5G Boot Camp

PART TWO:
7 KEY MEASUREMENT CHALLENGES AND CASE STUDIES

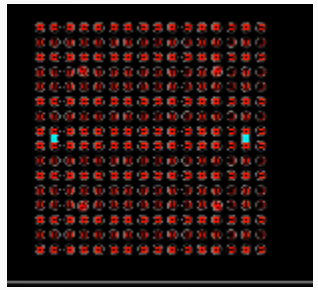
Keysight Technologies

2019 JAN

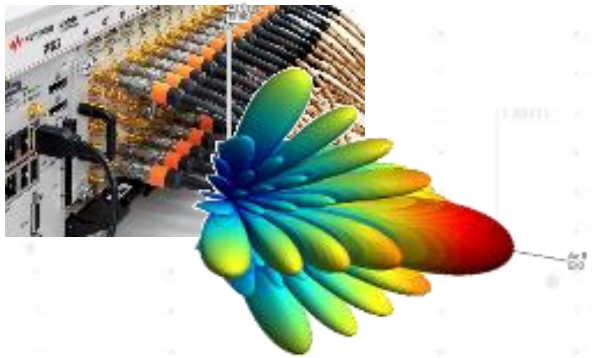
JianHuaWu

7 Key Measurement Challenges

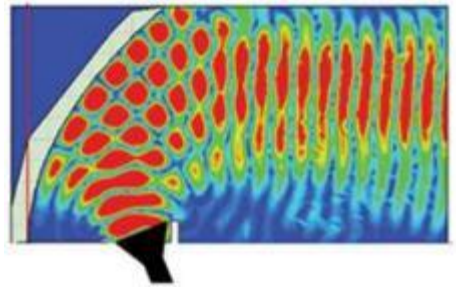
Signal Quality
mmW, Waveform, Fidelity



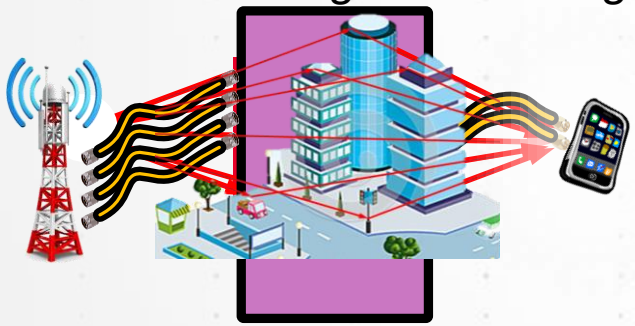
Lots of Channels
MIMO/Beamforming



Life Beyond Connectors
Over-the-Air



Channel
Characterizing & Emulating



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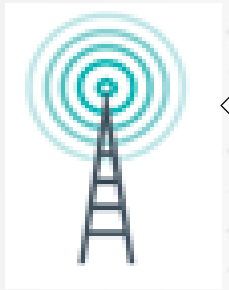
7

Suppose you want to design and test a motorbike

UNDERSTANDING THE CHANNEL IS OBVIOUSLY CRITICAL TO SUCCESS

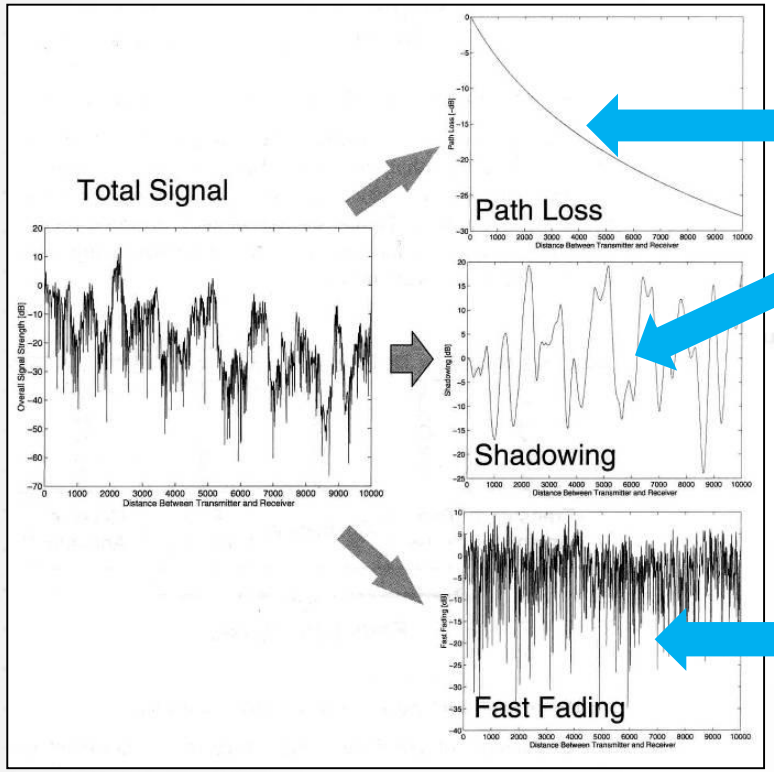
What is the Radio Channel?

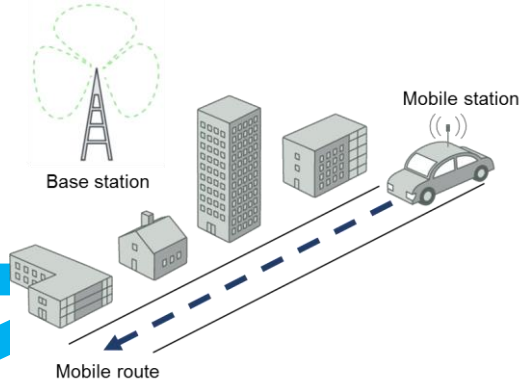


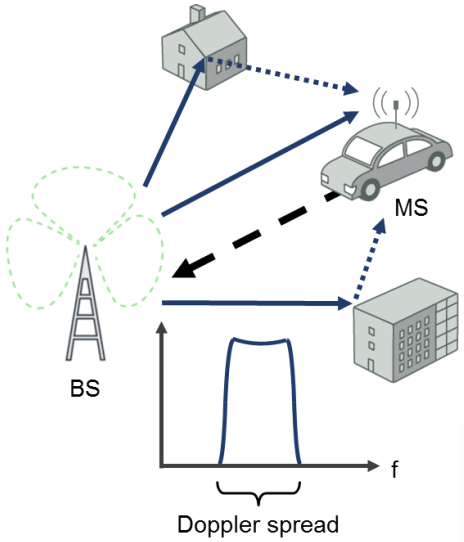
Channel
$h(t)$

Radio Channel = Propagation path between Tranceivers =>
Antenna beam pattern * Multipath Propagation * Mobility + Interference

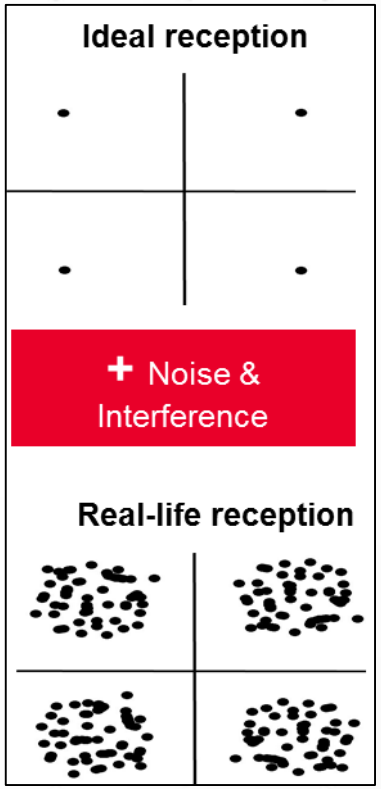
PROPAGATION







INTERFERENCE



Noise

- Thermal Noise
- Broadband noise from PAs

Adjacent cells/Users
Modulated waveforms

- Co-channel interference
- Adjacent channel interference

The evolution of channel models

- 2G <3 GHz, 200 kHz BW
- Non-spatial TDL
- 3G <3 GHz, 5 MHz BW
- Non-spatial TDL
- 4G < 6 GHz, 20 MHz BW
- Non-spatial TDL – conducted tests
- SCME CDL – MIMO OTA (radiated)
- 3D MIMO (for BS elevation beamforming studies)
- **5G** **0.5 – 100 GHz, >1 GHz BW**
- **Spatial CDL**

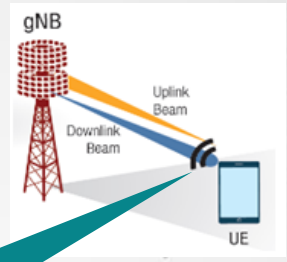
Channel models have been developed over many decades based primarily on channel measurements (sounding)

More recently, ***Ray Tracing*** of modelled environments has become possible

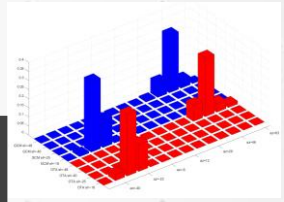
The trend is from non-spatial to spatial models which implies testing has to be done OTA

TDL - Tapped delay line (time only)
CDL – Cluster delay line (time and space)
SCME – Spatial channel model extended

5G Challenge: Highly Dynamic Fading Channel in Field – connected state UE mobility

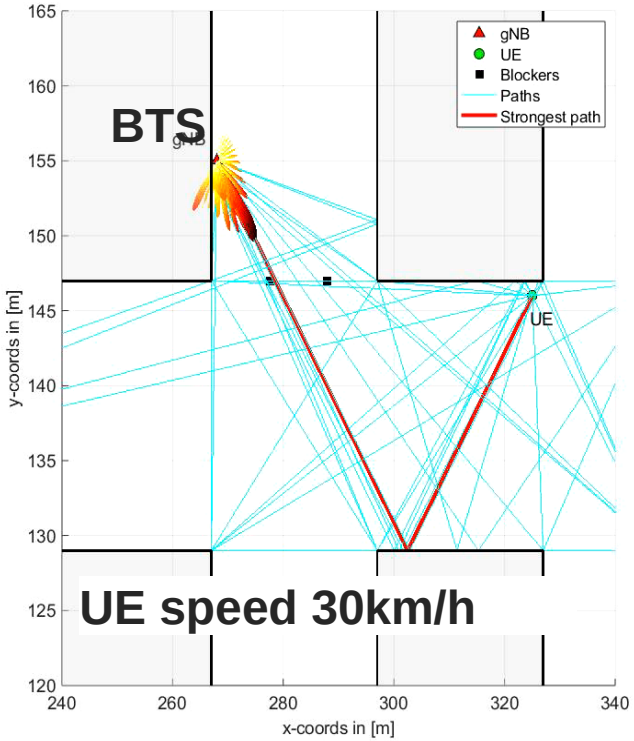


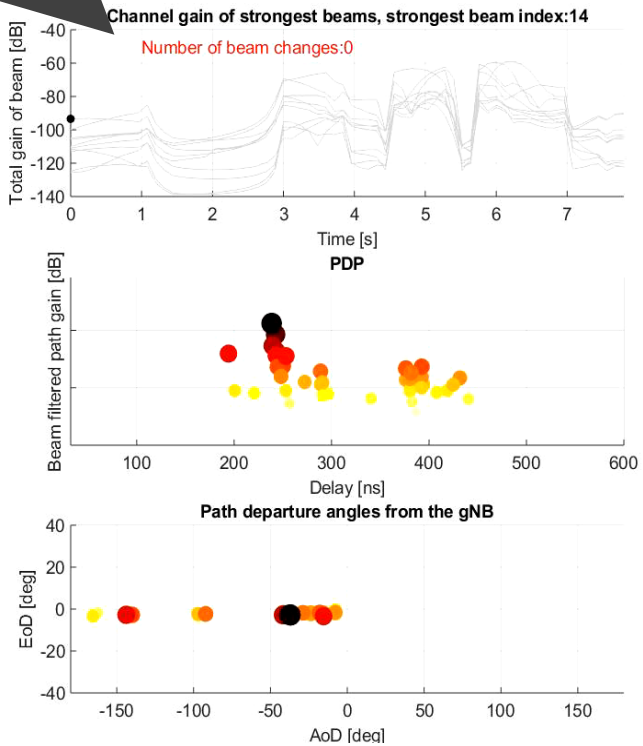
Where is my next Beam?
Fast & reliable beam management needed



Fast fading filtered out on gain curves to have clearer visual

- BTS and UE(s) need to have seamless interoperability on beam refinement and change, and eventually handover to next cell and/or fallback to LTE
- Highly blocking channel conditions – high probability on link collapse - how to mitigate?



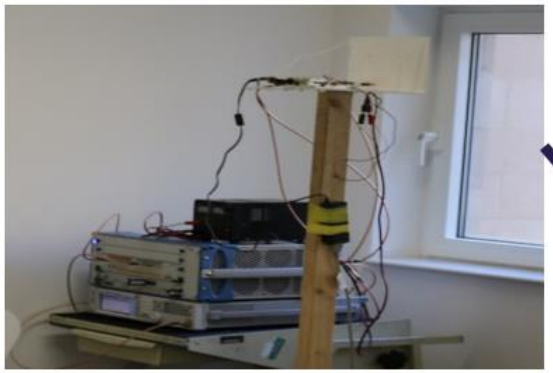


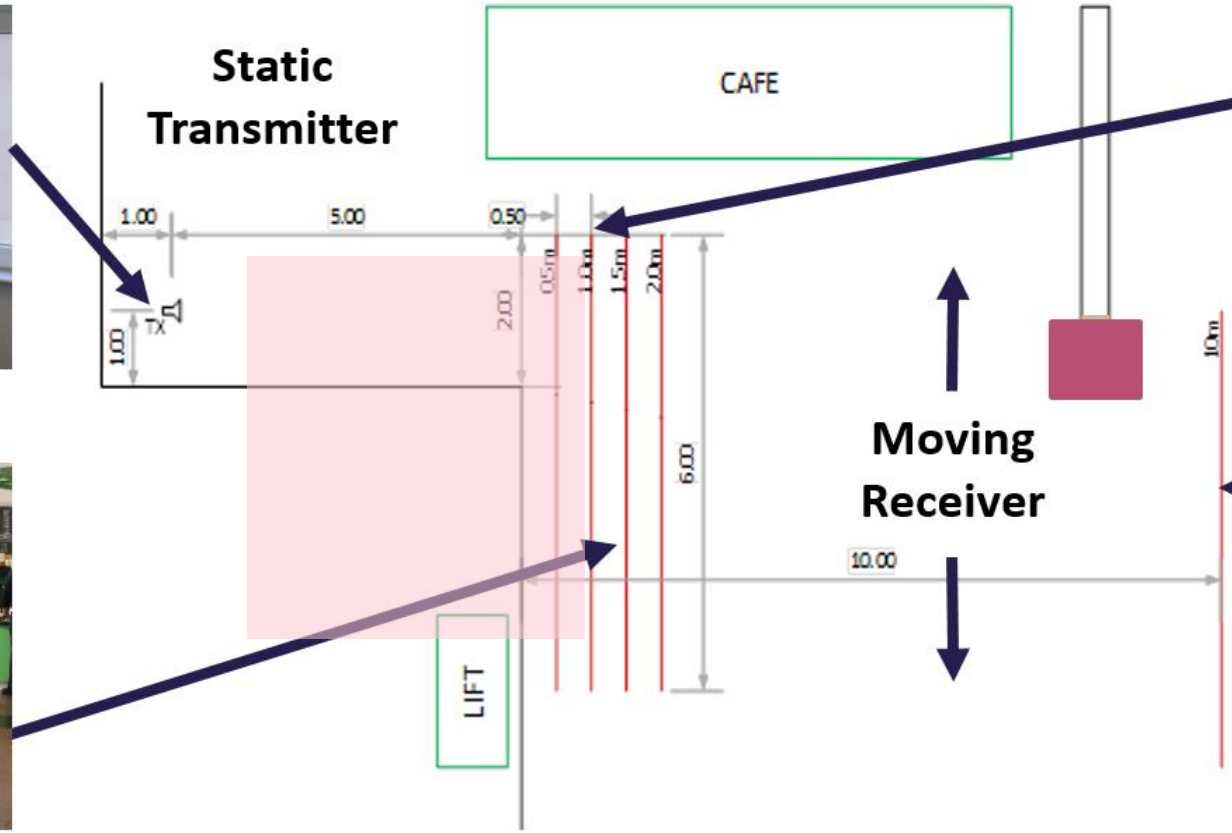
Fading Cluster AoD's are dynamic

What about the Channel at mmWave?

CORNER DIFFRACTION STUDY

ftp.3gpp.org/tsg_ran/WG1_RL1/TSGR1_84b/Docs/R1-162872.zip





How well do 60 GHz signals bend round corners?

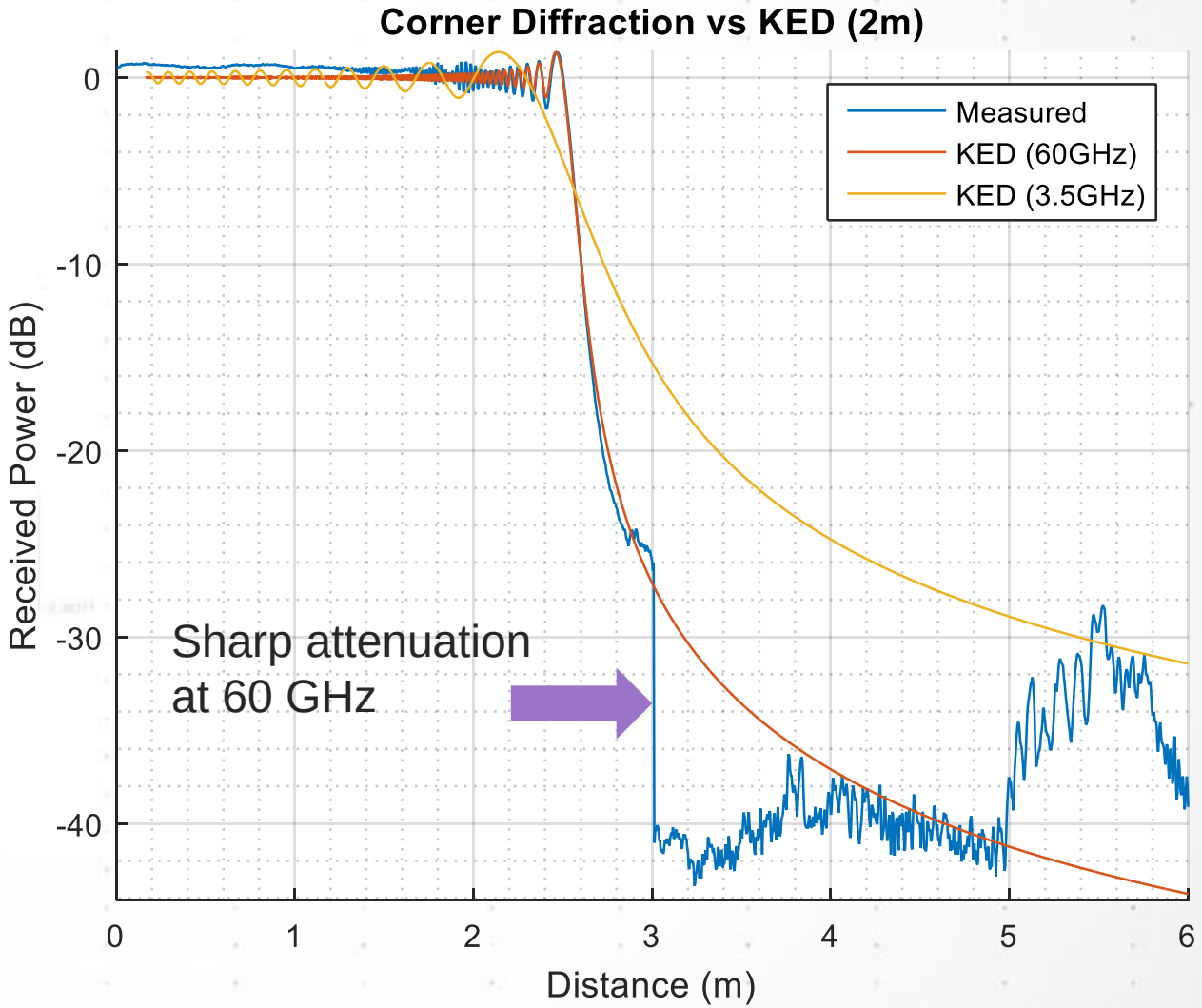
Simulated vs. measured at 3.5 GHz and 60 GHz

CORNER DIFFRACTION STUDY

AT 3.5 GHZ THE SHADOW EFFECT IS MUCH LESS PRONOUNCED

EVEN AT 2M DISTANCE WITH 40CM OF TRAVEL:

- 60 GHZ IS AT -25 DB
- 3.5 GHZ IS AT -8 DB



3GPP TR 38.901 - Stochastic model overview

CHANNEL MODEL FOR UP TO 100 GHZ

- **Extended from existing sub-6 GHz channel models:** 3D MIMO model (3GPP TR 36.873) or IMT-Advanced (ITU-R M.2135).
- Developed for **performance evaluations of 5G physical layer techniques**
- Designed to cover testing of both **Mobile Equipment and Access Network of 3GPP systems**
- **Supported scenarios are urban microcell street canyon, urban macro cell, indoor office, and rural macro cell**
- Key properties of the models
  - **Frequency range from 0.5 to 100 GHz**
  - **Bandwidth is supported up to 10% of the center frequency but no larger than 2 GHz**
  - **Spatial** consistency is supported
  - System-level, Link-level CDL-models and non-spatial TDL-models

Channel Model and Scenario	Description	LOS	NLOS
3GPP 5G 38.901 UMi CDL-A	[11]	-	√
3GPP 5G 38.901 UMi CDL-B	[11]	-	√
3GPP 5G 38.901 UMi CDL-C	[11]	-	√
3GPP 5G 38.901 UMi CDL-D	[11]	√	-
3GPP 5G 38.901 UMi CDL-E	[11]	√	-
3GPP 5G 38.901 UMi O2I	[11]	-	√
3GPP 5G 38.901 UMi O2I CDL-A	[11]	-	√
3GPP 5G 38.901 UMi O2I CDL-B	[11]	-	√
3GPP 5G 38.901 UMi O2I CDL-C	[11]	-	√
3GPP 5G 38.901 UMa	[11]	√	√
3GPP 5G 38.901 UMa CDL-A	[11]	-	√
3GPP 5G 38.901 UMa CDL-B	[11]	-	√
3GPP 5G 38.901 UMa CDL-C	[11]	-	√
3GPP 5G 38.901 UMa CDL-D	[11]	√	-
3GPP 5G 38.901 UMa CDL-E	[11]	√	-
3GPP 5G 38.901 UMa O2I	[11]	-	√
3GPP 5G 38.901 UMa O2I CDL-A	[11]	-	√
3GPP 5G 38.901 UMa O2I CDL-B	[11]	-	√
3GPP 5G 38.901 UMa O2I CDL-C	[11]	-	√
3GPP 5G 38.901 RMa	[11]	√	√
3GPP 5G 38.901 RMa CDL-A	[11]	-	√
3GPP 5G 38.901 RMa CDL-B	[11]	-	√
3GPP 5G 38.901 RMa CDL-C	[11]	-	√
3GPP 5G 38.901 RMa CDL-D	[11]	√	-
3GPP 5G 38.901 RMa CDL-E	[11]	√	-
3GPP 5G 38.901 InO	[11]	√	√
3GPP 5G 38.901 InO CDL-A	[11]	-	√
3GPP 5G 38.901 InO CDL-B	[11]	-	√
3GPP 5G 38.901 InO CDL-C	[11]	-	√
3GPP 5G 38.901 InO CDL-D	[11]	√	-
3GPP 5G 38.901 InO CDL-E	[11]	√	-

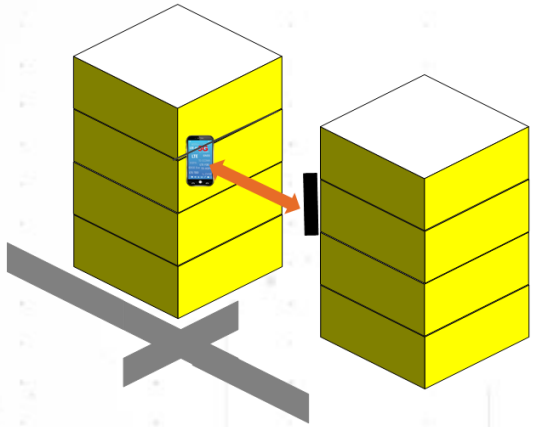
LOS / NLOS

Use cases for Massive MIMO testing

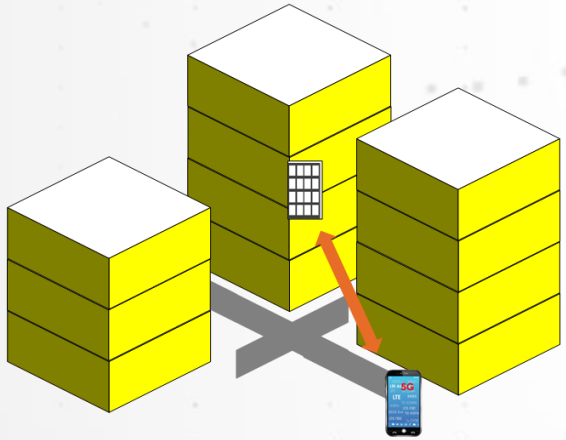
3GPP TR 38.901 CHANNEL MODEL SCENARIOS

Urban Microcell (UMi)

UMi Outdoor to Indoor (O2I)

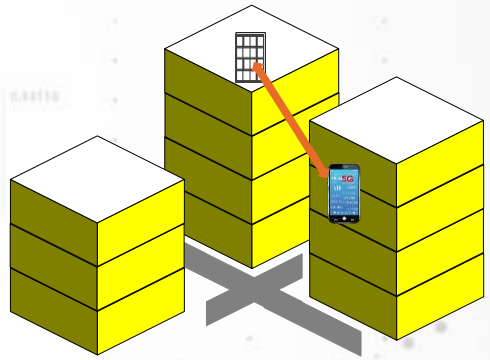


UMi street canyon (O2O)

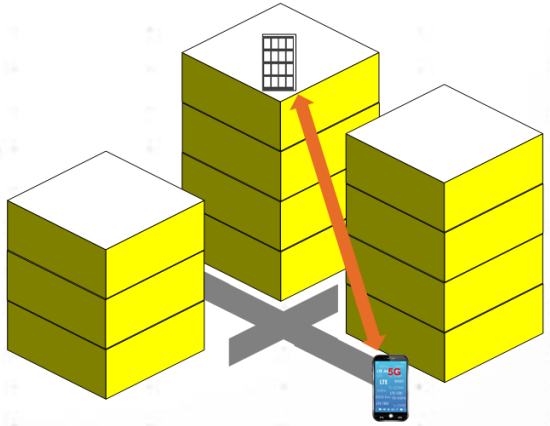


BSs mounted below rooftops

UMa Outdoor to Indoor (O2I)



UMa street canyon



Urban Macrocell (UMa)

BSs mounted above rooftops

Channel models for link-level evaluations

CLUSTERED DELAY LINE (CDL) MODELS

- TR 38.901 specifies five different CDL channel profiles;
  - CDL-A, CDL-B and CDL-C are constructed for **NLOS**
  - CDL-D and CDL-E are constructed for **LOS**
- The RMS delay spread values of both CDL models are normalized and they can be scaled in delay for a desired RMS delay spread

