

5G Boot Camp

**PART TWO:
7 KEY MEASUREMENT CHALLENGES AND CASE STUDIES**

Keysight Technologies

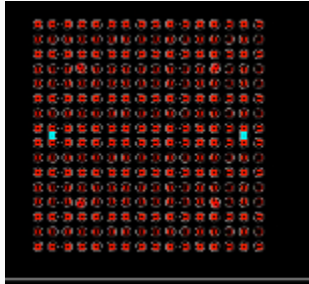
2019 JAN

JianHuaWu

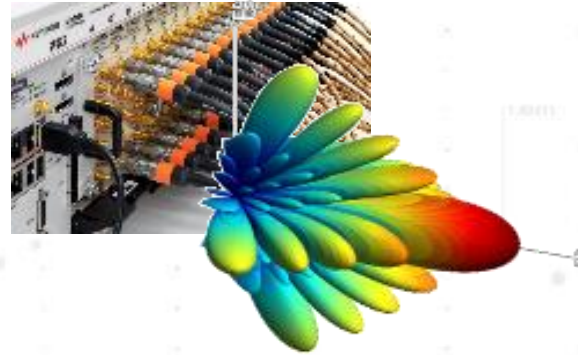


7 Key Measurement Challenges

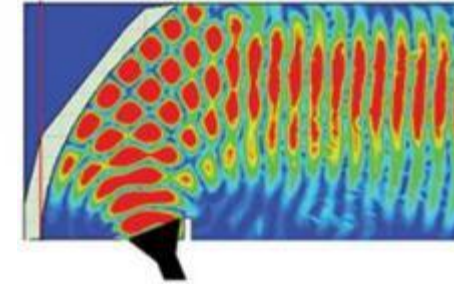
Signal Quality
mmW, Waveform, Fidelity



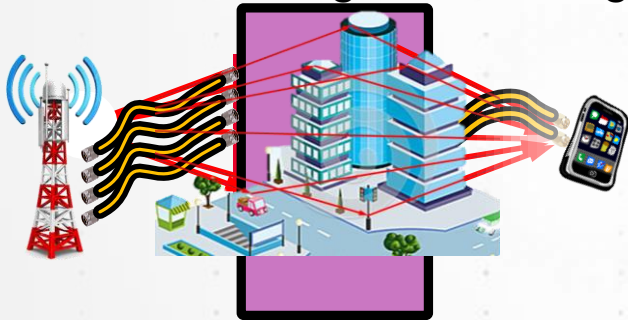
Lots of Channels
MIMO/Beamforming



Life Beyond Connectors
Over-the-Air



Channel
Characterizing & Emulating



5

6

7

Suppose you want to design and test a motorbike

UNDERSTANDING THE CHANNEL IS OBVIOUSLY CRITICAL TO SUCCESS



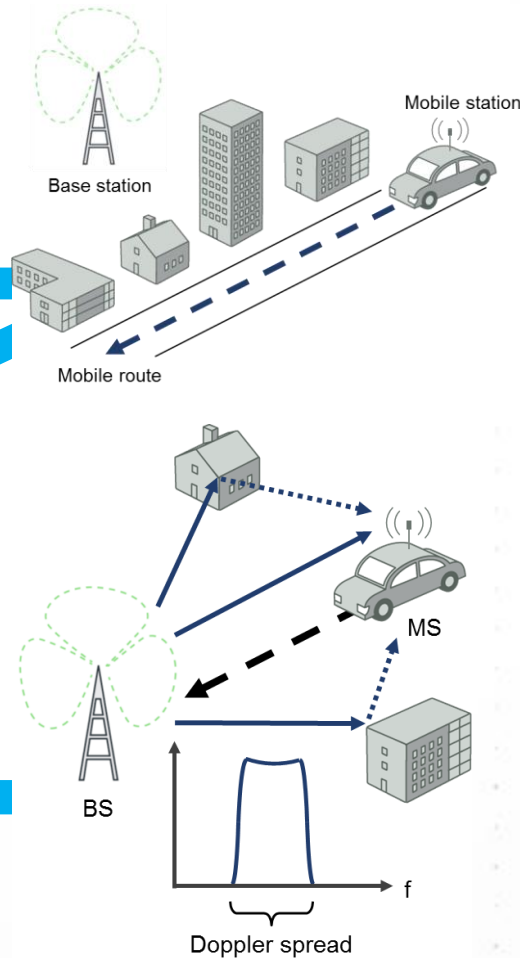
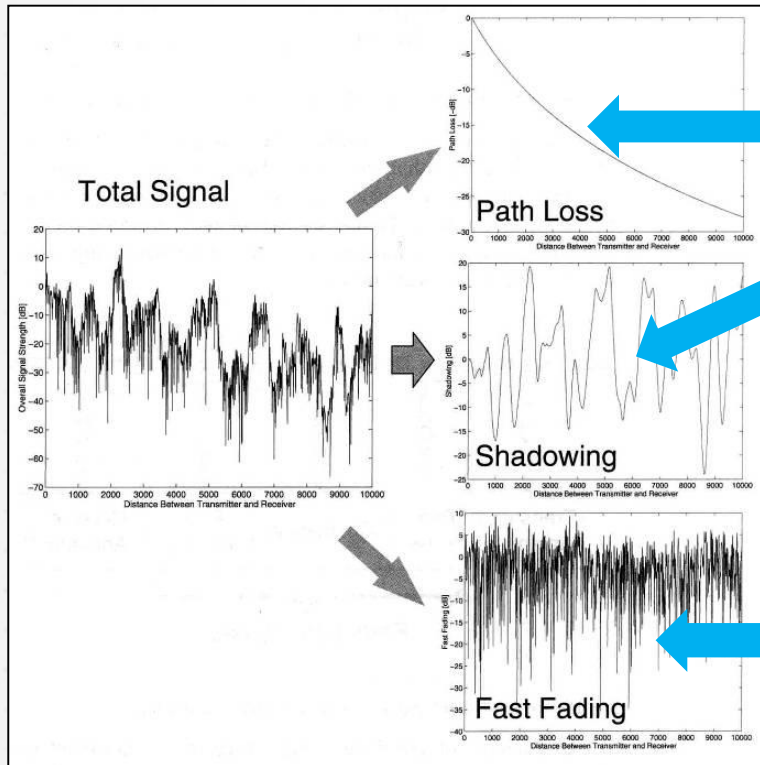
What is the Radio Channel?

Channel $h(t)$



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

PROPAGATION



INTERFERENCE

Ideal reception	
•	•
+	
+ Noise & Interference	
Real-life reception	
•••••	•••••
•••••	•••••

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**

TDL - Tapped delay line (time only)

CDL – Cluster delay line (time and space)

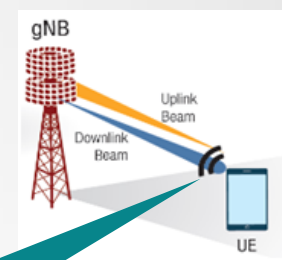
SCME – Spatial channel model extended

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

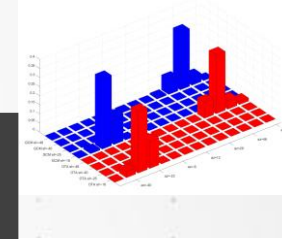
More recently, *Ray Tracing* of modelled environments has become possible

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

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

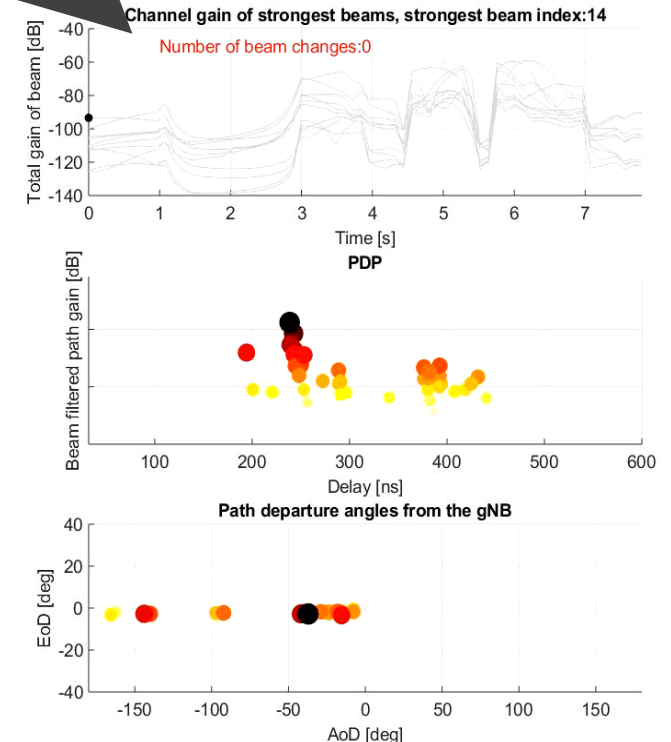
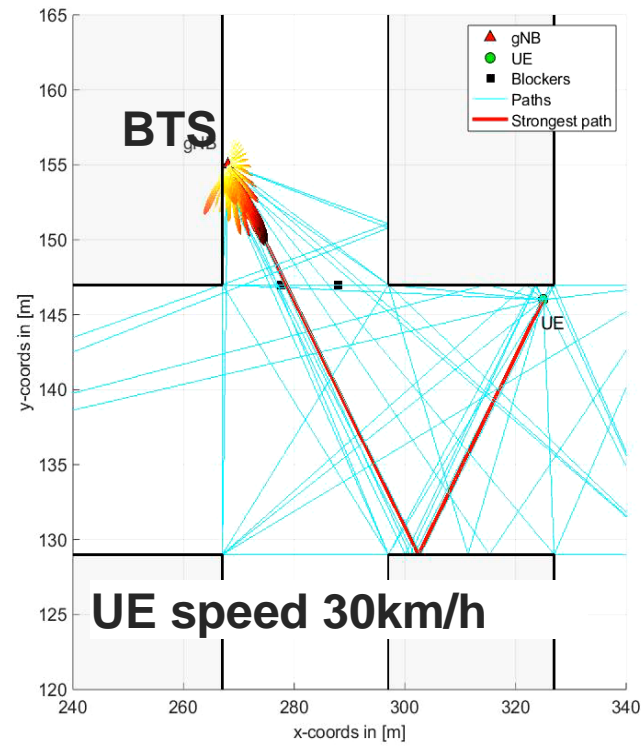


Where is my next Beam?
Fast & reliable beam management needed



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?

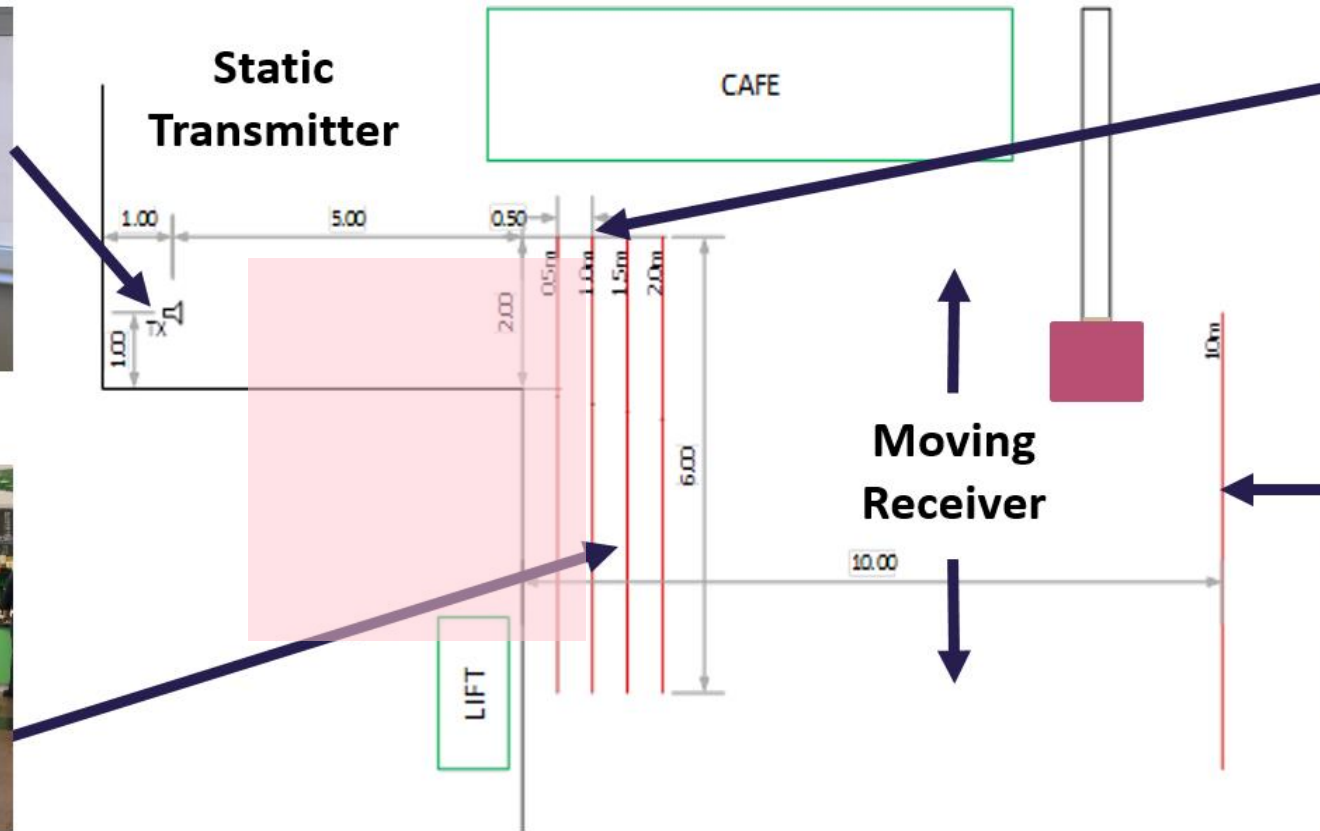
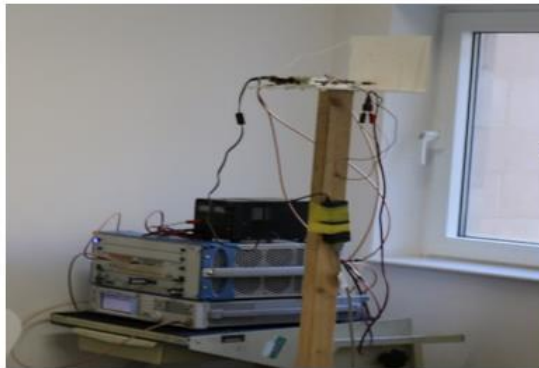


Fading Cluster AoD's are dynamic

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?

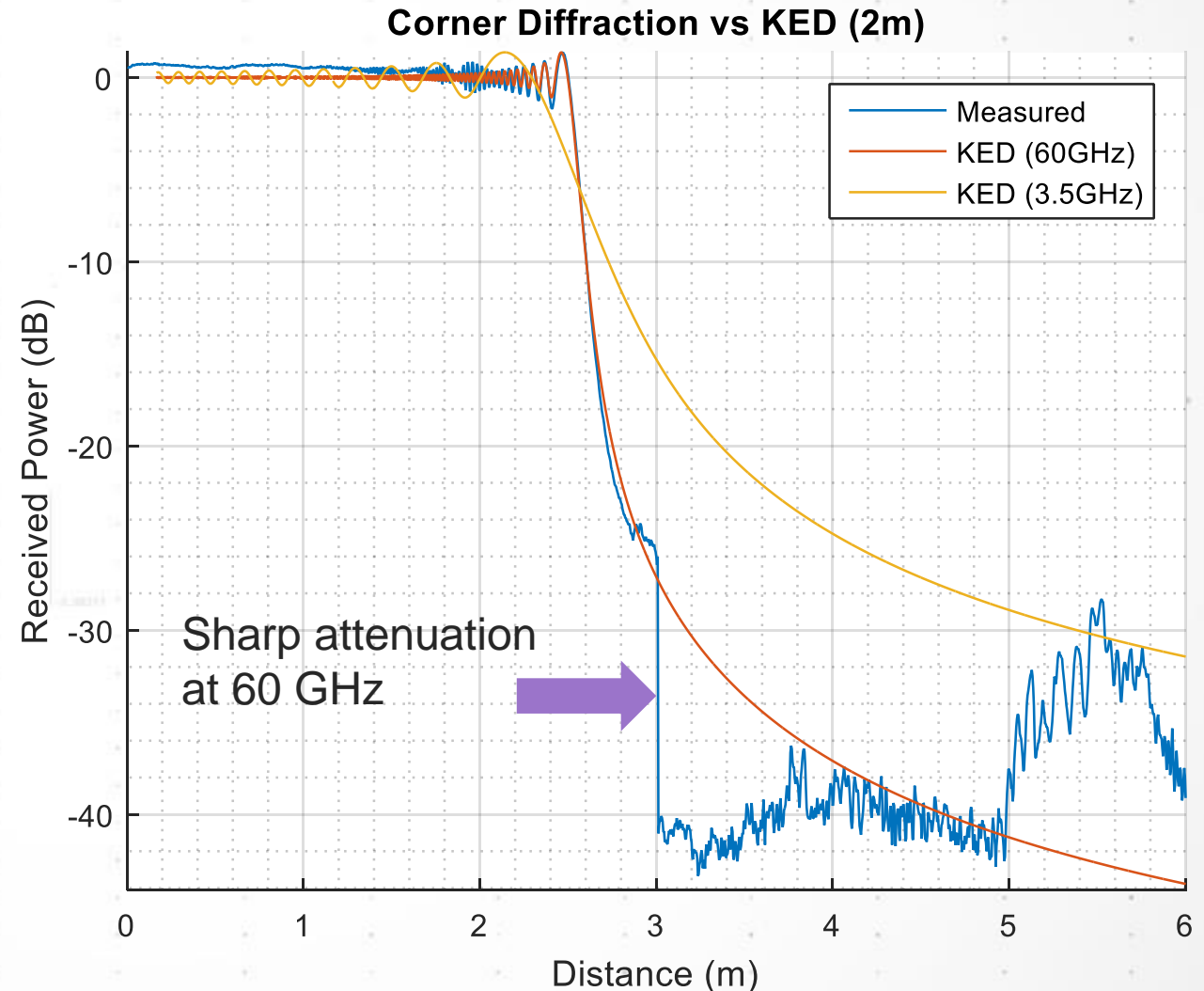
Simulated vs. measured at 3.5 GHz and 60 GHz

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]	√	-

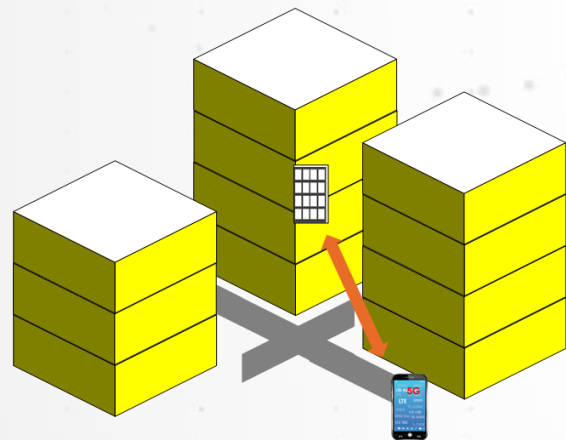
LOS / NLOS

Use cases for Massive MIMO testing

3GPP TR 38.901 CHANNEL MODEL SCENARIOS

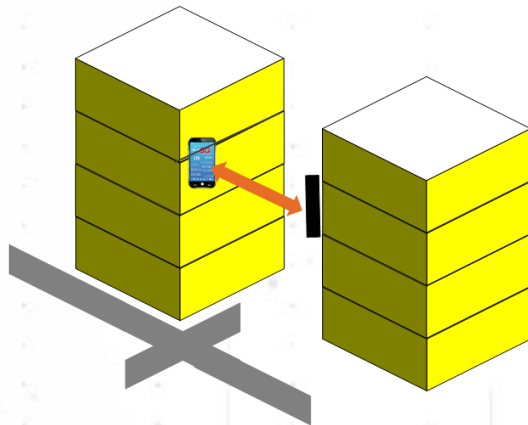
Urban Microcell
(UMi)

UMi street canyon (O2O)

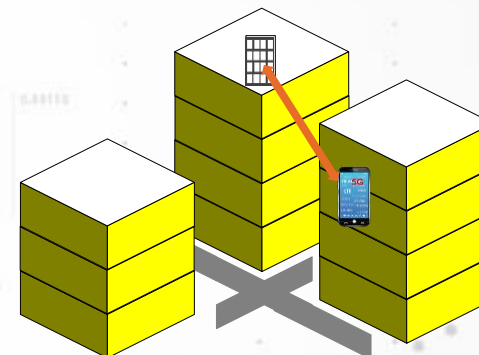


BSs mounted below rooftops

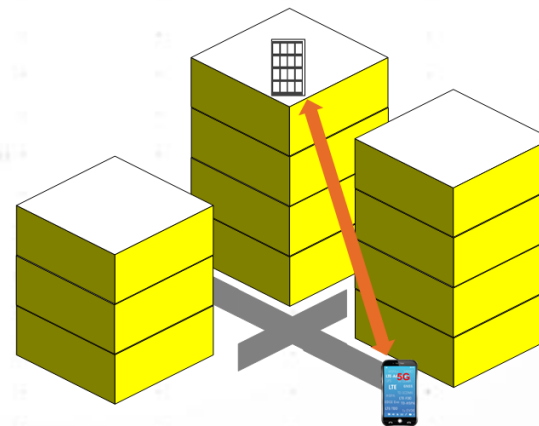
UMi Outdoor to Indoor (O2I)



UMa Outdoor to Indoor (O2I)



UMa street canyon



BSs mounted above rooftops

Urban Macrocell
(UMa)

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		

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	CASD in [°]	CASA in [°]	CZSD in [°]
Value	10	22	3

Per-Cluster Parameters					
Parameter	CASD in [°]	CASA in [°]	CZSD in [°]	CZSA in [°]	XPR in [dB]
Value	5	8	3	3	11

Channel Model Selection

Link: BS1 - MS1

MS Speed: [8.330] m/s

Emulation length: [34.605] s

Propagation Condition: [LOS]

Channel Model: [3GPP 5G 38.901 UMi]

Use angle spread scaling

Path Loss Model: [3GPP 5G 38.901 UMi]

Path Loss Exponent: [4]

Shadow Fading Model: [3GPP 5G 38.901 UMi]

Channel Model Selection

Link: BS1 - MS1

MS Speed: [8.330] m/s

Emulation length: [34.605] s

Propagation Condition: [LOS]

Channel Model: [3GPP 5G 38.901 UMi CDL-E]

Use angle spread scaling

Path Loss Model: [3GPP 5G 38.901 UMi CDL-E]

Path Loss Exponent: [4]

Shadow Fading Model: [3GPP 5G 38.901 UMi CDL-E]

std: [1]

Non-self-blocking:

Number of blockers: [0]

Speed for each blocker (m/s): [1: 8.33 2: 8.33]

PROPSIM UI

CDL Models

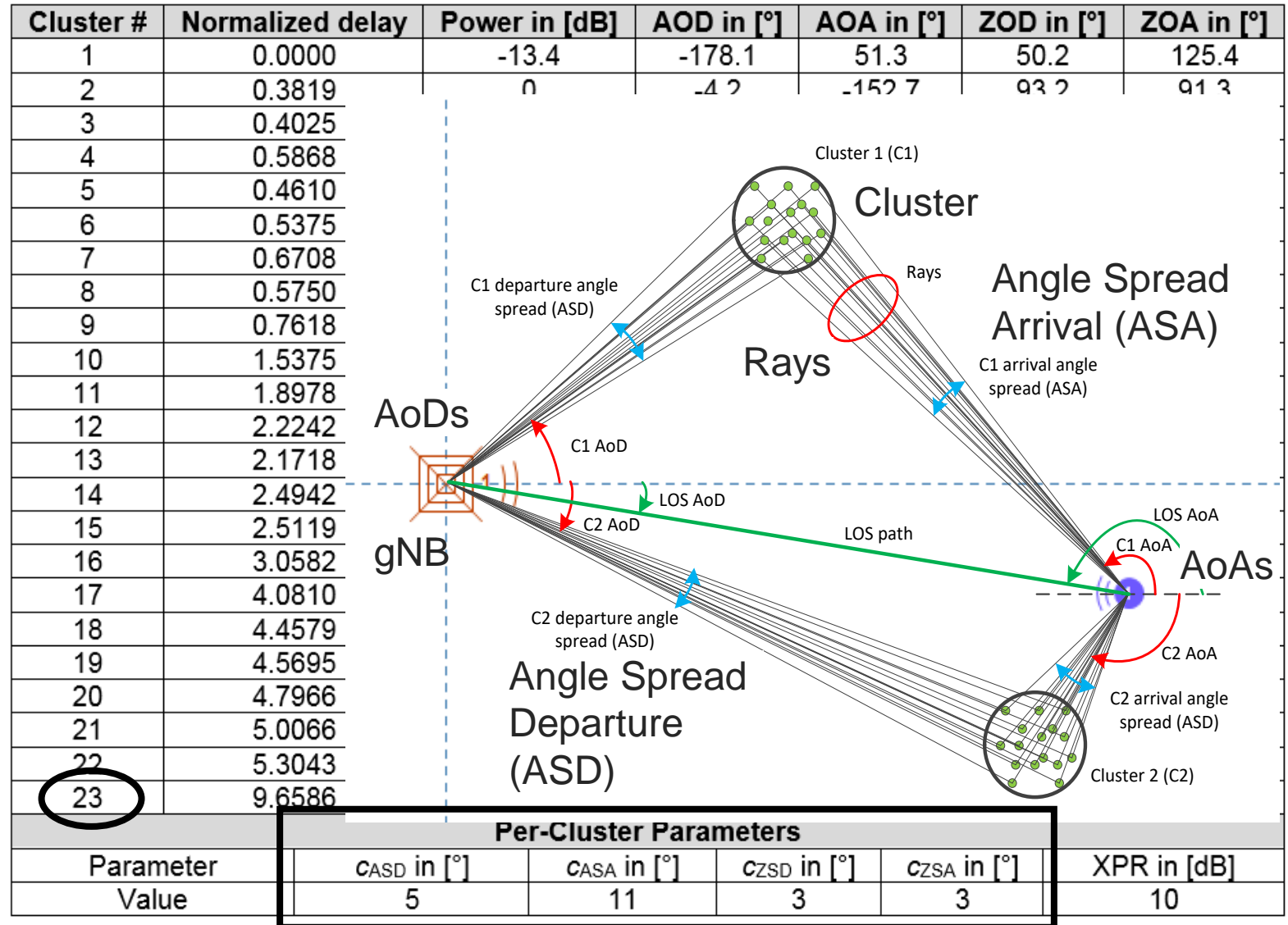
→

OK Cancel

Channel models for FR2: CDL-A

TR 38.901 Table 7.7.1-1. 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.



