

SMALL CELL TESTING IN FR2

Comprehensive test solutions guide for production and R&D

Products:

- ▶ R&S®CMP200
- ▶ R&S®CMQ200
- ▶ R&S®CMPHEAD30/CMPHEAD50
- ▶ R&S®WMT
- ▶ R&S®ATS1000
- ▶ R&S®AMS32-BST
- ▶ R&S®FSW
- ▶ R&S®SMW200A
- ▶ R&S®RTP/RTO
- ▶ R&S®RT-ZPR40/RT-ZPR20
- ▶ R&S®ZNA/ZNBT

Yong Shi | 1SL395 | Version 1e | 06.2023

<http://www.rohde-schwarz.com/appnote/1SL395>



Contents

	Abstract	3
1	Background	4
1.1	Small Cell	4
1.2	Over the Air Testing	5
1.2.1	Motivation	5
1.2.2	OTA System Calibration	5
2	Test Solution for Production	6
2.1	Used Hardware and Software	6
2.1.1	CMP200 and Remote Radio Head (RRH) CMPHEAD30/CMPHEAD50	7
2.1.2	CMQ200	8
2.1.3	Source of Frequency Reference and Timing Synchronization	8
2.1.4	Wireless Manufacturing Test (WMT)	9
2.1.5	CMsquares	10
2.1.6	R&S CM Spectrum Analyzer (RSCMSA)	11
2.1.7	VSE / WinIQSIM2	11
2.1.8	DUT Control Software	13
2.2	Getting Started	13
2.2.1	Cabling	13
2.2.2	System IP Configurations	15
2.2.3	Run Test and Collect Result	16
2.3	Summary	23
3	Test Solutions for R&D	23
3.1	Digital Design Test	24
3.2	Power Amplifier Characterization	28
3.3	Beamforming and MIMO	30
3.4	Antenna Measurements	31
3.5	Conformance	32
4	Conclusion	35
5	Literature	35
6	Appendix	37
A	RSCMSA Installation	37

Abstract

Small cell is a compact base station with smaller form factor and lower transmission power in comparison to the conventional macro base station. It covers relatively small area and serves less users. Usually, small cell can be integrated into the existing mobile network. By the evolution of radio access technology, the role of small cell has been changing through the evolution path. In the 2G/3G time, its role was to provide coverage in corner cases. Later during LTE, networks are not just providing coverage but capacity too. Small cells were then used to provide the addition capacity where required without adding additional spectrum. Now in 5G era, network operators use densification as an important strategy to provide seamless 5G services which demand coverage, capacity and performance too. With use cases requiring the 5G millimeter wave (mmW) rollouts, it makes sense to use small cells for densification due to the propagation characteristics of mmW.

In this application note, we will shed light on the testing aspects of a small cell throughout the product life cycle with particular focus on the production test solution for the small cell device under test (DUT) in FR2 (frequency range 2, mmW frequency band) in Over the Air (OTA) environment for option 6 split based on radio communication tester R&S®CMP200 and OTA chamber R&S®CMQ200. The document is complemented with more insights into test solutions used in typical R&D test applications towards the second half of the application note.

The application note is structured in the following way:

Chapter 1 briefly introduces small cells and OTA background

Chapter 2 describes in great details about the production test solution for the small cell testing in FR2 in OTA environment with R&S®CMP200, the Radio Communication Tester and OTA chamber R&S®CMQ200 with the automation framework R&S®WMT controlling the instrument, chamber and the small cell (DUT)

Chapter 3 presents other R&D testing aspects for a small cell

The following abbreviations are used for R&S® products throughout the whole application note:

- ▶ R&S®CMP200 Radio Communication Tester is referred to as CMP200
- ▶ R&S®CMQ200 Shielding Cube mmW is referred to as CMQ200
- ▶ R&S®CMPHEAD30 or R&S®CMPHEAD50 Remote Radio Head is referred to as CMPHEAD30 or CMPHEAD50, or RRH in short
- ▶ R&S®WMT Wireless Manufacturing Test Tool is referred to as WMT
- ▶ R&S®CMsquares Web-based user interface of CMP200 is referred to as CMsquares
- ▶ R&S®WinIQSIM2 signal generation software is referred to as WinIQSIM2
- ▶ R&S®VSE Vector Signal Explorer is referred to as VSE

1 Background

1.1 Small Cell

According to 3GPP TS38.104 [1], base stations (BS) are categorized into three types based on the BS to UE minimum distance and BS to UE minimum coupling loss (MCL), namely, Macro, Micro and Pico cells (see Table 1-1). Micro and Pico cells fall under small cell category.

Base Station Type	Coverage	BS to UE minimum distance (m)	BS to UE coupling loss (dB)
Macro Cell	Wide Area	35	70
Micro Cell	Medium Range	5	53
Pico Cell	Local Area	2	45

Table 1-1 Base station category (3GPP TS38.104 [1])

Looking at the small cell deployment, all-in-one integrated small cell provides layer 1 to 3 and RF functionality within a single unit and interface with the core network in the past. By entering 5G era, the latest technical trend shows that small cell is going to be deployed in the form of so-called virtualized disaggregated networks. It simply means that the functions of a small cell are split into different options as shown in Figure 1-1 by having standardized open interfaces. This approach enables more scaling efficiency of the network and to make it easier for the service providers to align with their customer needs and available infrastructure. The different splits allow the versatile use cases to be deployed in different scenarios, indoor or outdoor, density urban or suburb area, public or private to meet the end customer requirements in terms of latency, capacity, QoS and security aspects.

Industry consortiums like 3GPP, Small Cell Forum (SCF), O-RAN Alliance and CPRI/OBSAI standardize the disaggregation architectures, such as option 2, option 6, option 7.2x and option 8 respectively.

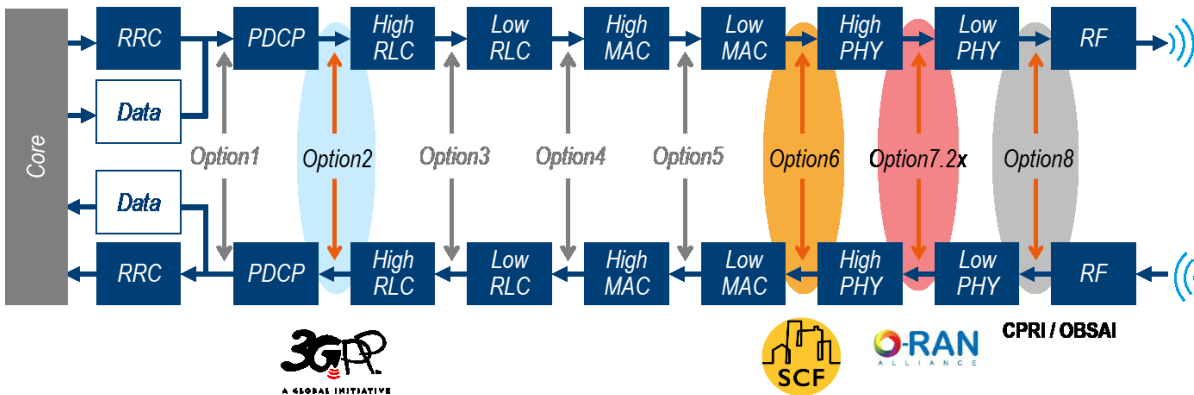


Figure 1-1 Split options for disaggregated Radio Access Network (RAN)

Option 2 is a split of centralized unit (CU) and distributed unit (DU) which is literally the separation of user and control plane.

Option 6 has a split between PHY and MAC layer which is promoted by SCF. Within option 6 split, the network FAPI (nFAPI) interface allows service providers to mix the S-DUs and S-CUs from different vendors

to connect to any small cell radio unit (S-RU) (shown in Figure 1-2).

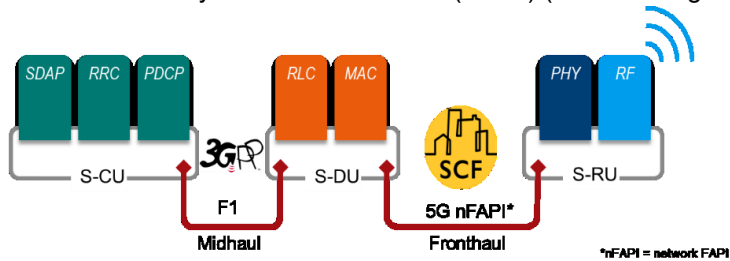


Figure 1-2 SCF split 6

In addition, O-RAN defines the low PHY and high PHY split option 7.2x within the PHY to support various fronthaul requirements and hence yield higher virtualization benefits.

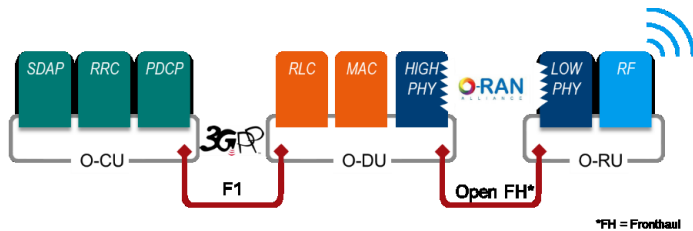


Figure 1-3 O-RAN split 7.2x

In this application note, test solutions for option 6 split are the focus.

1.2 Over the Air Testing

1.2.1 Motivation

In contrast to the conventional conducted test mode (DUT is connected physically to the measurement instrument via RF cable), OTA is the only methodology for a small cell product operating in FR2. This has good reasons. Massive MIMO and beamforming are the key features for the FR2 DUT. With short wavelength in mmW frequency band, the antenna elements used to steer the beam are placed more densely. This is nearly impossible to put connectors onto it for the conducted testing. Even if it were possible, due to the massive nature of the antenna elements, to connect all the connectors one after the other becomes impractical. From economy aspect, the cost is chased higher if everything is done in conducted mode with respect to the measurement equipment and all connected accessories (e.g. RF cables etc.).

1.2.2 OTA System Calibration

The aim of OTA system calibration is to determine the insertion loss occurred on the connected cables, the components in both Transmitter (Tx) path and Receiver (Rx) path, antenna loss, and free space path loss (FSPL) in the air throughout the entire signal propagation path. In other word, one end of the calibration plane is the signal source where signal is transmitted (e.g. at the Tx port of the signal generator) and the other end of the calibration plane is the signal sink where the signal is received (e.g. at the Rx port of the spectrum analyzer).

The calibration is frequency dependent and has to be performed prior to tests. There are several ways to conduct the calibration which differ in the used measurement equipment, using the signal generator and spectrum analyzer (suitable for modulated signals), vector network analyzer (suitable for CW signal) or simply using golden reference device. A conceptual illustration of OTA system calibration using the signal generator and spectrum analyzer is given in Figure 1-4. Details of the OTA system calibration can be further referred in Chapter 3 of the white paper (Demystifying over-the-air (OTA) testing) [2].

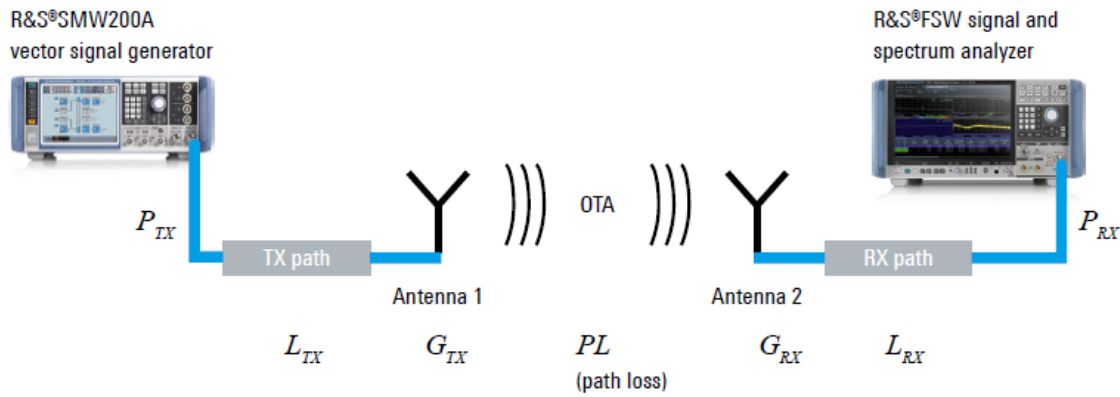


Figure 1-4 OTA calibration concept using signal generator and spectrum analyzer

As the outcome of the OTA system calibration, frequency dependent compensation (FDC) is obtained that consists of the information about the measured frequency and its corresponding signal loss in dB over the whole chain. The more frequency points that have been calibrated, the more precise that the compensated pathloss values are. The pathloss between the adjacent frequencies is linearly interpolated.

2 Test Solution for Production

In this chapter, a one-box solution based on CMP200, CMQ200, RRH for small cell production testing operating in FR2 frequency band controlled by R&S WMT automation framework is described.

In order to allow S-RU to be operated in isolated mode without the accompanying S-DU (see the split in Figure 1-2) in disaggregated network, the S-RU should essentially support test mode, i.e. Thin MAC [3], to generate and analyze 3GPP defined test model signals. This approach exposes cost and test efficiency advantages in comparison to the End2End solution that involves the DU emulator. Therefore, in this document, the support of test mode on S-RU is assumed.

2.1 Used Hardware and Software

The complete small cell test solution for production is shown in Figure 2-1.



Figure 2-1 Overview of FR2 small cell OTA solution for production

2.1.1 CMP200 and Remote Radio Head (RRH) CMPHEAD30/CMPHEAD50

CMP200 is a one-box radio communication tester suitable for 5G FR2 testing in non-signaling mode. It contains general purpose analyzer covering frequency range from 4 to 20 GHz and ARB generator. Replaying of predefined waveforms (-100 dBm) with frequency range from 6 to 20 GHz is supported. With three switchable ports with 1 GHz bandwidth each, the measurement speed is accelerated accordingly.

