5G Boot Camp

PART 3:
7 KEY MEASUREMENT CHALLENGES AND CASE STUDIES

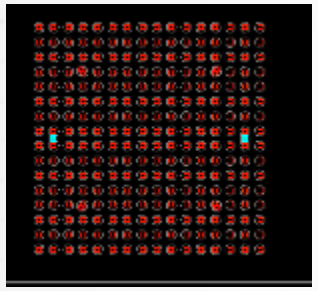
Keysight Technologies

AUG 2019

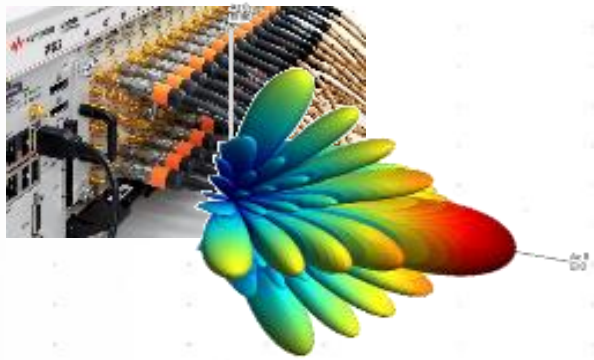
Philip Chang

7 Key Measurement Challenges

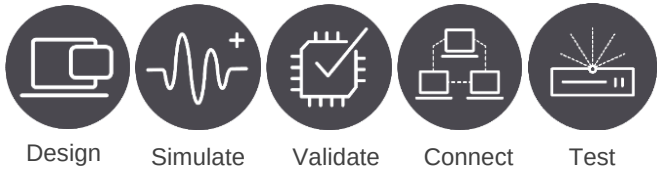
Signal Quality
mmW, Waveform, Fidelity



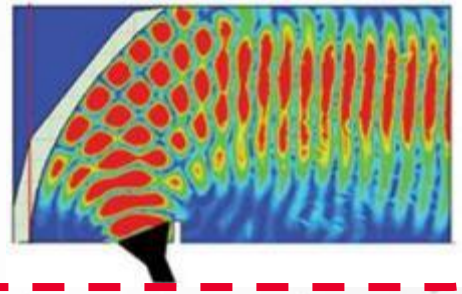
Lots of Channels
MIMO/Beamforming



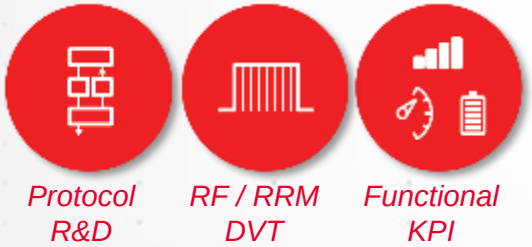
Connect Design & Test
Components, Systems



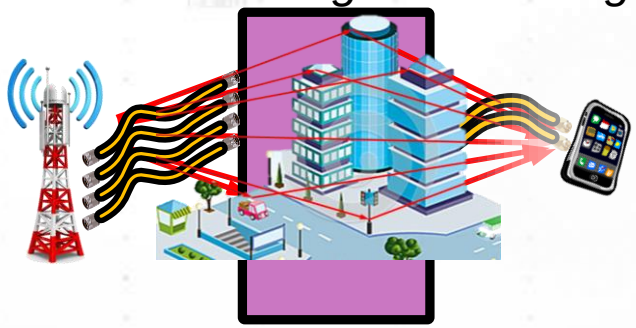
Life Beyond Connectors
Over-the-Air



Performance on the Network
Network Emulation



Channel
Characterizing & Emulating



Field Testing and Drive Test

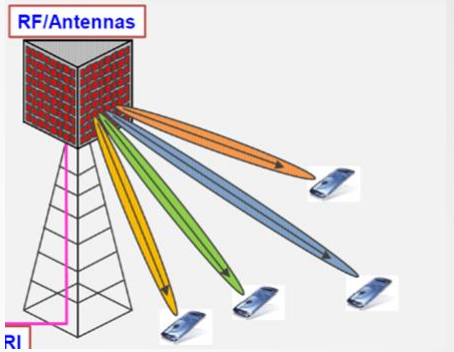
3GPP UE & gNB Tx Conformance Test requirement docs

3GPP NR UE Tx test requirement	Minimum Requirement (2018-06)	Conformance Requirement (2018-09 draft)*	UE
Part 1: Range 1 Standalone	TS38.101-1 v.15.2.0	TS38.521-1 v.1.0.1	FR1, Conducted
Part 2: Range 2 Standalone	TS38.101-2 v.15.2.0	TS38.521-2 v.1.0.0	FR2, Radiated
Part 3: Range 1 and 2 Interworking operation with other radios	TS38.101-3 v.15.2.0	TS38.521-3 v.1.0.0	FR1 and FR2 CA, EN-DC** FR1 Conducted, FR2 Radiated
(*) v.1.0.x is still draft or pre-release status. (Official version should be v.15.x.x) (**) EN-DC: E-UTRA and NR Dual Connectivity			

3GPP NR BTS Tx test requirement	Minimum Requirement (2018-06)	Conformance Requirement (2018-09 draft)*	gNB
Part 1: Conducted testing	TS38.104 v.15.2.0	TS38.141-1 v.1.0.0	FR1, Conducted
Part 2: Radiated testing		TS38.141-2 v.1.0.0	FR1 and FR2, Radiated
(*) v.1.0.x is still draft or pre-release status. (Official version should be v.15.x.x)			

Life Beyond Connectors

Active Antenna System (AAS)



Free-space Path Loss

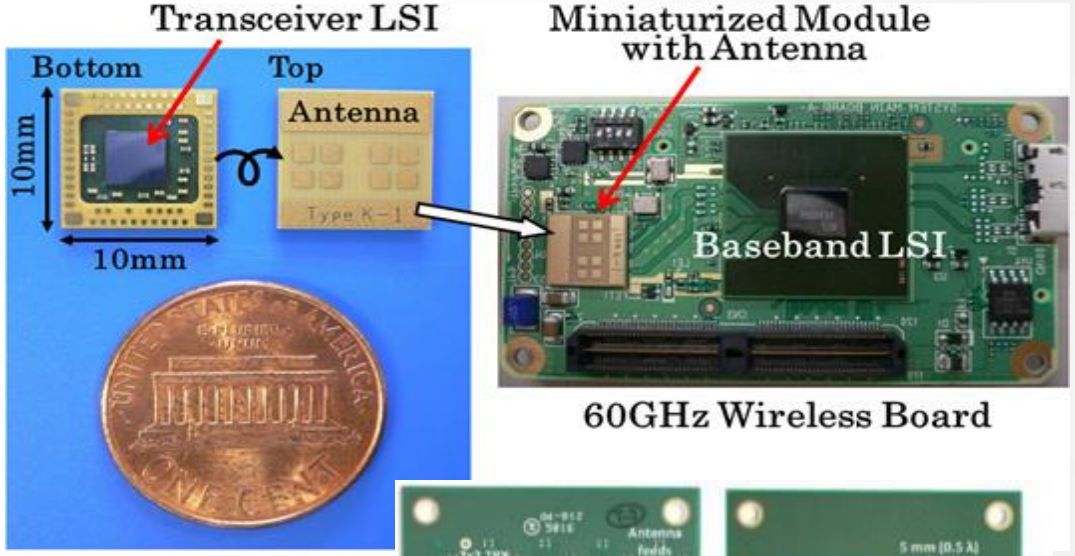
$$Power_{RX} = Power_{TX} + AntGain_{RX} + AntGain_{TX} - 20log_{10}(4\pi R) - 20log_{10}\left(\frac{f}{c}\right)$$

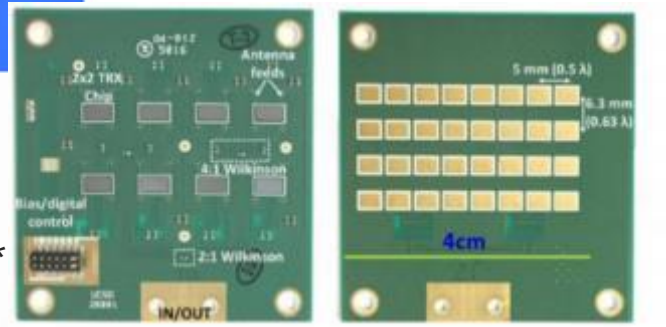
The Good News:

- Higher frequency antenna elements are smaller
- Easier to assemble into electronically steered arrays
- Reduced interference. Energy goes where it's needed
- Improve performance in dense crowds (5G goal)
- Higher frequencies ⟶ wider bandwidths: faster (5G goal)

Challenges:

- Antenna are directional
- Increased complexity with more elements, very small for probing or conducted test
- Multiple antenna arrays required for spherical coverage
- Traditional cabled test methods obsolete – **OTA needed**





28 GHz RFIC*

* Image courtesy of Professor G. Rebeiz of U of Ca, SD

Far-Field Test Challenges with mmWaves

From Keysight White Paper: OTA Test for Millimeter-Wave 5G NR Devices and Systems

LONGER FAR-FIELD AND HIGHER PATH LOSS

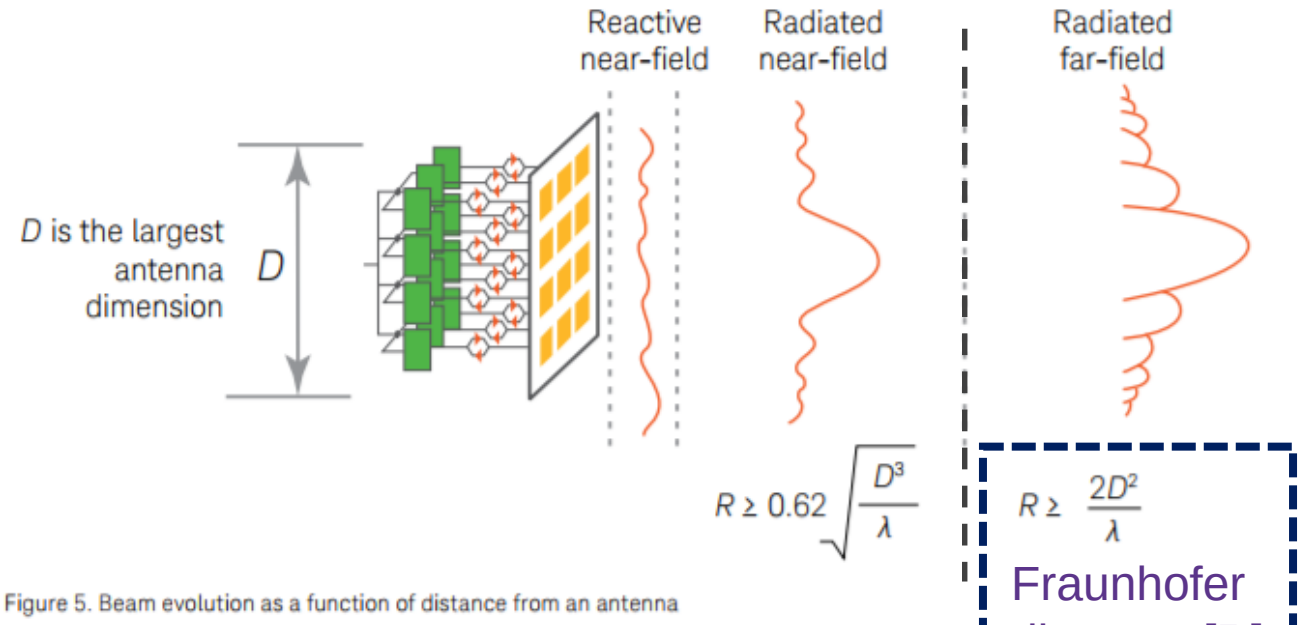
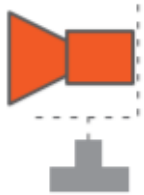


Figure 5. Beam evolution as a function of distance from an antenna

Ideal Plane wave is at ∞



What about Path Loss?

Friis Transmission Equation

$$\frac{P_r}{P_t} = \left(\frac{c}{4\pi R f}\right)^2 G_t G_r$$

Path loss proportional to R^2

	Far-Field Distance (m)		
D (mm)	28 GHz	39 GHz	60 GHz
50	0.47	0.65	1
100	1.9	2.6	4
150	4.2	5.9	9
200	7.5	10.4	16
300	16.8	23.4	36.0

What is D?

Fastback Networks V1000

Facebook Terragraph

DFF= $2D^2/\lambda$

DFF= $2 f D^2/c$

D ↑ → DFF ↑

f ↑ → DFF ↑

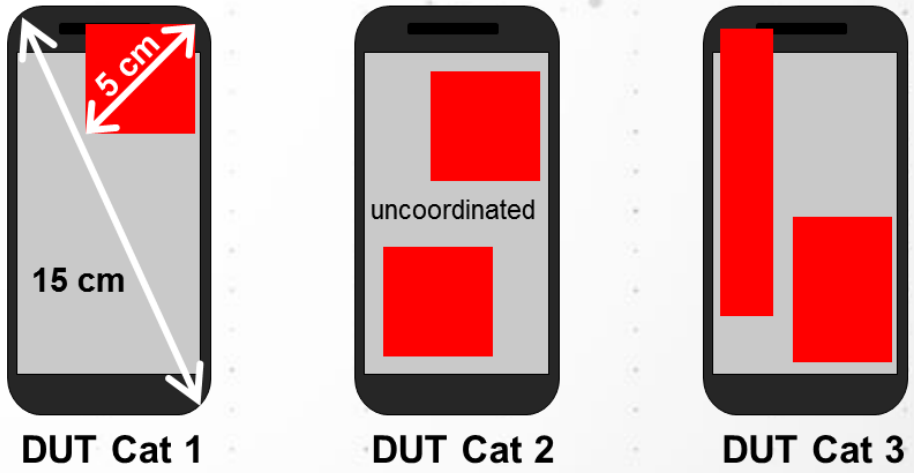
FR2 Measurement Challenges

HOW FAR IS THE FAR FIELD?

D (cm)	Freq. (GHz)	Far field (m)	Path Loss (dB)	Freq. (GHz)	Far field (m)	Path Loss (dB)	Freq. (GHz)	Far field (m)	Path Loss (dB)
5	2	0.03	8.93	28	0.47	54.77	43	0.72	62.23
10	2	0.13	20.97	28	1.87	[illegible]	43	2.87	[illegible]
15	2	0.30	28.01	28	4.20	73.86	43	6.45	81.31
20	2	0.53	33.01	28	7.47	78.86	43	11.47	86.31
30	2	1.20	40.05	28	16.80	85.90	43	25.80	93.35

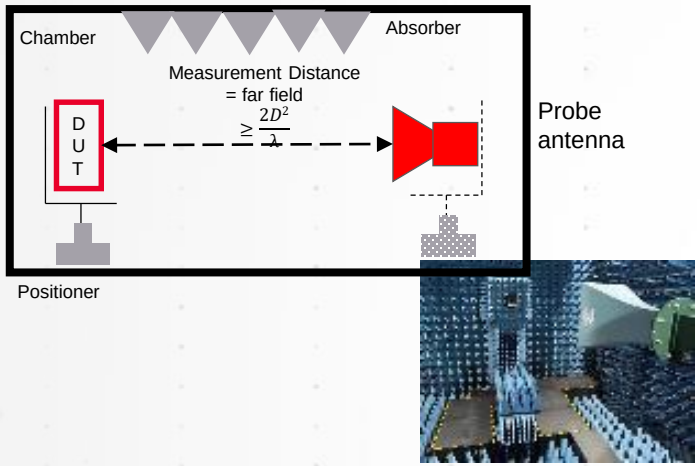
TR 38.810 Table 5.3-1: DUT Categories

DUT category	Description
Category 1	Maximum one antenna panel with D ≤ 5 cm illuminated by test signal at any one time
Category 2	More than one antenna panel D ≤ 5 cm without phase coherency between panels illuminated at any one time
Category 3	Any phase coherent antenna panel of any size (e.g. sparse array)



Common OTA Test Methods

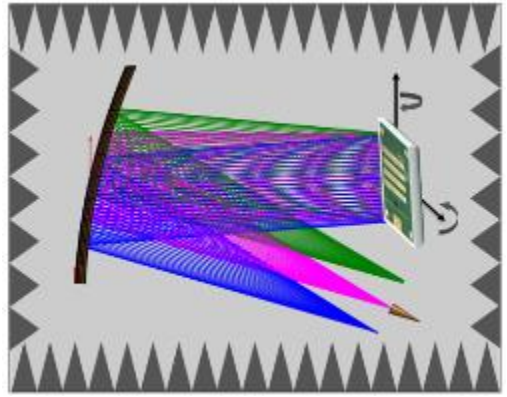
Direct Far Field



- ✓ Simple design, mature
- ✓ Measurement flexibility;
  - ✓ Antenna beam pattern characterization
  - ✓ Beamforming/beamsteering validation
  - ✓ RF parametric tests (if S/N high enough)
- ✓ How devices operate

- × Subject to higher path loss
- × Can get very large for smaller devices at mmWave frequencies
- × Can be slow (mechanical motion), expensive

