5G NR Signal Generation and Analysis
Application Note

Products:

- R&S®SMW200A
- R&S®SMW-K144
- R&S®FSW43
- R&S®FSW-K144
- R&S®FSW-K145
- R&S®VSE

This application note is step by step guide on 5G New Radio (5G NR) signal generation and analysis capabilities using the R&S®SMW200A Vector Signal Generator equipped with software option SMW-K144 (5G NR option), in combination with the R&S®FSW Signal and Spectrum Analyzer and the software options FSW-K144 & FSW-K145 (5G NR Downlink & Uplink Signal Analysis). The R&S®VSE Vector signal explorer has also been used for analysis purpose in parallel to the FSW-K144 & FSW-K145 software options.

It is assumed that the reader already has a deep understanding of the 5G New Radio standard as well as the testing aspects. If not, then please refer to the 5G eBook more a detailed overview on the fundamentals, procedures, testing aspects of the 5G NR technology.

5G NR eBook: https://www.rohde-schwarz.com/5G-ebook.

Note:

Please find the most up-to-date document on our homepage

https://www.rohde-schwarz.com/appnote/GFM322

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Application Note

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1 Introduction

In previous mobile technology generations, voice communication have always been the major focus. Progressively, new services were added, e.g. text massaging in 2G, video calls in 3G and always-on data connectivity in 4G. The upcoming generation, 5G, seeks to make further major changes to services with a wide range of requirements. The networks are capable of providing services ranging from high data rate mobile broadband to ultra-reliable low-latency communications.

5G is designed to support a variety of different services. 5G New Radio (NR) employs a much higher bandwidth (up to 400 MHz per carrier) compared with 4G. 5G NR is designed for deployment in two main frequency ranges. FR1 comprises spectrum from 410 MHz to 7.125 GHz and FR2 from 24.25 MHZ to 52.6 GHz.

In case of waveform, 5G NR retains the OFDM-based waveform just like in LTE. However, certain fundamental differences enable the high configuration flexibility required in this generation. 5G NR introduces flexible numerology and thus allowing subcarrier spacing (SCS) of 15 KHz, 30 KHz, 60 KHz, 120 KHz and 240 KHz. This leads to different symbol time durations since the SCS is inversely proportional to the symbol duration. Therefor the number of symbol in a fixed time duration is now variable. The synchronization signals and data channels may use a different SCS. Moreover, the synchronization signals and broadcast signals are no longer placed in the center of the carrier. This requires the definition of a reference point for allocation of resources in the frequency domain.

In 5G NR, the nominal channel bandwidth per frequency band can be segmented into smaller sub bands known as resource grids or bandwidth parts (BWP). Mixed numerology can be an option to provide various Quality of Service (QoS) on the radio interface. One BWP is one fixed numerology. BWPs are allocated to UEs.

This application note is a step-by-step guide on 5G New Radio (5G NR) signal generation and analysis. The R&S®SMW200A Vector Signal Generator equipped with software option SMW-K144 (5G NR option), SMW-K114 (OFDM Signal Generation option) in combination with the R&S®FSW Signal and Spectrum Analyzer and the options FSW-K144 (5G NR Downlink Signal Analysis) & FSW-K145 (5G NR Uplink Signal Analysis) is used in this application note. The R&S®VSE Vector signal explorer has also been used for analysis purpose in parallel to the FSW-K144 & FSW-K145 software options. The R&S®VSE Vector signal explorer is an analysis software that can be used remotely on a user PC in a multi-user environment but with the same test bench.

Abbreviations

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

- The R&S®SMW200A Signal Generator is referred to as SMW
- The R&S®FSW Signal and Spectrum Analyzer is referred to as FSW
- The R&S®VSE Vector signal explorer is referred to as VSE

2 5G NR DL & UL Signal Generation and Analysis

The standardization body, 3GPP creates the specification, which provides a comprehensive definition of the complete system. More specifically, the 3GPP RAN4 and RAN5 working groups define the base station and user equipment requirements to be tested and verified.

The radio transmission and reception (i.e. RF) requirements define the transmitter capabilities (e.g. maximum output power and transmit quality such as EVM and frequency error) and receiver capabilities (e.g. the sensitivity of an end-user device or its ability to maintain a certain throughput in the presence of an interferer or blocking signal).

The different 5G NR physical layer parameter can be generated and analyzed with ease. This chapter will explain systematically how this is performed, for both downlink and uplink, using the signal generator SMW and the spectrum analyzer FSW.

2.1 Downlink signal generation and analysis

This section describes a step-by-step guide on how to setup a FR1 Downlink (DL) cell where the maximum Bandwidth is 100MHz. The signal is centered at 3.5GHz.

2.1.1 Signal generator setting on the SMW

- To start off, open the 5G NR option from the Baseband menu on the SMW

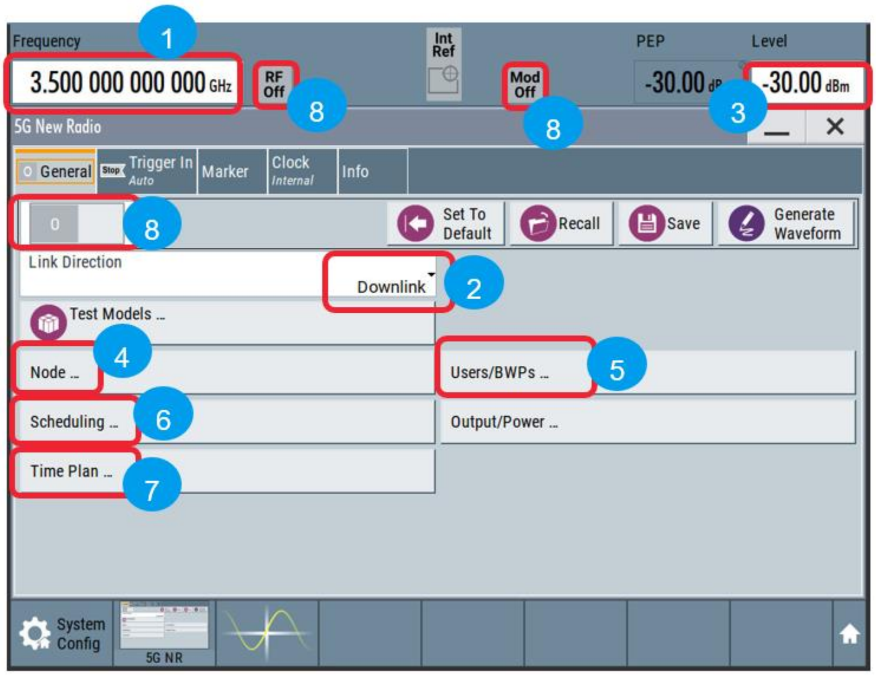


Fig. 2-1: 5G NR main configuration window on the SMW

Fig. 2-1 shows the main configuration window of the 5G NR physical layer baseband signal generation. The step numbers are marked in correct order in the figure to configure the physical layer downlink parameters. Follow the numerical sequence from from Fig. 2-1 and the configuration description is listed below:

1. Set Frequency: 3.5 GHz
2. Link direction : Downlink
3. Output power level: -30dBm
4. Node configuration settings

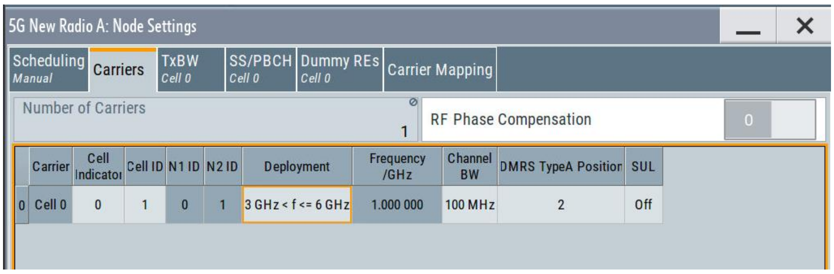


Fig. 2-2: Node settings window configuration for carrier

Under node setting, the sub windows Carriers, TxBW , SS/PBCH need to be configured as shown in Fig. 2-2.

- Carrier: Cell ID: 1, Deployment: 3 GHz <f <= 6 GHz, Channel BW : 100 MHz

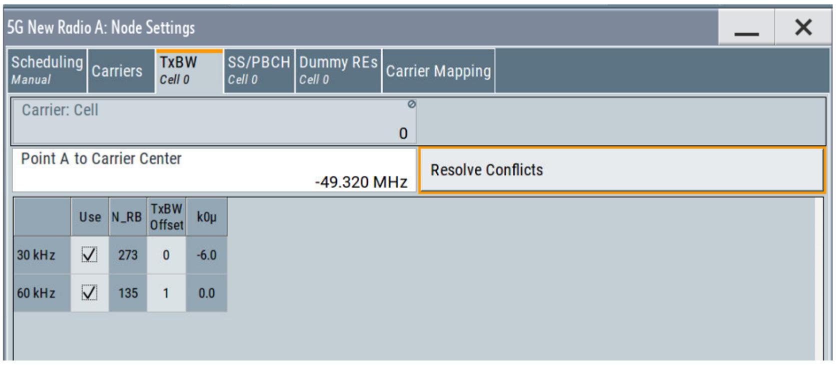


Fig. 2-3: Node settings window configuration for TxBW

- Select both 30 KHz and 60 KHz and hit Resolve Conflicts as shown in Fig. 2-3

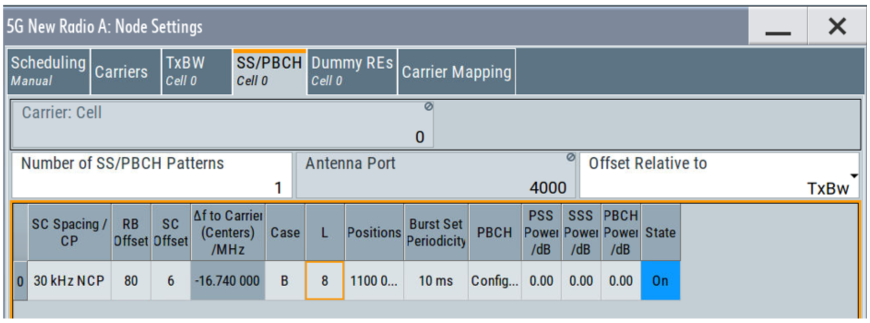
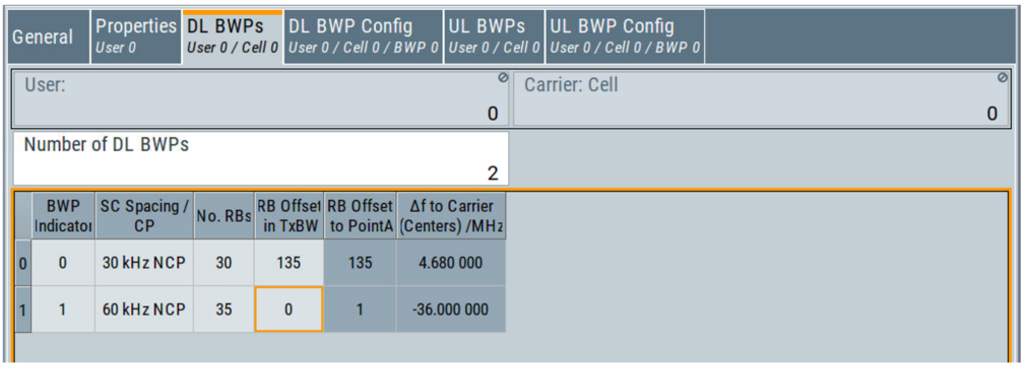


Fig. 2-4: Node settings window configuration for SS/PBCH

- Select SC spacing: 30 KHz NCP, RB offset:80, SC offset: 6, Case: B, Position: 1100 0000 as shown in Fig. 2-4

5. Users/ BWPs configuration from Fig. 2-1

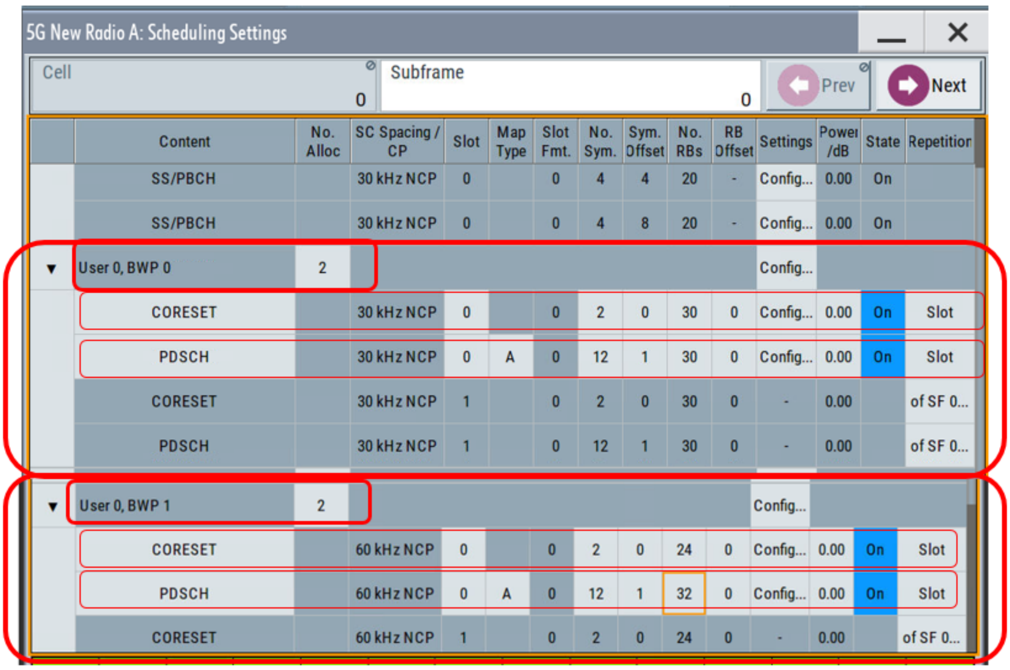


	BWP Indicator	SC Spacing / CP	No. RBs	RB Offset in TxBW	RB Offset to PointA	Δf to Carrier (Centers) /MHz
0	0	30 kHz NCP	30	135	135	4.680 000
1	1	60 kHz NCP	35	0	1	-36.000 000

Fig. 2-5: User/BWPs setting window configuration for DL BWPs

- As shown in Fig. 2-5, Insert Number of DL BWPs: 2
- Configure BWP indicator 0 with SC spacing: 30 KHz, no RBs: 30 & RB offset: 135
- Configure BWP indicator 1 with SC spacing: 60 KHz, no RBs: 35 & RB offset: 0

6. Now that there are two BWPs, both needs to be configured separately from the Scheduling window in Fig. 2-1. The first BWP is indicated with 0 and the second BWP is associated 1 in Fig. 2-6.



	Content	No. Alloc	SC Spacing / CP	Slot	Map Type	Slot Fmt.	No. Sym.	Sym. Offset	No. RBs	RB Offset	Settings	Power /dB	State	Repetition
	SS/PBCH		30 kHz NCP	0		0	4	4	20	-	Config...	0.00	On	
	SS/PBCH		30 kHz NCP	0		0	4	8	20	-	Config...	0.00	On	
▼	User 0, BWP 0	2									Config...			
	CORESET		30 kHz NCP	0		0	2	0	30	0	Config...	0.00	On	Slot
	PDSCH		30 kHz NCP	0	A	0	12	1	30	0	Config...	0.00	On	Slot
	CORESET		30 kHz NCP	1		0	2	0	30	0	-	0.00		of SF 0...
	PDSCH		30 kHz NCP	1		0	12	1	30	0	-	0.00		of SF 0...
▼	User 0, BWP 1	2									Config...			
	CORESET		60 kHz NCP	0		0	2	0	24	0	Config...	0.00	On	Slot
	PDSCH		60 kHz NCP	0	A	0	12	1	32	0	Config...	0.00	On	Slot
	CORESET		60 kHz NCP	1		0	2	0	24	0	-	0.00		of SF 0...

Fig. 2-6: Scheduling setting for the first BWP

- Configure the two BWP as shown in Fig. 2-6

- BWP 0 : 30 KHz NCP
  - CORESET, slot: 0, No. Sym: 2, Sym Offset: 0, No RB: 30
  - PDSCH, slot: 0, Map type: A, No. Sym: 12, Sym Offset: 1, No RB: 30, Config: Mod: QPSK
- BWP 1 : 60 KHz NCP
  - CORESET, slot: 0, No. Sym: 2, Sym Offset: 0, No RB: 24
  - PDSCH, slot: 0, Map type: A, No. Sym: 12, Sym Offset: 1, No RB: 32, Config: Mod: 64QAM

7. The time plan window (in Fig. 2-1) depicts a graphical overview of the configured physical layer parameters. Fig. 2-7 shows a signal with two BWPs with different SCSs as configured in this section.

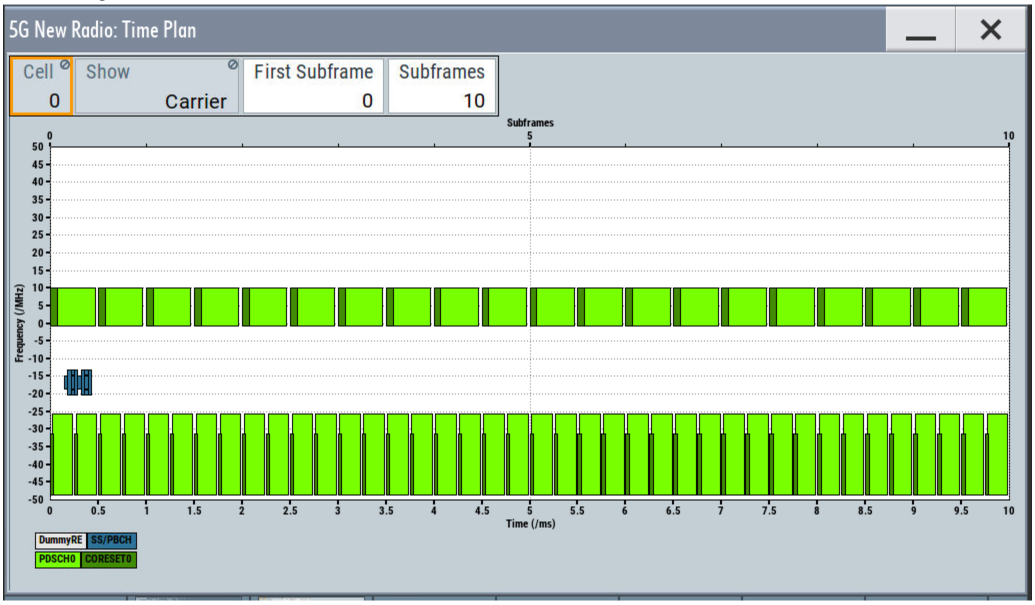


Fig. 2-7: Downlink signal parameter setting as visualized on the Time Plan window