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

Base stations



Mobile terminals



Why companies invest on Channel Emulation tools?

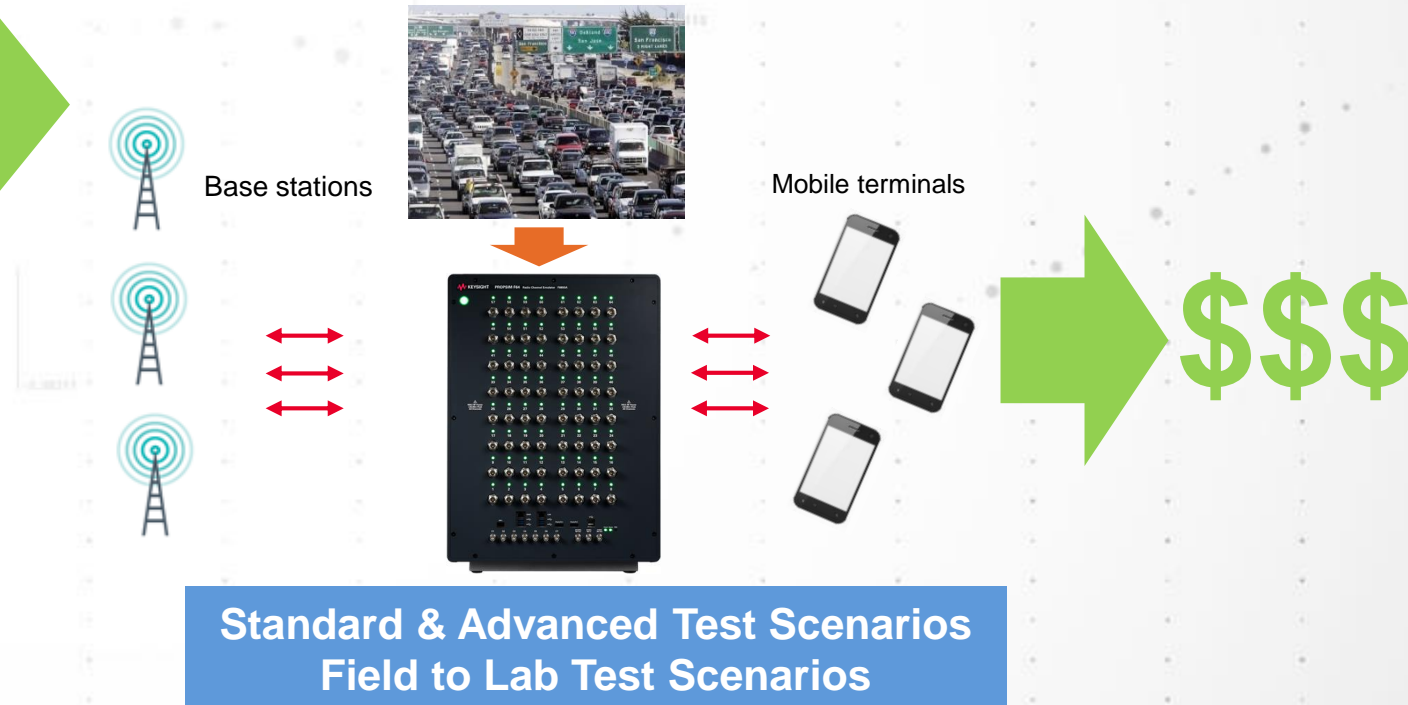
QUALITY OF SERVICE & TIME TO MARKET = SUCCESSFUL BUSINESS.

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

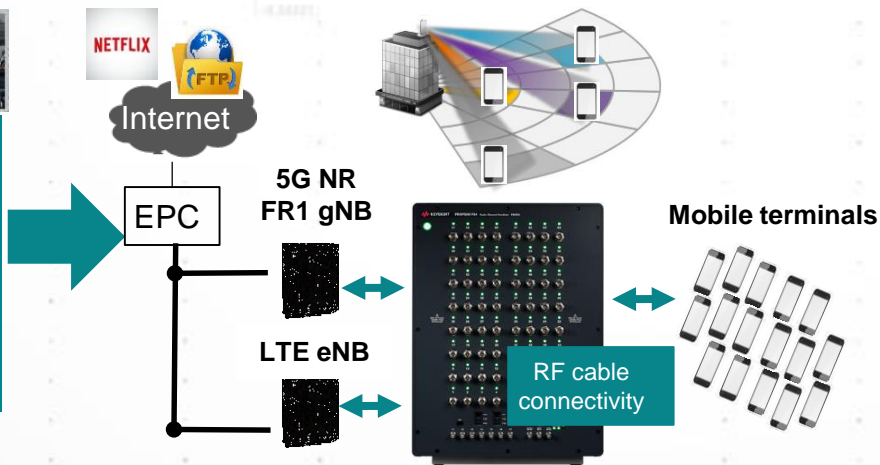
Sub-6GHz massive MIMO 16TRX, 32TRX, 64TRX, 128TRX
 MU-MIMO performance optimization up to 4/8/16/32 layers

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



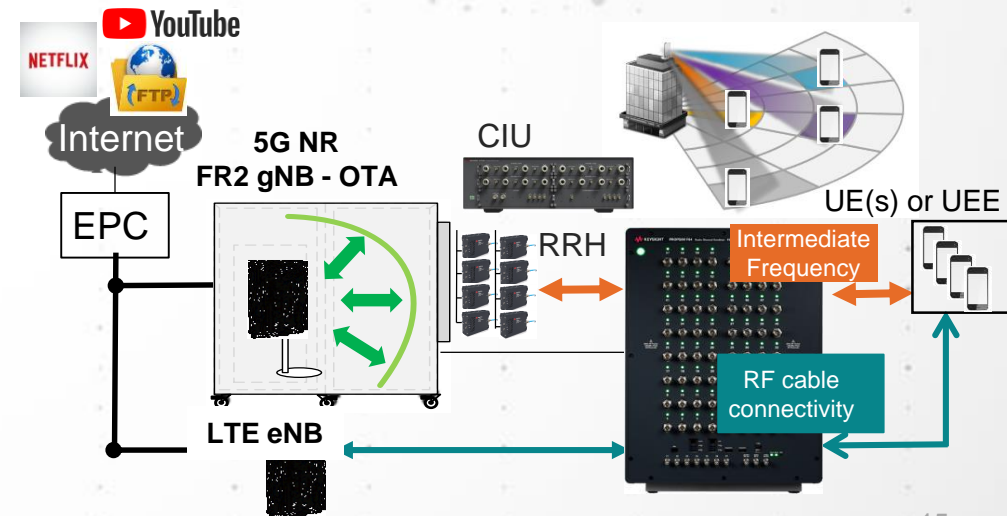
Solutions

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



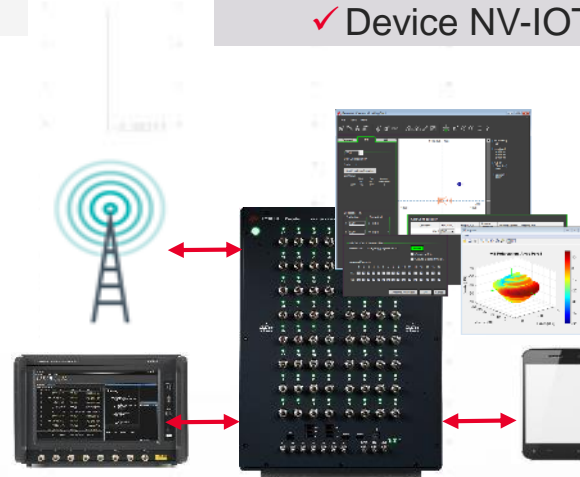
Solutions

PROPSIM Geometric Channel Modeling (GCM) 5G Tools

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PROPSIM 5G Channel Emulation solutions

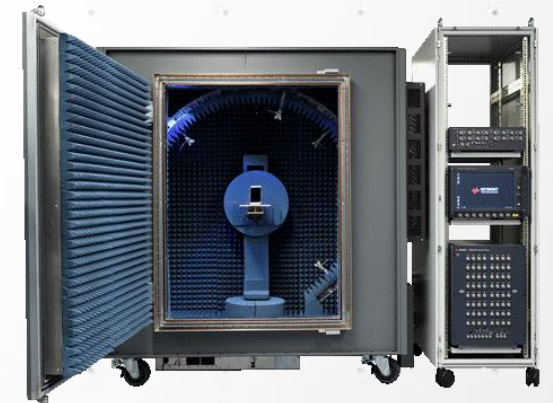
- ✓ Realtime very low insertion delay
- ✓ BW 100/200/400 MHz up to 1.2 GHz
- ✓ CA up to 12CC (1.2 GHz)
- ✓ Seamlessly integrates with **UXM 5G**, validated with 5G BTS
- ✓ Complete mmWave OTA solutions using CIU with RRHs
- ✓ Complete Sub 6 GHz performance test solutions
- ✓ Device NV-IOT solutions (Network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



RRH



mmWave



PROPSIM F64 Key Features

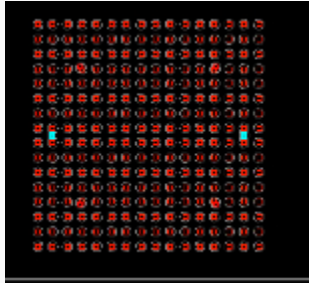
- **Single F8800A platform up to 64TRX, 1024 MIMO ch.**
 - HW configurations 8, 16, 24, 32, 40, 48, 56, 64 TRX
 - 64 TRX up to 100 MHz BW (160 MHz WLAN opt.)
 - 32 TRX up to 200 MHz BW
 - 16 TRX up to 400 MHz + 16 TRX up to 100/160 MHz BW
- **Carrier Aggregation TDD & FDD**
 - Non-contiguous CA up to 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

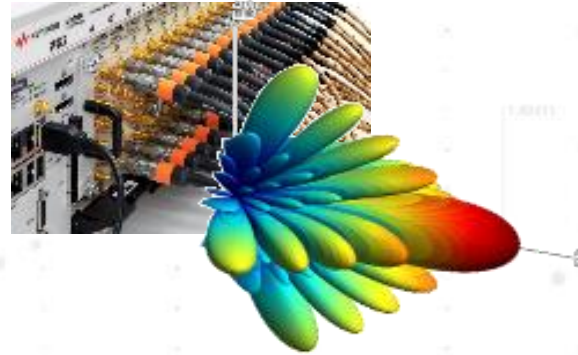
Signal Quality

mmW, Waveform, Fidelity



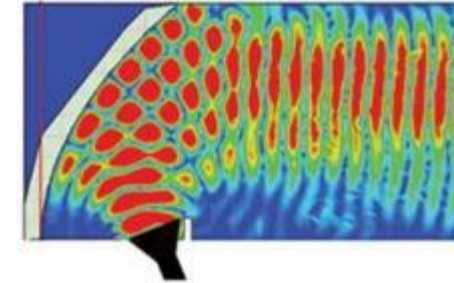
Lots of Channels

MIMO/Beamforming



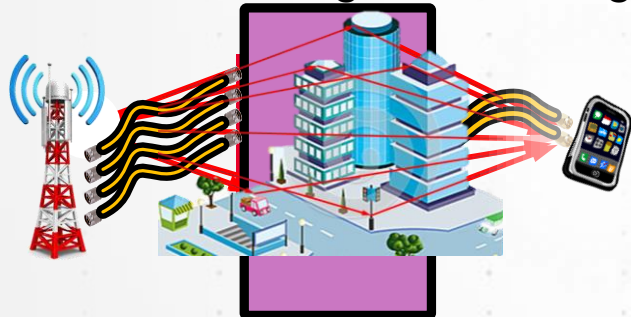
Life Beyond Connectors

Over-the-Air



Channel

Characterizing & Emulating



Performance on the Network

Network Emulation



*Protocol
R&D*



*RF / RRM
DVT*



*Functional
KPI*



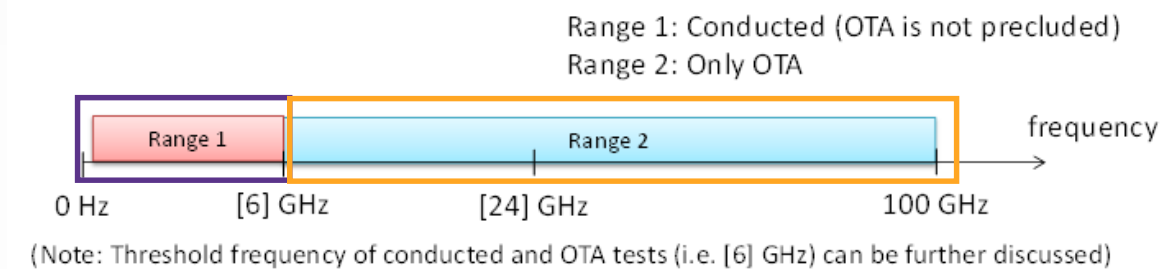
Challenge: Performance on the Network

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 adaptation, beam management
- Optimizing performance to meet KPI goals



5G, Something new, something old



Functional Performance

Modem Test,
Full Stack Testing,
Data Throughput,
Handover

OTA

Is my chipset working?

RF Parametric

EVM, ACLR
PER, Emissions

Is my RF working?

Antenna & Conformance OTA

Antenna
Parameters
TRP, TIS

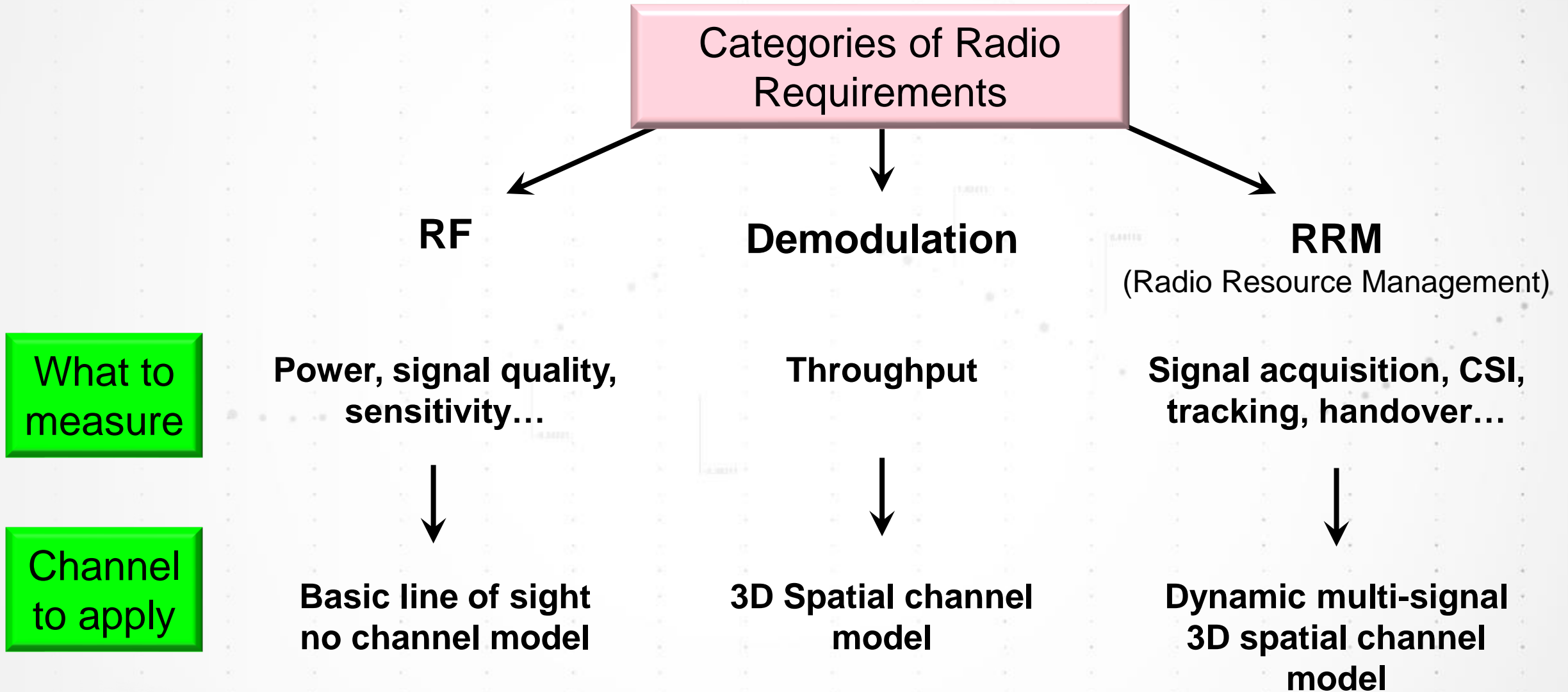
How good is my
antenna?

MIMO OTA

Throughput,
Virtual Drive Test,

How good is my
device?

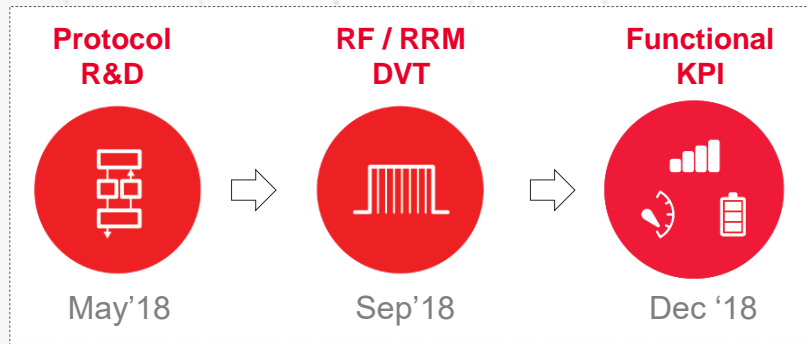
The OTA challenge



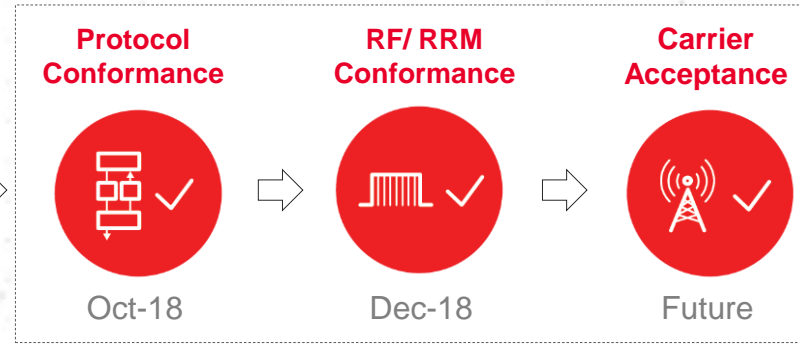
Get the fastest path to 5G Solutions

TARGETING CHIPSET AND DEVICE WORKFLOW

5G Interactive R&D Solutions



5G Device Acceptance Solutions



5G MFG Solutions



Keysight 1st Solutions across the entire device workflow



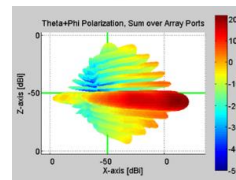
UXM 5G – E7515B

Network Emulator



PROPSIM

Channel Emulator



CIU



mmWave OTA Solutions

RRH



RMTS / CATR / MPAC



EXM – E6640A



VXT-II
M9410/11A

Non-Signaling Solution

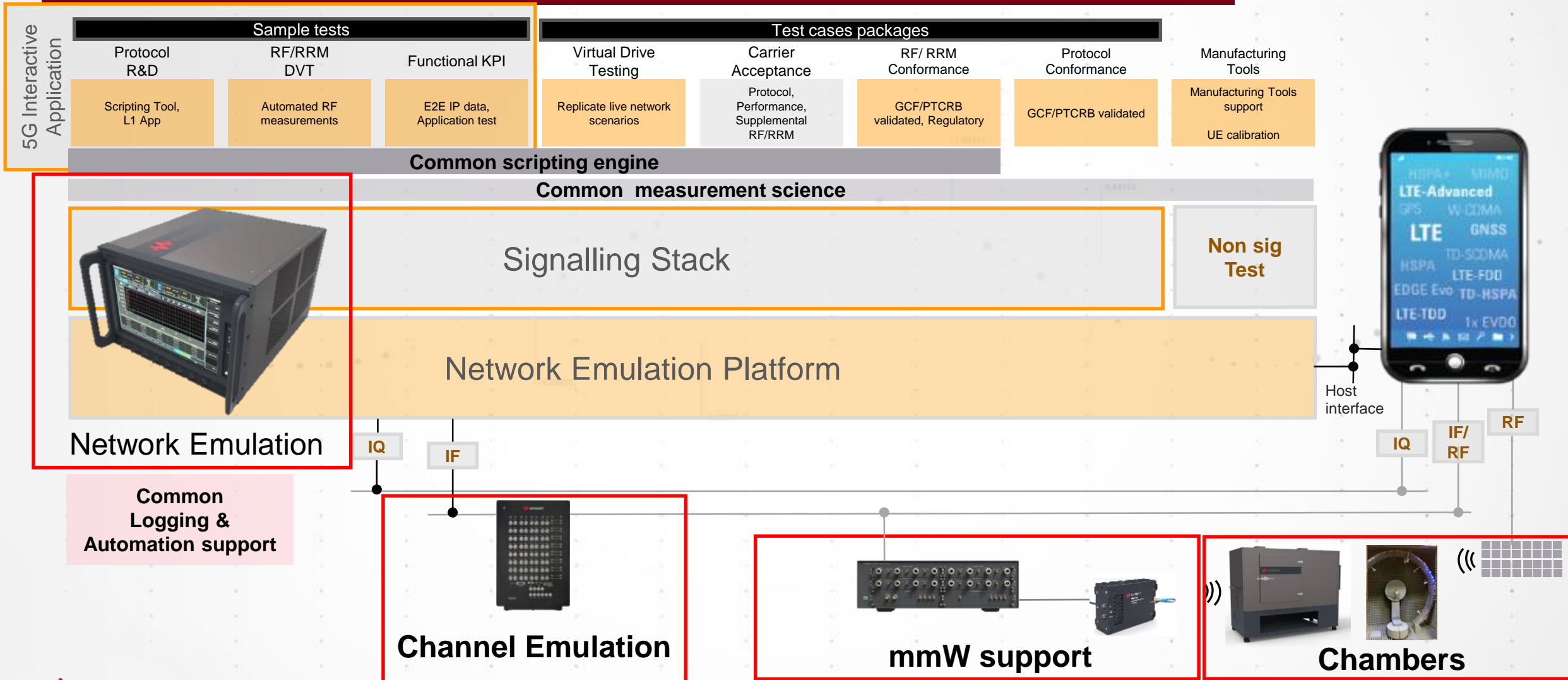
Seamless RF and Protocol Solution
Accumulates engineering know-how

Embodies ecosystem insights
Spans ecosystem with continuous releases

... ACCELERATE TOWARDS NEW 5G DEVICES

5G Network Emulation Test Solutions

PLATFORM HARDWARE BUILDING BLOCKS



5G 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

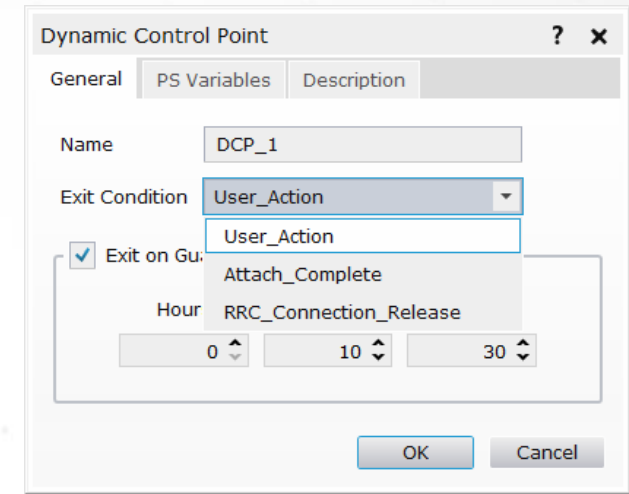
Sub-6 GHz and mmWave - Conducted and OTA

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



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

The screenshot displays the 'DL Scheduling' configuration window. At the top, there are tabs for 'General', 'DL Scheduling', and 'UL Scheduling'. The 'DL Scheduling' tab is active. The interface includes several configuration sections:

- Resource Allocation Type:** Fixed (dropdown)
- Transmission Mode:** TM1 (dropdown)
- Resource Block Allocation:** A grid showing resource block allocation for RBs 24-48, 48-74, and 74-99. RBs 24-48 and 48-74 are fully allocated (blue), while RBs 74-99 are partially allocated (white).
- xPDSCH Start Symbol:** Symbol 2 (dropdown)
- xPDSCH Stop Symbol:** Symbol 12 (dropdown)
- xPUCCH Resource Index:** 0 (text input)
- DL PCRS:** No PCRS (dropdown)
- UCI Request Configuration (Using xPUCCH - DCI B1/B2):**
 - Request Type: None (dropdown)
 - CSI-RS/BRRS OFDM Symbol Index: 0 (dropdown)
 - CSI-RS/BRRS Transmission Timing: 1 (text input)
 - CSI-RS/BRRS Process Indicator: Process 0 (dropdown)
 - Beam Switch Indication:
- Allocation Mode Configuration:**
 - Resource Allocation Mode: Normal (dropdown)
 - Trigger One Shot Allocation:
 - Antenna Ports Configuration:
 - Single Layer Transmission: 1 Layer - Port 8 (dropdown)
 - Two Layer Transmission: 2 Layers - Ports 8, 9 (dropdown)
- xPDCCH Search Space Configuration:**
 - DCI Allocation Mode: Dynamic (dropdown)
 - Search Space Index: 0 (text input)
 - Aggregation Level: 2 (dropdown)
 - Ofdm Symbol Index: Dynamic (dropdown)
- Other Parameters:**
 - Fixed MCS Index: MCS Index: 9 (text input)
 - DL MMIO Fixed Rank: Rank: Rank 1 (dropdown)
 - HARQ Auto Ack:
 - Scrambling Code Id: 0 (dropdown)

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

The screenshot shows the Log Viewer application interface. The main window displays a table of log records with columns for Index, Icons, Protocol, Record, Source, Destination, Summary, and Frame. The record at index 66389 is selected, showing a BCCH-BCH-Message from the RRC protocol. The Details pane on the right provides a hierarchical view of the message structure, including fields like dl-Bandwidth, phich-Config, and schedulingInfoSIB1-BR-r13. The Overview pane shows a 'PASS' status. The bottom status bar indicates a log size of 8.3 MB and 1223 records.