Indirect Far Field



- ✓ Measurement flexibility
  - ✓ Antenna beam pattern characterization
  - ✓ Beamforming/beamsteering validation
  - ✓ RF parametric tests
  - ✓ End-to-End performance (signaling)
- ✓ Small footprint, even for larger devices
- ✓ Lower path loss, better accuracy

- × Slow (limited by mechanical motion)
- × Expensive (slightly more than DFF)

Near-Field Scanning

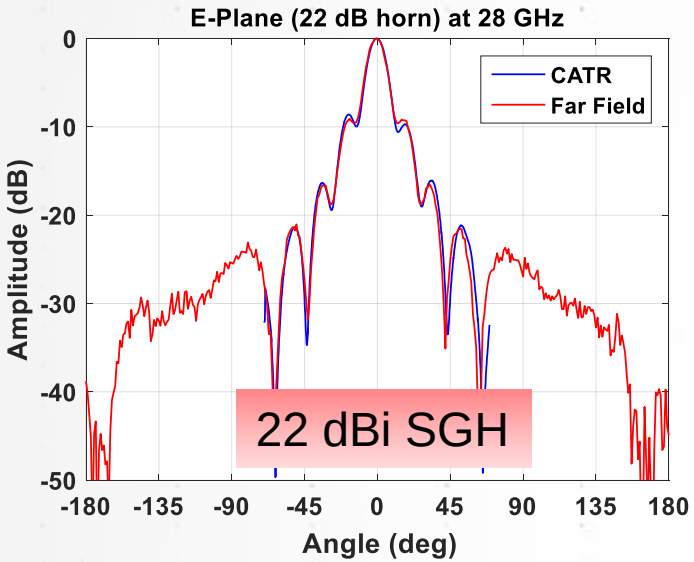
Image courtesy of NSI-MI

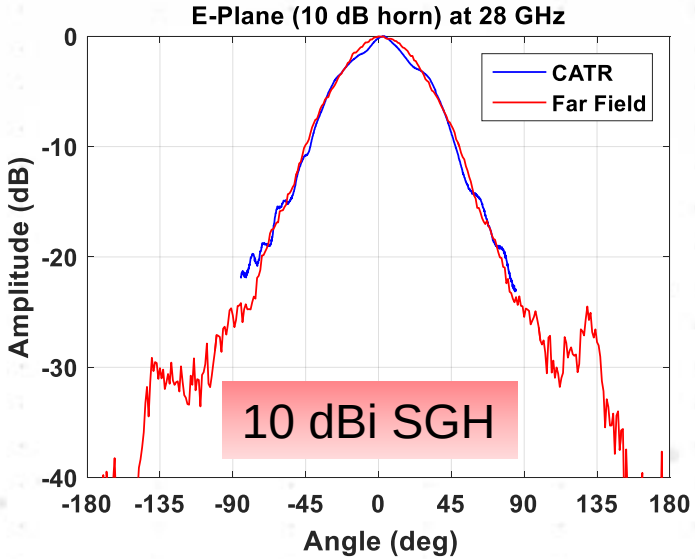
- ✓ Small, lower cost (at mmWave?)
- ✓ Passive antenna;
  - ✓ Antenna beam pattern characterization
  - ✓ Beamforming/beamsteering validation
  - ✓ RF parametric tests (with phase recovery)

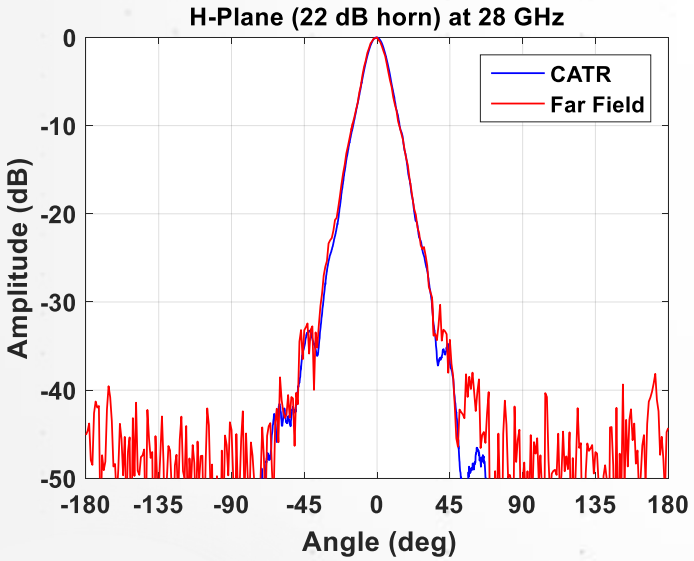
- × Requires highly accurate positioners for mmWave
- × Applicability to modulated signals
- × Tx tests for active devices
- × Rx tests
- × Can be slow

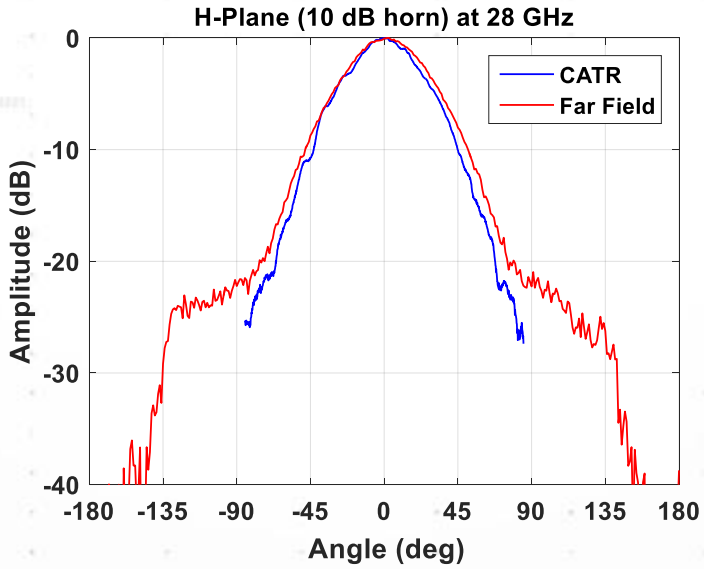
Keysight CATR vs. Far Field Range*

* http://allwavecorp.com/AntennaMeasurements.php









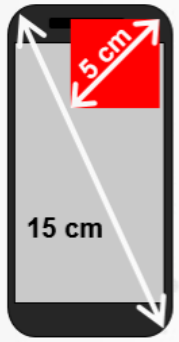
- Comparisons shown for high and low gain horn antennas
- Comparisons show high degree of correlation between the different types of chambers

- 22 dB horn : Sage SAR-2013-34-S2
- 10 dB horn : Pasternack PE9851-10

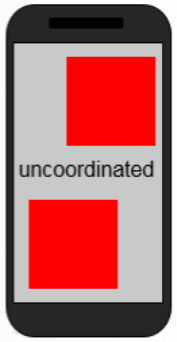
GREAT CORRELATION !

Measurement Systems for NR UE RF Test

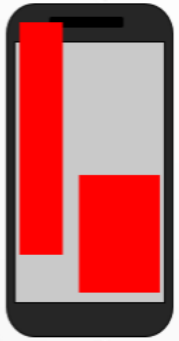
3GPP TR 38.810 STUDY ON TEST METHODS (OTA)



DUT Cat 1



DUT Cat 2


DUT Cat 3

	DFF (Direct Far Field)	IFF (CATR)	NF-TF (Near Field with Transform)
Single panel (Cat 1)	• Tx / Rx • High MU • Max D= 5cm • UE Declaration Required	✓ **Tx / Rx** ✓ **Lowest MU** ✓ **No Declaration (Blackbox)**	• Tx Only • N/A for RX tests • Max D= 5cm • UE Declaration required
Multi-panel with no coherence (Cat 2)	• Tx / Rx • Additional MU factor on Rx • Max D= 5cm • UE Declaration Required	✓ **Tx / Rx** ✓ **Lowest MU** ✓ **No Declaration (Blackbox)**	Not Applicable/Approved
Multi-panel with coherence (Cat 3)	Not Applicable/Approved	✓ **Tx / Rx** ✓ **Lowest MU** ✓ **No Declaration (Blackbox)**	Not Applicable/Approved

MU = Measurement Uncertainty

3GPP gNB Conformance Tests (TS 38.141-1,2)

CHAPTER 6,7,8 MEASUREMENT DETAILS

3GPP NR gNB Conformance Test Summary
(Conducted & Radiated)

Chap 6, Tx Characteristics

- Output Power
- Output Power Dynamics
  (RE Power Control DR / Total Power DR / ...)
- Transmit On/Off Power
  (TX Off Power / TX Transient Period)
- Signal Quality
  (Freq Error / EVM / Time Alignment Error /...)
- Unwanted Emissions
  (Occupied BW / ALCR / Spurious /...)
- Transmitter Intermodulation

Summary
- Requires time aligned digitizers Or digitizers with wide BW

Chap 7, Rx Characteristics Tests

- Reference sensitivity level
- Dynamic range
- Adjacent Channel Selectivity (ACS)
- Blocking characteristics
- Intermodulation characteristics
- In-channel selectivity
- Spurious emissions

Summary
- Tests are performed open loop
- Tests require interfering signals
- Performance metric = BLER (calculated by eNB)

Chap 8, Rx Performance Requirements Tests

- Performance requirements for PUSCH
  - Multipath fading propagation conditions
  - UL timing adjustment
  - HARQ-ACK multiplexed on PUSCH
  - High speed train conditions
- Performance requirements for PUCCH
  - ACK missed detection for single user PUCCH format 1a
  - CQI missed detection for PUCCH format 2
  - ACK missed detection for multi user PUCCH format 1a
- Performance Requirements for PRACH

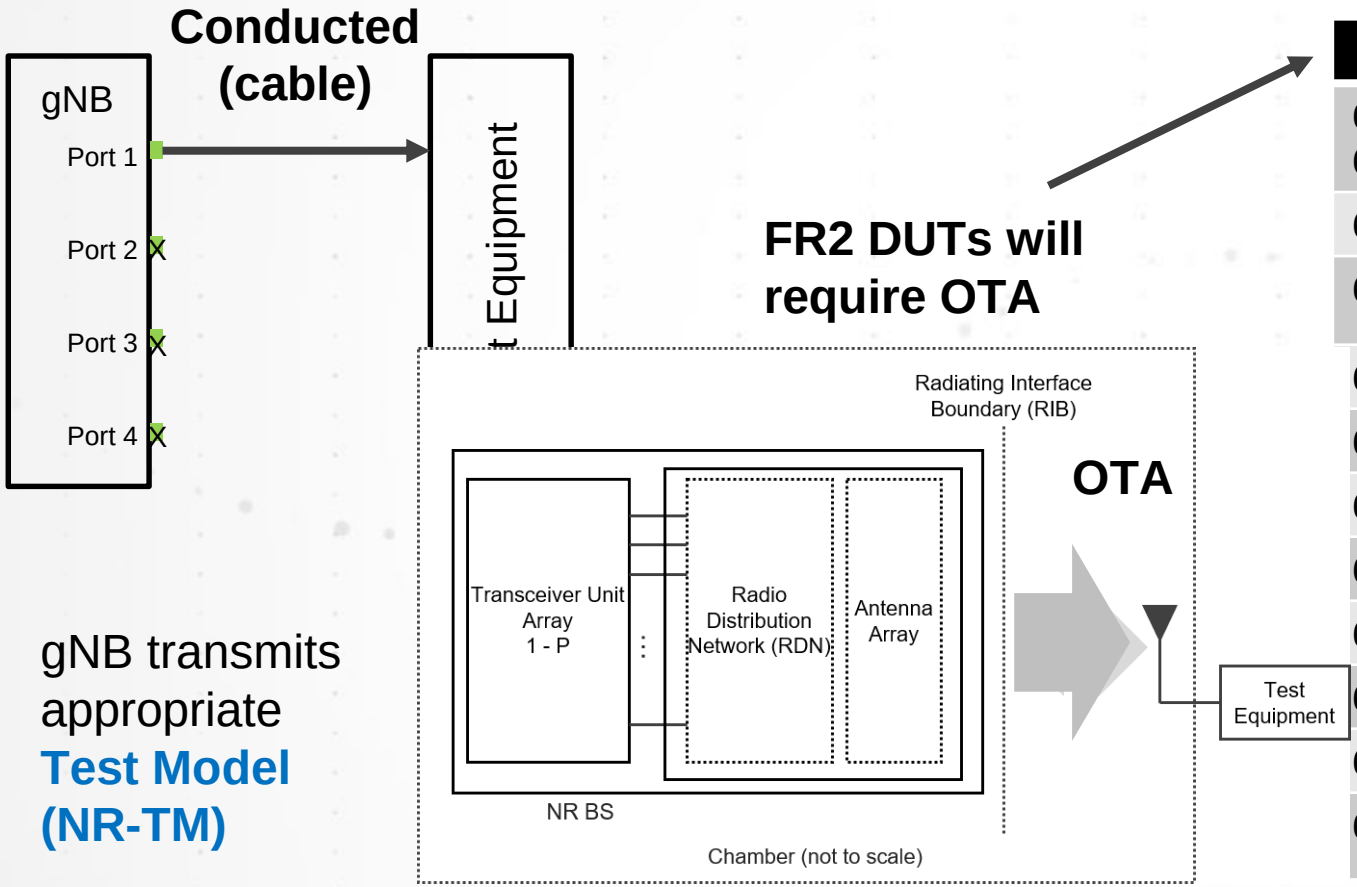
Chap 8 Structure not defined yet

Summary
- 3 tests performed closed loop (implies real-time sig gen)
- Tests require fading of 'wanted' & 'interfering' signals
- Performance metric = throughput (calculated by eNB)

3GPP gNB Transmitter Tests (Chap 6)

BASIC CONFIG FOR MOST TESTS

3GPP TS 38.141-1 (Conducted)
3GPP TS 38.141-2 (Radiated)



gNB transmits appropriate **Test Model (NR-TM)**

	Parameters	Metric
6.2, 6.3	OTA Base Station Output Power	EIRP TRP
6.4	OTA Output Power Dynamics	EIRP
6.5.1	OTA Transmit OFF Power	EIRP/TRP
6.5.2	OTA Transient Period	EIRP
6.6.2	OTA Frequency Error	EIRP
6.6.3	OTA modulation quality	EIRP
6.6.4	OTA Time alignment error	EIRP
6.7.2	OTA Occupied Bandwidth	EIRP
6.7.3	OTA ACLR	TRP
6.7.4	OTA Out of band Emissions	TRP
6.7.5	OTA Transmitter Spurious Emissions	TRP

*gNB tests will likely follow the eNB very closely with changes added for **FR2 OTA testing***

OTA Power Measurements

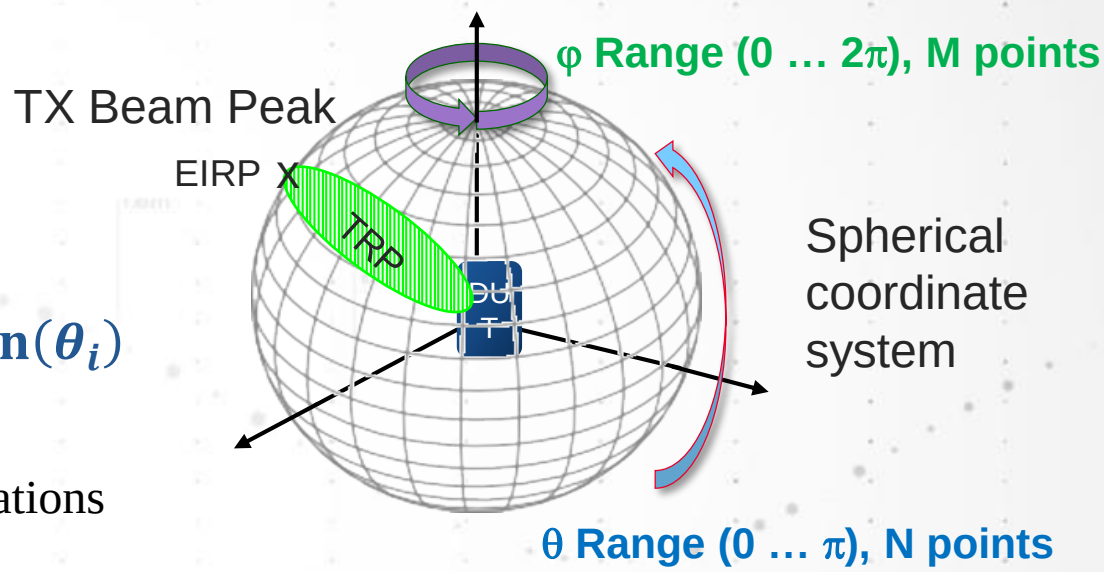
TRP AND EIRP

Beam Position:
- gNB – declared
- UE - beam locked

BTS: 3GPP TR37.842 & 843
UE: 3GPP TR38.810

Total Radiated Power (TRP) value for the uniform measurement grid:

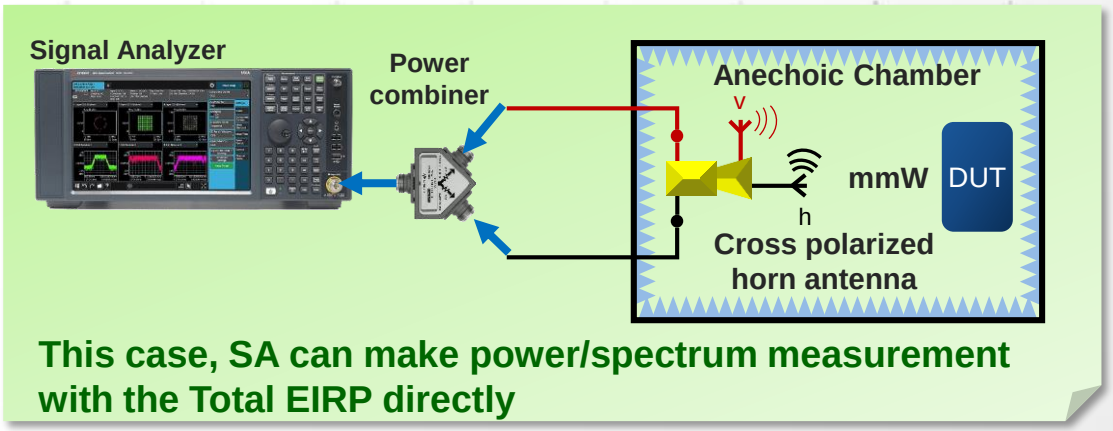
$$TRP = \frac{\pi}{2NM} \sum_{i=1}^{N-1} \sum_{j=0}^{M-1} \underbrace{\left[EIRP_{\theta}(\theta_i, \varphi_j) + EIRP_{\varphi}(\theta_i, \varphi_j)\right]}_{\text{EIRP measured at two orthogonal polarizations}} \sin(\theta_i)$$



where **N** is the number of angular intervals in the nominal θ range from 0 to π and **M** is the number of angular intervals in the nominal φ range from 0 to 2π.