8. Switch ON the Baseband signal, Modulator and RF using the buttons as marked on Fig. 2-1 .

2.1.2 Spectrum Analyzer setting on the FSW

- To get started, switch ON the 5G NR measurement personality from MODE

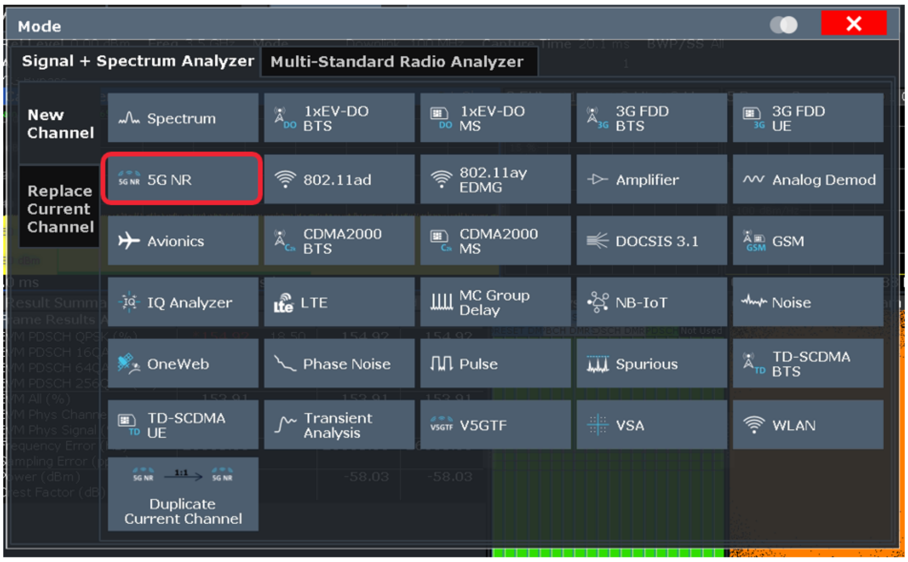


Fig. 2-8: Measurement Modes selection window on the FSW

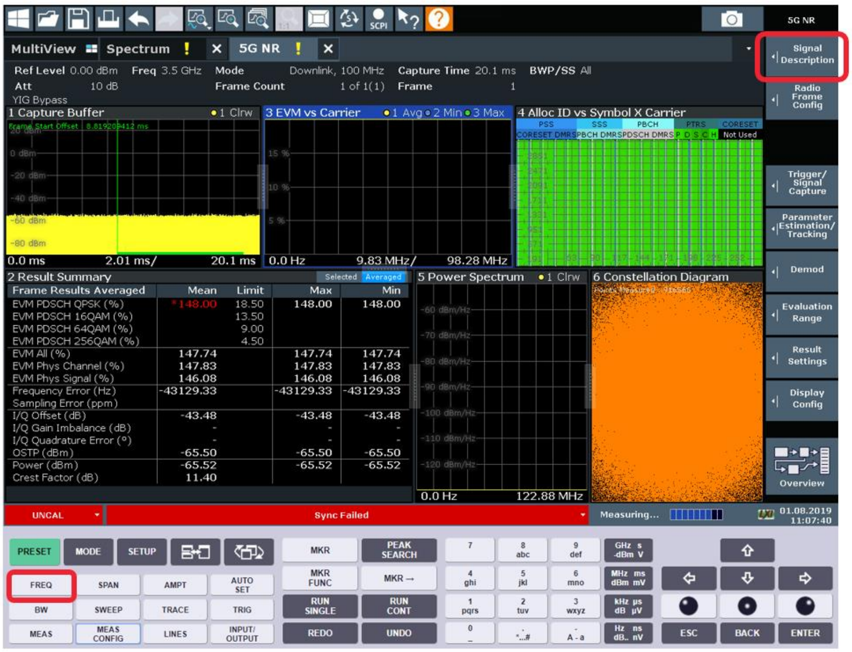


Fig. 2-9: 5G NR measurement Mode on the FSW

- Set Frequency: 3.5 GHz as shown in Fig. 2-9
- In the Signal description window, the signal parameter of the received signal needs to be configured

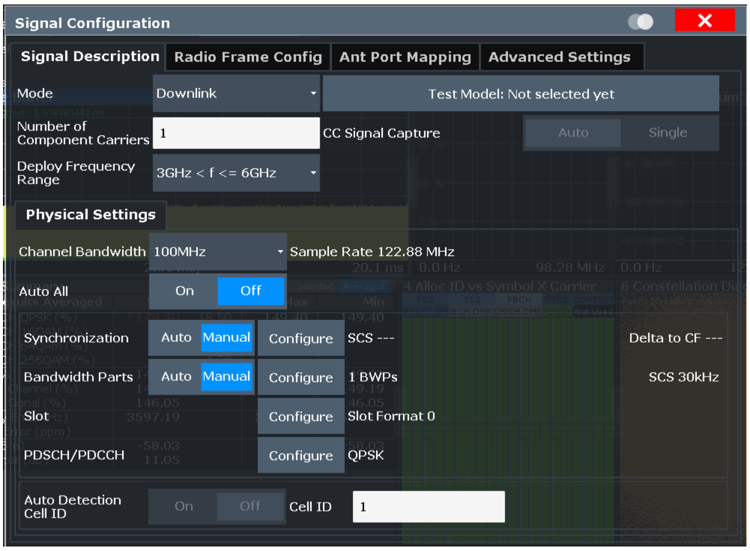


Fig. 2-10: Signal description configuration window in the 5G NR mode on the FSW

- Signal description settings is in Fig. 2-10,
  - Set Mode: Downlink, Number of component Carriers: 1
  - Deploy frequency Range: 3GHz < f <=6GHz
  - Channel Bandwidth: 100MHz
  - Bandwidth Part: 1 BWPS and SCS 30 KHz
  - PDSCH/PDCCH: QPSK
  - Cell ID: 1

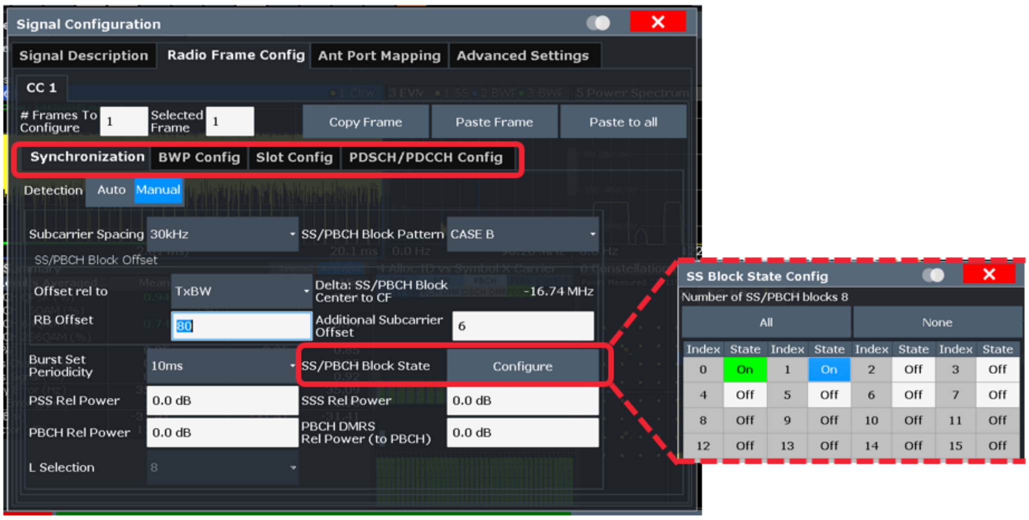


Fig. 2-11: Radio Frame Configuration window in the 5G NR mode on the FSW

- From the Radio Frame Config window, the sub categories (shown in Fig. 2-11) need to be configured
- In the Synchronization,
  - Select Detection: Manual, Subcarrier Spacing: 30 KHz
  - SS/PBCH Block Pattern : CASE B
  - Offset rel to: TxBW
  - RB Offset: 80, Additional Subcarrier Offset: 6

- Burst Set Periodicity: 10ms
- SS /PBCH Block State: Configuration shown in Fig. 2-11

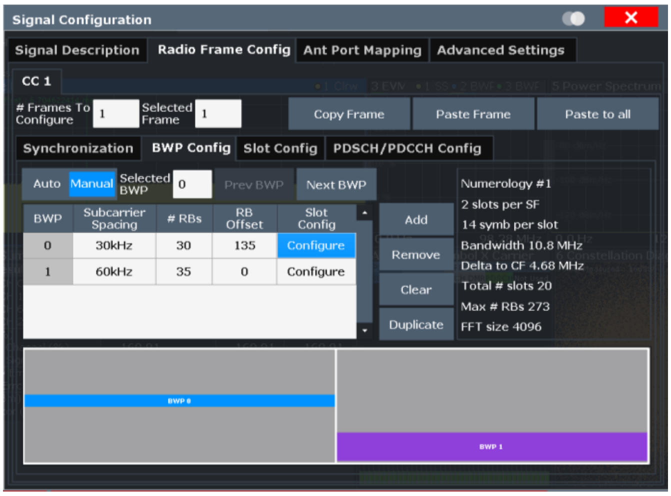


Fig. 2-12: BWP configuration settings in Radio Frame Config menu

- BWP o and 1 needs to be configured as shown in Fig. 2-12
  - BWP 0: SCS 30KHz, #RBs: 30, RB Offset: 135
  - BWP1: SCS 60KHz, #RBs: 35, RB Offset: 0

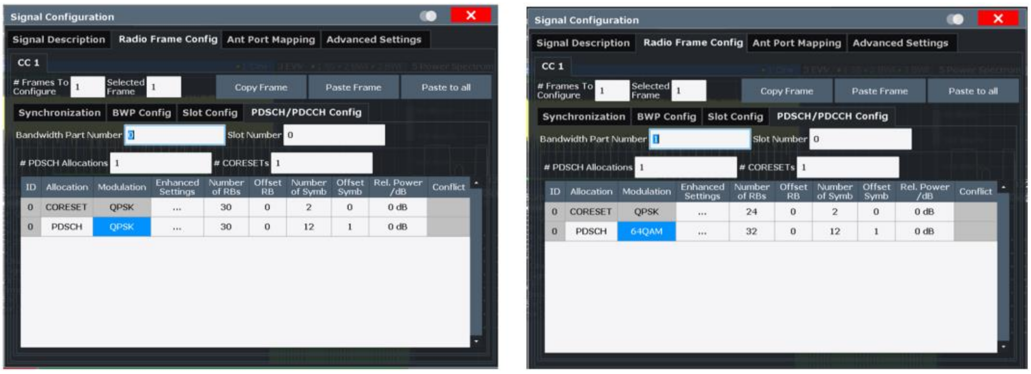


Fig. 2-13: PDSCH/PDCCH config settings in Radio Frame Configuration menu

- Fig. 2-13 shows the PDSCH/PDCCH configuration for the two BWPs and needs to be configured accordingly

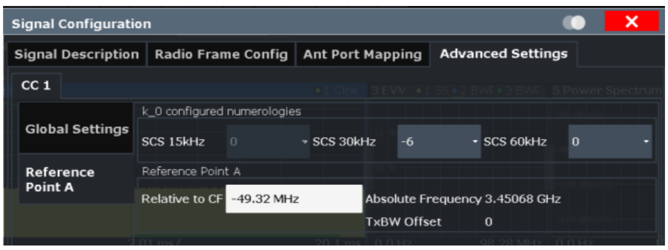


Fig. 2-14: Advanced Settings configuration in Signal Description menu

- Reference point A relative to CF is -49.32 MHz

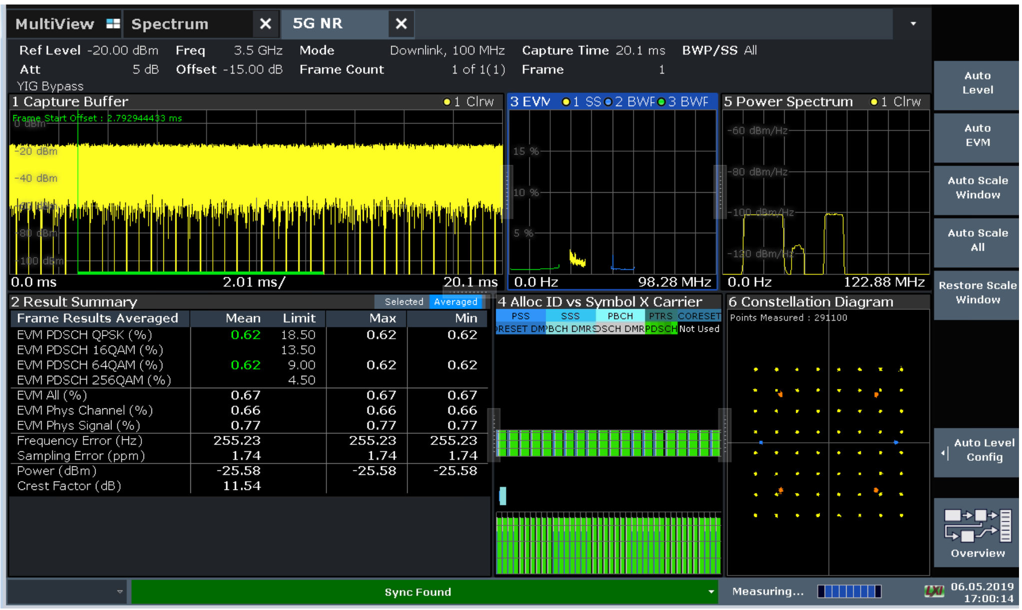


Fig. 2-15: Measurement Display Window of the 5GNR analysis personality on the FSW

Fig. 2-1 shows the measurement display of the 5G FR1 signal at 3.5 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PDSCH QPSK is 0.62% and PDSCH 64QAM is 0.62%.

2.1.3 Spectrum Analysis on the VSE

Configuring the 5G NR measurement personality on the VSE.

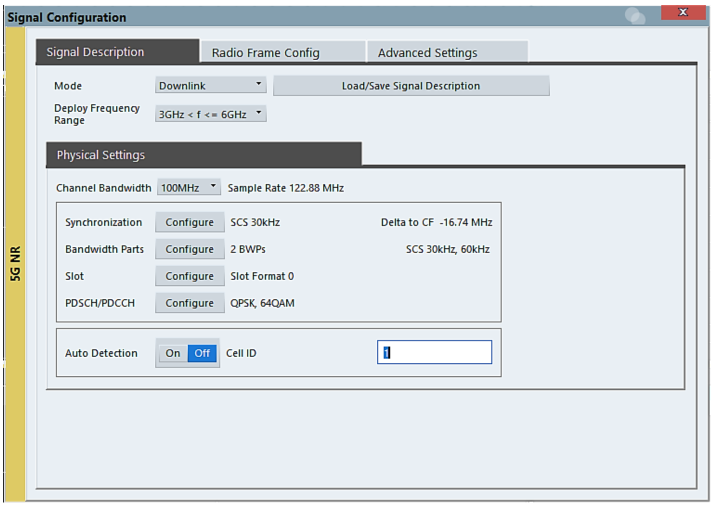


Fig. 2-16: 5G NR measurement Mode Signal Description configuration on the VSE

- Fig. 2-16 shows the Signal Description configuration of the 5G NR measurement modes

- Mode: Downlink, Deploy frequency Range: 3GHz < f <= 6GHz
- Channel Bandwidth: 100 MHz
- Synchronization: SCS 30KHz
- Bandwidth Parts: 2 BWPs
- DPSCH/PDCCH: QPSK, 64QAM
- Auto Detection: OFF, Cell ID: 1

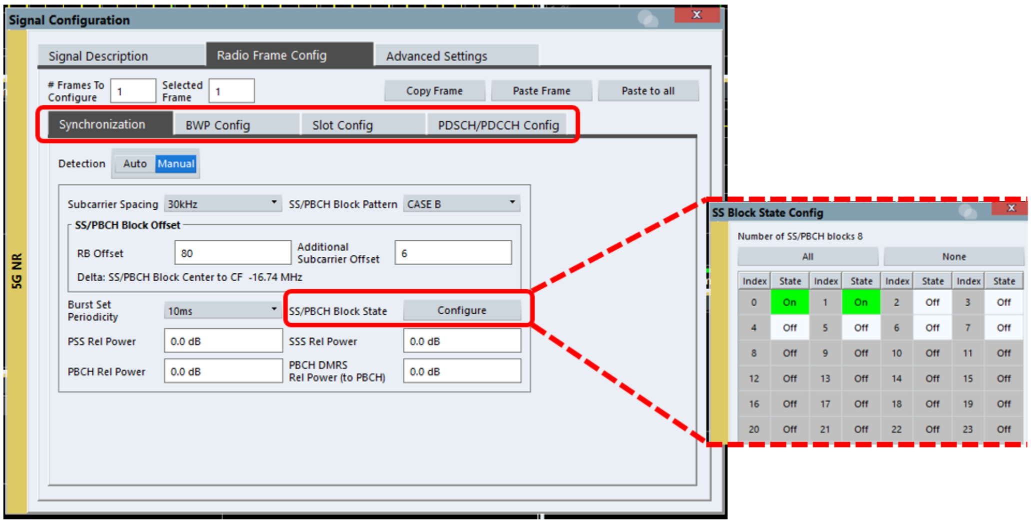


Fig. 2-17: Radio Frame Config on the VSE

- From the Radio Frame Config window, the sub categories (shown in Fig. 2-17) need to be configured
- Under the Synchronization tab,
  - Select Detection: Manual, Subcarrier Spacing: 30 KHz
  - SS/PBCH Block Pattern : CASE B
  - RB Offset: 80, Additional Subcarrier Offset: 6
  - Burst Set Periodicity: 10ms
  - SS /PBCH Block State: Configuration shown in Fig. 2-17

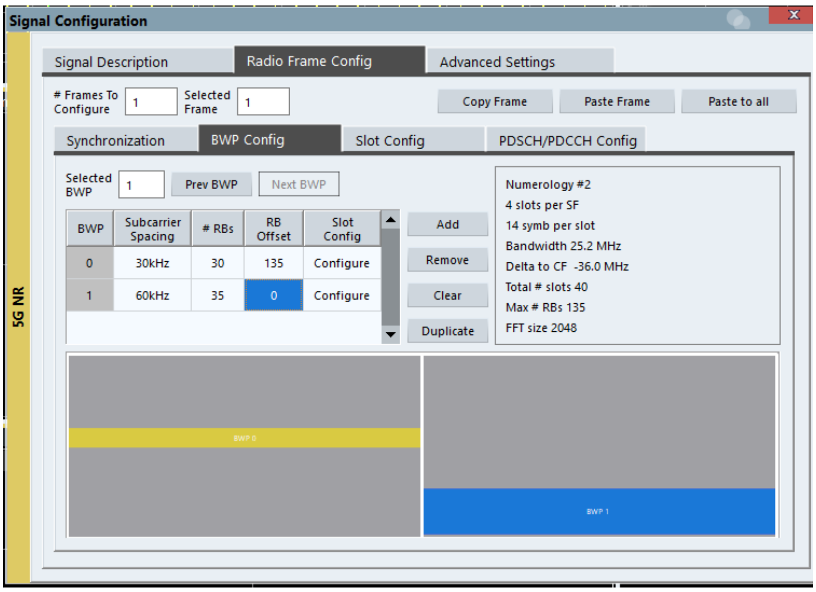


Fig. 2-18: BWP configuration settings in Radio Frame Config menu

- BWP o and 1 needs to be configured as shown in Fig. 2-18
  - BWP 0: SCS 30KHz, #RBs: 30, RB Offset: 135
  - BWP1: SCS 60KHz, #RBs: 35, RB Offset: 0

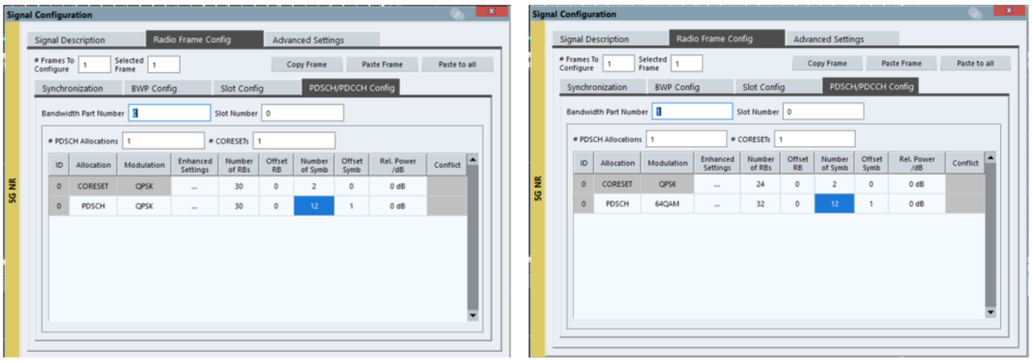


Fig. 2-19: PDSCH/PDCCH config settings in Radio Frame Configuration menu

Fig. 2-19 shows the PDSCH/PDCCH configuration for the two BWPs and needs to be configured accordingly