Table 7.7.1-2. CDL-B

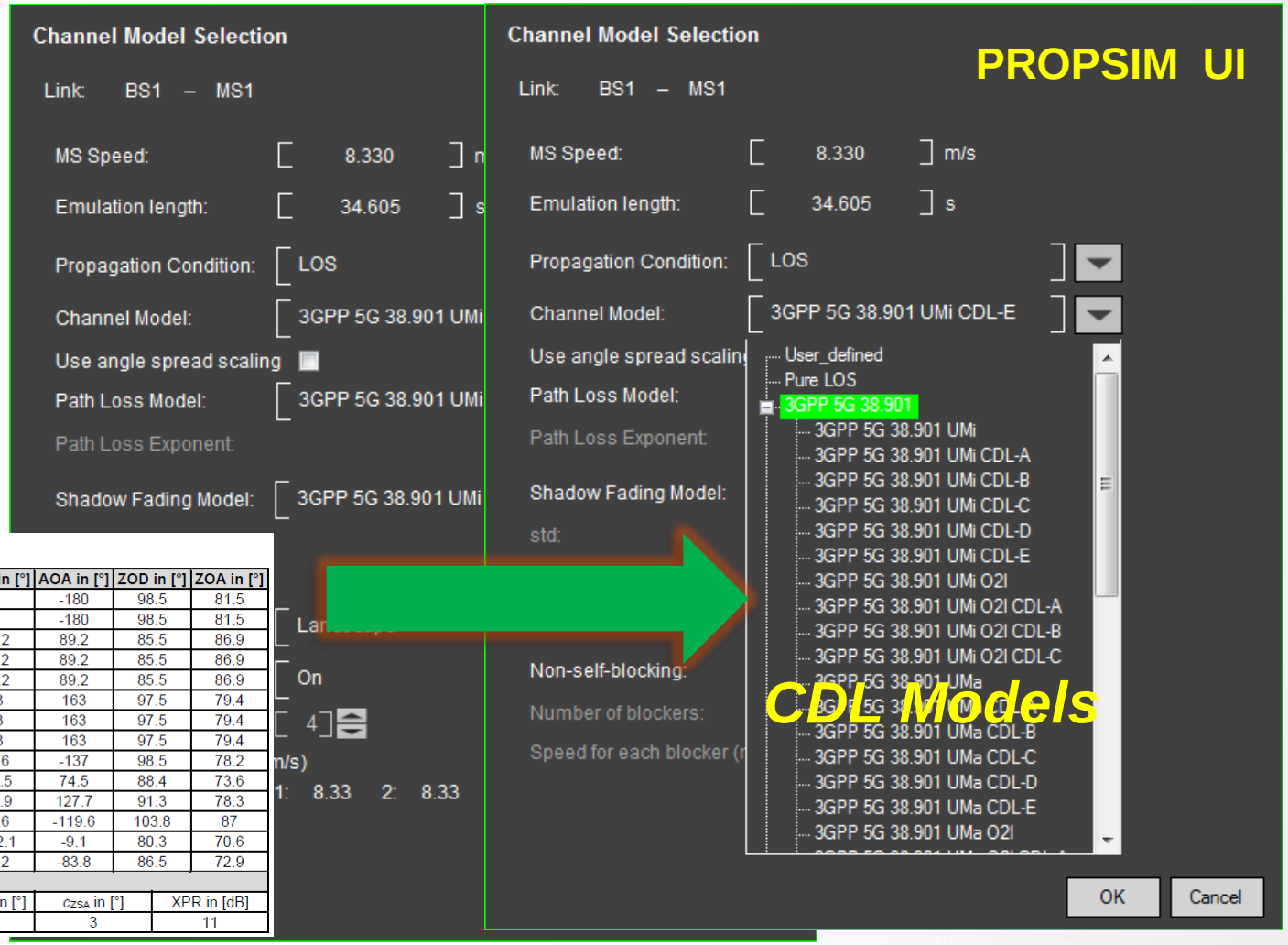
Cluster #	Normalized delay	Power in [dB]	AOD in [°]	AOA in [°]	ZOD in [°]	ZOA in [°]
1	0.0000	0	9.3	-173.3	105.8	78.9
2	0.1072	-2.2	9.3	-173.3	105.8	78.9
3	0.2155	-4	9.3	-173.3	105.8	78.9
4	0.2095	-3.2	-34.1	125.5	115.3	63.3
5	0.2870	-9.8	-65.4	-8		
6	0.2986	-1.2	-11.4	15		
7	0.3752	-3.4	-11.4	15		
8	0.5055	-5.2	-11.4	15		
9	0.3681	-7.6	-67.2	-8		
10	0.3697	-3	52.5	13		
11	0.5700	-8.9	-72	-8		
12	0.5283	-9	74.3	95		
13	1.1021	-4.8	-52.2	10		
14	1.2756	-5.7	-50.5	-8		
15	1.5474	-7.5	61.4	-9		
16	1.7842	-1.9	30.6	-13		
17	2.0169	-7.6	-72.5	-9		
18	2.8294	-12.2	-90.6	58		
19	3.0219	-9.8	-77.6	-7		
20	3.6187	-11.4	-82.6	65		
21	4.1067	-14.9	-103.6	52		
22	4.2790	-9.2	75.6	88		
23	4.7834	-11.3	-77.6	-6		

Per-Cluster Parameters			
Parameter	C_{ASD} in [°]	C_{ASA} in [°]	C_{ZSD} in [°]
Value	10	22	3

Table 7.7.1-4. CDL-D.

Cluster #	Cluster PAS	Normalized Delay	Power in [dB]	AOD in [°]	AOA in [°]	ZOD in [°]	ZOA in [°]
1	Specular(LOS path)	0	-0.2	0	-180	98.5	81.5
	Laplacian	0	-13.5	0	-180	98.5	81.5
2	Laplacian	0.035	-18.8	89.2	89.2	85.5	86.9
3	Laplacian	0.612	-21	89.2	89.2	85.5	86.9
4	Laplacian	1.363	-22.8	89.2	89.2	85.5	86.9
5	Laplacian	1.405	-17.9	13	163	97.5	79.4
6	Laplacian	1.804	-20.1	13	163	97.5	79.4
7	Laplacian	2.596	-21.9	13	163	97.5	79.4
8	Laplacian	1.775	-22.9	34.6	-137	98.5	78.2
9	Laplacian	4.042	-27.8	-64.5	74.5	88.4	73.6
10	Laplacian	7.937	-23.6	-32.9	127.7	91.3	78.3
11	Laplacian	9.424	-24.8	52.6	-119.6	103.8	87
12	Laplacian	9.708	-30.0	-132.1	-9.1	80.3	70.6
13	Laplacian	12.525	-27.7	77.2	-83.8	86.5	72.9

Per-Cluster Parameters					
Parameter	C_{ASD} in [°]	C_{ASA} in [°]	C_{ZSD} in [°]	C_{ZSA} in [°]	XPR in [dB]
Value	5	8	3	3	11

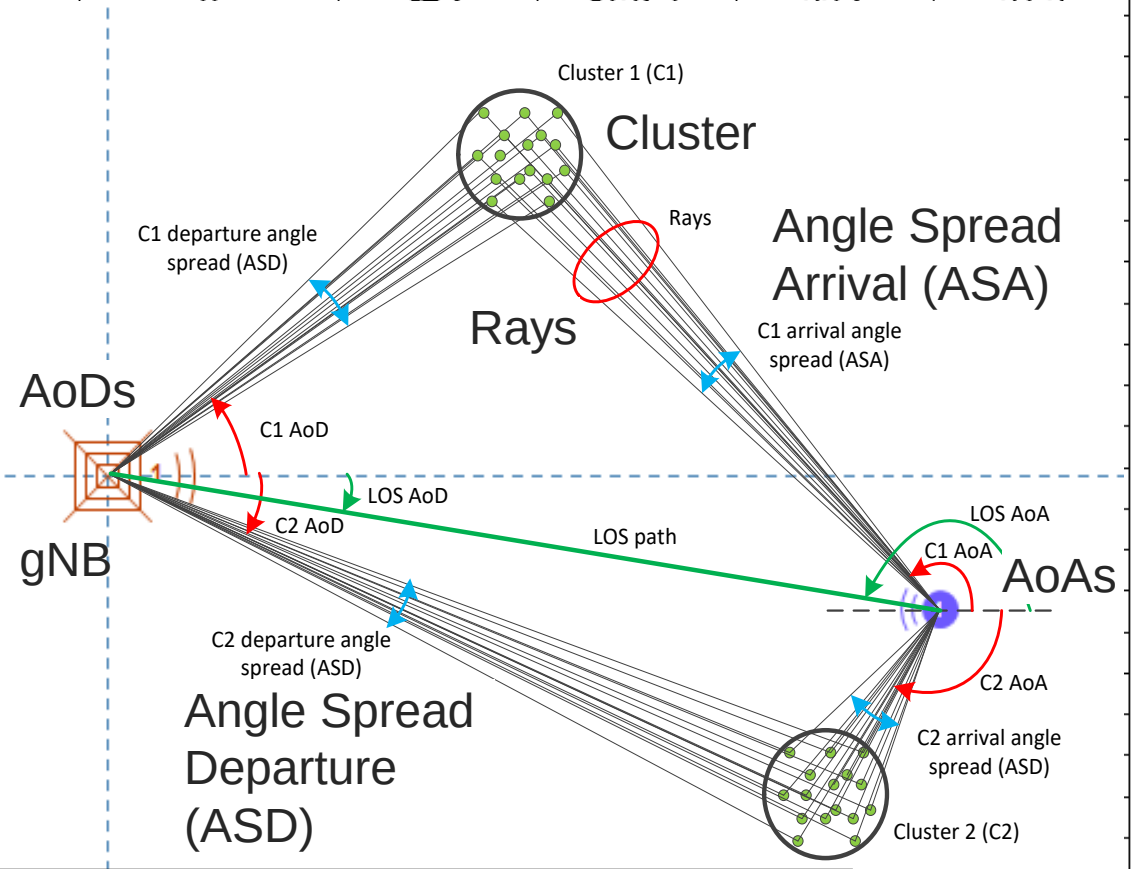


Channel models for FR2: CDL-A

- Example: TR 38.901 CDL-A
- CDL-A is a non line of sight (NLoS) model
- Each CDL comprises 23 clusters
- Each cluster comprises 20 multipath components (rays) around the cluster perimeter
- Each cluster has an AoD and AoA. These values are used to create the ray AoAs within a spread (ASA or ASD) defined by C_{ASA} and C_{ASD} in the table.
- **Etc -** Full details is in TR 38.901
- Diagram to the right shows the concept of the CDL models but showing only two clusters.

TR 38.901 Table 7.7.1-1. CDL-A

Cluster #	Normalized delay	Power in [dB]	AOD in [°]	AOA in [°]	ZOD in [°]	ZOA in [°]
1	0.0000	-13.4	-178.1	51.3	50.2	125.4
2	0.3819	0	-4.2	-152.7	93.2	91.3
3	0.4025					
4	0.5868					
5	0.4610					
6	0.5375					
7	0.6708					
8	0.5750					
9	0.7618					
10	1.5375					
11	1.8978					
12	2.2242					
13	2.1718					
14	2.4942					
15	2.5119					
16	3.0582					
17	4.0810					
18	4.4579					
19	4.5695					
20	4.7966					
21	5.0066					
22	5.3043					
23	9.6586					



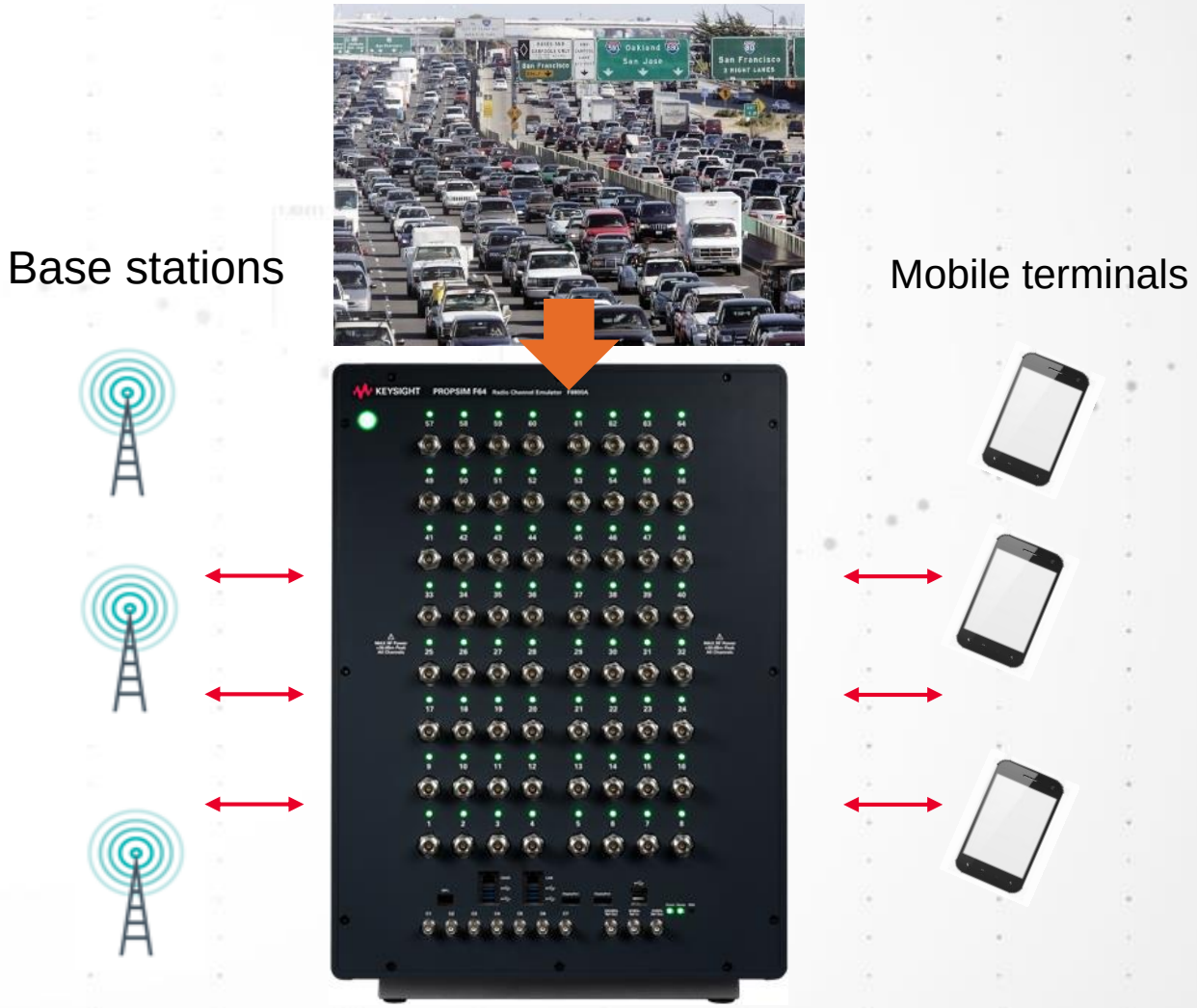
Per-Cluster Parameters					
Parameter	c_{ASD} in [°]	c_{ASA} in [°]	c_{ZSD} in [°]	c_{ZSA} in [°]	XPR in [dB]
Value	5	11	3	3	10

What is Standalone RF Channel Emulation?

ENABLES REAL-WORLD LIKE END-TO-END PERFORMANCE TESTING IN LAB

Real Time Emulation of radio wave propagation and interference to multiple BTS and Mobile simultaneously

- ✓Attenuation
- ✓Shadowing
- ✓Fast fading
- ✓Doppler effect
- ✓Noise and Interference
- ✓Antenna pattern embedding - Adaptive antenna systems
- ✓3D Beamform channels



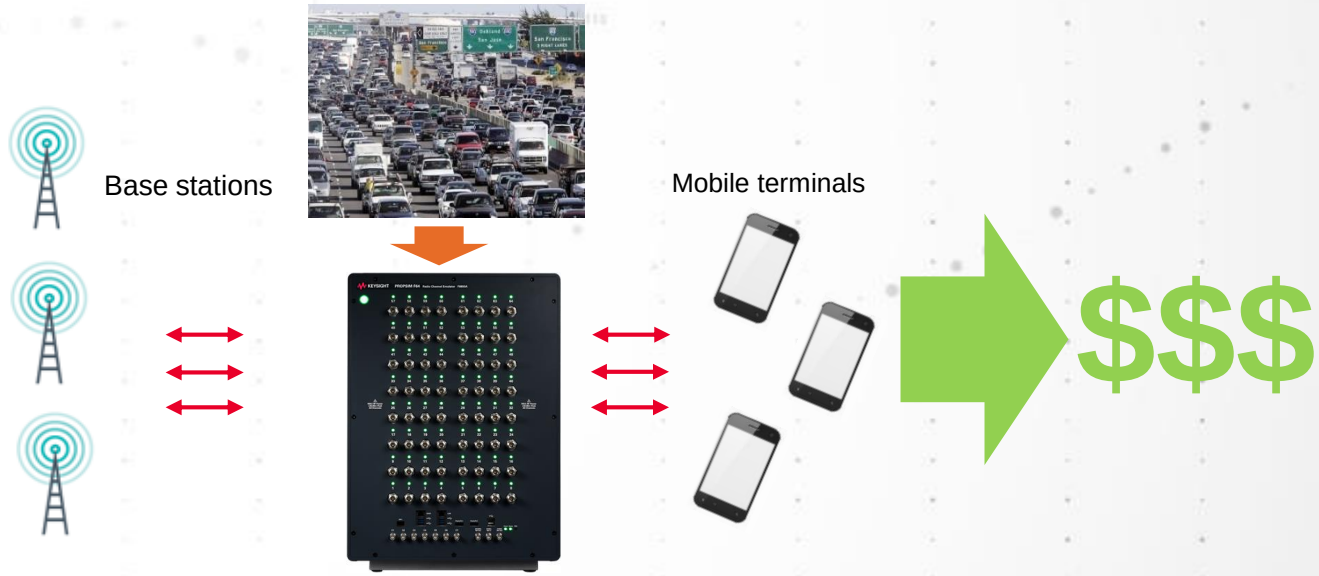
Why companies invest on Channel Emulation tools?

QUALITY OF SERVICE & TIME TO MARKET = SUCCESSFUL BUSINESS.

Each Mobile/Base Station/Device version (HW/SW) must be tested for

- ✓Receiver sensitivity and AGC
- ✓Channel Estimation algorithms
- ✓Min/max delay-Doppler (velocity scenarios)
- ✓Diversity/MIMO DSP Algorithms
- ✓Intersymbol/Intercarrier Interference, SNR mitigation
- ✓Synchronization
- ✓Radio Link Control, Radio Resource Management
- ✓Mobility Management
- ✓Network Vendor Interoperability, Device Vendor Interoperability

Radio Channel Emulation enables quick End-to-End full signaling Validation and Interoperability test in Lab



PROPSIM 5G Solutions for Base Station performance & device interoperability testing

Challenges

Complex RF conditions at field FR1 and FR2

Verification of the 5G NR BS performance

- Sub-6GHz massive MIMO 16TRX, 32TRX, 64TRX, 128TRX
- MU-MIMO performance optimization up to 4/8/16/32 layers

mmWave hybrid beamforming with wide signal BWs

- Beam management testing under various channel conditions
- Wide bandwidths up to 400 MHz per carrier, CA 800/1200 MHz
- Standalone (SA) and Non-Standalone (NSA) operating modes

Coexistence and mobility tests

- Scheduling and load management at network level

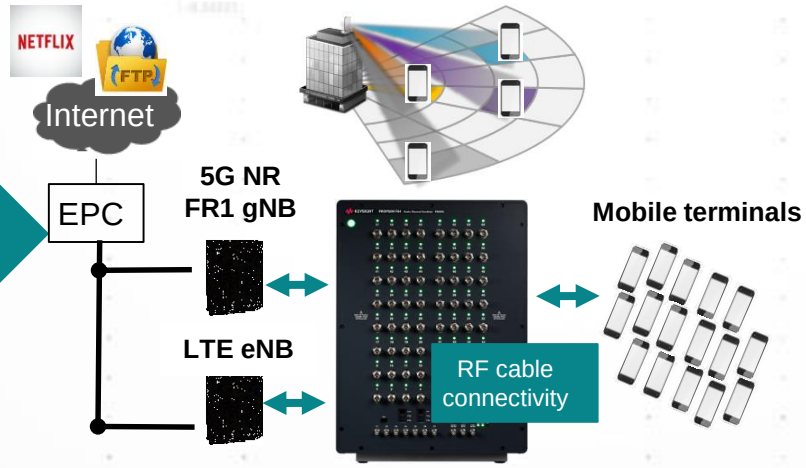
Solutions

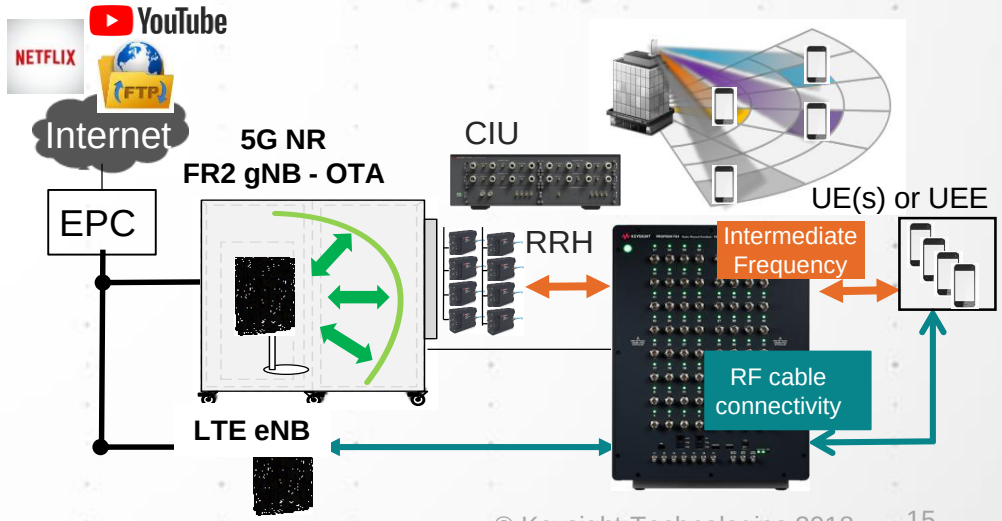
PROPSIM Geometric Channel Modeling (GCM) 5G Tools

- ✓ Channel modeling science ready & proven
- ✓ Antenna array modeling incl. patterns and DUT orientations in the scenario

PROPSIM 5G Channel Emulation solutions

- ✓ Capacity 16/32/64/128 element massive MIMO solutions sub 6 GHz
- ✓ All 5G NR BWs from 5 MHz up to 400 MHz
- ✓ CA up to 1.2 GHz Contiguous, 16CC non-contiguous
- ✓ Sub 6 GHz and mmWave solutions (CIU + RRH)
- ✓ Complete performance test solutions with UEE's and real UE's
- ✓ RF, IF and OTA*) connectivity methods





PROPSIM 5G Solutions for Device performance testing

Challenges

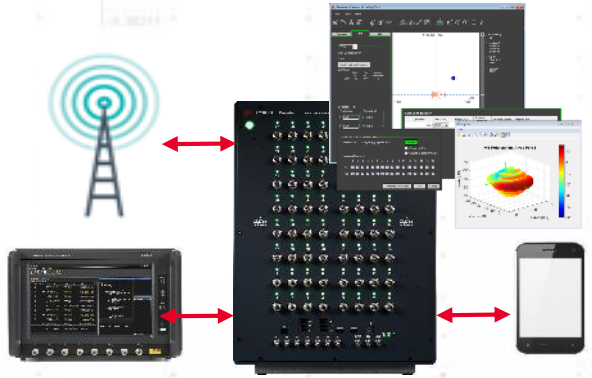
5G Channel Modeling
- Complex modeling science

5G Channel Emulation
- Realtime channel emulation
- Wide Bandwidths 100/200/400MHz
- CA 8CC/12CC/16CC
- Network Emulator and Real gNB support (NV-IOT)
- mmW OTA solutions
- Sub 6 GHz solutions

Solutions

PROPSIM Geometric Channel Modeling (GCM) 5G Tools
- ✓Channel Modeling Science ready & proven

PROPSIM 5G Channel Emulation solutions
- ✓Realtime very low insertion delay
- ✓BW 100/200/400 MHz up to 1.2 GHz
- ✓CA up to 12CC (1.2 GHz)
- ✓Seamslessly integrates with ***UXM 5G***, validated with 5G BTS
- ✓Complete mmWave OTA solutions using CIU with RRHs
- ✓Complete Sub 6 GHz performance test solutions
- ✓Device NV-IOT solutions (Network Vendor Interoperability)

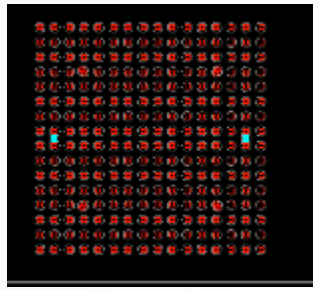


PROPSIM F64 Key Features

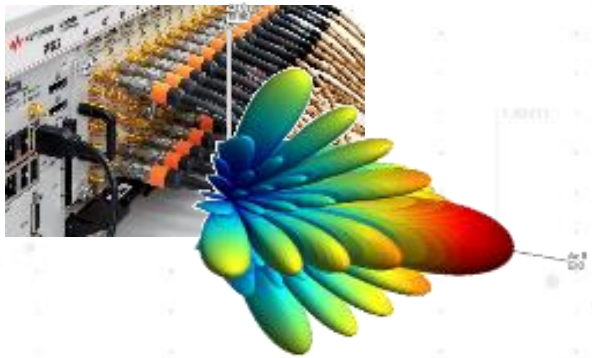
- **Single F8800A platform up to 64TRX, 1024 MIMO ch.**
  - HW configurations 8, 16, 24, 32, 40, 48, 56, 64 TRX
  - 64 TRX up to 100 MHz BW (160 MHz WLAN opt.)
  - 32 TRX up to 200 MHz BW
  - 16 TRX up to 400 MHz + 16 TRX up to 100/160 MHz BW
- **Carrier Aggregation TDD & FDD**
  - Non-contiguous CA up to 16CC
  - Contiguous up to 1200 MHz, other 200/400/600/800 MHz
- **RF range up to 450 - 6000 MHz per TRX port**
  - HIGH-IF 6-12 GHz with external HW (CIU)
  - mmW bands 28/39GHz with external HW (RRH)
- **5G Channel Models and test scenarios**
- **PROPSIM GCM 5G channel modeling software**
  - Advanced channel modeling science ready & proven
  - TR38.901 channel models available
- **Integrated calibration, no need for external VNA**

7 Key Measurement Challenges

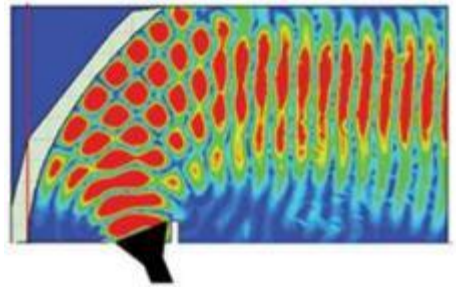
Signal Quality
mmW, Waveform, Fidelity



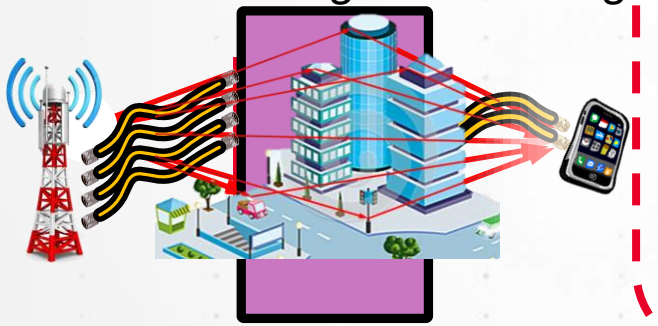
Lots of Channels
MIMO/Beamforming



Life Beyond Connectors
Over-the-Air



Channel
Characterizing & Emulating



Performance on the Network
Network Emulation

Protocol R&D | *RF / RRM DVT* | *Functional KPI*

6

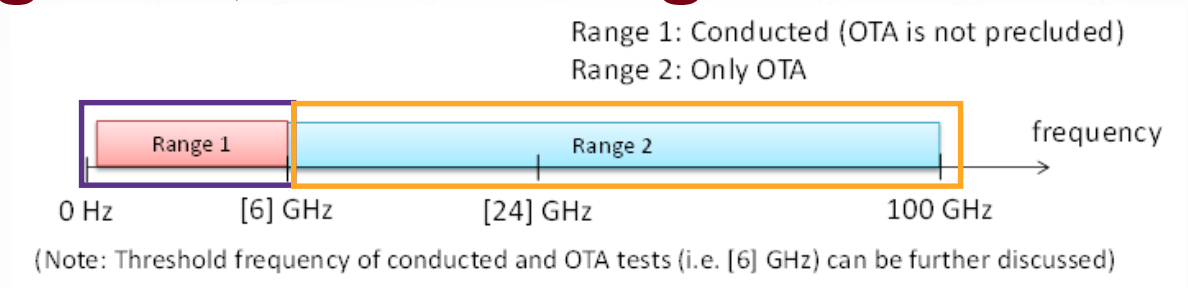
7

Challenge: Performance on the Network

Challenges

- Validate designs when standards are incomplete and still evolving
- Test the many different use cases introduced with numerology
- Troubleshoot issues between RF, Baseband, and Protocol
- Validate PHY control, link adaption, beam management
- Optimizing performance to meet KPI goals

5G, Something new, something old



Functional Performance

Modem Test,
Full Stack Testing,
Data Throughput,
Handover

OTA

RF Parametric

EVM, ACLR
PER, Emissions

Antenna & Conformance OTA

Antenna
Parameters
TRP, TIS

OTA

MIMO OTA

Throughput,
Virtual Drive Test,

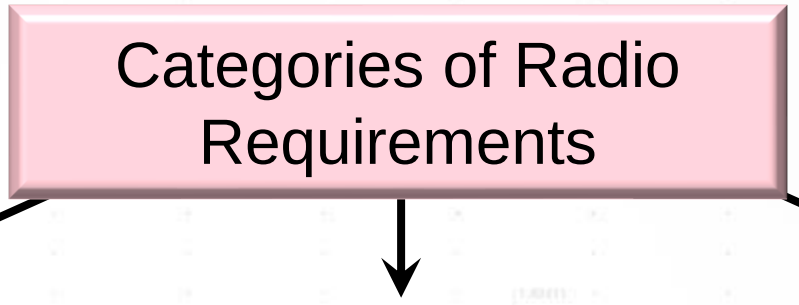
Is my chipset working?