EIRP = Effective (or Equivalent) Isotropic Radiated Power (usually in dBi).

Measurement taken at one setting of θ and φ



OTA Measurement – gNB Spatial Requirements

OTA AAS BS DECLARATION

Example from 3GPP TR 37.843

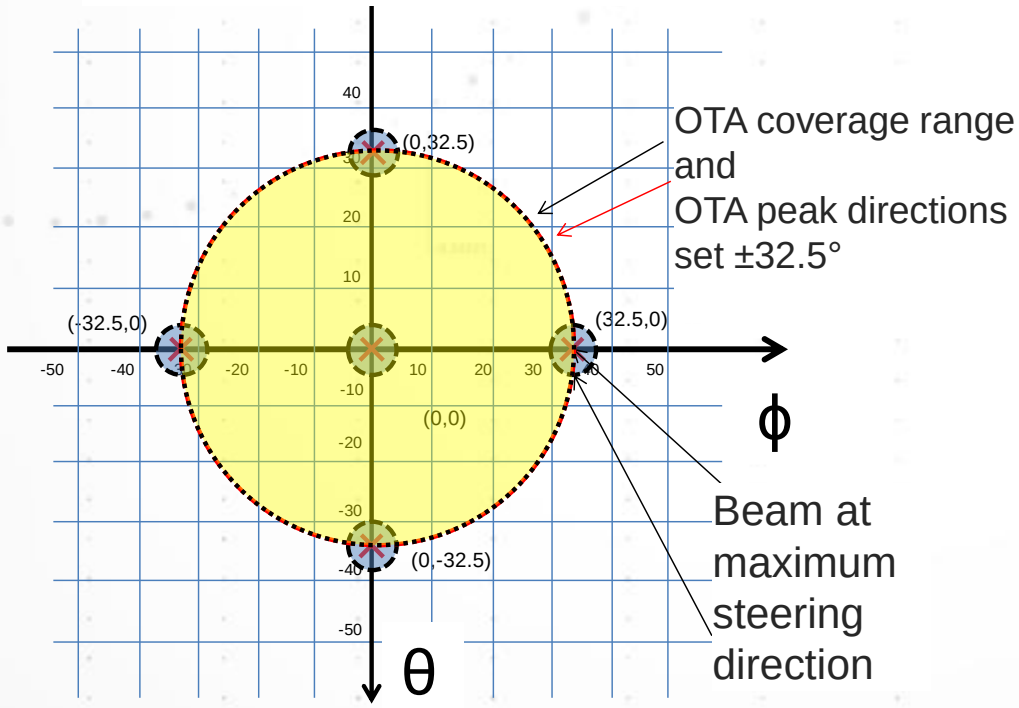
Example declarations of an OTA Active Antenna System (AAS) BS with multiple beam widths and beam steering capability;

- For the minimum beam width case: beam width (θ and ϕ) =10°, maximum steering (θ and ϕ) = ±32.5°
- For the maximum beam width case: beam width (θ and ϕ) =35°, maximum steering (θ and ϕ) = ±25°

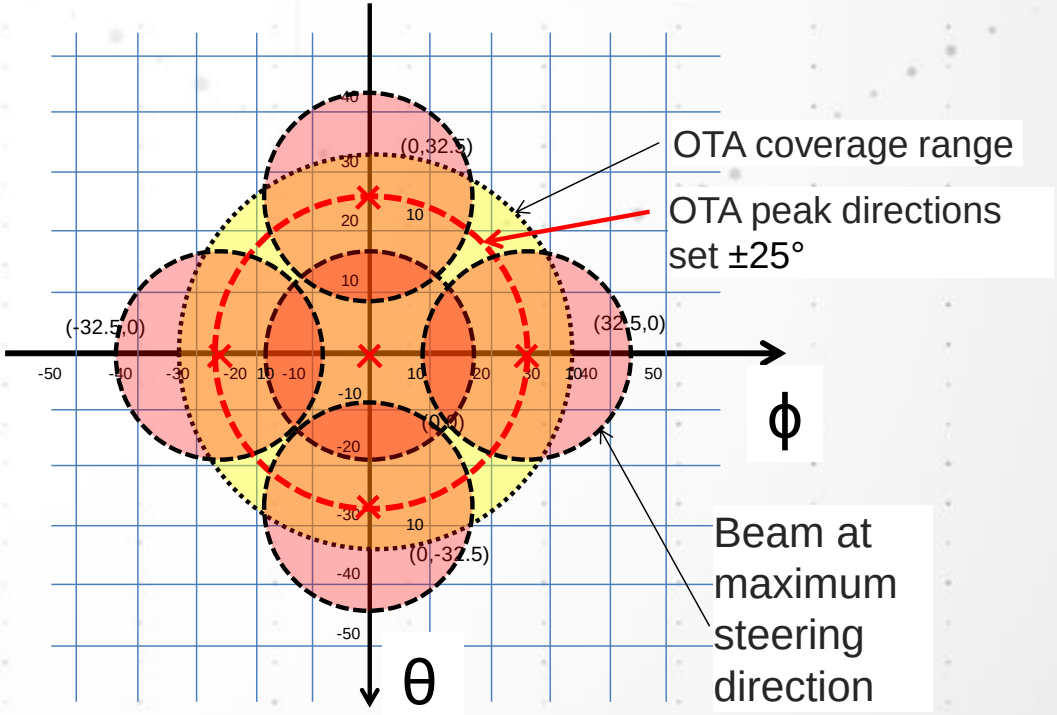
Some Tx measurements made at peak beam position and/or max steering direction;
- Tx Power
- Freq Error
- EVM

Other measurements made at peak beam position and over grid (TRP);
- Tx Power
- ACLR
- Out-of-Band

Minimum beam width case



Maximum beam width case



What about those NR gNB Test Models?

TS38.141-1 SECTION 4.9.2 NR TEST MODELS FOR FR1 TDD

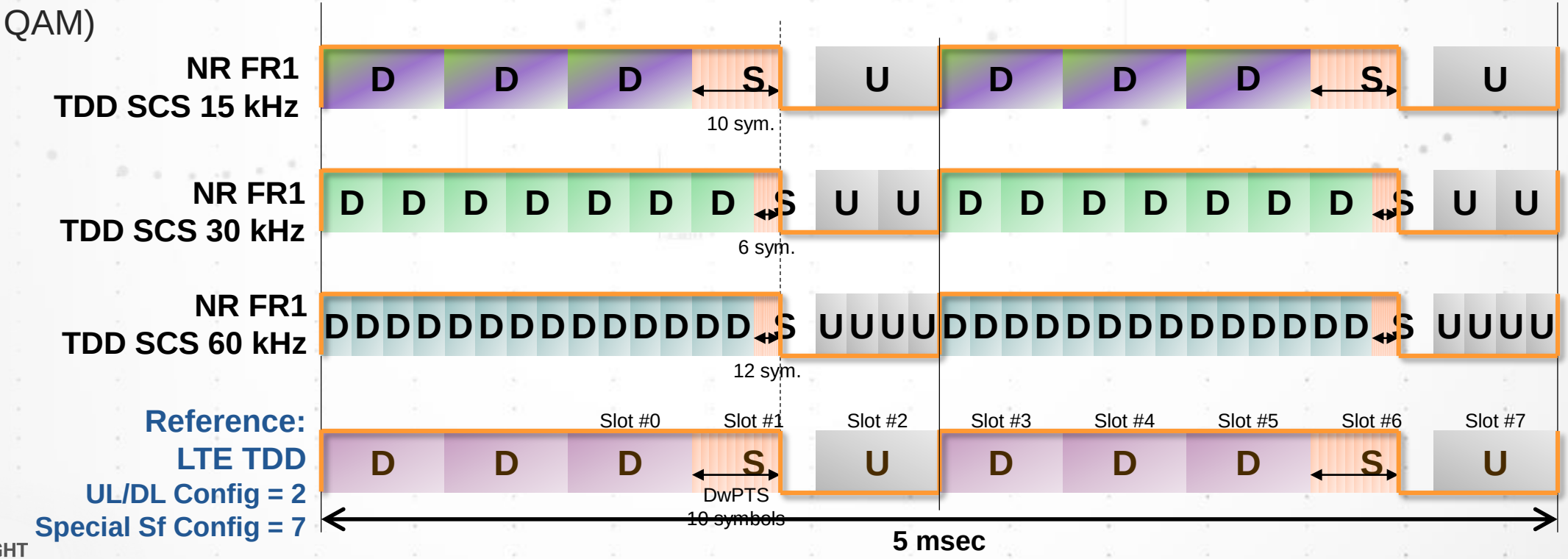
Test model for FR1 TDD frame structure is defined but not the physical parameters.

We can generate this frame structure and populate PRB with any modulation type (eg 64 QAM)

Table 4.9.2.2-1:
Configurations of TDD gNB test models for NR FR1

SCS [kHz]	Number of DL slots	Number of DL symbols in S slot	Number of UL symbols in S slot	Number of UL slots
15	3	10	2	1
30	7	6	4	2
60 (Note)	14	12	8	4

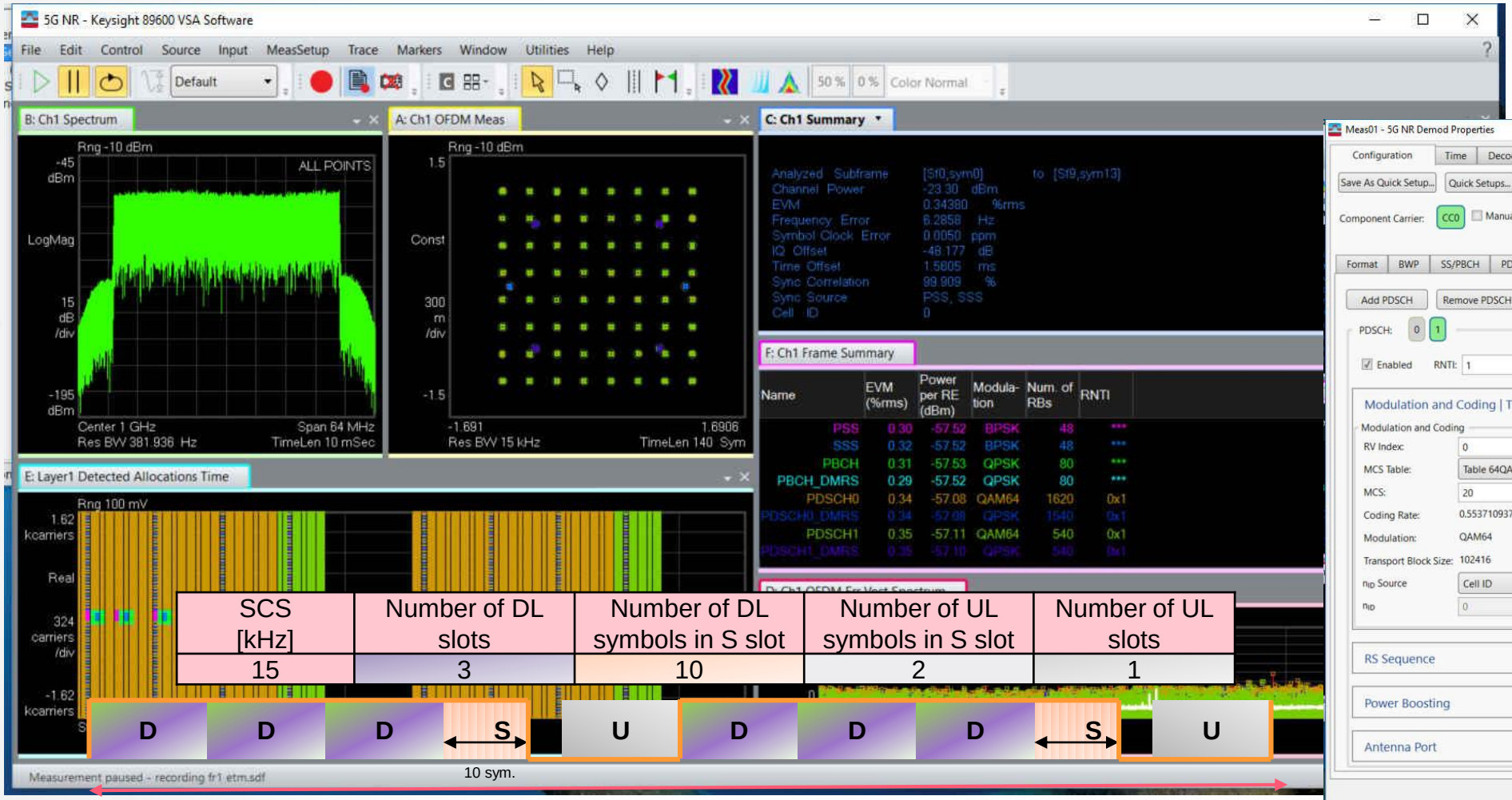
Note: There are two S slots. First S slot has 12 DL symbols followed by 2 flexible symbols; second S slot has 6 flexible symbols followed by 8 UL symbols.



What about those NR gNB Test Models?

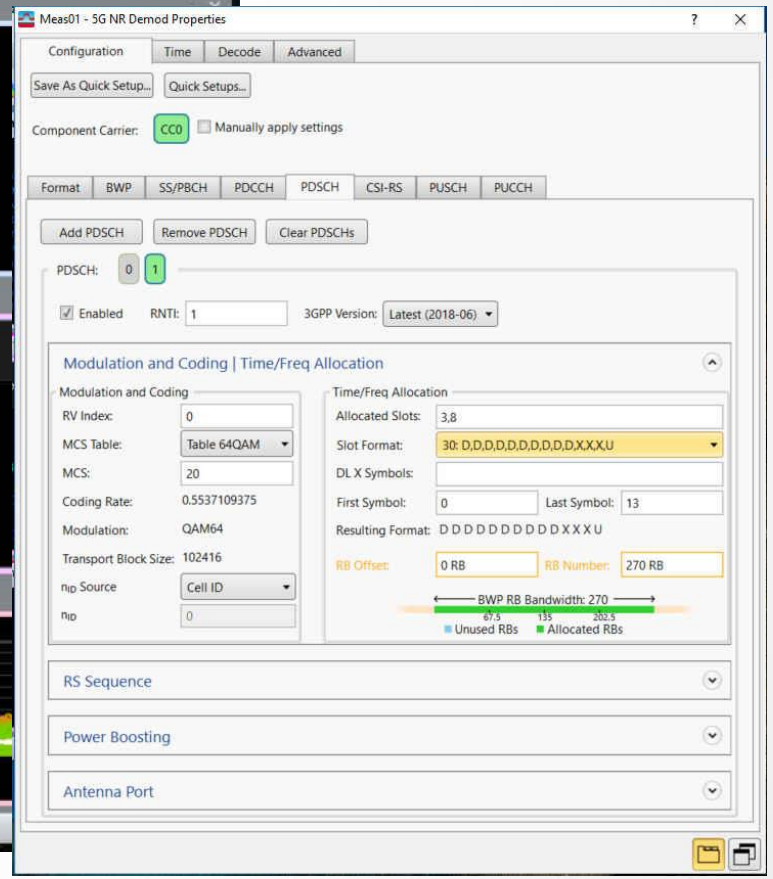
VSA DEMOD OF NR TEST MODEL FOR FR1 50 MHZ TDD 64QAM

Used signal studio for 5G NR to generate a FR1 TDD **NR-TM** frame and filled all PRBs with 64QAM. Then used VSA to demodulate the frame.