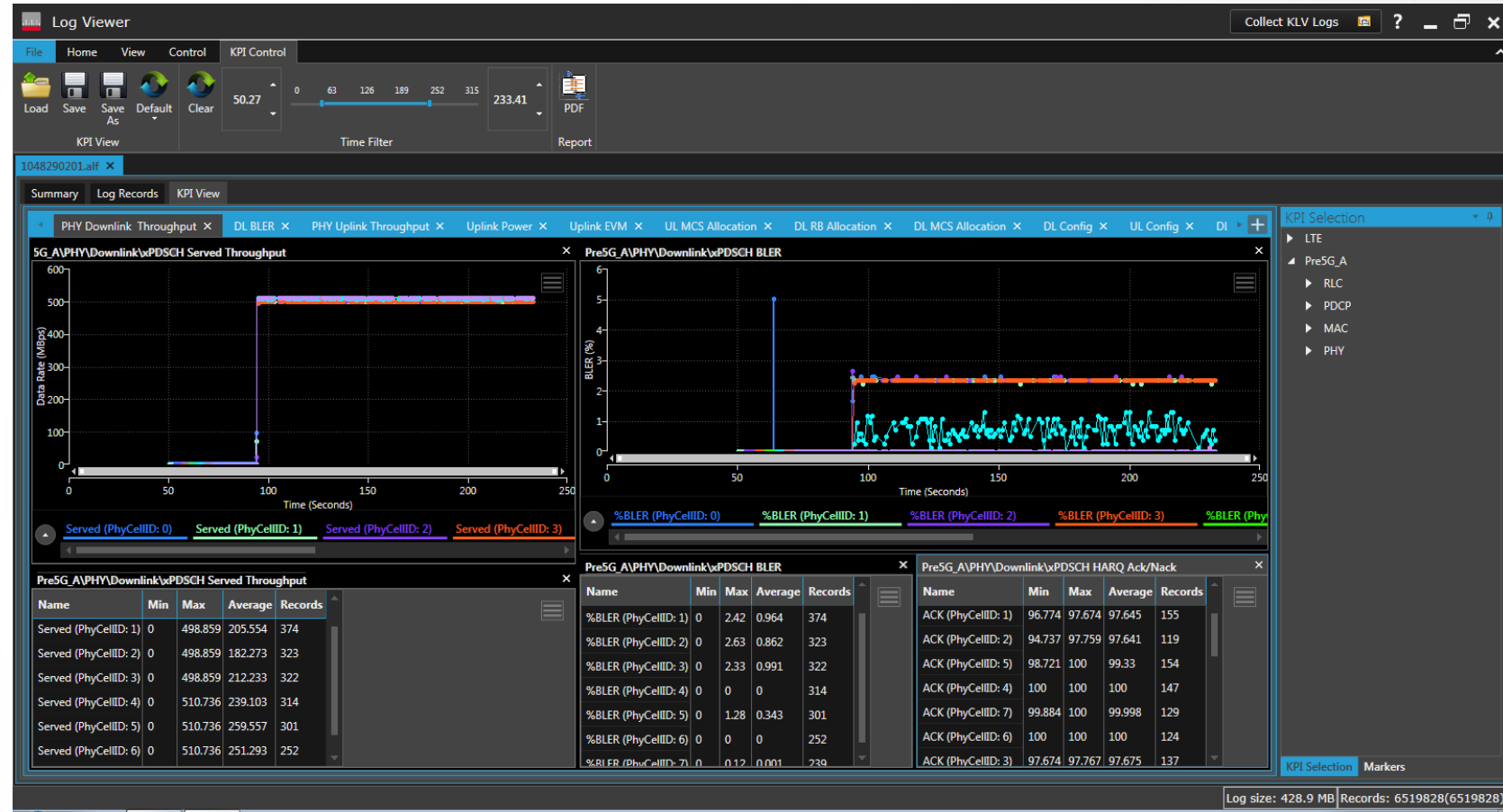
Index	Icons	Protocol	Record	Source	Destination	Summary	Frame
66369		Developers AP	Property Set	\\Test Control\De		E-Cell A->ULFrequency = 1950	
66370		Developers AP	Property Set	\\Test Control\De		E-Cell A->ULEarfcn = 18300	
66373		Developers AP	Property Set	\\Test Control\De		E-Cell A->DLFrequency = 2140	
66374		Developers AP	Property Set	\\Test Control\De		E-Cell A->DLearfcn = 300	
66375		Developers AP	Property Set	\\Test Control\De		E-Cell A->PhysicalLayerCellIdentity	
66376		Developers AP	Property Set	\\Test Control\De		E-Cell A->PhysicalLayerCellIdentityC	
66377		Developers AP	Property Set	\\Test Control\De		E-Cell A->TimingOffset = 0	
66378		Developers AP	Property Set	\\Test Control\De		E-Cell A->AntennaCount = 1	
66379		Developers AP	Property Set	\\Test Control\De		E-Cell A->NumAntennaElements =	
66380		Developers AP	Property Set	\\Test Control\De		E-Cell A->AntennaMapping = ANTI	
66381		Developers AP	Property Set	\\Test Control\De		E-Cell A->Enabled = VARIANT_TRU	
66382		Developers AP	Property Set	\\Test Control\De		E-Cell A->EtwPrimaryNotificationE	
66383		Developers AP	Property Set	\\Test Control\De		E-Cell A->EtwSecondaryNotificatio	
66389		RRC	BCCH-BCH-Message	\\Protocol\3GPP\		MasterInformationBlock	
66390		Developers AP	Property Set	\\Test Control\De		E-Cell A->Macs->Mac [1]->SIs->MI	
66393		RRC	BCCH-DL-SCH-Message	\\Protocol\3GPP\		systemInformationBlockType1	
66394		Developers AP	Property Set	\\Test Control\De		E-Cell A->Macs->Mac [1]->SIs->SII	
66397		RRC	BCCH-DL-SCH-Message	\\Protocol\3GPP\		systemInformation	
66398		Developers AP	Property Set	\\Test Control\De		E-Cell A->Macs->Mac [1]->SIs->SI-	
66401		Developers AP	Method Called	\\Test Control\De		E-Cell A->Signals->AddNew(SignalF	
66403		Developers AP	Method Called	\\Test Control\De		E-Cell A->Signals->AddNew(SignalF	
66405		Developers AP	Method Called	\\Test Control\De		E-Cell A->Signals->AddNew(SignalF	
66407		Developers AP	Method Called	\\Test Control\De		E-Cell A->Signals->AddNew(SignalF	
66408		Developers AP	Method Called	\\Test Control\De		E-Cell A->PhysicalChannels->AddN	
66409		Developers AP	Method Called	\\Test Control\De		E-Cell A->PhysicalChannels->AddN	
66410		Developers AP	Method Called	\\Test Control\De		E-Cell A->TransportChannels->Add	
66411		Developers AP	Method Called	\\Test Control\De		E-Cell A->TransportChannels->Rch	

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



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



Keysight Test Automation Platform

Test Automation Platform (TAP)

Step Name	Verdict	Duration	Step Type
Wireless Test - 5G - 3GPP.6.2.2 UE Maximum Output Power			Wireless Test - 5G \ 3GPP \ 6.2.2 UE Maximum Output Power
Wireless Test - 5G - RF Parametrics.Sensitivity			Wireless Test - 5G \ RF Parametrics \ Sensitivity
Wireless Test - 5G - RF Parametrics.Transmit Signal Quality			Wireless Test - 5G \ RF Parametrics \ Transmit Signal Quality

Create test plans

External Name	Value	Test Step \ Property
Band	1	Wireless Test - 5G - 3GPP.6.2.2 UE Maximum Output Power \ Band
DL Channel Bandwidth	20 MHz	Wireless Test - 5G - 3GPP.6.2.2 UE Maximum Output Power \ DL Channel Bandwidth
Like 3GPP	<input type="checkbox"/>	Wireless Test - 5G - 3GPP.6.2.2 UE Maximum Output Power \ Like 3GPP
Test Environment	<input checked="" type="checkbox"/>	Wireless Test - 5G - 3GPP.6.2.2 UE Maximum Output Power \ Test Environment
Test Frequency	<input checked="" type="checkbox"/>	Wireless Test - 5G - 3GPP.6.2.2 UE Maximum Output Power \ Test Frequency
UL RB Number	1	Wireless Test - 5G - 3GPP.6.2.2 UE Maximum Output Power \ UL RB Number

Log
Errors 0

Transceiver A

VMA 1
Custom OFDM

1 IQ Mean Time (Q)

2 Error Summary

Metric	Value
EVMMER	2.63%
EVMPeak	10.57%
PilotEvm	1.00%
DataEvm	2.73%

VMA 2
IQ Waveform

1 RF Envelope

2 Metrics

VMA 3
Occupied BW

1 Graph

2 Metrics

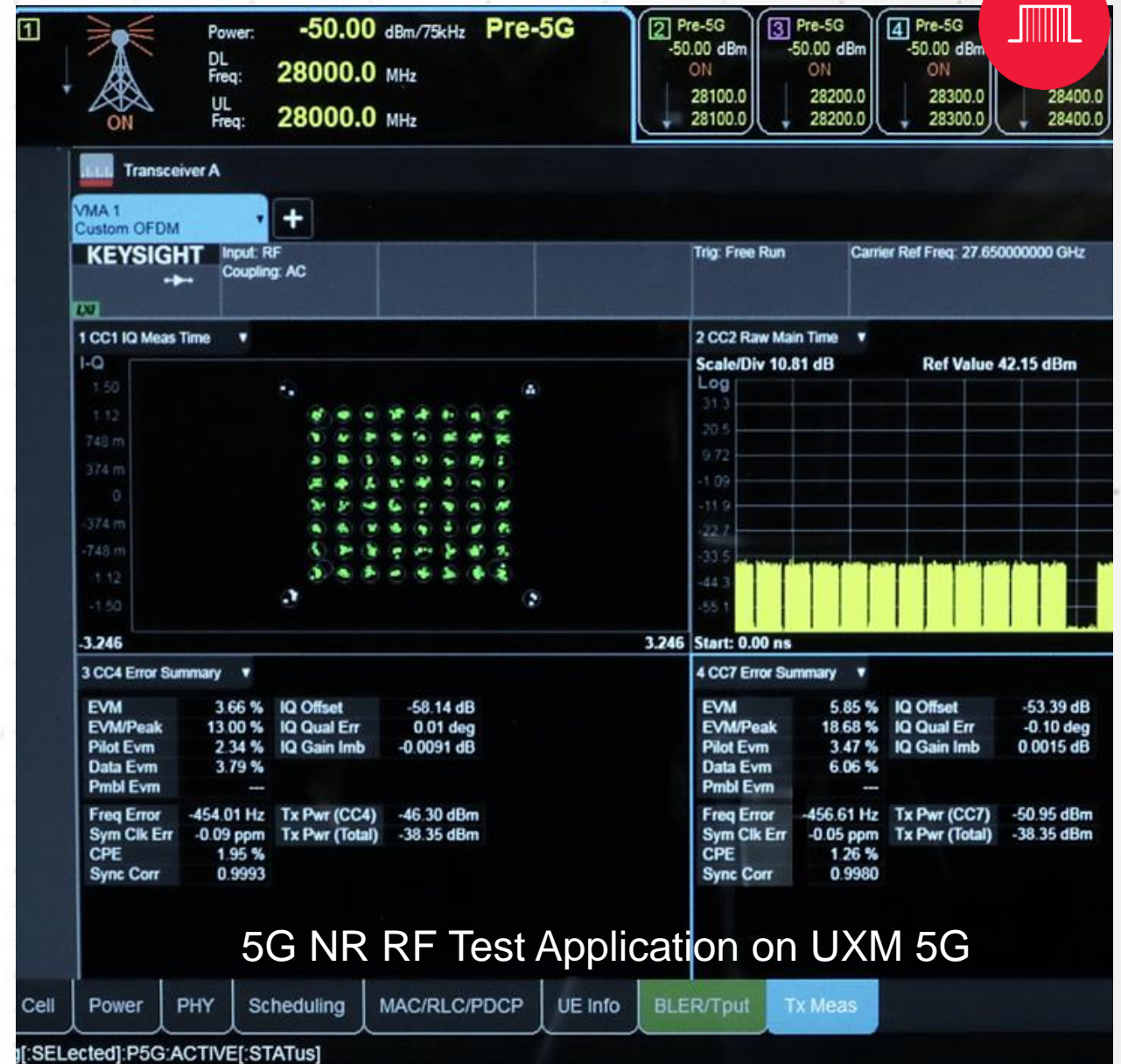
Metric	Value
Occupied Bandwidth	89.143 MHz
Total Power	24.9 dBm
% of OBW Power	99.00 %

5G NR X-App

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)

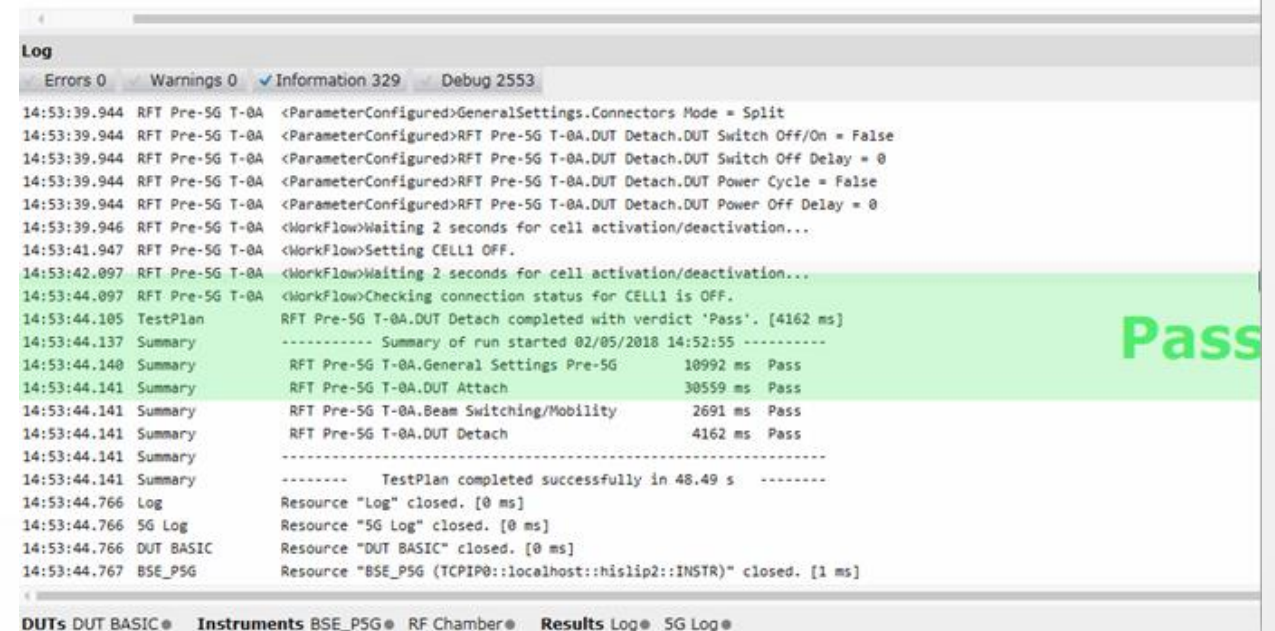


File Settings Tools Help

Test Plan Untitled *

Completed in 48.49 s

ame	Verdict	Duration	Step Type
-5G T-0A.General Settings Pre-5G	Pass	10.99 s	RFT Pre-5G T-0A: Measurement tools for 5GTF \ Common \ General Settings Pre-5G
-5G T-0A.DUT Attach	Pass	30.56 s	RFT Pre-5G T-0A: Measurement tools for 5GTF \ Connection \ DUT Attach
-5G T-0A.Beam Switching/Mobility	Pass	2.69 s	RFT Pre-5G T-0A: Measurement tools for 5GTF \ Measurements \ RRM Measurements \ Beamforming
-5G T-0A.DUT Detach	Pass	4.16 s	RFT Pre-5G T-0A: Measurement tools for 5GTF \ Connection \ DUT Detach



Log

Errors 0 Warnings 0 Information 329 Debug 2553

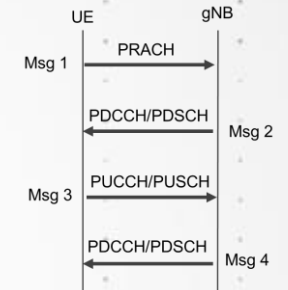
```
14:53:39.944 RFT Pre-5G T-0A <ParameterConfigured>GeneralSettings.Connectors Mode = Split
14:53:39.944 RFT Pre-5G T-0A <ParameterConfigured>RFT Pre-5G T-0A.DUT Detach.DUT Switch Off/On = False
14:53:39.944 RFT Pre-5G T-0A <ParameterConfigured>RFT Pre-5G T-0A.DUT Detach.DUT Switch Off Delay = 0
14:53:39.944 RFT Pre-5G T-0A <ParameterConfigured>RFT Pre-5G T-0A.DUT Detach.DUT Power Cycle = False
14:53:39.944 RFT Pre-5G T-0A <ParameterConfigured>RFT Pre-5G T-0A.DUT Detach.DUT Power Off Delay = 0
14:53:39.946 RFT Pre-5G T-0A <Workflow>Waiting 2 seconds for cell activation/deactivation...
14:53:41.947 RFT Pre-5G T-0A <Workflow>Setting CELL1 OFF.
14:53:42.097 RFT Pre-5G T-0A <Workflow>Waiting 2 seconds for cell activation/deactivation...
14:53:44.097 RFT Pre-5G T-0A <Workflow>Checking connection status for CELL1 is OFF.
14:53:44.105 TestPlan RFT Pre-5G T-0A.DUT Detach completed with verdict 'Pass'. [4162 ms]
14:53:44.137 Summary ----- Summary of run started 02/05/2018 14:52:55 -----
14:53:44.140 Summary RFT Pre-5G T-0A.General Settings Pre-5G 10992 ms Pass
14:53:44.141 Summary RFT Pre-5G T-0A.DUT Attach 30559 ms Pass
14:53:44.141 Summary RFT Pre-5G T-0A.Beam Switching/Mobility 2691 ms Pass
14:53:44.141 Summary RFT Pre-5G T-0A.DUT Detach 4162 ms Pass
14:53:44.141 Summary ----- TestPlan completed successfully in 48.49 s -----
14:53:44.766 Log Resource "Log" closed. [0 ms]
14:53:44.766 5G Log Resource "5G Log" closed. [0 ms]
14:53:44.766 DUT_BASIC Resource "DUT_BASIC" closed. [0 ms]
14:53:44.767 BSE_P5G Resource "BSE_P5G (TCPIP0::localhost::hislip2::INSTR)" closed. [1 ms]
```

DUTs DUT_BASIC Instruments BSE_P5G RF Chamber Results Log 5G Log

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

The screenshot displays the Keysight C8700200A 5G NSA Full Stack Test Application interface. At the top, five cell configurations are shown, each with a radio tower icon and status 'OFF'. Cell 1 is labeled 'Main Cell (LTE)' and has a power level of -85.00 dBm/15KHz. Cells 2 through 5 are labeled 'Secondary Cells (NR)' and have power levels of -26.01 dBm/MHz. Below the cell list, the 'Config' tab is active, showing detailed settings for a selected cell. The 'Frequency' section includes Duplex Mode (TDD), Frequency Range (FR2 (mmWave)), DL Bandwidth (FR1 (sub-6GHz)), DL ARFCN (FR2 (mmWave)), DL Frequency (28017.12 MHz), DL Point A (2078659), and Phase Compensation (DL, UL). The 'Power' section includes Reference Signal EPRE (-55 dBm/SCS), Expected UL Power (-20 dBm), and DL Cable Loss (0 dB). The 'Timing' section includes Cell Timing (0 ms) and Uplink Delay (-215 samples). The 'Antenna' section includes DL Physical Antenna Ports (N2) and UL Physical Antenna Ports (N2). A callout box on the right points to the Frequency Range, Band, and Bandwidth settings, stating 'Frequency range, band, bandwidth...'. Another callout box on the right points to the Uplink Delay setting, stating 'Power, Timings, Antenna Ports'. The bottom of the interface shows a navigation bar with tabs for System, Cell, SSB, PHY, Scheduling, MAC/RLC/PDCP, Data Generation, BLER/Tput, and Tx Meas. A status bar at the bottom indicates a configuration error: 'Configuration error: Application configuration file has been changed. Instrument behaviour may not be as expected. (Error 137)'. The 'Apply' button is visible in the bottom right corner.