Is my RF working?

How good is my antenna?

How good is my device?

The OTA challenge



	RF	Demodulation	RRM (Radio Resource Management)
What to measure	**Power, signal quality, sensitivity…**	**Throughput**	**Signal acquisition, CSI, tracking, handover…**
Channel to apply	**Basic line of sight no channel model**	**3D Spatial channel model**	**Dynamic multi-signal 3D spatial channel model**

Get the fastest path to 5G Solutions

TARGETING CHIPSET AND DEVICE WORKFLOW

5G Interactive R&D Solutions

- **Protocol R&D** — May'18
- **RF / RRM DVT** — 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

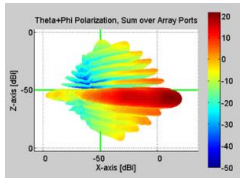
- **Manufacturing** — Apr '18

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 Network Emulation Test Solutions

PLATFORM HARDWARE BUILDING BLOCKS

5G Interactive Application

Sample tests

Protocol R&D	RF/RRM DVT	Functional KPI
Scripting Tool, L1 App	Automated RF measurements	E2E IP data, Application test

Test cases packages

Virtual Drive Testing	Carrier Acceptance	RF/ RRM Conformance	Protocol Conformance	Manufacturing Tools
Replicate live network scenarios	Protocol, Performance, Supplemental RF/RRM	GCF/PTCRB validated, Regulatory	GCF/PTCRB validated	Manufacturing Tools support UE calibration

Common scripting engine

Common measurement science

Signalling Stack

Non sig Test

Network Emulation Platform

Network Emulation

Host interface

IQ

IF

IQ

IF/ RF

RF

Common Logging & Automation support

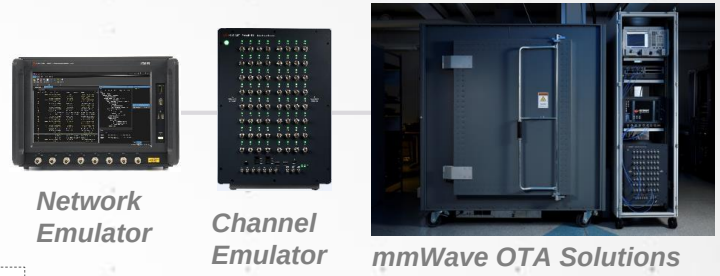
Channel Emulation

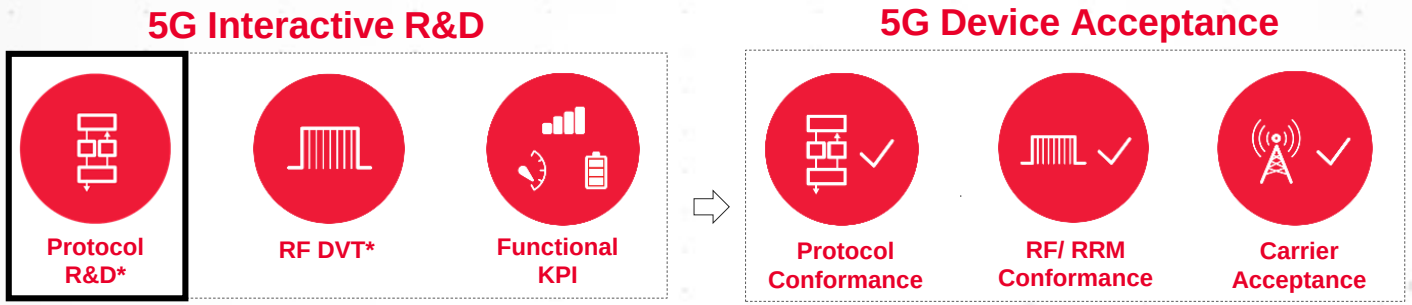
mmW support

Chambers

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:

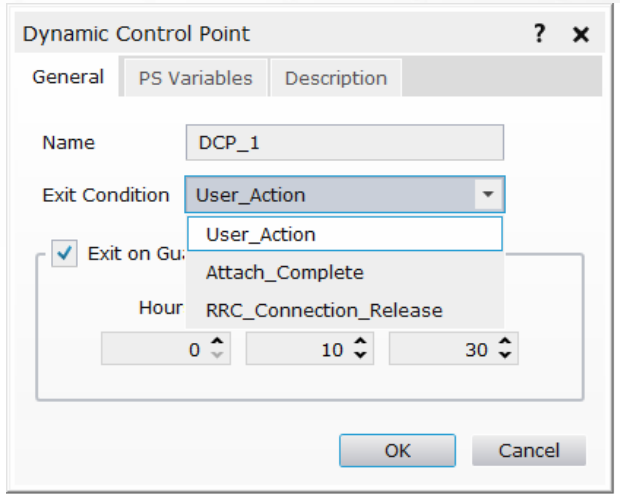
- ✓Earliest availability of new 5G features
- ✓Replicate desired network behavior whilst reducing test complexity with Built-in Protocol State Machine and Dynamic Control Points
- ✓L1/L2 parameter change without programming
- ✓Flexible automation and logging
- ✓Results viewer

Sub-6 GHz and mmWave - Conducted and OTA

Replicate network behaviour

5G PROTOCOL R&D TOOLSET

- Built-in Protocol State Machine and Dynamic Control Points simulates a “Live Network”
- Allows for interactive testing where the behaviour of a device can be investigated in an easy manner to facilitate debugging



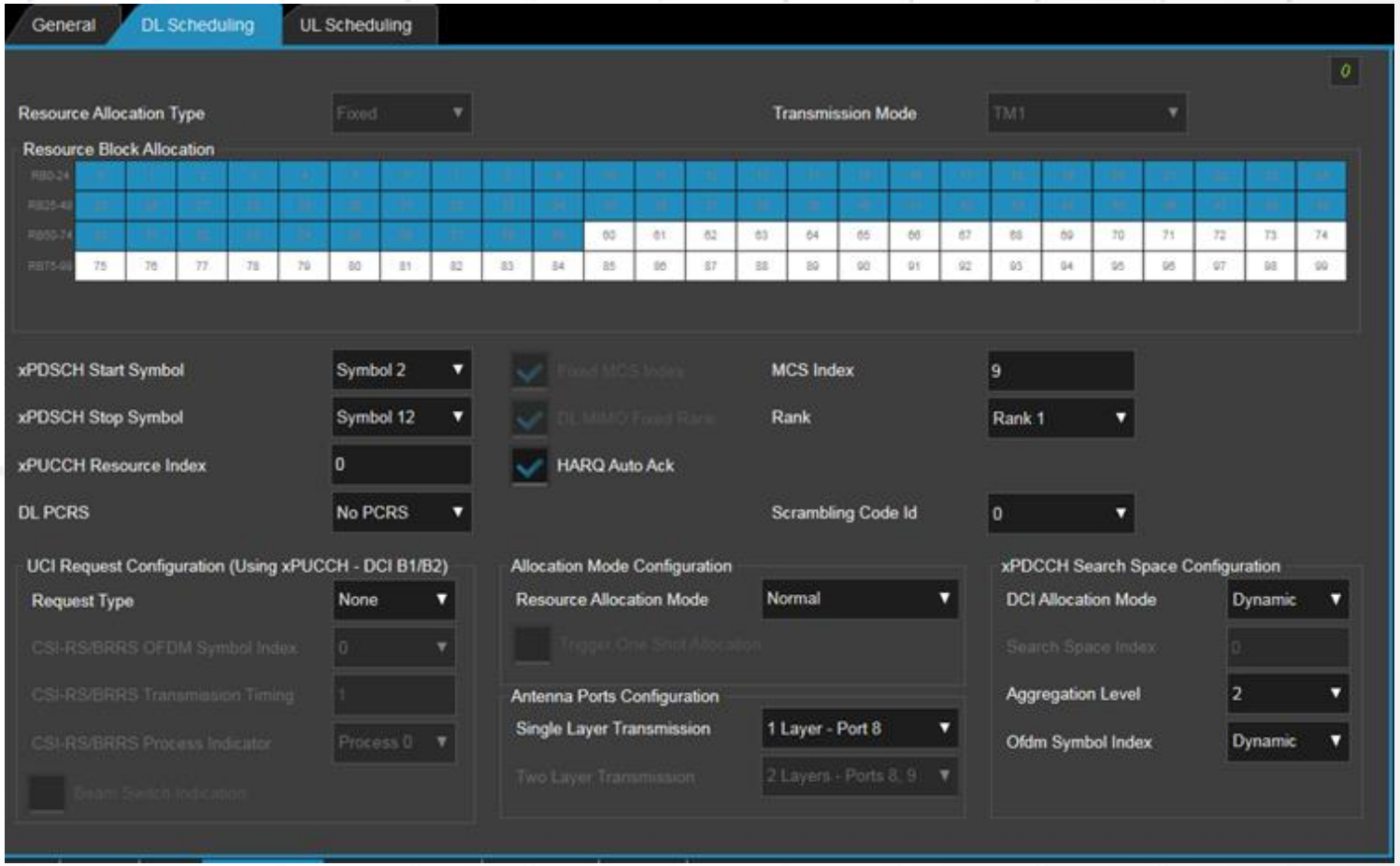
Script

Line	Time	Id	Direction	Details
1				Script Details [NR5G_LTE_PSCellAdd]
2				SIM Information [Explicitly defined]
3	00:00.00			5G User Prompt [Activate NR5G Cell]
4	00:00.00	NR-Cell A		Activate NR5G Cell [NR-Cell A :DL Power = -80 dBm/75kHz]
5	00:00.00	N-Cell A		5G DYNAMIC CONTROL POINT [Continue after User Action]
6	00:00.00			5G User Prompt [Start NR5GUEDemonstrator.exe]
7	00:05.00	E-Cell A		Activate LTE Cell
8	00:00.00	E-Cell A	SS --> MS	RRC Connection Reconfiguration
9	00:00.00			5G User Prompt [Wait, Press Ok to Exit]

Modify network behaviour easily

5G PROTOCOL R&D TOOLSET

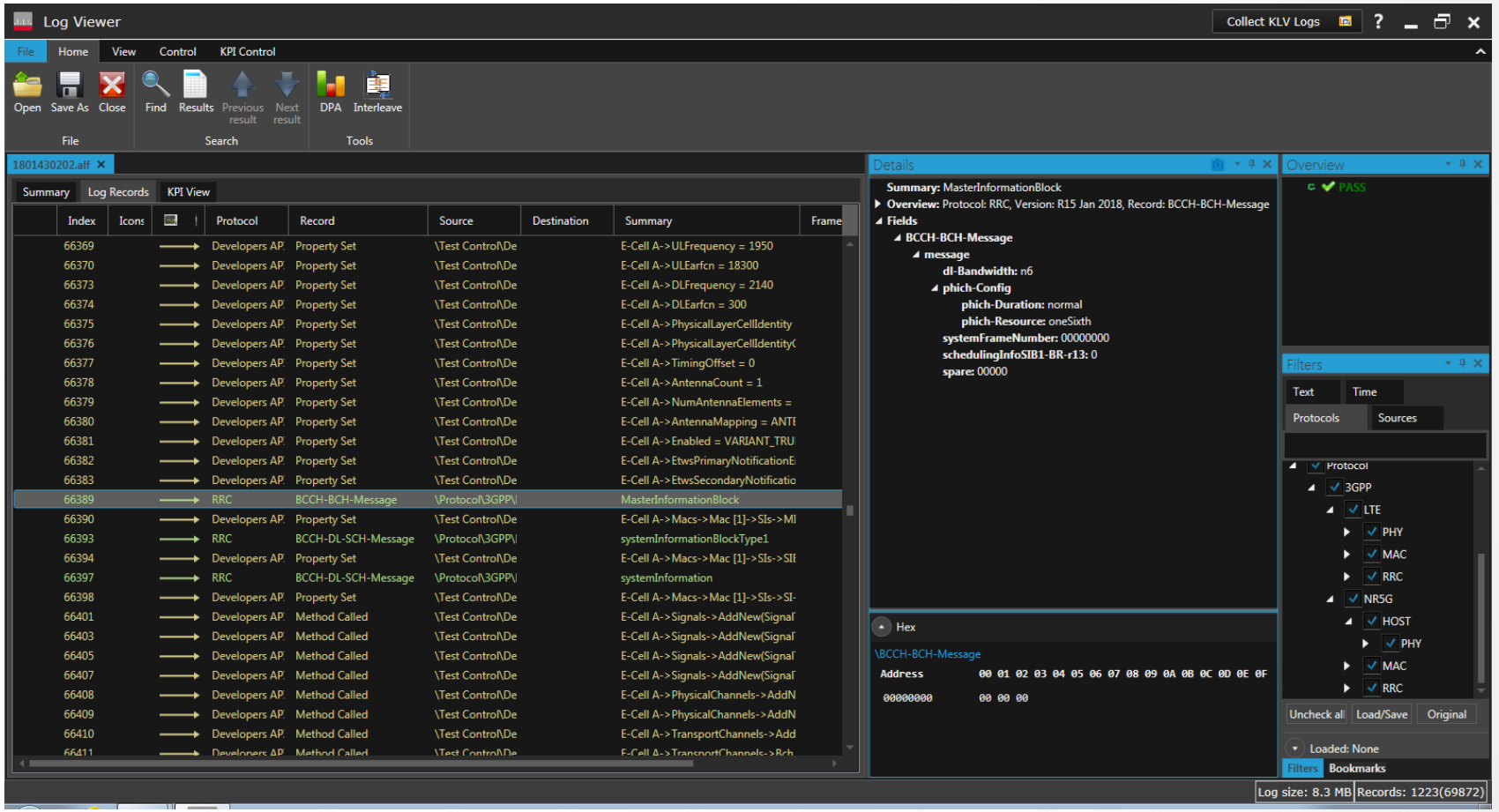
- Allow dynamic L1/L2 parameter changes without the need for programming
- Very useful in early development testing of prototypes



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



Results viewer

5G PROTOCOL R&D TOOLSET

- Customised view with multiple graphs
- Enhanced debugging as relationship between various KPIs such as data rate and BLER can easily be seen graphically
- Link from graph to relevant location in the log to facilitate debugging
- Report generation to share results with other teams

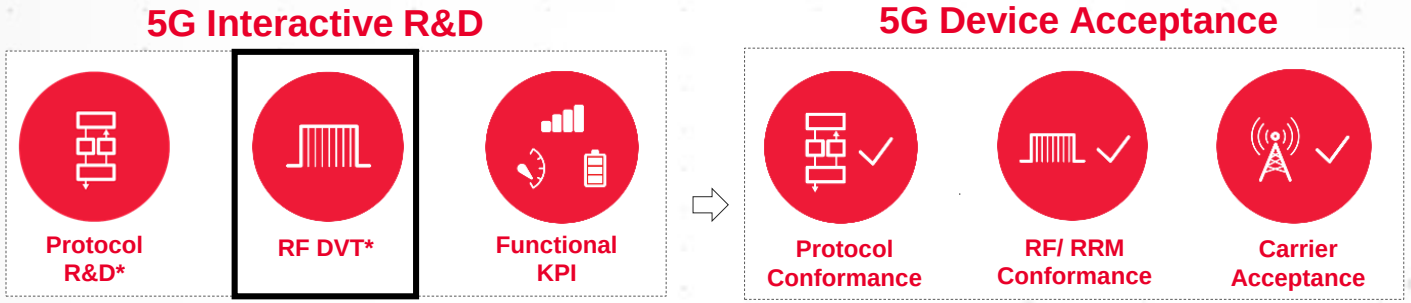
5G Device End-to-End Workflow

R&D CHALLENGES – RF DVT

Network Emulator

Channel Emulator

mmWave OTA Solutions



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:

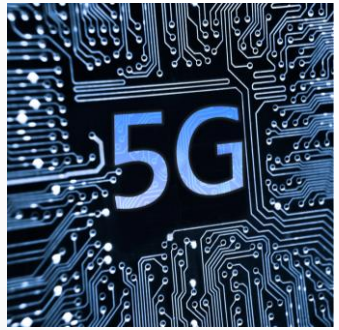
- ✓ 5G NR support
- ✓ RF Test Application
- ✓ Automation & Scripting
- ✓ Pre-conformance ready
- ✓ Traceability to conformance

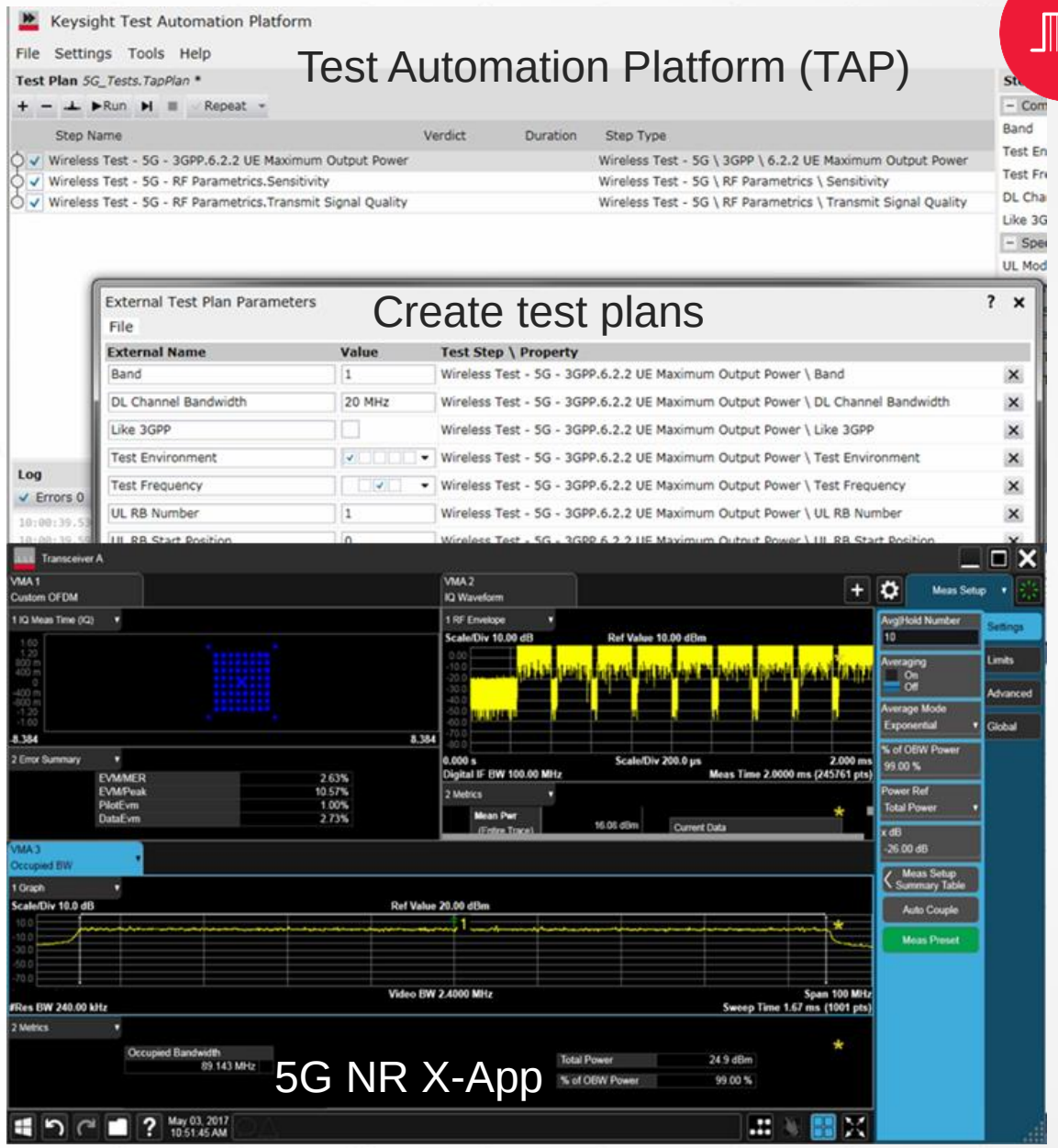
Sub-6 GHz and mmWave - Conducted and OTA

5G NR support

5G RF DVT TOOLSET

- Sub-6 GHz and mmWave
- Deployed standalone or with LTE anchor
- Flexible numerology
- High directivity phase-array antennas and beamforming
- OTA test challenges

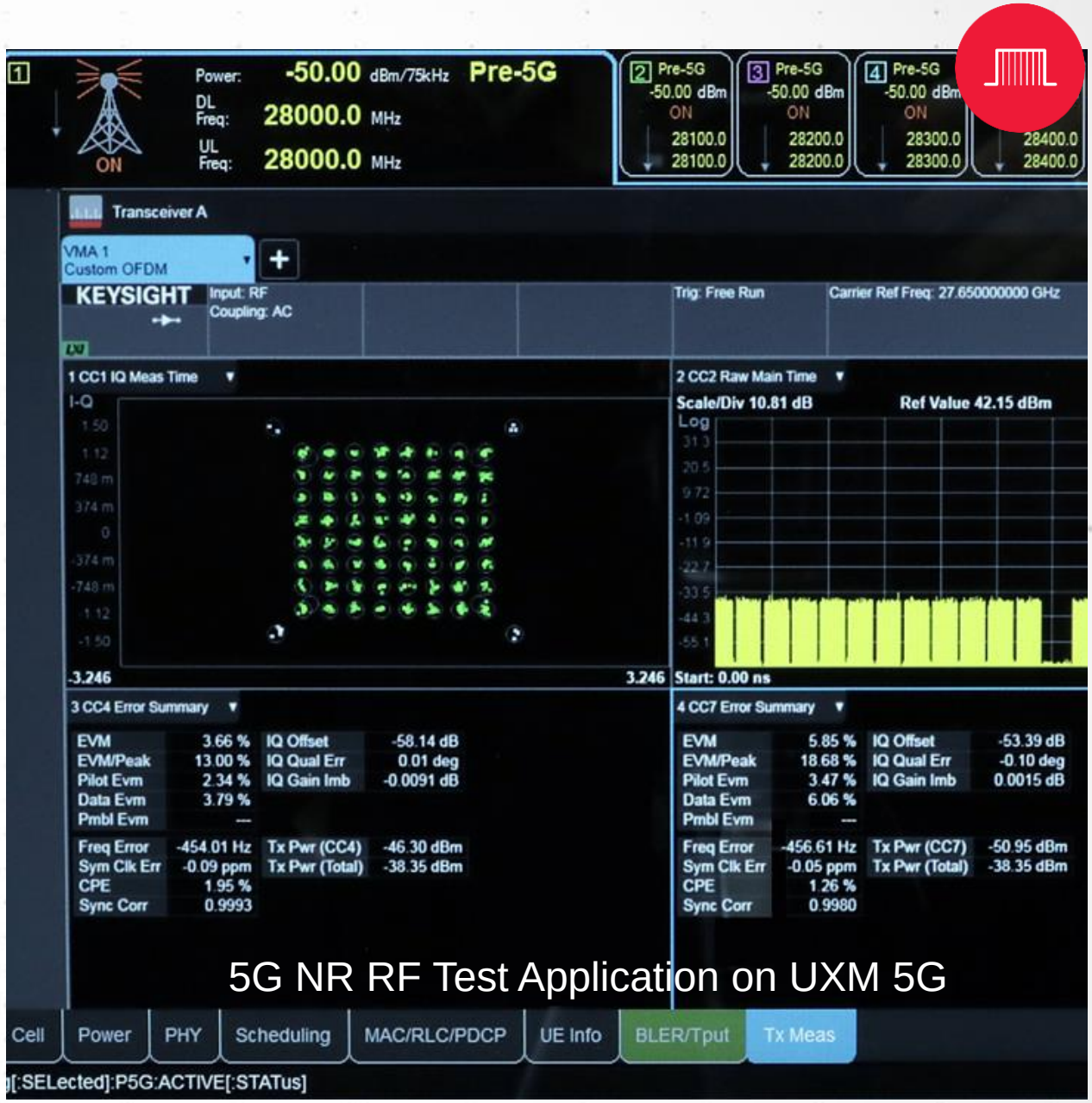




RF Test Application

5G RF DVT TOOLSET

- Flexible manual testing
- On-a-call UL RF measurements
- Common Keysight measurement science through X-Apps measurement application
- Automate test set up Keysight 5G Interactive tools

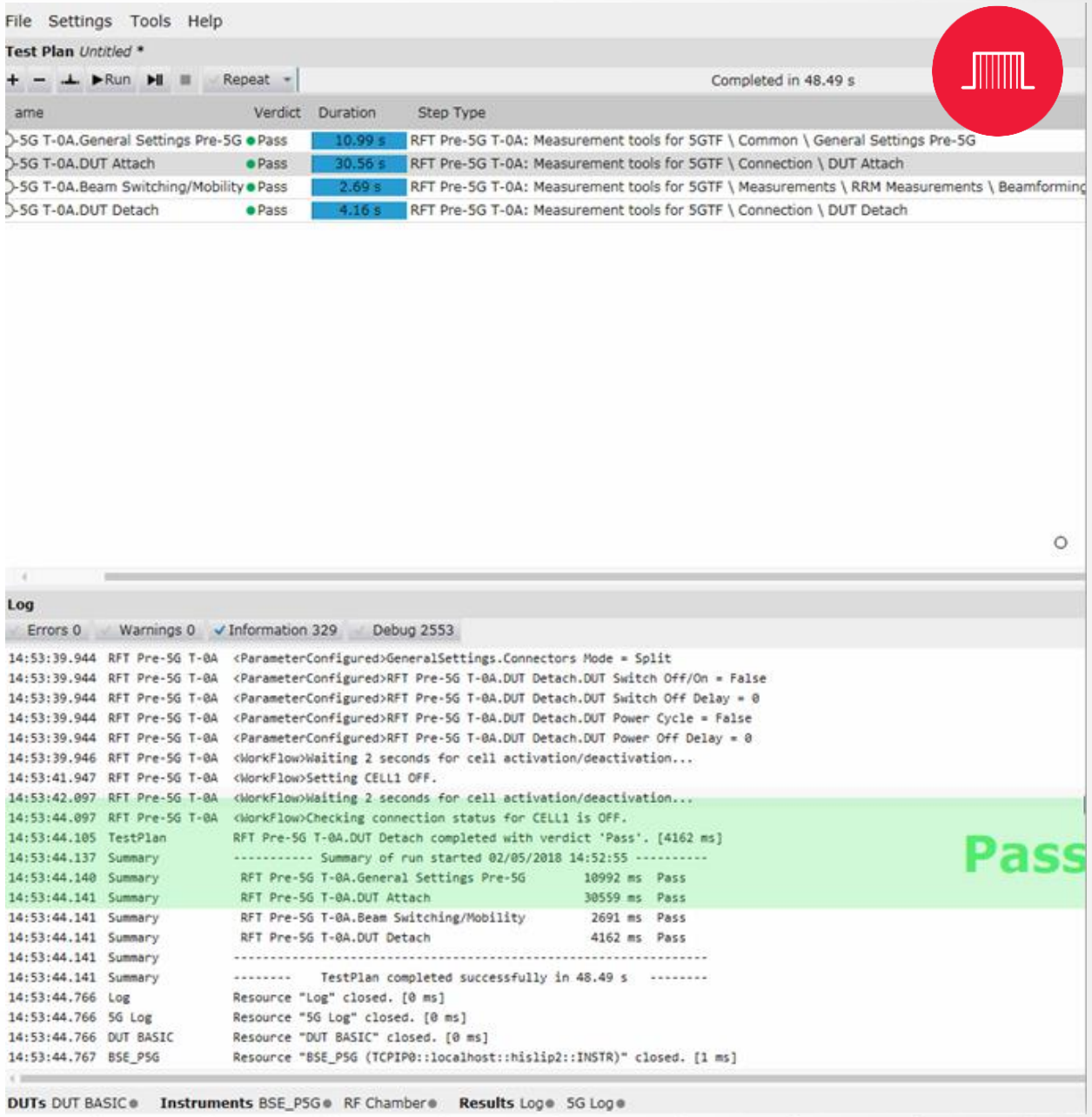


5G NR RF Test Application on UXM 5G

Automation & Scripting

5G RF DVT TOOLSET

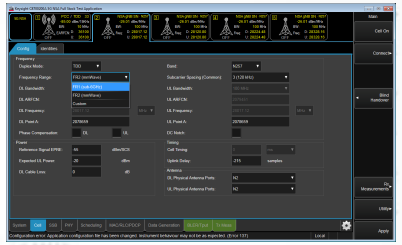
- Automate complete test set up including device and mmWave OTA measurements
- Test cases scripting with Keysight measurement tools or customized test steps
- Examples
- Initial Access
- Beam Management
- Downlink Channels demodulation
- UE reporting
- Total Radiated Power (TRP)