For testing 5G FR2 mmW band, a remote radio head (RRH) CMPHEAD30 facilitating the frequency range extension to FR2 mmW band (24 GHz to 44 GHz) is required. Thanks to the built-in IF frontend, up to three RRHs can be connected to a CMP200. Each RRH has two 2.4 mm RF interfaces that can be activated one after the other via solid-state switches. The overall setup with three RRHs provides up to $3 \times 2 = 6$ paths (TDD mode), giving users the flexibility to operate multi-DUT and multi-array test concepts.



Figure 2-2 CMP200 and CMPHEAD30 RRH

This hardware tandem mentioned above was also validated for FR2 small cell testing by Qualcomm®. Please find the details in the [press release](#).

Alternative to CMPHEAD30, CMPHEAD50 covering FR2 frequency range from 22 GHz to 50 GHz can be adopted for FR2 small cell testing as well. The additional Rx low-noise input ensures wider dynamic range, thus enhances the Rx sensitivity. Thanks to the individual external local oscillator (LO) inputs for both Tx and Rx paths, superb EVM performance for RF measurements can be achieved. In Figure 2-3, top, front and rear view of a CMPHEAD50 RRH are presented.



Figure 2-3 CMPHEAD50 RRH (top, front and rear view)

In the remaining of this document, the captured screenshots are based on CMPHEAD30.

2.1.2 CMQ200

CMQ200 is the OTA shielding chamber from R&S. It supports the mmW range from 20 GHz to 77 GHz. In combination with CMP200 and RRH, it is ideal for RF parametric tests on 5G FR2 devices in non-signaling mode.



Figure 2-4 CMQ200 shielding cube

For FR2 measurement, dual polarized Vivaldi antenna (probe antenna) is utilized in CMQ200.

2.1.3 Source of Frequency Reference and Timing Synchronization

An extra instrument or device needs to be adopted to provide the following functionality to the whole small cell test solution:

- ▶ Frequency reference (10 MHz reference)
- ▶ 1 pulse per second (PPS) signal that serves accurate timing signal for precise synchronization of each small cell

As an example, R&S signal generator R&S®SMBV100A (Figure 2-5) can well serve the functionalities mentioned above.



Figure 2-5 R&S vector signal generator R&S®SMBV100A

2.1.4 Wireless Manufacturing Test (WMT)

WMT is Python based software solution for chipset and module RF testing that is installed on external control PC. It is tailored for high volume production testing and R&D applications. Modular architecture enables the flexible integration and minimum time-to-market.

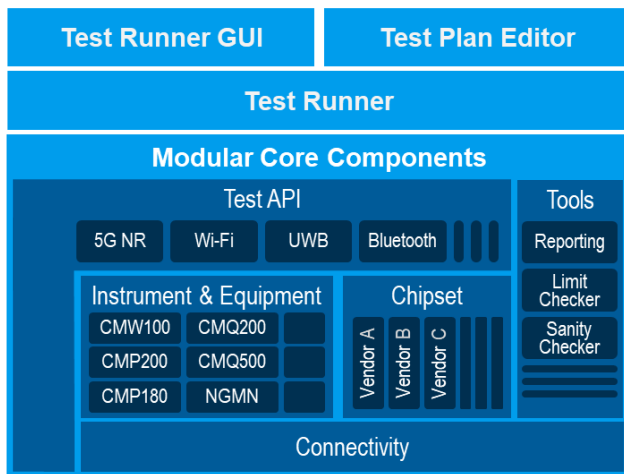


Figure 2-6 WMT architecture

As illustrated in Figure 2-6, WMT provides a single point for instrument control (e.g. CMP200), DUT control, testcase creation (Test Plan Editor), testcase execution (Test Runner) and its associated limit check and report collection. If needed, WMT integrates also the chamber control as well.

Two GUIs are included in WMT, namely, WMT Test Plan Editor and WMT Test Runner.

In the Test Plan Editor (Figure 2-7), as the name already implies, a test plan can be newly created or the existing one can be modified. The expected limits of the test items can be defined. In each test plan, it is possible to include multiple test cases with individual parameter settings.

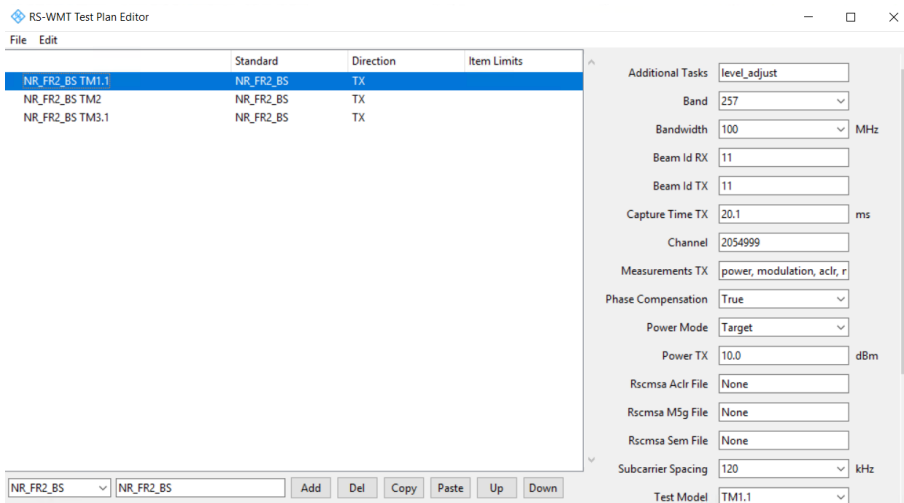


Figure 2-7 WMT Test Plan Editor

WMT Test Runner (Figure 2-8) provides the environment for the test execution of a selected test plan as well as multi-DUT parallel testing. After each test plan is executed, test report can be inspected. Debug log associated to the test run can be checked in the test runner, if required.

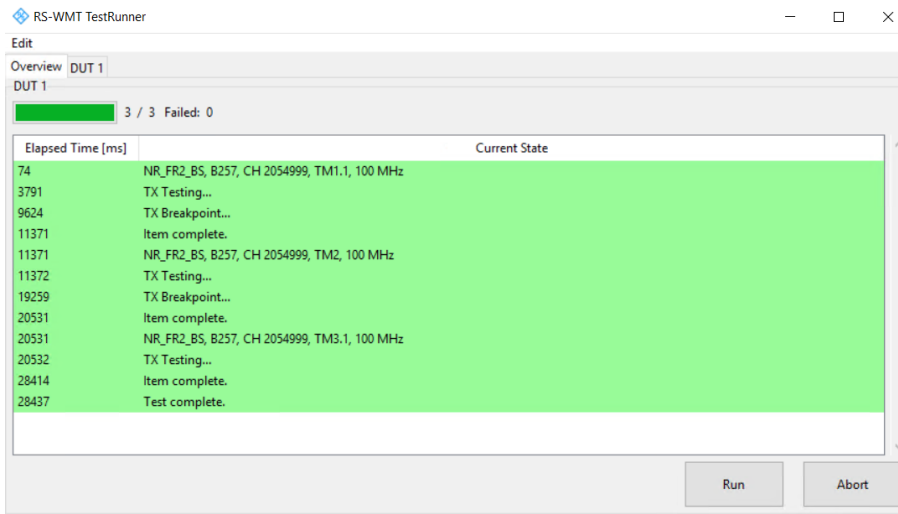


Figure 2-8 WMT Test Runner

2.1.5 CMSquares

CMSquares is the Web-based user interface of CMP200. It comes along with the CMP200 firmware installation. The CMSquares is accessible from the browser of any remotely connected PC that is located in the same network as CMP200 (i.e. IPs belong to the same network segment) by entering the CMP200 IP address in the browser address field or locally on CMP200.

For small cell testing, the captured IQ samples are presented in the IQ Recorder square as shown in Figure 2-9.

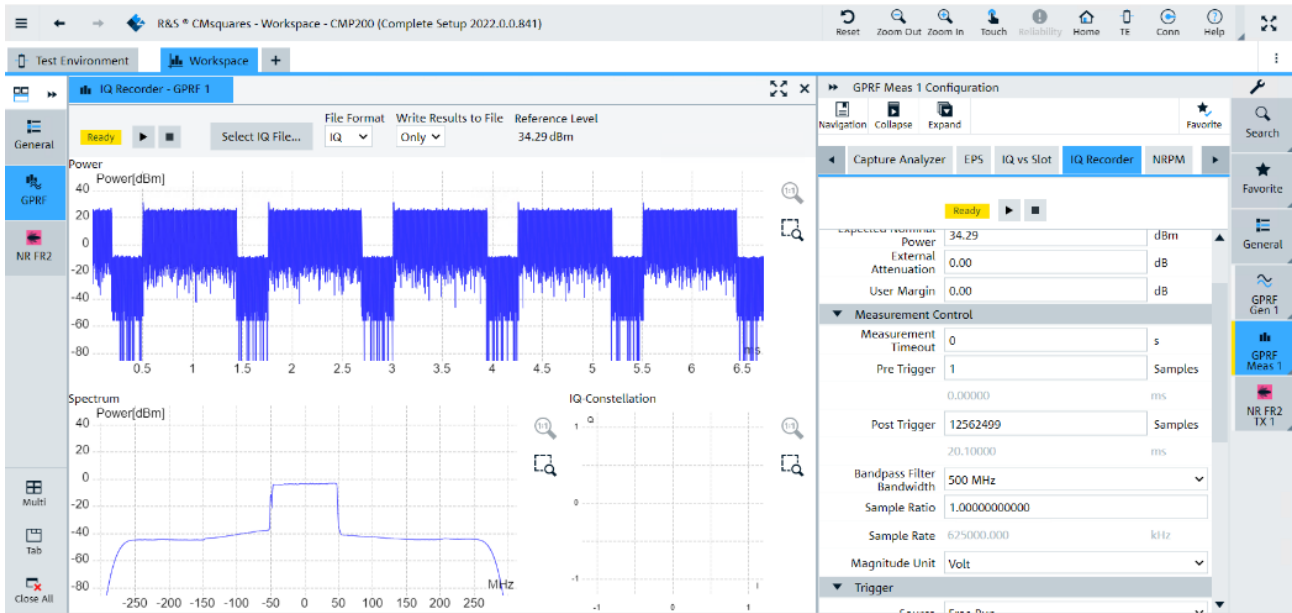


Figure 2-9 IQ Recorder square in CMSquares (CMP200 Web GUI)

2.1.6 R&S CM Spectrum Analyzer (RSCMSA)

RSCMSA is software (license option KN601 is required) for FR2 downlink modulation and spectrum analysis on CMP200.

The software distribution is in a form of windows installer which can be downloaded from Gloris customer portal of R&S (<https://gloris.rohde-schwarz.com/>).

The installation is straightforward and the steps can be found in Appendix A of this document.

Figure 2-10 illustrates the measurement concept between CMP200 (with RSCMSA software) and WMT. The WMT configures and controls the instrument via SCPI commands. On CMP200, the captured IQ data is then parsed to RSCMSA software for spectrum analysis. The analysis results are then fetched by WMT and presented in WMT in the end. The biggest advantage of this approach is that the parallel processing of multiple jobs is possible. That means, while RSCMSA analyzing the IQ data, the next IQ capturing can be already started independently. This enhances the efficiency of the testing.

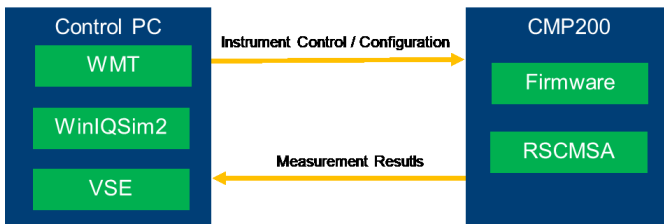


Figure 2-10 Measurement concept of CMP200/WMT with RSCMSA software

2.1.7 VSE / WinIQSIM2

VSE is a software tool for signal analysis installed on control PC.

IQ samples recorded on CMP200 can be optionally transferred to VSE for post processing. The signal analysis results are then presented in VSE as shown in Figure 2-11.



Figure 2-11 Signal analysis in VSE

As indicated in Figure 2-12, VSE for signal analysis is per default enabled in section 'vsa' of 'testconfig.ini' config file in WMT Test Runner. This provides finer granularity of signal analysis for debugging purpose especially for R&D applications.

```
[vsa]
enabled = True
connection = socket
host = 127.0.0.1
port = 5025
timeout = 20
display_capture = True
display_update = True
```

Figure 2-12 Enable the VSE visualization in 'testconfig.ini' in WMT

In production application, it is however recommended to disable the signal analysis in VSE in order to speed up the production process.

WinIQSIM2 is the tool to generate the ARB wave file which is necessary for the small cell receiver tests that is installed on the control PC as well. The generated waveform file is then transferred to and later on played back on CMP200. The configuration and generation of the waveform file is controlled by WMT. It does not require direct user interaction on WinIQSIM2. WinIQSIM2 application only needs to be manually launched and run in the background before it is called by WMT.

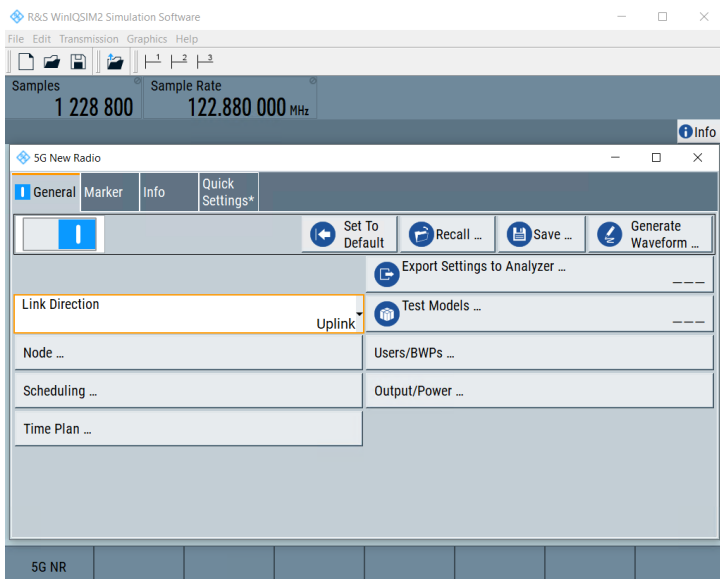


Figure 2-13 WinIQSIM2 GUI

2.1.8 DUT Control Software

DUT control software evtl. the driver for DUT needs to be installed on the control PC. This is however DUT manufacture proprietary. For example. QMSL library from Qualcomm. The user has to ensure that the environment with respect to the DUT control is setup properly. Based on this prerequisite, the corresponding WMT version that contains this specific DUT control should be applied.