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

Establish a 5G NR Call

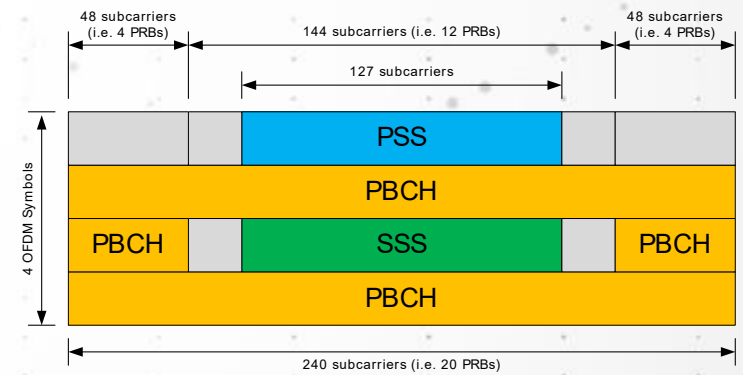
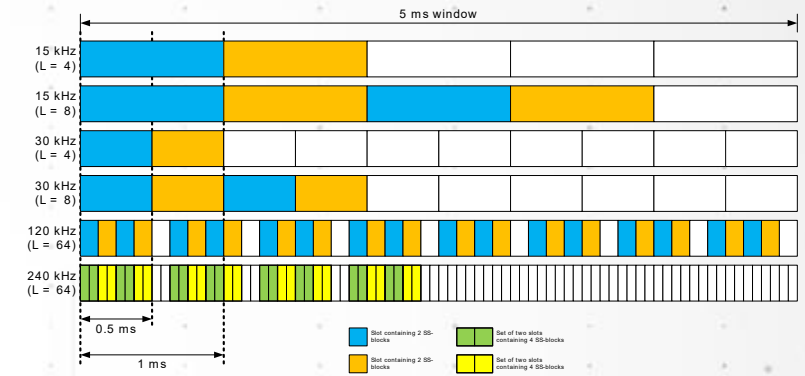


BEAM CONFIGURATION

The screenshot shows the 'Beam Configuration' window for two frequency ranges:

- FR1, L = 8:** The SSB Position Bitmap (hex) is 'FF'. The SSB Positions are 0 through 7.
- FR2, L = 64:** The SSB Position Bitmap (hex) is 'FFFFFFFFFFFFFFFF'. The SSB Positions are 0 through 63.

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

The screenshot displays the 'PHY' configuration page of the Keysight C8700200A 5G NSA Full Stack Test Application. At the top, five radio bearers are listed with their respective parameters:

- 1** PCC / TDD 33: -85.00 dBm/15kHz, BW: 10 MHz, EARFCN: D: 36100, U: 36100
- 2** NSA gNB SN N77: -19.85 dBm/MHz, BW: 100 MHz, Freq: D: 3550.56, U: 3550.56
- 3** NSA gNB SN N257: -26.01 dBm/MHz, BW: 100 MHz, Freq: D: 28120.80, U: 28120.80
- 4** NSA gNB SN N257: -26.01 dBm/MHz, BW: 100 MHz, Freq: D: 28224.48, U: 28224.48
- 5** NSA gNB SN N257: -26.01 dBm/MHz, BW: 100 MHz, Freq: D: 28328.16, U: 28328.16

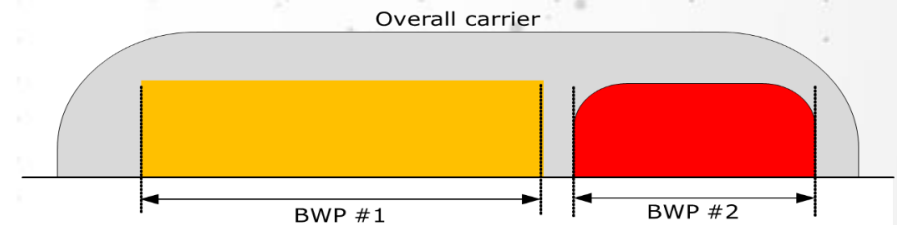
The main configuration area is divided into sections:

- Initial Bandwidth Part:** DL and UL Initial BWP Subcarrier Spacing (1 (30 kHz)), DL and UL Initial BWP Starting CRB (0), and DL and UL Initial BWP Number of PRBs (273).
- Carrier Bandwidth Parts:** DL and UL First Active Bandwidth Part (0).
- Configuration:** Radio buttons for Downlink and Uplink. A table below shows settings for 1st, 2nd, 3rd, and 4th Bandwidth Parts.

Setting	1st Bandwidth Part	2nd Bandwidth Part	3rd Bandwidth Part	4th Bandwidth Part
Enabled:	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
BWP ID:	0	0	0	0
Starting CRB:	0	0	0	0
Number of PRBs:	273	0	0	0
Subcarrier Spacing:	1 (30 kHz)			
Extended Cyclic Prefix:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

At the bottom, a status bar shows 'Configuration error: Application configuration file has been changed. Instrument behaviour may not be as expected. (Error 137)'. The interface also includes a 'Main' sidebar with 'Cell On', 'Connect', 'Blind Handover', 'Rx Measurements', 'Utility', and 'Apply' buttons.

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

The screenshot displays the Keysight C8700200A 5G NSA Full Stack Test Application interface. The top section shows five 5G NSA signal sources with their respective parameters:

- 1. PCC / TDD 33: -85.00 dBm/15KHz, BW: 10 MHz, EARFCN: D: 36100, U: 36100
- 2. NSA gNB SN N177: -19.85 dBm/MHz, BW: 100 MHz, Freq: D: 3550.56, U: 3550.56
- 3. NSA gNB SN N257: -26.01 dBm/MHz, BW: 100 MHz, Freq: D: 28120.80, U: 28120.80
- 4. NSA gNB SN N257: -26.01 dBm/MHz, BW: 100 MHz, Freq: D: 28224.48, U: 28224.48
- 5. NSA gNB SN N257: -26.01 dBm/MHz, BW: 100 MHz, Freq: D: 28328.16, U: 28328.16

The interface is divided into several sections:

- DL HARQ:** Includes 'Num DL Harq Processes' (set to 10) and 'Enable Spatial Bundling (PUCCH)' and 'Enable Spatial Bundling (PUSCH)' checkboxes.
- UL HARQ:** Includes 'Num UL Harq Processes' (set to 10).
- PRACH Config:** Includes 'Enable PRACH' (checked), 'Preamble Format' (Format A1), 'Subcarrier Spacing' (1 (30 kHz)), 'Config Index' (81), 'uRoot' (0), 'Preamble RX Target Power' (0), 'Frequency Start' (0), 'Msg1 FDM' (1), 'Restricted Set Config' (Unrestricted), and 'Zero Correlation Zone Config' (0).

The bottom navigation bar includes tabs for System, Cell, SSB, PHY (selected), Scheduling, MAC/RLC/PDCP, Data Generation, BLER/Tput, Tx Meas, and Apply. A status bar at the bottom indicates a configuration error: 'Configuration error: Application configuration file has been changed. Instrument behaviour may not be as expected. (Error 137)'.

HARQ, DL and UL channels and signals configuration

Establish a 5G NR Call



SCHEDULING

The screenshot displays the Keysight C8700200A 5G NSA Full Stack Test Application interface. The main window is titled "Keysight C8700200A 5G NSA Full Stack Test Application" and shows a "Scheduling Map" and "Slot Config" view. The interface is divided into several sections:

- Radio Frame Map:** Shows the number of radio frames per repetition (8) and a grid for configuring frames. The grid has columns 0-7 and rows for different frame types.
- Slot Map:** Shows a grid for configuring slots. The grid has columns 0-13 and rows for different slot types. Slots 2, 5, and 9 are highlighted in green.
- Slot Config:** Shows the configuration for a specific slot (Slot index: 0). The configuration includes:
 - Frame Configuration: FC 0
 - Slot index: 0
 - Direction: Uplink
 - UL Settings:
 - Fixed MCS Index: 0 - QPSK
 - Fixed RB Allocation: 0
 - PUSCH Mapping Type A: 0
 - Time Domain Resource Assignmt: 0
 - Bandwidth Part Index: 0
 - DCI Type: Format_0_0
 - DCI Allocation Mode: Dynamic
 - DCI Search Space Type: UE Specific Search Space
 - Precoding Info/Number of Layers: -1
 - Symbol Start / Length: 0 / 14
 - RB Allocation Start / Count: 0 / 273
 - PUSCH Slot Offset K2: 4
 - PUSCH Numerology: 1 (30 kHz)
 - Aggregation Factor: 0
 - Antenna Ports: -1
 - DCI Aggregation Level: 1
 - SRS Resource Indicator: 0

The interface also shows a "Main" panel on the right with buttons for "Cell On", "Connect", "Blind Handover", "Rx Measurements", "Utility", and "Apply". A status bar at the bottom indicates a configuration error: "Configuration error: Application configuration file has been changed. Instrument behaviour may not be as expected. (Error 137)".

Establish a 5G NR Call

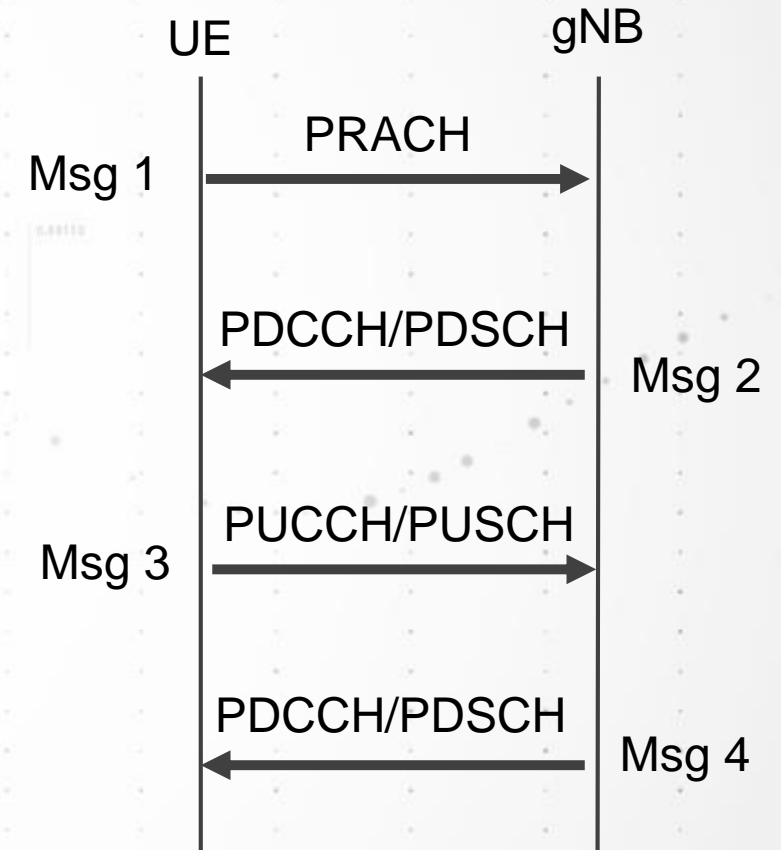


RANDOM ACCESS CHANNEL

The screenshot shows the 'Rach' configuration page in the Keysight Z2160A 5G NR Non-sig Test Application. The interface includes several configuration sections:

- Enable RACH:** A checked checkbox.
- RACH Config:**
 - Temp C-RNTI: 100
 - Rach Response Delay: 0
 - Expected Dedicated Preamble Index: 0
 - Validate: [button]
- Msg1 Subcarrier Spacing:** 3 (120 kHz)
- Msg2 Subcarrier Spacing:** 3 (120 kHz)
- Msg3 Subcarrier Spacing:** 3 (120 kHz)
- Msg3SizeGroupA:** 0 Bits (selected in a dropdown menu)
- Contention-Based Resolution:**
 - SSB: 0
 - Start Index RA Preamble Group A: 0
 - Num RA Preambles Group A: 0
 - Num RA Preambles: 0
- Contention-Free Resolution:**
 - SSB: 0
 - RA Preamble Index: 0

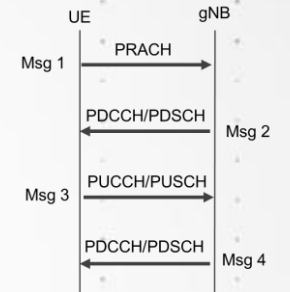
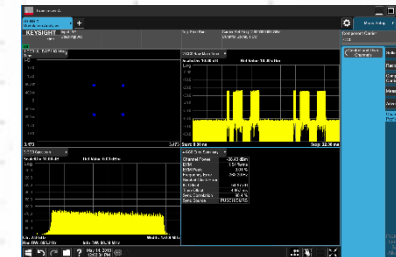
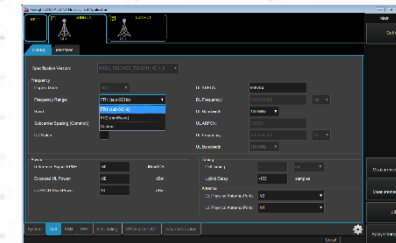
At the bottom, there are tabs for System, Cell, SSB, PHY, Scheduling, MAC/RLC/PDCP (selected), and Data Generation. A 'Local' indicator and an 'Apply Changes' button are also visible.



Test Application

RF TEST

More RF bands,
wider bandwidths,
and beamforming



RF tests

1

Establish the 5G NR Call

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

2

Test Tx and Rx

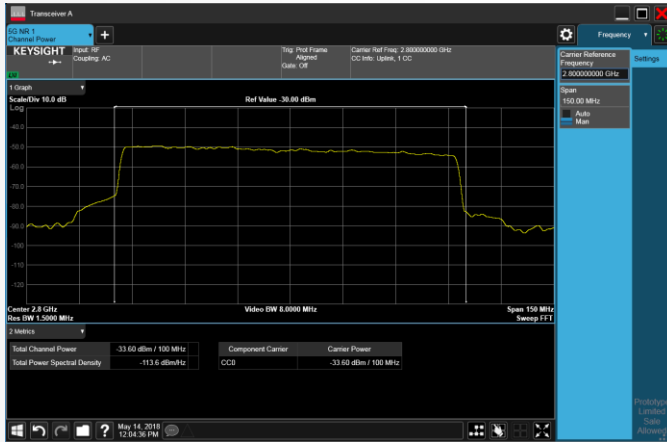
- Transceiver; Channel Power, EVM, Freq Error, In-band emissions, ACLR, SEM, OBW
- Receiver; BLER statistics

RF test on-a-call

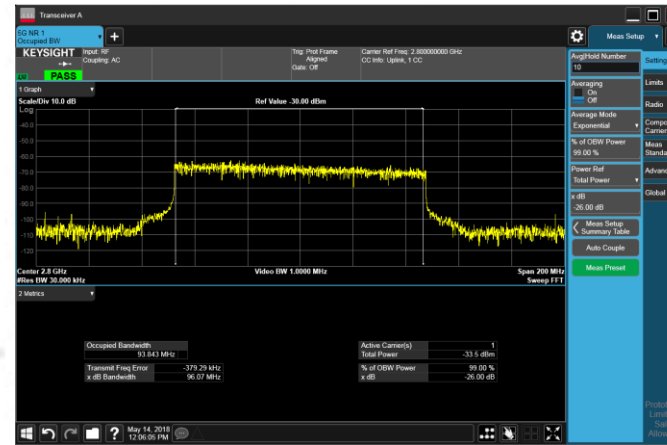


TRANSMITTER

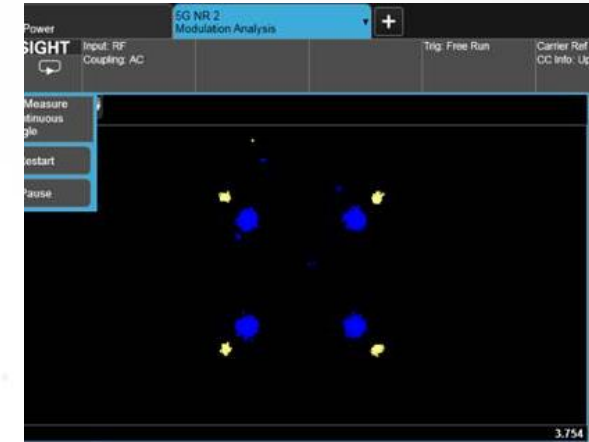
Channel Power



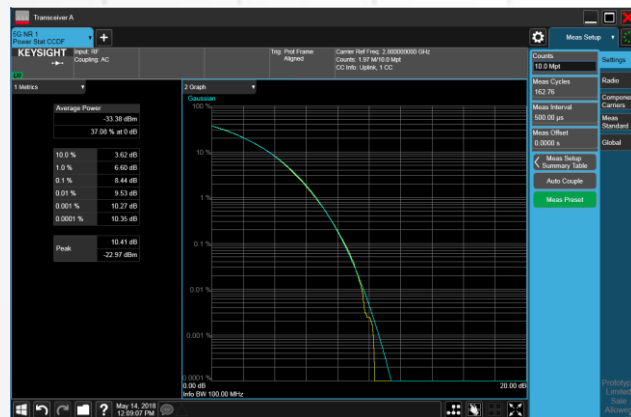
Occupied Bandwidth



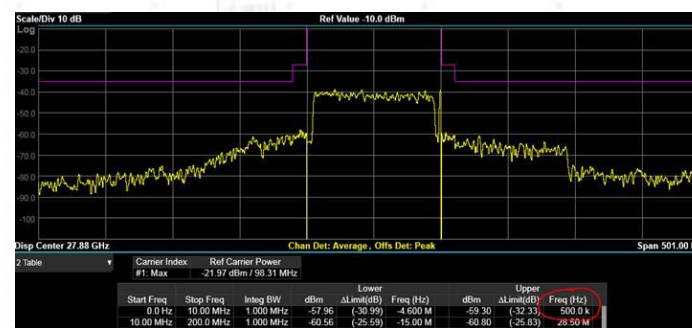
Modulation Parameters



Power Statistics



Spectrum Emission Mask



IQ Waveform

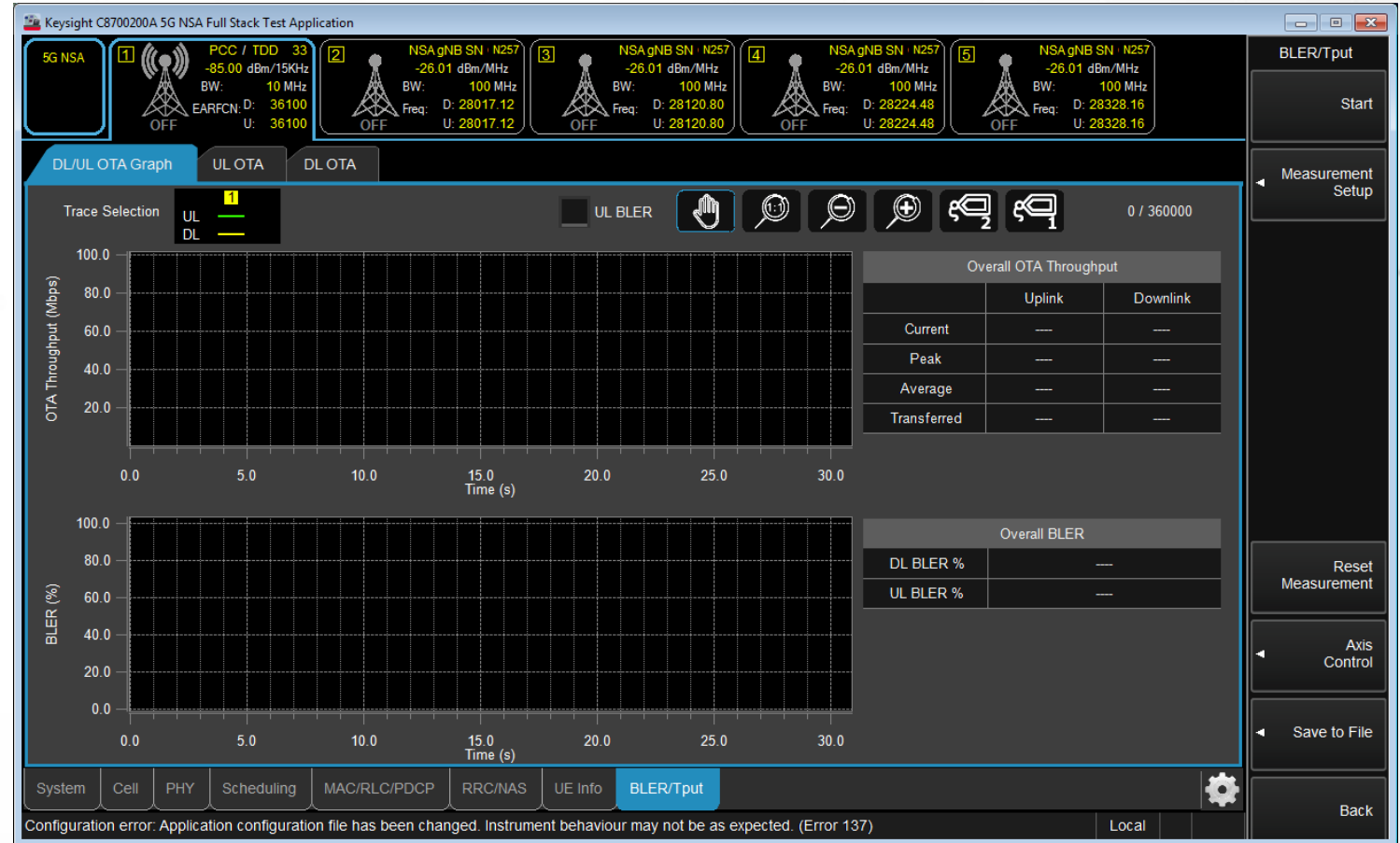


RF test on-a-call

RECEIVER

Rx Measurements

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



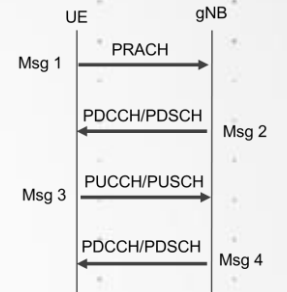
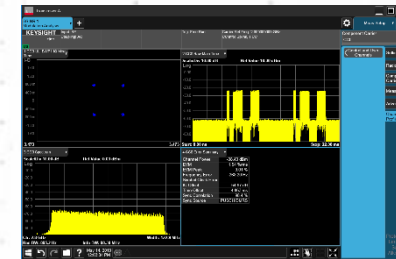
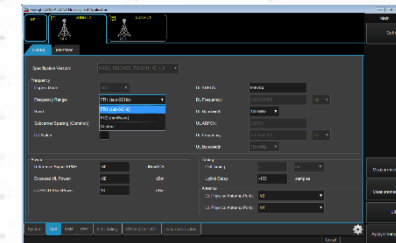
More RF bands, wider BW, BF

SIGNALING RF TEST

More RF bands,
wider bandwidths,
and beamforming



- 1 Establish the 5G NR Call**
 - Configuring; 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

Steps

Search...

- > Basic Steps
- > DUT_UE
- > E7515A
- > E7515A-GSM
- > E7515A-IoT
- > E7515A-LTE
- > E7515A-Protocol Analysis
- > E7515A-WCDMA
- > E7515B
- > E7515B-5G-NR**
- > E7515B-P5G
- > Flow Control
- > Results
- > RF CHAMBER
- > RFT 5G NR T-0A: Measurement tools for 5G NR
- > Test

XsaStep_N9020A Add Add Child

- ▼ E7515B-5G-NR
 - ▼ 5G NR BSE
 - > Cell Actions
 - > Cell Setup**
 - > Throughput Measurements
 - > Utils
 - > General
 - ▼ LTE BSE
 - > Cell Actions
 - > Cell Setup
 - > NAS And Bearers
 - > Throughput Measurements
 - > Utils

- ▼ Cell Setup
 - > Cell Config
 - > Frequency
 - > PHY
 - > Power
 - ▼ Scheduler
 - DL Slot Config** Add Add Child
 - Scheduling Map Add Add Child
 - UL Slot Config Add Add Child
 - > SSB Config
 - > Substeps
 - Antenna Port Configu... Add Add Child
 - Basic Cell Config Add Add Child

Step Settings

▼ Common

5G BSE

▼ Common Settings

CELL1

CELL2

CELL3

CELL4

CELL5

CELL6

CELL7

CELL8

cell

fc FC0

sc SC0

▼ Settings

DL Fixed MCS Index 0

DL HARQ Feedback Slot Timing K1 2

DL Symbol Start 1

DL Symbol Length 11

DL RB Allocation Start 0

DL RB Allocation Count 66

DL PDSCH Slot Offset K0 0

▼ DCI Settings

DL DCI Type Format

DL DCI Allocation Mode Dynam

DL DCI Search Space Type UESS

DL DCI Aggregation Level 1

KS8360A

UXM 5G TAP Plugin



TAP STEPS TO CONTROL UXM 5G AND CHAMBER

Steps

Search...

- > Basic Steps
- > DUT_UE
- > E7515A
- > E7515A-GSM
- > E7515A-IoT
- > E7515A-LTE
- > E7515A-Protocol Analysis
- > E7515A-WCDMA
- > E7515B
- > E7515B-5G-NR
- > E7515B-P5G
- > Flow Control
- > Results
- > RF CHAMBER**
- > RFT 5G NR T-0A: Measurement tools for 5G NR
- > Test

XsaStep_N9020A Add Add Child

RF CHAMBER

- Calibration
 - Fetch Path Loss Add Add Child
 - Import Path Loss Add Add Child
 - Path Alignment Add Add Child
 - System Loss Add Add Child
 - User Cal Add Add Child
- Information
- Movement
 - Direct Move**
 - Helper
 - Speed
 - Sweep
- Coordinate System Add Add Child
- Current Position Add Add Child
- DUT Orientation in Nest Add Add Child

Direct Move

- Go To Positioner Home Add Add Child
- Move Add Add Child**
- Move Execute Add Add Child
- Set Positioner Zero Add Add Child
- Wait Positioner Moving Add Add Child

Step Settings

- Common
 - Instrument
 - Generate Result
 - Set Verdict on Fail Fail
- Position
 - Control Coordinate MOTor
 - Motor Azimuth 0°
- Action
 - Immediate Execution
- Positioner State
 - Wait until destination reached
 - Timeout 60000 ms
 - Positioner Moving State OFF
 - Polling Frequency 1000 ms

5G NR T-0A: Measurement tools



TAP STEPS TO MEASURE RF TX AND RX CHARACTERISTICS

Steps

Search...