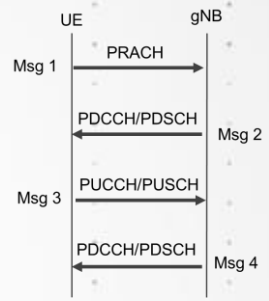


Test Application

SIGNALING

More RF bands, wider bandwidths, and beamforming



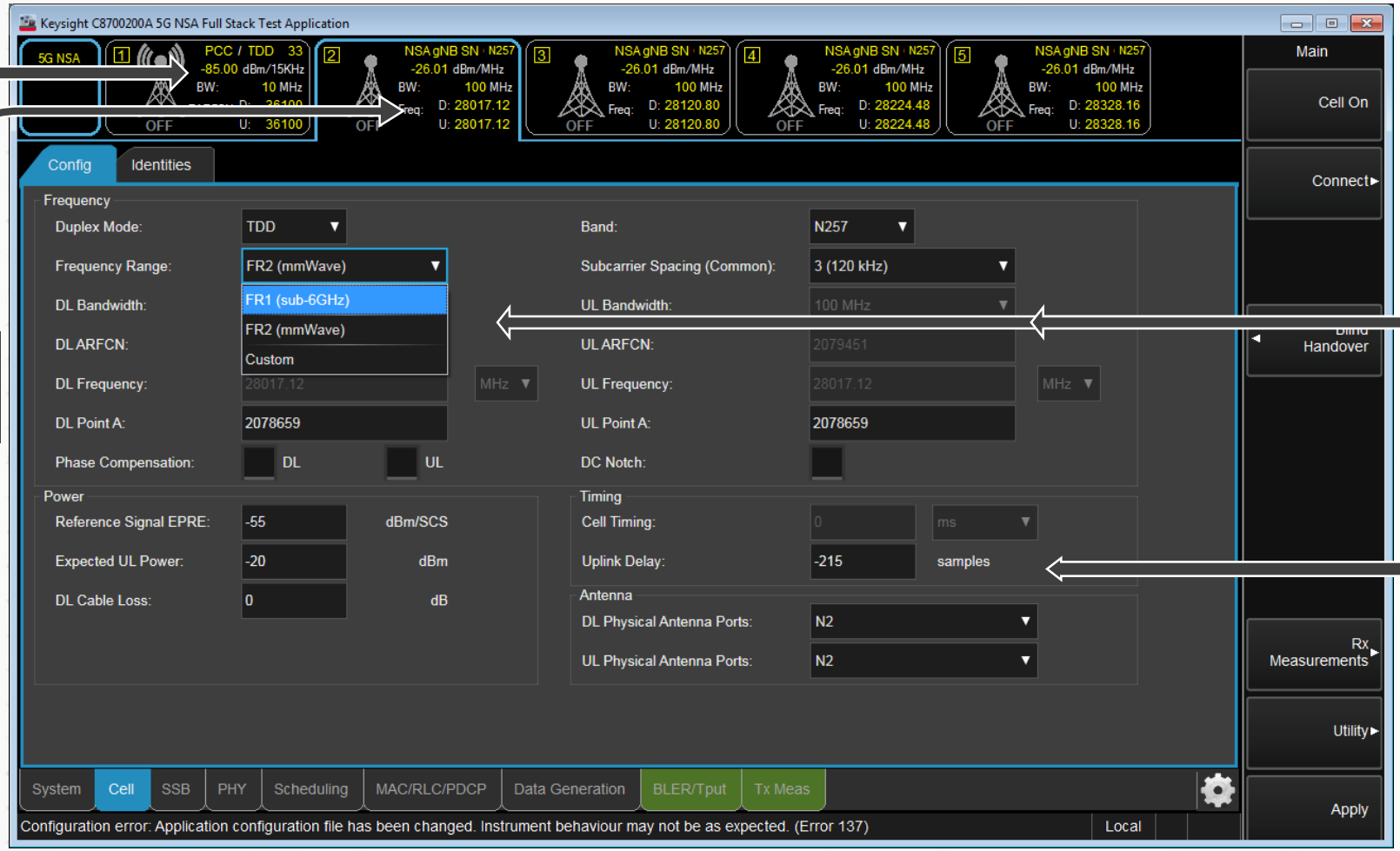


1 **Establish the 5G NR Call**

- Configure; Cell, Beam, DL/UL channels and signals, scheduler
- Complete PRACH

Establish a 5G NR Call

SINGLE CELL AND CARRIER AGGREGATION



Main Cell (LTE)

Secondary Cells (NR)

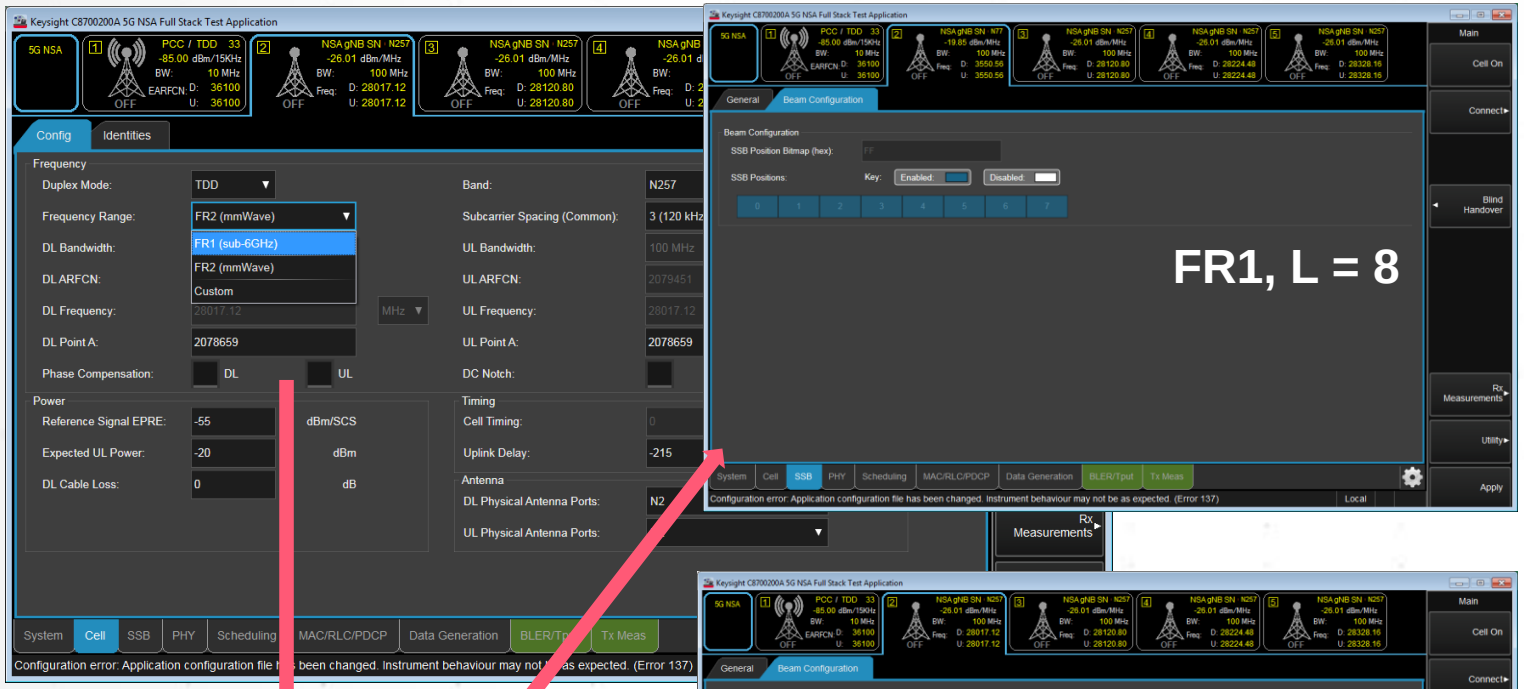
Frequency range, band, bandwidth…

Power, Timings, Antenna Ports

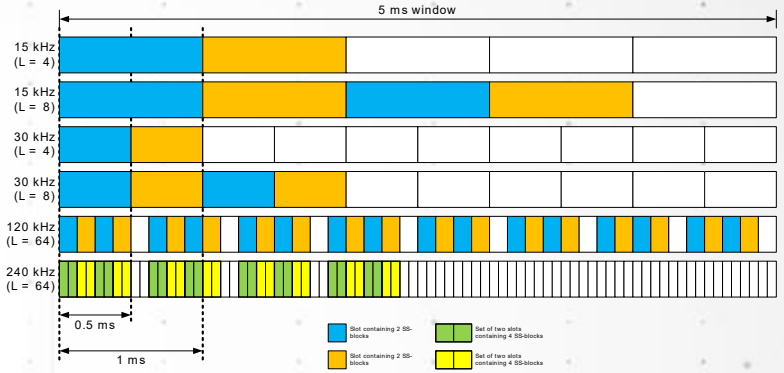
Note: Maximum number of Cells may depend on technology, bands and HW configuration

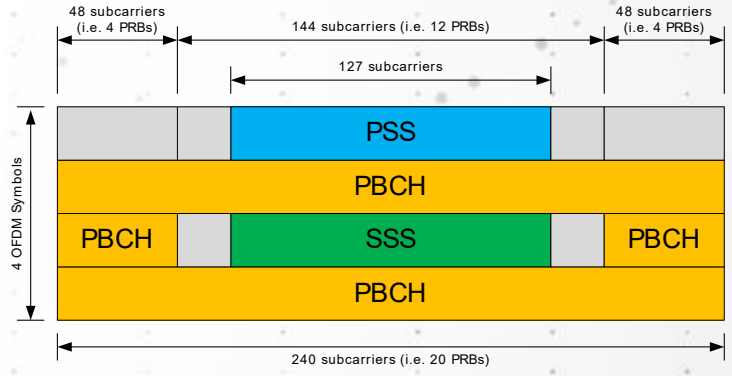
Establish a 5G NR Call

BEAM CONFIGURATION



Select SSB position, FR1 and FR2 has different bitmaps



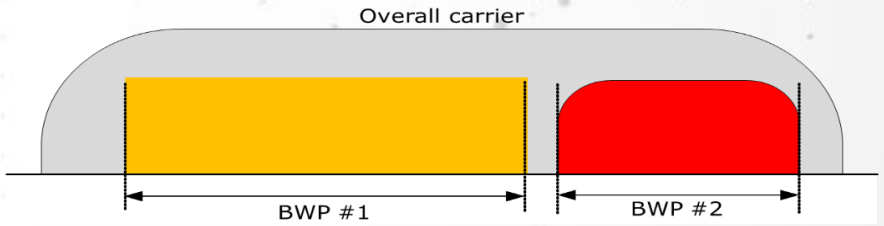


SSB includes 1 PSS, 1 SSS and 2 PBCH OFDM symbols the random access, transmitted over the same single antenna transmission scheme

Establish a 5G NR Call

PHYSICAL LAYER PARAMETERS

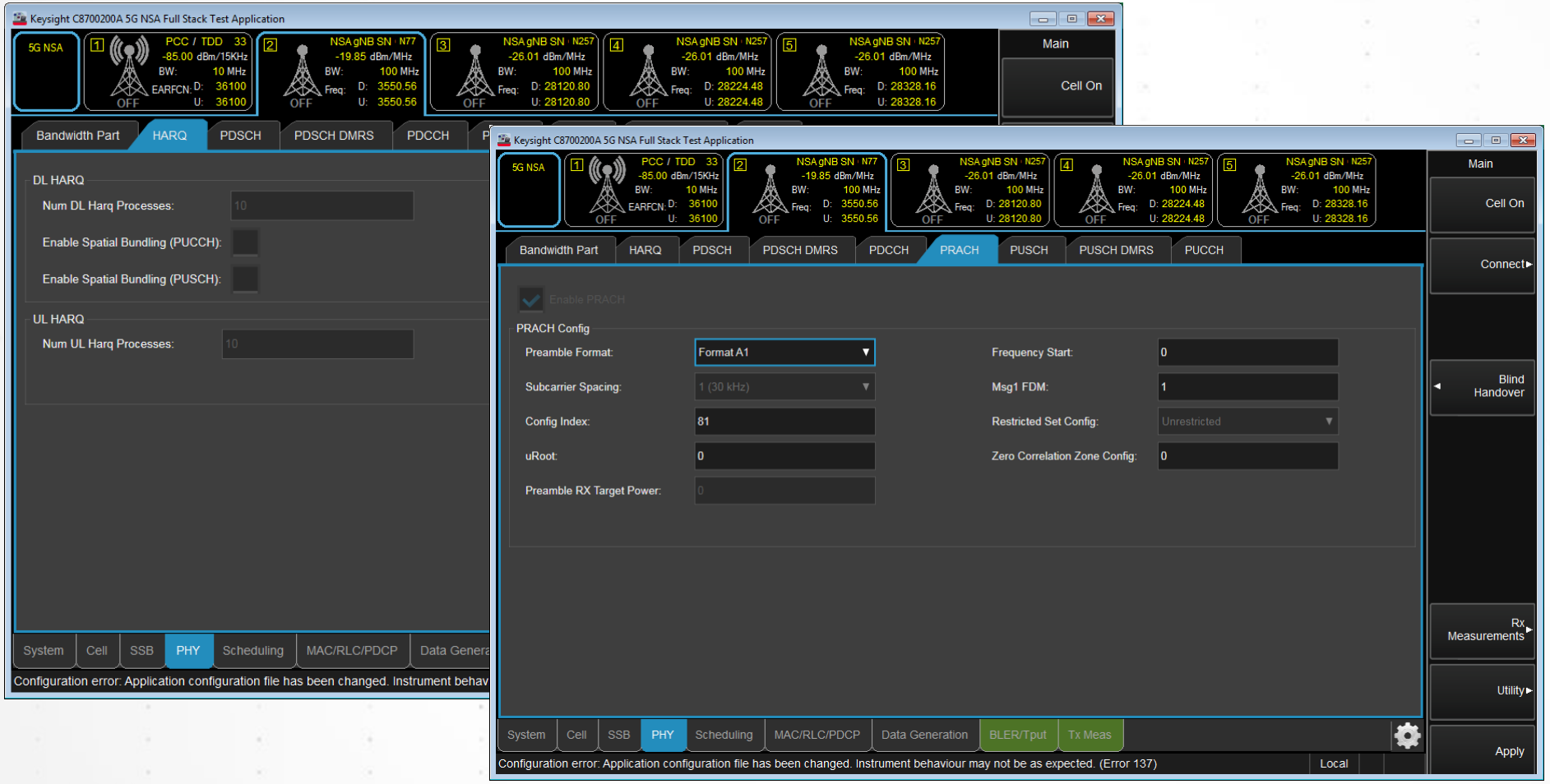
Define DL and UL Bandwidth parts; starting CRB, duration expressed in PRBs, Sub Carrier Spacing, Code Prefix



Each BWP consist on a group of contiguous PRBs

Establish a 5G NR Call

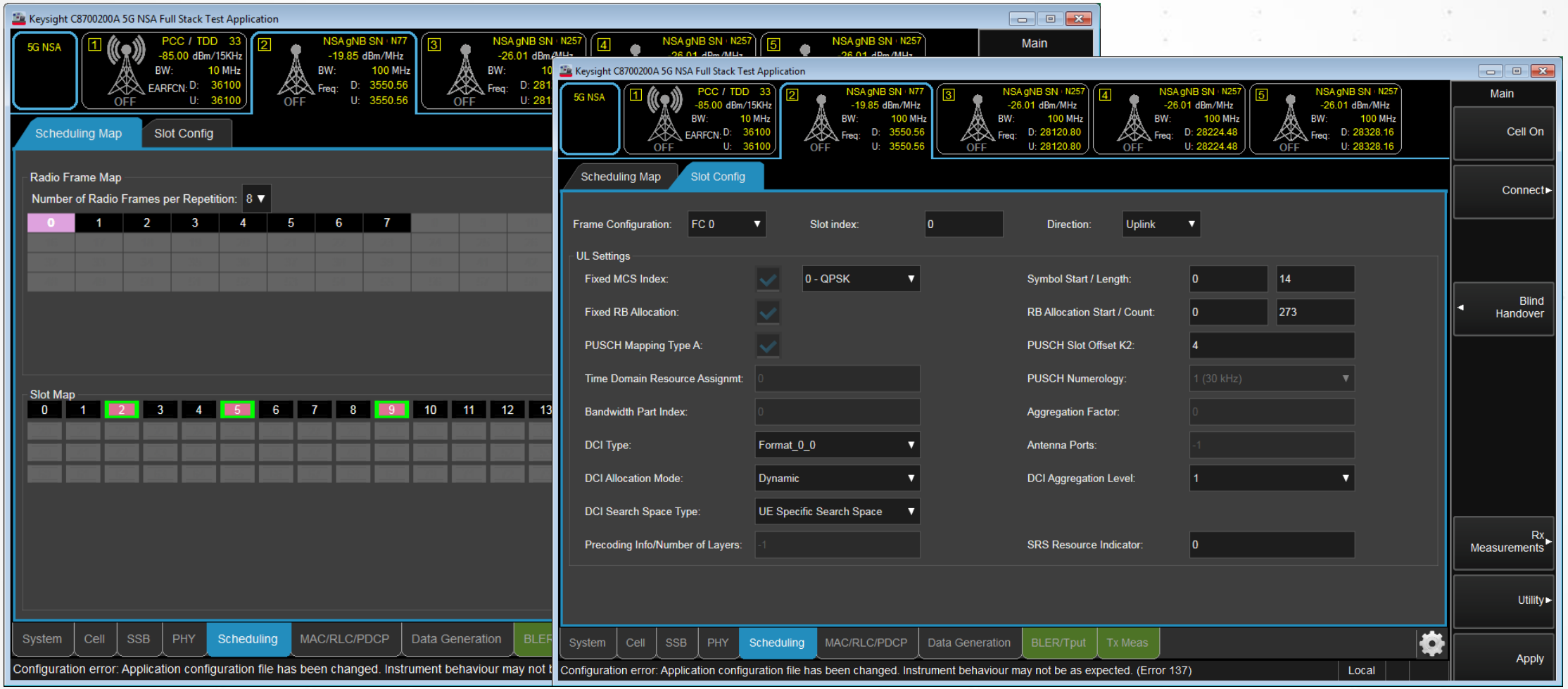
PHYSICAL LAYER PARAMETERS



HARQ, DL and UL channels and signals configuration

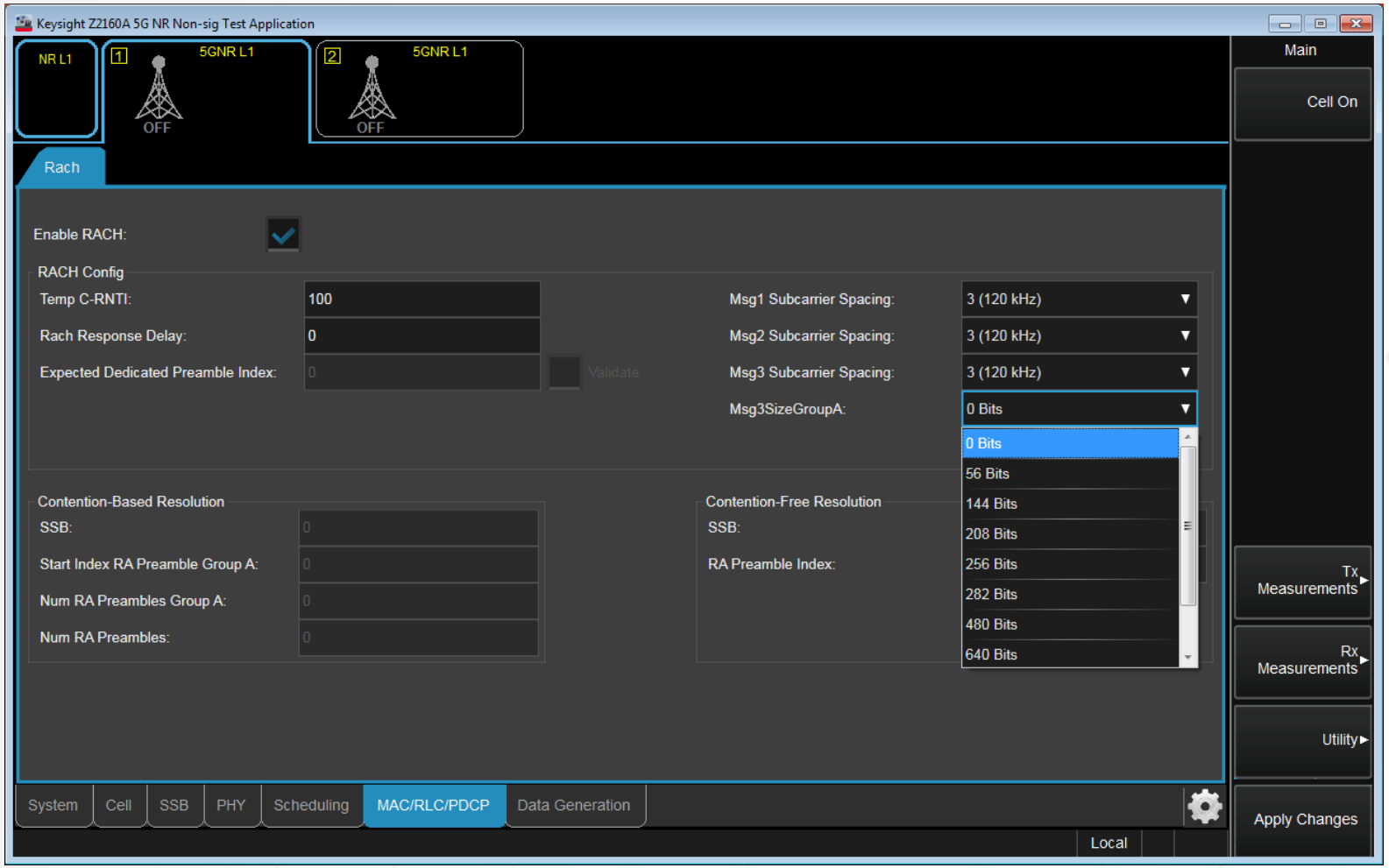
Establish a 5G NR Call

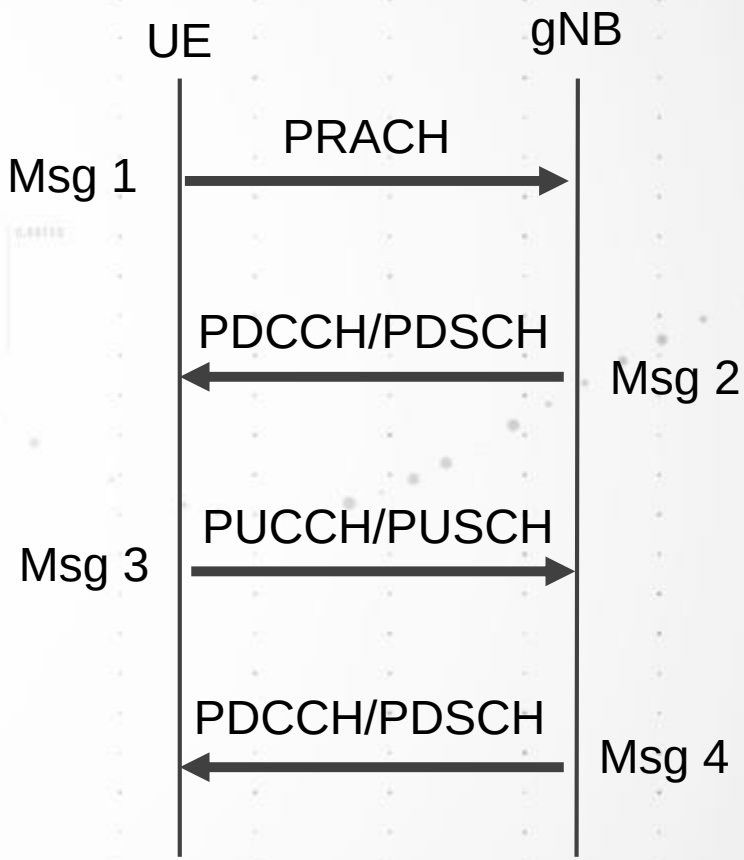
SCHEDULING



Establish a 5G NR Call

RANDOM ACCESS CHANNEL





Test Application

RF TEST

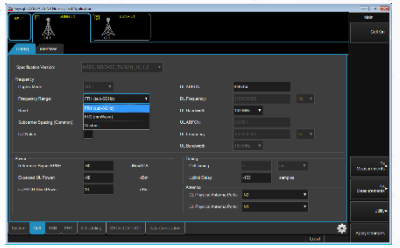
More RF bands, wider bandwidths, and beamforming

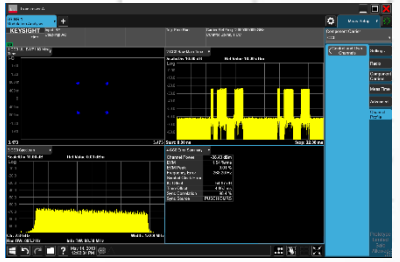
1 **Establish the 5G NR Call**

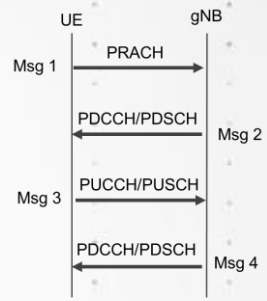
- Configure; Cell, Beam, DL/UL channels and signals, scheduler
- Complete PRACH

2 **Test Tx and Rx**

- Transceiver; Channel Power, EVM, Freq Error, In-band emissions, ACLR, SEM, OBW
- Receiver; BLER statistics





