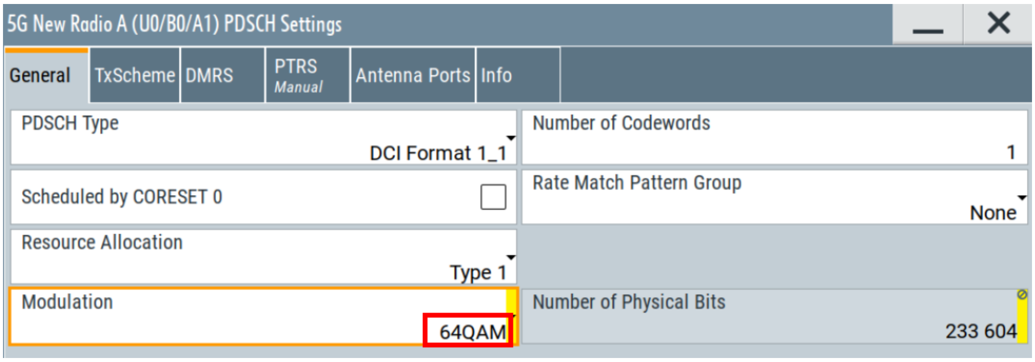


Fig. 7-9 PDSCH general settings

In tab "**TxScheme**", set Number of Layers **2** (MIMO layers), see Fig. 7-10

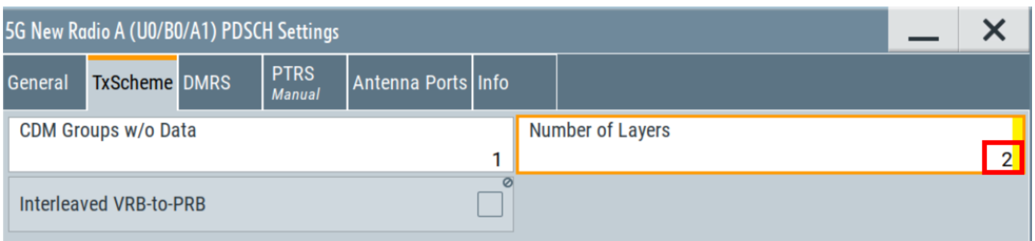


Fig. 7-10 PDSCH TxScheme settings

In tab "**Antenna Ports**", see Fig. 7-11

Set Mapping Coordia **Cylindrical**

Map PDSCH antenna port to physical transmission antenna (Baseband). In this example, the mapping is as follows:

AP1000 - MIMO layer 1 - Physical antenna A (baseband A)

AP1001 - MIMO layer 2 - Physical antenna B (baseband B)

No cross component between two MIMO layers are defined here, since the signal is going to be tested under MIMO conducted test mode

Furthermore, the magnitude and phase of the signal on each AP can be set individually. By doing that, we can set phase deviation between two APs, i.e. two MIMO layers.