- > Basic Steps
- > DUT_UE
- > E7515A
- > E7515A-GSM
- > E7515A-IoT
- > E7515A-LTE
- > E7515A-Protocol Analysis
- > E7515A-WCDMA
- > E7515B
- > E7515B-5G-NR
- > E7515B-P5G
- > Flow Control
- > Results
- > RF CHAMBER
- > RFT 5G NR T-0A: Measurement tools for 5G NR
- > Test

XsaStep_N9020A Add Add Child

▼ RFT 5G NR T-0A: Measurement tools for 5G NR

- > Common
- ▼ Measurements
 - > 5G NR FR2 Metrics
 - > 5G NR Rx
 - > 5G NR XSA

▼ Measurements

- ▼ 5G NR FR2 Metrics
 - EIRP Add Add Child
 - Maximum EIRP Add Add Child
 - Minimum EIRP at CDF Add Add Child
 - Minimum Peak EIRP Add Add Child
 - Tx Beam Peak Add Add Child
- > 5G NR Rx
- ▼ 5G NR XSA
 - Adjacent Channel Po... Add Add Child
 - Channel Power Add Add Child
 - Modulation Analysis Add Add Child
 - Occupied Bandwidth Add Add Child
 - Spectrum Emission... Add Add Child

Step Settings

- ▼ Common
 - XSA 5G NR
- ▼ Sweep Settings
 - Continuous Measurement State OF
- ▼ Radio Settings
 - RF Port RF
 - Measurement Direction Up
- ▼ Frequency Settings
 - Center Frequency 28 GHz
 - Measurement Span 200 MHz
- ▼ Measurement Settings
 - Multicarrier Measurement
 - Averaging State OF
 - Frequency Range FR
 - Bandwidth 10
 - Frequency Offset 0 Hz
 - IBW 100 MHz
- ▼ Trigger Settings
 - Trigger Source Pr
 - Trigger Delay State OF
 - Trigger Delay 0.008C
- ▼ Verdict Settings
 - Enable Verdict
- ▼ Results Settings
 - Generate Report

C870250AA RFT

5G NR T-0A: Measurement tools



TAP PLAN EXAMPLES

Step Name	Verdict	Duration	Flow	Step Type
--- LTE cell configuration ---				Basic Steps \ Log Output
☑ RFT 5G NR T-0A.LTE Cell Configuration - CELL1				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ LTE Cell Configuration
☑ RFT 5G NR T-0A.LTE DL Scheduler Configuration				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ LTE DL Scheduler Configuration
☑ RFT 5G NR T-0A.LTE UL Scheduler Configuration				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ LTE UL Scheduler Configuration
--- NR cell configuration ---				Basic Steps \ Log Output
☑ RFT 5G NR T-0A.NR Cell Configuration - CELL2				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ NR Cell Configuration
--- Set UE State ---				Basic Steps \ Log Output
☑ E7515B-5G-NR.LTE.NR Cell Reconfiguration with SgNB Addition				E7515B-5G-NR \ LTE BSE \ Cell Actions \ BSE Procedures \ NR Cell Reconfiguration with SgNB Addition
☑ RFT 5G NR T-0A.NR Set UE State				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ NR Set UE State
☑ If Verdict (NR Cell Connected)				Flow Control \ If Verdict
--- Set Measurement Conditions ---				Basic Steps \ Log Output
☑ RFT 5G NR T-0A.NR Set Measurement Conditions				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ NR Set Measurement Conditions
--- Search TX Beam Peak ---				Basic Steps \ Log Output
☑ RFT 5G NR T-0A.OTA Positioning: Spherical Sweep				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ OTA Positioning
☑ RFT 5G NR T-0A.Tx Beam Peak				RFT 5G NR T-0A: Measurement tools for 5G NR \ Measurements \ 5G NR FR2 Metrics \ Tx Beam Peak
--- Positioning and measurement ---				Basic Steps \ Log Output
☑ RFT 5G NR T-0A.OTA Positioning : Direct Move				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ OTA Positioning
--- Set UE State Disconnect ---				Basic Steps \ Log Output
☑ RFT 5G NR T-0A.NR Set UE State IDLE				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ NR Set UE State
☑ RFT 5G NR T-0A.NR Set UE State IDLE				RFT 5G NR T-0A: Measurement tools for 5G NR \ Common \ NR Set UE State
☑ E7515B-5G-NR.LTE.NR Cell Reconfiguration with SgNB Addition				E7515B-5G-NR \ LTE BSE \ Cell Actions \ BSE Procedures \ NR Cell Reconfiguration with SgNB Addition
☑ E7515B-5G-NR.Activate Cells				E7515B-5G-NR \ General \ Cell Actions \ BSE Procedures \ Activate Cells
☑ E7515B-5G-NR.Activate Cells				E7515B-5G-NR \ General \ Cell Actions \ BSE Procedures \ Activate Cells

NR NSA Connection

Measurements Conditions

Positioning

Measurement

RF DVT Toolset

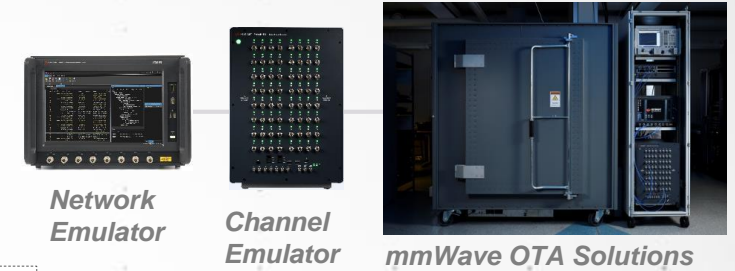
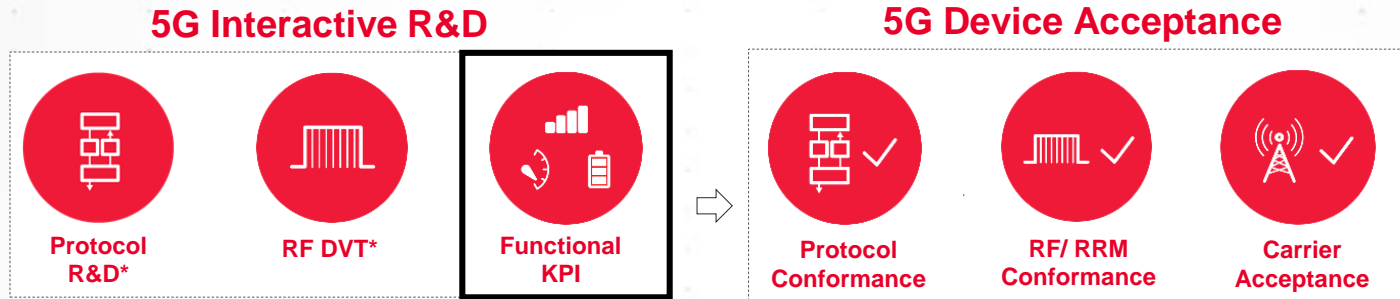


Solution
Common Components
E7515B



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

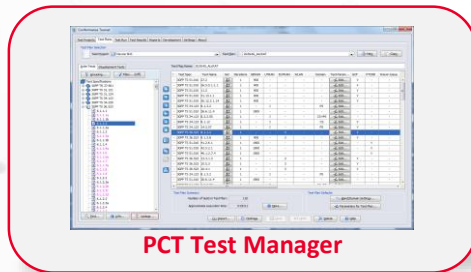
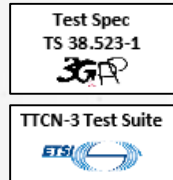
5G Interactive R&D



5G Device Acceptance



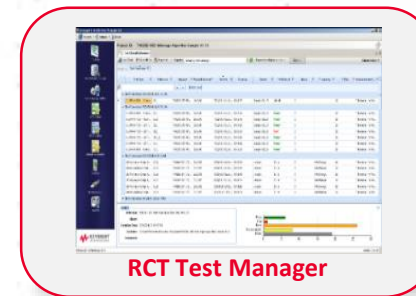
Protocol



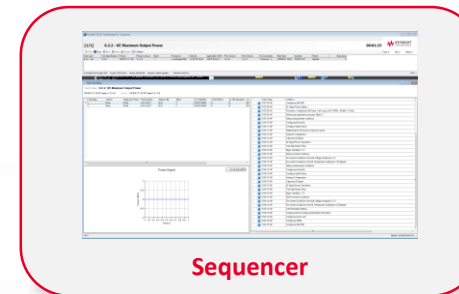
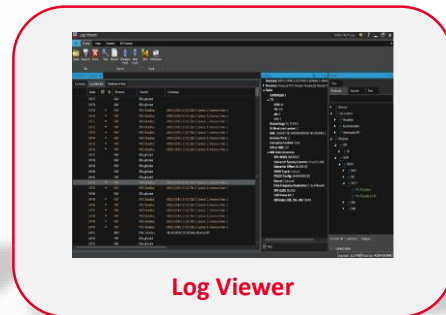
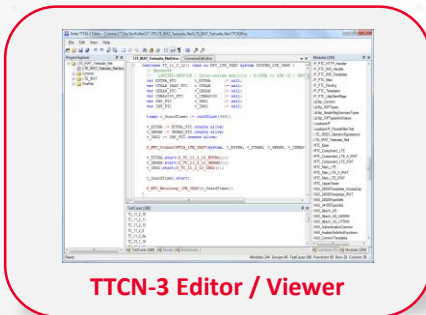
RF/RRM

Test Spec 38.521-1/2/3
3GPP
RF Rx/TX Test cases

Test Spec 38.521-4
3GPP
Performance testing *Future*



Test Spec 38.533
3GPP
Radio Resource Management (RRM) *Future*



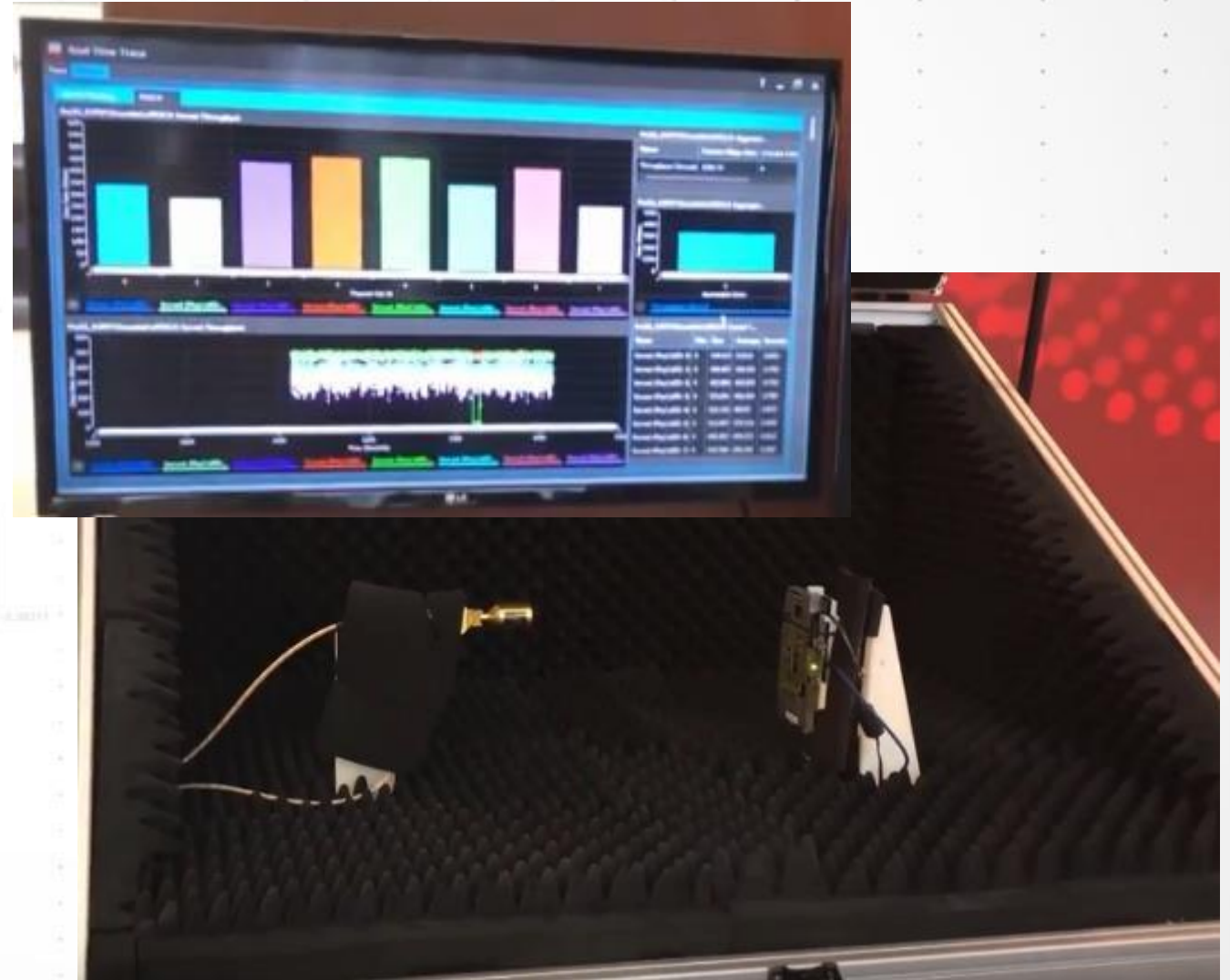
Case Study: 5G Chipset OTA Test

Demonstrated at *MWC 2018*

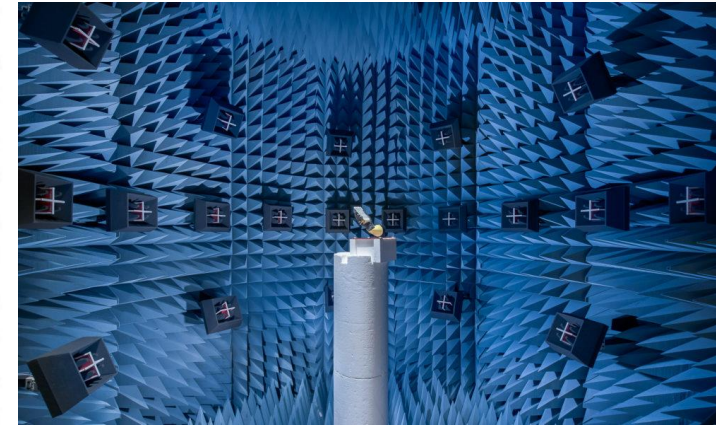
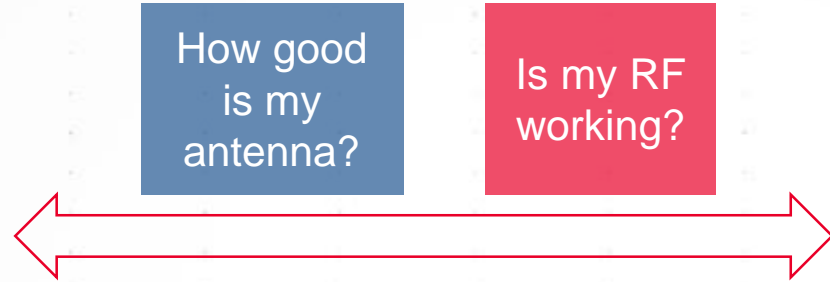
Challenge: Measure the 5G download throughput rate OTA with full protocol stack

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



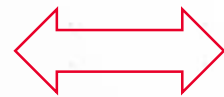
CATR

Cable Replacement
2D MPAC
RMTC

Spatial
MPAC
3D MPAC



Is my chipset working?



How good is my device?



FR2 mWave support

What are your mm-Wave OTA testing needs?

5G DEVICE END-END SOLUTIONS



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)



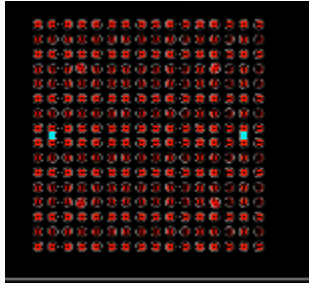
mmWave Transceiver for 5G (RRH)

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

7 Key Measurement Challenges

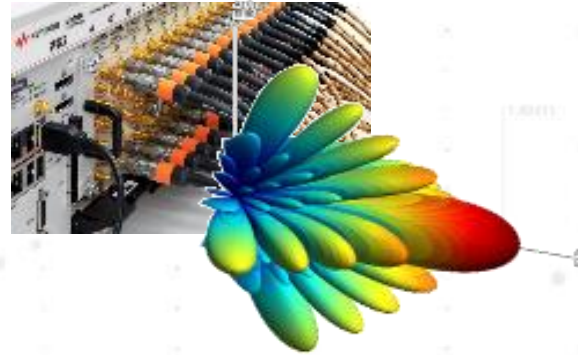
Signal Quality

mmW, Waveform, Fidelity



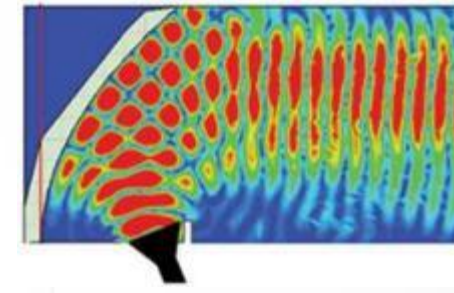
Lots of Channels

MIMO/Beamforming



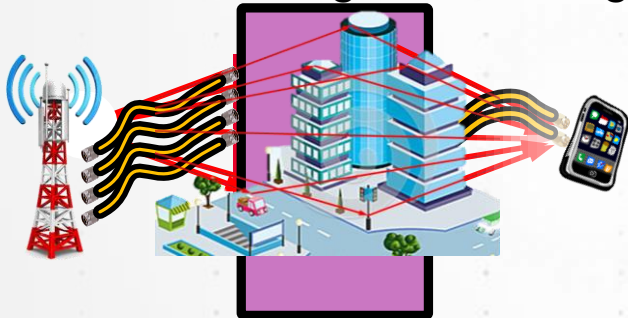
Life Beyond Connectors

Over-the-Air



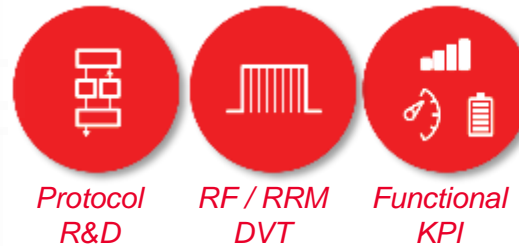
Channel

Characterizing & Emulating



Performance on the Network

Network Emulation



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

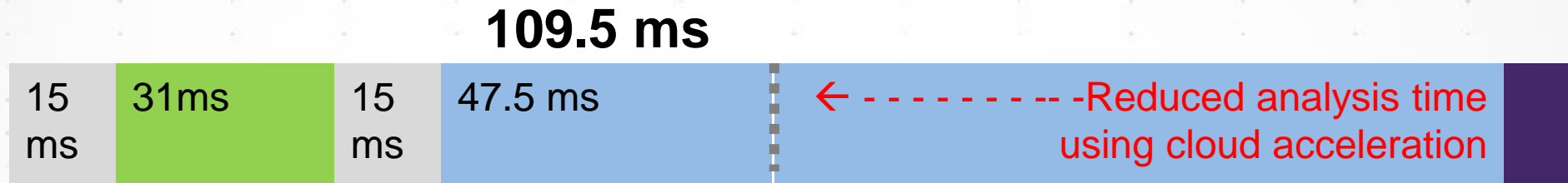
Enablers

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

Case study – Test Acceleration of Individual Measurements

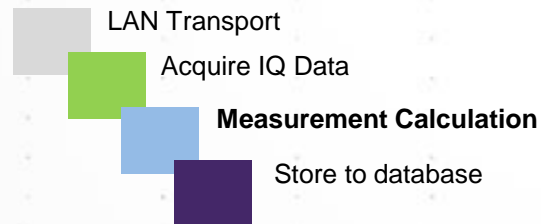
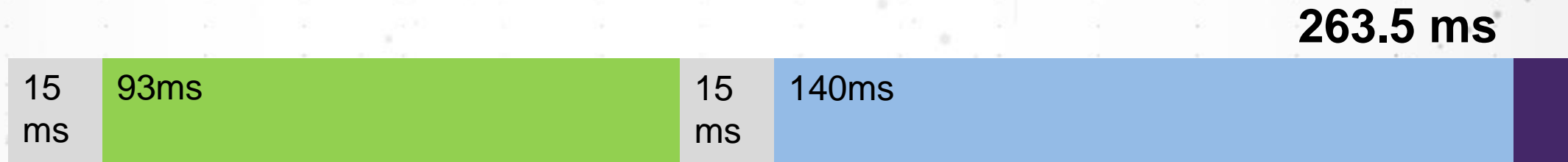
EVM

32 MHz Sample Rate
0.012s Time Span



ACP

125 MHz Sample Rate
0.040052s Time Span



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

Testing Scenarios

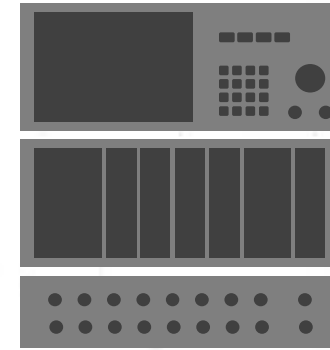
BASELINE

Test Executive

Step Name	Verdict	Duration
Repeat	<input checked="" type="checkbox"/>	0.00 s
GMSK Power vs Time	<input checked="" type="checkbox"/>	0.00 s
GMSK Phase and Frequency	<input checked="" type="checkbox"/>	0.00 s
EDGE Power vs Time	<input checked="" type="checkbox"/>	0.00 s
EDGE Output RF Spectrum	<input checked="" type="checkbox"/>	0.00 s
Transmit Power	<input checked="" type="checkbox"/>	0.00 s
EDGE EVM	<input checked="" type="checkbox"/>	0.00 s
GMSK Output RF Spectrum	<input checked="" type="checkbox"/>	0.00 s
Sweep Loop	<input checked="" type="checkbox"/>	0.00 s
ACP	<input checked="" type="checkbox"/>	0.00 s
If Verdict	<input checked="" type="checkbox"/>	0.00 s
Modulation Analysis	<input checked="" type="checkbox"/>	0.00 s

Step Settings
<input checked="" type="checkbox"/> General
VSA
VSG
Center Frequency
<input checked="" type="checkbox"/> Trigger
Auto Trigger
Trigger Source
<input checked="" type="checkbox"/> Attenuation
Mechanical Attenuation
Electrical Attenuation
Electrical Attenuation
Pre-Adjust for Min Clip
<input checked="" type="checkbox"/> System
Automatic Alignment

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



DUT

COST \$10.17
OF TEST



Testing Scenarios

BASELINE

+ Add Server CPU

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

Test Executive

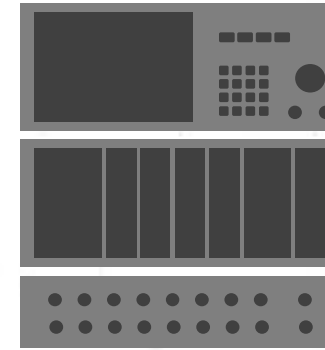
Step Name	Verdict	Duration	Step Settings
Repeat		0.00 s	General
GMSK Power vs Time		0.00 s	VSA
GMSK Phase and Frequency		0.00 s	VSG
EDGE Power vs Time		0.00 s	Center Frequency
EDGE Output RF Spectrum		0.00 s	Trigger
Transmit Power		0.00 s	Auto Trigger
EDGE EVM		0.00 s	Trigger Source
GMSK Output RF Spectrum		0.00 s	Attenuation
Sweep Loop		0.00 s	Mechanical Attenuation
ACP		0.00 s	Electrical Attenuation
If Verdict		0.00 s	Electrical Attenuation
Modulation Analysis		0.00 s	Pre-Adjust for Min Clip
			System
			Automatic Alignment



CLOUD

Process Algorithms

Acquire IQ data



DUT

COST -16%
OF TEST

Process in parallel
Process on a fast CPU



Testing Scenarios

CLOUD

BASELINE

+ Add DUTs

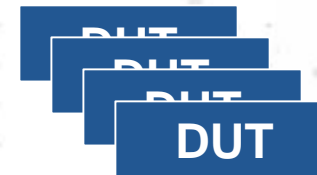
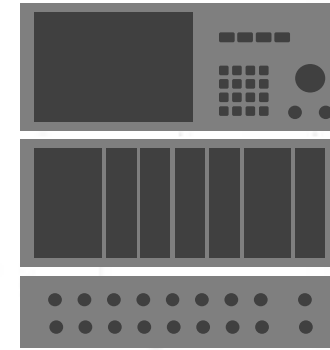
Share a test station
to test multiple DUTs
in “pipeline” fashion