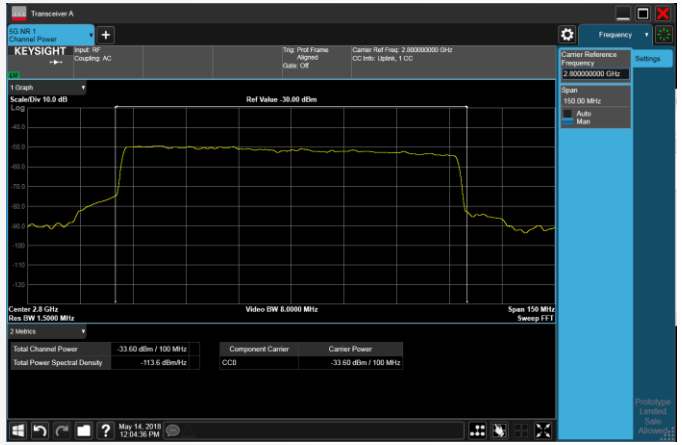


RF tests

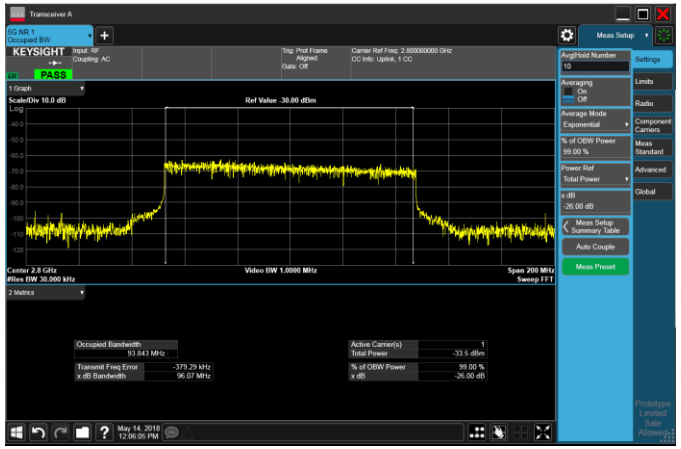
RF test on-a-call

TRANSMITTER

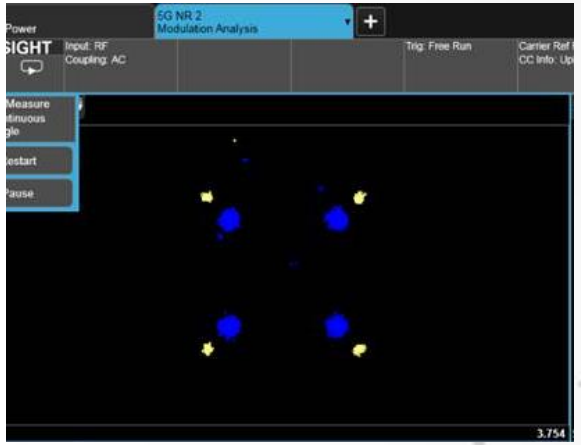
Channel Power



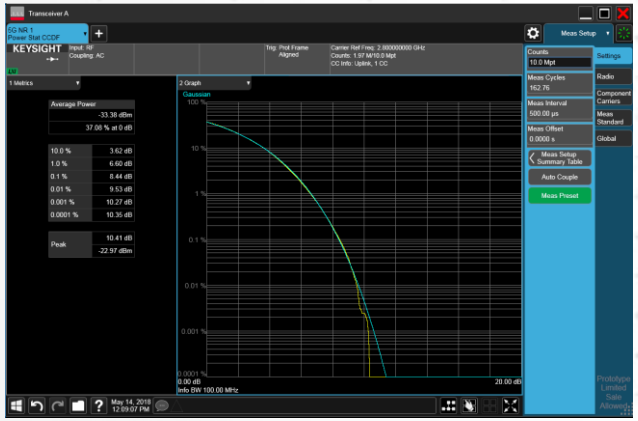
Occupied Bandwidth



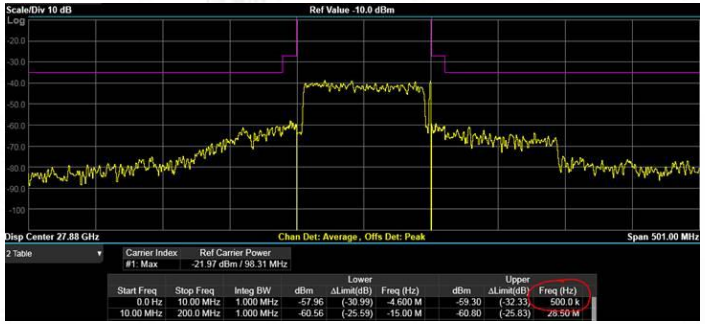
Modulation Parameters



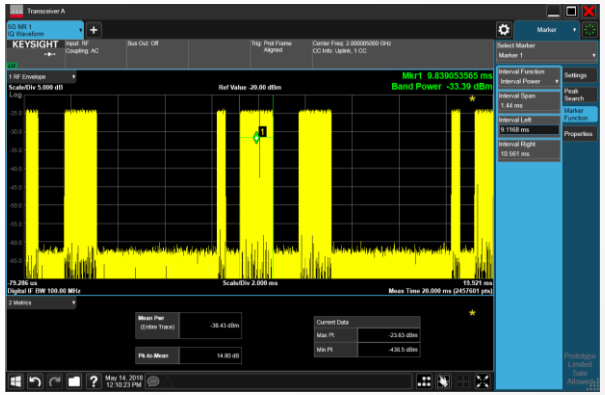
Power Statistics



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

More RF bands, wider BW, BF

SIGNALING RF TEST

More RF bands, wider bandwidths, and beamforming

1 **Establish the 5G NR Call**

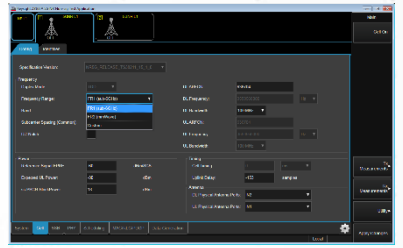
- Configure; Cell, Beam, DL/UL channels and signals, scheduler
- Complete PRACH

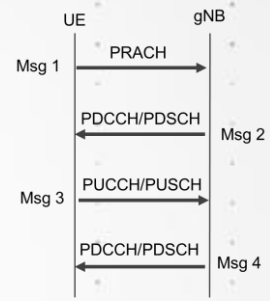
2 **Test Tx and Rx**

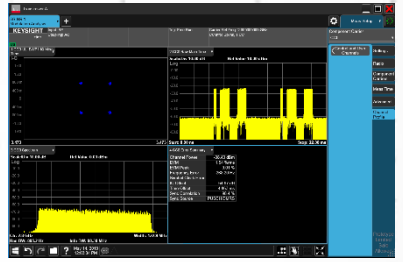
- Transceiver; Channel Power, EVM, Freq Error, In-band emissions, ACLR, SEM, OBW
- Receiver; BLER statistics

3 **Automate test for thorough verification**

- Create Scripts using Keysight Measurement blocks
- Test with power, frequency sweeps
- Test Executive Environment

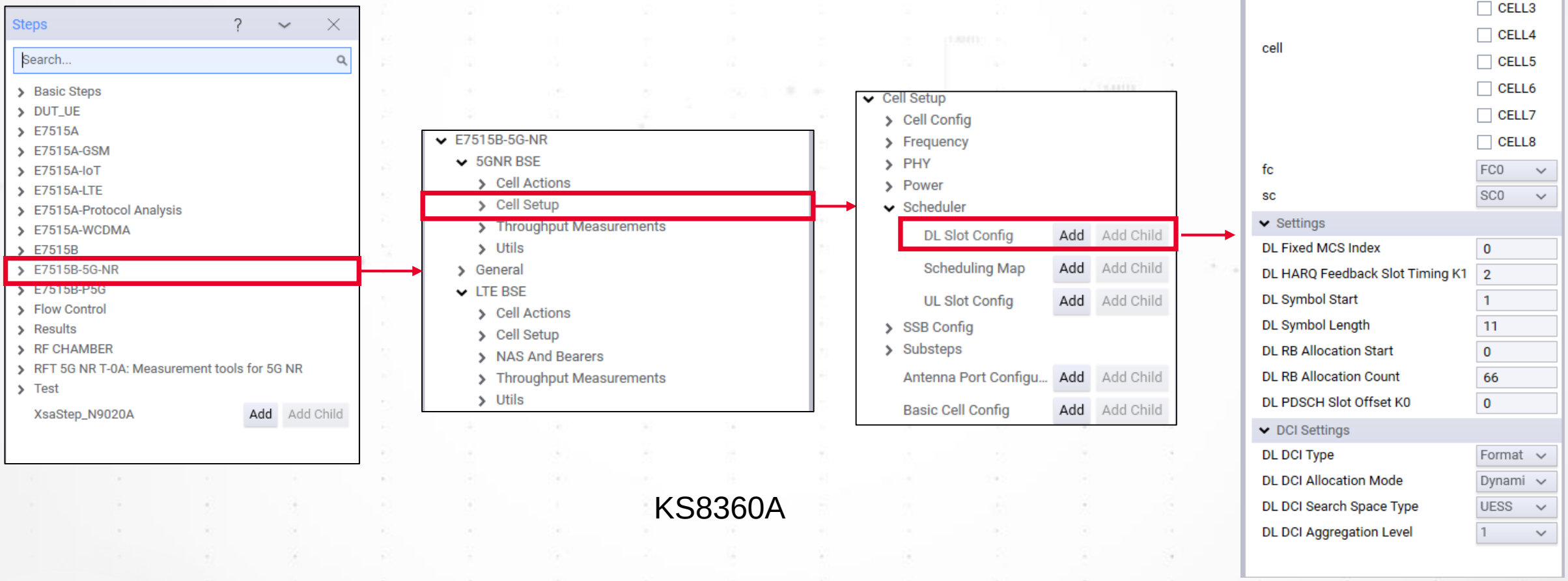






UXM 5G TAP Plugin

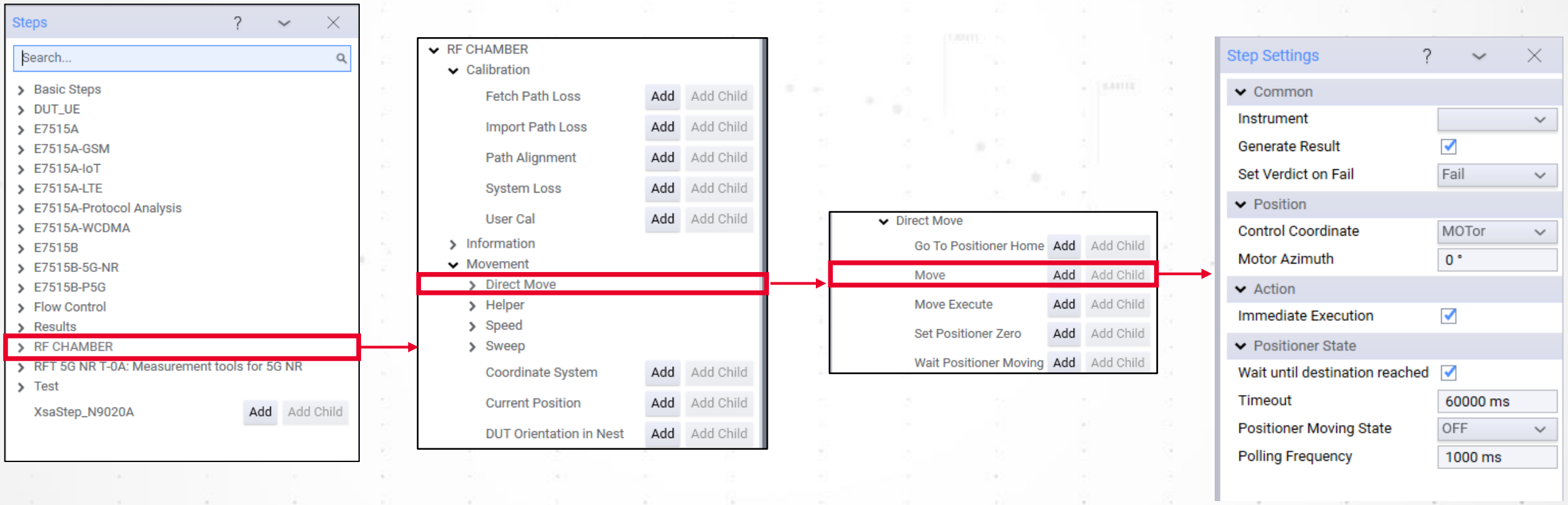
TAP STEPS TO CONTROL UXM 5G AND CHAMBER



KS8360A

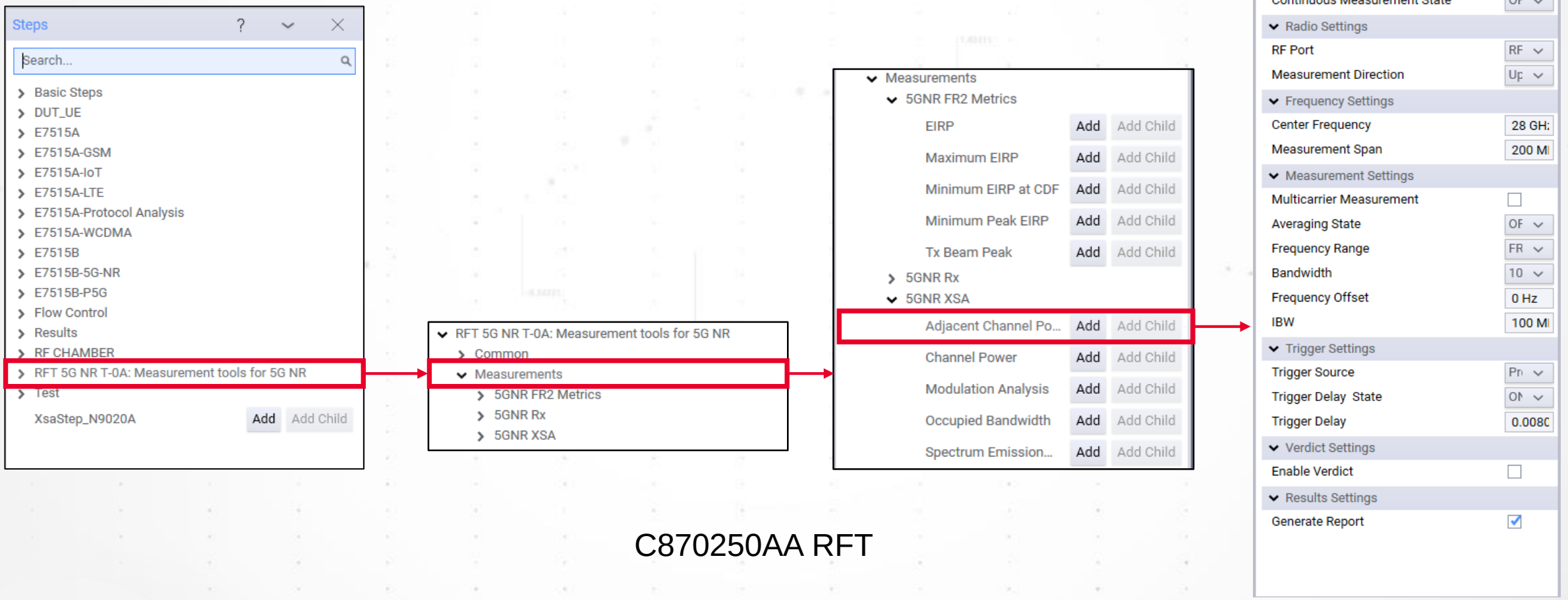
UXM 5G TAP Plugin

TAP STEPS TO CONTROL UXM 5G AND CHAMBER



5G NR T-0A: Measurement tools

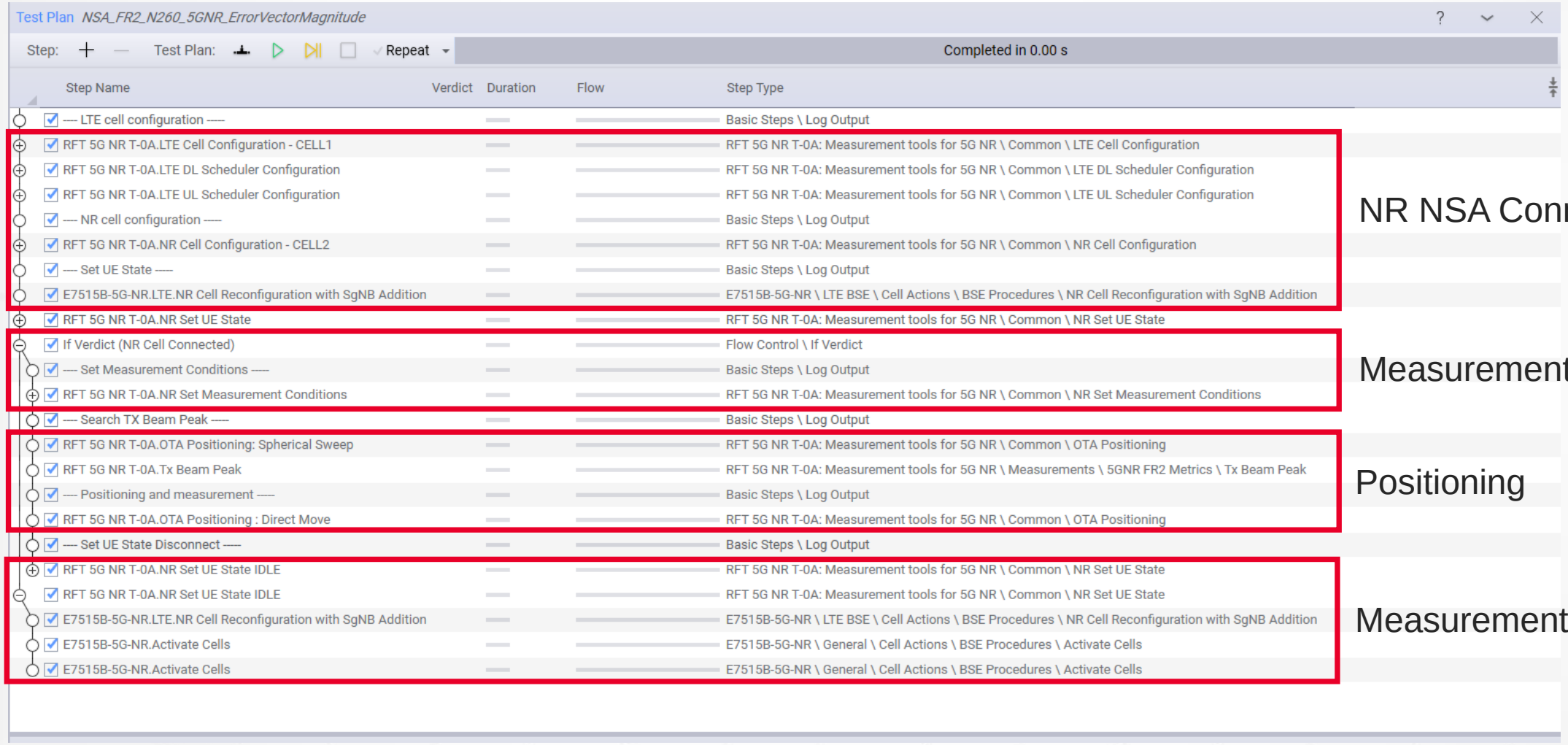
TAP STEPS TO MEASURE RF TX AND RX CHARACTERISTICS



C870250AA RFT

5G NR T-0A: Measurement tools

TAP PLAN EXAMPLES



NR NSA Connection

Measurements Conditions

Positioning

Measurement

RF DVT Toolset

5G Device End-to-End Workflow

FUNCTIONAL KPI

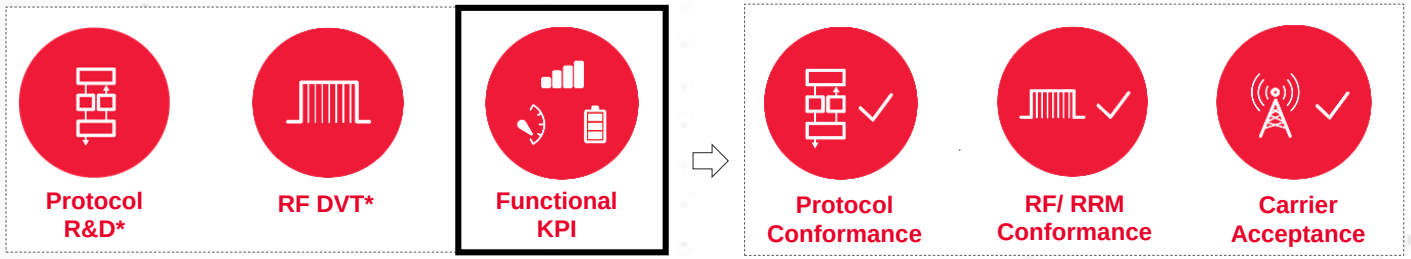
Network Emulator

Channel Emulator

mmWave OTA Solutions

5G Interactive R&D

5G Device Acceptance



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 DVT*
- Functional KPI

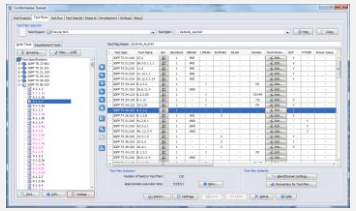
5G Device Acceptance

- Protocol Conformance
- RF/ RRM Conformance
- Carrier Acceptance

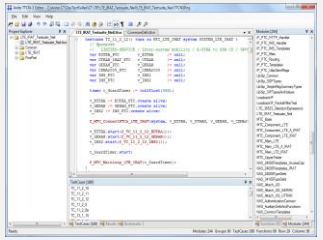
Protocol

Test Spec TS 38.523-1

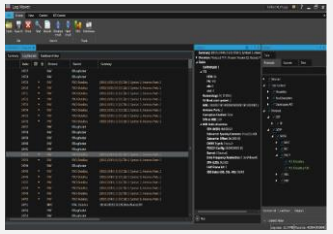
TTCN-3 Test Suite



PCT Test Manager



TTCN-3 Editor / Viewer



Log Viewer

RF/RRM

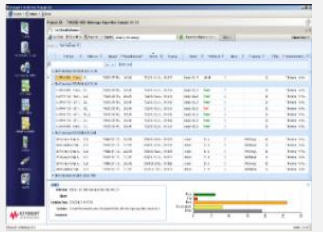
Test Spec 38.521-1/2/3

RF Rx/TX Test cases

Test Spec 38.521-4

Future

Performance testing

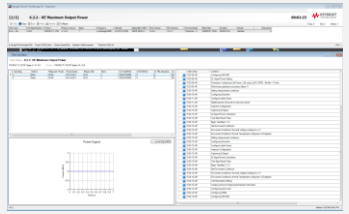


RCT Test Manager

Test Spec 38.533

Future

Radio Resource Management (RRM)



Sequencer

Log Viewer

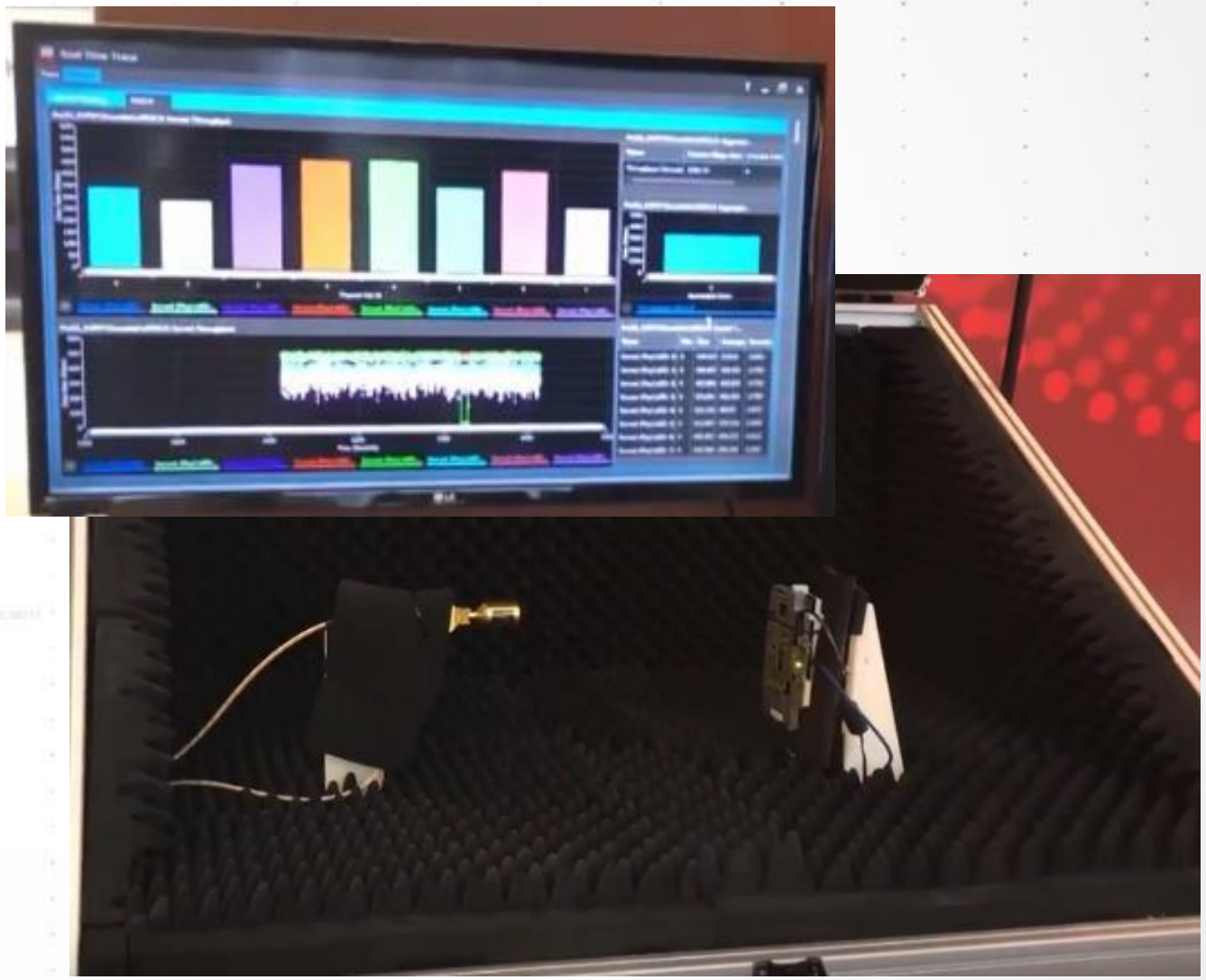
Case Study: 5G Chipset OTA Test

Demonstrated at *MWC 2018*

Challenge: Measure the 5G download throughput rate OTA with full protocol stack

Solution: CATR with UXM and Protocol Toolkit

- Qualcomm x50 5G Modem
- 4 Gbps download speeds
- Full protocol stack
- 8 x 100 MHz Carriers
- 800 MHz aggregated bandwidth



What does an OTA Solution Look Like

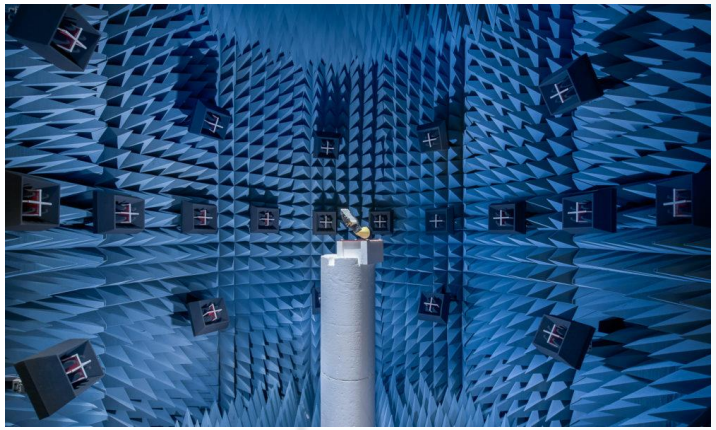
UXM 5G

EXM

PNA-X

How good is my antenna?

Is my RF working?



CATR

Cable Replacement
2D MPAC
RMTC

Is my chipset working?

Spatial MPAC
3D MPAC

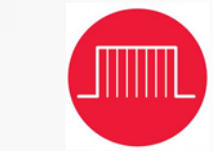
How good is my device?