- BWP 0 configuration:
  - CORESET: Modulation: QPSK, No of RBs: 30, No of Symbol: 2
  - PDSCH: Modulation: QPSK, No of RBs: 30, No of Symbol: 12, Offset Syb: 1
- BWP 1 configuration:
  - CORESET: Modulation: QPSK, No of RBs: 24, No of Symbol: 2
  - PDSCH: Modulation: 64QAM, No of RBs: 32, No of Symbol: 12, Offset Syb: 1

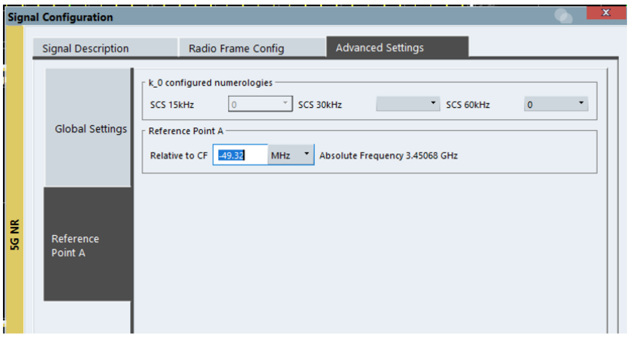


Fig. 2-20: Advanced Settings configuration

- Reference point A : Relative to CF is -49.32 MHz

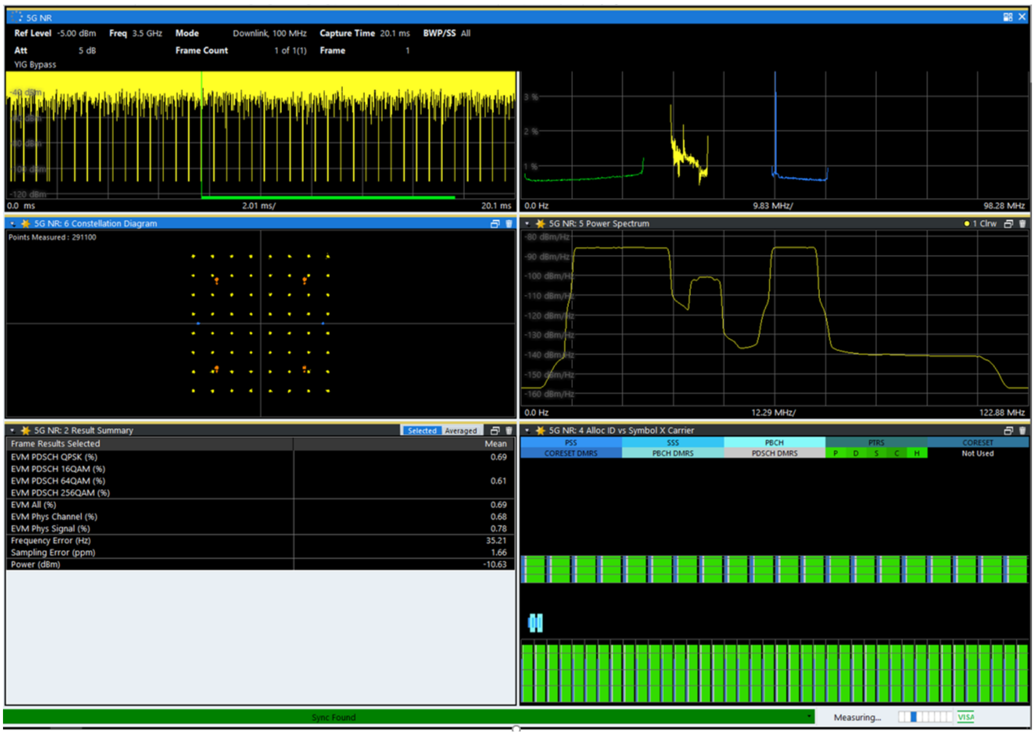


Fig. 2-21: Measurement Display Window of the 5GNR analysis personality on the FSW

Fig. 2-21 shows the measurement display of the 5G FR1 signal at 3.5 GHz. The EVM for PDSCH QPSK is 0.69% and PDSCH 64QAM is 0.61%.

2.2 Uplink signal generation and analysis

2.2.1 Signal generator setting on the SMW

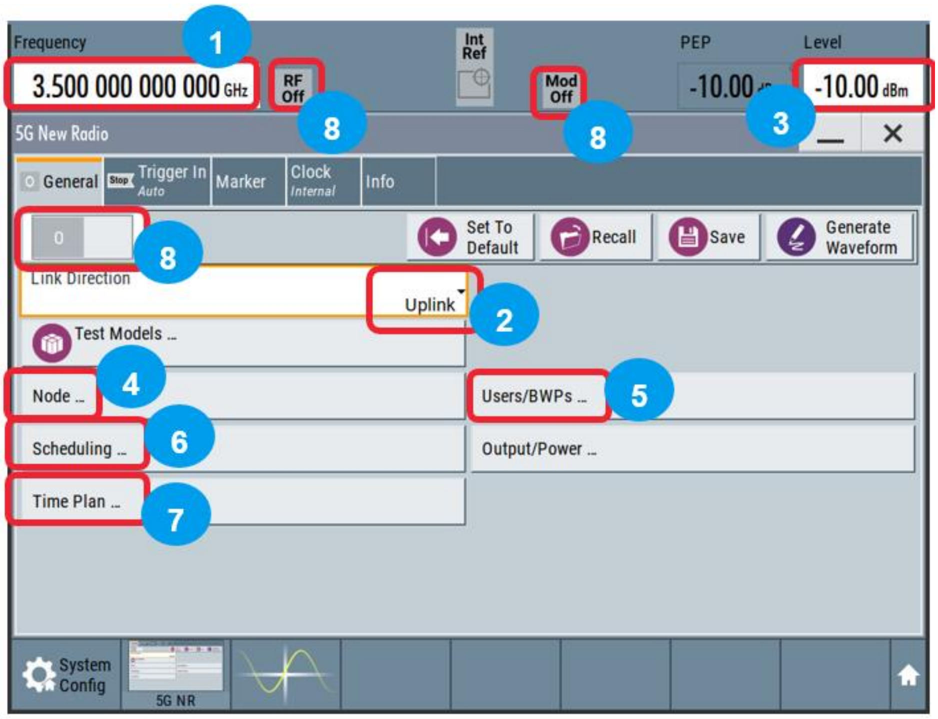


Fig. 2-22: 5G NR main uplink configuration window on the SMW

Fig. 2-22 shows the main configuration window of the 5G NR physical layer baseband signal generation. The steps numbers are marked in correct order in the figure to configure the physical layer uplink parameters. Following Fig. 2-22:

1. Set Frequency: 3.5 GHz
2. Link direction : Uplink
3. Output power level: -10dBm
4. Node configuration settings from Fig. 2-22

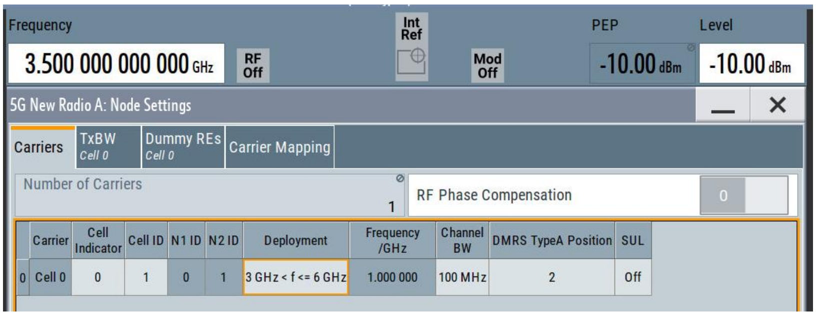


Fig. 2-23: Node settings window configuration for carrier

Under node setting, the sub windows Carriers, TxBW needs to be configured as shown in Fig. 2-23.

- Carrier: Cell ID: 1, Deployment: 3 GHz <f <= 6 GHz, Channel BW : 100 MHz

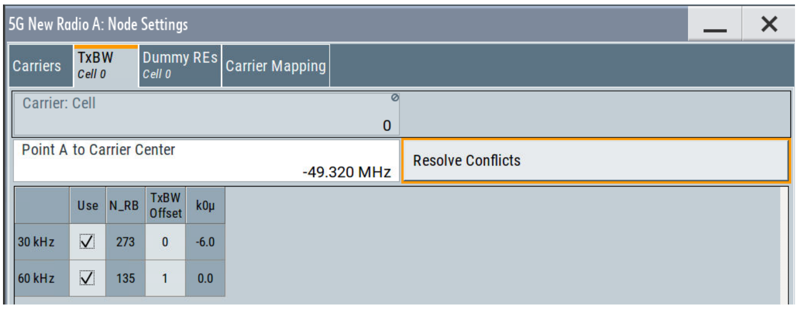


Fig. 2-24: Node settings window configuration for TxBW

- Select both 30 KHz and 60 KHz and hit Resolve Conflicts as shown in Fig. 2-24

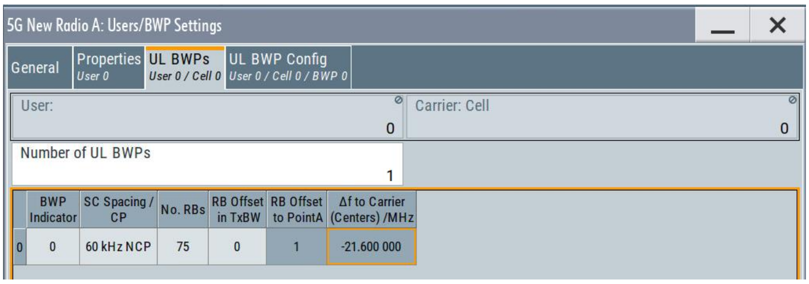


Fig. 2-25: User/BWPs setting window configuration for UL BWP

- Users/ BWPs configuration is shown in Fig. 2-25,
  - Insert Number of UL BWPs: 1
  - Set BWP indicator 0 with SC spacing: 60 KHz, no RBs: 75 & RB offset: 0

6. Now the BWP needs to be configured separately from the scheduling window in Fig. 2-22. The BWP configuration is shown in Fig. 2-26.

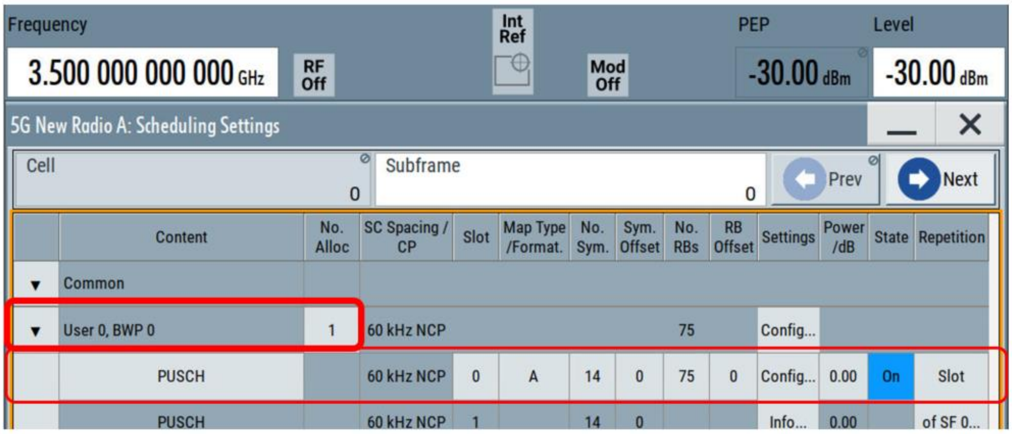


Fig. 2-26: Scheduling setting for the BWP

- BWP 0 has No allocation :1
  - Sub carrier spacing 60 KHz NCP , content: PUSCH, Map format: A
  - Slot : 0, No Sym: 14, No RBs: 75; Config: Mod: 64QAM

7. The time plan (from Fig. 2-22) window shown in Fig. 2-27 depicts a graphical overview of the configured physical layer parameters.

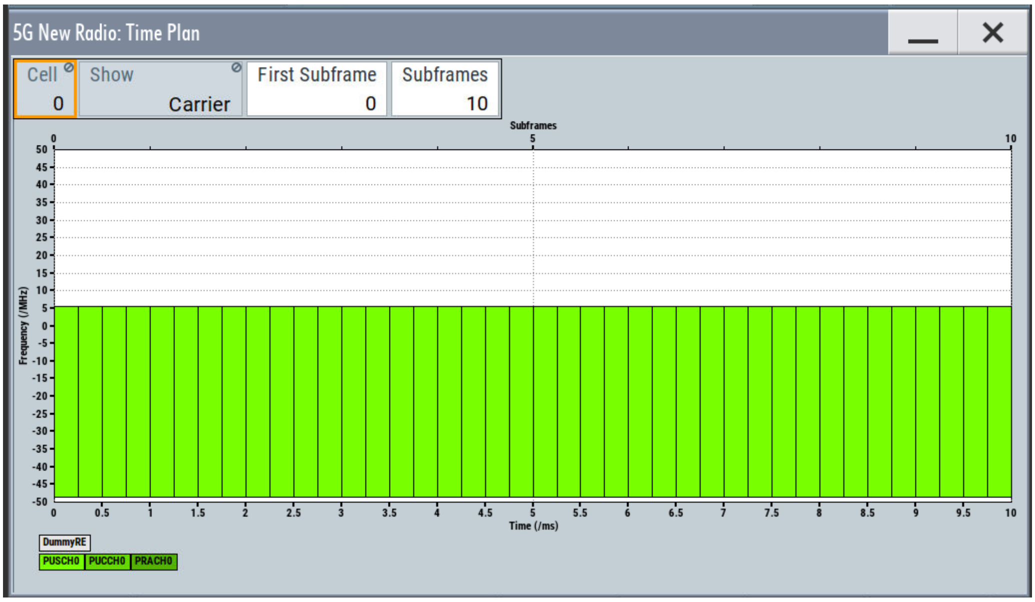


Fig. 2-27: Uplink signal parameter setting as visualized on the Time Plan window

8. Switch ON the Baseband signal, Modulator and RF using the buttons as marked on Fig. 2-22.

2.2.2 Spectrum Analyzer setting on the FSW

- To get started, switch ON the 5G NR measurement personality from MODE

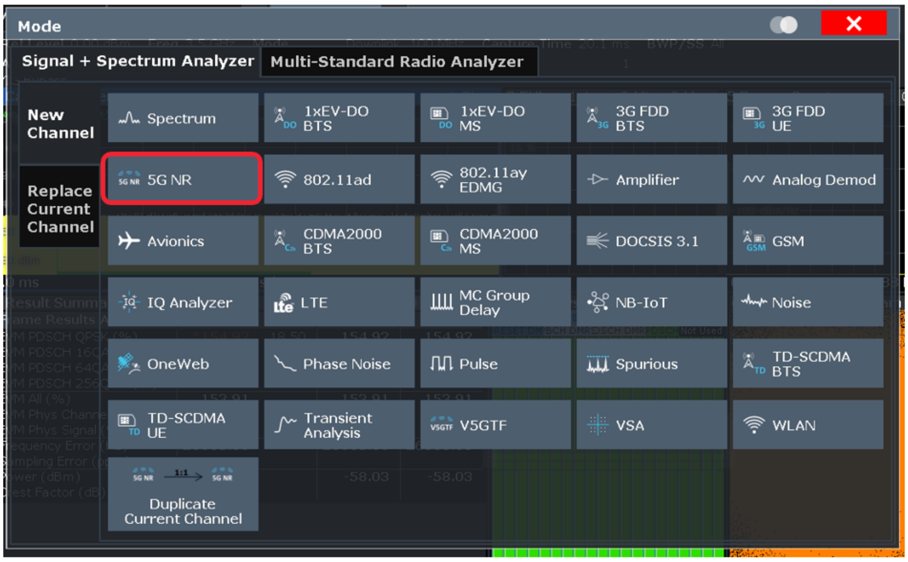


Fig. 2-28: Measurement Modes selection window on the FSW

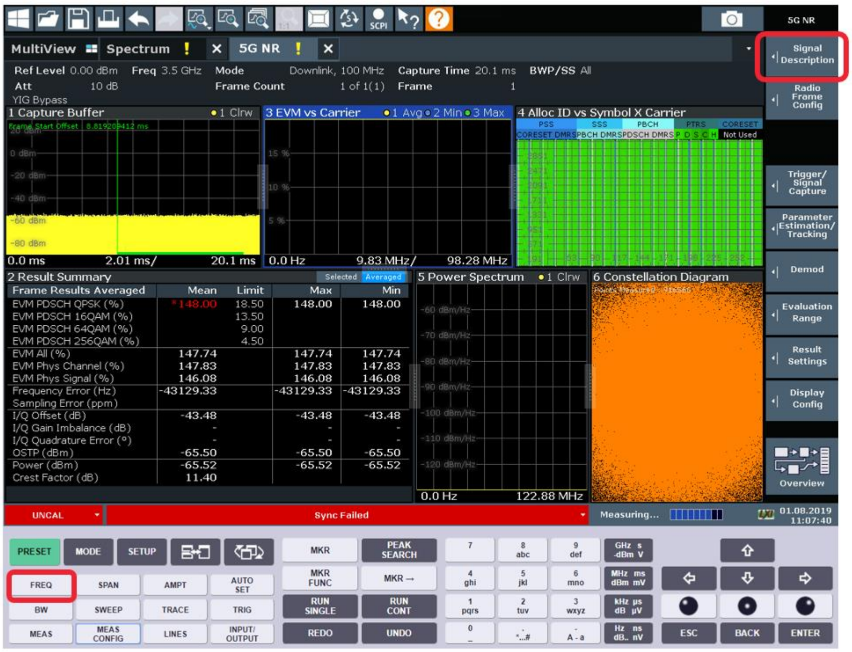


Fig. 2-29: 5G NR measurement Mode on the FSW

- Set Frequency: 3.5 GHz as shown in Fig. 2-29
- In the Signal description window, the signal parameter of the received signal needs to be configured

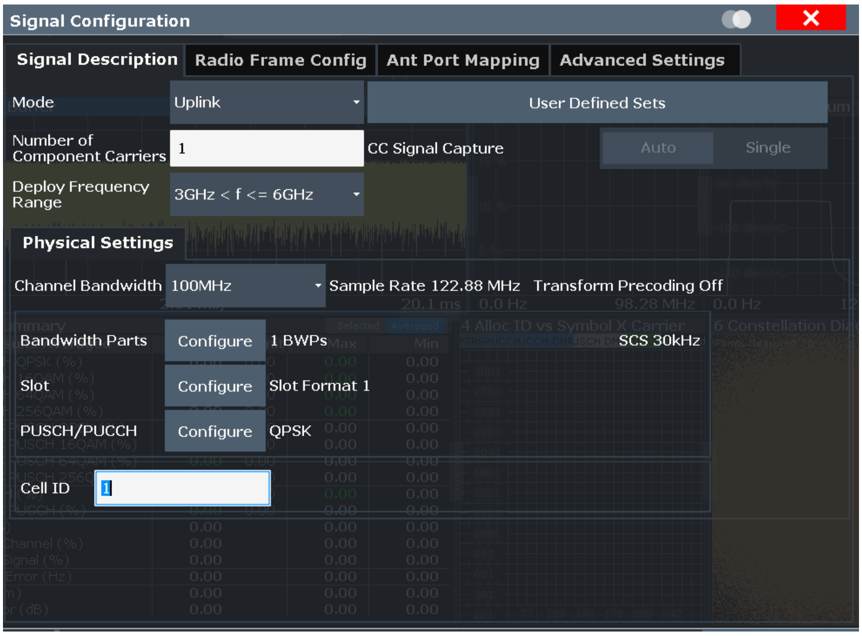


Fig. 2-30: Signal description configuration window in the 5G NR mode on the FSW

- Signal description settings is in Fig. 2-30,
  - Set Mode: Uplink, Number of Component Carriers: 1
  - Deploy frequency Range: 3GHz < f <= 6GHz
  - Channel Bandwidth: 100MHz
  - Bandwidth Part: 1 BWPS and SCS 30 KHz
  - PDSCH/PDCCH: QPSK
  - Cell ID: 1