SCS [kHz]	Number of DL slots	Number of DL symbols in S slot	Number of UL symbols in S slot	Number of UL slots
15	3	10	2	1

1 Frame = 10 ms = 10 slots

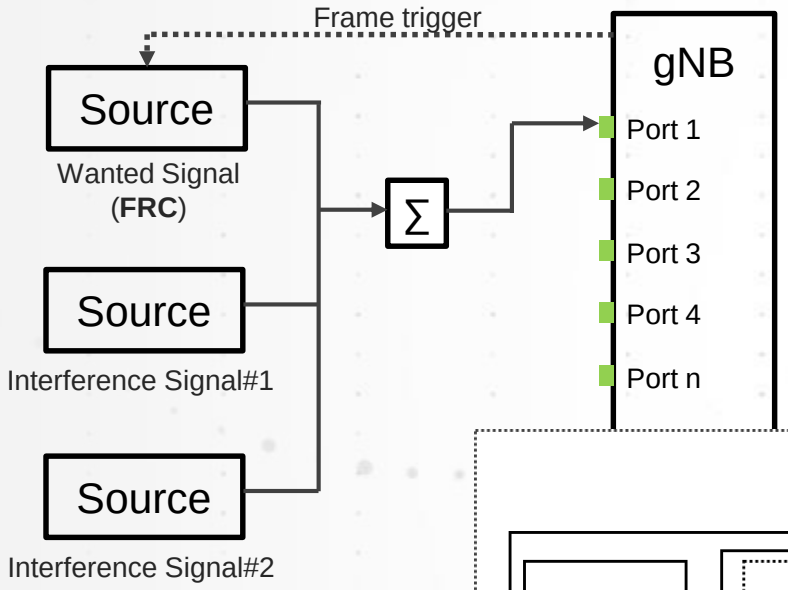


3GPP gNB Receiver Characteristics (Chap 7)

ADDITIONAL TEST CONFIGS

3GPP TS 38.141-1 (Conducted)
3GPP TS 38.141-2 (Radiated)

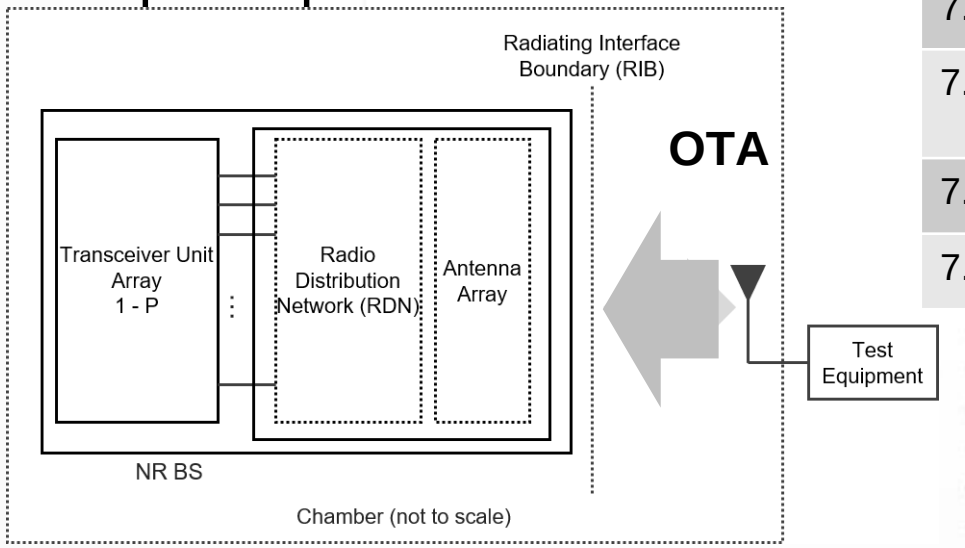
Conducted (cable)



gNB Calculates throughput based on received CRC

Intermodulation Tests
(Blocking & Selectivity tests similar)

FR2 DUTs will require OTA



	Parameters	Metric
7.3	OTA Reference Sensitivity Level	EIS
7.4	OTA Dynamic Range	EIS
7.5.1	OTA adjacent channel selectivity	EIS
7.5.2	OTA in-band blocking	EIS
7.6	OTA Out-of-band Blocking	EIS
7.7	OTA Receiver Spurious Emissions	TRP
7.8	OTA Receiver Intermodulation	EIS
7.9	OTA In-channel Selectivity	EIS

OTA Sensitivity Measurements

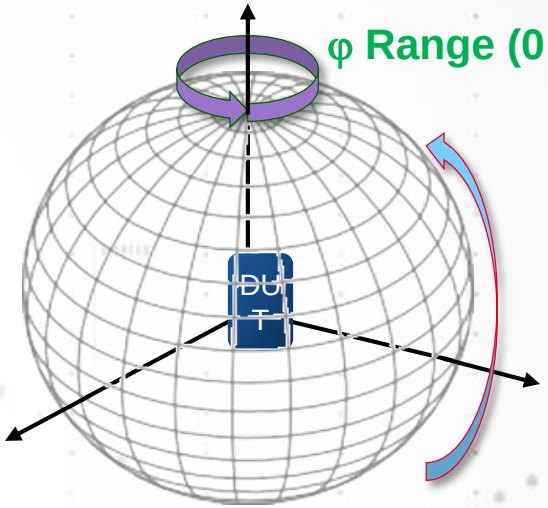
TIS AND EIS

Effective Isotropic Sensitivity (EIS) is the measured sensitivity in a single direction (fixed $\boldsymbol{\theta}$ and $\boldsymbol{\varphi}$). Usually expressed in dBm.

Total Isotropic Sensitivity (TIS) value for the uniform measurement grid:

$$TIS = \frac{2NM}{\pi \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \left[\frac{1}{EIS_{\theta}(\theta_i, \varphi_j)} + \frac{1}{EIS_{\varphi}(\theta_i, \varphi_j)} \right] sin\theta_i}$$

$$TIS = \frac{4\pi}{\int_0^{2\pi} \int_0^{\pi} \left[\frac{1}{EIS_{\theta}(\theta_1, \phi_1)} + \frac{1}{EIS_{\phi}(\theta_1, \phi_1)} \right] \sin\theta_1 d\theta_1 d\phi_1}$$



This summation approximation is valid for TIS in the same way as for TRP.

Fixed Reference Channels (FRC) for gNB Rx Testing

DEFINED IN ANNEX A.X IN TS 38.141-1 & 38.141-2

Annex A (normative):
Reference measurement channels

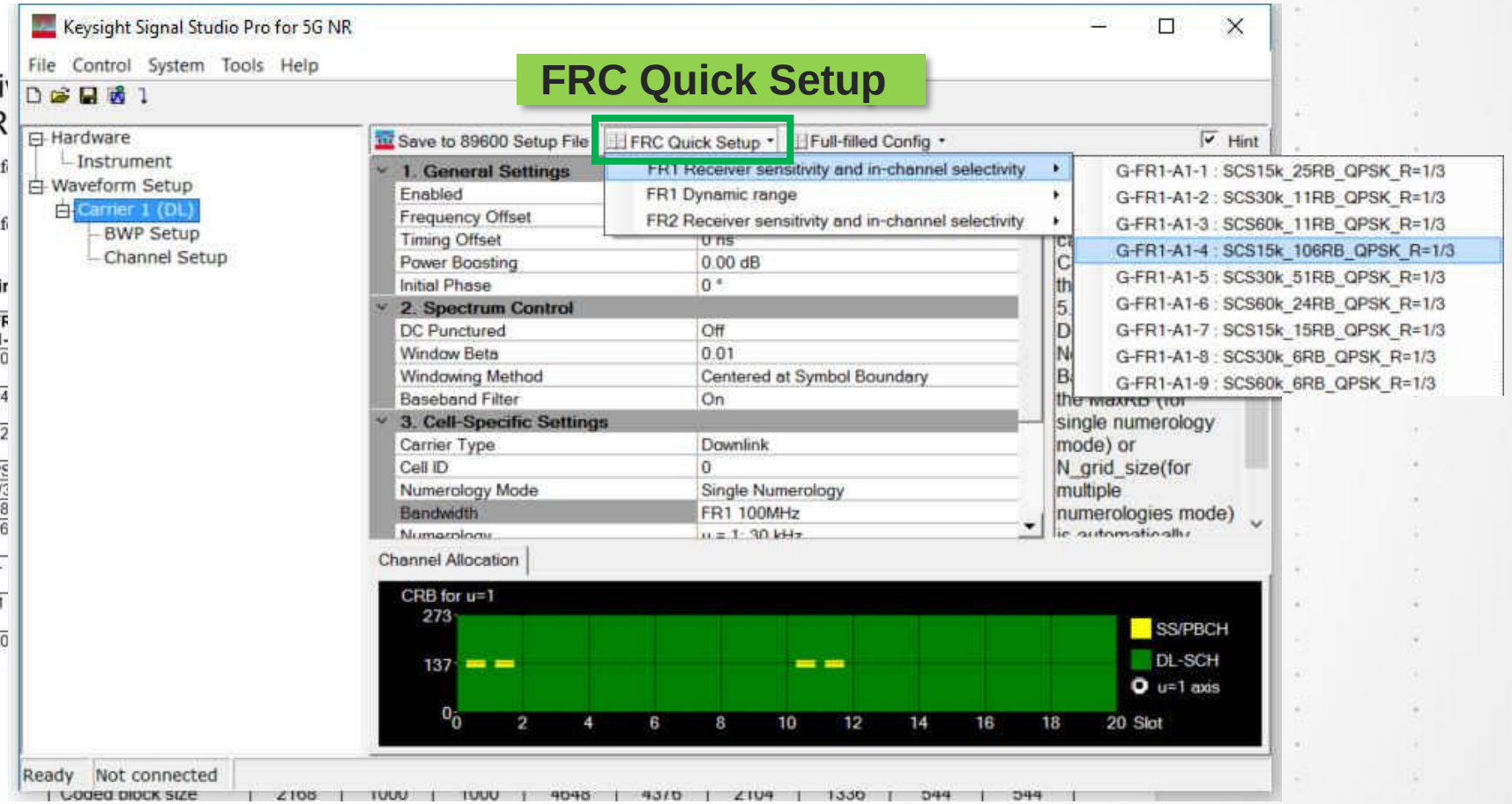
A.1 Fixed Reference Channels for recei
and in-channel selectivity (QPSK, R

The parameters for the reference measurement channels are specified in table A.1-1 f
channel selectivity.

The parameters for the reference measurement channels are specified in table A.1-2 f
channel selectivity.

Table A.1-1: FRC parameters for FR1 receiver sensitivity and ir

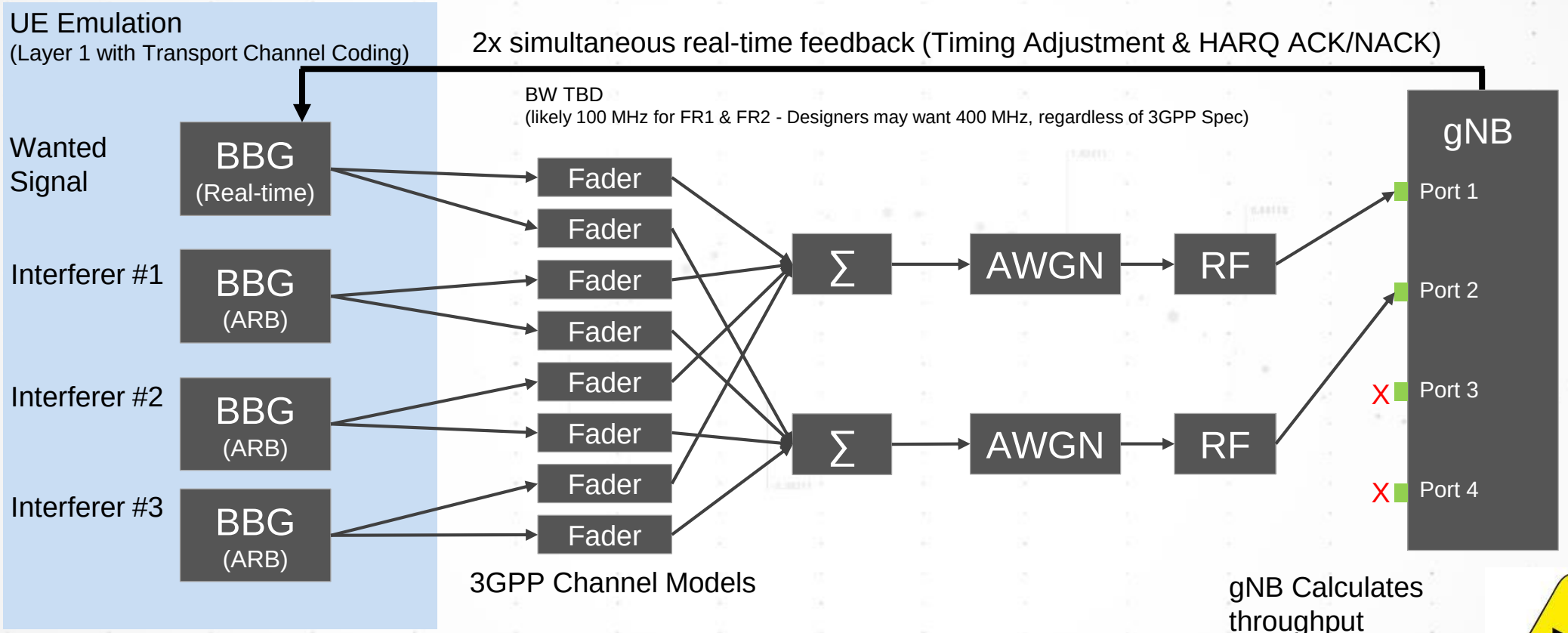
Reference channel	G-FR1-A1-1	G-FR1-A1-2	G-FR1-A1-3	G-FR1-A1-4	G-FR1-A1-5	G-FR A1-
Subcarrier spacing[kHz]	15	30	60	15	30	60
Allocated resource blocks	25	11	11	106	51	24
CP-OFDM Symbols per slot (Note 1)	12	12	12	12	12	12
Modulation	QPSK	QPSK	QPSK	QPSK	QPSK	QPS
Code rate (Note 2)	1/3	1/3	1/3	1/3	1/3	1/3
Payload size (bits)	2152	984	984	9224	4352	208
Transport block CRC (bits)	16	16	16	24	24	16
Code block CRC size (bits)	-	-	-	24	-	-
Number of code blocks - C	1	1	1	2	1	1
Coded block size	2168	1000	1000	4648	4376	210



Signal Studio Pro for 5G NR
N7631C

3GPP gNB Receiver Performance Requirements (Chap 8)

EXAMPLE 4X2 TEST CASE



Do this OTA!