Please contact your local R&S support team to get more detailed information on the suitable WMT distribution that matches your DUT.

2.2 Getting Started

2.2.1 Cabling

Figure 2-14 gives an overview of the system cabling of the test solution described in Chapter 2.1.

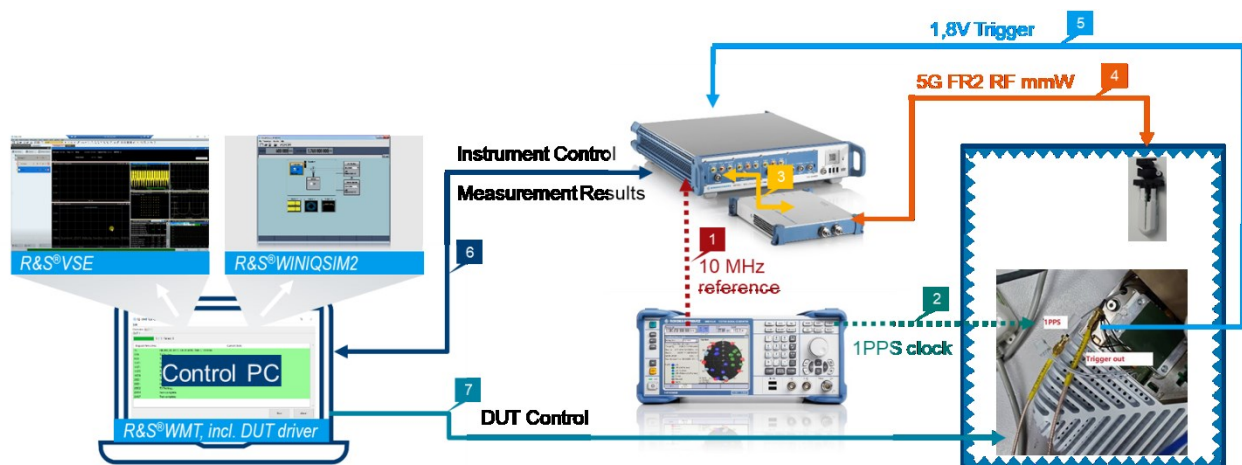


Figure 2-14 Overview of system cabling

Details of each labeled connection can be referred as follows:

1. Cabling of 10 MHz reference signal

Since the used signal source might differ to R&S®SMBV100A, the name of source port shown in Figure 2-15 is exemplary.



Figure 2-15 Cabling of 10 MHz reference between R&S®SMBV100A and CMP200

2. Cabling of 1 PPS clock signal

Since the used signal source might differ to R&S®SMBV100A, the name of source port shown in Figure 2-16 is exemplary.

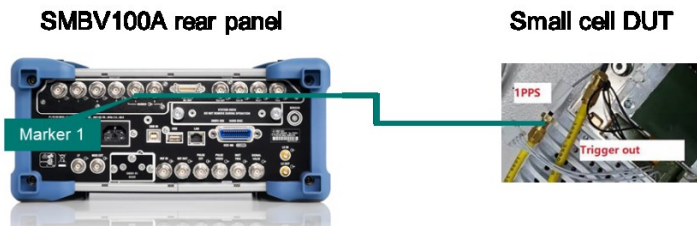


Figure 2-16 Cabling of 1 PPS clock between R&S®SMBV100A and small cell DUT

3. Cabling between CMP200 and CMPHEAD30 (RRH)

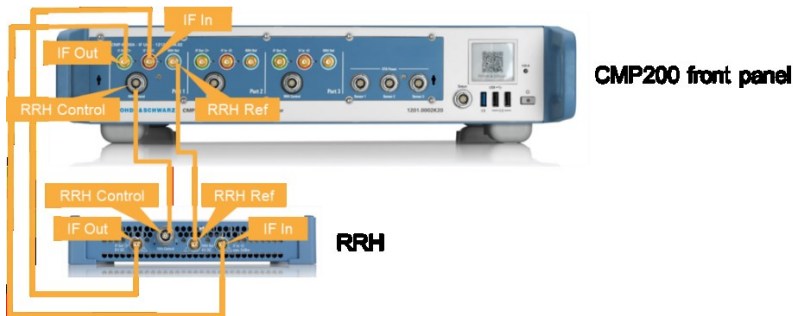


Figure 2-17 Cabling between CMP200 and CMPHEAD30 (RRH)

4. Cabling between CMPHEAD30 (RRH) and Vivaldi

The cross polarized Vivaldi probe antenna is placed in the CMQ200 chamber and accessible from outside of the chamber through an RF feedthrough which has two separate RF connectors connecting to horizontal polarization and the vertical polarization of the Vivaldi antenna, respectively.

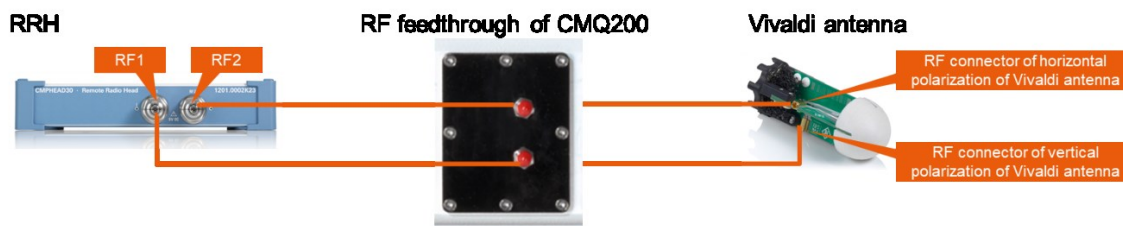


Figure 2-18 Cabling between CMPHEAD30 (RRH) and Vivaldi antenna through an RF feedthrough

5. Cabling of trigger signal between the small cell DUT and CMP200

This connection is required if receiver tests are performed.



Figure 2-19 Cabling of trigger signal between small cell DUT and CMP200

6. Connection between control PC and CMP200

Control PC (WMT) configures and controls the CMP200 via IP interface. Therefore, LAN connection between both of them are required.

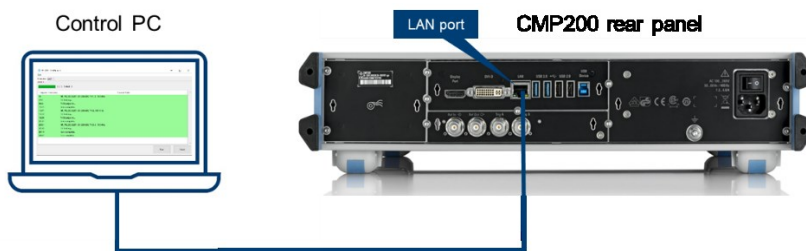


Figure 2-20 Cabling between CMP200 and control PC

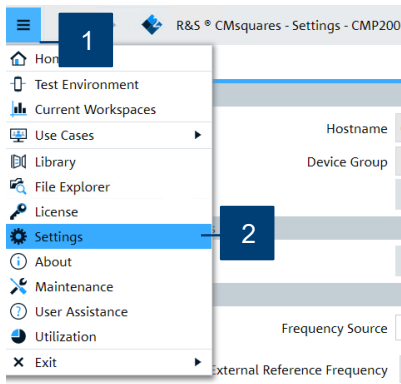
7. Connection between control PC and DUT

Used interface for DUT control is proprietary (via USB, COM port, IP etc.). It is the integrated function of WMT delivery for each individual implementation.

2.2.2 System IP Configurations

Ensure that the IP of windows control PC and CMP200 are in the same network segment. Either both of them are assigned automatically by the DHCP server from the connected network or set manually with the static IPs.

In this section, the IP settings in CMsquares on CMP200 is highlighted in Figure 2-21. For more details about the CMP200 operations, please refer to CMP200 user manual [4].



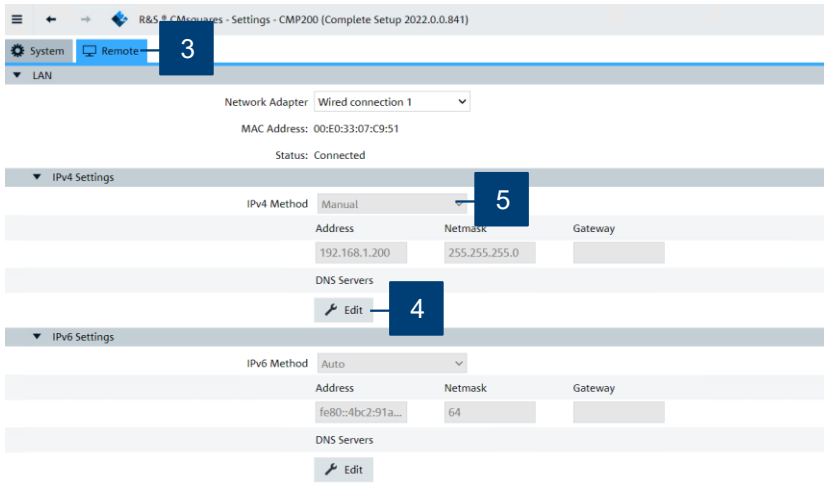
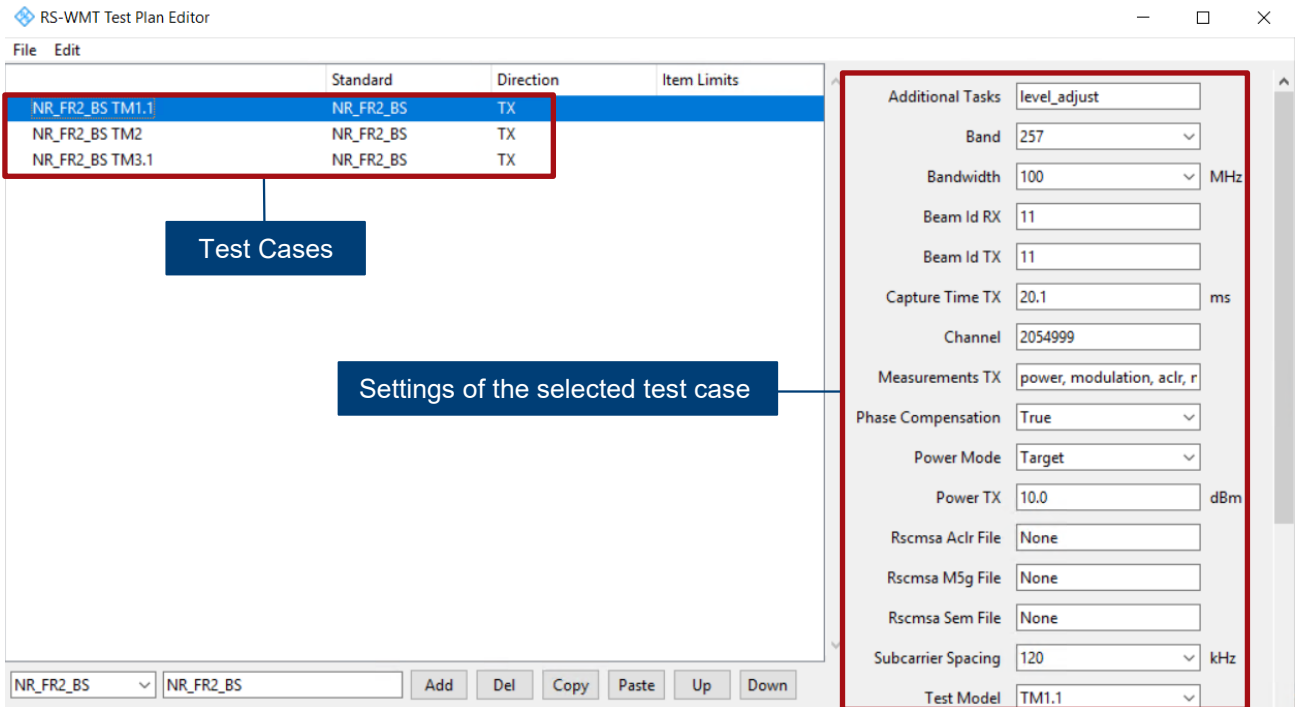


Figure 2-21 Modification of the IP settings in CM Squares on CMP200

2.2.3 Run Test and Collect Result

In this section, a step-by-step guide is given to show the workflow of testing using WMT. Moreover, the available measurement results are also introduced here.

1. Make sure that the DUT is powered on and is in the right idle operation mode (e.g. DUT is detected by its DUT control software)¹
2. On control PC, launch WMT Test Plan Editor GUI. Create the test plan and make proper settings for each test case from there (Figure 2-22). The test case relevant parameter settings can be found in Table 2-1.