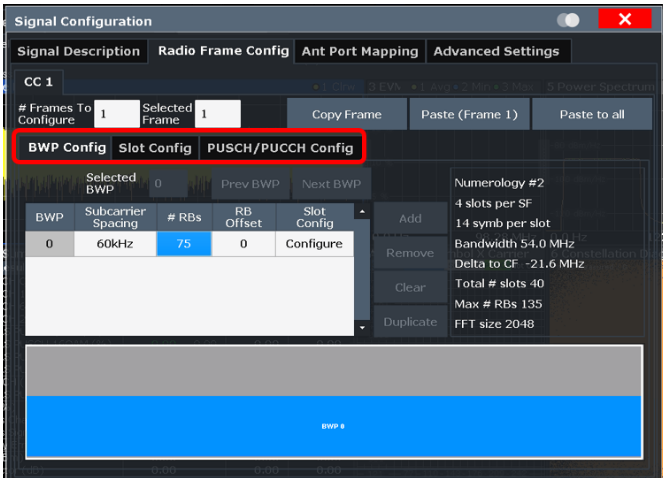


Fig. 2-31: Radio Frame Configuration window in the 5G NR mode on the FSW

- From the Radio Frame Config window, the sub categories need to be configured as shown in Fig. 2-31
- In the BWP Config sub category,
  - Subcarrier Spacing: 60 KHz
  - #RBs: 75, RB offset: 0

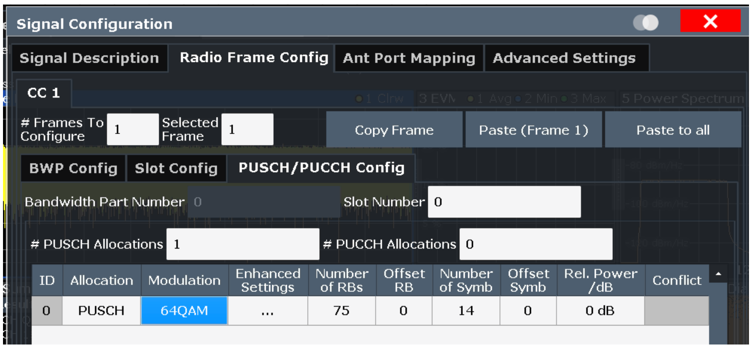


Fig. 2-32: PUSCH/PUCCH config settings in Radio Frame Configuration menu

- Fig. 2-32 shows the PUSCH/PUCCH configuration for the BWPs and needs to be configured accordingly

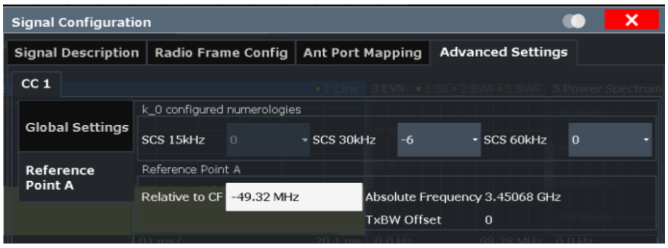


Fig. 2-33: Advanced Settings configuration in Signal Description menu

- Reference point A relative to CF is -49.32 MHz as shown in Fig. 2-33

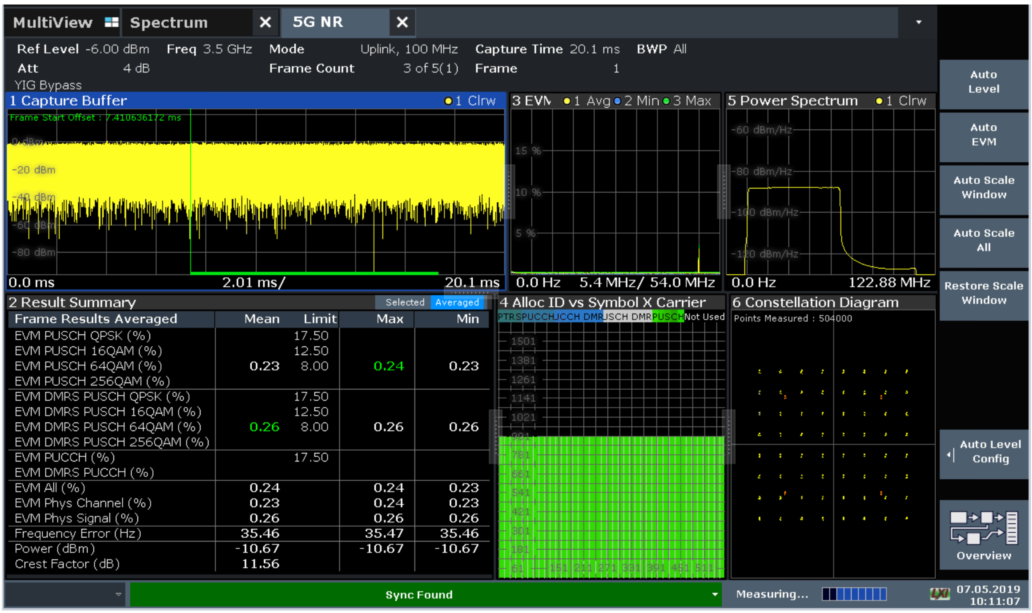


Fig. 2-34: Measurement Display Window of the 5GNR analysis personality on the FSW

Fig. 2-34 shows the uplink measurement display of the 5G FR1 signal at 3.5 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PUSCH 64QAM is 0.23% and the DMRS PUSCH 64QAM is 0.26%.

2.2.3 Spectrum Analysis setting on the VSE

Configuring the 5G NR measurement personality on the VSE.

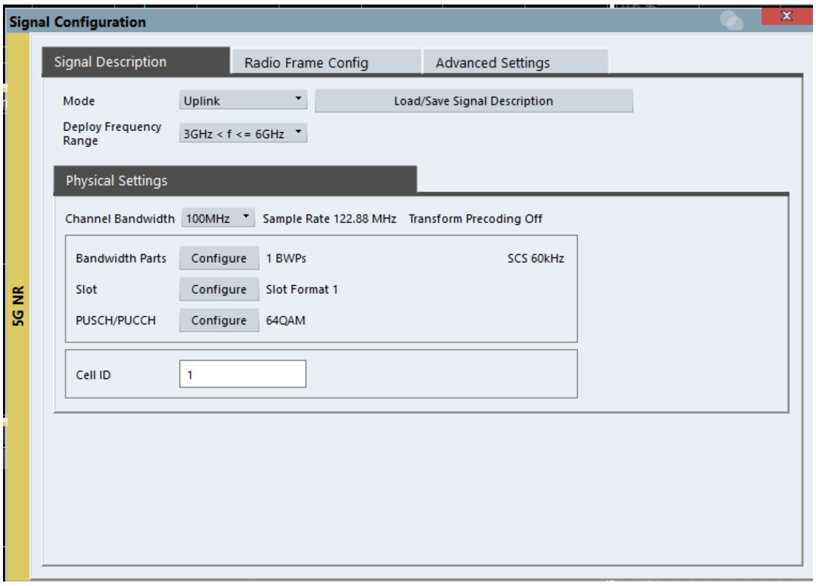


Fig. 2-35: 5G NR measurement Mode Signal Description configuration on the VSE

- Fig. 2-35 shows the Signal Description configuration of the 5G NR measurement modes
  - Mode: Uplink, Deploy frequency Range: 3GHz < f <= 6GHz
  - Channel Bandwidth: 100 MHz
  - Synchronization: SCS 60KHz
  - Bandwidth Parts: 1 BWPs
  - PUSCH/PUCCH: 64QAM
  - Cell ID: 1

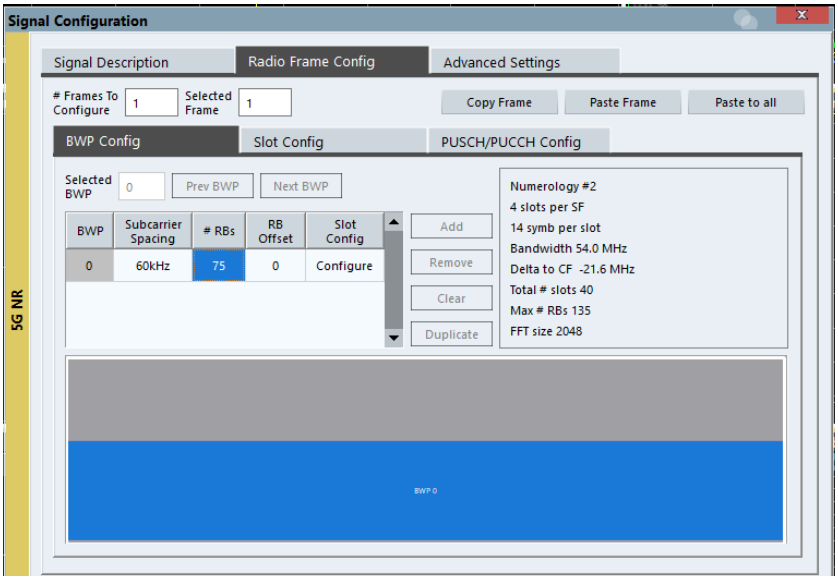


Fig. 2-36: Radio Frame Config on the VSE

- From the Radio Frame Config window, the sub categories (shown in Fig. 2-36) need to be configured
- Under the BWP Config tab,
  - Subcarrier Spacing: 60 KHz
  - #RBs: 75, RB offset: 0

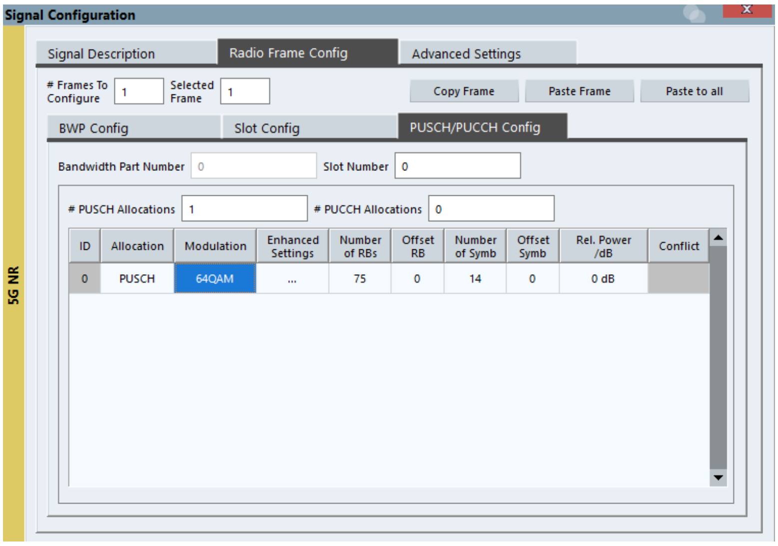


Fig. 2-37: PUSCH/PUCCH configuration settings in Radio Frame Config menu

- PUSCH/PUCCH needs to be configured as shown in Fig. 2-37
  - PUSCH 0, Mod: 64QAM, #RBs: 75, RB Offset: 0, #Symbols: 14, Offset Symb: 0

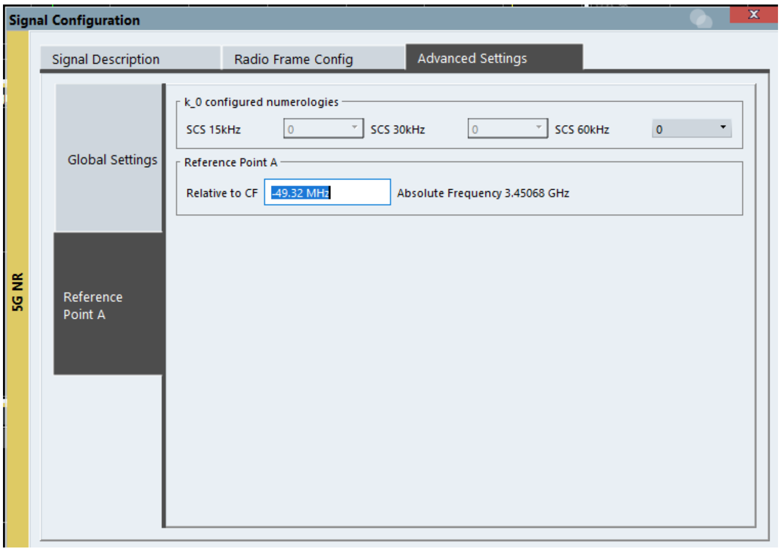


Fig. 2-38: Advanced Settings configuration

- Reference point A : Relative to CF is -49.32 MHz as shown in Fig. 2-38

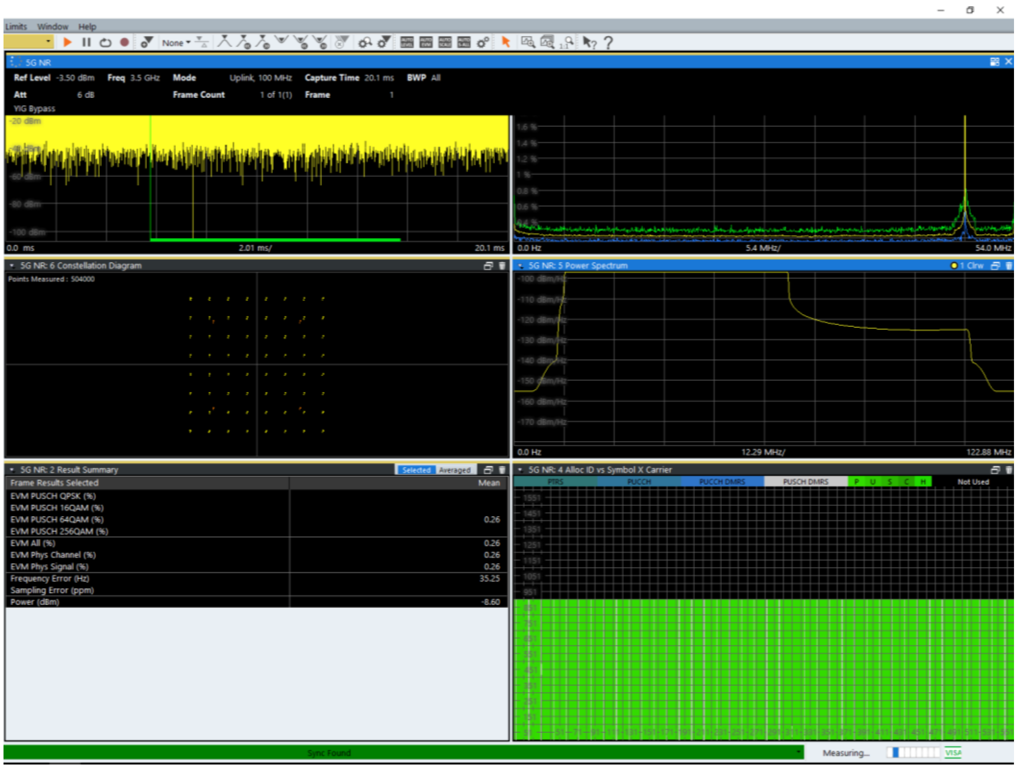


Fig. 2-39: Measurement Display Window of the 5GNR analysis personality on the FSW

Fig. 2-39 shows the measurement display of the 5G FR1 uplink signal at 3.5 GHz. The EVM for PUSCH 64QAM is 0.26%.

3 Measurement result for FR1 & FR2 signals

This chapter is a summary of the measurement results for the signal quality of the generated 5G NR uplink and downlink signals. The signals are centered at 3.5 GHz in the FR1 band and at 26 GHz in FR2 band. The same signal has been used and the measurement result are analyzed using the FSW on device software as well as the VSE signal analysis software. The measurements are performed for both uplink and downlink signals.

3.1 FR1 Measurement Results

This chapter is a summary of the measurement results for the signal quality of the generated 5G NR uplink and downlink signals. The signals are centered at 3.5 GHz in the FR1 band and at 26 GHz in FR2 band. The same signal has been used and the measurement result are analyzed using the FSW on device software as well as the VSE signal analysis software. And is the case for both uplink and downlink signals.

3.1.1 FR1 DL Measurement result on the FSW

Signal Description:

Frequency: 3.5 GHz (Downlink); Bandwidth: 100 MHz

SC spacing: 30 KHz NCP, RB offset: 80, SC offset: 6, Case: B, Position: 1100 0000

BWP 1: indicator 0 with SC spacing: 30 KHz, no RBs: 30 & RB offset: 135, Mod: QPSK

BWP2: indicator 1 with SC spacing: 60 KHz, no RBs: 35 & RB offset: 0, Mod: 64QAM

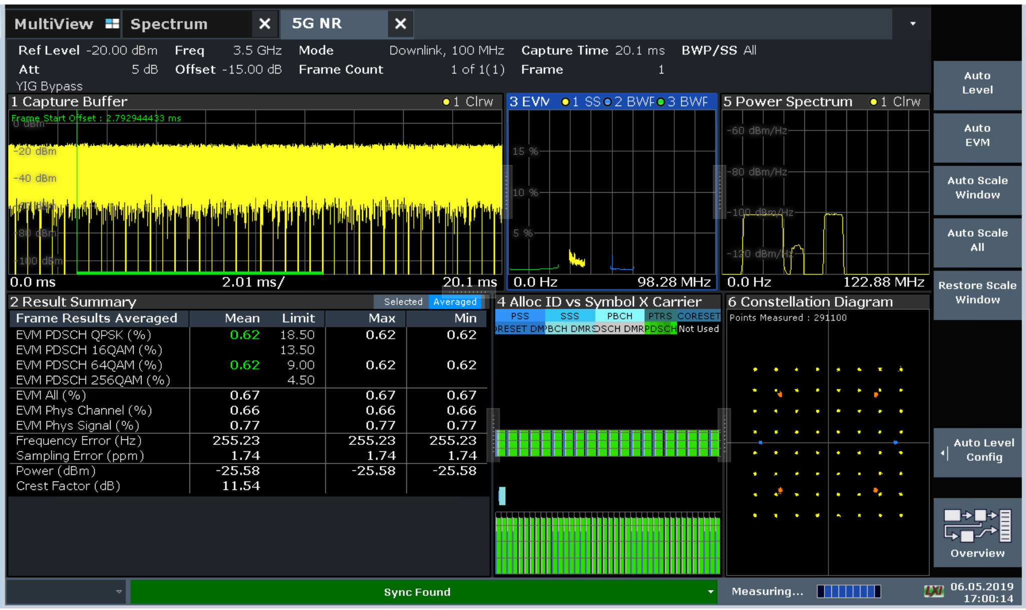


Fig. 3-1: Measurement Results of the 5GNR FR1 downlink signal at 3.5 GHz on the FSW

Fig. 3-1 shows the measurement display of the 5G FR1 downlink signal at 3.5 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PDSCH QPSK is 0.62% and PDSCH 64QAM is 0.62%.