- FR2 DUTs will require OTA
- Legacy LTE supports 8x8 spatial multiplexing (not required in conformance test but of interest in R&D)
- Depending on gNB capability, some tests require: 1x2, 4x2, 2x2, 3x2, **3x4, 3x8**

3GPP UE Conformance Test Requirements: Radiated

TS38.521-2 V.1.0.0 (V.2018-09) - DRAFT

TS38.521-2	Transmitter Test	Measurement	OTA
6.2.1	UE maximum output power	Chan Power	EIRP, TRP
6.2.2	UE maximum output power reduction (MPR)	Chan Power	<FFS>
6.2.3	UE maximum output power with additional requirements	Chan Power	<FFS>
6.2.4	Configured transmitted power	Chan Power	EIRP, TRP
6.3.1	Minimum output power	Chan Power	EIRP
6.3.2	Transmit OFF power	Tx On/Off Power	TRP
6.3.3	Transmit ON/OFF time mask	Tx On/Off Power	EIRP
6.3.4	Power control		EIRP?
6.4.1	Frequency error	Mod Analysis	q- & j- each
6.4.2.1	Error Vector Magnitude	Mod Analysis	q- & j- each
6.4.2.2	Carrier leakage	Mod Analysis	EIRP?
6.4.2.3	In-band emissions (IBE)	Mod Analysis	<FFS>
6.4.2.4, 6.4.2.5	EVM equalizer spectrum flatness, EVM spectrum flatness for pi/2 BPSK with spectrum shaping	Mod Analysis	<FFS>
6.5.1	Occupied bandwidth	OBW	EIRP
6.5.2.1, 6.5.2.2	Spectrum emission mask Additional Spectrum emission mask	SEM	TRP
6.5.2.3	Adjacent channel leakage ratio	ACP	TRP
6.5.3	Spurious emissions	Spur Emissions	TRP

3GPP TS 38.521-2 (Radiated) – UE FR2

TS38.521-2	Receiver Test	Metrics	Assumed Link Direction
7.3	Reference sensitivity level	EIS CDF	Each beam peak search grid
7.4	Maximum input level	Beam peak	RX beam peak direction
7.5	Adjacent Channel Selectivity (ACS)	Beam peak	RX beam peak direction
7.6.2	In-band blocking	Beam peak	RX beam peak direction
7.6.3, 7.7	Out-of-band blocking and Spurious response	FFS	FSS
7.9	Receiver Spurious emissions	FFS	TX beam peak direction
7.10	Receiver image	FFS	FFS

FFS – For Further Study

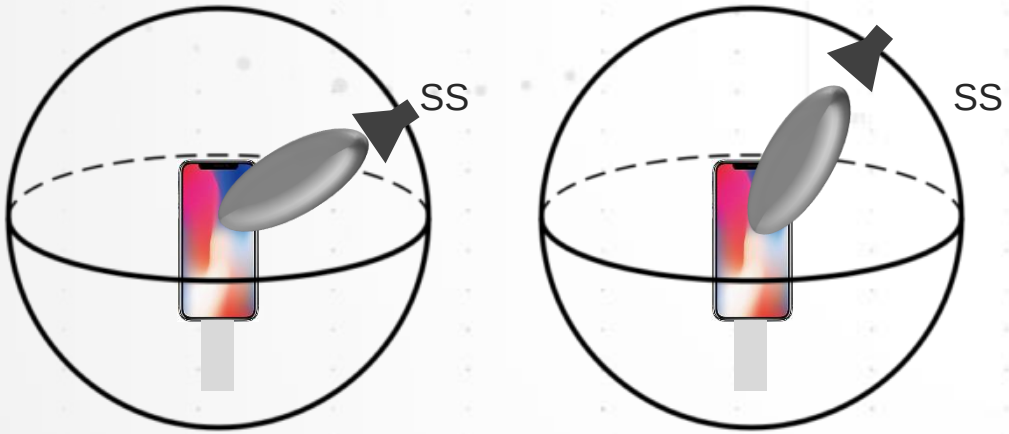
3GPP UE Test Requirements: Radiated

UE BEAMLOCK FUNCTION (UBF)

3GPP TS 38.521-2 (Radiated) – UE FR2

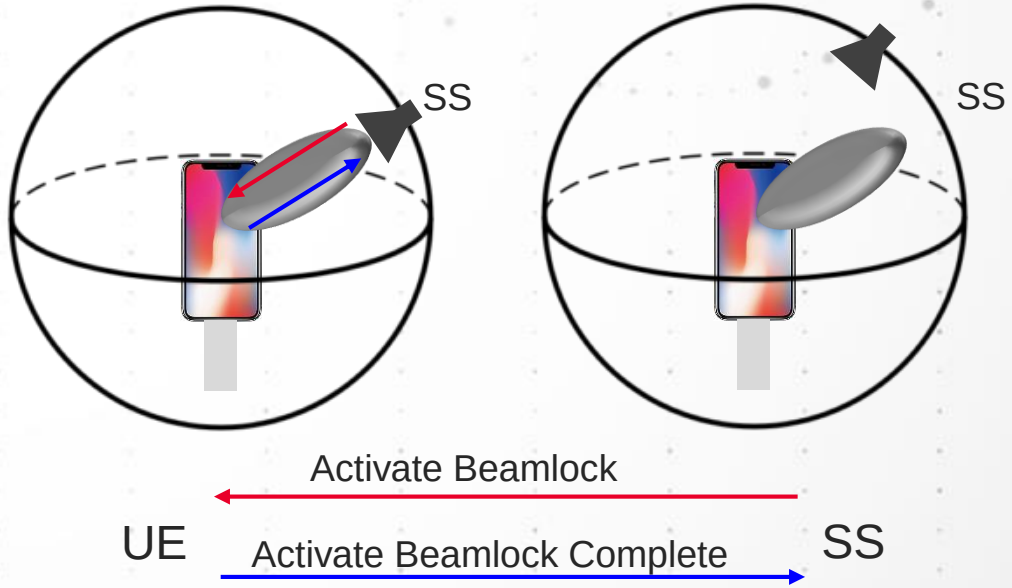
Without UE Beamlock Function (UBF), the UE keeps forming the beam towards the SS

- Required for Spherical Coverage, TX & RX Beam Peak Searches, EIS, EIRP measurements



The **UBF** is intended for making the UE to lock the UE antenna pattern once it has formed a beam towards the base station (SS) direction

- ***Required for TRP measurements***
- Recommended to prevent the beam from moving when performing measurements at low SNRs



Keysight OTA Solutions for mmWave UE Test

FROM R&D TO CONFORMANCE TO CARRIER COMPLIANCE

Rack Mount Test Chamber (RMTC)

- Fits in 19” rack
- 5-cm QZ size
- Single AoA
- Direct far-field
- 1x dual-polarized probe

Light weight, Cable replacement

UE Calibration / Array Calibration / Functional / Protocol Signaling / Performance / Demod tests

Compact Antenna Test Range (CATR) or IFF

- Multiple sizes
- Single AoA
- Indirect Far-field
- 1x dual polarized probe

Black-box testing - 3GPP Approved Solution for RF Test

Antenna / RF Parametric / TRP & TIS / Functional (incl. beam tracking) / Protocol testing / Throughput (clean channel)

2D MPAC

- Multiple AoA
- Far-field
- 3-4 dual polarized probe
- 45º 2D arch
- Benchtop installation

Functional (beam forming/ Protocol testing

3D MPAC

- Multiple AoA
- Far-field
- 4 out of 6 X-polarized probes
- 180º basic 3D or sectorized

Performance test (with fading – 38.901) / RRM (HO & Throughput) / Virtual drive test / Beam Management

Multi-Channel 5G Testbed for gNB

3GPP CONFORMANCE READY – HIGH PERFORMANCE

Test Signal
2x2 MIMO at 28 GHz

Key Features

- 44 GHz Signal Creation / 110 GHz Analysis
- Multi-channel
- High Output Power
- 2 GHz signal Creation BW
- 110 GHz BW Demodulation Analysis
- Swept-tuned measurements to 110 GHz
- Import S-Parameters to de-embed test fixture

Device Under Test
Cross-polarized 28 GHz phased array

DC Power Analyzer

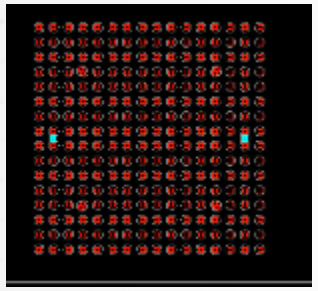
VXG
44 GHz Dual Ch. Source

UXR
110 GHz Oscilloscope

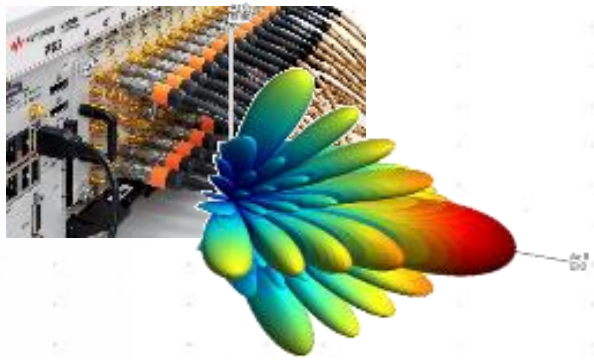
UXA
110 GHz Signal Analyzer

7 Key Measurement Challenges

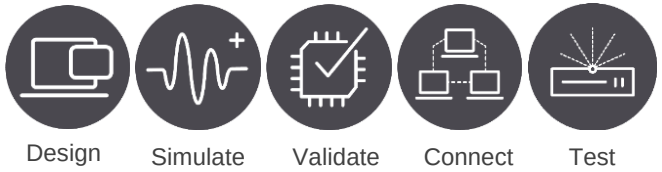
Signal Quality
mmW, Waveform, Fidelity



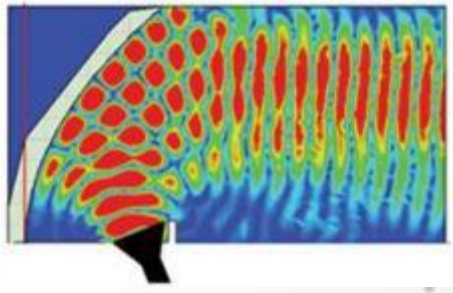
Lots of Channels
MIMO/Beamforming



Connect Design & Test
Components, Systems

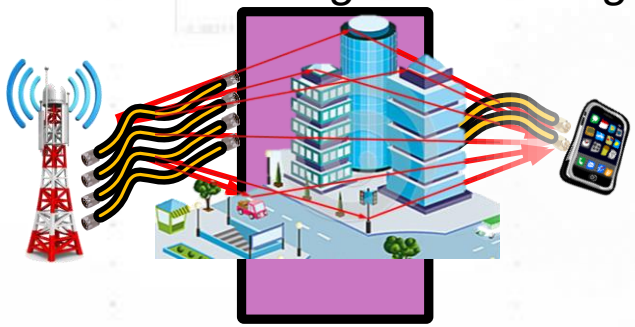


Life Beyond Connectors
Over-the-Air



Performance on the Network
Network Emulation

Channel
Characterizing & Emulating



Field Testing and Drive Test

Get the fastest path to 5G Solutions

TARGETING CHIPSET AND DEVICE WORKFLOW

5G Interactive R&D Solutions

- **Protocol R&D** — May'18
- **RF Toolset** — Sep'18
- **Functional KPI** — Dec '18

5G Device Acceptance Solutions

- **Protocol Conformance** — Oct-18
- **RF/ RRM Conformance** — Dec-18
- **Carrier Acceptance** — Future

5G MFG Solutions

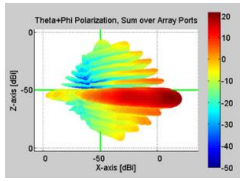
- **Manufacturing** — Apr '18

Keysight 1st Solutions across the entire device workflow

UXM 5G – E7515B

Network Emulator

PROPSIM



RRH

CIU

Channel Emulator

RMTC / CATR / MPAC

mmWave OTA Solutions

EXM – E6640A

VXT-II
M9410/11A

Non-Signaling Solution

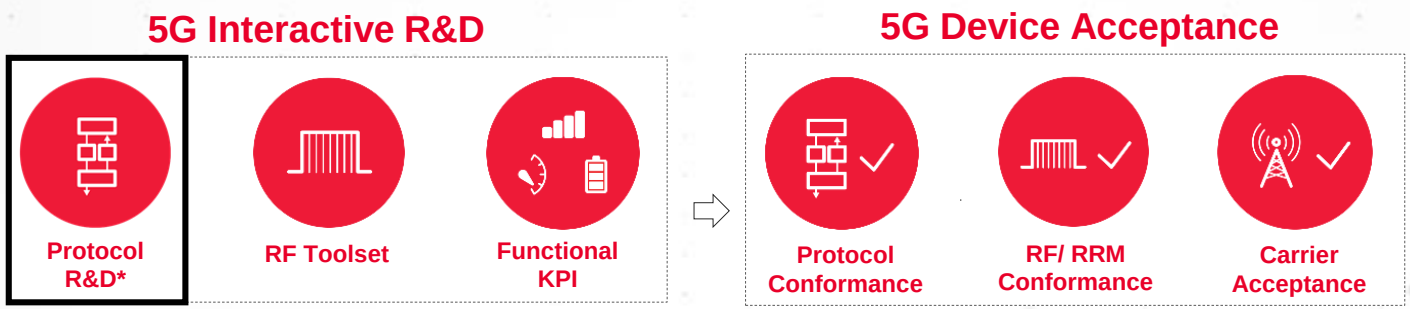
Seamless RF and Protocol Solution
Accumulates engineering know-how

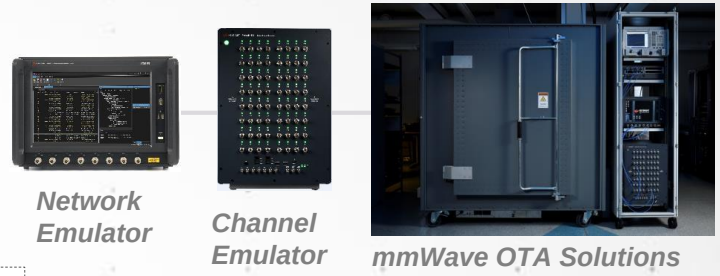
Embodies ecosystem insights
Spans ecosystem with continuous releases

… ACCELERATE TOWARDS NEW 5G DEVICES

5G Device End-to-End Workflow

PROTOCOL DEVELOPMENT





Early protocol development while keeping up with evolving 5G standards;

- Progress stack and gain insights to optimize performance
- Customize scripts, automate efficiently, and debug quickly
- Leverage work across workflow stages, stay current with standards cost effectively

Key Features:

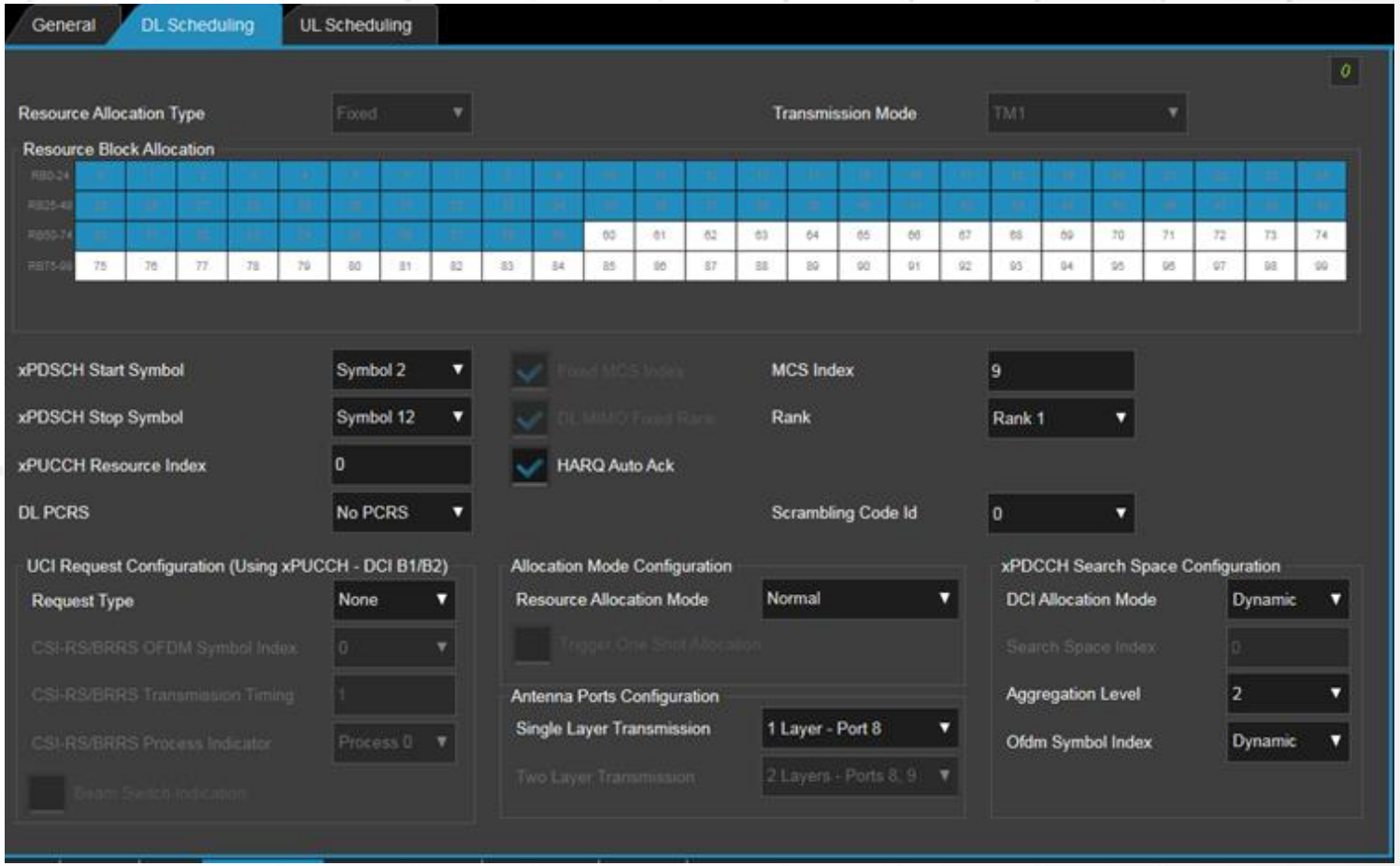
- ✓Earliest availability of new 5G features
- ✓Replicate desired network behavior whilst reducing test complexity with Built-in Protocol State Machine and Dynamic Control Points
- ✓L1/L2 parameter change without programming
- ✓Flexible automation and logging
- ✓Results viewer