¹ This is proprietary which means that the status differs from vendor to vendor

Figure 2-22 Test plan and settings in WMT Test Plan Editor

Designation	Description	Values
Additional Tasks	Adjust the expected nominal power level automatically on CMP200 (Auto Ranging)	Enable / Disable
Band	NR operating band	
Bandwidth	Channel bandwidth	
Beam Id RX	Set the receiver beam ID on DUT to ensure the boresight of the antenna is perpendicular to the antenna plane of the DUT and centered to the Vivaldi test antenna in CMQ200	The value selection is product specific that can be recommended by the antenna designer of the product.
Beam Id TX	Set the transmitter beam ID on DUT to ensure the boresight of the antenna is perpendicular to the antenna plane of the DUT and centered to the Vivaldi test antenna in CMQ200	The value selection is product specific that can be recommended by the antenna designer of the product.
Capture Time Tx	Time duration of IQ recording	
Channel	NR ARFCN	
Measurement Tx	Selection of Tx test	Power, modulation, ACLR, Spurious Emission Mask (SEM)
Phase Compensation	Enable/Disable the phase compensation during baseband signal up-conversion according to 3GPP TS38.211, Chapter 5.4	True / False
Power Mode	Set the power mode on DUT	Target / Max / Min
Power Tx	Set the transmit power level on DUT, if Power Mode is set to 'Target'	
RSCMSA ACLR file	Specify the filename that contains limit line definition of ACLR (.xml file extension). The file is generated by VSE or FSW and should be made available on CMP200	None (Default) aclr_nr5g_100mhz__1adj.xml
RSCMSA M5g file	Specify the filename that contains 5G NR signal configuration (.m5g file extension) defining frequency range, direction, test model, bandwidth and subcarrier spacing etc. The file is generated by VSE or FSW and should be made available on CMP200	None (Default)
RSCMSA SEM file	Specify the filename that contains limit line and ranges definition of SEM (.xml file extension) The file is generated by VSE or FSW and should be made available on CMP200	None (Default)
Subcarrier Spacing	Subcarrier spacing	
Test Model	Selection of test models defined by 3GPP 38.141-2	

Table 2-1 Parameter settings for small cell testing in WMT test editor

3. Launch VSE software on control PC unless signal analysis in VSE is disabled in test configuration 'testconfig.ini' file. Default setting will enable the VSE for signal analysis (details see Figure 2-24).
4. Launch WMT Test Runner GUI and follow the steps shown in Figure 2-23 to run the test plan.

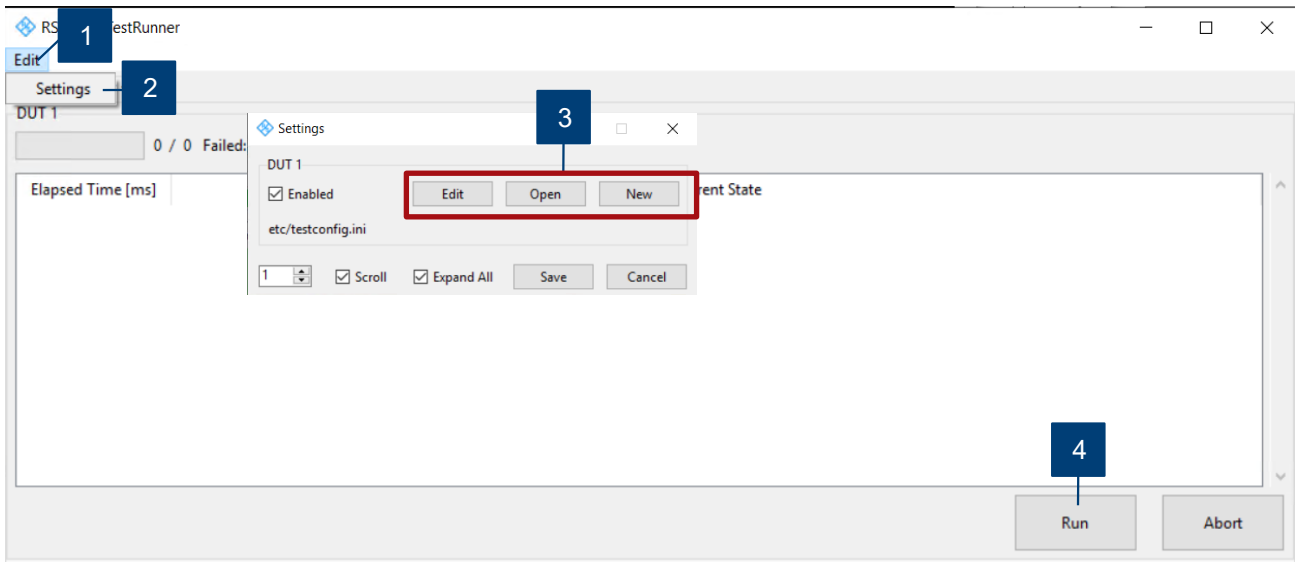


Figure 2-23 Run test plan in WMT TestRunner

The Step 3 shown in Figure 2-23 contains following options:

Edit - Modify an existing configuration file, e.g. 'testconfig.ini'

Open - Open a configuration file from local file system

New - Create a completely new configuration file

An example test configuration file named 'testconfig.ini' where the most relevant settings are highlighted in Figure 2-24. Bear in mind that the FDC values entered in the configuration file are based on the OTA system calibration described conceptually in Chapter 1.2.2.

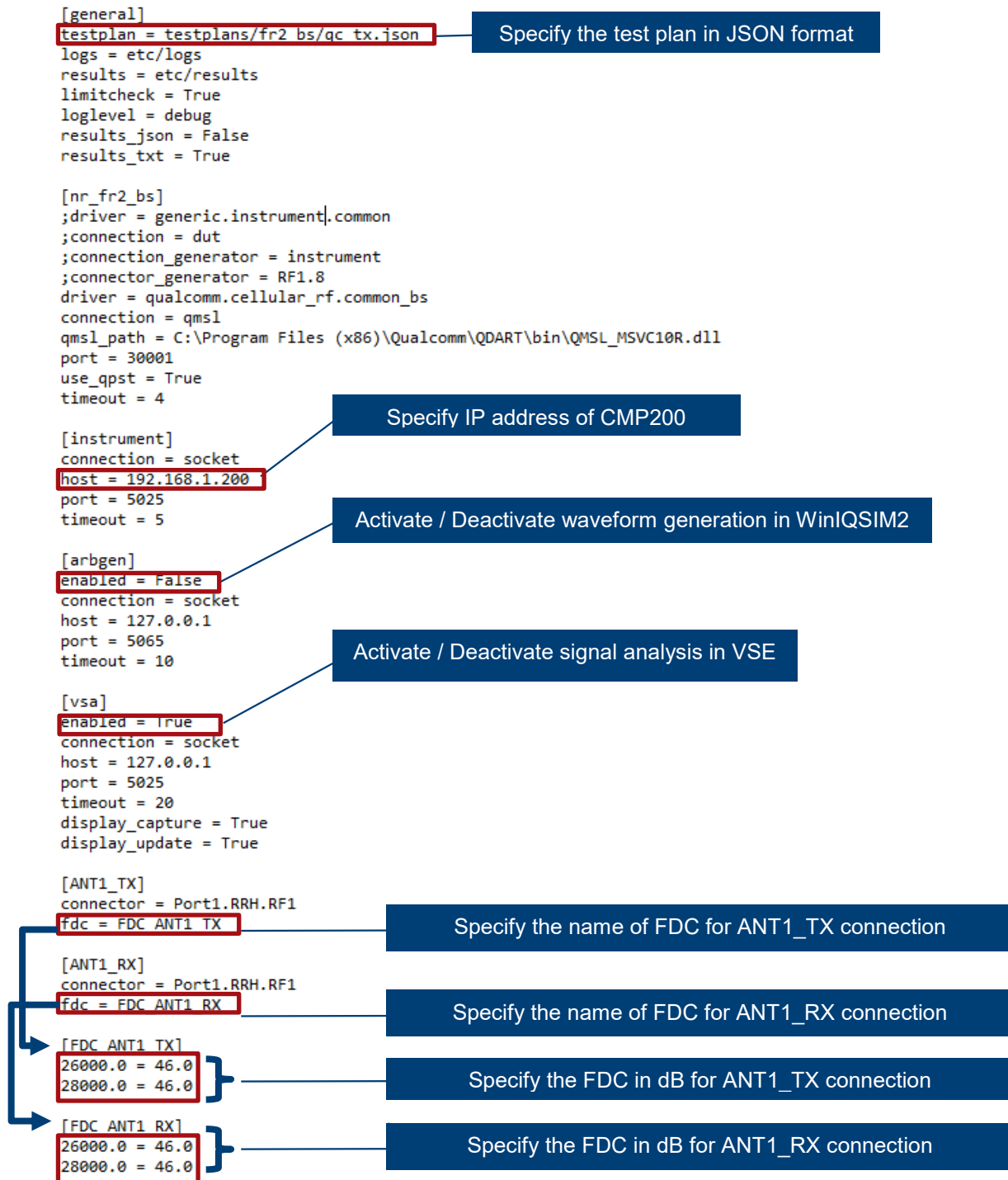


Figure 2-24 Example 'testconfig.ini' configuration file

5. After the test plan execution is terminated in WMT Test Runner, the 'Overview' page (Figure 2-25) summarizes the status of the test execution.

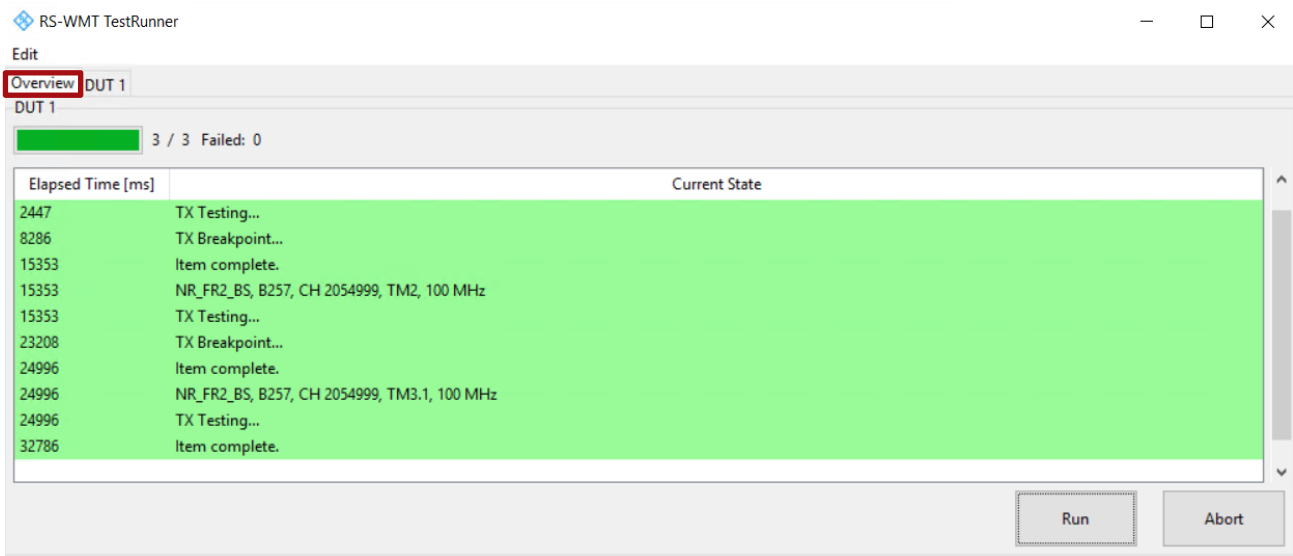


Figure 2-25 Overview of test run in WMT Test Runner

The measurement results are presented in 'DUT1' page (Figure 2-26).

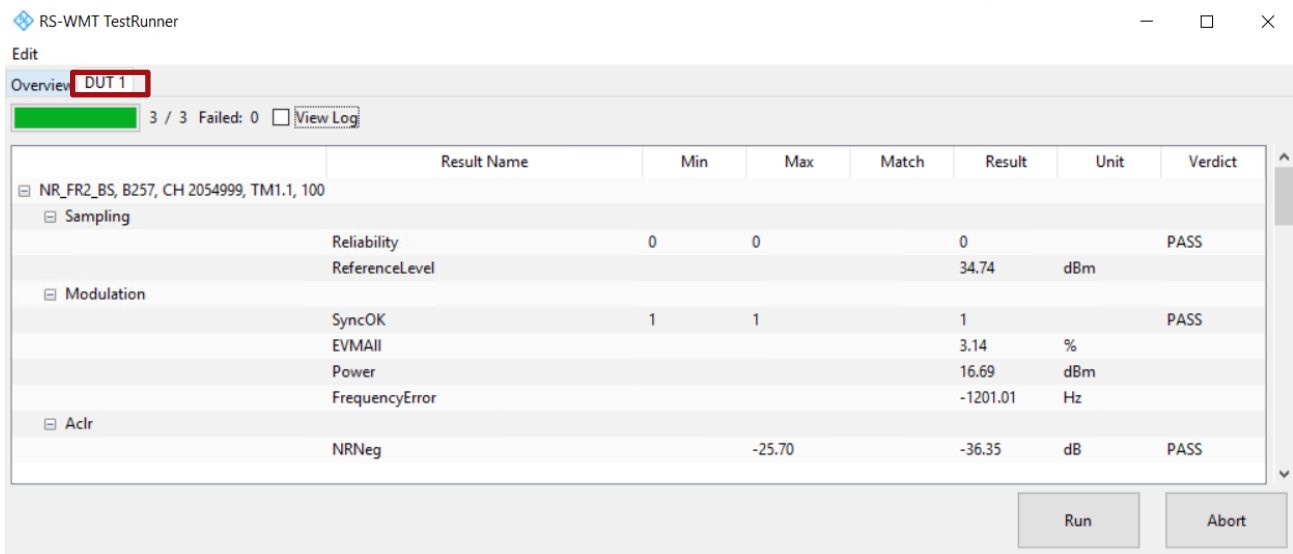


Figure 2-26 Measurement results in WMT Test Runner

If necessary, activate 'View Log' checkbox (Figure 2-27) will give a debugging view of the communications between control PC, CMP200 and DUT.



Figure 2-27 Debugging logfile in WMT Test Runner

- In case signal analysis in VSE is desired (as described above in Step 3), open the VSE window (already run in the background) will populate the 5G NR measurement results, like constellation diagram, EVM vs. Carrier, power spectrum etc (Figure 2-28).