Test Executives

Step Name	Verdict	Duration
Repeat	<input checked="" type="checkbox"/>	0.00 s
GMSK Power vs Time	<input checked="" type="checkbox"/>	0.00 s
GMSK Phase and Frequency	<input checked="" type="checkbox"/>	0.00 s
EDGE Power vs Time	<input checked="" type="checkbox"/>	0.00 s
EDGE Output RF Spectrum	<input checked="" type="checkbox"/>	0.00 s
Transmit Power	<input checked="" type="checkbox"/>	0.00 s
EDGE EVM	<input checked="" type="checkbox"/>	0.00 s
GMSK Output RF Spectrum	<input checked="" type="checkbox"/>	0.00 s
Sweep Loop	<input checked="" type="checkbox"/>	0.00 s
ACP	<input checked="" type="checkbox"/>	0.00 s
If Verdict	<input checked="" type="checkbox"/>	0.00 s
Modulation Analysis	<input checked="" type="checkbox"/>	0.00 s

Step Settings

- General
 - VSA
 - VSG
 - Center Frequency
- Trigger
 - Auto Trigger
 - Trigger Source
- Attenuation
 - Mechanical Attenuation
 - Electrical Attenuation
 - Electrical Attenuation
 - Pre-Adjust for Min Clip
- System
 - Automatic Alignment



COST
OF TEST **-26%**

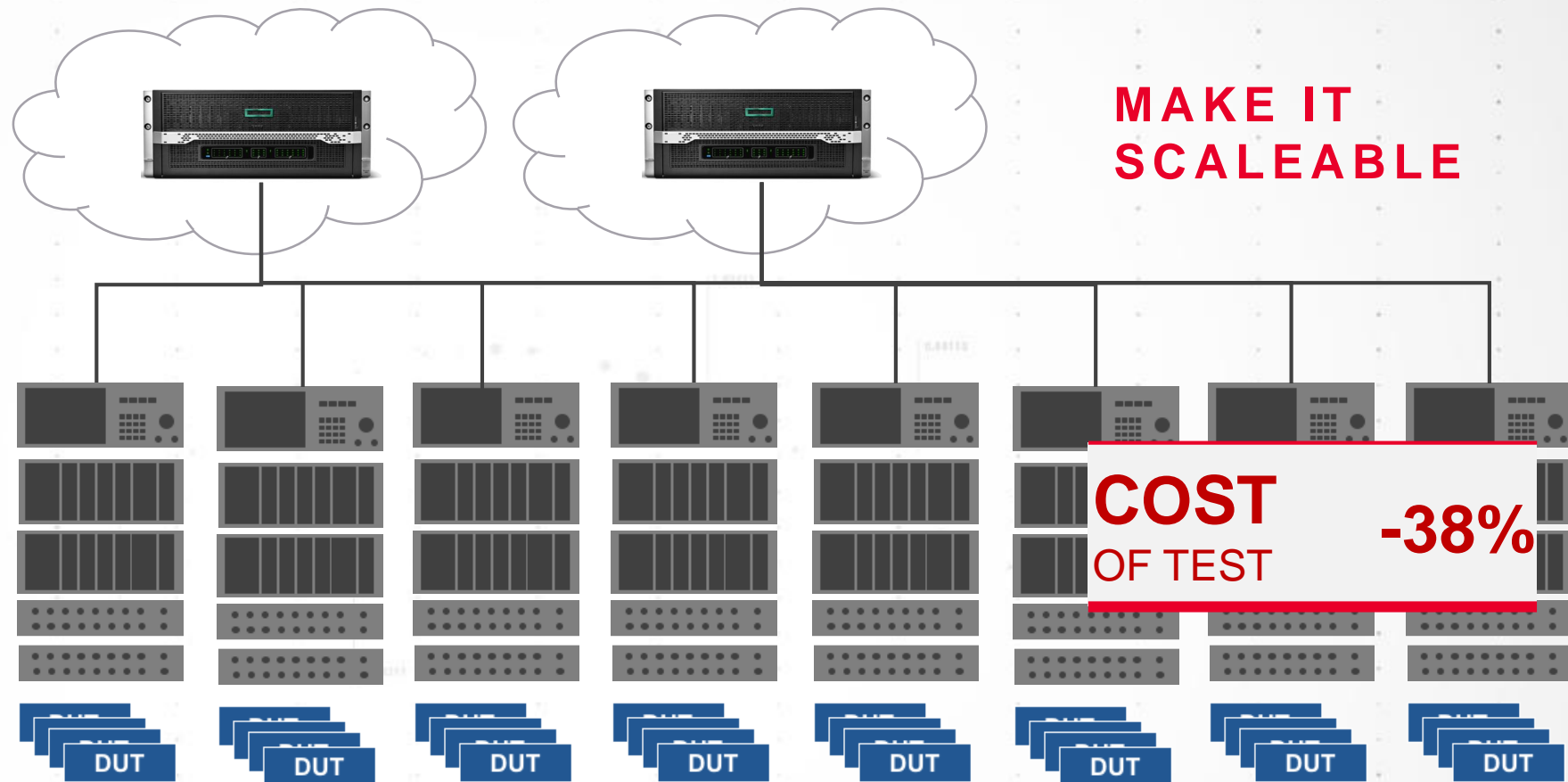


Testing Scenarios

BASELINE

- + Add Server CPU
- + Add Instruments
- + Add DUTs

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



MAKE IT SCALEABLE

COST OF TEST -38%

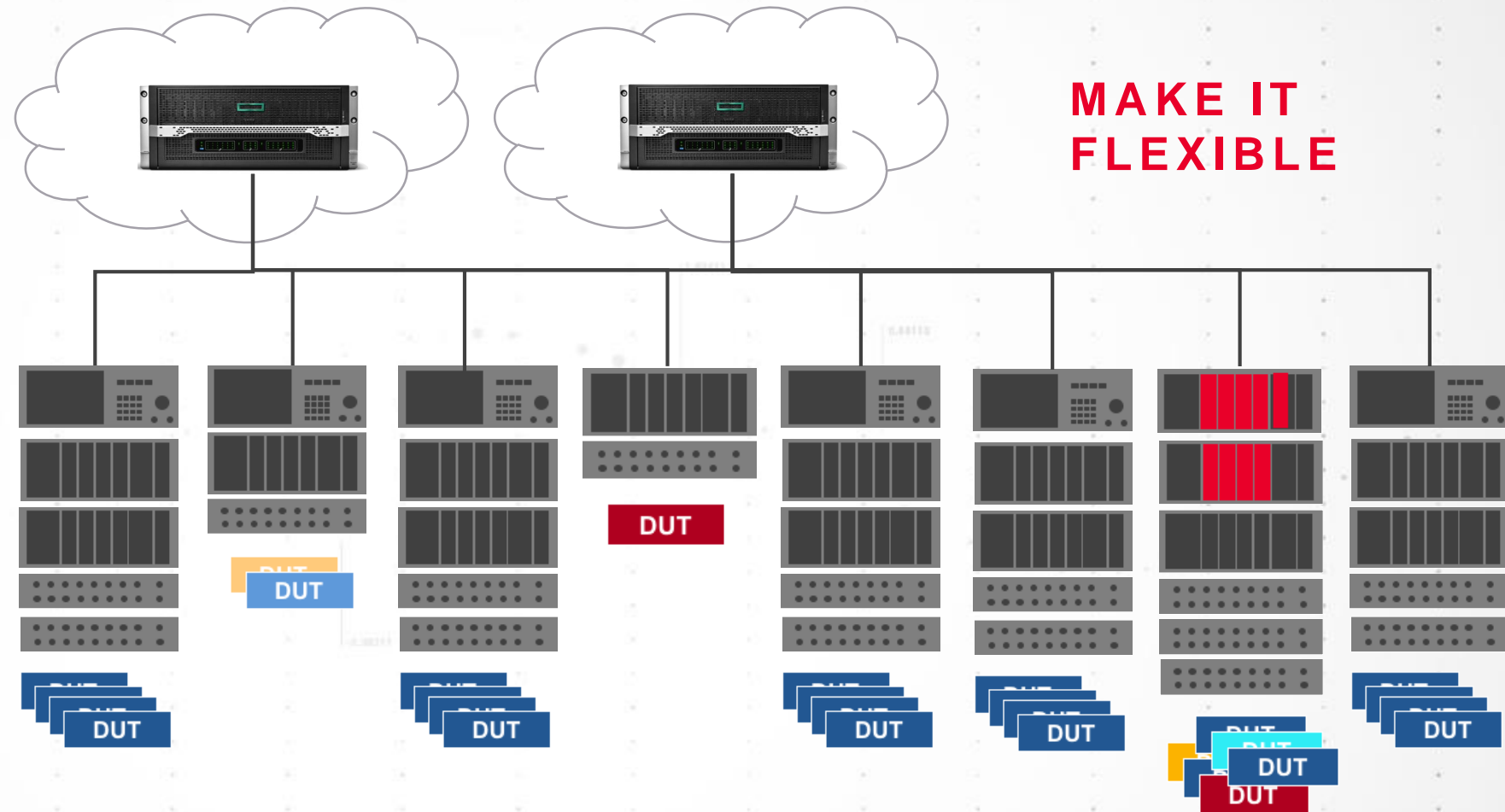
Testing Scenarios

BASELINE

- + Add Server CPU
- + Add Instruments
- + Add DUTs

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

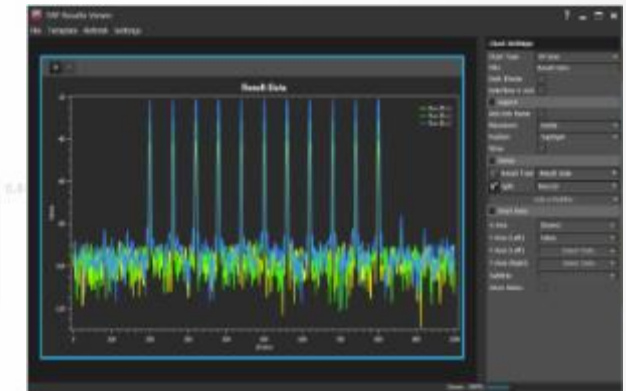
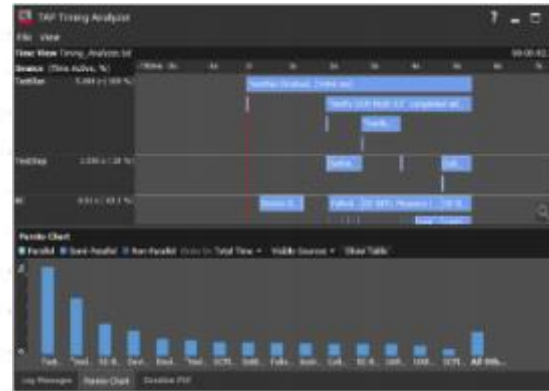
Test systems can be “software defined” to execute any test plan.



Automation: Simplified sequencing, test plan creation

KS8400A TEST AUTOMATION ON PATHWAVE (TAP)

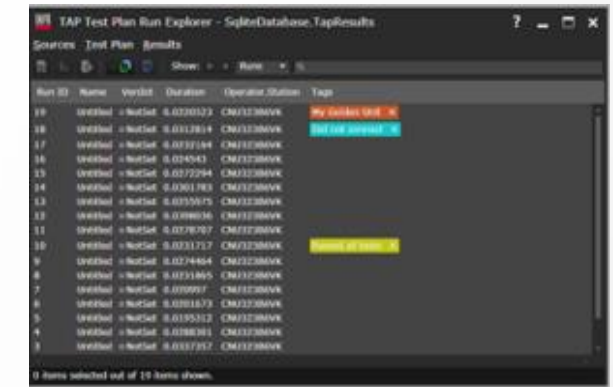
- Fast execution and test flow analysis
- User interfaces
 - GUI
 - Command line interface
 - API
- Modular “plug-in” software architecture
- Microsoft .NET test step development



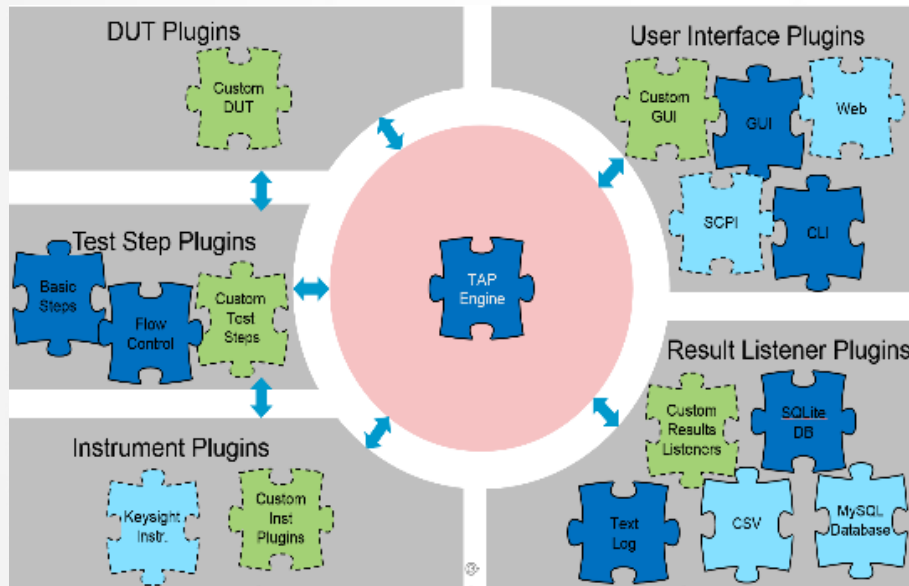
Powerful Speed and Results Analytics



Create Custom GUIs

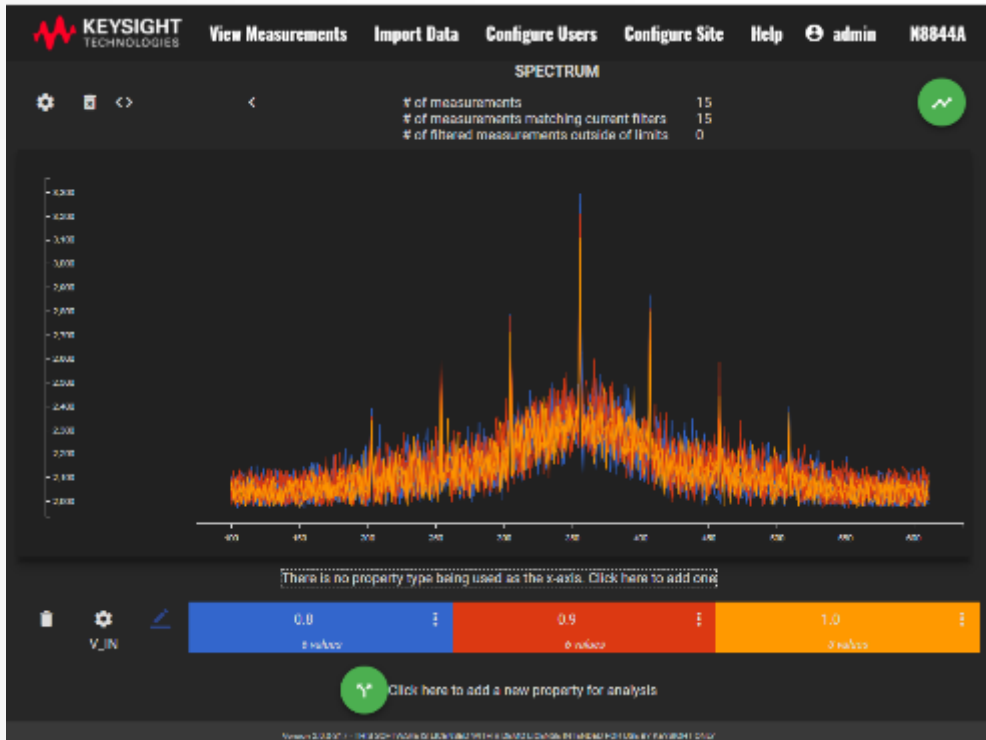


Efficient Data Exploration



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

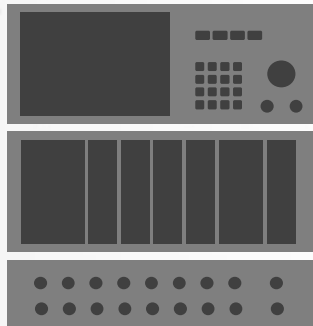
- Across org
- Across tools
- Processes
- Predictive

New Degrees of Scalability & Flexibility

MULTI-DUT



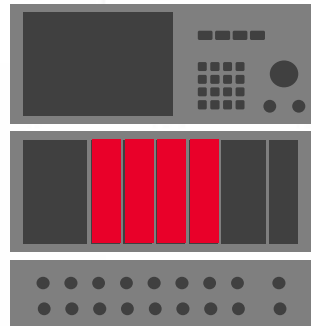
DUTs PER TEST STATION



MULTI-INSTRUMENT

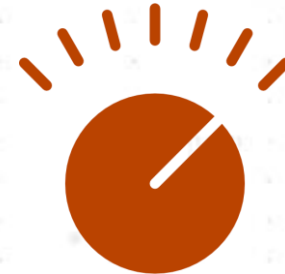


INSTRUMENTS PER TEST STATION

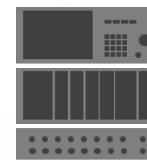


DUT

SERVER CPUs



ACCELERATION SERVER SPEED

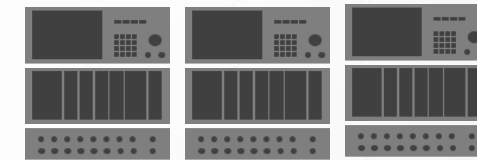


DUT

CPU SHARING



TEST STATIONS PER SERVER CPU



DUT

DUT

DUT

Introducing: S9100A 5G Multi-band Vector Transceiver



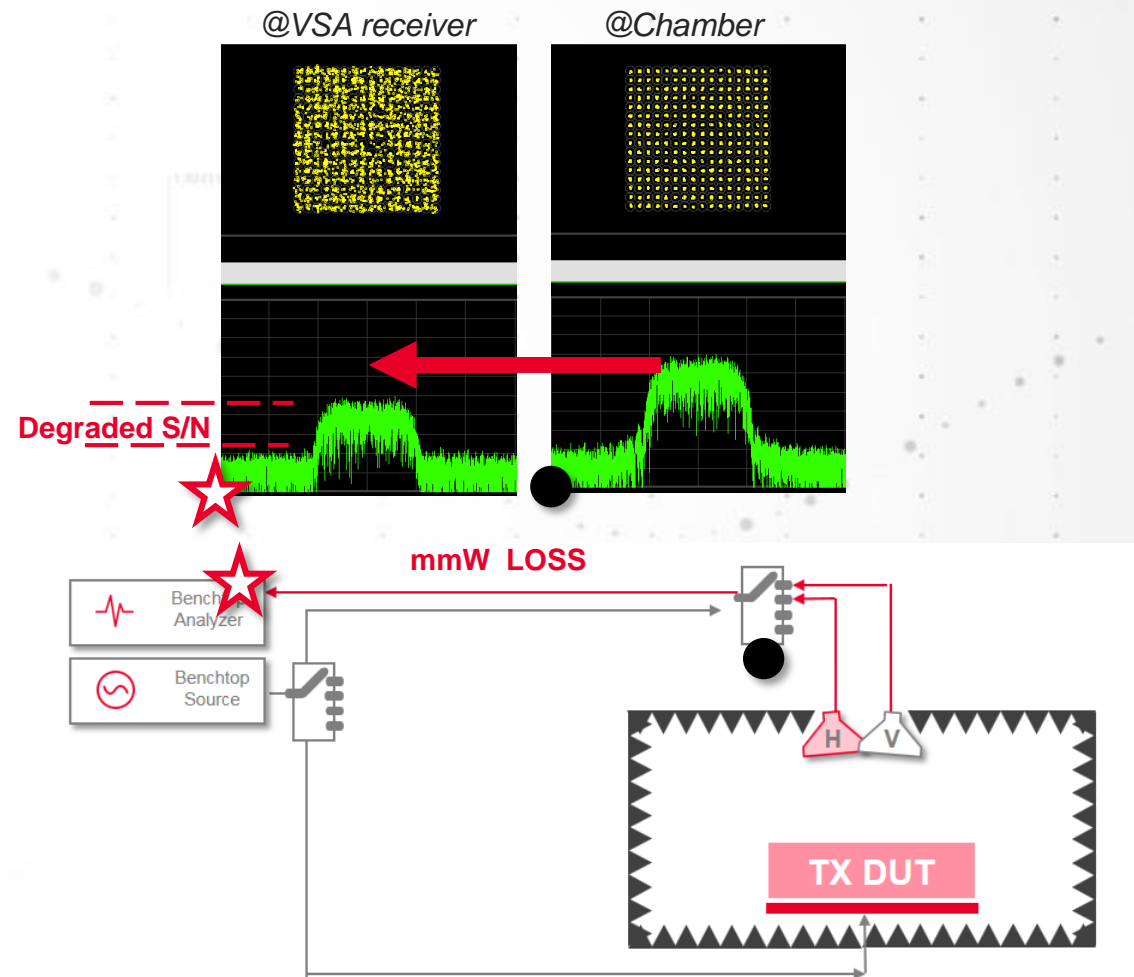
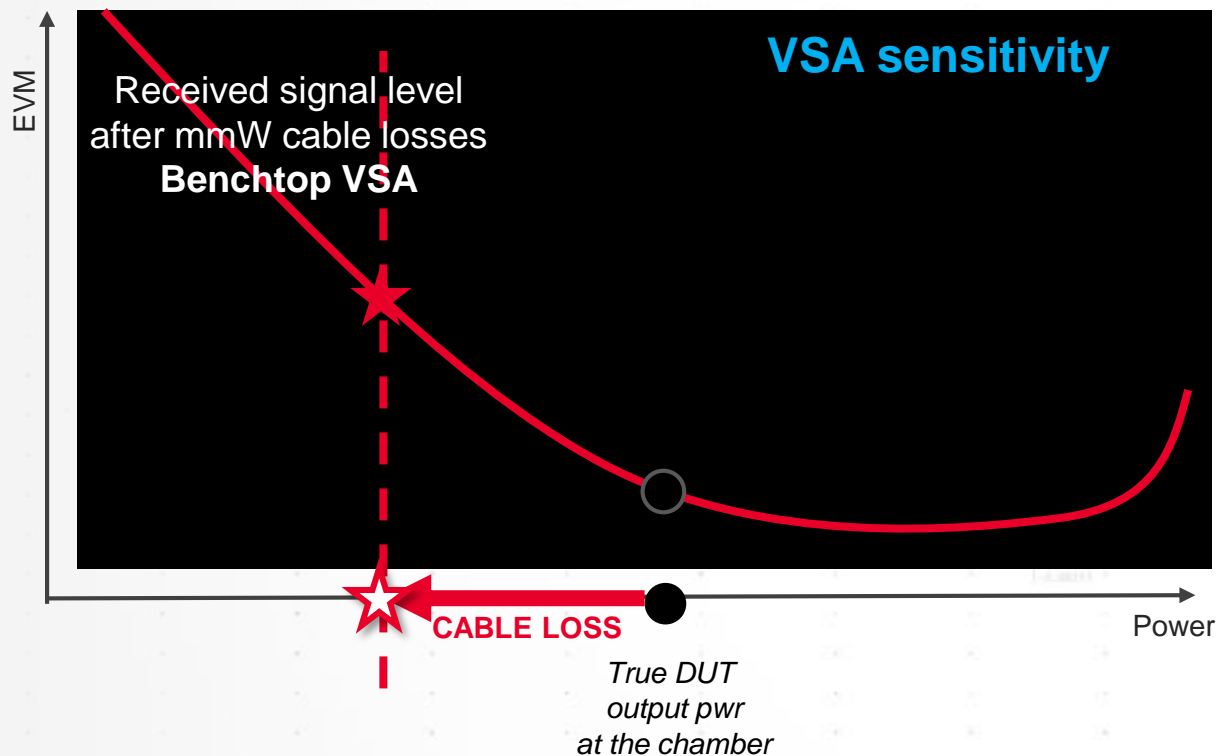
“LEAN ENOUGH FOR MFG - POWERFUL ENOUGH FOR DESIGN VALIDATION”



- ✓ **Sub-6GHz, easily scalable to 24-44 GHz bands**
no wasted modules in order to cover both 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