Sub-6 GHz and mmWave - Conducted and OTA

Modify network behaviour easily

5G PROTOCOL R&D TOOLSET

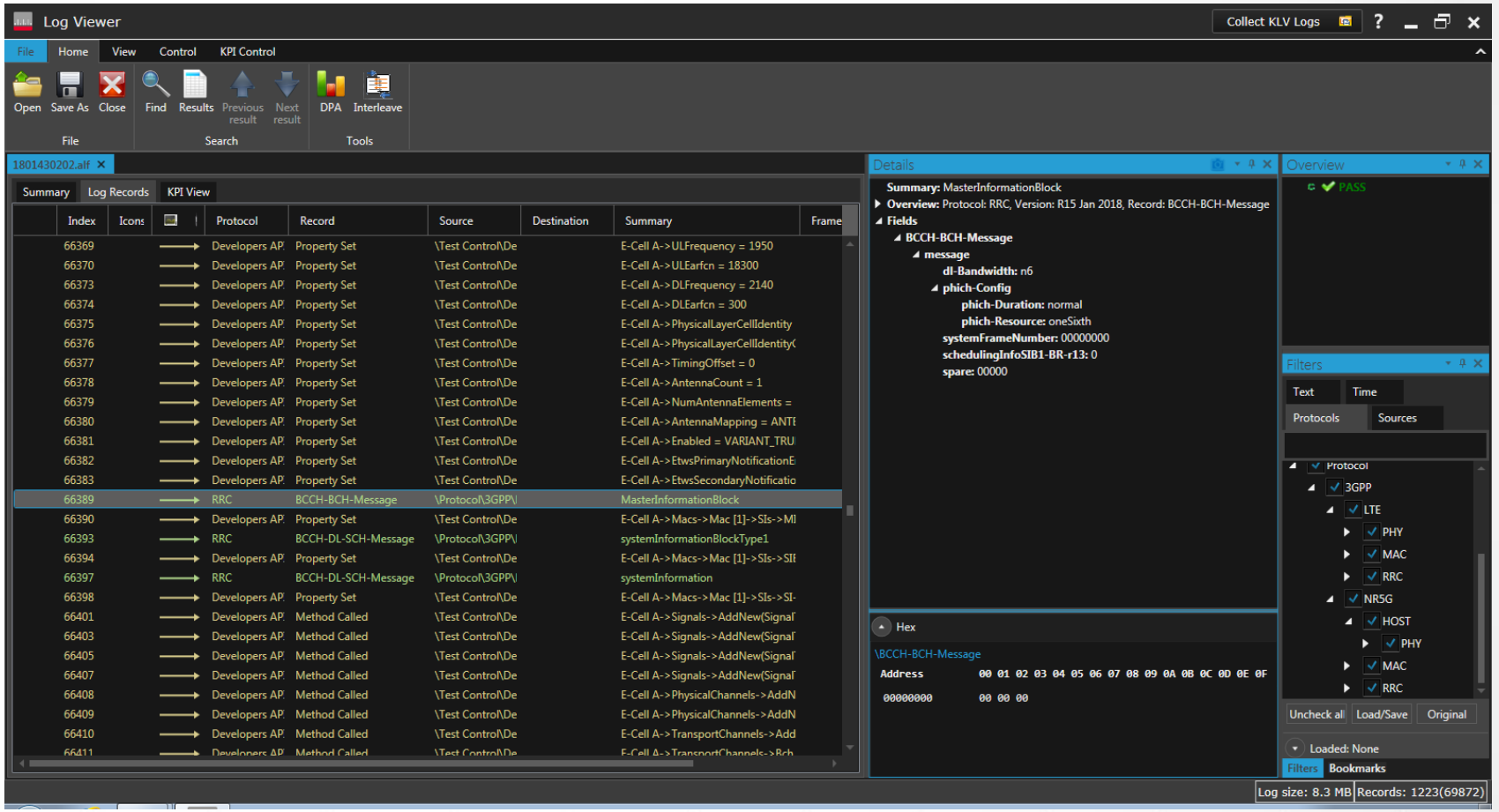
- Allow dynamic L1/L2 parameter changes without the need for programming
- Very useful in early development testing of prototypes



5G logging

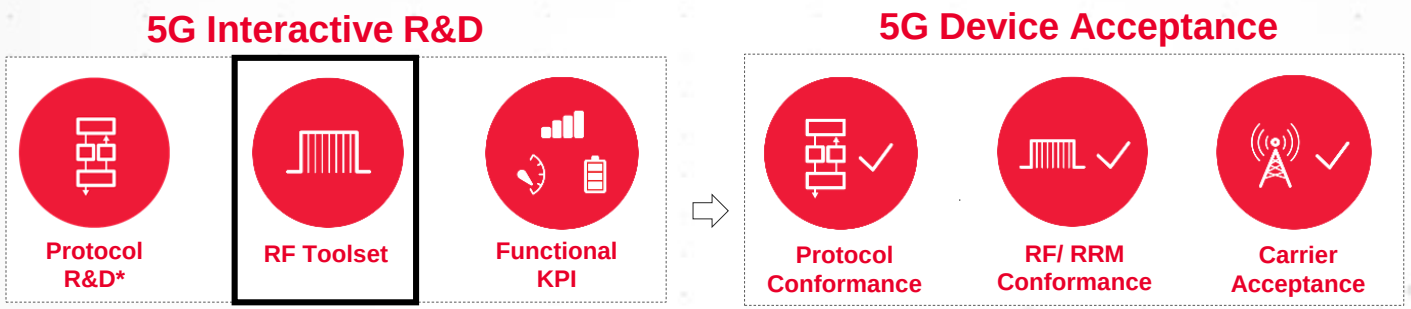
5G PROTOCOL R&D TOOLSET

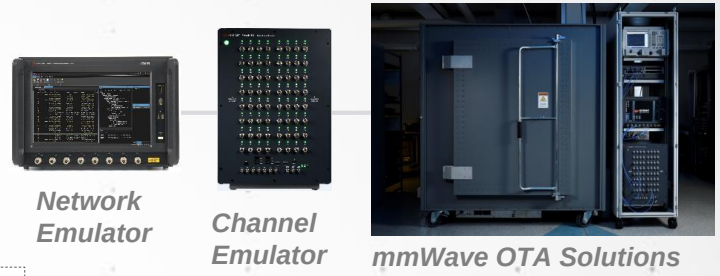
- Displays all layers of the protocol stack; PHY, MAC, RLC, RRC, PDCP
- Filtering allows the user to view the data of interest
- Advanced search features and bookmarks make debugging easier
- User friendly as all information needed is available in one view



5G Device End-to-End Workflow

R&D CHALLENGES – RF DVT





More RF bands, wider bandwidths, and beamforming;

- Wideband calibration and verification
- New waveforms, flexible numerology
- Beamforming & beam management
- More band combination complexity

DVT = Design Validation Test

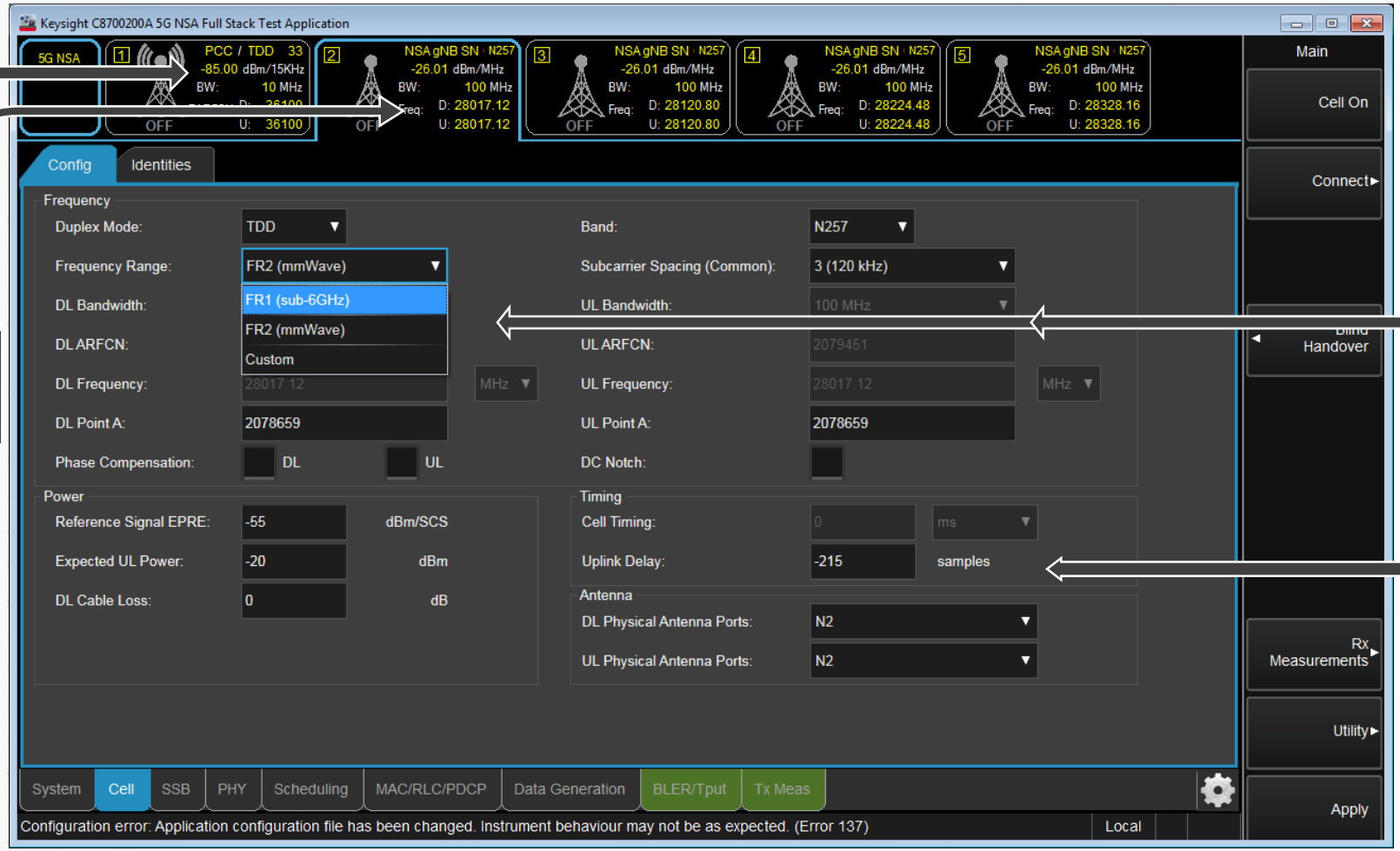
Key Features:

- ✓ 5G NR support
- ✓ RF Test Application
- ✓ Automation & Scripting
- ✓ Pre-conformance ready
- ✓ Traceability to conformance

Sub-6 GHz and mmWave - Conducted and OTA

Establish a 5G NR Call

SINGLE CELL AND CARRIER AGGREGATION



Main Cell (LTE)

Secondary Cells (NR)

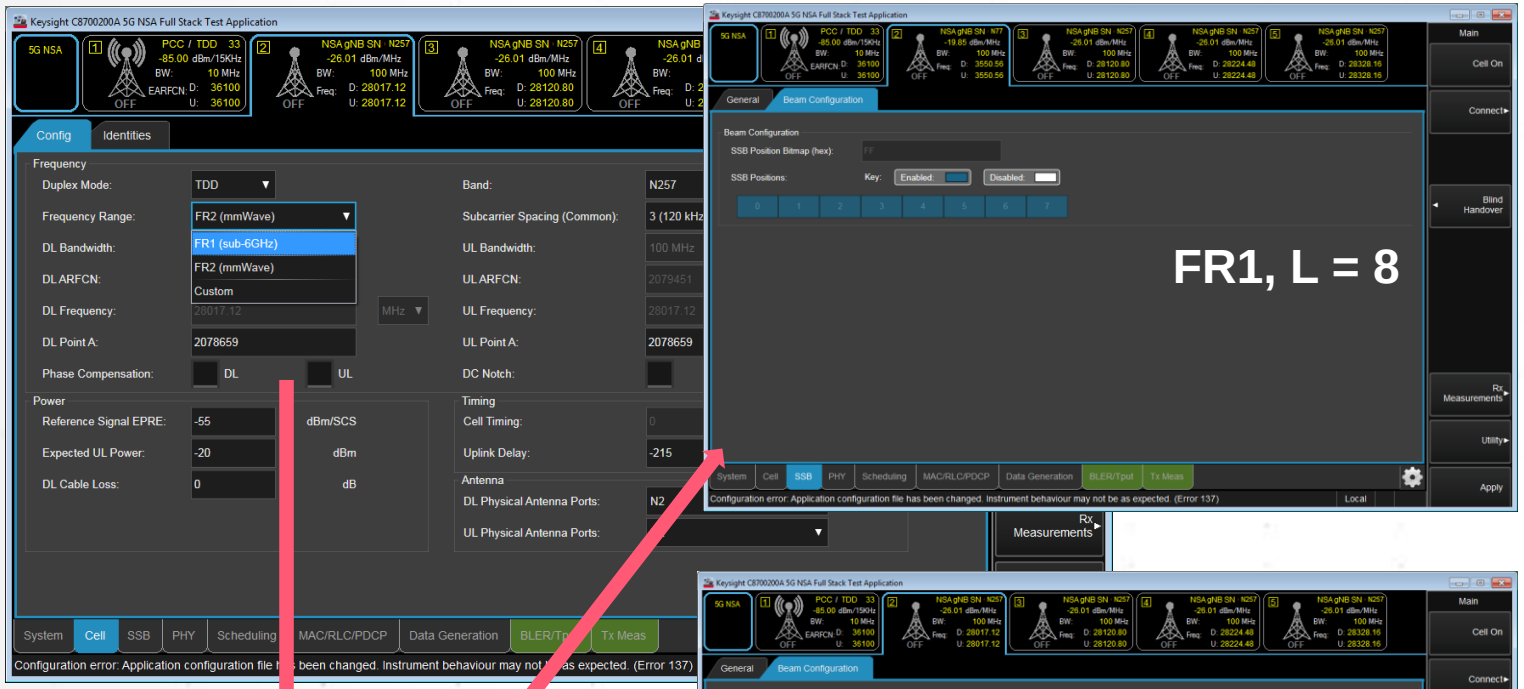
Frequency range, band, bandwidth…

Power, Timings, Antenna Ports

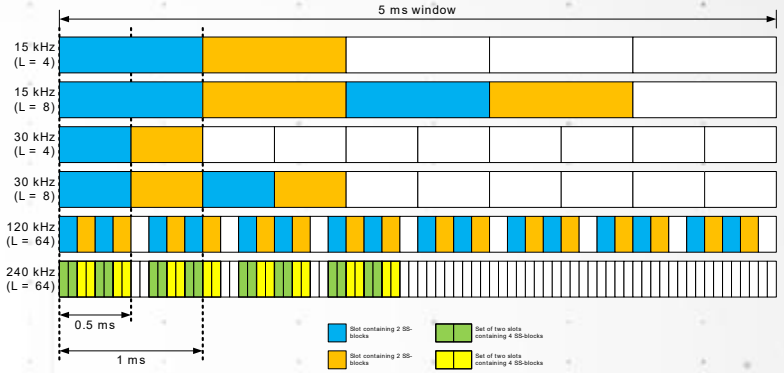
Note: Maximum number of Cells may depend on technology, bands and HW configuration

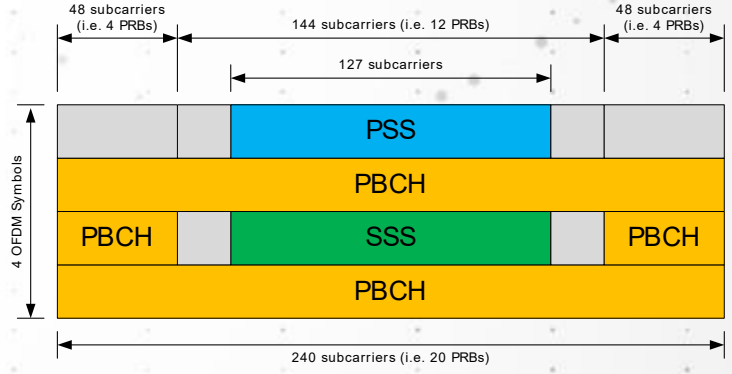
Establish a 5G NR Call

BEAM CONFIGURATION



Select SSB position, FR1 and FR2 has different bitmaps



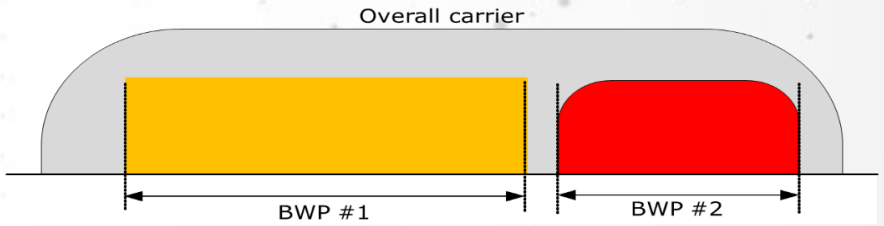


SSB includes 1 PSS, 1 SSS and 2 PBCH OFDM symbols the random access, transmitted over the same single antenna transmission scheme