3.1.2 FR1 DL Measurement result on the VSE

Signal Description:

Frequency: 3.5 GHz (Downlink); Bandwidth: 100 MHz

SC spacing: 30 KHz NCP, RB offset: 80, SC offset: 6, Case: B, Position: 1100 0000

BWP 1: indicator 0 with SC spacing: 30 KHz, no RBs: 30 & RB offset: 135, Mod: QPSK

BWP2: indicator 1 with SC spacing: 60 KHz, no RBs: 35 & RB offset: 0, Mod: 64QAM

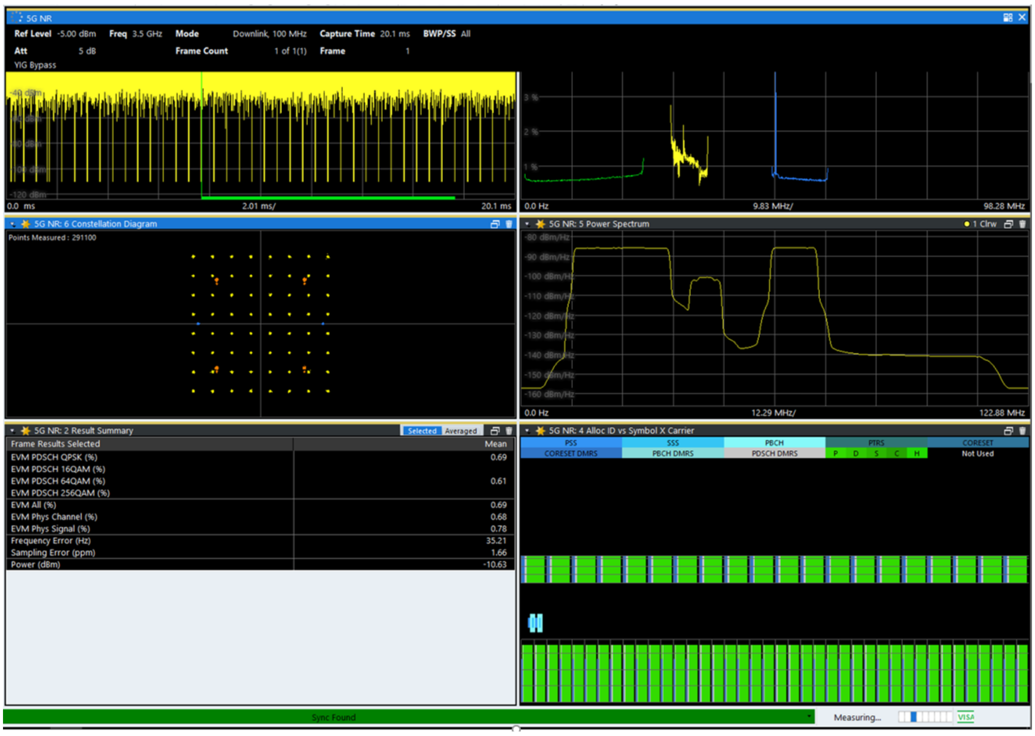


Fig. 3-2: Measurement Results of the 5GNR FR1 downlink signal at 3.5 GHz on the VSE

Fig. 3-2 shows the measurement display of the 5G FR1 downlink signal at 3.5 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PDSCH QPSK is 0.69% and PDSCH 64QAM is 0.61%.

3.1.3 FR1 UL Measurement result on the FSW

Signal Description:

Frequency: 3.5 GHz (Uplink); Bandwidth: 100 MHz

SC spacing: 60 KHz NCP, No. RBs: 75, RB offset: 0

BWP 0, Allocation: 1, Sub carrier spacing 60 KHz NCP, content: PUSCH, Map format: A, Slot : 0, No Sym: 14, Mod: 64QAM

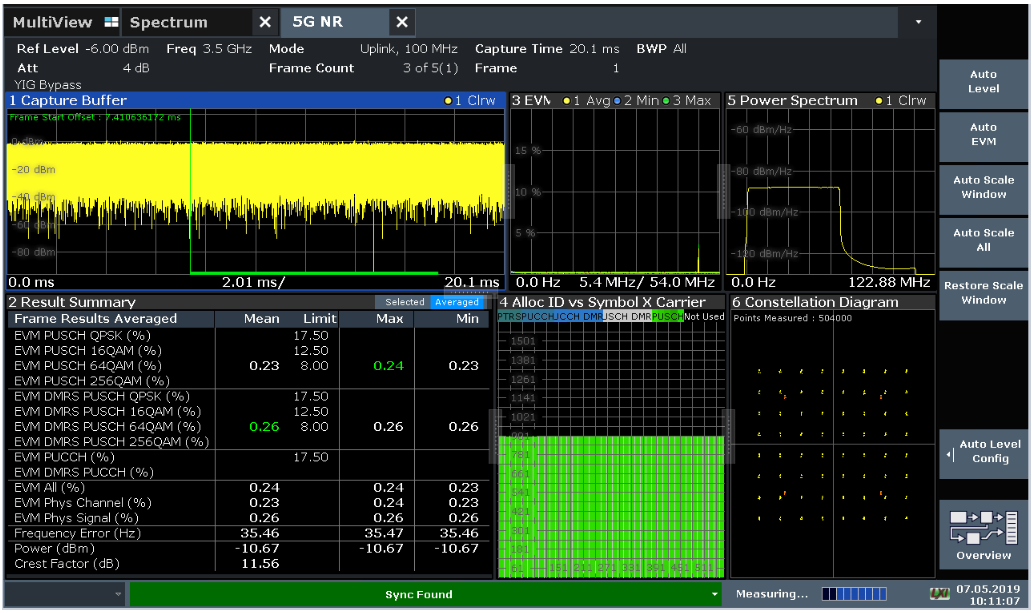


Fig. 3-3: Measurement Results of the 5GNR FR1 uplink signal at 3.5 GHz on the FSW

Fig. 3-3 shows the measurement display of the 5G FR1 uplink signal at 3.5 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PUSCH 64QAM is 0.23%.

3.1.4 FR1 UL Measurement result on the VSE

Signal Description:

Frequency: 3.5 GHz (Uplink); Bandwidth: 100 MHz

SC spacing: 60 KHz NCP, No. RBs: 75, RB offset: 0

BWP 0, Allocation: 1, Sub carrier spacing 60 KHz NCP, content: PUSCH, Map format: A, Slot : 0, No Sym: 14, Mod: 64QAM

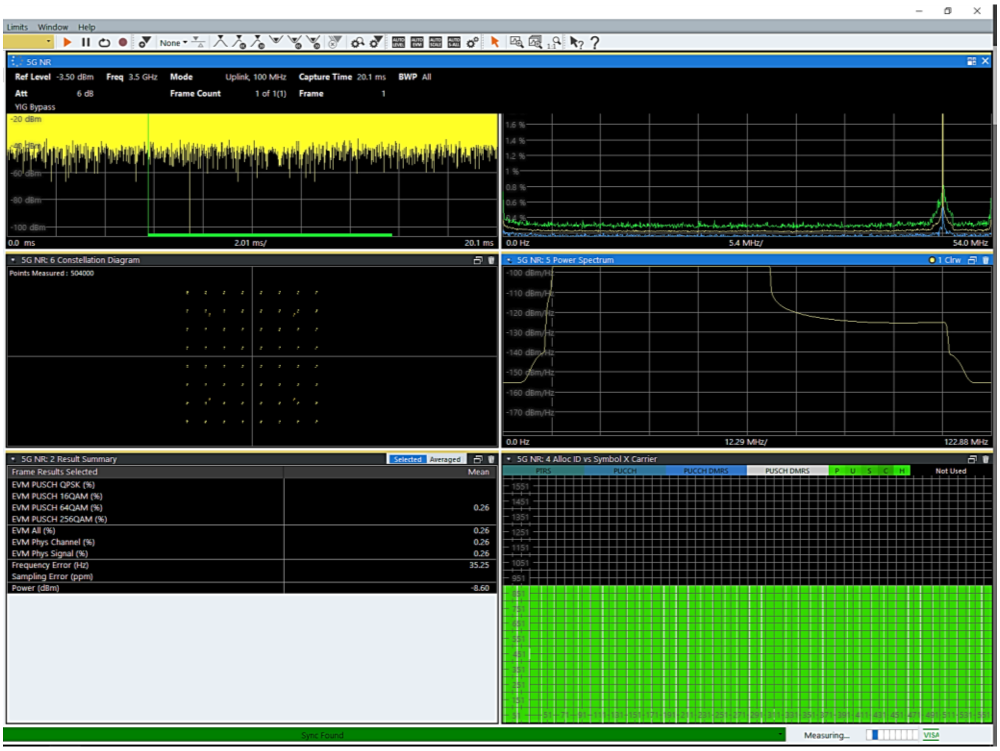


Fig. 3-4: Measurement Results of the 5GNR FR1 uplink signal at 3.5 GHz on the VSE

Fig. 3-4 shows the measurement display of the 5G FR1 uplink signal at 3.5 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PUSCH 64QAM is 0.26%.

3.2 FR2 Measurement Results

3.2.1 FR2 DL Measurement result on the FSW

Signal Description:

Frequency: 26 GHz (Downlink); Bandwidth: 100 MHz

SC spacing: 120 KHz NCP, RB offset: 23, SC offset: 0, Case: D, Position: 1100 0000 …

BWP 1: indicator 0 with SC spacing: 120 KHz NCP, no RBs: 45 & RB offset: 0, Mod: 64QAM

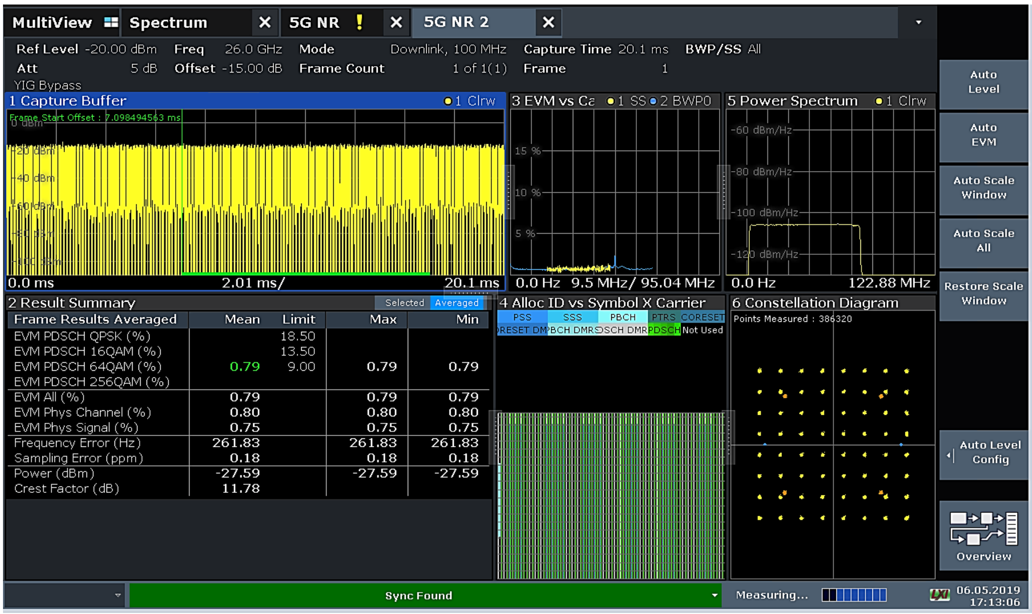


Fig. 3-5: Measurement Results of the 5GNR FR2 downlink signal at 26 GHz on the FSW

Fig. 3-5 shows the measurement display of the 5G FR2 downlink signal at 26 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PDSCH 64QAM is 0.79%.

3.2.2 FR2 DL Measurement result on the VSE

Signal Description:

Frequency: 26 GHz (Downlink); Bandwidth: 100 MHz

SC spacing: 120 KHz NCP, RB offset: 23, SC offset: 0, Case: D, Position: 1100 0000 …

BWP 1: indicator 0 with SC spacing: 120 KHz NCP, no RBs: 45 & RB offset: 0, Mod: 64QAM

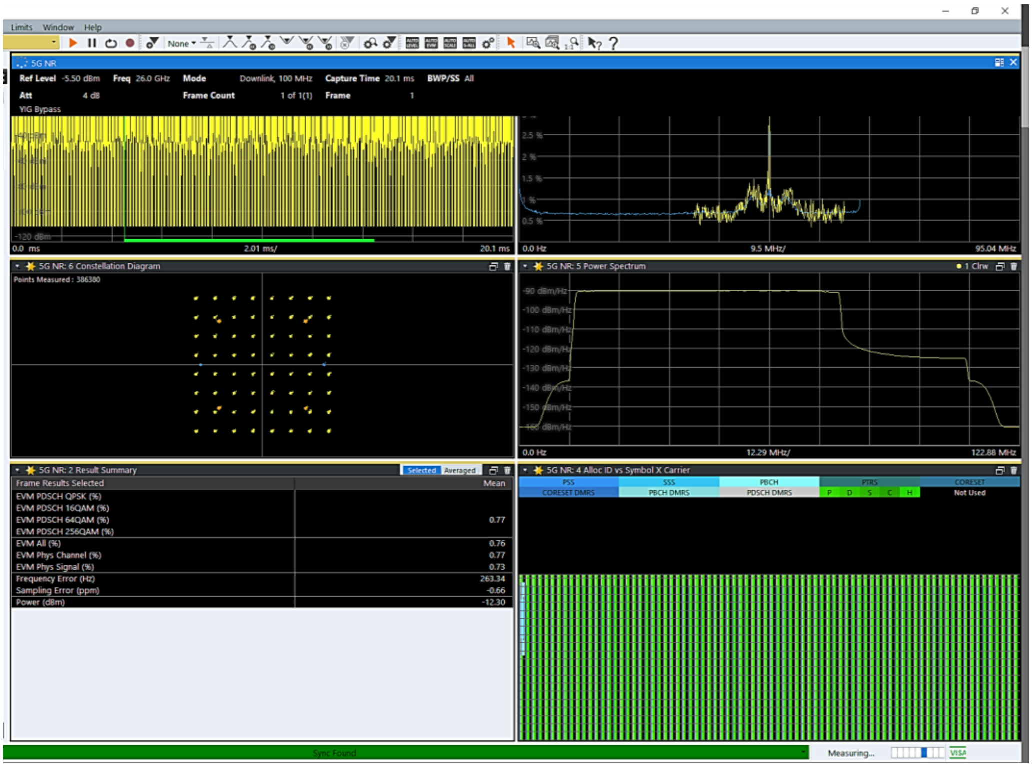


Fig. 3-6: Measurement Results of the 5GNR FR2 downlink signal at 26 GHz on the VSE

Fig. 3-6 shows the measurement display of the 5G FR2 downlink signal at 26 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PDSCH 64QAM is 0.77%.

3.2.3 FR2 UL Measurement result on the FSW

Signal Description:

Frequency: 26 GHz (Uplink); Bandwidth: 100 MHz

SC spacing: 120 KHz NCP, No. RBs: 66, RB offset: 0

BWP 0: Allocation: 1, SCS 120 KHz NCP, content: PUSCH, Map format: A, Slot: 0, No Sym: 10, No. RB: 35, Mod: 16QAM

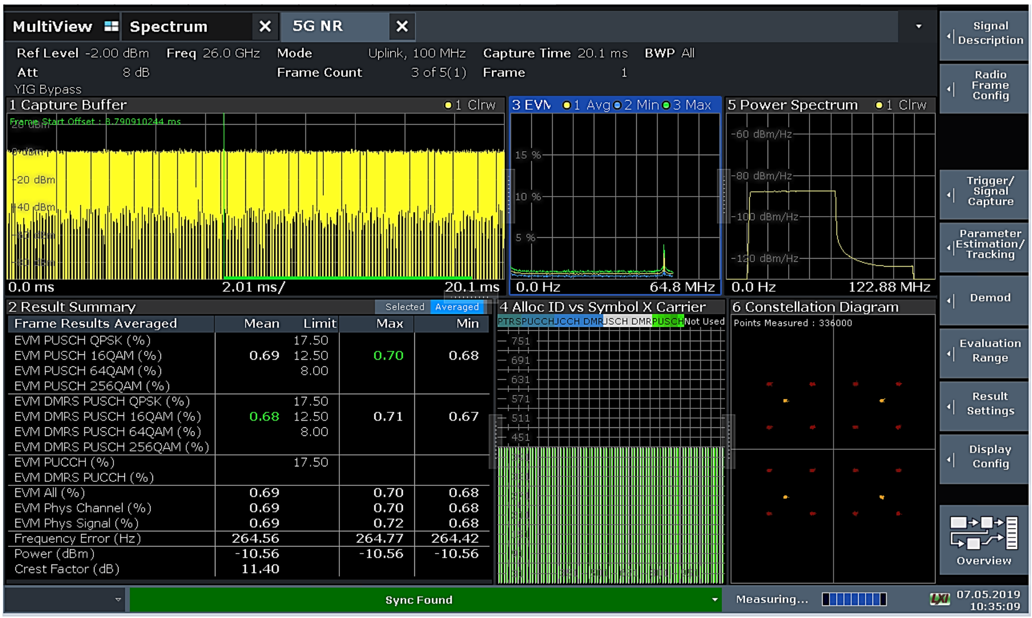


Fig. 3-7: Measurement Results of the 5GNR FR2 uplink signal at 26 GHz on the FSW

Fig. 3-7 shows the measurement display of the 5G FR2 uplink signal at 26 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PUSCH 16QAM is 0.69%.

3.2.4 FR2 UL Measurement result on the VSE

Signal Description:

Frequency: 26 GHz (Uplink); Bandwidth: 100 MHz

SC spacing: 120 KHz NCP, No. RBs: 66, RB offset: 0

BWP 0: Allocation: 1, SCS 120 KHz NCP, content: PUSCH, Map format: A, Slot: 0, No Sym: 10, No. RB: 35, Mod: 16QAM

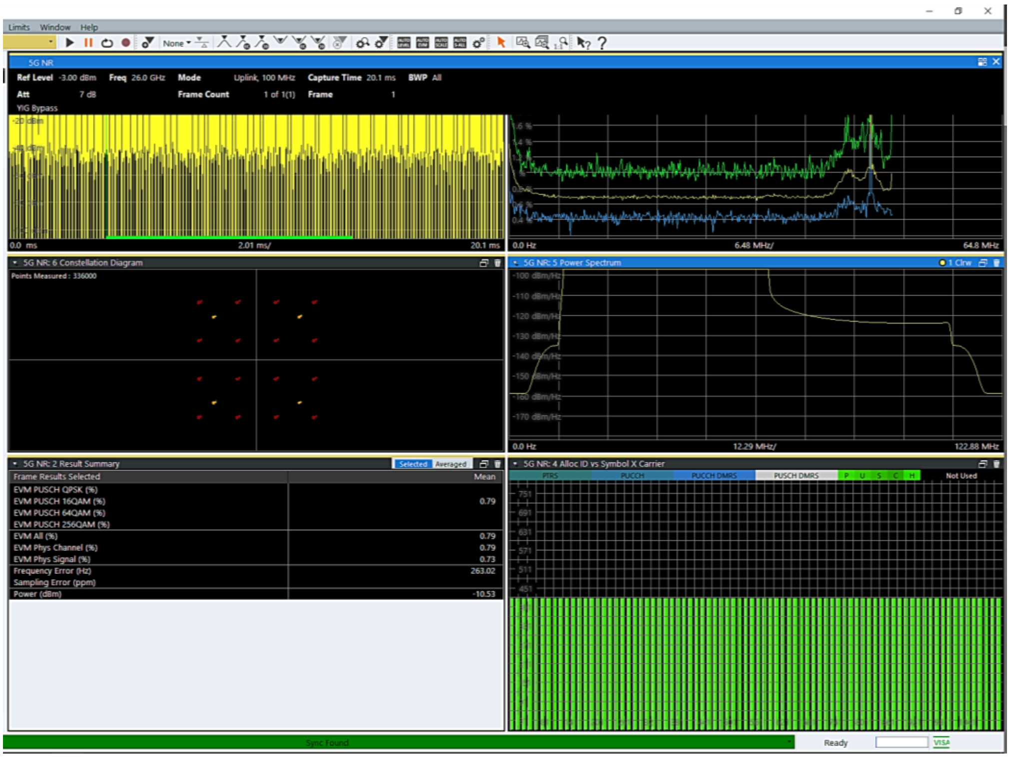


Fig. 3-8: Measurement Results of the 5GNR FR2 uplink signal at 26 GHz on the VSE

Fig. 3-8 shows the measurement display of the 5G FR2 uplink signal at 26 GHz. The auto EVM can be selected to optimize the analysis of the signal. The EVM for PUSCH 16QAM is 0.79%.

4 Advanced Measurement Methods

4.1 Phase Noise

Wireless communication at mmW frequencies provide many challenges. Phase noise effects are very significant at those frequencies. The two type of errors due to phase noise are Common Phase Error (CPE) and Inter-Carrier Interference (ICI).

ICI is addressed through wider subcarrier spacing (SCS): Data and control channel could utilize 60 or 120 KHz and synchronization Signal Block (SSB) can utilize the 120 or 240 KHz.

The CPE is addressed by adding Phase Tracking Reference Signal (PTRS). The PTRS is optional in the standard and can be applied both in the downlink and as well in the uplink. This should be implemented in the receiver to compensate for the CPE. Nevertheless, in order to emulate the phase noise in the development phase, in the AWGN block of the SMW, there is a configurable sub block for Phase Noise.