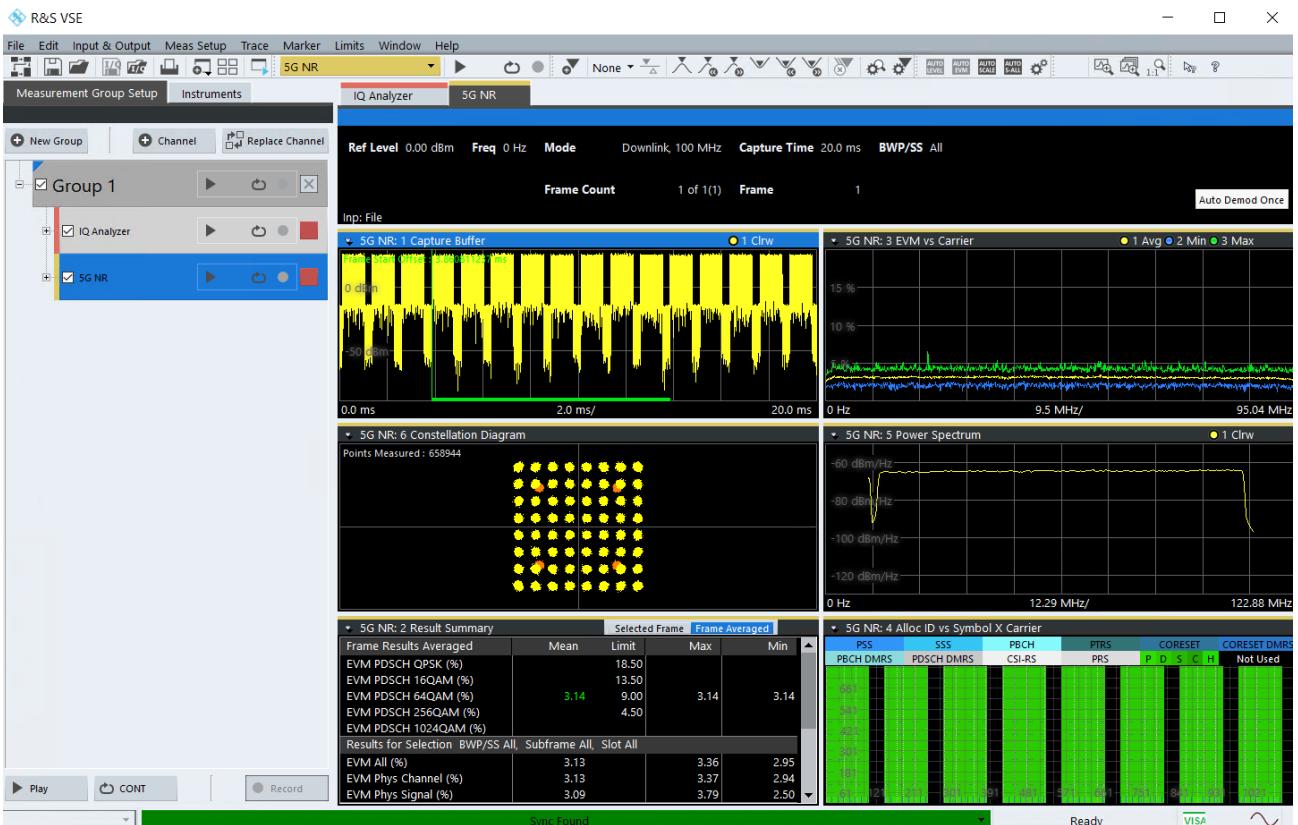


Figure 2-28 5G NR measurements in VSE (standard items)

For in-depth debugging, more 5G NR signal analysis results can be opened in VSE through the steps shown in Figure 2-29.

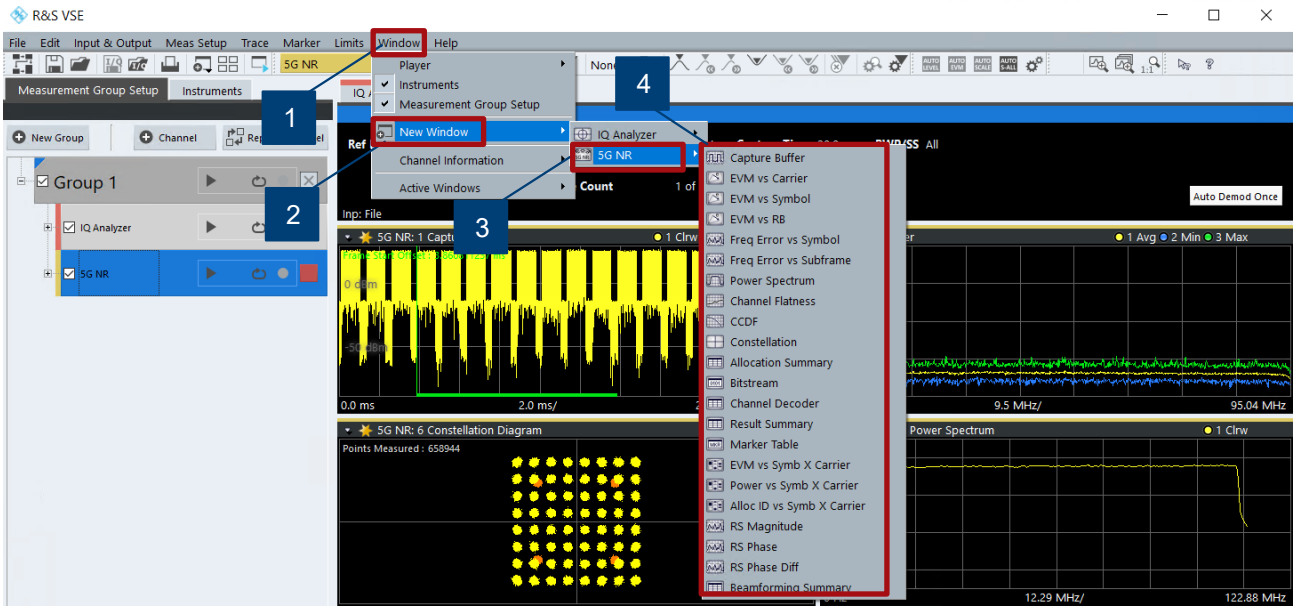


Figure 2-29 Other 5G NR measurements in VSE

Follow the steps shown in Figure 2-30 will provide the additional access to the IQ analysis results.

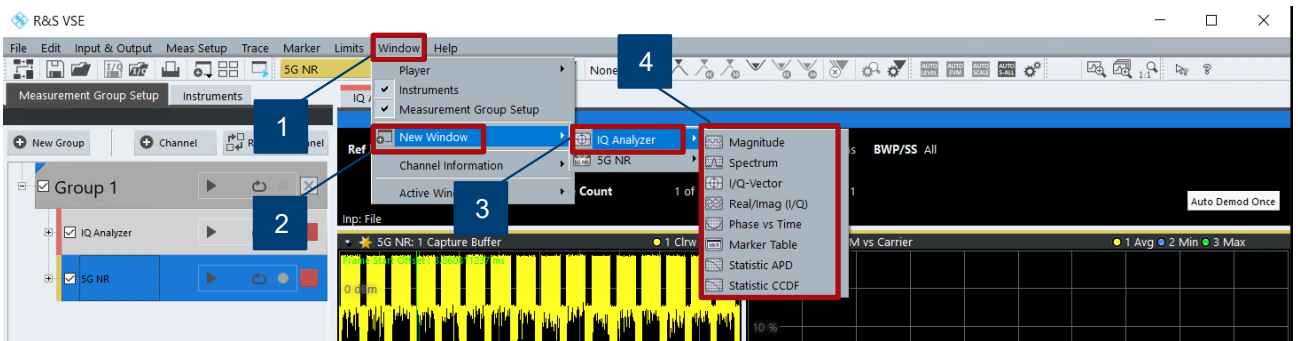


Figure 2-30 IQ analysis in VSE

Furthermore, the steps shown in Figure 2-31 will bring the user to access 5G NR ACLR and SEM measurements in VSE.

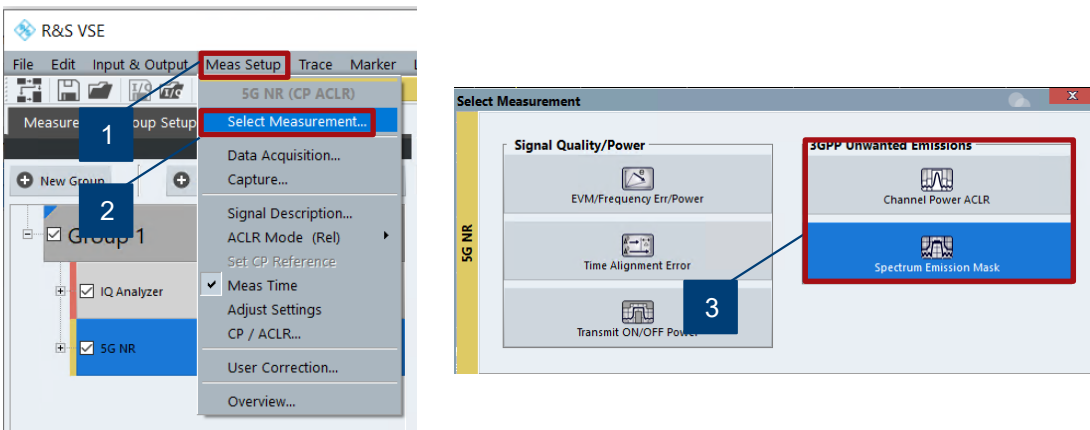


Figure 2-31 Access the 5G NR ACLR and SEM measurements in VSE

An example of ACLR measurement and its limit check in VSE is given in Figure 2-32.

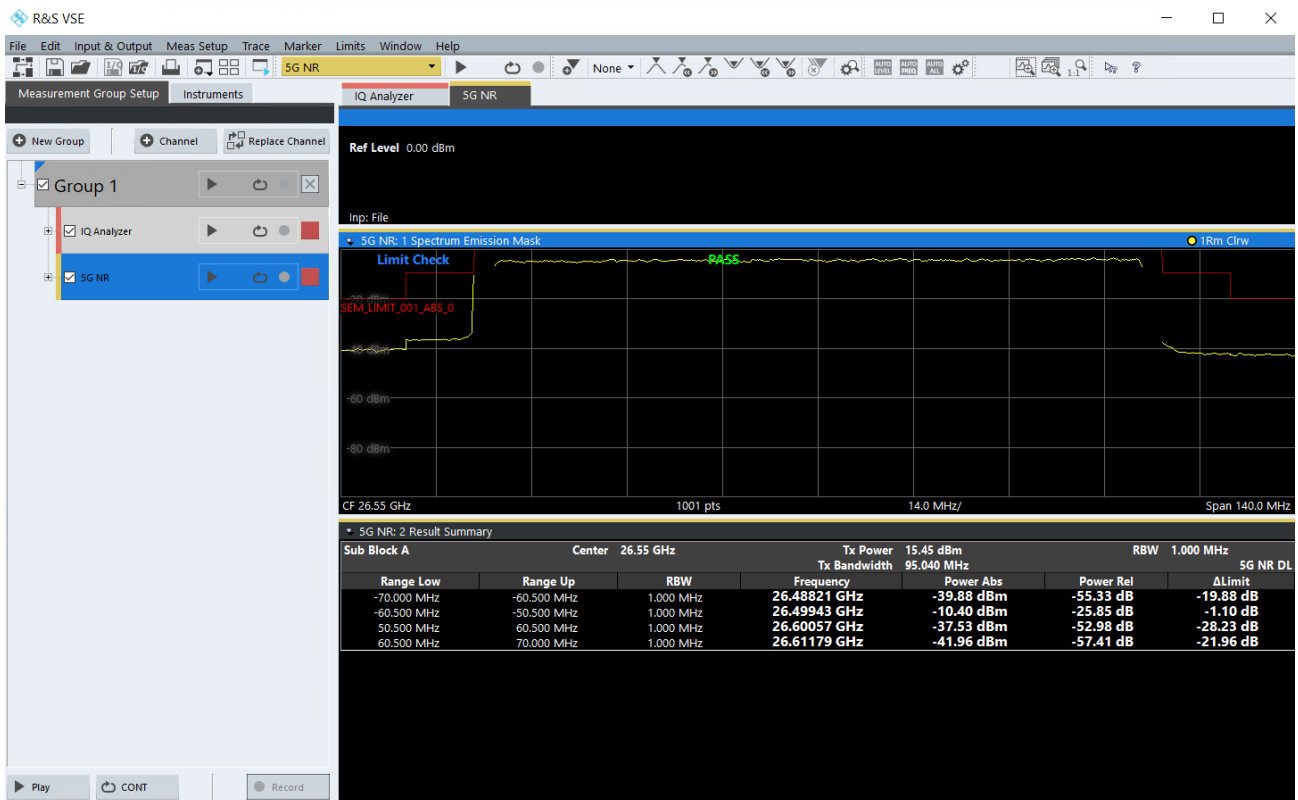


Figure 2-32 5G NR ACLR measurement with limit check in VSE

2.3 Summary

With WMT as a turn-key solution for FR2 small cell testing for production. It is easy and fast to run tests on a production floor with central controlling of CMP200, CMQ200 and DUT. Multiple DUT testing in parallel is possible which dramatically enhances the test efficiency for the production. Thanks to Python based R&S WMT, it can be easily integrated into existing customer automation framework. More debugging functionalities are supported by utilizing the external VSE software.

3 Test Solutions for R&D

Figure 3-1 illustrates at high-level of the 5G base station architecture that is divided into two units, i.e. baseband (BB) unit and radio unit.