Establish a 5G NR Call

PHYSICAL LAYER PARAMETERS

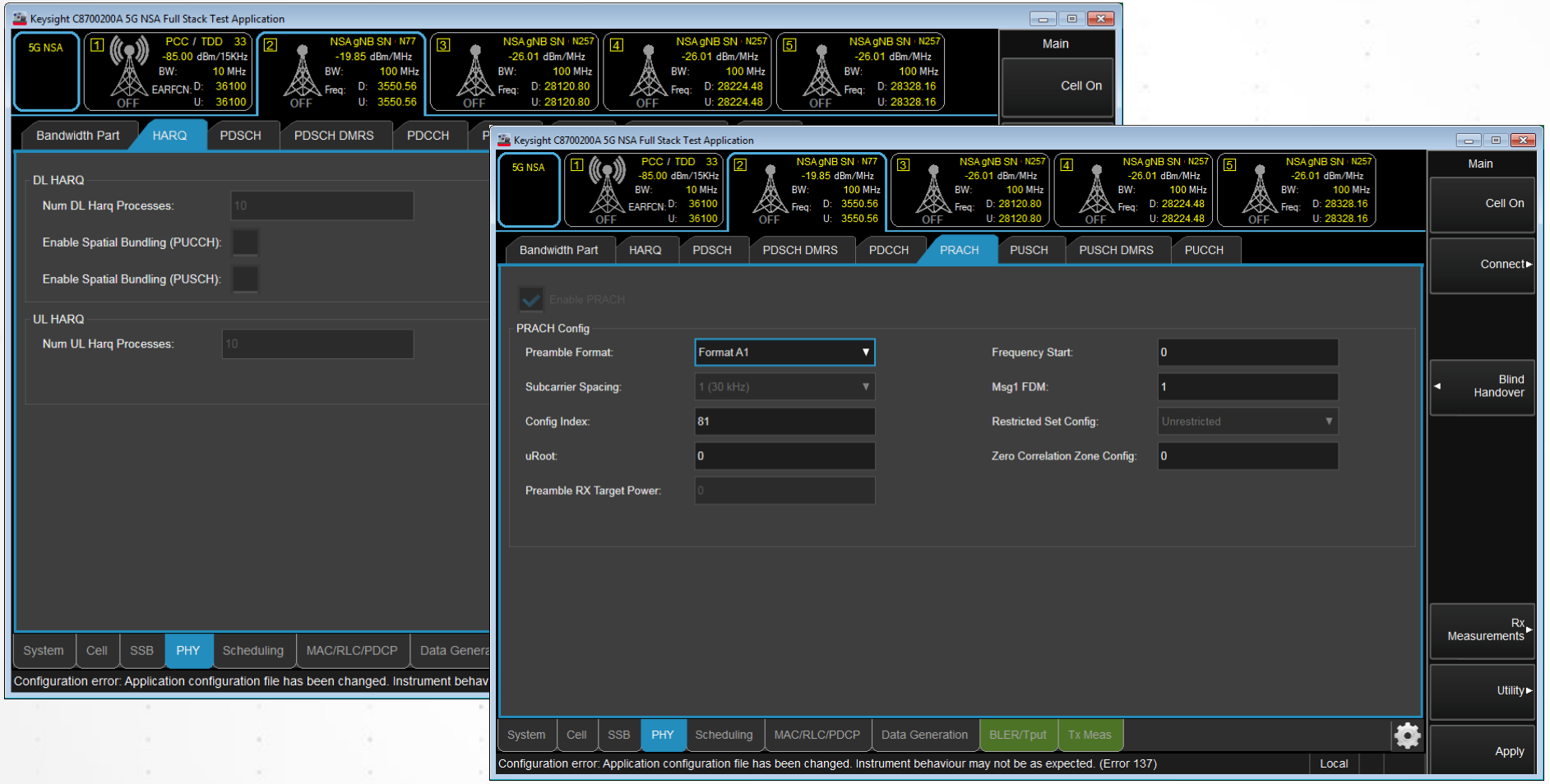
Define DL and UL Bandwidth parts; starting CRB, duration expressed in PRBs, Sub Carrier Spacing, Code Prefix



Each BWP consist on a group of contiguous PRBs

Establish a 5G NR Call

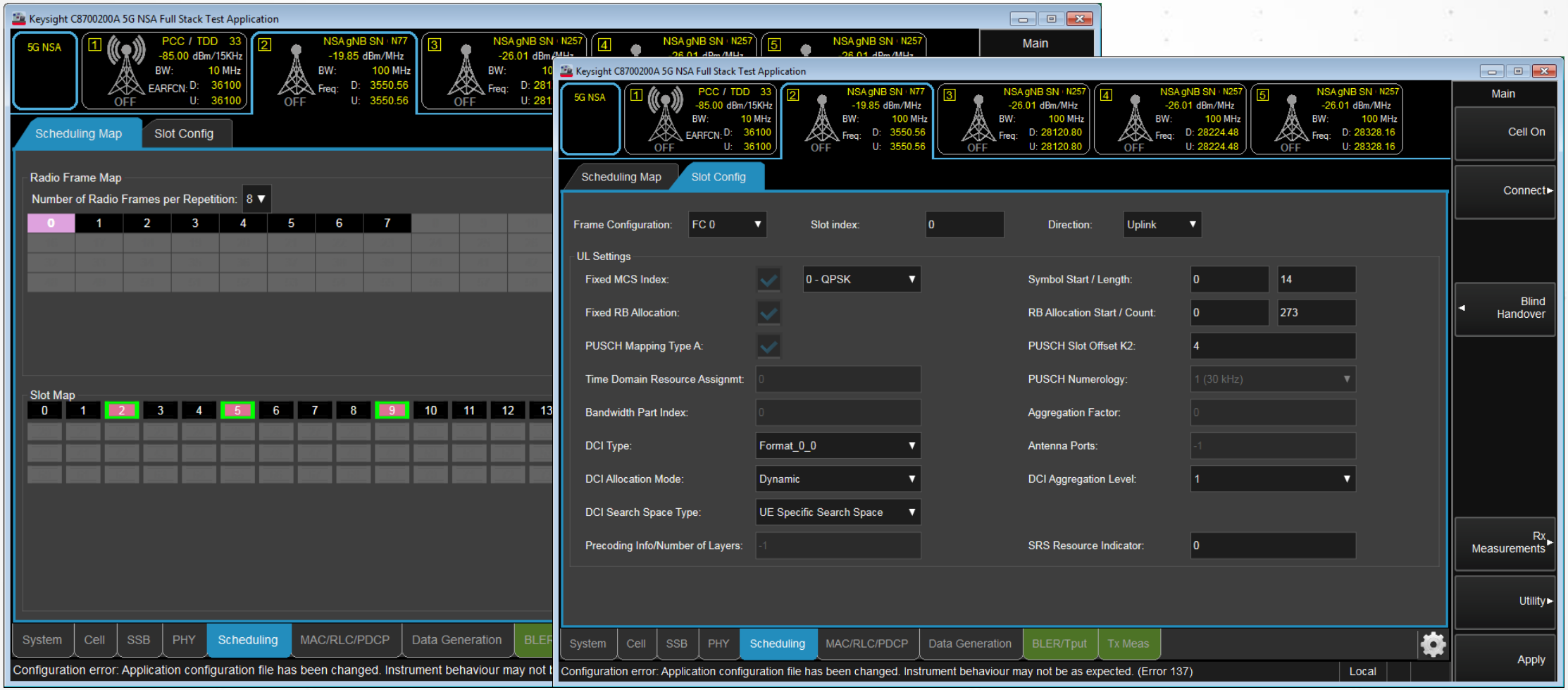
PHYSICAL LAYER PARAMETERS



HARQ, DL and UL channels and signals configuration

Establish a 5G NR Call

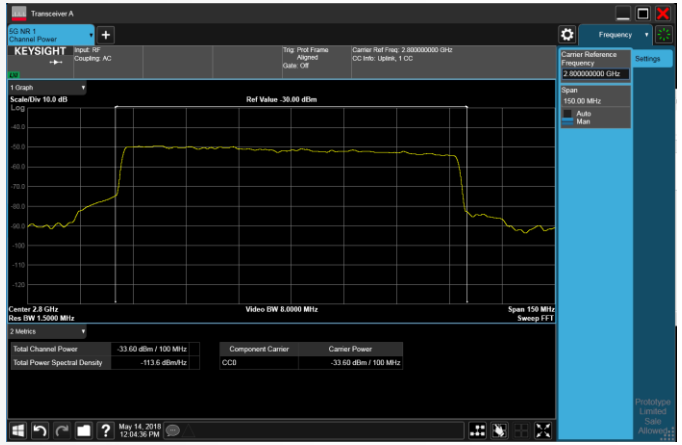
SCHEDULING



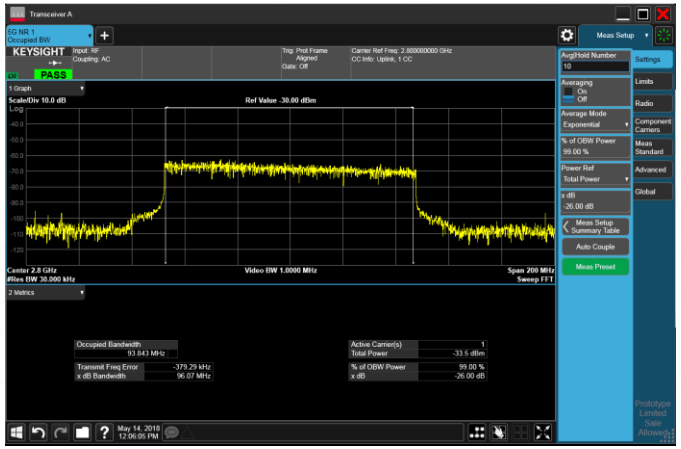
RF test on-a-call

TRANSMITTER

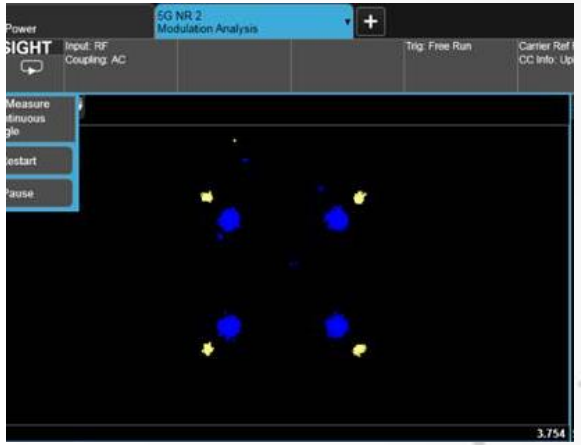
Channel Power



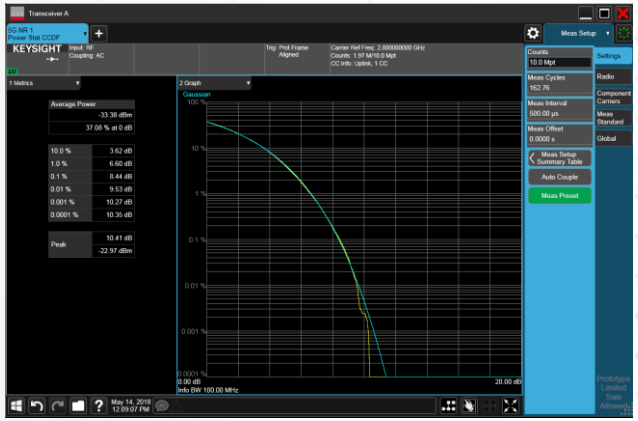
Occupied Bandwidth



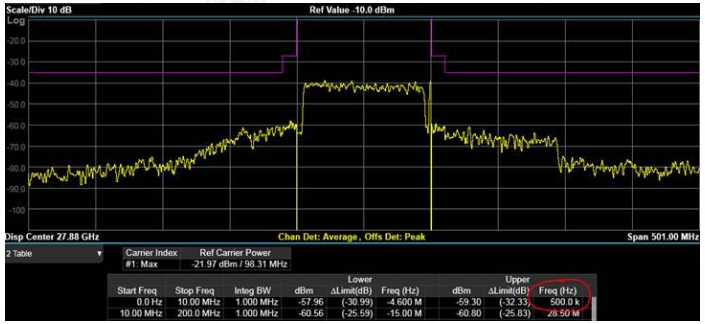
Modulation Parameters



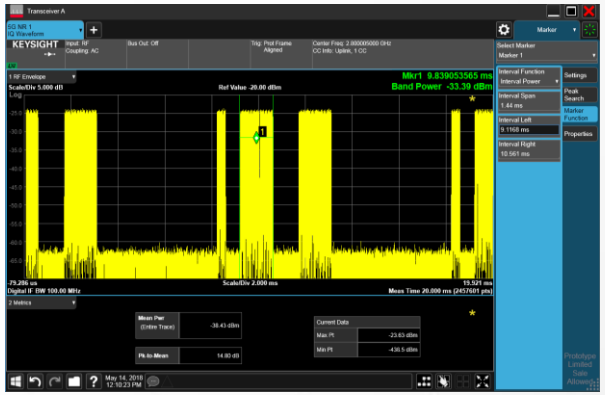
Power Statistics



Spectrum Emission Mask



IQ Waveform



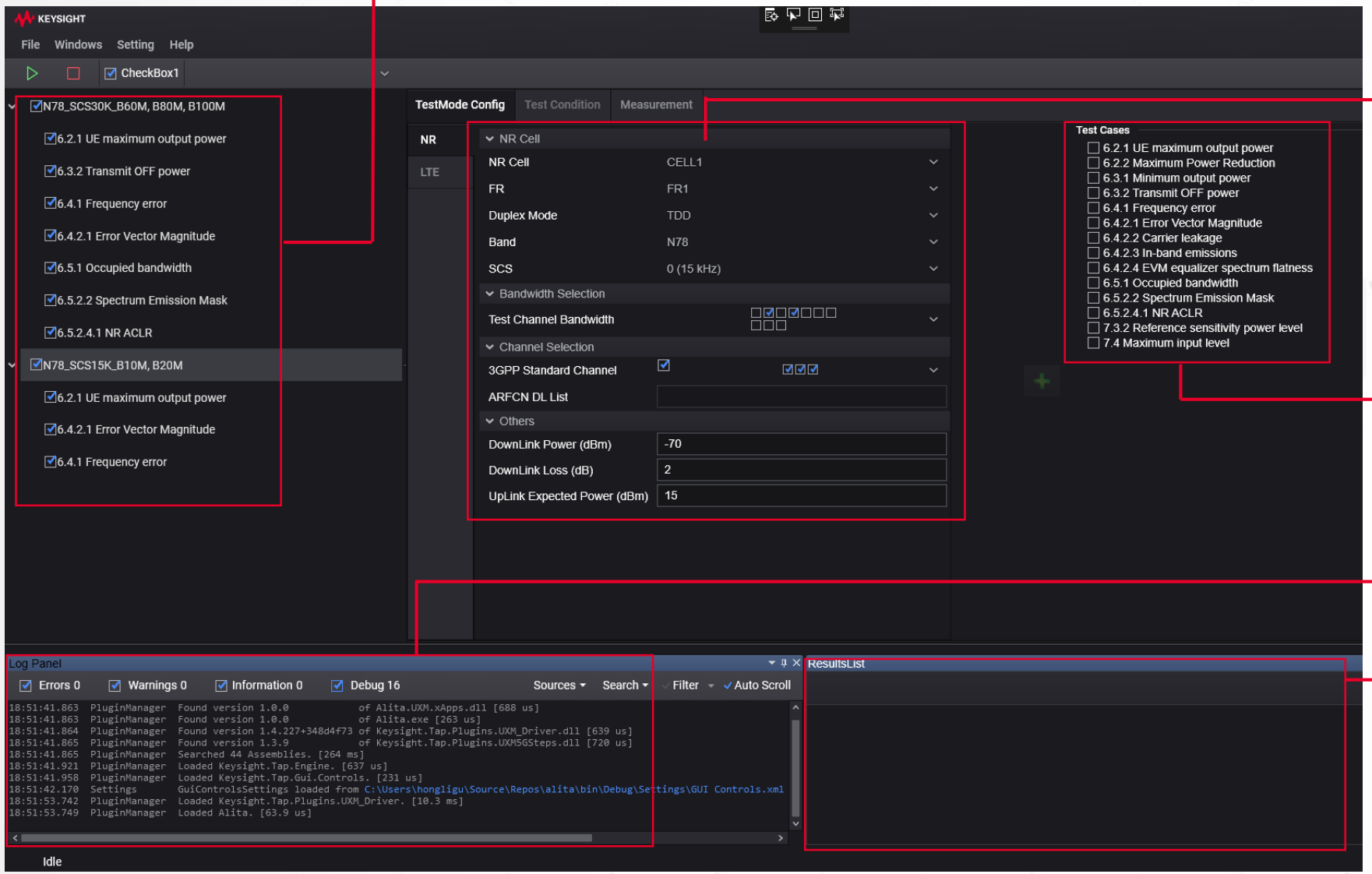
RF test on-a-call

RECEIVER

Rx Measurements

- Cell Power Selection
- Sensitivity through ACK/NACK count
- BLER is the Rx performance metric
- Throughput

RF Automation Toolset



Test Campaign

- Add test cases into one Test Mode Condition
- Add multi Test Mode Condition into Test Plan

Test Condition

- Set measurement Band, SCS, Bandwidth and Channel
- Load 3GPP default H/M/L channel from database

Test Cases

- All test cases refer to 3GPP 38.521 chapter 6 and chapter7
- Load 3GPP default test condition like RB Allocation, OFDM type and MCS.