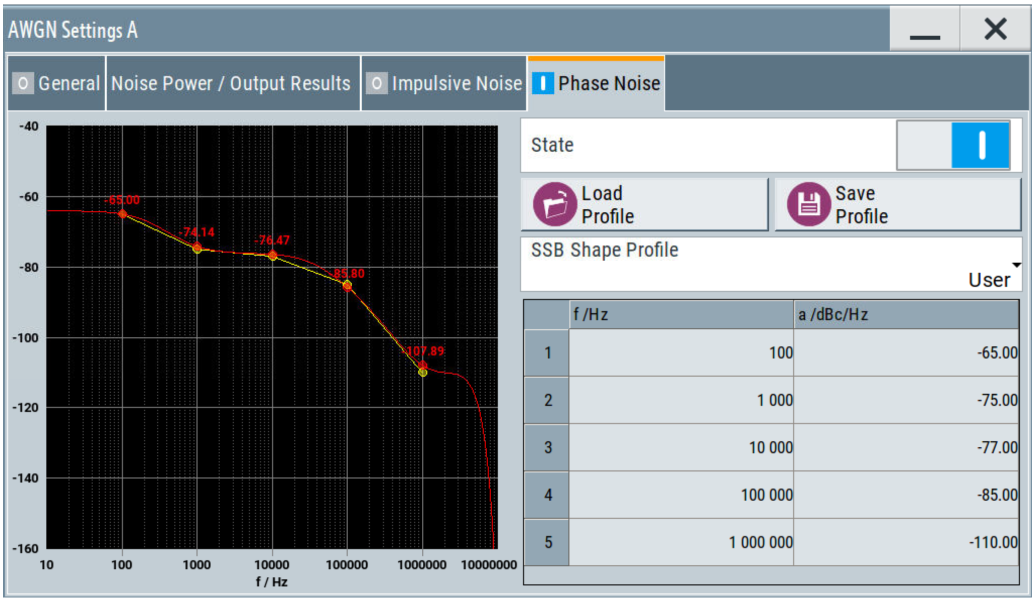


Fig. 4-1: Phase noise configuration window on the SMW vector signal generator

Fig. 4-1 shows the window to configure phase noise. On the right side of this window, there is a numerical representation model and on the left side, there is a graphical representation model.

The frequencies and the corresponding phase noise parameters can be adjusted here. The profile can be saved and loaded here. After activation, the current signal quality will be adjusted with the controlled phase noise setting. This enables the testing of performance of the DUT behavior under different emulated phase noise settings.

4.1.1 Performance check of PTRS signals

For this example, a 100 MHz, 64QAM signal 5G NR signal is configured on the SMW200A. The downlink signal has no PTRS active for PDSCH and has a single symbol PDSCH DMRS. With the Phase Tracking ON (3GPP Definition) on the FSW, the corresponding EVM measurement result -40.85 dB is shown in Fig. 4-2.

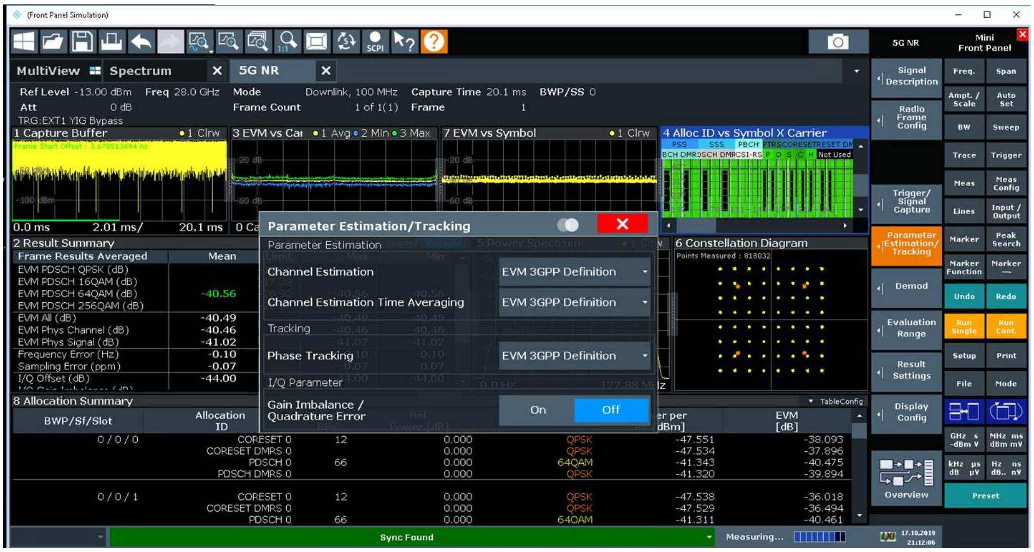


Fig. 4-2: EVM measument with no PTRS active on 100MHz 5G NR DL signal at 28 GHz

No change in measurement result is observed with phase tracking to OFF, as shown in Fig. 4-3.

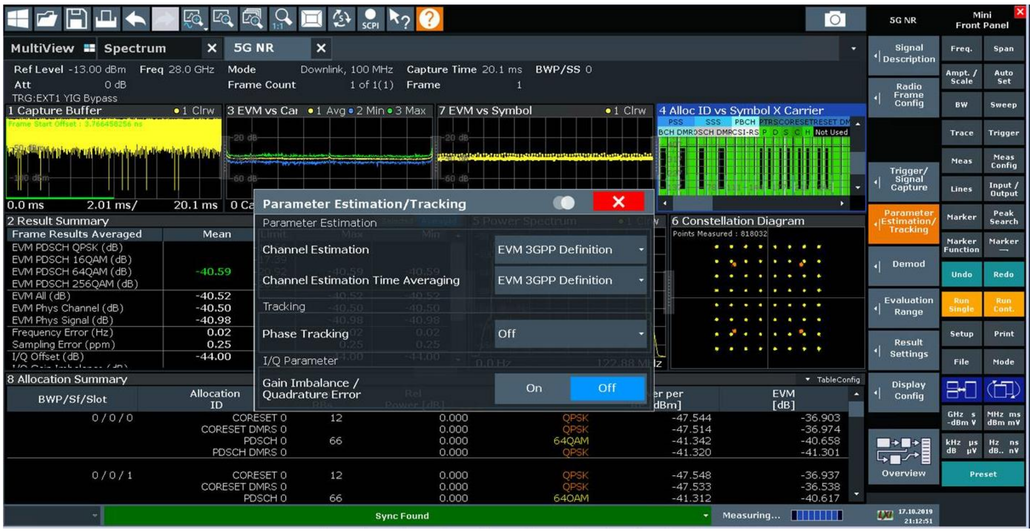


Fig. 4-3: EVM measurement with no PTRS active and Phase tracking switched off on FSW

The signal in this example is almost ideal as the signal generator is connected to the analyzer. There is actually nothing to compensate for. The using the SMW it is possible to add phase noise to emulate a more realistic real world RF environment.

For simplicity, the pre-defined module ‘pll1’ is loaded and set the starting point for PSD to -55 dBc/Hz as shown in Fig. 4-4.

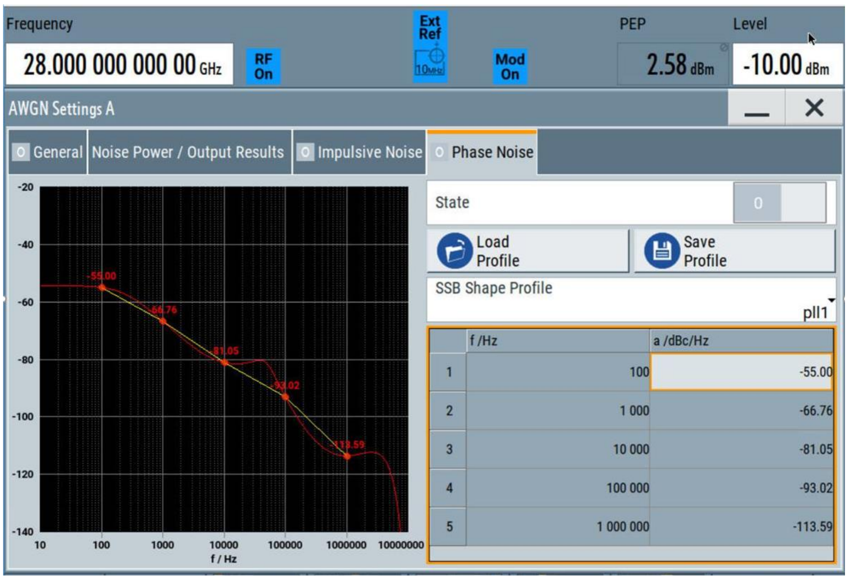


Fig. 4-4: Phase noise configuration on the SMW

With the phase noise emulation switched ON the EVM of the signal on FSW with phase tracking set to OFF or “EVM definition”, degrades to -26.15 dB as shown in Fig. 4-5.

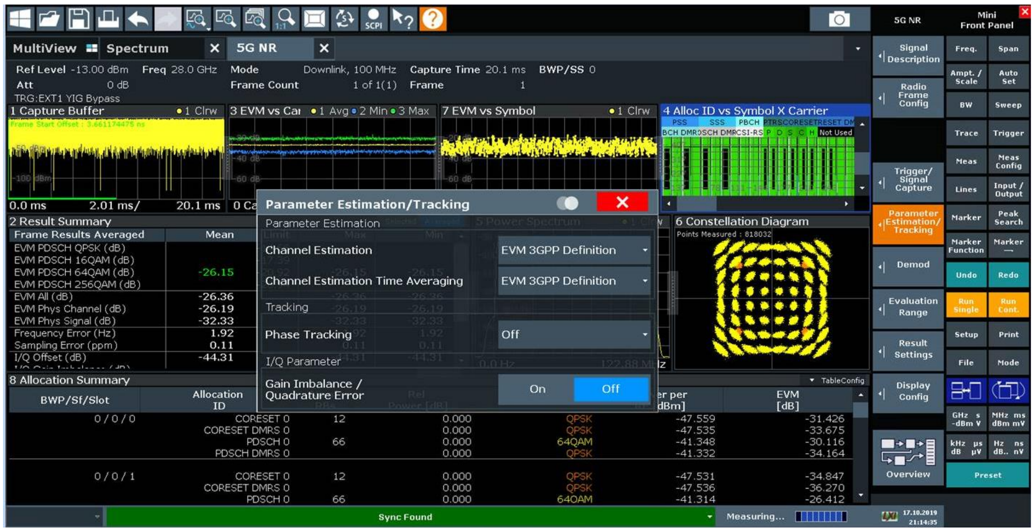


Fig. 4-5: EVM measurement with no PTRS active and emulated phase noise

The Phase tracking configured to “Pilot only” on the FSW does not improve the EVM performance of the signal as shown in Fig. 4-6:

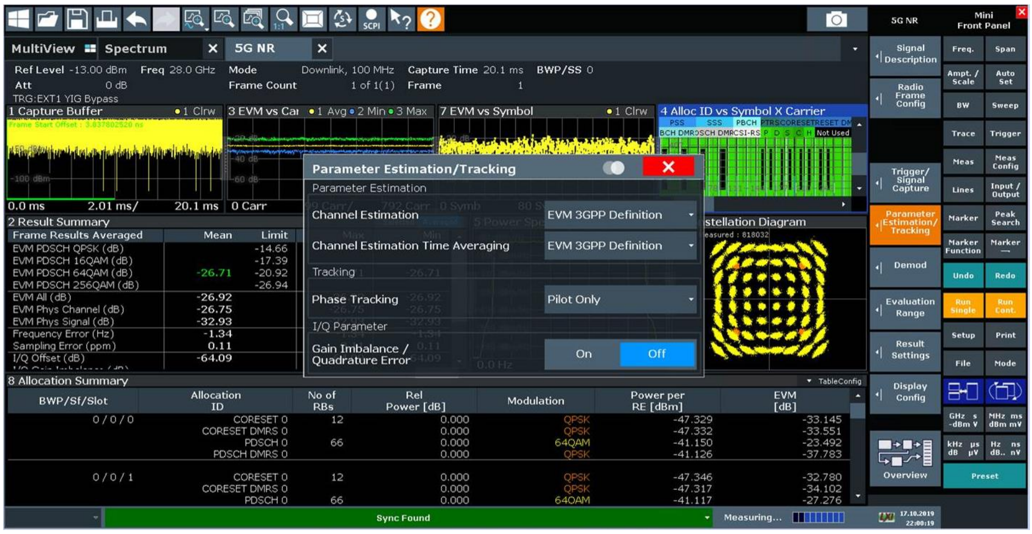


Fig. 4-6: EVM measurement with Phase tracking switch ON

In this case, “Pilot only” means to perform phase tracking based on the PDSCH DMRS as no other pilot signals are configured. As PDSCH DMRS is only in OFDM symbol, of course there is not much of a compensation possible. The compensation improves when signals are being used on a per symbol basis. That is why the situation always improves when the “Pilot & Payload”, because Payload is PDSCH present in this case in every symbol and thus compensation works much better.

To see performance of PTRS, it is now clear to compare “Pilot only” case when PDSCH DMRS and PTRS is active. Therefore, the PTRS is configured in every symbol and every second PRB on the SMW200A and FSW. As shown in Fig. 4-7, EVM improved by about 5 dB, -26.71 dB to -31.96 dB.

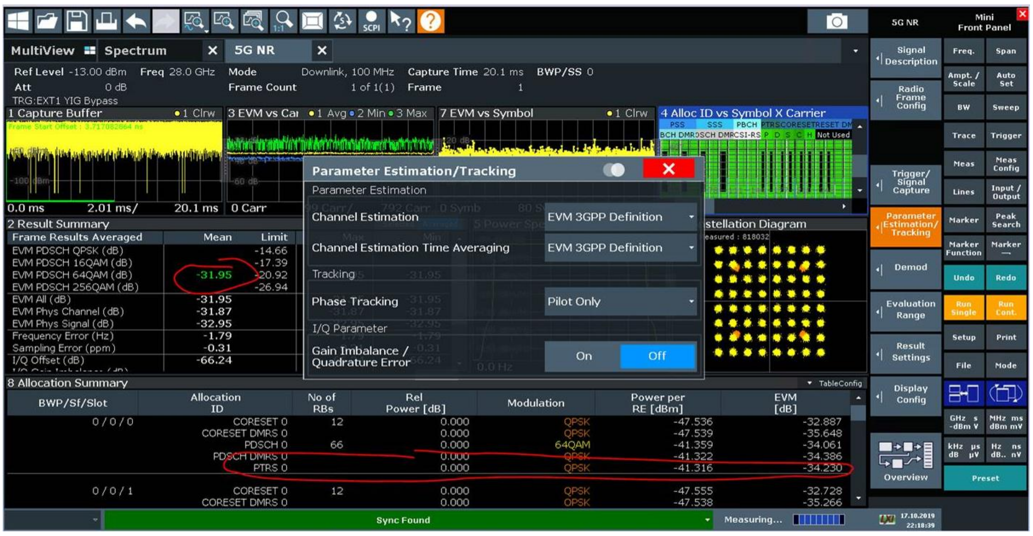


Fig. 4-7: EVM measurement with Phase tracking switch ON

To prove the theory about density in time, the PTRS is configured to less symbols, e.g. for every second OFDM symbol, the improvement is only about 2 dB compared to PDSCH DMRS only, as shown in Fig. 4-8.

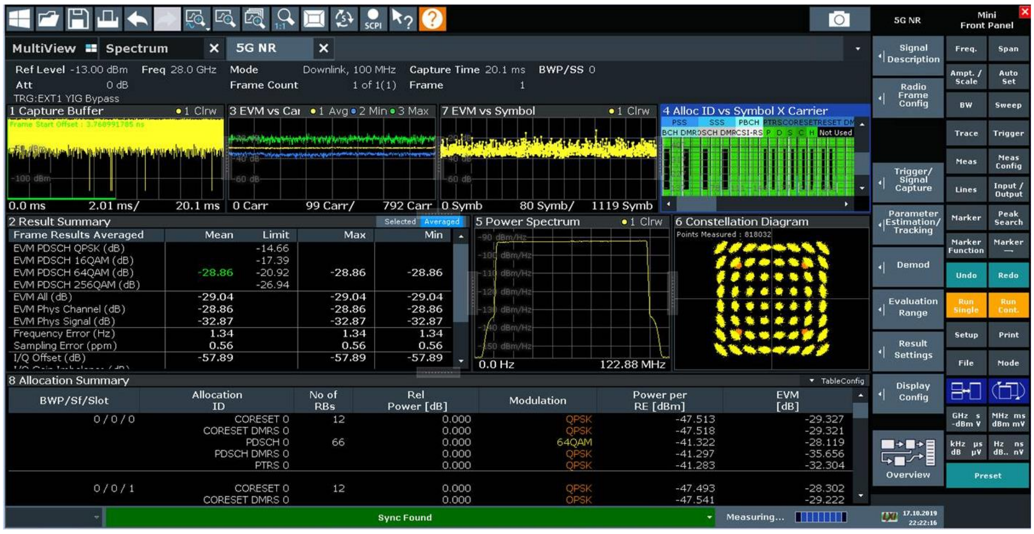


Fig. 4-8: EVM measurement with Phase tracking switch ON

For every fourth OFDM symbol, the improvement is only about 1 dB compared to PDSCH DMRS only, as shown in Fig. 4-9.

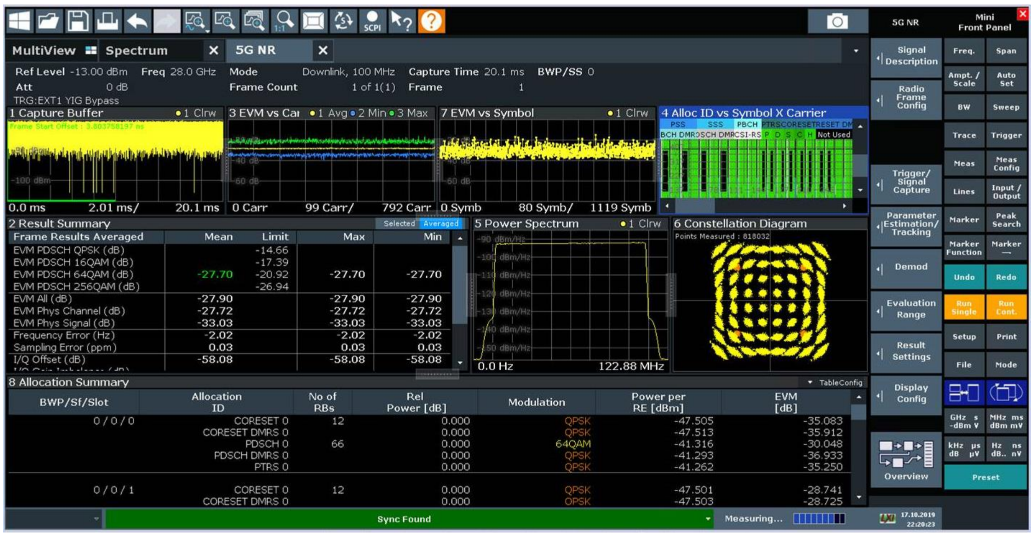


Fig. 4-9: EVM measurement with Phase tracking switch ON

Phase tracking and compensation on the FSW is implemented according to 38.104, Annex C.6 and 38.141-2, Annex L.6

4.2 DC sub carrier

The handling of the DC subcarrier is up to the receiver implementation. In LTE, it was specially notched out. For 5G NR, FSW offers three options of do nothing, ignore DC and compensate. In this application note, Ignore DC configuration in the Advanced Settings menu for Handling of Carrier Leakage was configured and is shown in Fig. 4-10.