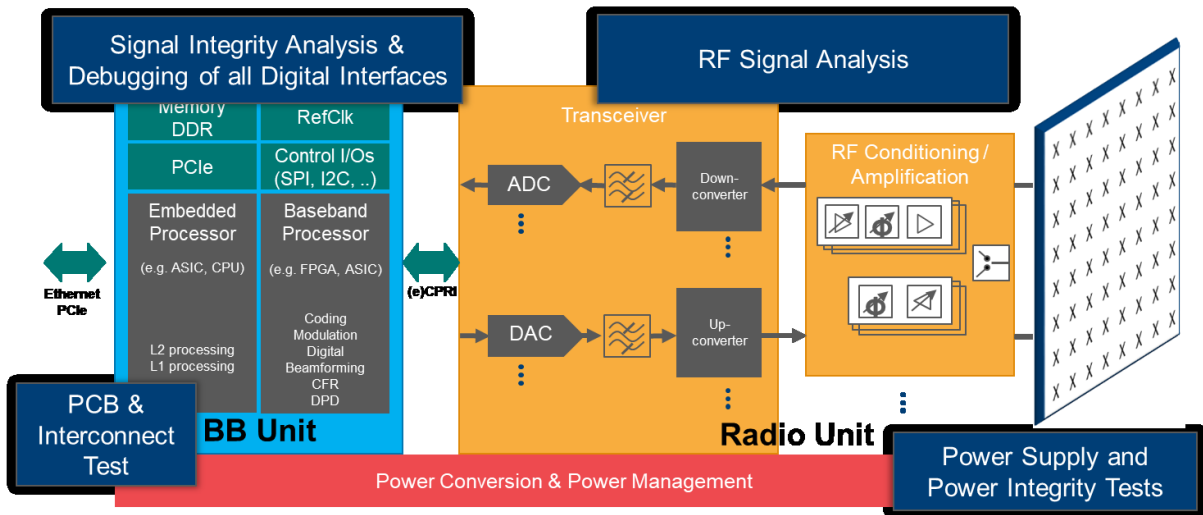


Figure 3-1 5G Base Station architecture

From small cell R&D testing perspective, it can be broken down into four main areas as illustrated in Figure 3-2. In this chapter, we will shed a light on major test solutions to cover some of the test requirements here.

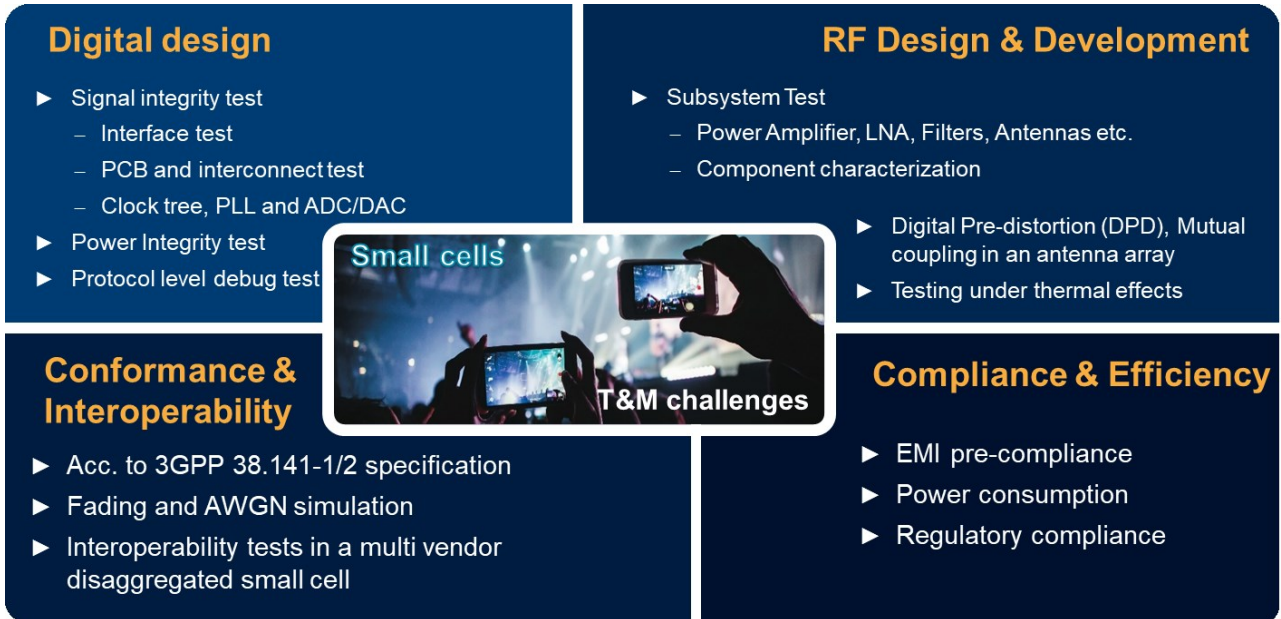


Figure 3-2 Small cell testing aspects for R&D

3.1 Digital Design Test

In this chapter, a comprehensive view of the digital design tests with main focus in time-domain based on the oscilloscope and power rail probe is given. As illustrated in Figure 3-3, some testing aspects that we are going to tackle here involve:

- ▶ Signal Integrity (SI), including interface, PCB and interconnect test, clock tree, ADC/DAC verification
- ▶ Power Integrity (PI)
- ▶ Protocol level debug

DIGITAL DESIGN TEST

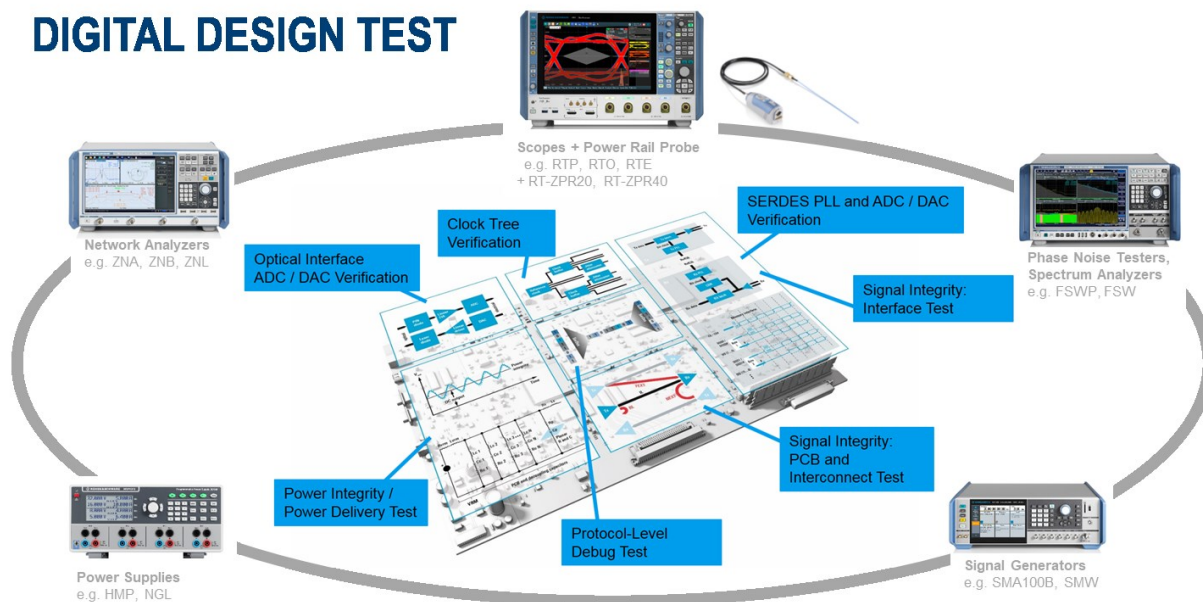


Figure 3-3 A glance at digital design test in time domain and required test measurement instruments

Signal Integrity (SI) is the ability of a system to transfer signal without excessive loss, noise and distortion. It ensures that the transmitted signal can be accurately reconstructed at the receiver side. While Power integrity (PI) serves as an analysis to check the quality of DC power from the output of the DC converter to the ICs. SI and PI are of fundamental importance in digital design which are two distinct but related realms. They are crucial for the small cell digital design and driven by the increasing data rates and shrinking supply voltages as well as increasing integration densities that impose lower jitter and noise limits for signals and clocks and lead to tighter voltage variance.

The degradation of SI is usually caused by impedance mismatches, frequency response of the components and connectors (frequency dependent group delay / attenuation), crosstalk (caused by mutual inductance and/or mutual capacitance between conductors, e.g. near end crosstalk (NEXT) and far end crosstalk (FEXT) and noise caused by crosstalk effect, external noise, power variation and electromagnetic susceptibility (EMS) etc. on the printed circuit board (PCB) and interconnect parts (connectors and cables) of the design [5].

SI measurement utilizes typically the oscilloscope and vector network analyzer (VNA) where oscilloscope is mainly used to SI measurement in time domain with focus on jitter analysis (e.g. NEXT, FEXT) and eye diagram measurement, whereas VNA can be used for SI analysis in frequency domain, such as S-parameter and Time-domain Reflectometry (TDR) measurements.

In time-domain, following measurements need to be conducted on high speed interfaces,:

- Eye diagram

It assesses the quality of the signal. The eye-closing indicates the degradation of the signal (a measurement example is shown in Figure 3-4).

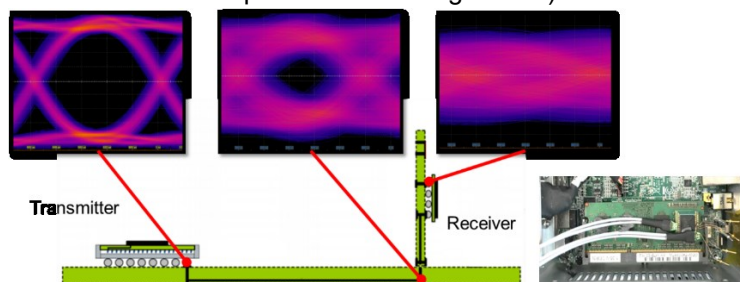


Figure 3-4 An eye-closing eye diagram indicates the degradation of the signal transmission on the path

► Jitter

Variation of the signal in time that leads to an incorrect decision at the receiver (RX). This will in turn create bit errors. Jitter analysis with jitter separation breaks down jitter and noise into individual components (bounded deterministic jitter DJ with sub-components and unbounded random jitter RJ) for characterization and debugging (see Figure 3-5).

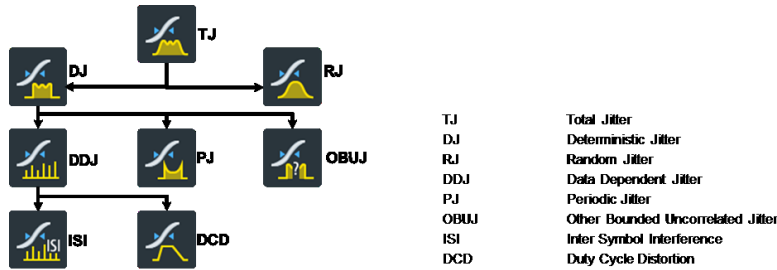


Figure 3-5 Overview of jitter components

In Figure 3-6, it shows a snippet of the Jitter analysis on R&S Oscilloscope.

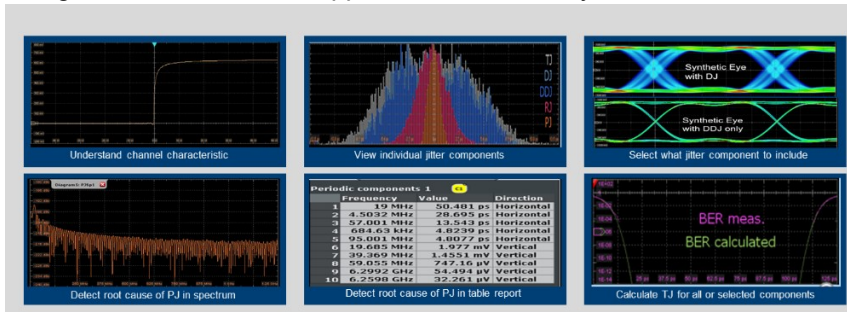


Figure 3-6 Jitter analysis on oscilloscope for fast debugging

The goal of PI is to ensure stable power rail voltages that are the basis for proper performance of any electronic design [6]. Excessive noise and ripple riding on the DC output should be suppressed. Low voltage levels of FPGAs and others digital components have to be resided in a strict tolerance window.

Plethora of challenges oppose to perform PI, mainly due to the increasing number of power rails in the design, demanding of fast load response, lower margins due to lower supply voltages and interfaces come alone with the dense design of mixed technologies. To overcome all these challenges and fulfill the measurement task, the test measurement equipment should possess following features:

- scope with fast update rate, fast FFT and low noise (R&S®RTP, R&S®RTO)
- specialized PI probe with bandwidth > 2GHz, adaptive impedance and extended offset range (R&S®RT-ZPR20, R&S®RT-ZPR40²) to achieve high measurement accuracy

Typical PI measurements as shown in Figure 3-7 include:

- Periodic and random disturbances (PARD)
- Drift
- Load response

² Power rail probe R&S®RT-ZPR20 with 2 GHz probe bandwidth, R&S®RT-ZPR40 with 4 GHz probe bandwidth

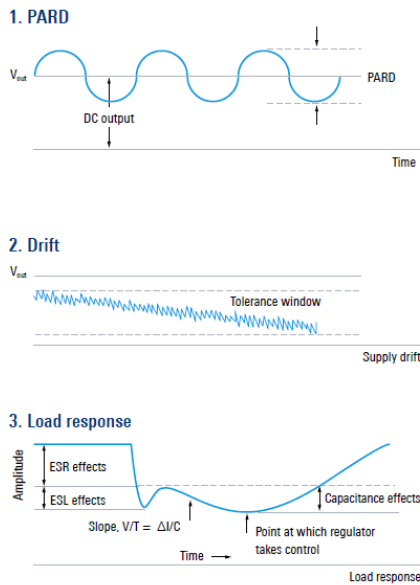


Figure 3-7 Typical PI measurements

Figure 3-8 presents exemplarily power rail measurement on R&S®RTP by using a 2 GHz probe bandwidth power rail probe R&S®RT-ZPR20.