FR2 mWave support

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)

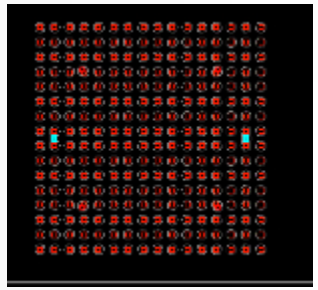
- Same unit for both PROPSIM CE and UXM 5G
- Supports up to 8x heads, with scalability for more
- Flexibility to add new heads to support new bands
- Supports high IF connection (6-12 GHz)

mmWave Transceiver for 5G (RRH)

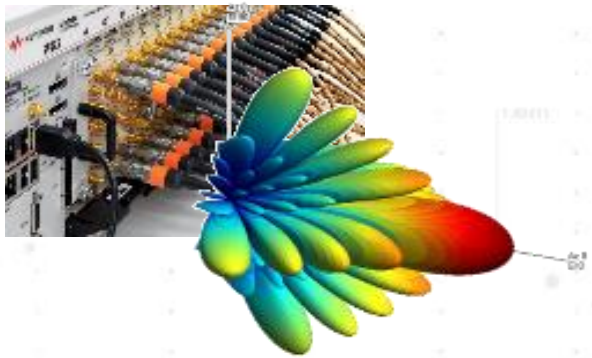
- Supports 28, 39 and 40GHz bands
- Compact, bi-directional

7 Key Measurement Challenges

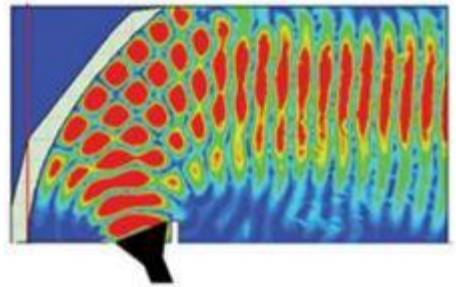
Signal Quality
mmW, Waveform, Fidelity



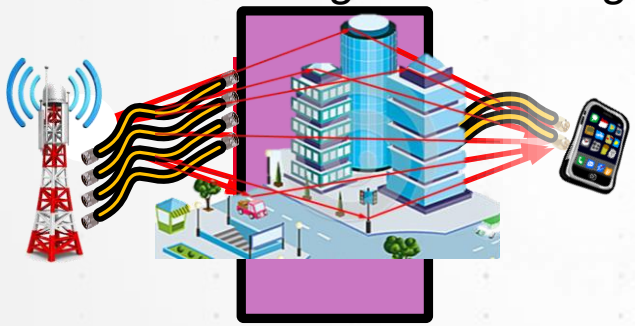
Lots of Channels
MIMO/Beamforming



Life Beyond Connectors
Over-the-Air



Channel
Characterizing & Emulating



Performance on the Network
Network Emulation

Protocol R&D | *RF / RRM DVT* | *Functional KPI*

Cost of Test
Assets, throughput

7

Challenge: Cost of Test

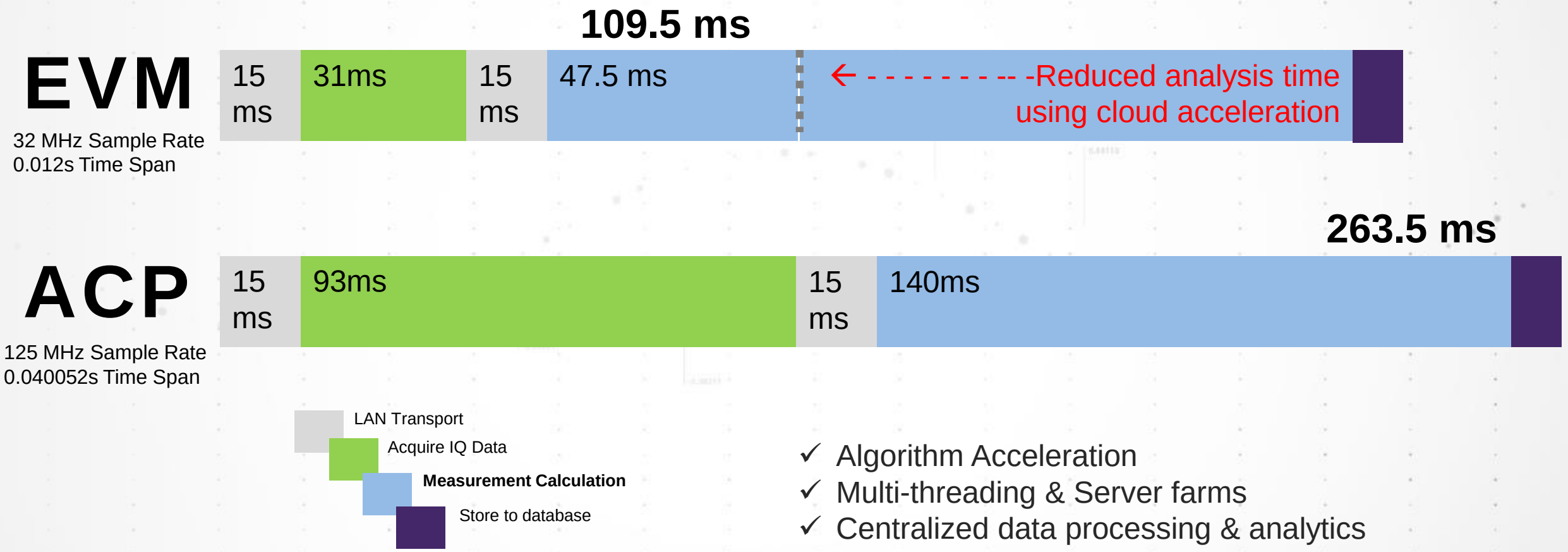
Challenges

- 5G NR Standard Complexity
  - LTE-A has grown to 3500 pages. 5G?
- 10x Bandwidth. 1-100x Channels
  - If measurements were slow for LTE, now what?
- Flexibility, Ease of Automation
  - How to quickly develop apps, APIs?
- Compressed timeframes, cost envelopes
  - How to continue to evolve with the Industry, 3GPP
  - How to transition from R&D → DVT → MFG volumes
  - How to leverage Industry 4.0 technologies & approaches

Enablers

- ✓ Greater modularity (SW, API, HW)
- ✓ Cloud acceleration
- ✓ Ease of Automation
- ✓ Data Analytics
- ✓ Services and whole-enterprise approaches

Case study – Test Acceleration of Individual Measurements



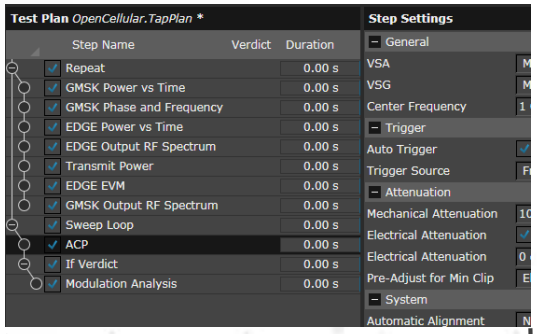
- ✓ Algorithm Acceleration
- ✓ Multi-threading & Server farms
- ✓ Centralized data processing & analytics

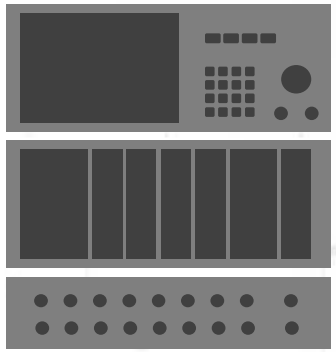
Testing Scenarios

BASELINE

Measurement calculation is performed on instrument (using X-App)

Test Executive





DUT

COST OF TEST **$10.17**

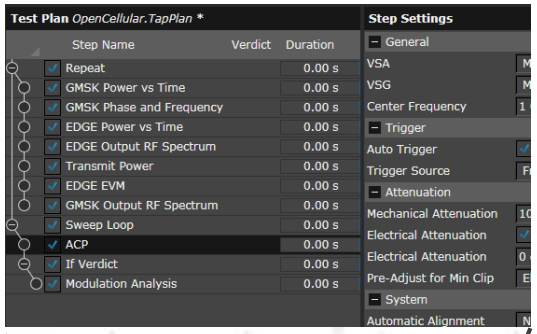
Testing Scenarios

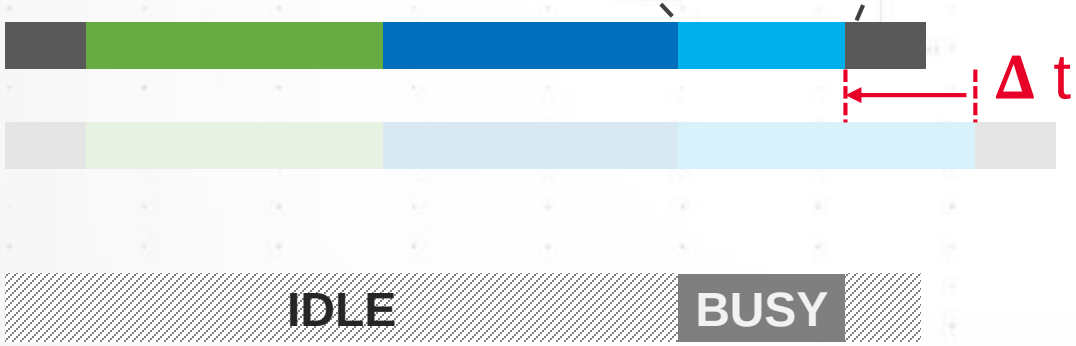
BASELINE

+ Add Server CPU

Instead of X-App processing on-instrument, process acquired IQ samples on external server

Test Executive

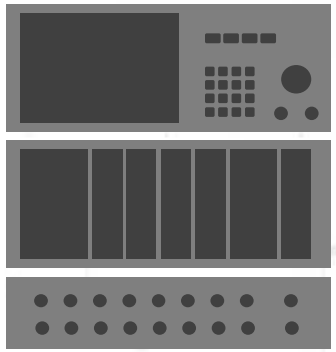




Process in parallel
Process on a fast CPU

Process Algorithms

Acquire IQ data



DUT

COST OF TEST **-16%**

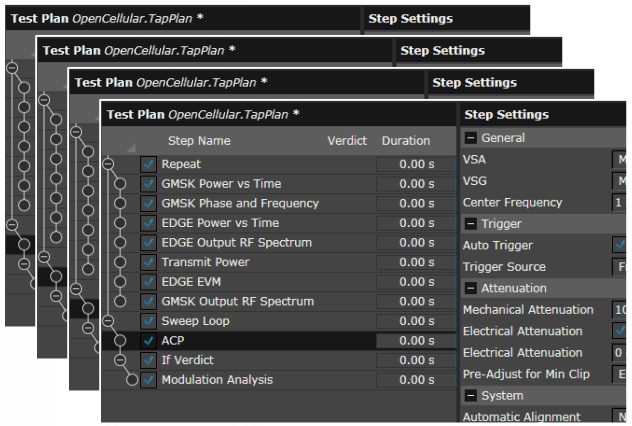
Testing Scenarios

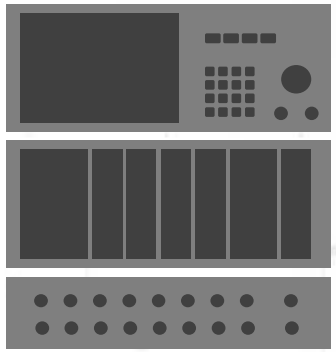
BASELINE

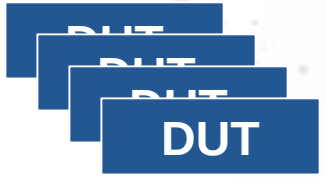
+ Add DUTs

Share a test station to test multiple DUTs in “pipeline” fashion

Test Executives







COST OF TEST **-26%**

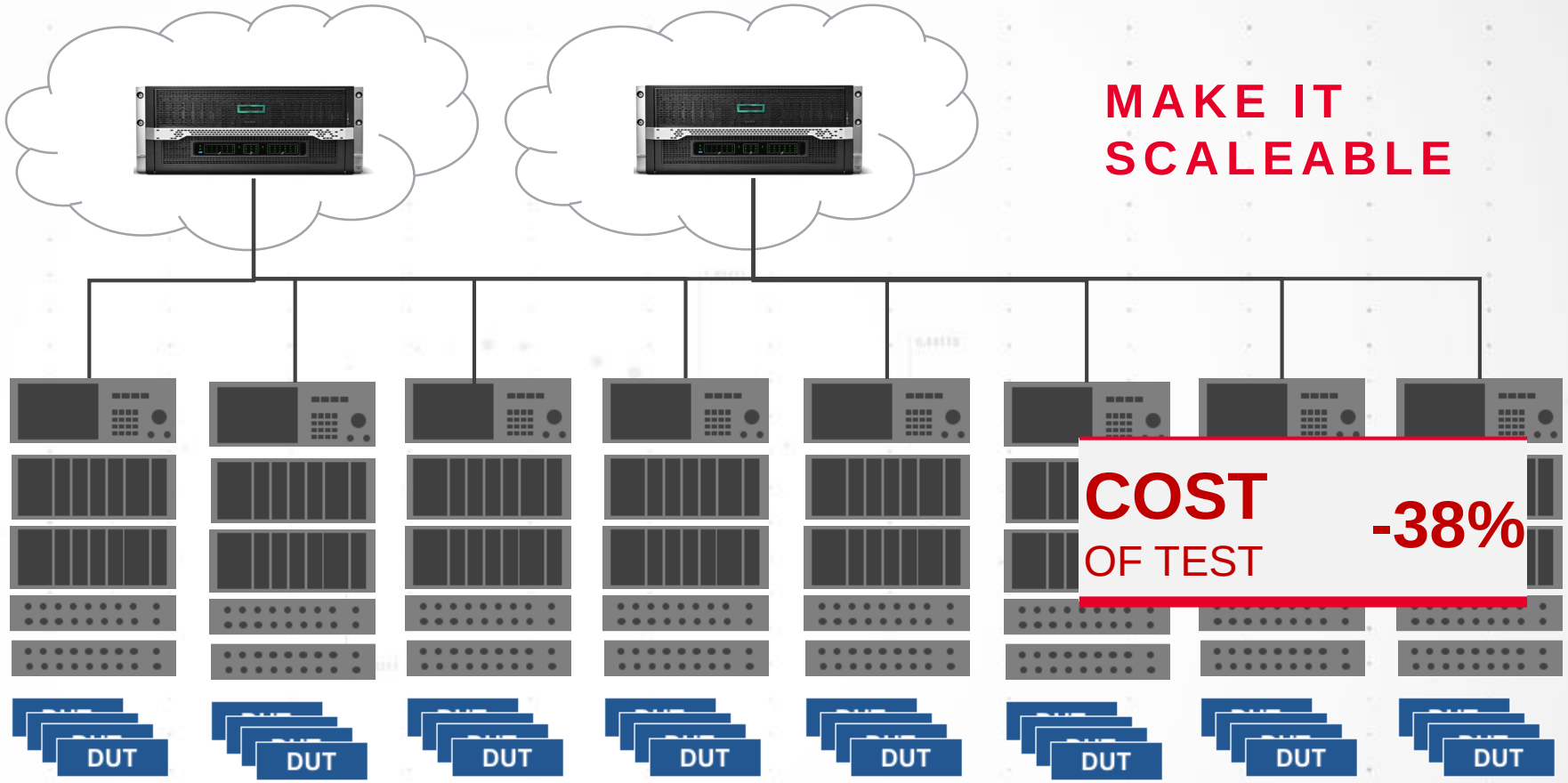
Testing Scenarios

CLOUD

BASELINE

+ Add Server CPU
+ Add Instruments
+ Add DUTs

Share a test station to test multiple DUTs in “pipeline” fashion



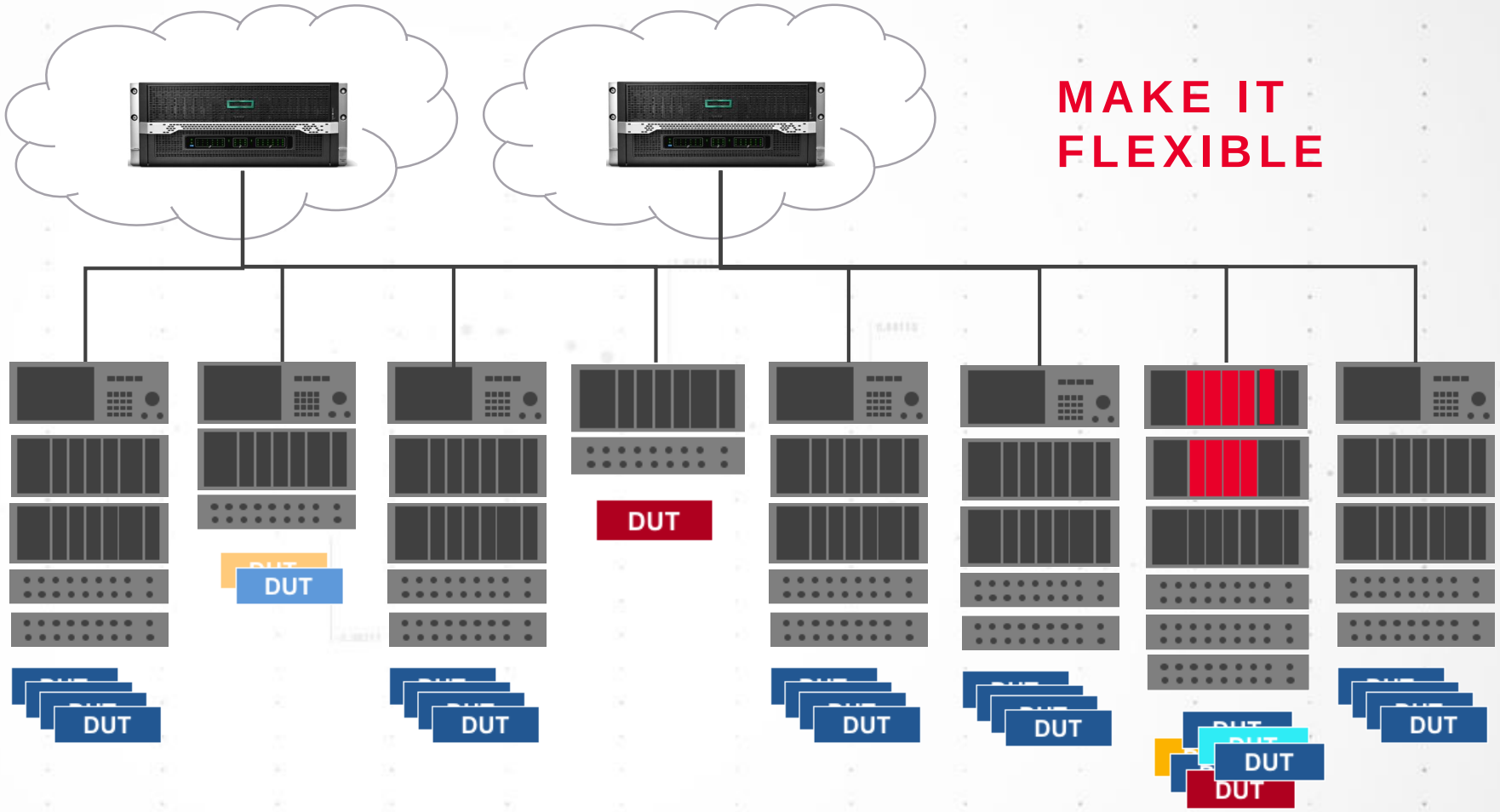
Testing Scenarios

CLOUD

BASELINE

+ Add Server CPU
+ Add Instruments
+ Add DUTs

MAKE IT FLEXIBLE



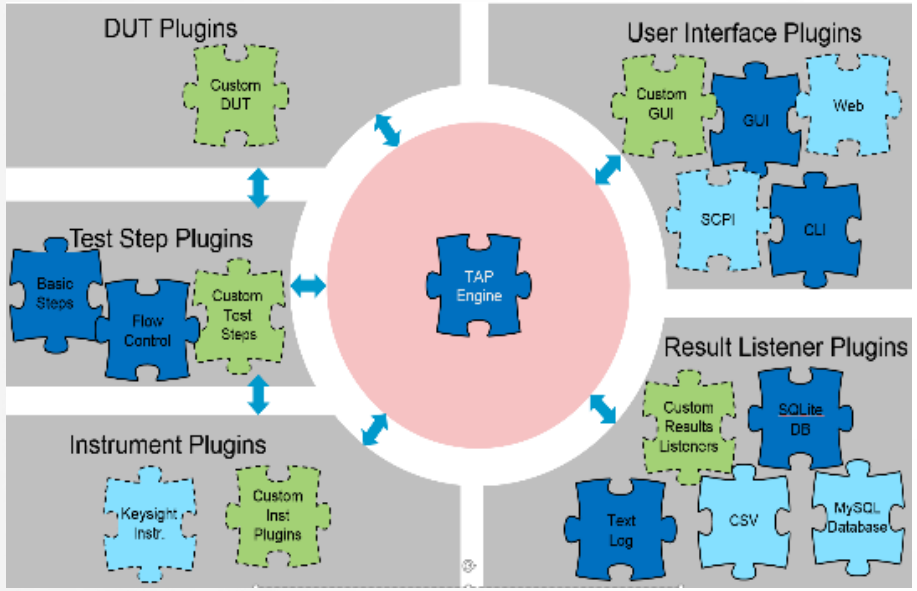
Test development / test execution are decoupled from test system configuration.

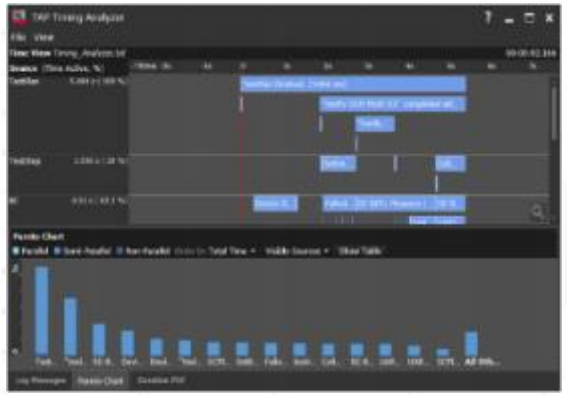
Test systems can be “software defined” to execute any test plan.

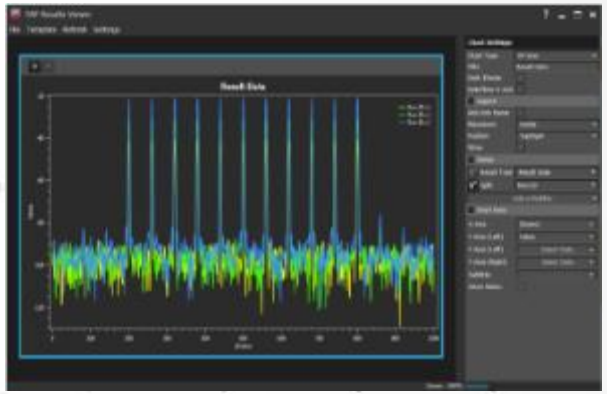
Automation: Simplified sequencing, test plan creation

KS8400A TEST AUTOMATION ON PATHWAVE (TAP)

- Fast execution and test flow analysis
- User interfaces
  - GUI
  - Command line interface
  - API
- Modular “plug-in” software architecture
- Microsoft .NET test step development

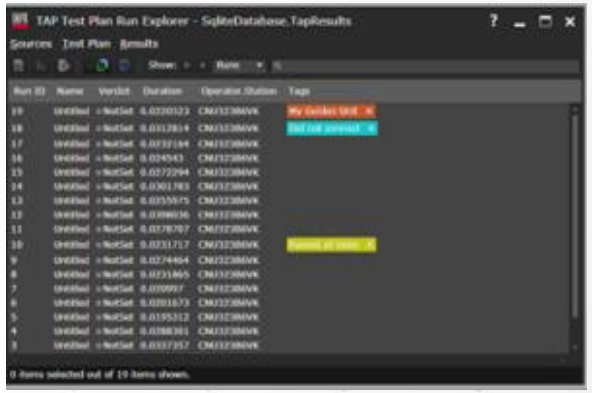






Powerful Speed and Results Analytics

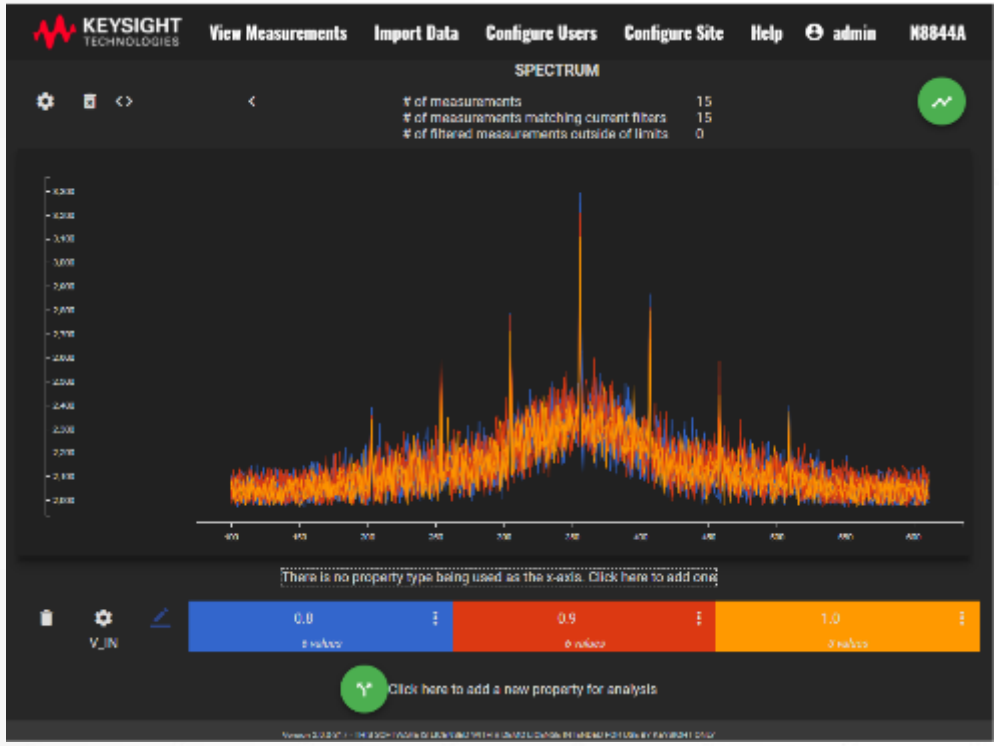
Create Custom GUIs



Efficient Data Exploration

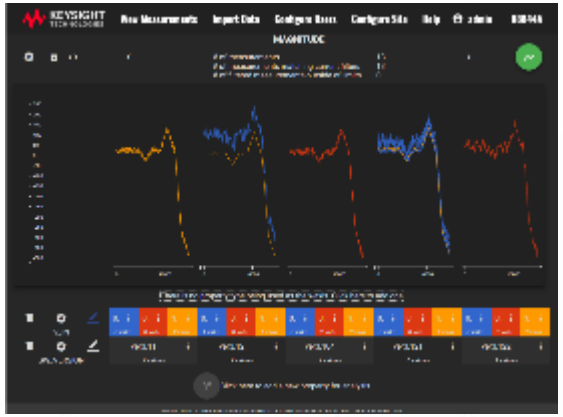
Advanced Analytics for RF Measurements

MULTIPLE MEASUREMENTS (ACPR, EVM, SEM, POWER)



SPECTRUM VS. INPUT VOLTAGE

CONSTELLATION VS. TEST OPERATOR



FREQUENCY RESPONSE VS. Software Revision AND V_{in}

Big Data Insights

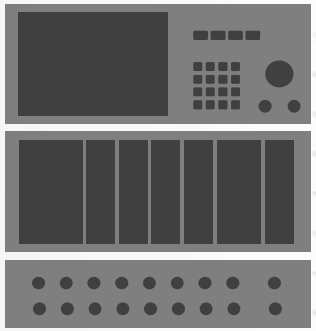
- Across org
- Across tools
- Processes
- Predictive

New Degrees of Scalability & Flexibility

CLOUD

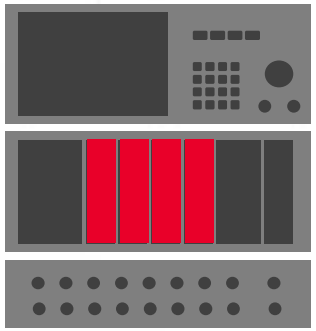
MULTI-DUT

DUTs PER TEST STATION



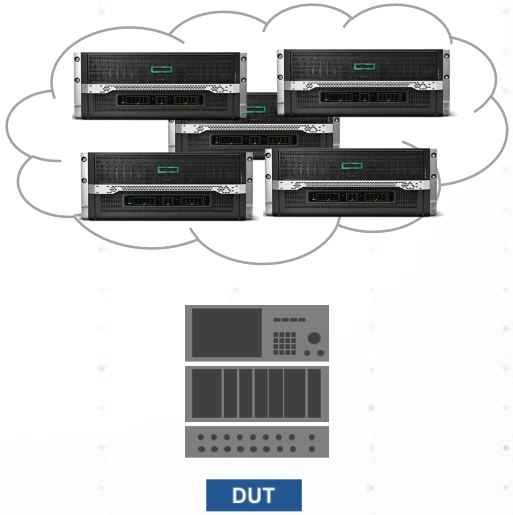
MULTI-INSTRUMENT

INSTRUMENTS PER TEST STATION



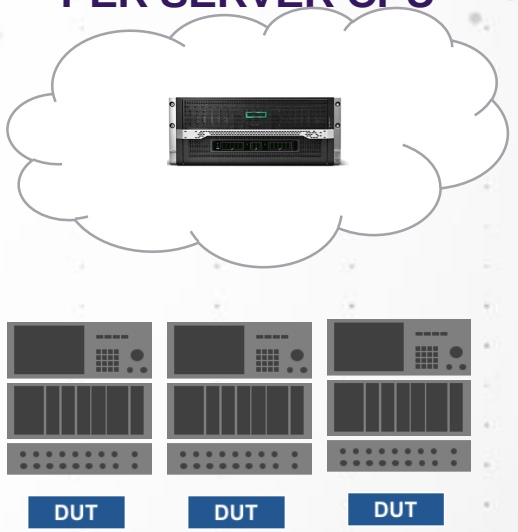
SERVER CPUs

ACCELERATION SERVER SPEED



CPU SHARING

TEST STATIONS PER SERVER CPU



Introducing: S9100A 5G Multi-band Vector Transceiver

"LEAN ENOUGH FOR MFG - POWERFUL ENOUGH FOR DESIGN VALIDATION"