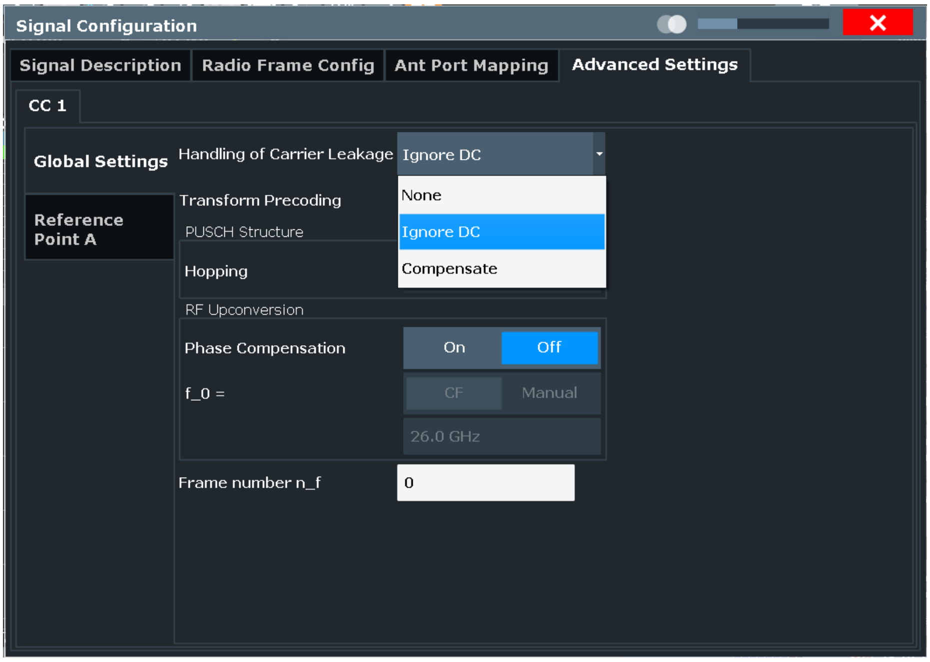


Fig. 4-10: Configuration of the Advanced Settings menu

4.3 IF overload, Optimized EVM and Crest Factor

In order to alleviate IF overload and optimize EVM, Auto Level and Auto EVM could be used as shown in Fig. 4-11 .

The Auto level automatically determines the ideal reference level. The automatic leveling process measures the signal and defines the ideal reference signal for the measured signal. Auto Level will also optimize RF attenuation.

The Auto EVM adjusts the amplitude settings to achieve the optimal EVM using the maximum dynamic range. This routine measure the signal several times at various levels to achieve the best results.

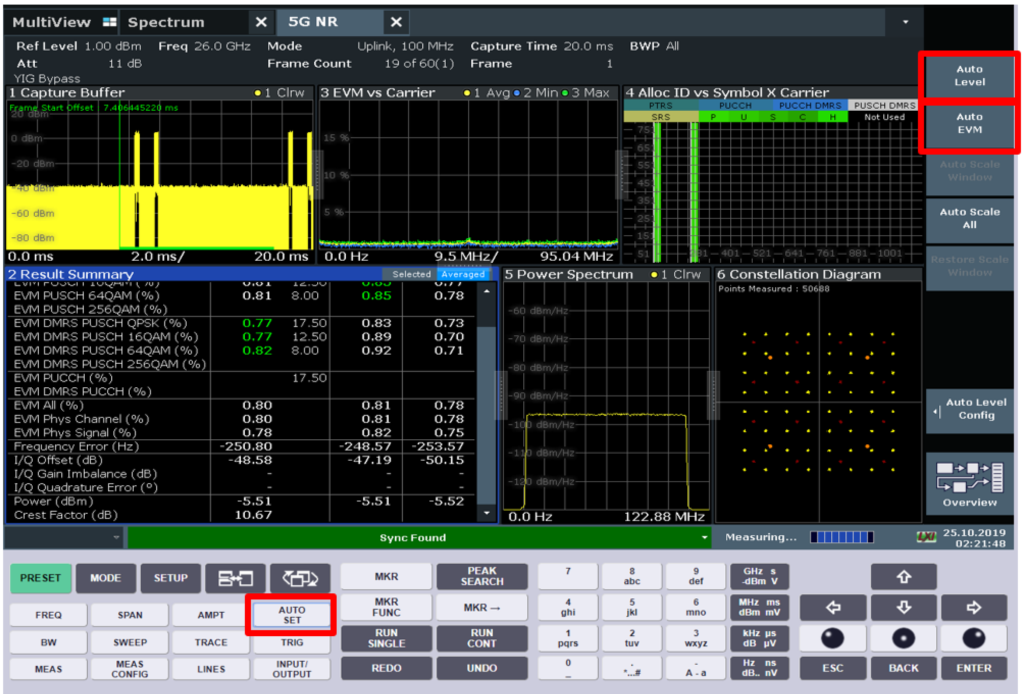


Fig. 4-11: Auto Set configuration window

4.4 Capture time and Tigger setting

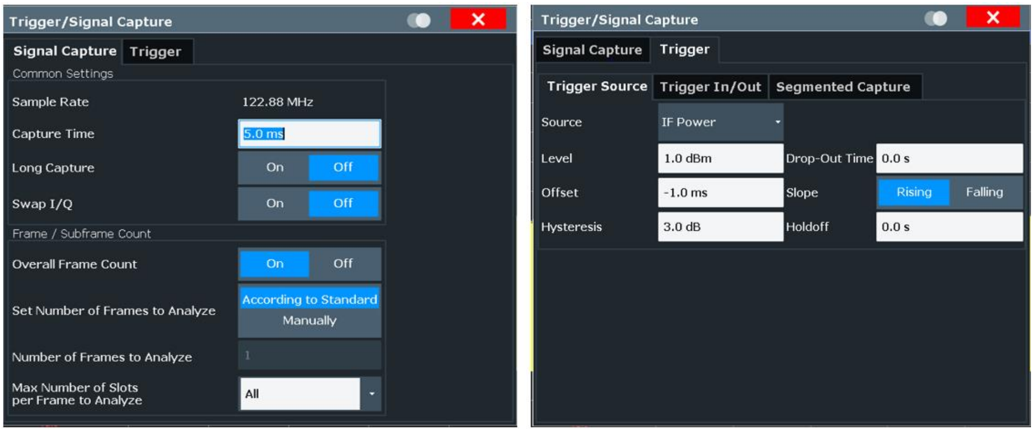


Fig. 4-12: Signal and Trigger configuration window

In order to analyze the signal faster and only the part of the signal that is of interest, i.e. for signal capturing length less than the default 20.1ms, the settings can be configured for the Trigger and Signal capture window as shown in Fig. 4-12. The capture time can be set as desired (for example here is set to 5 ms). The trigger source is set as IF power and the corresponding IF power lever and time offset is configured as shown.

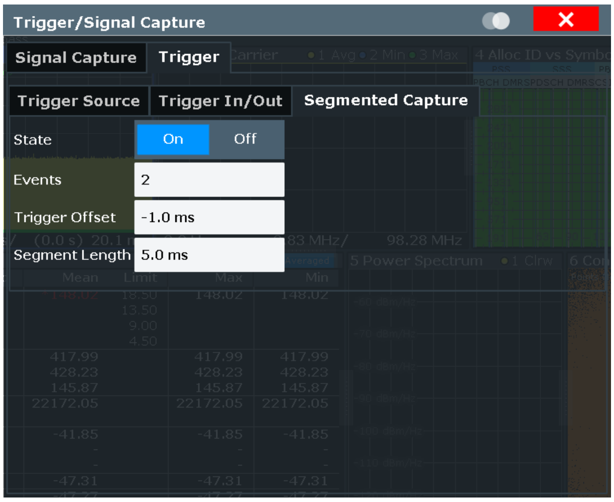


Fig. 4-13: Segmented Capture configuration window

In order to measure and analyze a particular section of the frame, the segmented capture window can be configured and the segment length can be predefined and analyzed. The settings are shown in Fig. 4-13 and segment length of 5ms is shown in the example.

4.5 Parameter/ Estimation Tracking

In order to optimize and compensate measurement results for various errors, the parameter/estimation tracking feature can be used. The channel estimation can be configured for Pilot and payload, linear interpolation or according to the 3GPP EVM specification. As a measure of good practice for the channel estimation setting, the pilot and payload can be configured, which performs the channel estimation by examining both the reference signal and the payload resource elements. The linear interpolation can also be configured but in this case, the channel estimation is performed by interpolating the missing information.

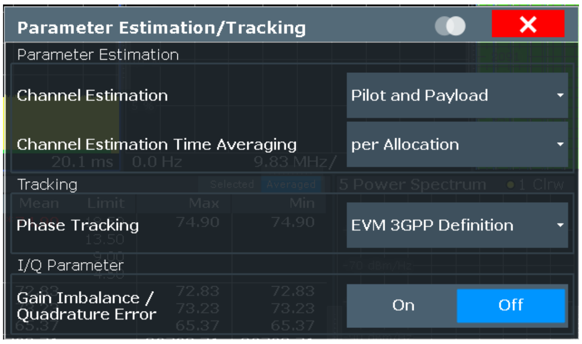


Fig. 4-14: Parameter Estimation/ Tracking menu configuration

Fig. 4-14 shows the tracking configuration menu. The channel estimation time averaging can be performed for each allocation or every 10ms according to the 3GPP definition. For phase tracking, there is a possibility of choosing between 3 options. Phase tracking with "pilot only" will enable phase estimation using only the reference signal. The "Pilot and Payload" option uses the reference and the payload resource elements for phase estimation and lastly the 3GPP EVM Definition is according to the 3GPP specification.

4.6 Slot Allocation and Slot format

5G NR supports FDD and TDD in the duplex mode.

Slot formats are a fundamentally new concept in 5G NR. Unlike LTE, 5G NR doesnot have defined UL-DL configurations. In 5G NR there are 62 different slot formats defined. They help to realize different downlink and uplink allocations, particularly in time division duplex (TDD) mode.

Based on an example with 120 kHz subcarrier spacing, the chapter explains some unique characteristics compared to TD-LTE, such as the mismatch between required periodicity and subframe duration.

FDD uses only slot format "0" (downlink) or slot format "1" (uplink) which is dependent on direction. In case of TDD, the information is provided via RRC signaling or by Downlink Control Information DCI (Slot format indicator) transmitted on PDCCH.

As an example, for FR2 TDD-UL-DL configuration,

- SCS: 120KHz, Periodicity (ms): 1.25, NrDL slots: 7, NrDL Sym: 6, NrUL slots: 2 and NrULSym: 4

Based on this information,

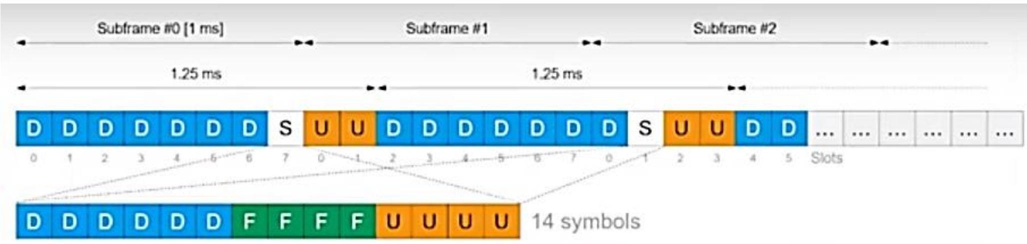


Fig. 4-15: Slot allocation for FR2 TDD-UL-DL 5G NR configuration

A slot is 14 symbols and Subframe is 1ms. However, the periodicity is 1.25ms. This means the subframe boundaries and periodicity do not align and makes signal configuration more challenging. The flexible special slot in Fig. 4-15 contains 6 DL symbols, followed by 4 flexible symbols and 4 UL symbols.

4.7 Generate and analyze 5G NR TDD signals

In this chapter, the generation of the uplink portion of a 5G NR TDD signal is explained. The 5G NR signal uses a subcarrier spacing of 120 kHz by applying a periodicity of 1.25 ms and is generated with the SMW vector signal generator. Detailed signal analysis is performed using the FSW signal and spectrum analyzer. Fig. 4-16 shows the TDD frame structure.

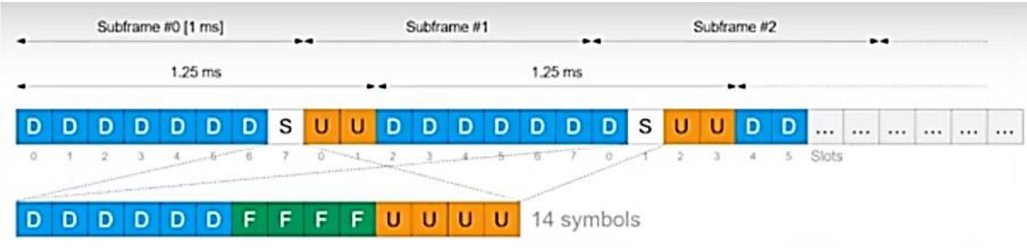


Fig. 4-16: 5G NR Uplink TDD frame structure

The configuration steps are explained for setting up the frame structure shown in Fig. 4-16. The frame comprises of 2 subframes. In the first subframes, slot #7 is special slot with 6 DL symbols, 4 blank symbols and 4 UL symbols. The second sub frame has 2 UL slots (slot #2 & #3) and slot #1 is a special flexible slot.

4.7.1 Signal Generator configuration

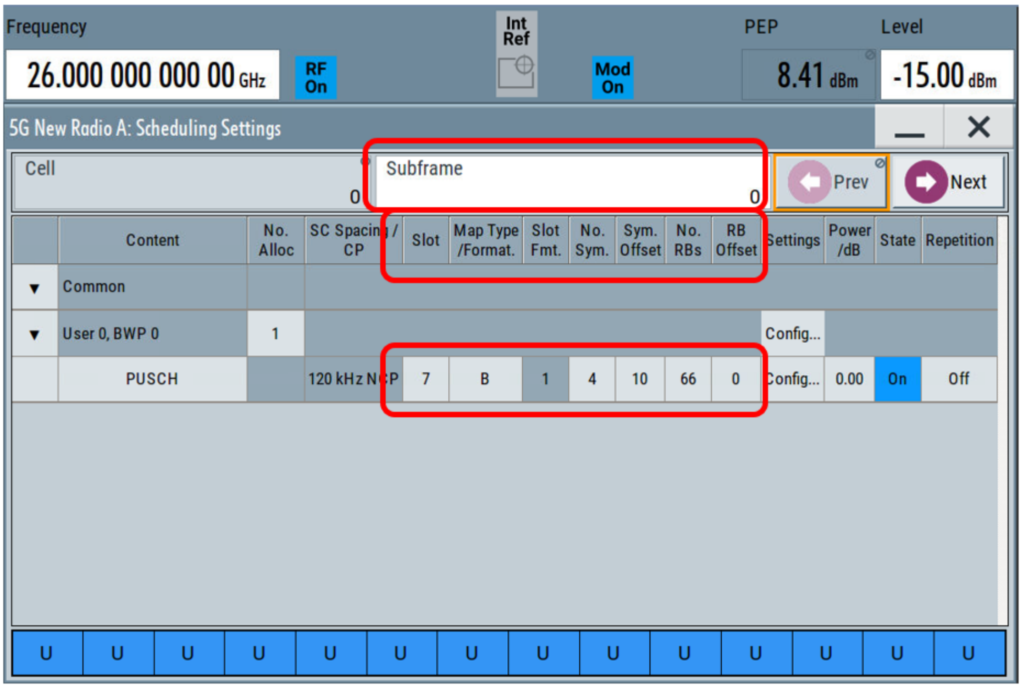


Fig. 4-17: Subframe 0 configuration for 5G NR TDD UL

Fig. 4-17 shows the signal generation configuration of the first subframe. In this case, the first 7 DL slots are left blank. Slot #7 is configured with Map format B. Out of the 14 symbols in slot #8, the first 10 symbols are left blank and 4 UL symbols are configured with a symbol offset of 10 symbols.

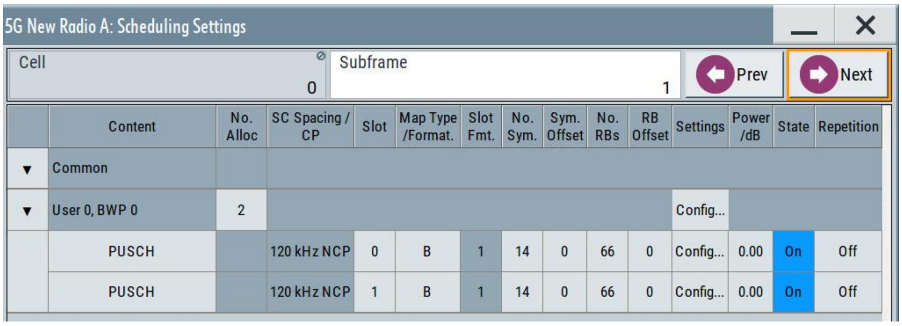


Fig. 4-18: Subframe 1 configuration for 5G NR TDD UL

In the second subframe, the first two slots are UL and the rest 6 slots are all DL slots.

In this case, two PUSCH allocations are configured. Slot 0 and slot 1 are configured to have Map format B, No of symbol 14 and symbol Offset 0. The modulation of the UL

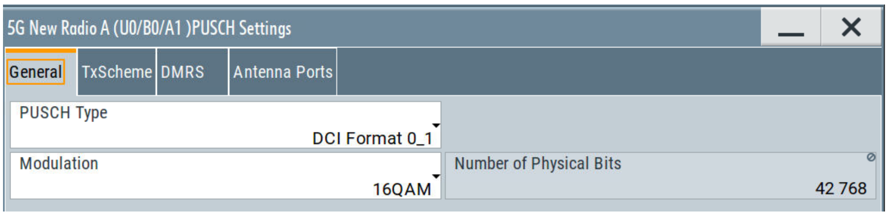


Fig. 4-19: Modulation configuration for 5G NR TDD UL signal

can be configured as shown in Fig. 4-19. For subframe 1, the two PUSCH UL slots are configured with 16QAM modulation scheme.

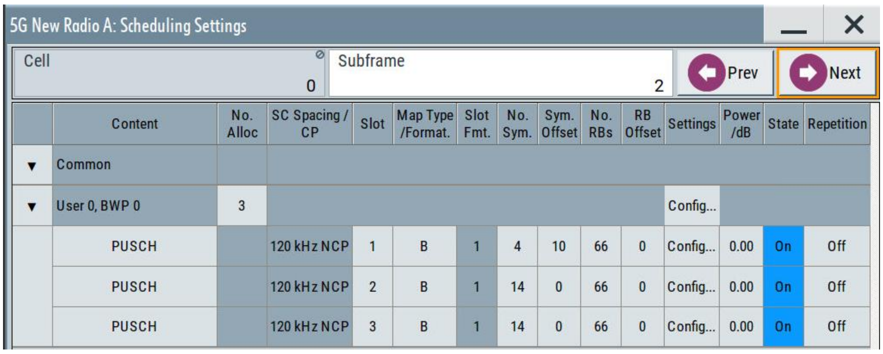


Fig. 4-20: Subframe 2 configuration for 5G NR TDD UL

Fig. 4-20 shows the configuration of the subframe 2. Here there are 3 PUSCH allocations. Slot 0 is a special slot with 4 UL symbols at 10 symbol offset. Slot 1 and 2 are 14 symbol UL with no symbol offsets.

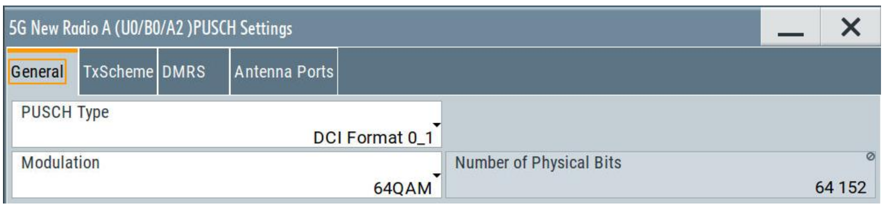


Fig. 4-21: Modulation configuration for 5G NR TDD UL signal

Fig. 4-21 shows the modulation configuration of subframe 2. The 2 UL slots are configured with 64QAM modulation.

4.7.2 Spectrum Analyzer Configuration

For the slot configuration on the FSW, each slot allocation needs to be individually configure. 3 subframes have a total of 24 slot allocations. The special slots are numbered 8 and 18. The UL slots are numbered 9, 10, 19 and 20.