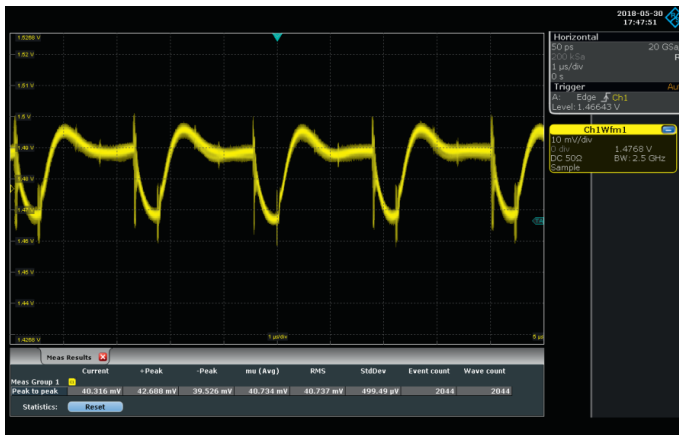


Figure 3-8 Power rail measurement using power rail probe R&S®RT-ZPR20 on R&S®RTP

Further reading in [6] and [7] to get more information on topic PI.

Multi-domain analysis is a function on the oscilloscope that features the fast signal analysis from different aspects in a time and event correlated manner. This includes:

- ▶ Time domain analysis
- ▶ Frequency domain analysis
- ▶ Protocol analysis
- ▶ Power analysis
- ▶ Logic analysis

Figure 3-9 shows an example of multi-domain analysis on a wireless product conducted on R&S RTP.



Figure 3-9 An example of multi-domain analysis on R&S®RTP

Last but not least, it is necessary to verify I/O interfaces following different protocols. Typically, small cell includes Ethernet interface. Sometimes, USB or console interface may also be part of the small cell for maintenance and operation purpose. All these require protocol level debugging in addition to SI and PI. An example of USB3.1 protocol level testing on R&S® oscilloscope RTP is given in Figure 3-10.

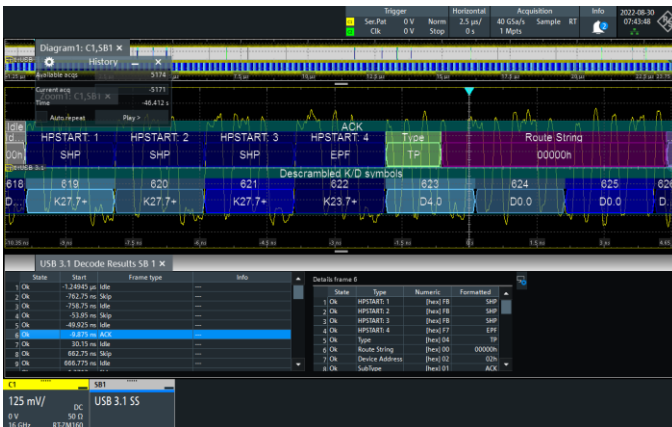


Figure 3-10 An example of USB3.1 interface verification on R&S®RTP

3.2 Power Amplifier Characterization

RF frontend contains the circuit, components between the digital baseband unit and antenna (see Figure 3-1). Components, such as RF filter, RF amplifier, Low-noise amplifier (LNA), and mixer are involved here. In this chapter, we are going to tackle the power amplifier (PA) characterization and optimization.

To increase the PA efficiency, digital pre-distortion (DPD) is a common approach to linearize the output signal of a PA, which is being operated in its non-linear operating range. High bandwidth and high carrier frequency operated in FR2 opposes a big challenge for the PA design. The memory effect impacts on the PA performance significantly.

With proper implementation of DPD, Effective Isotropic Radiated Power (EIRP) can be improved by up to 3dB. As a result, it allows 30% reduction in the number of antenna array elements, relative to an array without DPD, for the same target EIRP [8].

For PA DPD characterization and development, R&S facilitates the test solutions with following advantages:

- Fast and easy characterization of PA (raw EVM, ACLR, crest factor, gain compression etc.), including AM/AM and AM/PM traces
- Capability of applying direct DPD that compensates the memory and other effects.

- Modeling and computation of a polynomial model of PA. The resultant polynomial coefficients can be used directly in the DPD algorithm that speeds up the DPD algorithm development

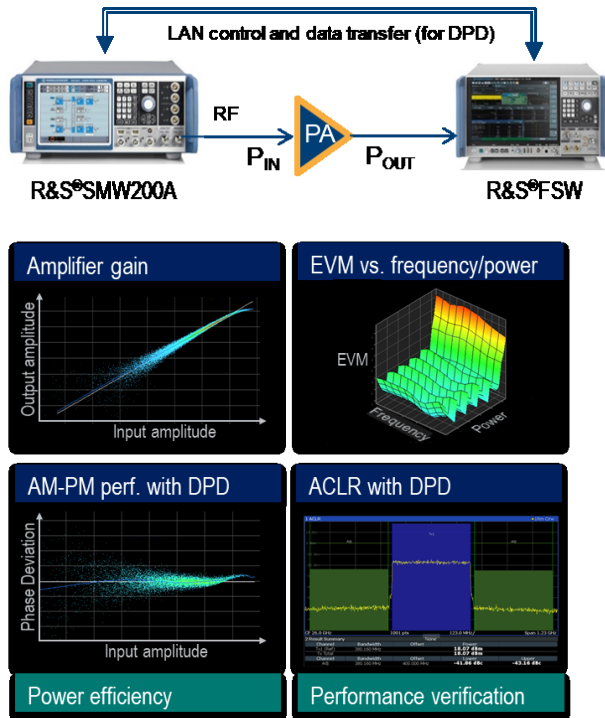


Figure 3-11 A solution of PA characterization (signal generator R&S®SMW200A + signal analyzer R&S®FSW) and exemplary measurements

Figure 3-11 shows in the upper part a test solution based on signal generator R&S®SMW200A and signal analyzer R&S®FSW to characterize the PA design. The lower part of the graph presents some exemplary measurements. Further reading, please refer to [9] [10].

The measurement personality on R&S®FSW with product options out of FSW-K18 option family covers different use cases as can be seen in Table 3-1 below.

Use Case	Description	Product Option
Full characterization of PA	Distortion analysis with digital modulated or CW signals and known reference for RFFEs without and with frequency conversion. It includes the basic table or polynomial DPD modeling among other functions: <ul style="list-style-type: none"> ▶ AM/AM, AM/PM, Gain Compression ▶ Channel Response in Magnitude and Phase, Group Delay ▶ Input and output crest factor ▶ Accurate Psat measurement on sample basis ▶ P1dB, P2dB, P3dB compression points as input and output power levels ▶ Raw EVM without or with equalization on sample basis with known reference, which is more accurate in compression or low SNR scenarios. ▶ Raw EVM vs Power on sample basis without a power sweep ▶ IQ averaging ▶ Equalizer with coefficients export ▶ Percentual estimation of distortion contributors (Detailed MSE) ▶ ACLR ▶ etc. 	R&S®FSW-K18 R&S®FSW-K18F (Channel Response Magnitude / Channel Response Phase / Group Delay)
Benchmarking of PA linearization without modeling	Direct DPD is iterative and based on sample by sample comparison of measurement and reference signal. Direct DPD delivers an I/Q file containing a pre-distorted waveform that can be played back on a signal generator	R&S®FSW-K18 and K18D

Use Case	Description	Product Option
PA DPD modeling	Memory Polynomial DPD, an extension to direct DPD. A memory polynomial equation that transfers the reference signal to the pre-distorted waveform is derived with specified polynomial order and memory order. Hammerstein model is a simplified memory polynomial model operating in real-time manner. The pre-distortion is applied in real time on the signal generator as it plays the undistorted signal.	R&S®FSW-K18, K18D and K18M R&S®SMx-K541 and K544 (options on signal generator, required for Hammerstein model approach)

Table 3-1 Power Amplifier characterization on R&S®FSW

3.3 Beamforming and MIMO

Beamforming and MIMO are the key technologies that are deployed in 5G to increase energy efficiency and to support higher data rate. Due to the high path loss at high frequency range, beamforming technology is even essential for FR2. It enhances the antenna gain through bundling transmitted energy and directing it towards particular direction or dedicated user.

Linearity and stability of the phase and level are important to ensure stable and reliable beamforming. Therefore, phase and gain adjustment per path as well as amplification capabilities for the Tx and Rx channels of an integrated beamformer IC have to be performed. Full characterization and calibration require simultaneous assessment of all antenna ports. With a multiport vector network analyzer (VNA), this task can be easily mastered. Simultaneous measurements on up to 24 ports makes it possible to characterize a beamforming IC in full detail and see the cross-correlation effects while monitoring all antenna connections. A glimpse of the test solution is illustrated in Figure 3-12. Further read in [11] to get more details about the test solution using multiport VNA R&S®ZNBT.

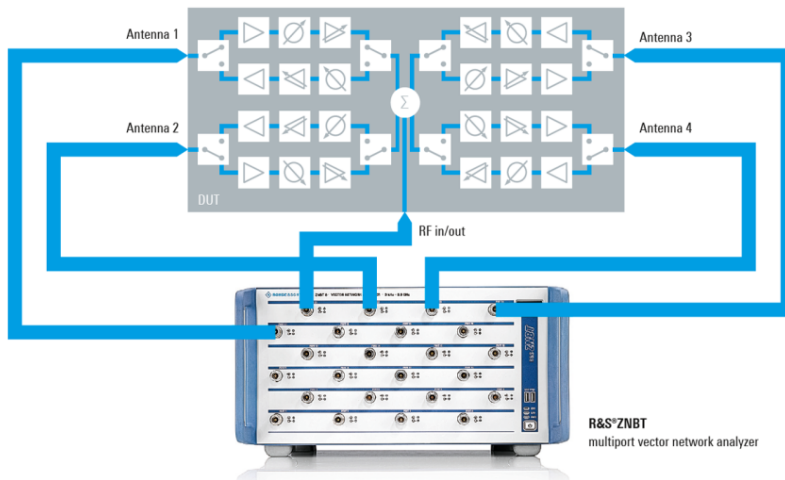


Figure 3-12 Characterization of a beamformer IC using multiport VNA R&S®ZNBT

3.4 Antenna Measurements

Antenna in Package (AiP) is widely used technology in mmW application, e.g. in 5G FR2. The antenna module that adopts the AiP miniaturizes the antenna. The module will also have more antenna elements, which increases radiation gain and enables more economical and energy efficient solutions. An example of AiP is given in Figure 3-13. Since RF components are fully integrated into the self-contained module, conducted tests are no longer feasible. Requirements for module optimization and validations all point to OTA tests during system level testing, integration and production.

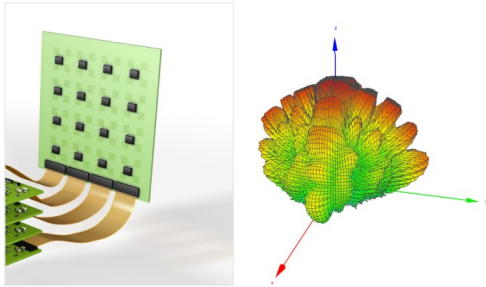


Figure 3-13 An example of phased array antenna and its 3D antenna radiation pattern

Beamforming in FR2 demands accurate, reliable and efficient solutions. Figure 3-14 shows an antenna system consists of test measurement instrument (R&S®ZNA, R&S®FSW, R&S®SMW200A), software R&S®AMS32 and OTA chamber, e.g. R&S®ATS1000. The system enables fast and accurate characterization of phased array antenna and AiP featuring

- ▶ Direct far-field measurements with a quite zone 5 cm in diameter
- ▶ Integrated high-precision conical cut positioner with a 0.03° angular resolution
- ▶ 5G antenna module test and passive (CW) antenna measurements from 18 GHz to 67 GHz. Further reading in [12]
 - Very fast measurement due to trigger functionality of positioner VNA
 - Measurement of classic antenna parameters: directivity, realized gain, efficiency, 2D and 3D radiation pattern, half power beam-width, EIRP or TRP of active devices.
 - With VNA, also NF/FF transformation is possible in R&S®AMS32 based on magnitude and phase data
- ▶ 5G transceiver module tests: passive and active measurements using modulated signals. Utilizing signal generator (R&S®SMW200A) and/or spectrum analyzer (R&S®FSW), additional parameters like EVM, ACLR, SEM, also RX sensitivity, TIS, EIS can be measured along with the classic antenna parameters.



Figure 3-14 R&S®ATS1000 antenna test system

On top of the antenna characterization, since radiation patterns of miniaturized antennas can be influenced by temperature, so thermal diagnosis is gaining traction, especially in AiP. The R&S®ATS1000 can be equipped with a temperature testing option (see Figure 3-15, OTA chamber with temperature bubble) to perform fast and precise 3D thermal measurements from -40 °C to +85 °C.



Figure 3-15 R&S®ATS1000 with temperature bubble

More details of this test solution, please refer to [13].

Alternatively, OTA chamber R&S®ATS800R can also be facilitated for the antenna measurement.

3.5 Conformance

FR2 small cell as an integrated unit needs to be tested at system level against 3GPP TS38.141-2 conformance test specification [14] under OTA environment requiring anechoic chambers and positioners etc.

Conformance tests in [14] consist of transmitter (Tx) tests (chapter 6), receiver (Rx) tests (chapter 7), and performance verification in presence of a fading channel and AWGN generators (chapter 8).



Figure 3-16 Instruments for small cell conformance (R&S®SMW200A and R&S®FSW)

Small cell FR2 Tx and Rx conformance testing utilizes the R&S®SMW200A (signal generator) and R&S®FSW (signal analyzer) as test and measurement instruments (see Figure 3-16) plus OTA chamber. There are multiple choices of an OTA chamber as shown in Figure 3-17 for small cell testing in R&D. DUT form factor (determines the required Quiet Zone size) and its weight are the main parameters of the chamber selection.



Figure 3-17 Recommendations of OTA chambers for small cell testing in R&D

More information about the base station transmitter and receiver testing in OTA environment according to [14] can be found in the R&S application note GFM324 [15] and GFM325 [16], respectively. Unless otherwise stated, test requirements related to medium range BS or local area BS specified in [14] should be applied for small cell testing.