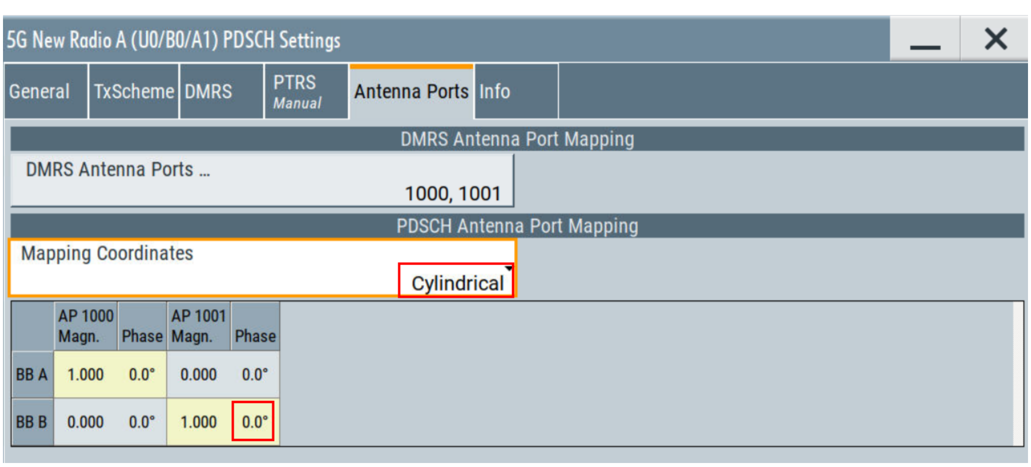


Fig. 7-11 PDSCH DMRS antenna ports settings

6. Switch on Baseband, see Fig. 7-12

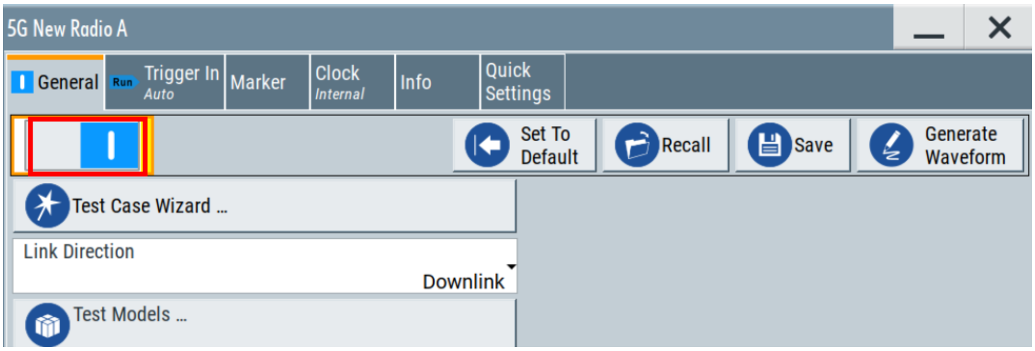


Fig. 7-12 Turn on the 5G NR baseband

7. Last step, see Fig. 7-13

   a) Set carrier frequency **3.5 GHz**

   b) Set output power level and switch on the RF output on both port A and B

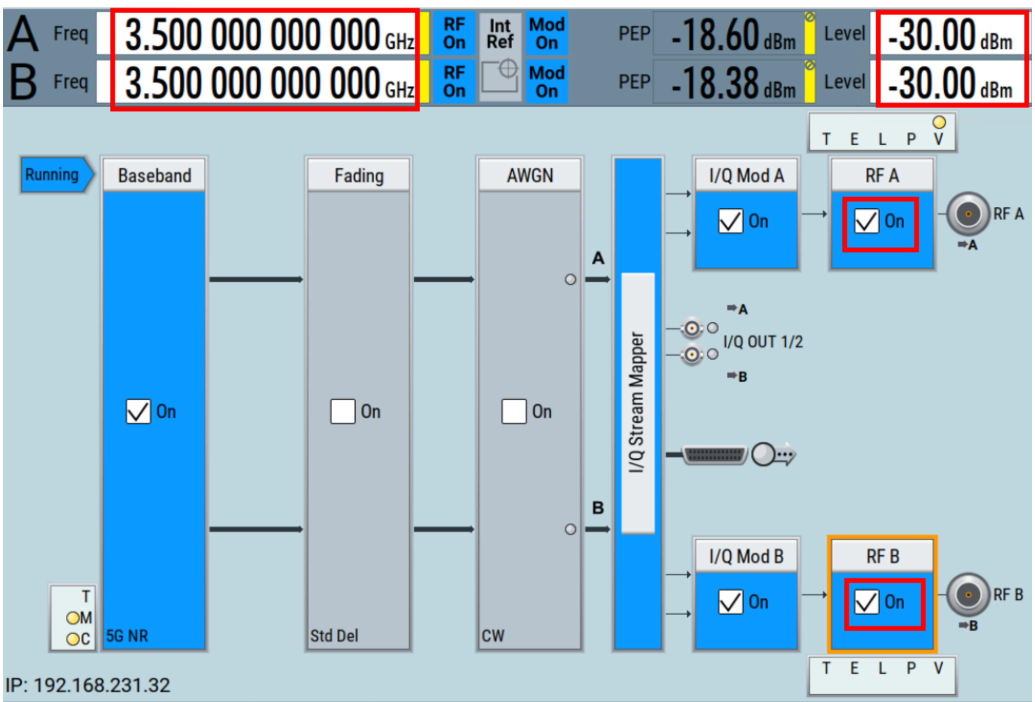


Fig. 7-13 Set carrier frequency and output power level

C Antenna Port

Antenna Port (AP) is a logical concept that was firstly introduced in LTE and now further adopted by 5G NR.

The AP is said to be associated with the transmitted reference signal which is used by the receiver for the channel estimation. The transmitted reference signals over the same AP can be assumed at the receiver side that they experience the same radio channel condition

The set of AP defined in 3GPP specification 38.211 for 5G NR is listed below in Table 7-6 and Table 7-7 for downlink and uplink, respectively. Of course, in this application note, we focus only on downlink APs. The uplink APs listed here is just for the completeness of the information.

Downlink

Channel/Reference Signal	Antenna Port numbers
PDSCH + DMRS	Starting from 1000 (1000 Series)
PDCCH	Starting from 2000 (2000 Series)
CSI-RS	Starting from 3000 (3000 Series)
SS-Block/PBCH	Starting from 4000 (4000 Series)

Table 7-6 Overview of 5G NR downlink antenna port

Uplink

Channel/Reference Signal	Antenna Port numbers
PUSCH + DMRS	Starting from 0 (0 Series)
SRS	Starting from 1000 (1000 Series)
PUCCH	Starting from 2000 (2000 Series)
PRACH	Starting from 4000 (4000 Series)

Table 7-7 Overview of 5G NR uplink antenna port

For example, downlink antenna ports starting with 1000 are used for PDSCH DMRS. Different transmission layers for PDSCH DMRS can use antenna ports in this series. For example, 1000 and 1001 for a two-layer PDSCH DMRS transmission, i.e. in 2x2 MIMO case.

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GFM343 | Version 0e | 06.2020
Application Note | 5G FR1 Downlink MIMO Phase Coherent Signal Analysis
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