✓ **Sub-6GHz, easily scalable to 24-44 GHz bands**
no wasted modules in order to cover <u>both</u> FR1, FR2 → highest asset utilization

✓ **Extremely lean, compact design**
Smallest footprint, easy to expand up to 8x8 MIMO in 1 chassis without the size, cost, or overkill of R&D benchtop boxes

✓ **High quality EVM, including millimeter wave**
< 0.7% at 28 GHz in loopback mode for accurate DVT and fewer false positives in MFG (5G NR signal, 100MHz bandwidth, OFDM signal type with 12dB PAPR)

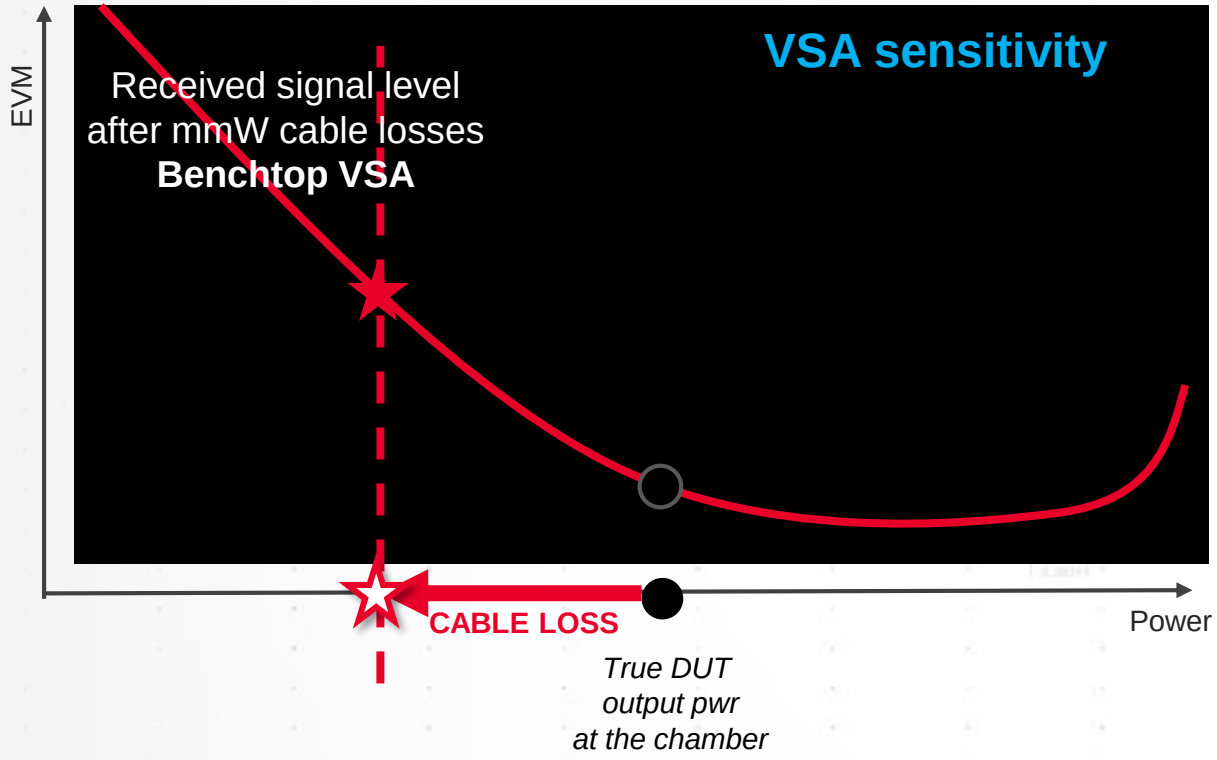
✓ **Fast and Easy to Automate *("cloud ready")***
- Blazing fast PXIe transfer rates & clean API streamline your 5G automation
- Accelerate your 5G DVT, then transition quickly to MFG (time to market)

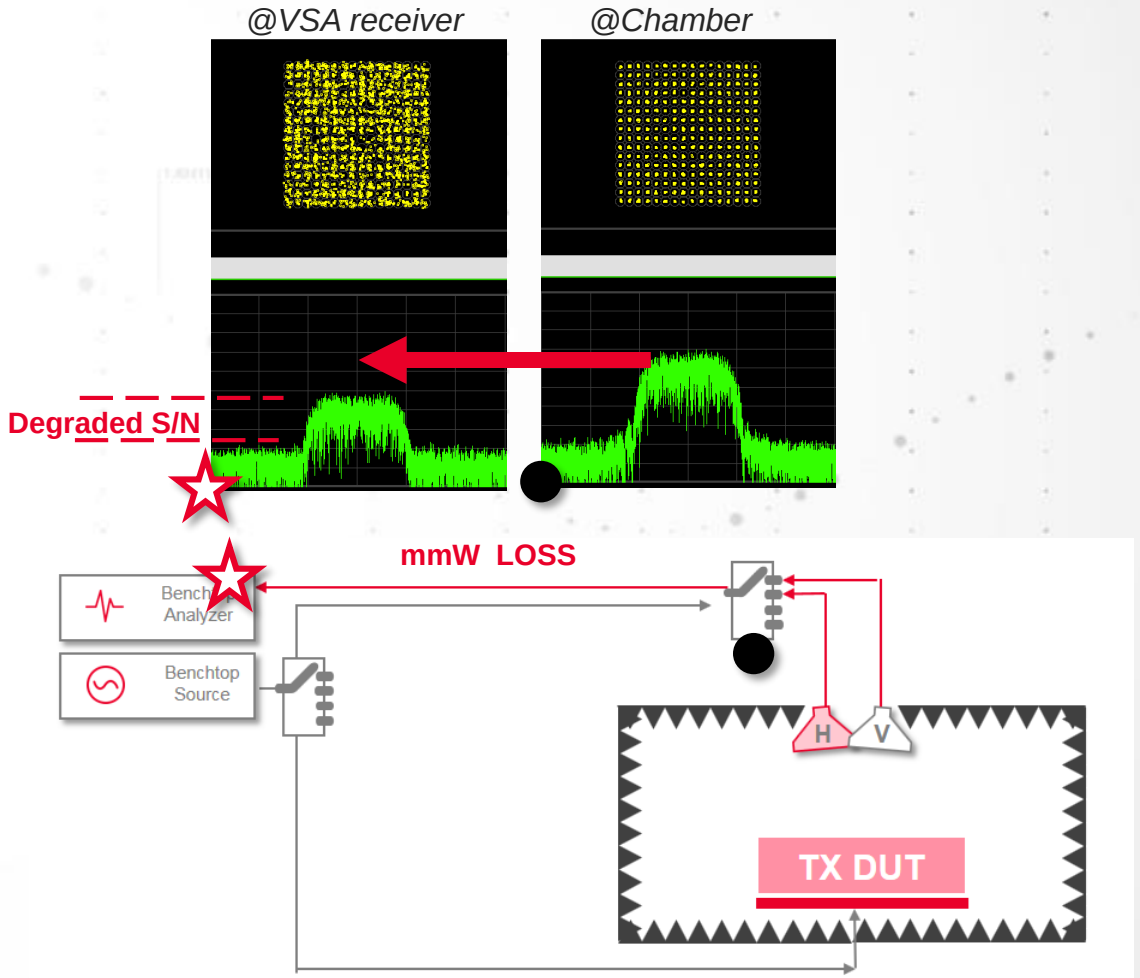
✓ **Flexible and Versatile *("OTA ready")***
Remote millimeter wave heads deliver highest OTA measurement quality at the chamber

✓ **Keysight system integration**
- S9100A systems can be customized.
- Delivered pre-assembled, calibrated, with typical system-level performance

OTA Benefits of the Remote Head at 28/39 GHz

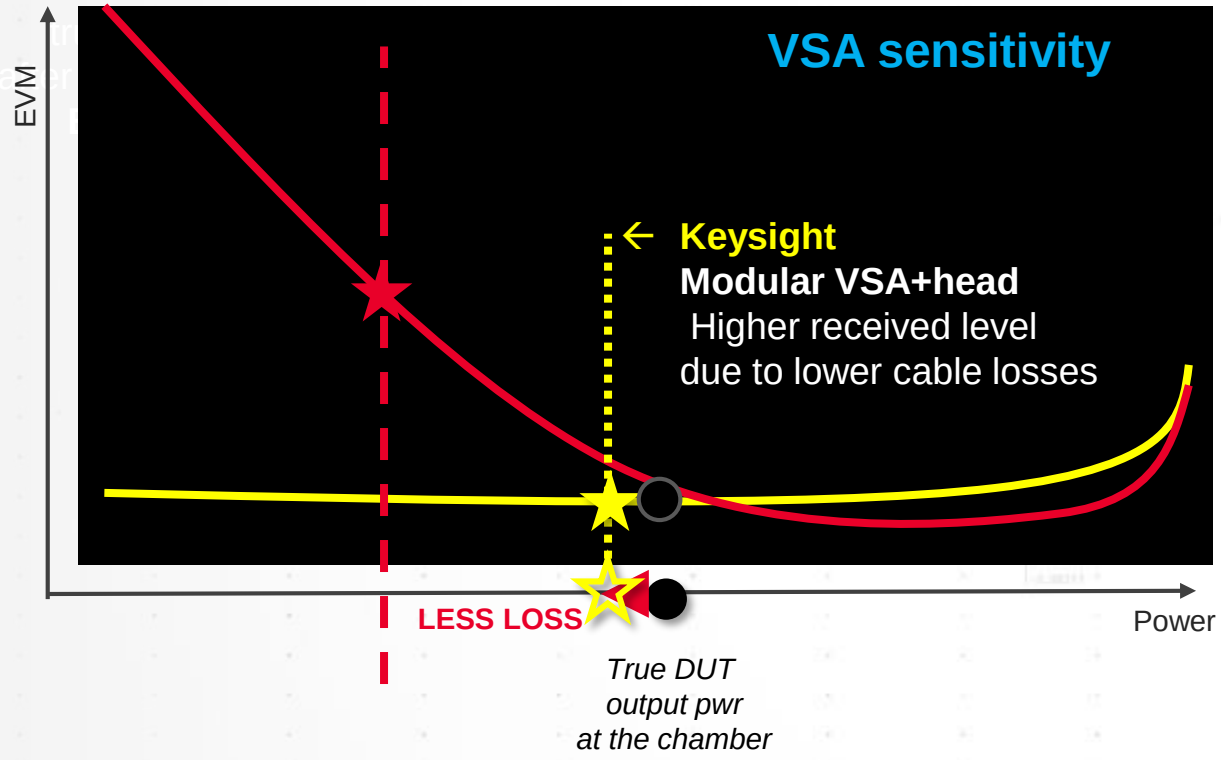
VSA SENSITIVITY – BENCHTOP WITH HIGH LOSSES

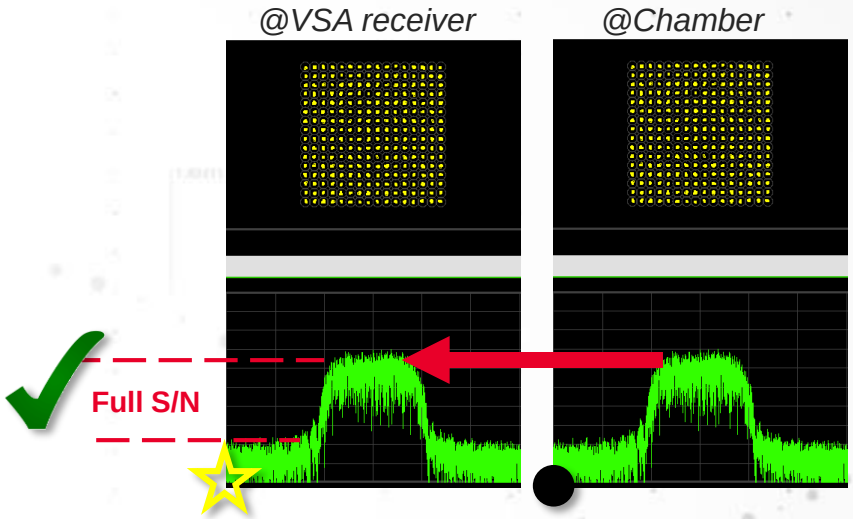


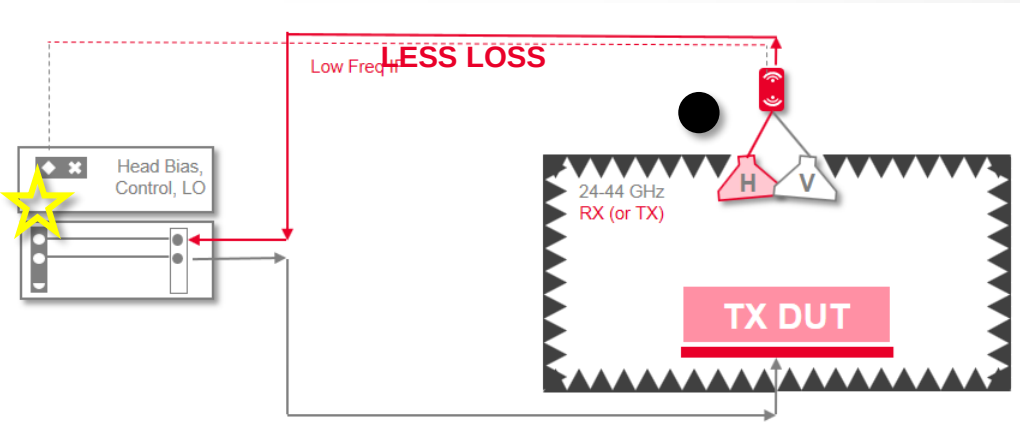


OTA Benefits of the Remote Head at 28/39 GHz

VSA SENSITIVITY – REMOTE HEAD WITH LOW LOSSES

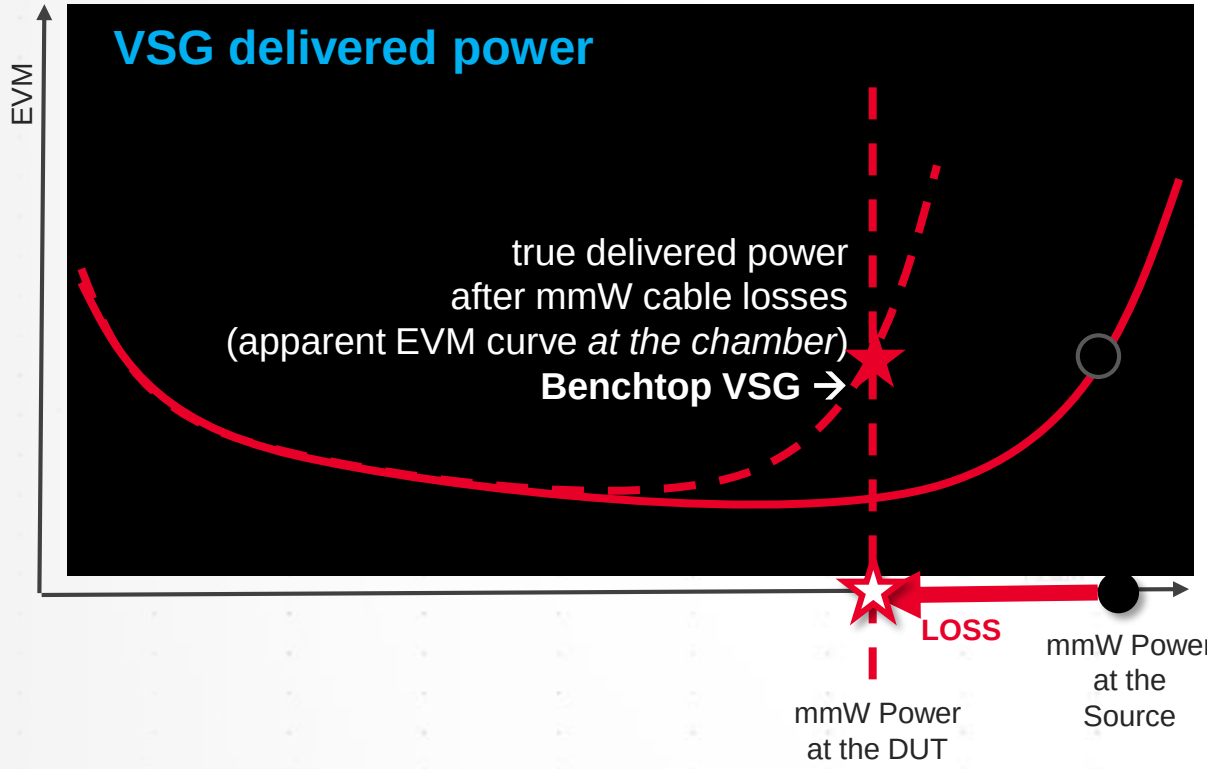


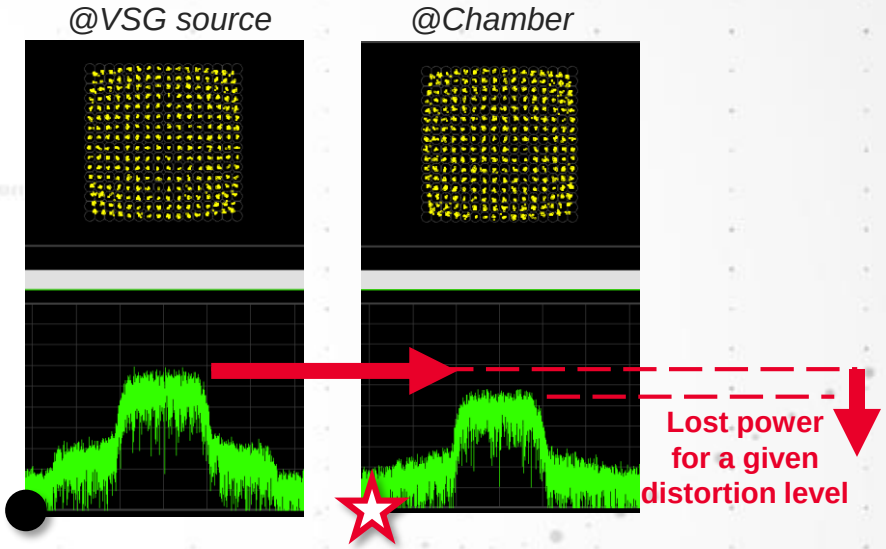


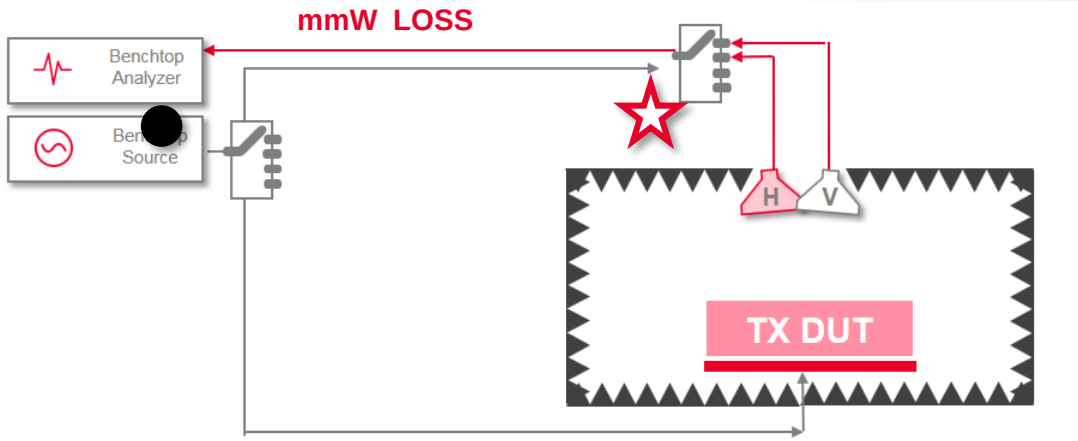


OTA Benefits of the Remote Head at 28/39 GHz

VSG DELIVERED POWER – BENCHTOP WITH HIGH LOSSES

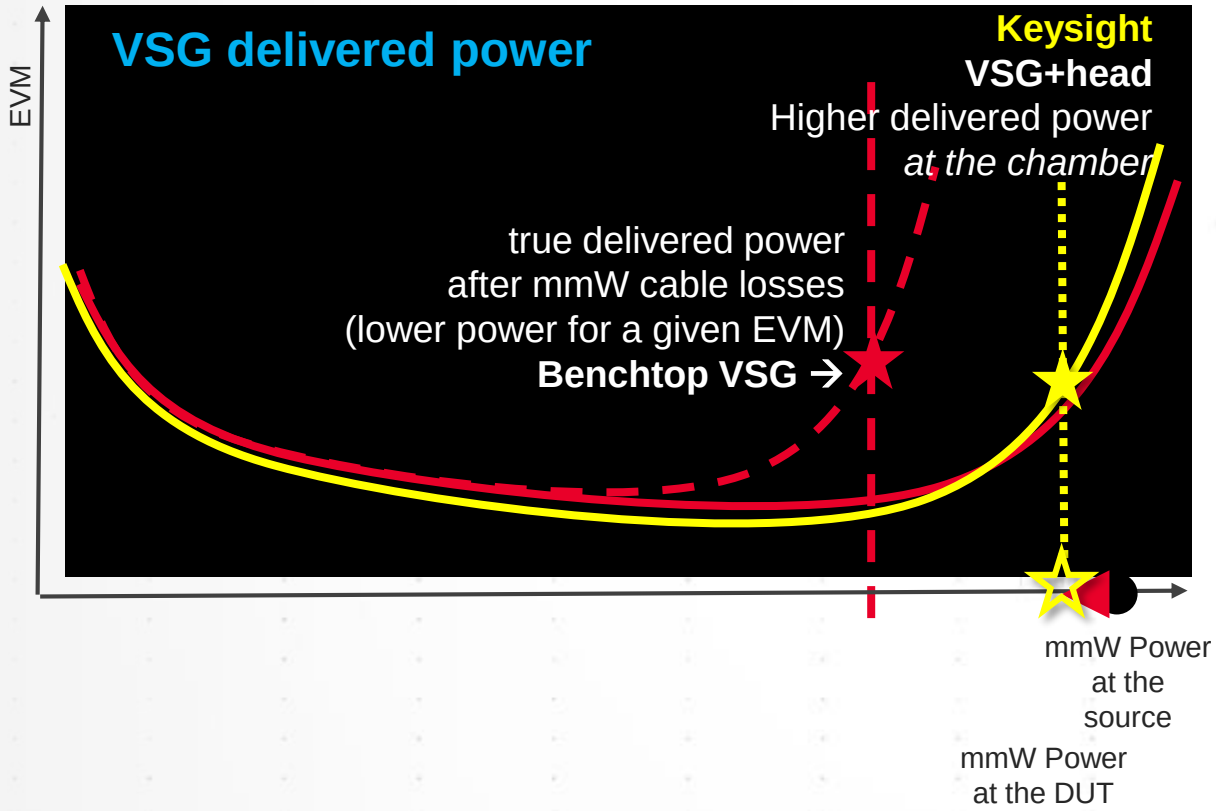


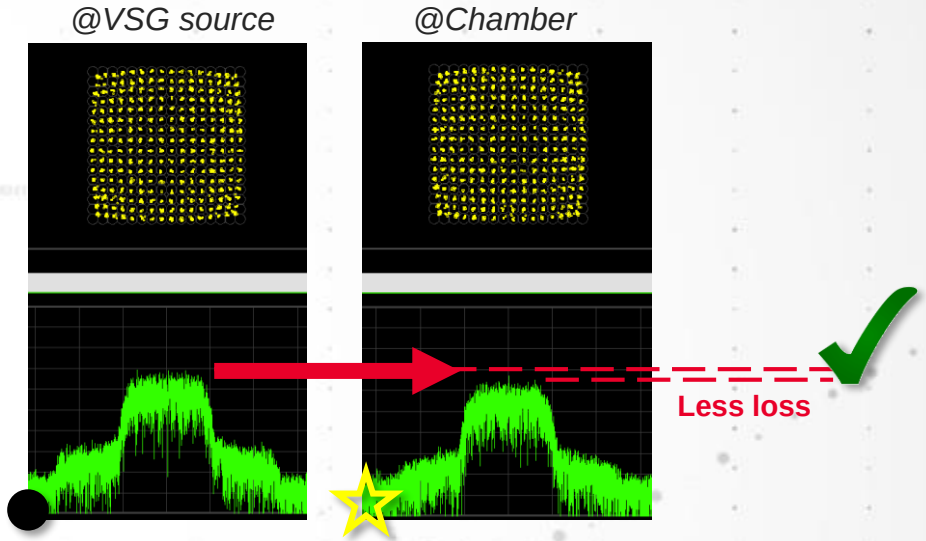


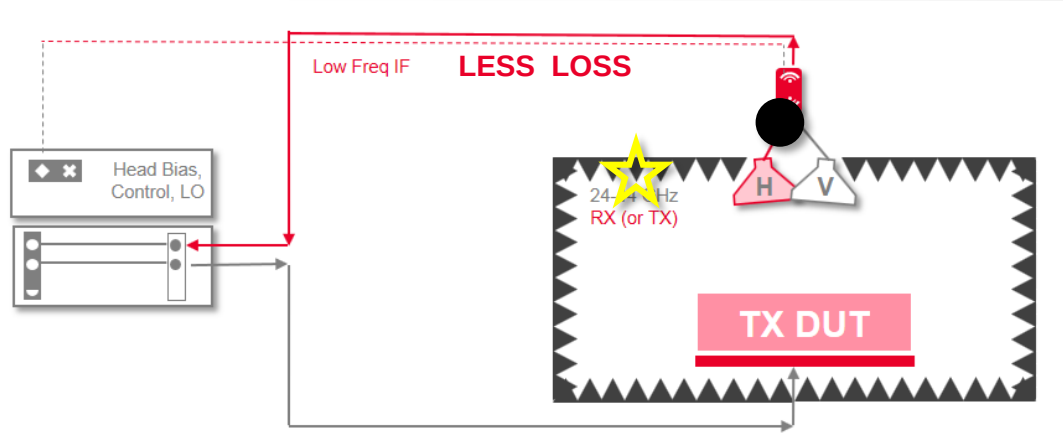


OTA Benefits of the Remote Head at 28/39 GHz

VSG DELIVERED POWER – REMOTE HEAD WITH LOW LOSSES







The NEW M9410A/11A PXIe Vector Transceiver

OPTIMIZED FOR 5G DVT & VOLUME MFG

Best-in-class integrated vector transceiver for DVT & volume Mfg, with combined advantages of performance, cost and size:

- Frequency range up to 6 GHz with 2-slot size
- Frequency extension to cover mmWave (FR2) with M1740A mmWave transceiver
- Built-in 1.2 GHz signal generation and analysis bandwidth
- Phase coherent & timing synchronization for multi-channel RF tests
- Built-in Half Duplex (HD) port for different test scenarios.
- Signal Studio for signal creation, and 89601B and X-Series measurement apps for signal analysis
- The 3-slot VXT M9411A adds optical data Interface for IQ data streaming, and custom FPGA (PathWave FPGA) for measurement acceleration and proprietary signal processing for extended applications beyond measurement.