Based on OTA measurement software R&S®AMS32 together with its R&S®AMS32-BST option extension, FR2 small cell conformance testcases in OTA environment in line with 3GPP TS38.141-2 [14] (Tx and Rx) are supported and can be executed in an automatic and sequential way. To know more about the actual test coverage, please refer to the latest R&S®AMS32 release note. In Figure 3-18, it shows the small cell conformance testcase support in R&S®AMS32 that features the testcase batch run to enhance the test execution efficiency in addition.

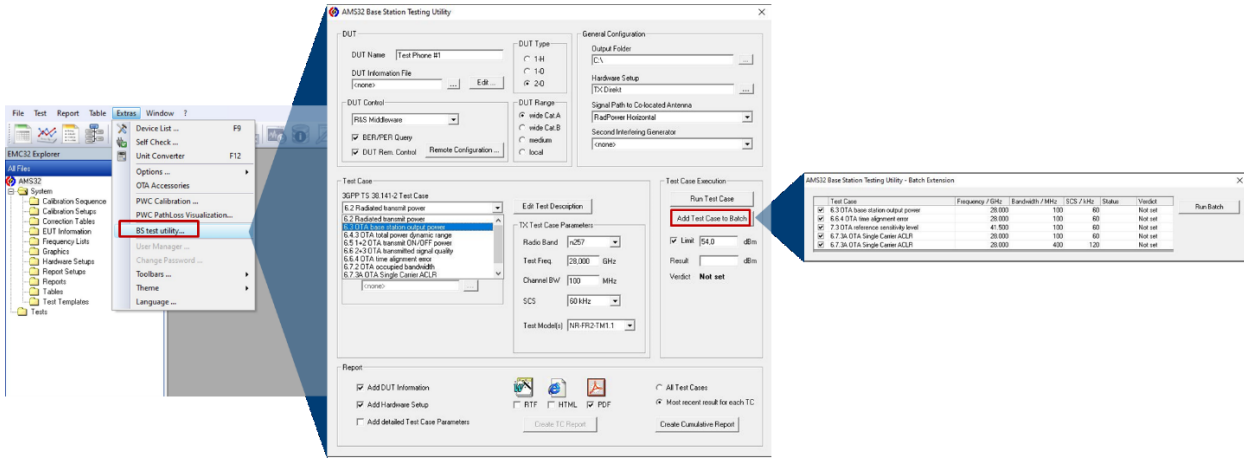
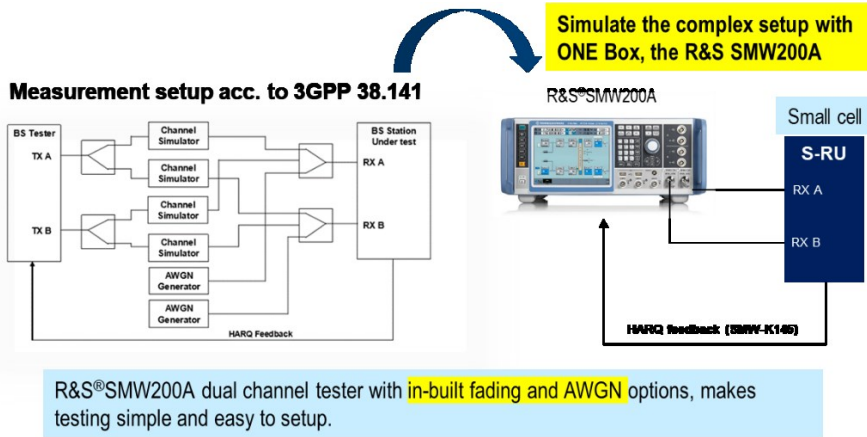


Figure 3-18 Base Station Test Utility in R&S®AMS32 (R&S®AMS32-BST)

In compliance with the performance requirements for PUSCH specified by TS38.141-2 [14], the one-box solution features the integrated fading and AWGN functionality as well as the handling of HARQ feedback signal (see Figure 3-19 and Figure 3-20). This requires single R&S® SMW200A with option K145 (option for 5G NR Closed-Loop BS Test). More information about base station performance testing can be found in [17].



R&S®SMW200A dual channel tester with in-built fading and AWGN options, makes testing simple and easy to setup.

Figure 3-19 BS performance test solution based on R&S®SMW200A and R&S®SMW-K145 option

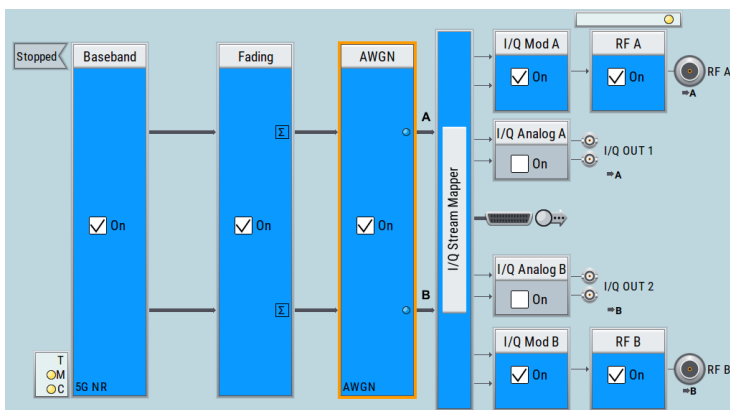


Figure 3-20 Fading and AWGN function block on R&S®SMW200A

4 Conclusion

A comprehensive guide of test solutions for small cell testing in FR2 is given in this document. As shown in Figure 4-1, R&S has the whole solution portfolio for a small cell vendor to design, develop, produce and certify the small cells. In a nutshell, one-shop for all T&M needs.



Figure 4-1 One-stop small cell T&M solutions from R&S

5 Literature

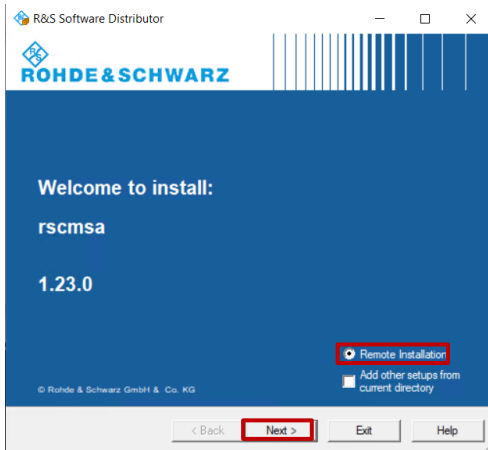
- [1] 3GPP, "3GPP TS38.104 V15.11.0 (2020-09); NR Base Station (BS) radio transmission and reception (Release 15)".
- [2] R&S, Alexander Nähring, "Demystifying over-the-air (OTA) testing - important antenna parameters, test system setup and calibration".
- [3] SCF, "S-RU and S-DU Test Support".
- [4] R&S, "R&S®CMP200 Radio Communication Tester User Manual".
- [5] R&S, "Understanding Signal Integrity," R, [Online]. Available: <https://www.youtube.com/watch?v=anX8QZMhVjI>.
- [6] R&S, "Power integrity pocket guide," [Online]. Available: https://www.rohde-schwarz.com/us/solutions/test-and-measurement/electronic-design/digital-design-testing/signal-power-integrity/power-integrity-pocket-guide-register_254052.html.

- [7] R&S, "Power integrity measurements with R&S®RTP oscilloscopes," [Online]. Available: https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_application/pdfs/Power_integrity_measurements_RTP_ac_en_5215-4152-92_v0200.pdf.
- [8] P. Hindle, "Anatomy of the 5G Small Cell," *Microwave Journal*, p. 18 www.mwjjournal.com/articles/38108, 13 May 2022.
- [9] R&S, "White Paper: Iterative Direct DPD," [Online]. Available: <http://www.rohde-schwarz.com/appnote/1EF99>.
- [10] R&S, "Application Note, K18D Matlab Modeling Toolkit," [Online]. Available: <http://www.rohde-schwarz.com/appnote/1EF105>.
- [11] R&S, "Verify beamformer ICs for phased array antennas," [Online]. Available: https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_application/pdfs/Verify-beamformer_ac_en_5216-5046-92_v0100.pdf.
- [12] R&S, "Application Note 1MA304, ATS1000 Passive Antenna Measurement and Nearfield - Farfield Transformation," [Online]. Available: <http://www.rohde-schwarz.com/appnote/1MA304>.
- [13] R&S, "Application Card, OTA Characterization of phased array antennas and antenna in package (AiP)," [Online]. Available: https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_application/pdfs/ATS1000-OTA-characterization_ac_en_3608-0985-92_v0100.pdf.
- [14] 3GPP, "3GPP TS38.141-2 Base Station (BS) conformance testing Part 2: Radiated conformance testing".
- [15] R&S, "Application Note GFM324, 5G New Radio Over-the-Air Base Station Transmitter Tests," [Online]. Available: <https://www.rohde-schwarz.com/appnote/GFM324>.
- [16] R&S, "Application Note GFM325, 5G New Radio Over-the-Air Base Station Receiver Tests," [Online]. Available: <https://www.rohde-schwarz.com/appnote/GFM325>.
- [17] R&S, "Application Note GFM315, 5G New Radio Conducted Base Station Performance Tests," [Online]. Available: <https://www.rohde-schwarz.com/appnote/GFM315>.
- [18] SCF, "5G small cell architecture and product definitions," [Online]. Available: https://scf.io/en/documents/238_5G_Small_cell_architecture_and_product_definitions.php.
- [19] R&S, "5G FR1 downlink MIMO phase coherent signal analysis," [Online]. Available: https://www.rohde-schwarz.com/us/applications/5g-fr1-downlink-mimo-phase-coherent-signal-analysis-application-note_56280-855488.html.
- [20] R&S, "Accurate and fast power integrity measurement," [Online]. Available: https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_application/pdfs/RT-ZPR20_Accurate_ac_en_5214-9515_92_v0200.pdf.
- [21] 3GPP, "3GPP TS38.141-2 Base Station (BS) conformance testing Part 2: Radiated conformance testing".

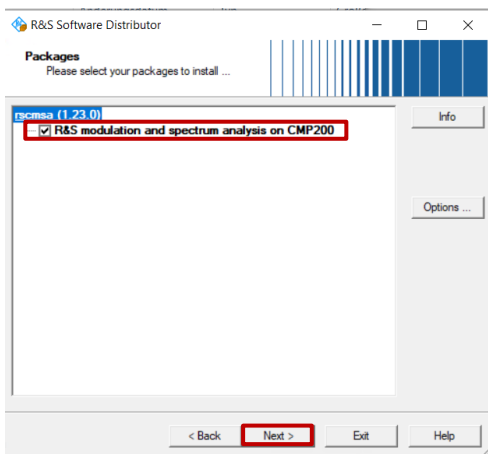
6 Appendix

A RSCMSA Installation

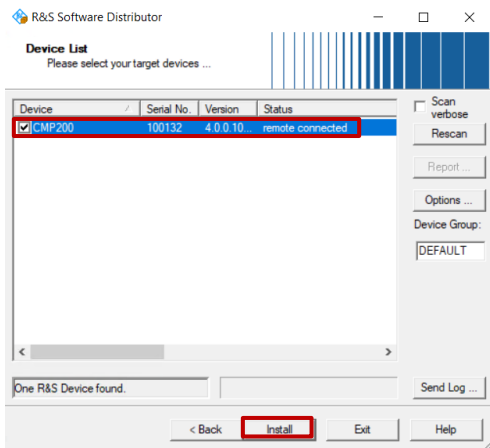
1. Download RSCMSA Windows installer from R&S's Gloris customer portal (<https://gloris.rohde-schwarz.com/>), e.g. setup_rscmsa_1.23.0.exe
2. Run the installer. In 'R&S Software Distributor' window, ensure the 'Remote Installation' option is checked and press on 'Next' button to proceed



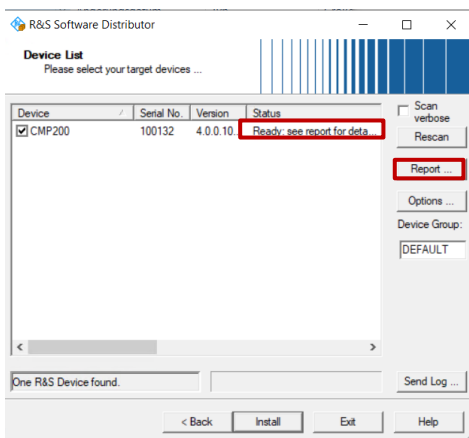
3. Select the rscmsa package and press on 'Next' button to proceed



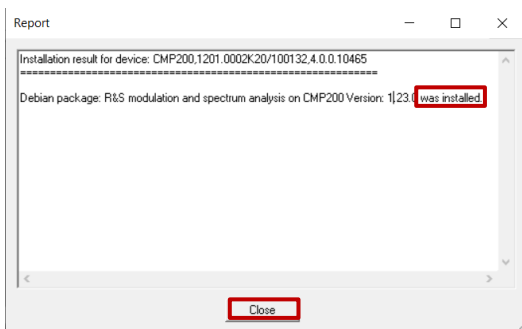
4. Select the target CMP200 (identified by the displayed serial number) and press on 'Install' button to start the installation



5. Wait until the installation process is finished. This can be confirmed in the status (Ready: see report for ..)



6. Click on the 'Report ...' button to launch the report window and the text '...was installed' indicates the successful installation



7. Close report window and exit from software distributor by clicking 'Exit'
8. Reboot the CMP200 to complete installation.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, monitoring and network testing. Founded more than 80 years ago, the independent company which is headquartered in Munich, Germany, has an extensive sales and service network with locations in more than 70 countries.

www.rohde-schwarz.com



Rohde & Schwarz training

www.rohde-schwarz.com/training



Rohde & Schwarz customer support

www.rohde-schwarz.com/support