Test Log Panel

- Error information and SCPI command Logs

Test Result List

- Result display with P/F indication
- Automatically export result to csv and Excel files.

Others

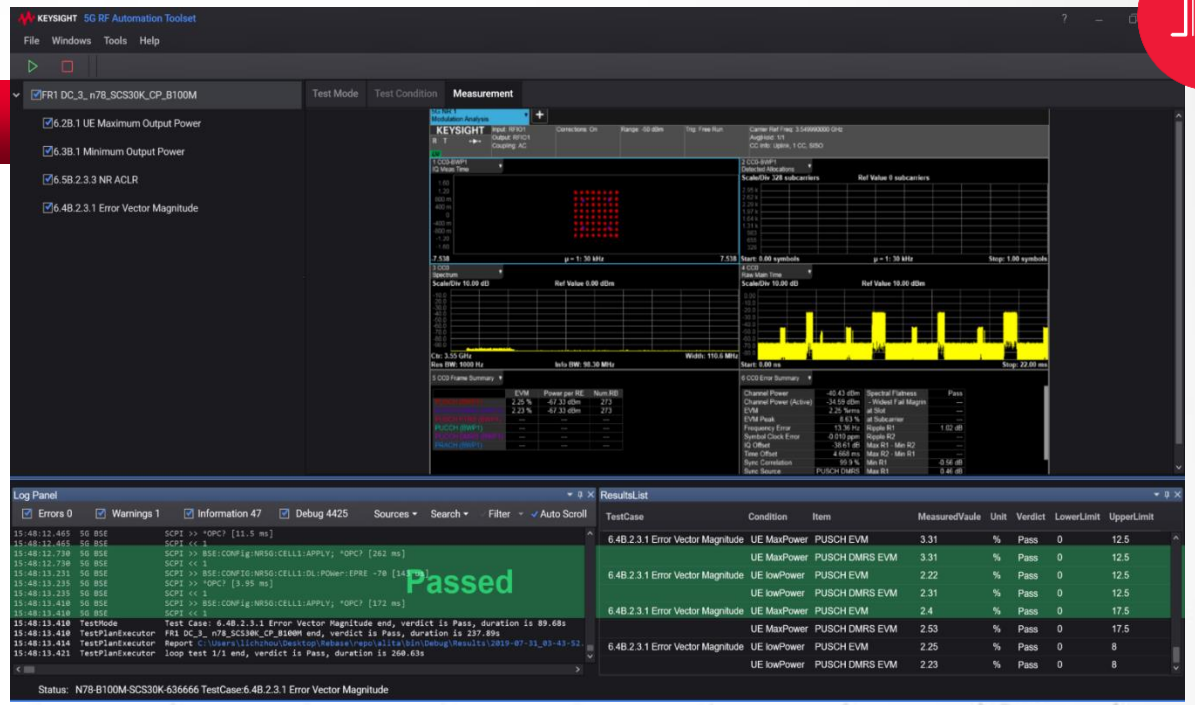
- Support report in text and CSV format
- Support adb command for flight mode

RF Automation Toolset

REPORTING TOOLS

- Real-time measurements (via X-Apps), logs and results are visible in the user interface

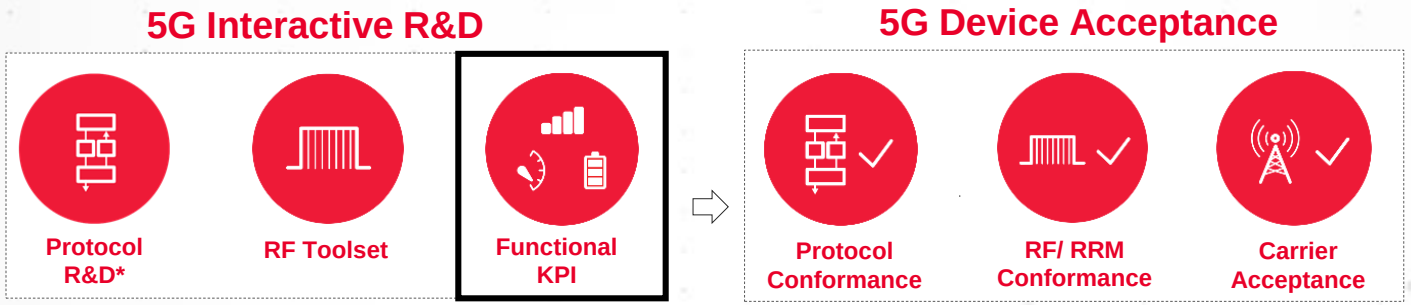
- Campaign summary reports may be generated in .csv and .xlsx formats



Time	System	Test Case	Band	Bandwidth [MHz]	SCS [kHz]	ARFCN	Freq [MHz]	Expect Power [dBm]	OFDM	Modulation	RB Allocation	Condition	Item	Lower Limit	Value	Upper Limit	Unit	P/F
2019-07-31T15:58:30	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QPSK_2	InnerFull	UE MaxPower	PUSCH EVM	0	6.66	17.5	%	Pass
												UE MaxPower	PUSCH DMRS EVM	0	5.96	17.5	%	Pass
2019-07-31T15:58:38	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QPSK_2	InnerFull	UE lowPower	PUSCH EVM	0	2.1	17.5	%	Pass
												UE lowPower	PUSCH DMRS EVM	0	2.24	17.5	%	Pass
2019-07-31T15:58:47	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QPSK_2	OuterFull	UE MaxPower	PUSCH EVM	0	3.06	17.5	%	Pass
												UE MaxPower	PUSCH DMRS EVM	0	2.78	17.5	%	Pass
2019-07-31T15:58:57	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QPSK_2	OuterFull	UE lowPower	PUSCH EVM	0	2.13	17.5	%	Pass
												UE lowPower	PUSCH DMRS EVM	0	2.21	17.5	%	Pass
2019-07-31T15:59:06	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QAM16_10	InnerFull	UE MaxPower	PUSCH EVM	0	4.66	12.5	%	Pass
												UE MaxPower	PUSCH DMRS EVM	0	4.25	12.5	%	Pass
2019-07-31T15:59:14	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QAM16_10	InnerFull	UE lowPower	PUSCH EVM	0	1.99	12.5	%	Pass
												UE lowPower	PUSCH DMRS EVM	0	1.83	12.5	%	Pass
2019-07-31T15:59:23	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QAM16_10	OuterFull	UE MaxPower	PUSCH EVM	0	3.27	12.5	%	Pass
												UE MaxPower	PUSCH DMRS EVM	0	3.24	12.5	%	Pass
2019-07-31T15:59:33	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QAM16_10	OuterFull	UE lowPower	PUSCH EVM	0	2.23	12.5	%	Pass
												UE lowPower	PUSCH DMRS EVM	0	2.15	12.5	%	Pass
2019-07-31T15:59:42	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QAM64_18	OuterFull	UE MaxPower	PUSCH EVM	0	2.55	17.5	%	Pass
												UE MaxPower	PUSCH DMRS EVM	0	2.51	17.5	%	Pass
2019-07-31T15:59:51	ENDC	6.4B.2.3.1 Error Vector Magnitude	N78	100MHz	SCS30K	636666	3549.99MHz	0	CP-OFDM	QAM64_18	OuterFull	UE lowPower	PUSCH EVM	0	2.19	8	%	Pass
												UE lowPower	PUSCH DMRS EVM	0	2.29	8	%	Pass

5G Device End-to-End Workflow

FUNCTIONAL KPI



COMING SOON

Support for sustained maximum E2E throughput, meet power consumption goals;

- Stress test the device at maximum E2E data throughput
- Benchmark battery life performance for different 5G use cases

KPI = Key Performance Indicators

Key Features:

- ✓ Easy to use GUI enables complex tests without the need to define protocol scripts
- ✓ Network configurations optimized to measure device performance
- ✓ Throughput, Battery life, Beam management
- ✓ Flexible automation, including use of external measurement equipment
- ✓ Simple Test case development
- ✓ Use results viewer for off line analysis

Sub-6 GHz and mmWave - Conducted and OTA

5G Device End-to-End Workflow

DEVICE ACCEPTANCE

5G Interactive R&D

- Protocol R&D*
- RF Toolset
- Functional KPI

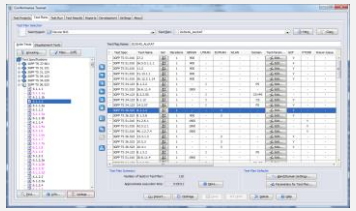
5G Device Acceptance

- Protocol Conformance
- RF/ RRM Conformance
- Carrier Acceptance

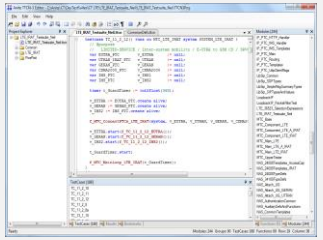
Protocol

Test Spec TS 38.523-1

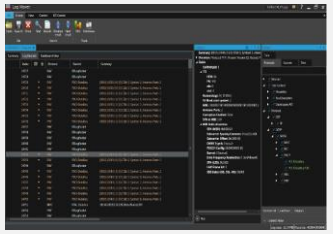
TTCN-3 Test Suite



PCT Test Manager



TTCN-3 Editor / Viewer



Log Viewer

RF/RRM

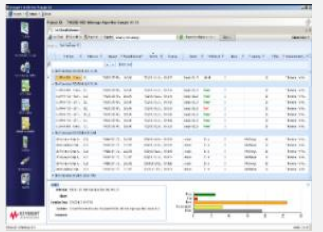
Test Spec 38.521-1/2/3

RF Rx/TX Test cases

Test Spec 38.521-4

Future

Performance testing

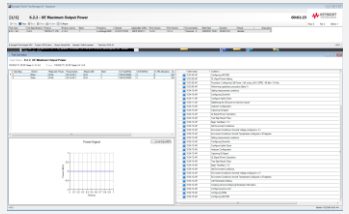


RCT Test Manager

Test Spec 38.533

Future

Radio Resource Management (RRM)

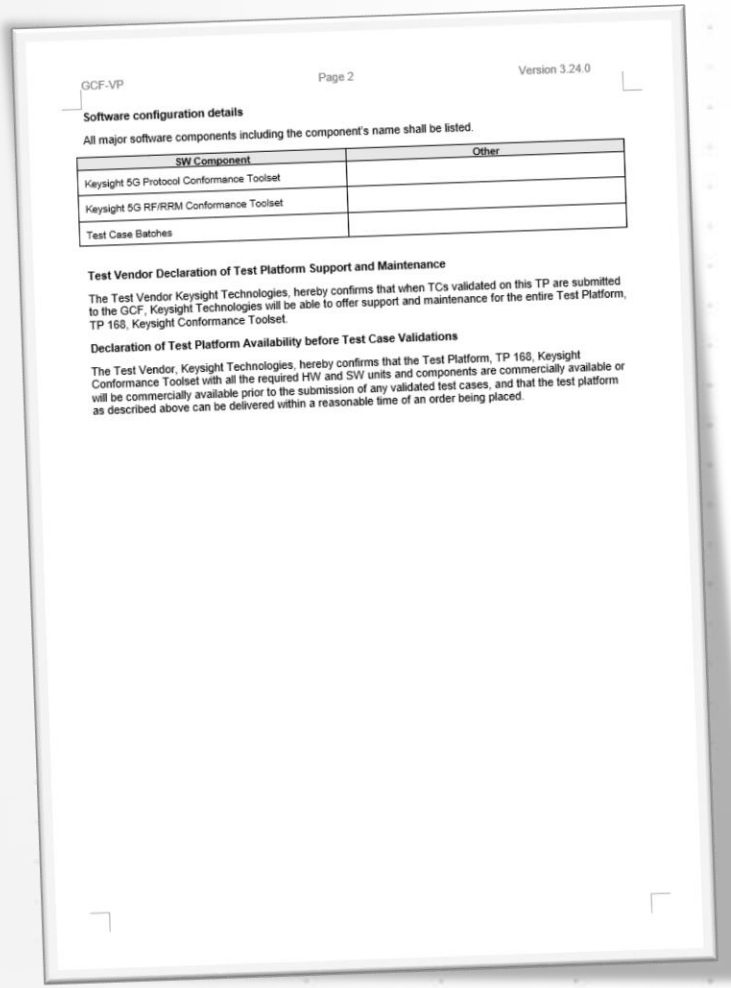


Sequencer

Log Viewer

Keysight 5G NR Conformance Test Platform

TP168 INTRODUCED BY AUGUST 2018 IN GCF



GCF-VP Page 2 Version 3.24.0

Software configuration details

All major software components including the component's name shall be listed.

SW Component	Other
Keysight 5G Protocol Conformance Toolset	
Keysight 5G RF/RRM Conformance Toolset	
Test Case Batches	

Test Vendor Declaration of Test Platform Support and Maintenance

The Test Vendor Keysight Technologies, hereby confirms that when TCs validated on this TP are submitted to the GCF, Keysight Technologies will be able to offer support and maintenance for the entire Test Platform, TP 168, Keysight Conformance Toolset.

Declaration of Test Platform Availability before Test Case Validations

The Test Vendor, Keysight Technologies, hereby confirms that the Test Platform, TP 168, Keysight Conformance Toolset with all the required HW and SW units and components are commercially available or will be commercially available prior to the submission of any validated test cases, and that the test platform as described above can be delivered within a reasonable time of an order being placed.

GCF-VP Page 1 Version 3.24.0

Annex D: New Test Platform Declaration Form

GCF Global Certification Forum — KEYSIGHT TECHNOLOGIES

Title:	New Test Platform declaration for presentation to the CAG
Test Platform Number:	The following TP number has been allocated from the DCC Database: TP 168.
GCF Work Item:	The Test Platform is initially intended to provide test capabilities for the following Work Items: WI 501, WI-502, WI-503, WI-504, WI-505.
Description:	Keysight Conformance Toolset for 5G Protocol, RF and RRM conformance testing.
Source:	Keysight Technologies
Date:	21st August 2018
For presentation at:	CAG#56 / 23th – 24th October / Lexington, KY, USA

Test Platform Declaration

Test Platform(s) manufacturer, name: Keysight Technologies, Keysight Conformance Toolset

Test Platform(s) Details:

TP168 represents the Protocol and RF/RRM Conformance Toolset solutions from Keysight Technologies.

All main components of the test system (hardware and software) are manufactured and supported by Keysight Technologies. The major components of the Test System are detailed below.

Hardware configuration details

Hardware Manufacturer	HW Components Name	Other
Keysight Technologies	UXM 5G Wireless Test Set	www.keysight.com/find/5G
Keysight Technologies	Common Interface IF Unit	
Keysight Technologies	mmWave Transceiver	
Keysight Technologies	OTA Chamber	
Keysight Technologies	Signal Analyzer	
Keysight Technologies	Signal Generator	
Keysight Technologies	Switching Unit	

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What are your mm-Wave OTA testing needs?

5G DEVICE END-END SOLUTIONS

RF/Antenna	Protocol/Functional Single Link	Beamforming with Clean channel	Mobility and Performance

CATR

RMTC

2D MPAC

3D MPAC

5G NES Hardware Components

3 KEY BUILDING BLOCKS

UXM 5G Wireless Test Platform (E7515B)

- <6GHz Frequency range
- Scalable bandwidth 8Tx/4Rx @800MHz, 4Tx/2Rx @1600MHz
- Integrated RFIO + Internal fading
- Support for RF, IF, Host and BBIQ interfaces (slow and full rate)
- Support for 10GbE connectivity

Common Interfacing Unit (E7770A)

- Same unit for both PROPSIM CE and UXM 5G
- Supports up to 8x heads, with scalability for more
- Flexibility to add new heads to support new bands
- Supports high IF connection (6-12 GHz)

mmWave Transceiver for 5G (RRH)

- Supports 28, 39 and 40GHz bands
- Compact, bi-directional

Questions and Resources

WHERE TO GO FOR HELP

www.keysight.com/find/5GNR

- Simulation
  - www.keysight.com/find/Systemvue
- Signal Generation:
  - www.keysight.com/find/N7631C
  - www.keysight.com/find/N5182B
  - www.keysight.com/find/N9383A
  - www.keysight.com/find/M8190A
  - www.keysight.com/find/M8195A
- Signal Analysis:
  - www.keysight.com/find/89601B
  - www.keysight.com/find/N9085E
  - www.keysight.com/find/N
  - www.keysight.com/find/M9393A
  - www.keysight.com/find/PXA
  - www.keysight.com/find/UXA
- Channel Emulation:
  - www.keysight.com/find/Propsim
- DVT and Manufacturing;
  - www.keysight.com/find/E6640A
  - www.keysight.com/find/M9410A
  - www.keysight.com/find/M9411A
  - www.keysight.com/find/S9100A
- Contact your local Field Engineer for;
  - gNB Emulator for UE Testing: (UXM 5G – E7515B)
  - Test chambers
  - mmWave extenders (CIU and RRH)
- Field Testing;
  - www.keysight.com/find/Fieldfox
  - www.keysight.com/find/NEMO

5G Boot Camp presentations available from:
www.keysight.com/find/5GBootCampPresentations