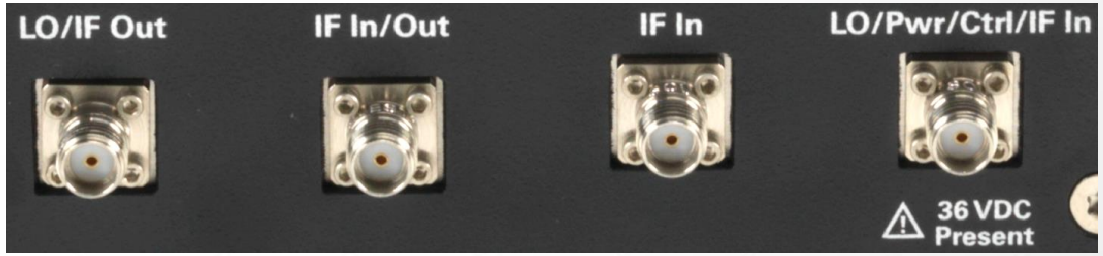
M1740 mmW Vector Transceiver head

EXTENDING YOUR FR1 SYSTEM TO FR2

- One head covers FR2 bands (24-44 GHz)
  (No need to purchase multiple heads)
- Integrated bi-directional ports, with
  TX & RX swapping (select V vs. H polarizations)
- Integrated signal conditioning
  (gain & attenuation)
- OTA-Ready design (low loss at IF, configuration flexibility)

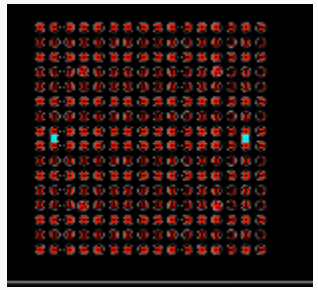
FRONT PANEL – mmW to DUT

BACK PANEL – LO, IF, Control

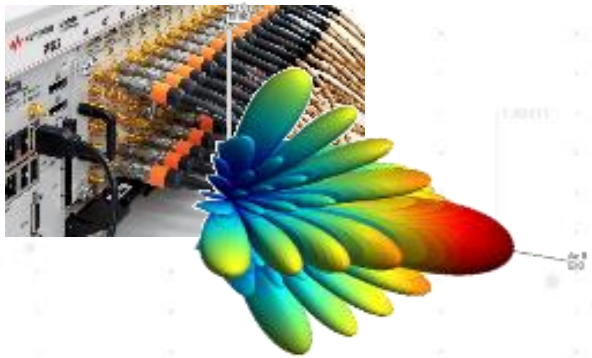


7 Key Measurement Challenges

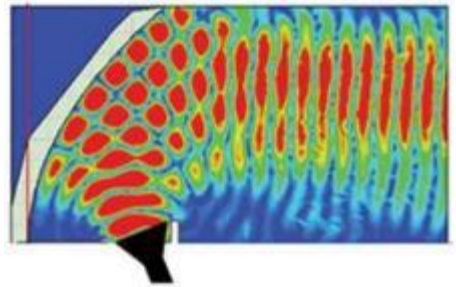
Signal Quality
mmW, Waveform, Fidelity



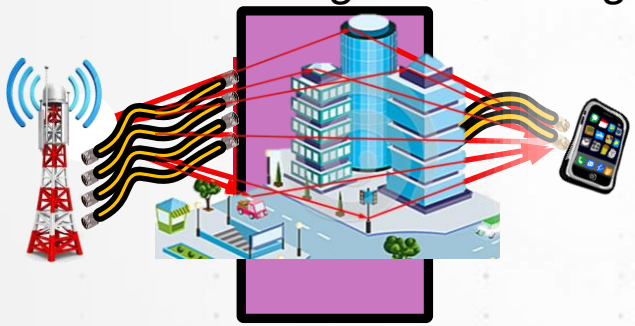
Lots of Channels
MIMO/Beamforming



Life Beyond Connectors
Over-the-Air



Channel
Characterizing & Emulating



Performance on the Network
Network Emulation

Cost of Test
Assets, throughput

Field Testing and Drive Test

Solutions for Full Wireless Network Lifecycle

FROM RF MEASUREMENTS TO ANALYTICS

NEMO

Network Optimization & Roll-out				Network Benchmarking
		Network Control & Monitoring		
	Post-Processing, Reporting, and Analytics			

Field Testing/ Drive Test Challenges

Drive Preparation

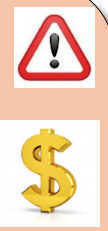
- Script errors
- Setup time
- Drive Route preparation

Drive Test

- 2 people in car
- Deviation from planned route
- Tool issues:
  - Antennas
  - Instabilities

Data Management

- Manual management
- No central repository

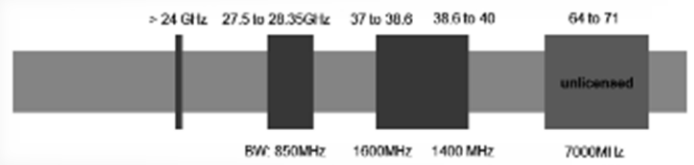


Reporting

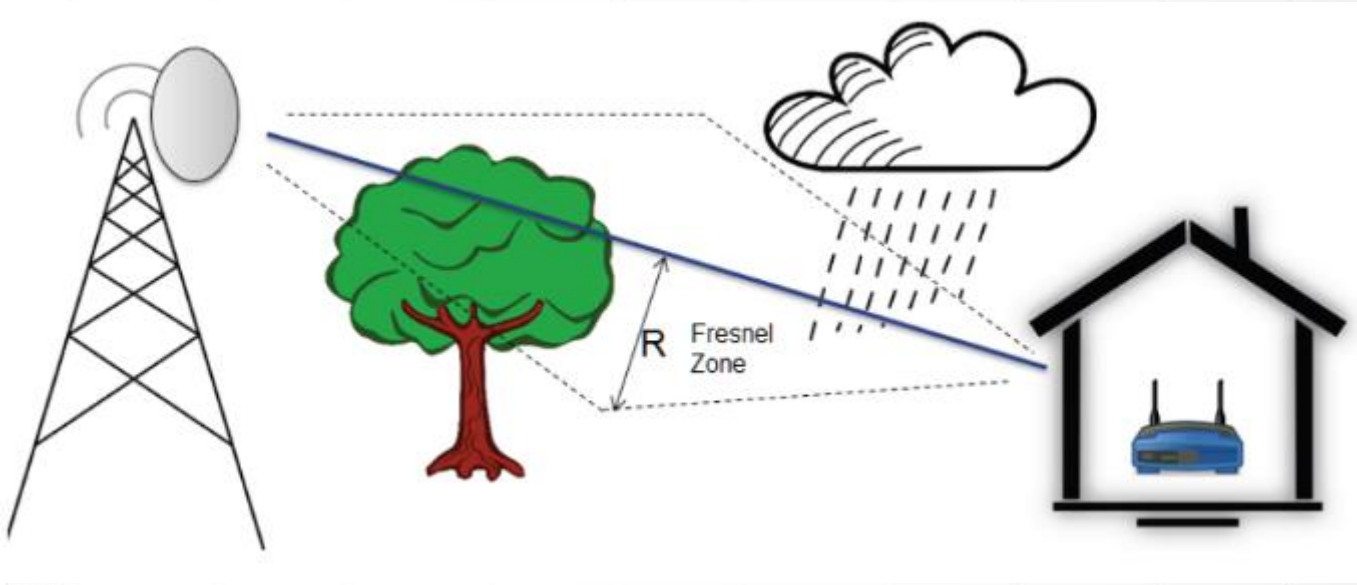
- Can be done late after drive test
- Most often include manual steps
- Repetitive (e.g. in-building)

mm-wave Challenge

FCC 5G frontier bands up to 71 GHz

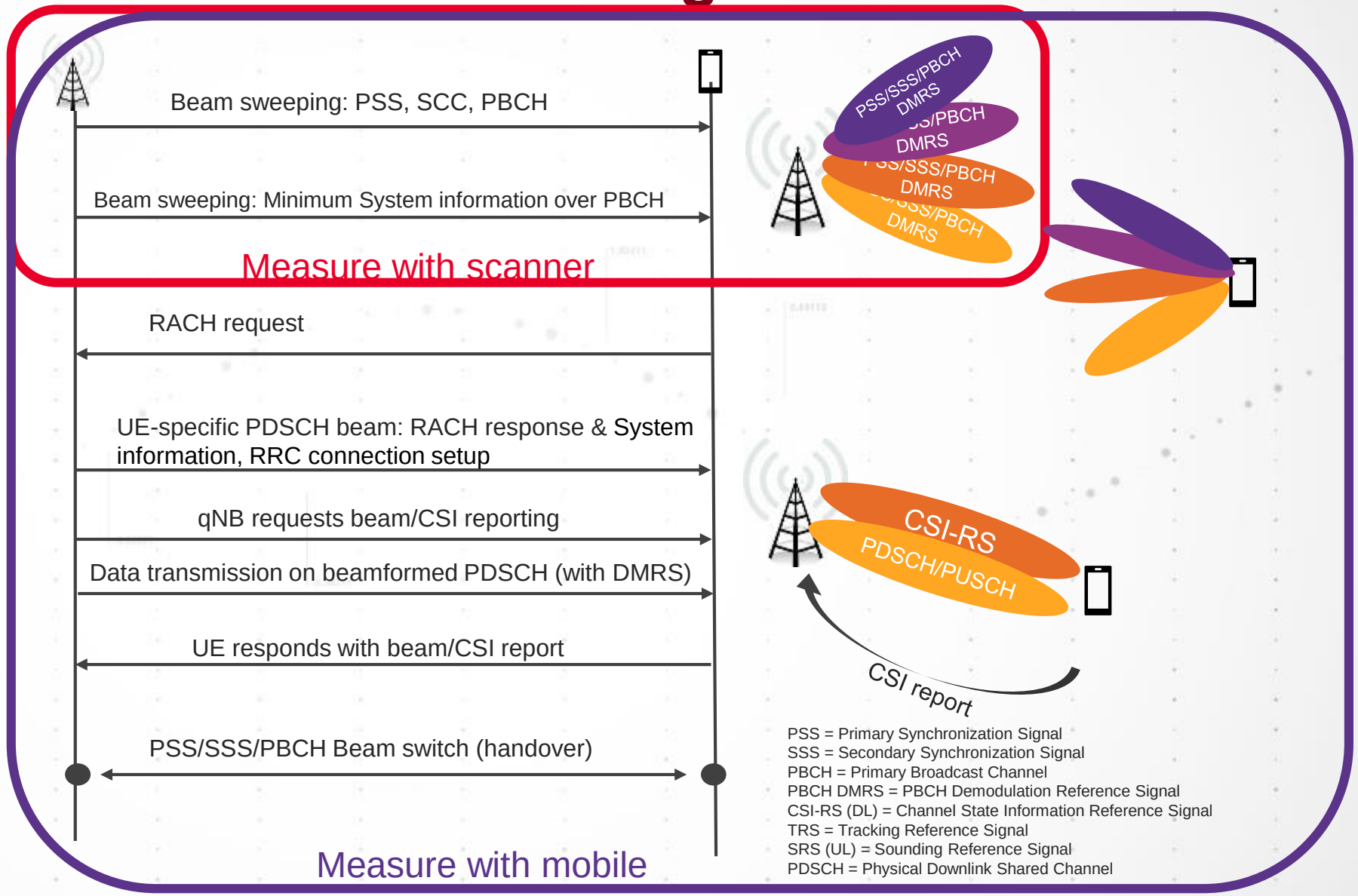


- 5G mm-wave link budget is quite different from traditional sub 6 GHz wireless link budget
- Extra losses due to rain fade, shadowing loss, foliage, atmosphere absorption, humidity and, Fresnel blockage



5G NR – Beam Based Network Coverage

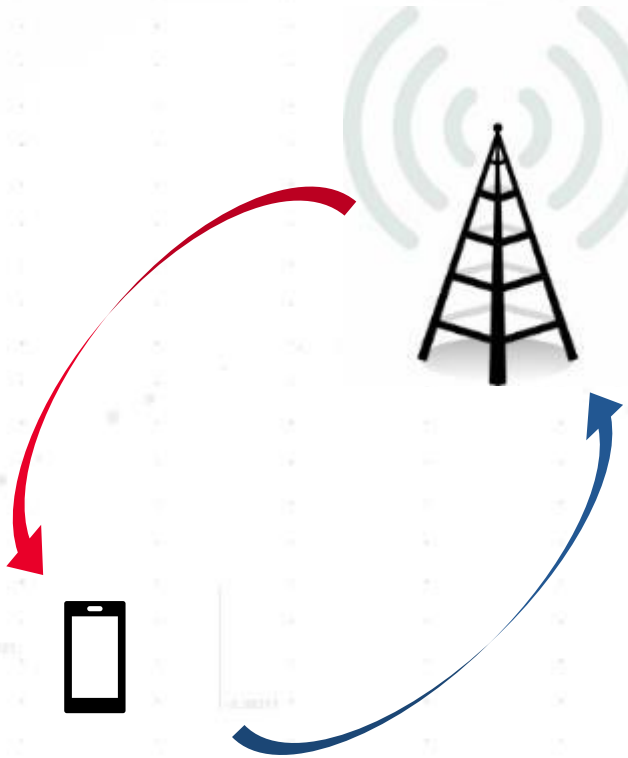
- Paradigm shift from cell coverage to beam coverage
- There are many kind of beams, static and dynamic, mobile, and network side
  - DL reference beams
  - UL beams (UE/CPE-specific)
  - DL/UL traffic beams
  - Vendor-specific



5G L1 channels and signals

DOWNLINK

- Common (visible in scanner and UE measurements):
  - PSS (Primary Synchronization Signal)
  - SSS (Secondary Synchronization Siqnal)
  - PBCH (Physical Broadcast Channel)
- User level (UE measurements only):
  - CSI-RS (Channel State Info Reference Signal)
  - DMRS (Demodulation Reference Signal)
  - PTRS (Phase-tracking Reference Signal)
  - PDSCH (Physical UL Shared Channel)
  - PDCCH (Physical UL Control Channel)



UPLINK

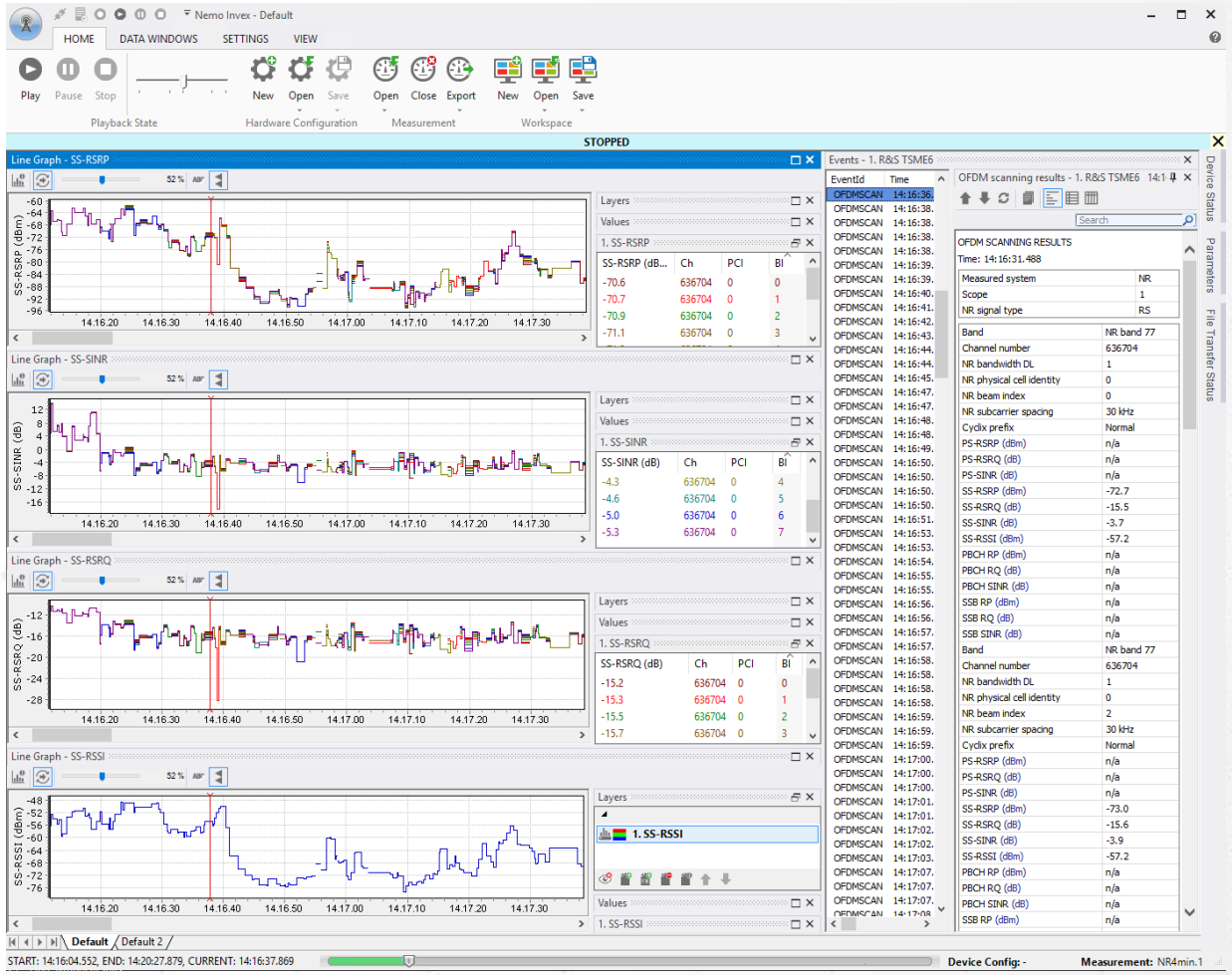
- User level (UE measurements only)
  - PUSCH (Physical UL Shared Channel
  - PUCCH (Physical UL Control Channel)
  - PRACH (Physical Random Access Channel)
  - DMRS (Demodulation Reference Signal)
  - PTRS (Phase-tracking Reference Signal)
  - SRS (Sounding Reference Signal)

3GPP 5G NR Scanner Measurements with Nemo Outdoor

SS BLOCK REFERENCE BEAM DEMODULATION- MULTIPLE BEAMS

- Reference beam coverage and quality measurements, demodulated reference signals
- Reported per Sync beam (SS block):
  - Channel
  - Physical Cell Identity (PCI)
  - Beam ID (BI)
  - SS-RSRP
  - SS-RSRQ
  - SS-CINR
  - RSSI

View from Nemo Outdoor, measuring one cell (PCI 0) with 8 beams, beam ids 0-7



3GPP 5G NR Scanner Measurements with Nemo Outdoor

SINGLE BEAM WITH DRIVE ROUTE

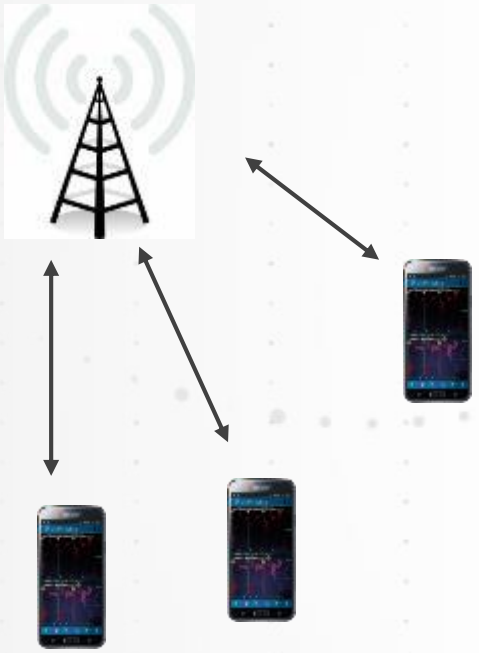
Massive MIMO Field Testing Challenges

- Massive MIMO is a cell capacity feature for sub 6GHz
- Gain achieved only when multiple UEs simultaneously generating downlink traffic
- Many variables:
  - Distribution of users in the cell (horizontal and vertical)
  - Multi-path radio environment
  - Network configuration
  - NEM implementations
- Field testing needed to verify the capacity gain provided
- Test setup is complicated, involving multiple UEs doing coordinated active data transfers

Massive MIMO Cell Testing

FIELD TESTING

Field units distributed
in the cell area



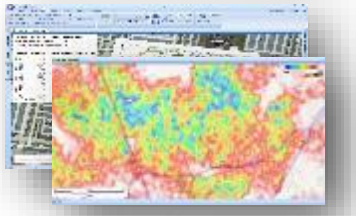
Collection

Control
measurement coordination
Real time monitoring

Nemo Cloud

Data analytics tools
Aggregated cell-level KPIs
Per-UE drill down

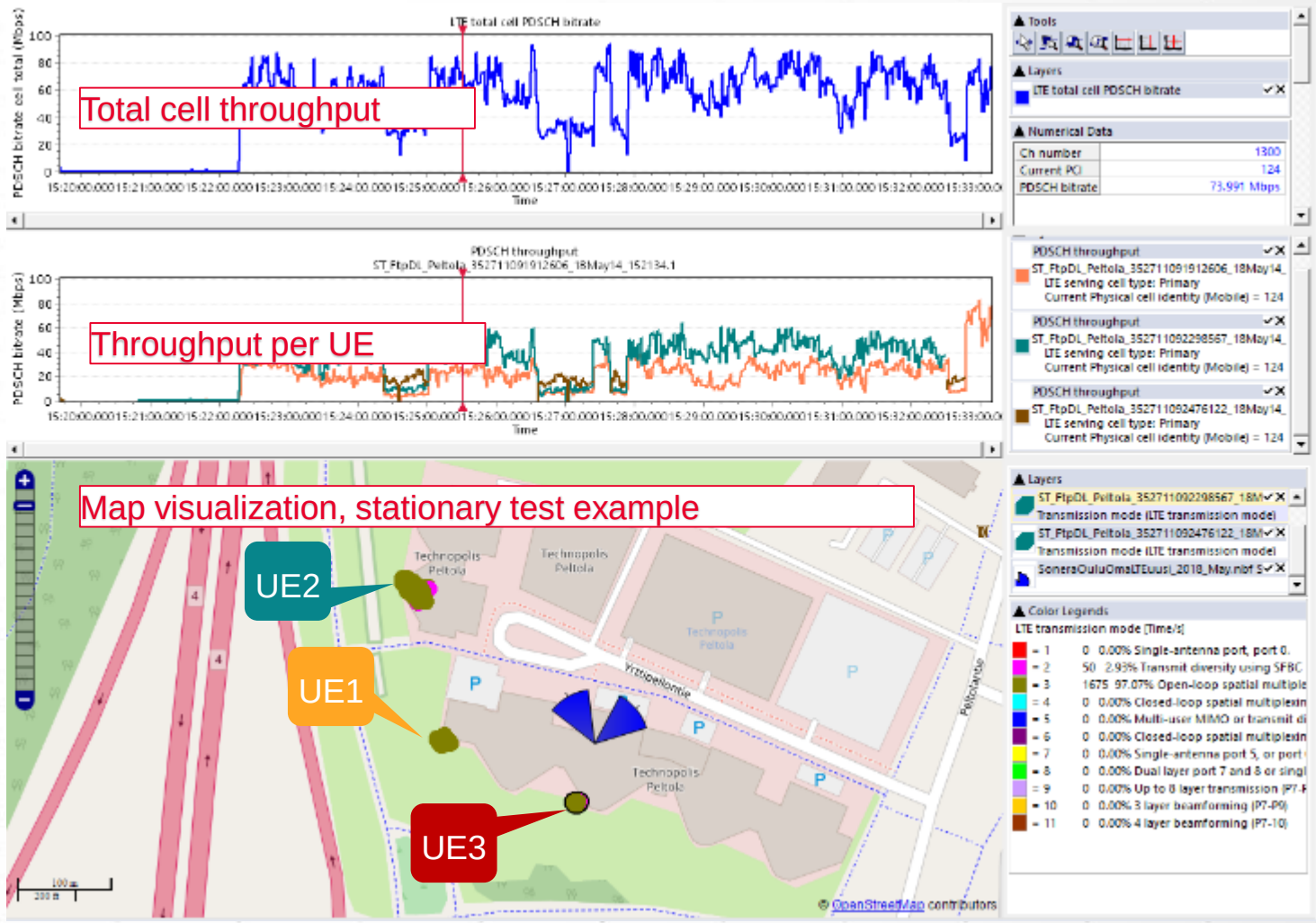
Analytics



Massive MIMO Cell Testing

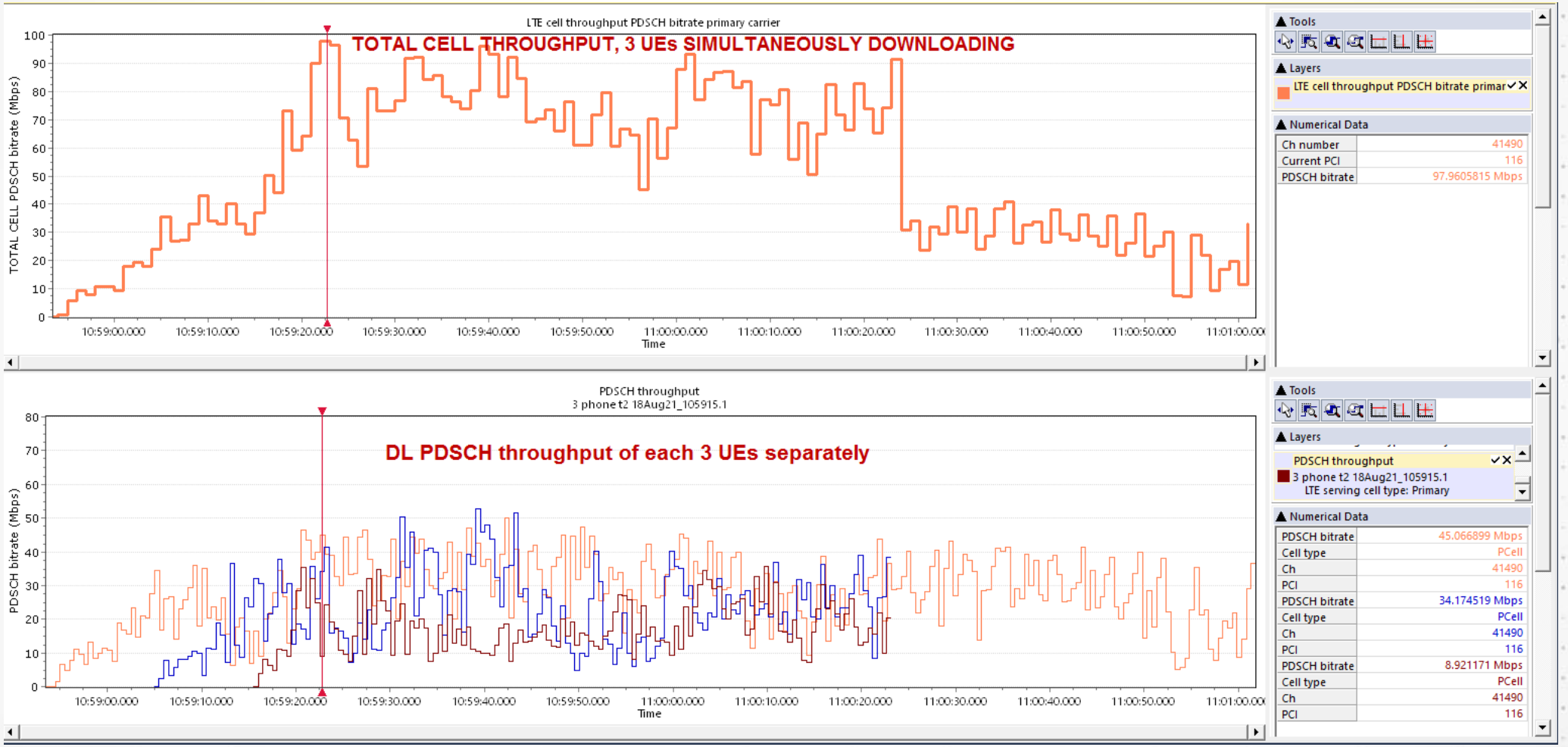
ANALYTICS

- Automated aggregation of cell-level KPIs
  - Total cell throughput
  - PRB utilization
  - Etc.
- Per-UE analysis
  - SNR, RSRQ, transmission mode, throughput, Rank, number of MIMO streams
- Map visualization of all UEs



LTE TDD mMIMO Testing

TOTAL CELL THROUGHPUT



Keysight Nemo wireless network testing solutions