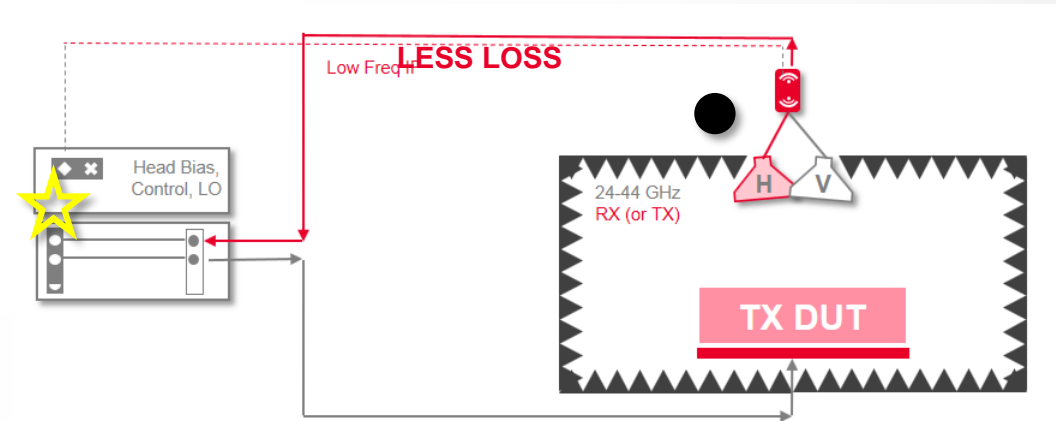
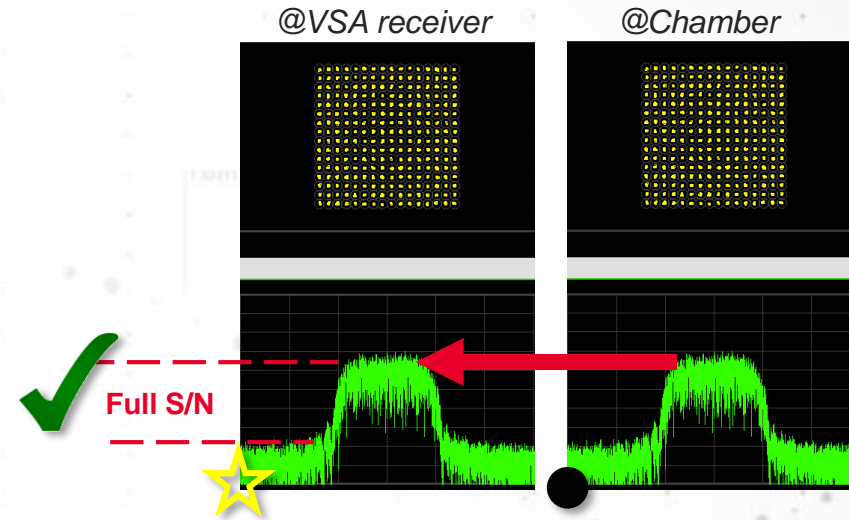
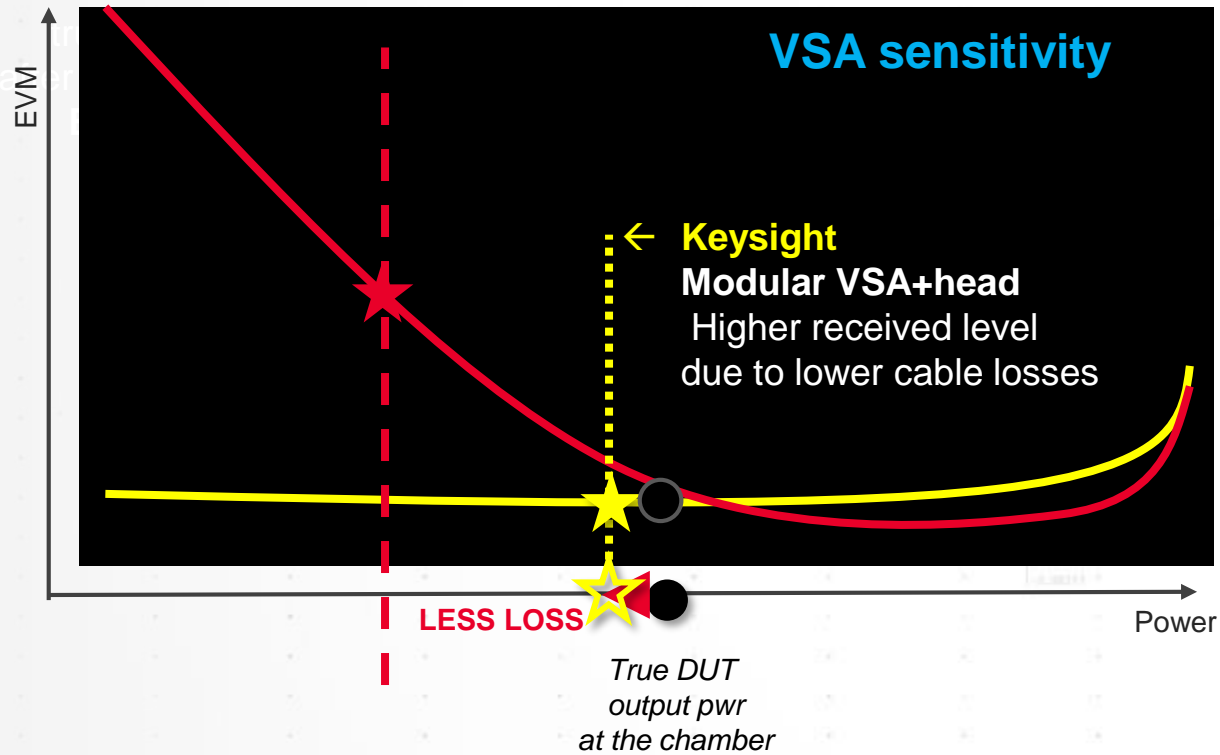
OTA Benefits of the Remote Head at 28/39 GHz

VSA SENSITIVITY – BENCHTOP WITH HIGH LOSSES



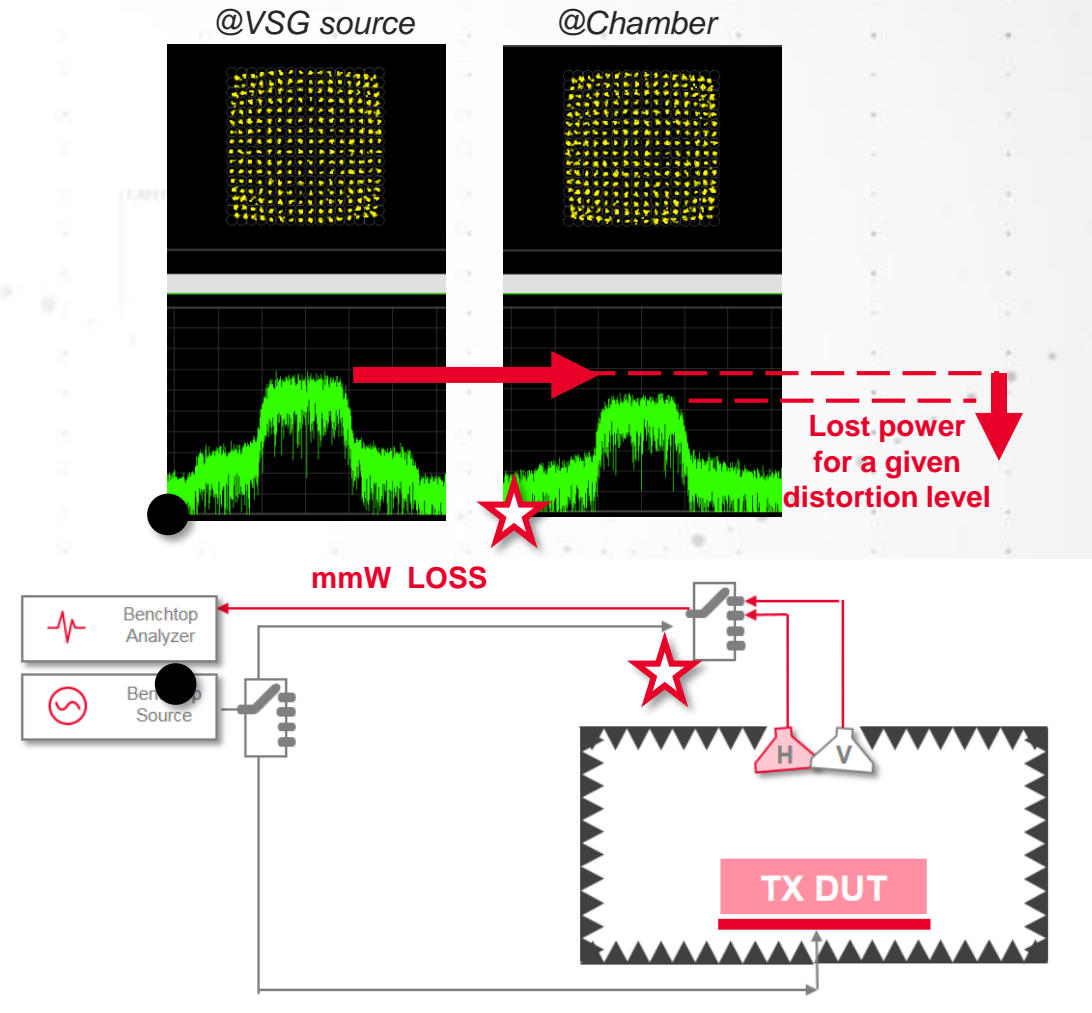
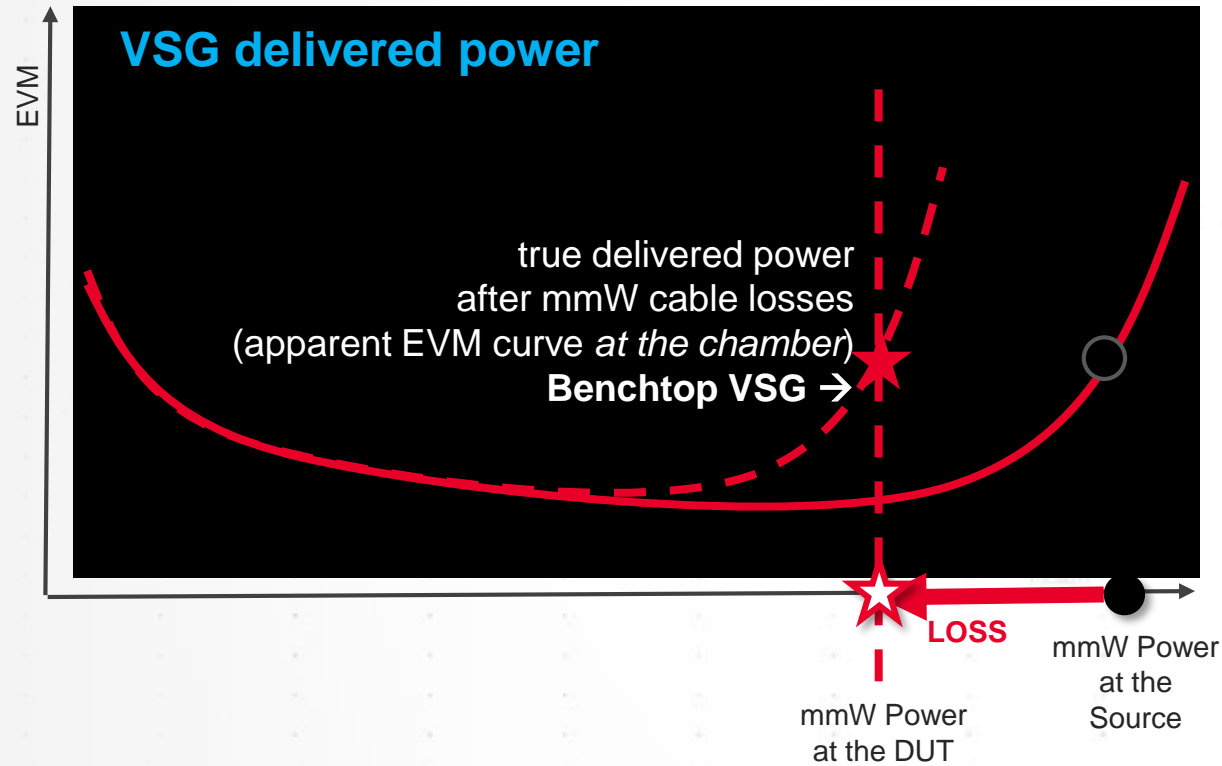
OTA Benefits of the Remote Head at 28/39 GHz

VSA SENSITIVITY – REMOTE HEAD WITH LOW LOSSES



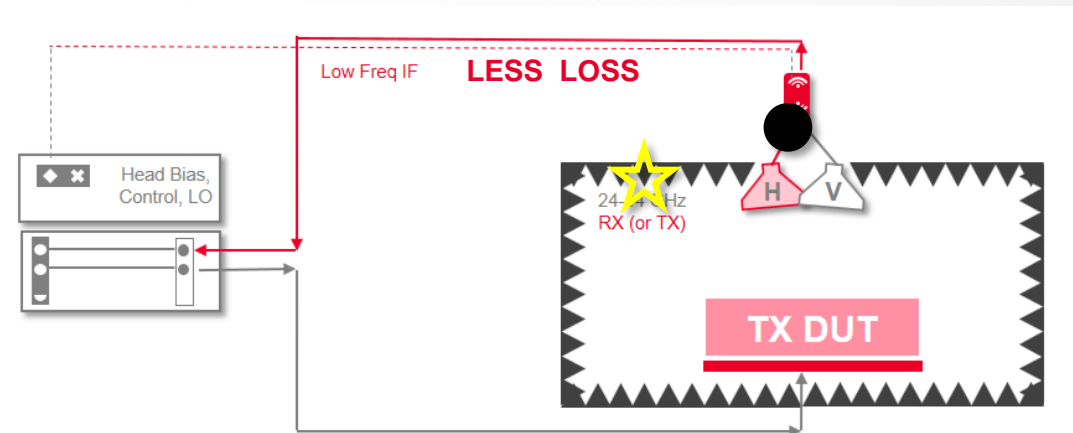
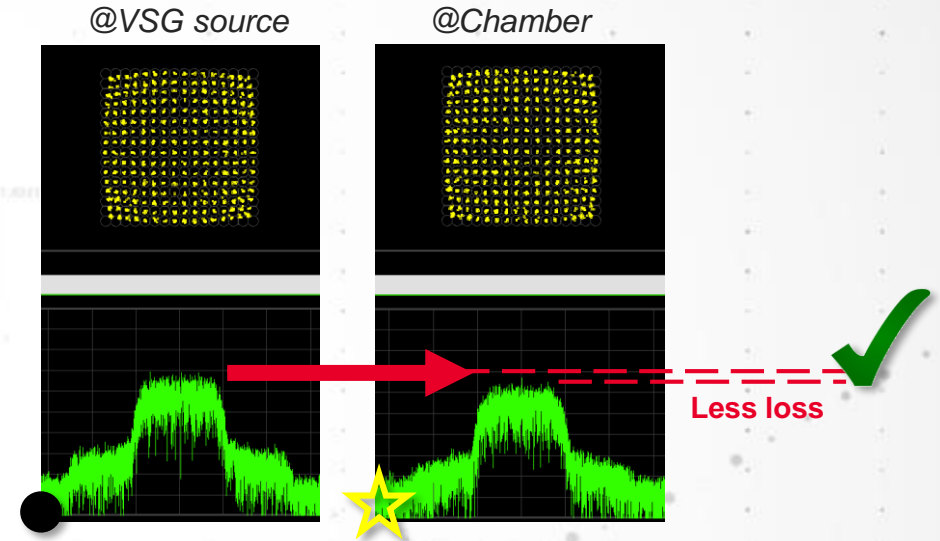
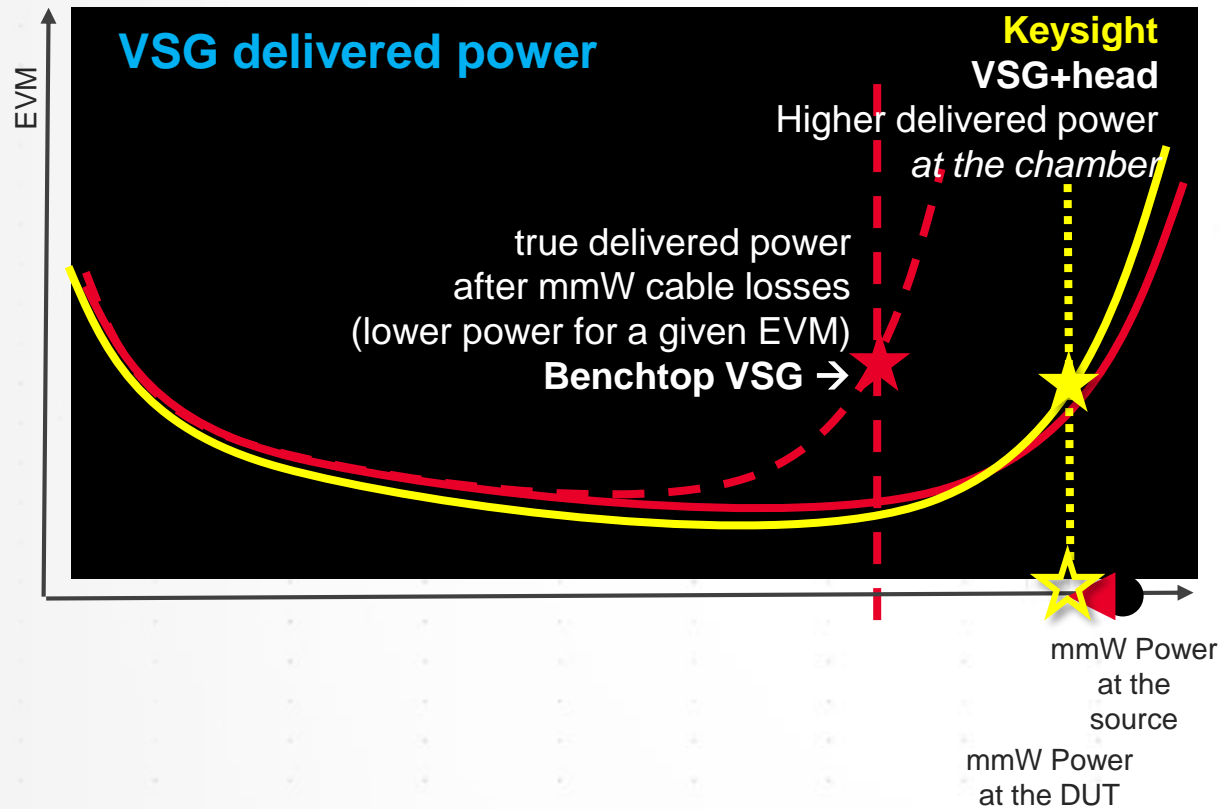
OTA Benefits of the Remote Head at 28/39 GHz

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

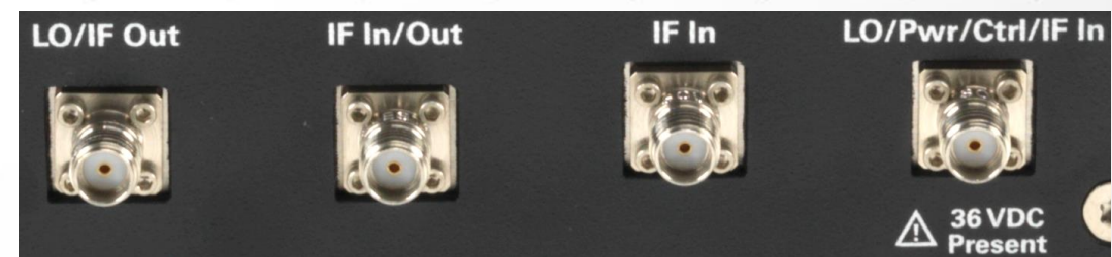
- One head covers FR2 bands (24-44 GHz)
(No need to purchase multiple heads)
- Integrated bi-directional ports, with TX & RX swapping (select V vs. H polarizations)
- Integrated signal conditioning (gain & attenuation)
- OTA-Ready design (low loss at IF, configuration flexibility)