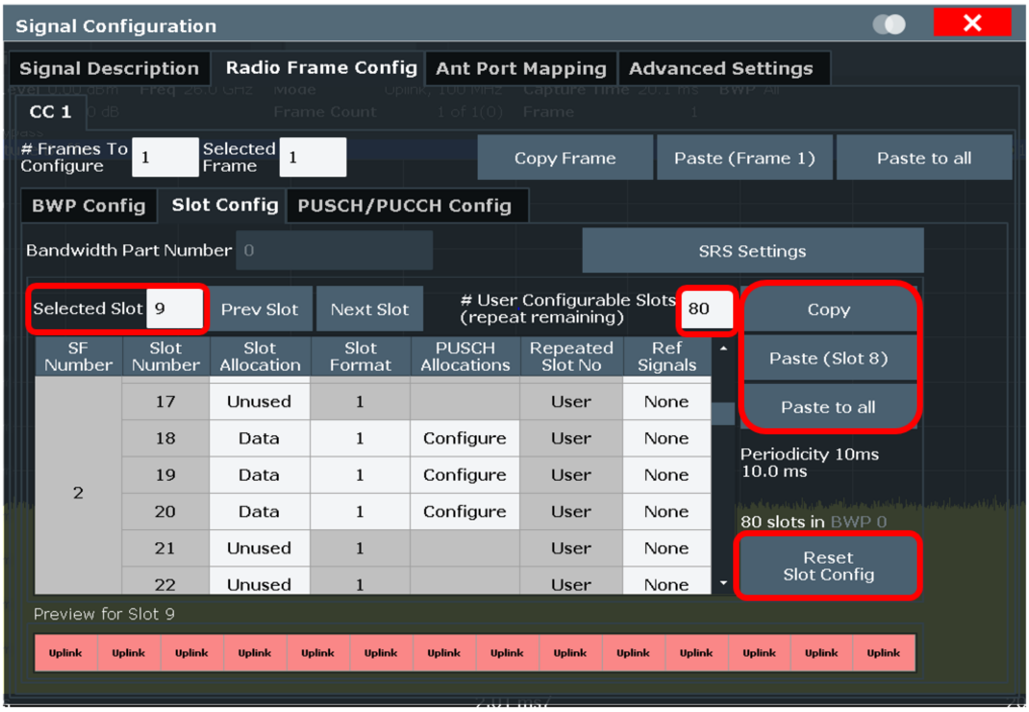


Fig. 4-22: Radio Frame Slot configuration for TDD UL

Fig. 4-22 shows the slot configuration for the TDD UL 5G NR signal analysis on the FSW. In the slot configuration menu,

- First of all, reset Slot config
- Set 80 User Configurable Slot (This value needs to be 24 or higher)
- Set Slot 0 as unused and copy & paste to all of the 8 slots.
- Now configure only the Special and UL slots individually with data allocation
- Slot 8, 18 are special slot and Slot 9, 10, 19, 20 are UL slots

Configuring the special slots, Slot #7

- Hit Configure on the PUSCH allocation column (shown in Fig. 4-23)
- Next in the configuration window , go into enhanced setting
- Select the DMRS Mapping format: PUSCH start (B) as shown in Fig. 4-24

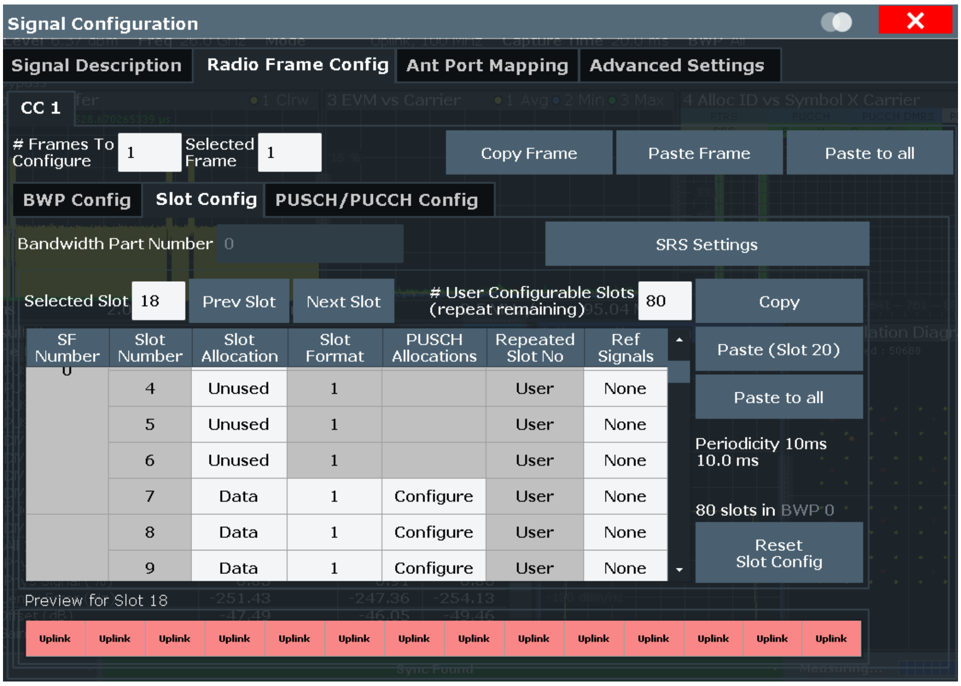


Fig. 4-23: 5G NR TDD UL slot configuration

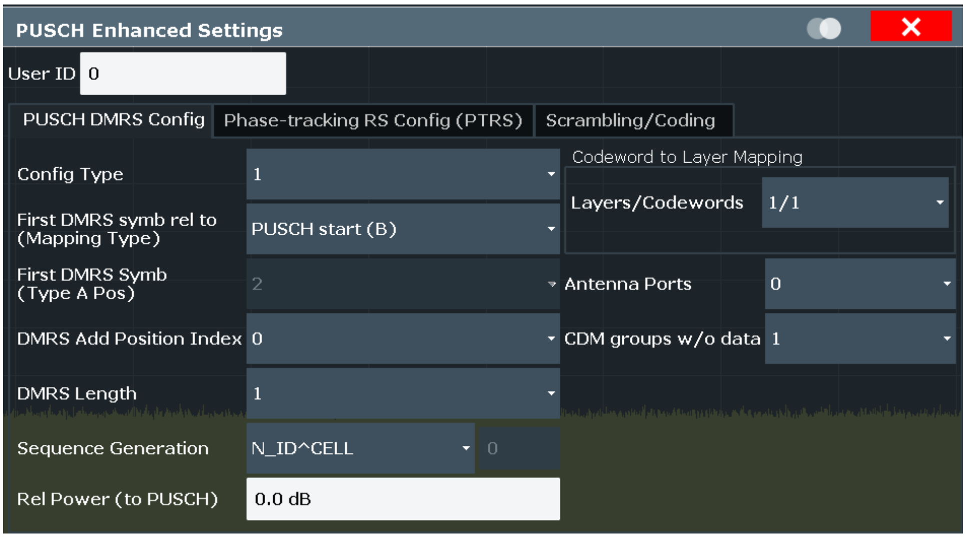


Fig. 4-24: PUSCH enhanced settings configuration window

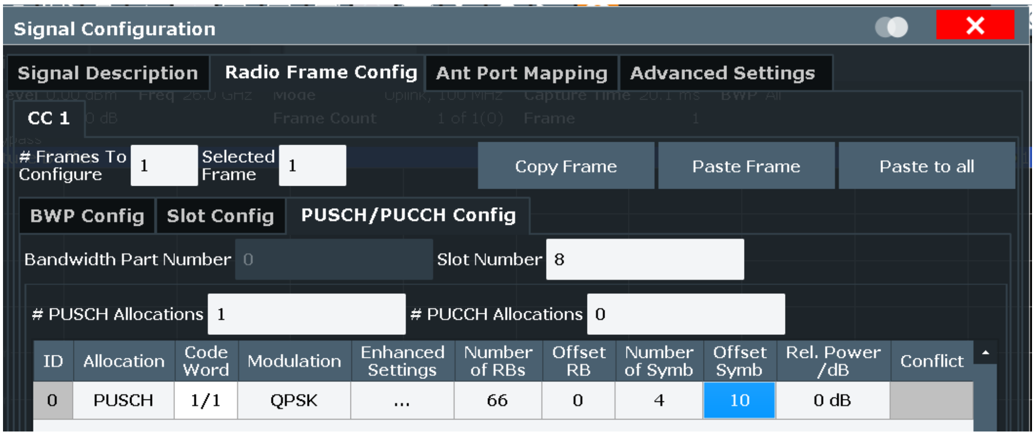


Fig. 4-25: PUSCH/ PUCCH configuration window for the special slot

Fig. 4-25 shows the PUSCH configuration for the special slot.

- Modulation: QPSK
- # of symbol: 4
- Offset Symbol: 10
- Copy and paste slot 8 to slot 18 as shown in Fig. 4-22

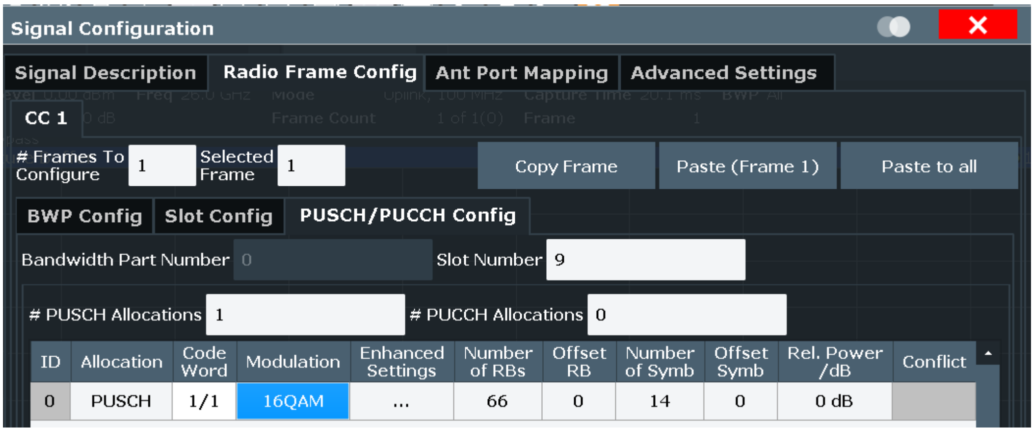


Fig. 4-26: PUSCH/ PUCCH configuration window for the UL slot (9 and 10)

Fig. 4-26 shows the PUSCH configuration for the UL slot (9 and 10).

- Modulation: 16QAM
- # of symbol: 4
- Offset Symbol: 10
- Copy and paste slot 9 to slot 10 as shown in Fig. 4-22

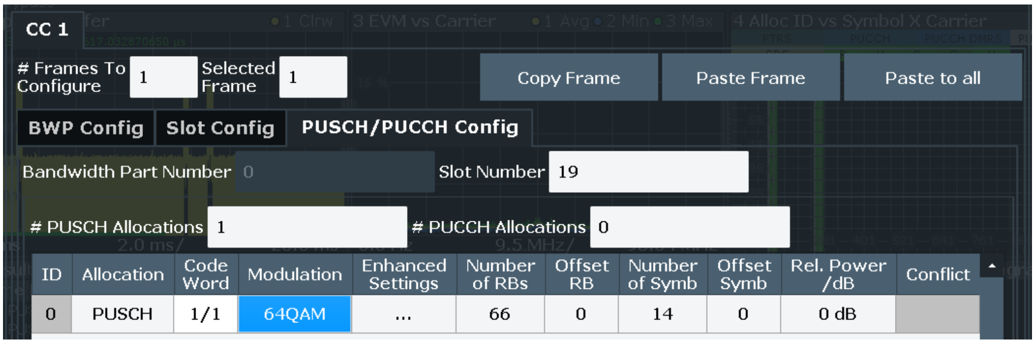


Fig. 4-27: PUSCH/ PUCCH configuration window for the UL slot (19 and 20)

Fig. 4-27 shows the PUSCH configuration for the UL slot (9 and 10).

- Modulation: 64QAM
- # of symbol: 4
- Offset Symbol: 10
- Copy and paste slot 19 to slot 20 as shown in Fig. 4-22

The spectrum analyzer is now properly configured to measure the complex 5G NR TDD UL signal as described at the start of this chapter. Fig. 4-28 shows the measurement results of the signal at 26GHz. The EVM of the QPSK slots are 0.85%, 16QAM signals are 0.87% and 64QAM signals are 0.87%.

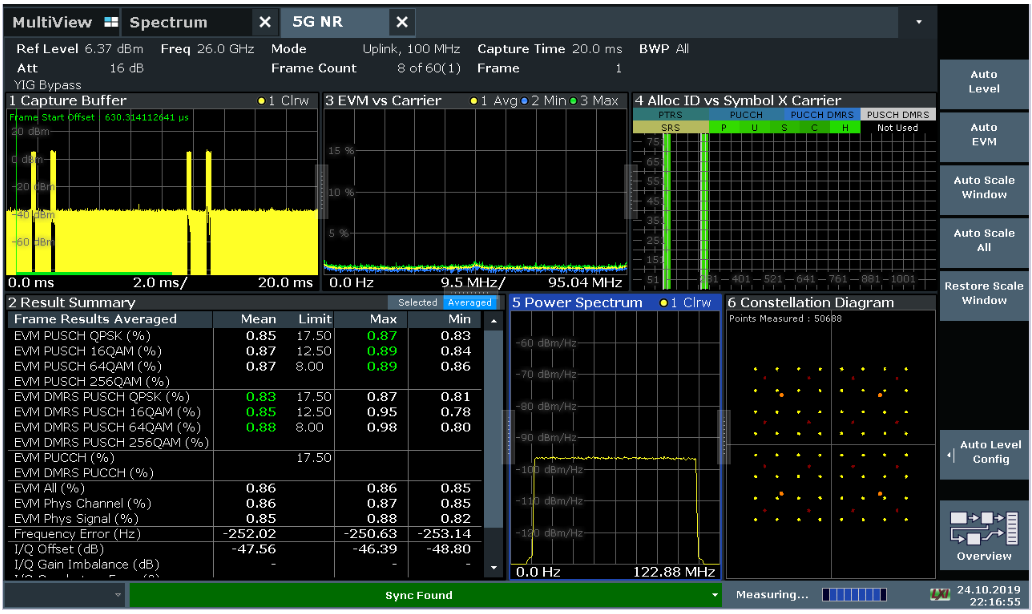


Fig. 4-28: Signal quality Measurement results of 5G NR TDD UL signal at 26GHz

4.8 Evaluation Range and Display setting

In order to analyze with higher granularity and look at a specific part of the 5G NR signal, the FSW offers the flexibility to analyze only the segment of interest. Fig. 4-29 shows the configuration window of the Evaluation Range. From this menu, any specific BWP, Subframe, Slot, modulation type or Symbol can be selected for analysis. Thus making the measurement faster.

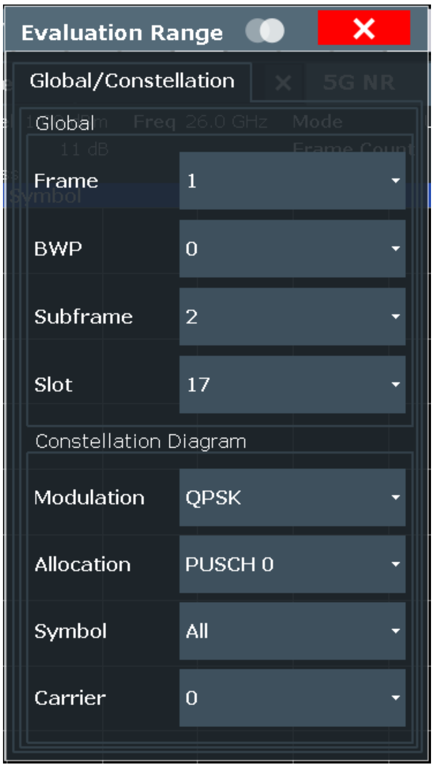


Fig. 4-29: Configuration Window of the Evaluation Range on the FSW

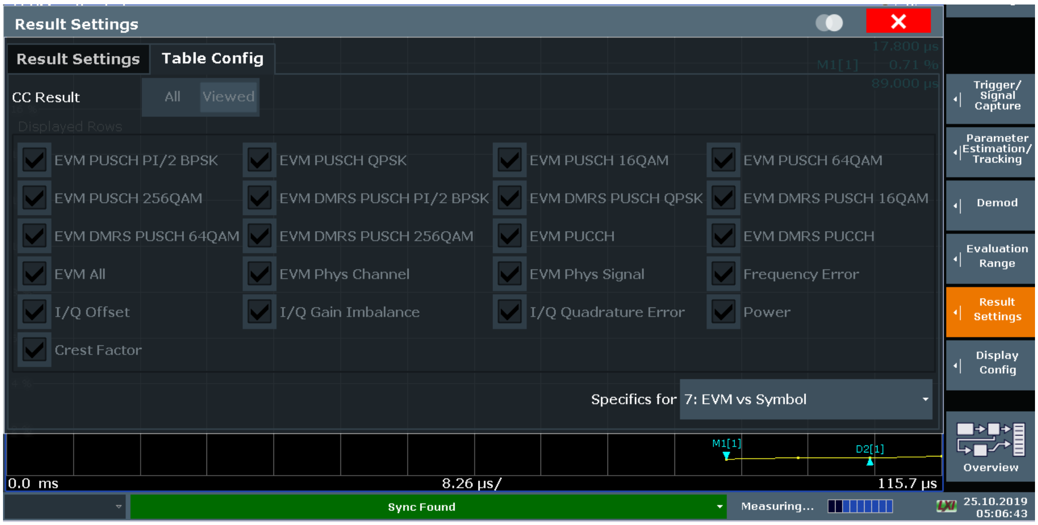


Fig. 4-30: Result setting configuration menu for EVM vs symbol measurements

Fig. 4-30 shows the configuration window of the Results settings menu.

Fig. 4-31: EVM Vs Symbol measurement for a specific part of the signal

Fig. 4-31 shows the EVM VS symbol measurement results of only slot 19 in subframe 2 with 64QAM modulation.

Fig. 4-32: EVM Vs Symbol measurement for a specific part of the signal

Fig. 4-32 shows the EVM VS symbol measurement results of only slot 18 in subframe 2 with 16QAM modulation.

5 Ordering Information

Designation	Type	Order No.
Signal- and Spectrum Analyzer 2 Hz to 43 GHz	R&S®FSW43	1331.5003.43
OCXO, precision frequency reference	R&S®FSW-B4	1313.0703.02
Resolution bandwidth >10MHz (HW opt.)	R&S®FSW-B8	1313.2464.02
High pass filter (SL)	R&S®FSW-B13	1313.0761.02
Digital Baseband Interface (SL)	R&S®FSW-B17	1313.0784.02
SSD 128 GB, with FW, for IPC11 CPU board, Win 10	R&S®FSW-B18	1313.0790.10
RF preamplifier, 30dB, 100kHz to 43GHz	R&S®FSW-B24	1313.0832.43
Extension to 160 MHz signal analysis bandwidth	R&S®FSW-B160	1325.4850.14
3GPP 5G-NR DL Measurements	R&S®FSW-K144	1338.3606.02
3GPP 5G-NR UL Measurements	R&S®FSW-K145	1338.3612.02
Vector signal generator, base unit	R&S®SMW200A	1412.0000.02
Frequency range: 100kHz to 40GHz, for RF path A	R&S®SMW-B140	1413.0604.02
Frequency range: 100 kHz to 7. 5 GHz	R&S®SMW-B207	1434.7350.02
Baseband main module, one I/Q path to RF section (	R&S®SMW-B13	1413.2807.02
Baseband generator with realtime coder and ARB	R&S®SMW-B10	1413.1200.02
5G New Radio	R&S®SMW-K144	1414.4990.02
VSE BASIC EDITIION (PR)	VSE	1345.1011.06
License dongle for PC software	FSPC	1310.0002.03
3GPP 5G-NR DL/UL Measurements	VSE-K144	1309.9574.06

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