FRONT PANEL – mmW to DUT

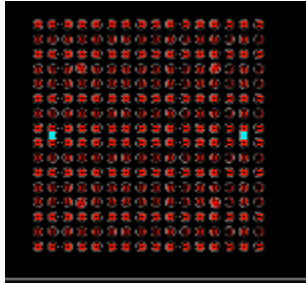


BACK PANEL – LO, IF, Control

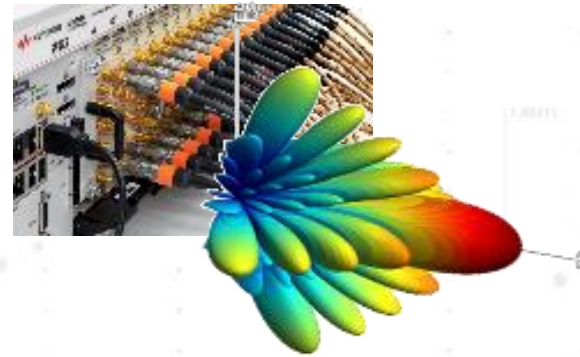


7 Key Measurement Challenges

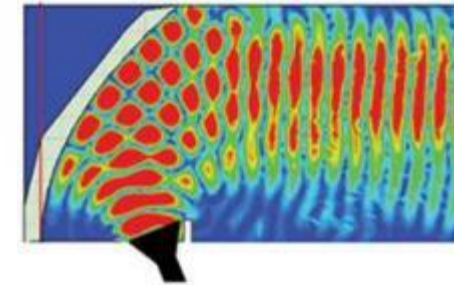
Signal Quality
mmW, Waveform, Fidelity



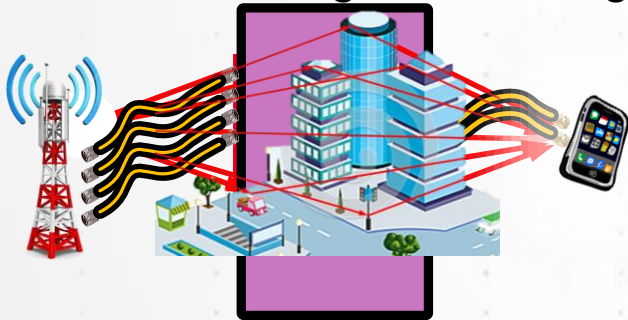
Lots of Channels
MIMO/Beamforming



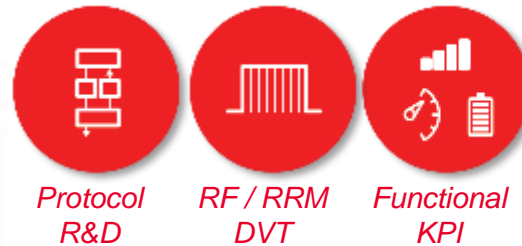
Life Beyond Connectors
Over-the-Air



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



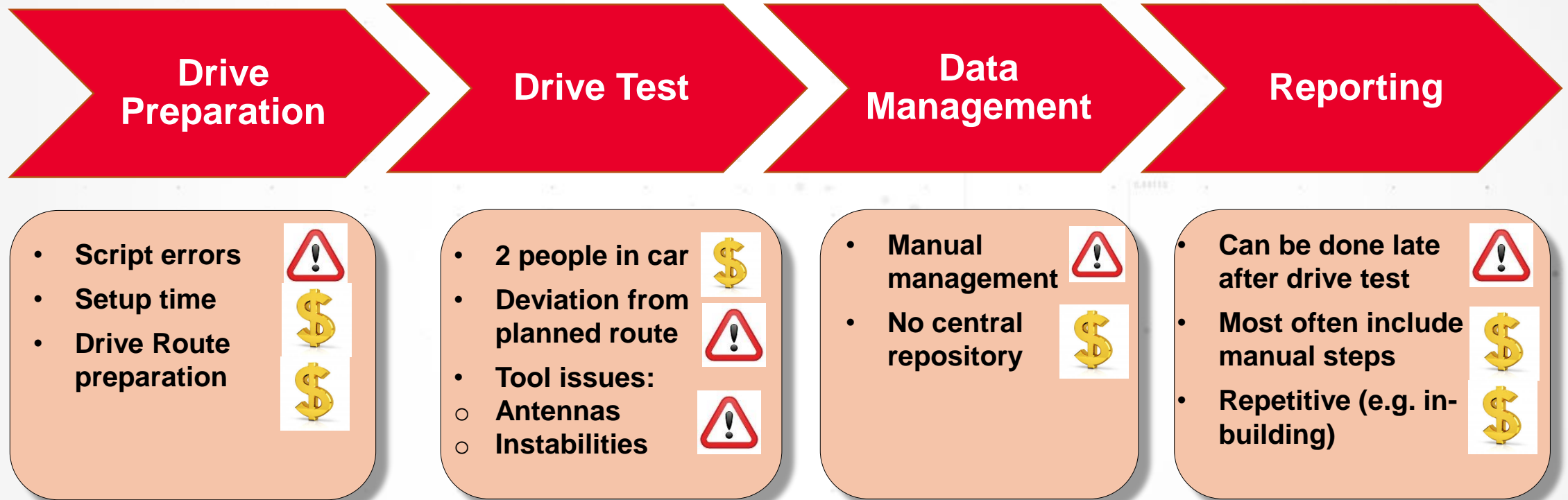
Network Control
& Monitoring



Post-Processing,
Reporting, and
Analytics

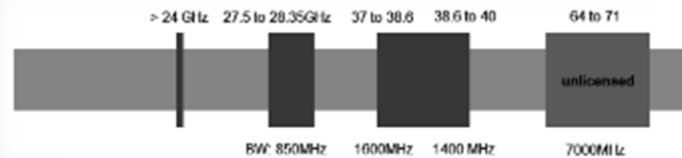


Field Testing/ Drive Test Challenges

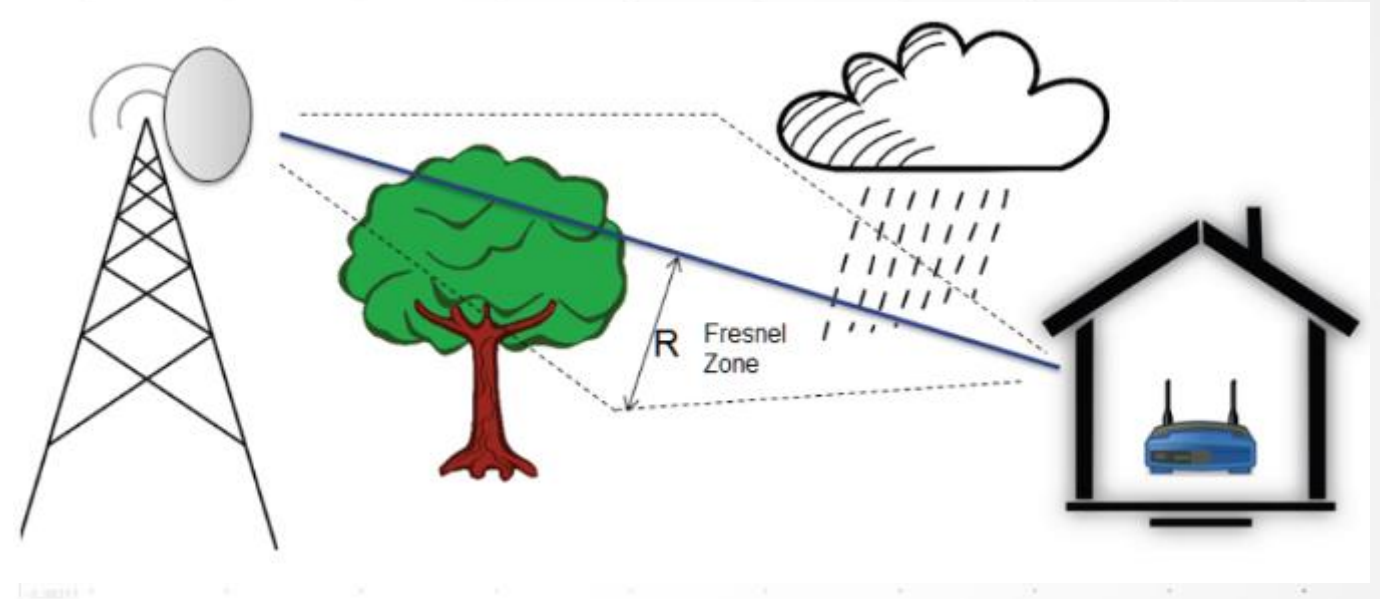


mm-wave Challenge

FCC 5G frontier bands up to 71 GHz

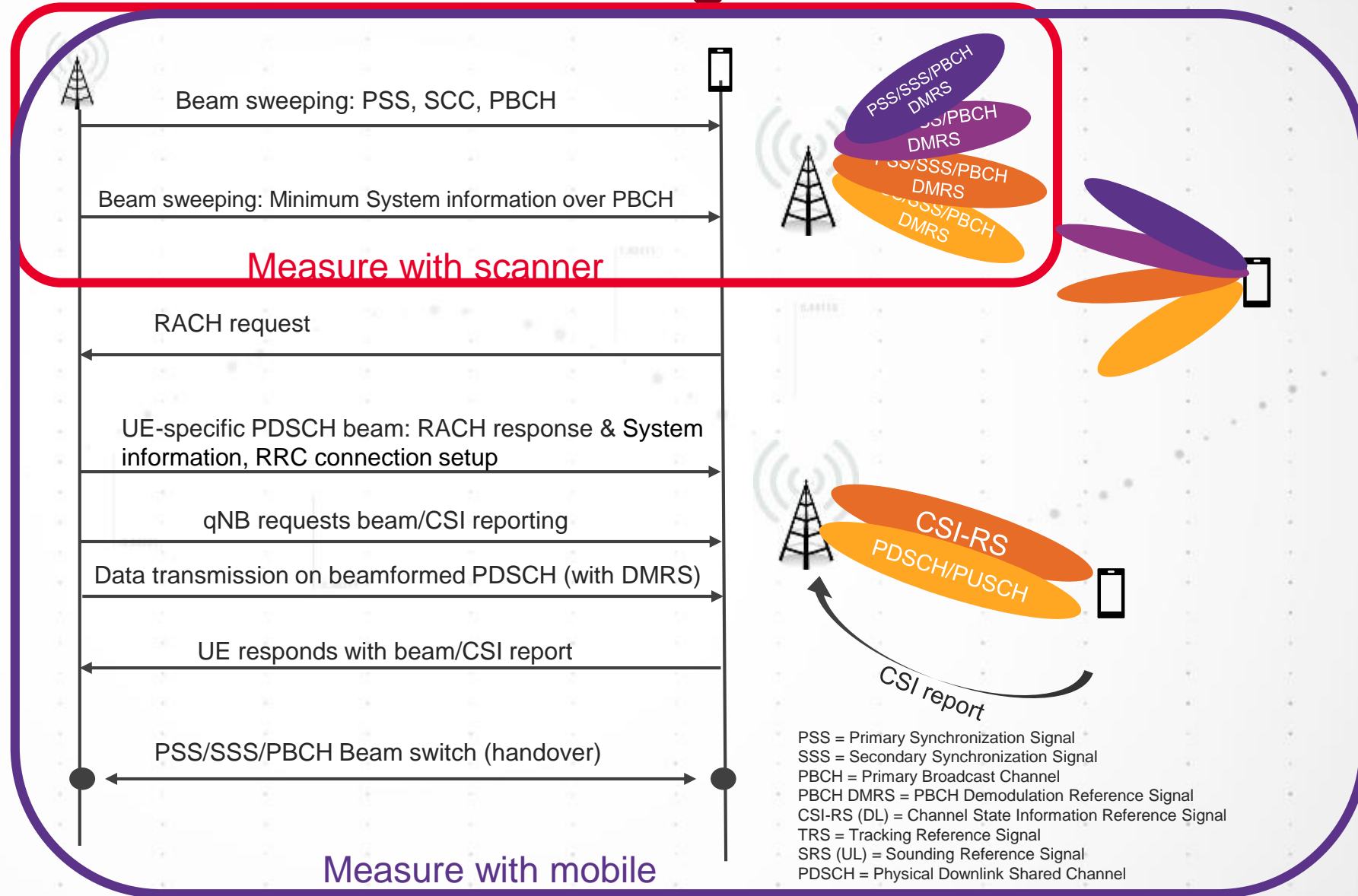


- 5G mm-wave link budget is quite different from traditional sub 6 GHz wireless link budget
- Extra losses due to rain fade, shadowing loss, foliage, atmosphere absorption, humidity and, Fresnel blockage



5G NR – Beam Based Network Coverage

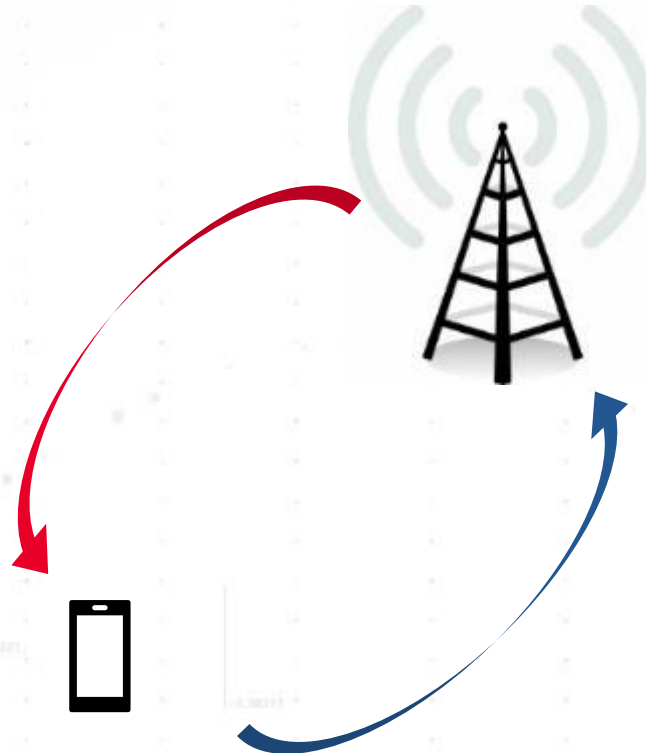
- Paradigm shift from cell coverage to beam coverage
- There are many kind of beams, static and dynamic, mobile, and network side
 - DL reference beams
 - UL beams (UE/CPE-specific)
 - DL/UL traffic beams
 - Vendor-specific



5G L1 channels and signals

DOWNLINK

- Common (visible in scanner and UE measurements):
 - PSS (Primary Synchronization Signal)
 - SSS (Secondary Synchronization Signal)
 - 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

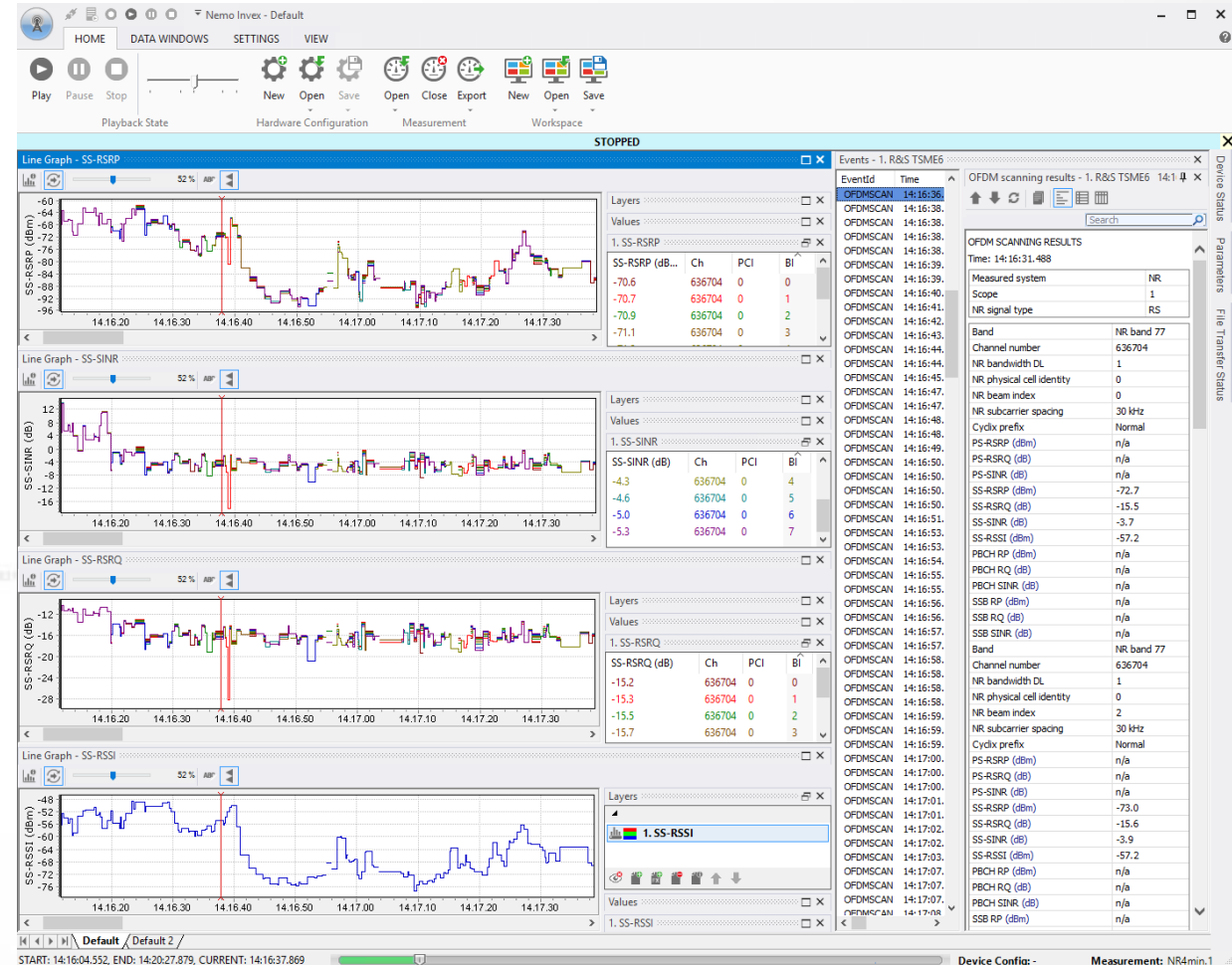
- User level (UE measurements only)
 - PUSCH (Physical UL Shared Channel)
 - PUCCH (Physical UL Control Channel)
 - PRACH (Physical Random Access Channel)
 - DMRS (Demodulation Reference Signal)
 - PTRS (Phase-tracking Reference Signal)
 - SRS (Sounding Reference Signal)

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



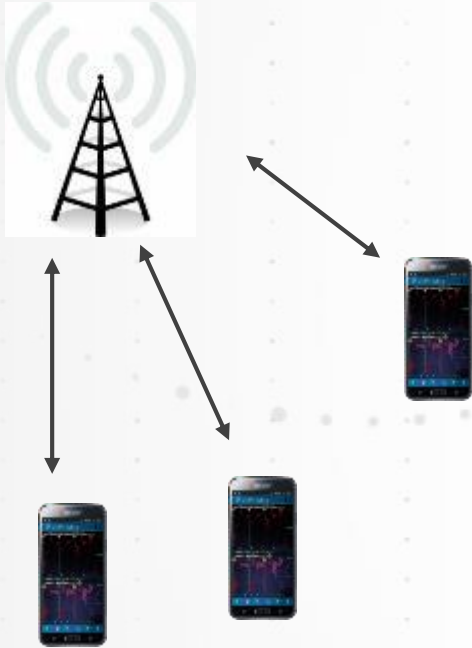
Massive MIMO Field Testing Challenges

- 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

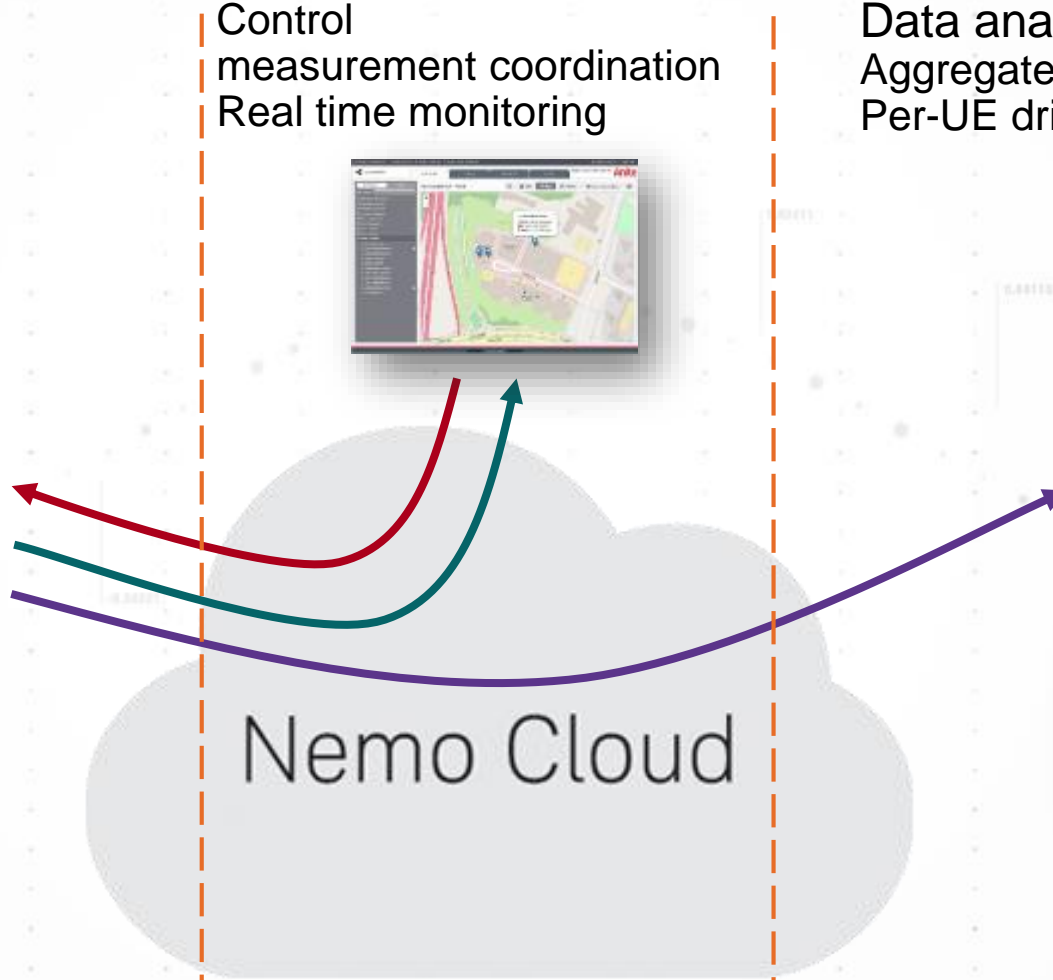
Control
measurement coordination
Real time monitoring



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



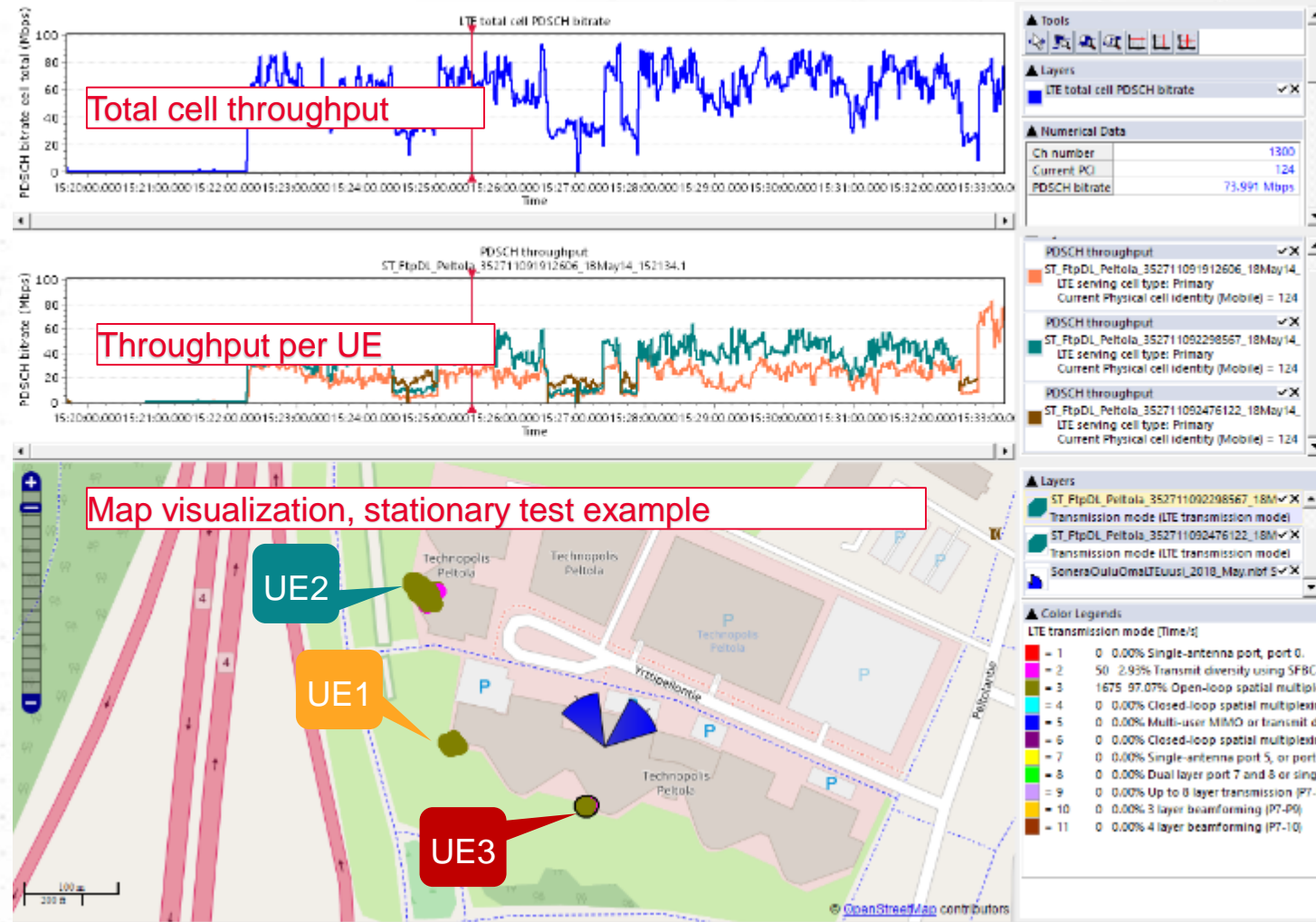
Analytics



Massive MIMO Cell Testing

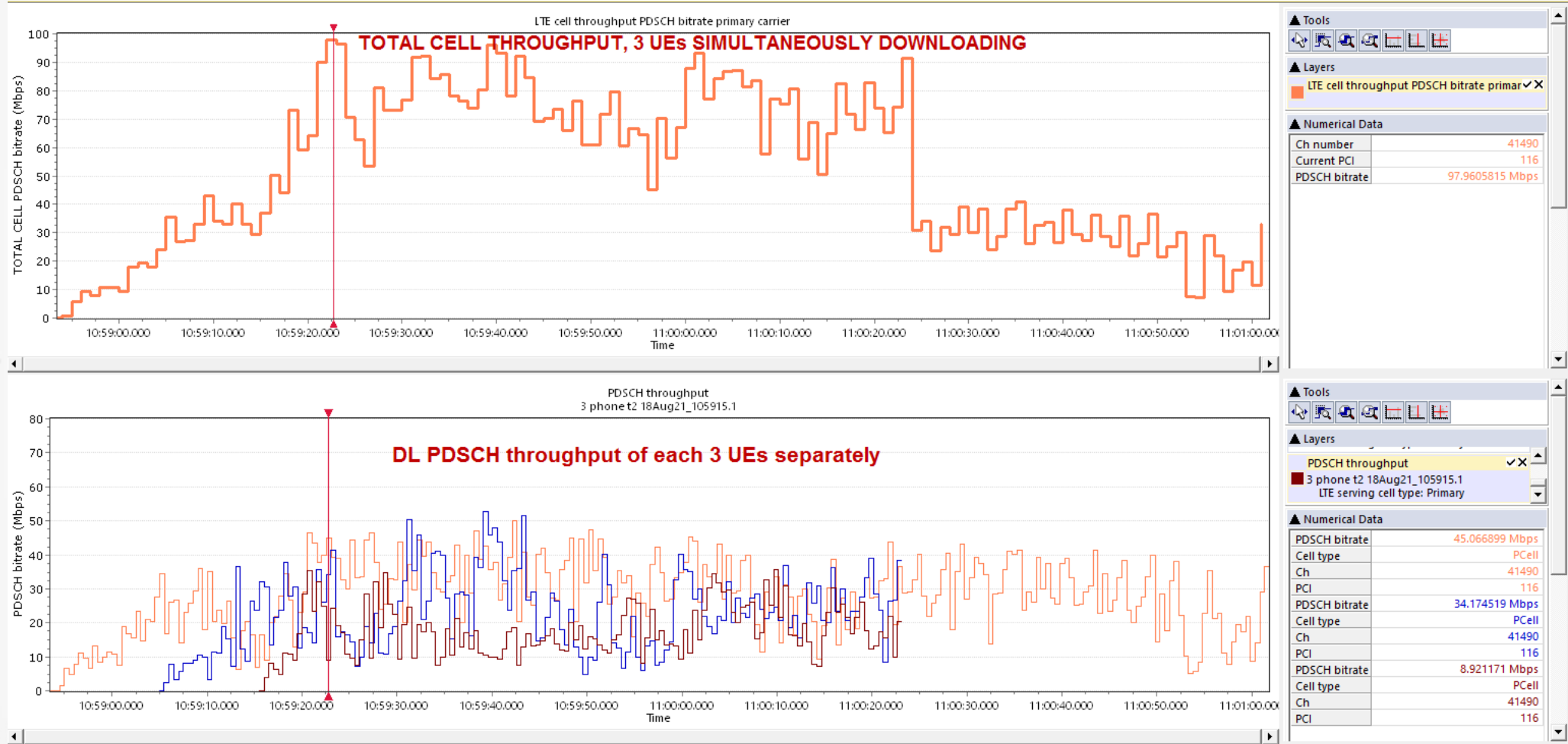
ANALYTICS

- 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

