Massive MIMO Test and Measurement Challenges and OTA Solutions

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KEYSIGHT
TECHNOLOGIES

5G: What Will it Be?

From vision to reality

Courtesy of METIS: 2014

Amazingly Fast	Great Service In a Crowd	Best Experience Follows You	Real-Time & Reliable Communications	Ubiquitous Things Communicating

Multiple Use Cases

Mobile Broadband

Connectivity Requirement:
- Peak data rate > 10 Gbps
- Minimum data rate > 50 Mbps
- High user mobility
- Broadband access in dense area

Ultra-large volume transfers

Staying connected everywhere including in a crowd

Augmented reality

Massive Machine Communication

Connectivity Requirement:
- Low-cost
- Low-energy
- Low packet size

Mission-Critical Machine Communication

Connectivity Requirement:
- Ultra-high reliability
  - Failure not an option!
- Ultra-low latency

Vehicle-to-vehicle (V2V) communication

Driverless car

Remote surgery

Smart grid

Manufacturing Robot

5G Enabling Technologies

Evolution of existing technology + Revolution of new technology

New Technology (Revolution)

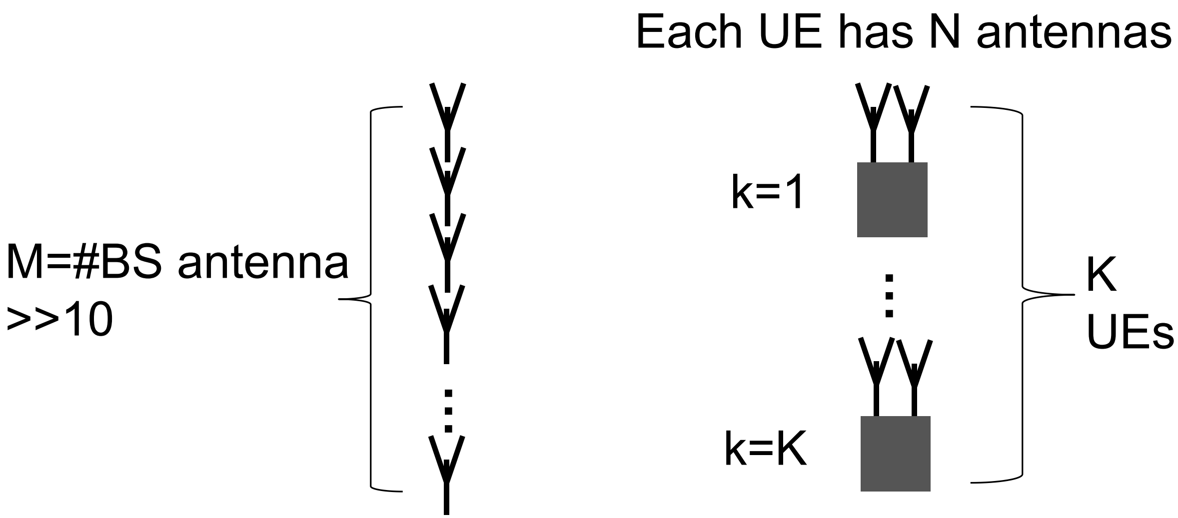
- Centimeter and millimeter wave bands (licensed and unlicensed)
- Wide bandwidth – up to 2 GHz or wider
- Massive MIMO - Number of BTS antennas >> Number of UE antennas
- New waveforms and new radio access technology (RAT)
- Full duplex
- Software based network architecture: SDN, NFV and SDAI

Evolution of existing technology (Sub-6 GHz)

- Evolution of current cellular technologies – LTE/LTE-A
  - Example: LTE co-existence with WiFi also known as license assisted access (LAA); machine type communication (MTC) or IoT/M2M, 3D MIMO etc..
- Evolution of WLAN
- New frequency bands below 6 GHz
- New waveforms and new radio access technology (RAT)
- Ultra-dense networks – small cells and WLAN access points
- Evolution of RAN architecture (Advanced C-RAN)

With tight interworking between exiting technologies (Cellular & WLAN) and the new technology

Massive MIMO Processing Principles

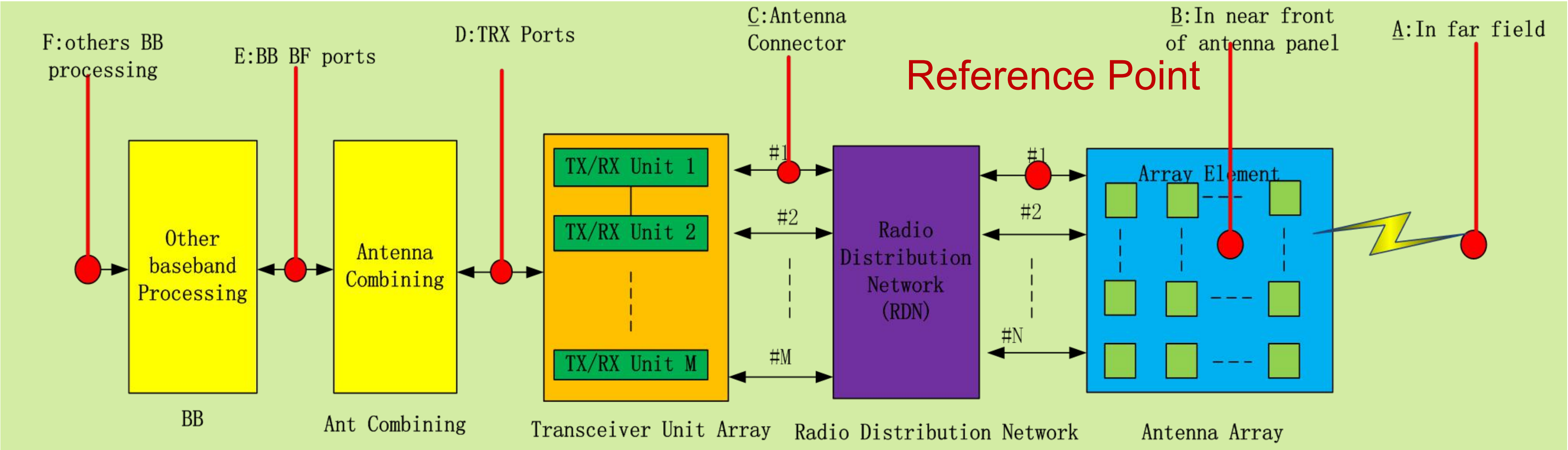


– Massive MIMO is a multi-user MIMO where M (#BS antenna)>>KN (#UE antennas)

– Massive MIMO depends on channel orthogonality (favorable channel characteristics)

– Effective CSI estimation → preference of TDD due to channel reciprocity

Massive MIMO Architecture and Key Test Technologies



Massive MIMO Structure and Different Test Reference Points

Key Test Technologies:

- Massive MIMO algorithm\link level\system level simulation tool
- Massive MIMO channel measurement and emulation
- Massive MIMO test methods at different reference points: baseband, RF, antenna, over the air system
- Prototype platform development for massive MIMO measurement research

Massive MIMO Test and Measurement Needs

Test needs	Category	Test life cycle
System Design and Simulation Solutions Massive MIMO prototype development	Design and simulation	R&D
Multi-channel RF calibration Passive array measurement Active antenna array calibration Active antenna array beam measurement and calibration Over the air RF parametric measurement	RF calibration and test	R&D, Manufacturing, Conformance
Massive MIMO channel measurement and emulation Beam dynamics measurement Multi-user system performance test Virtual in field performance test	Functional and system performance test	R&D, Conformance System end-to-end test Installation

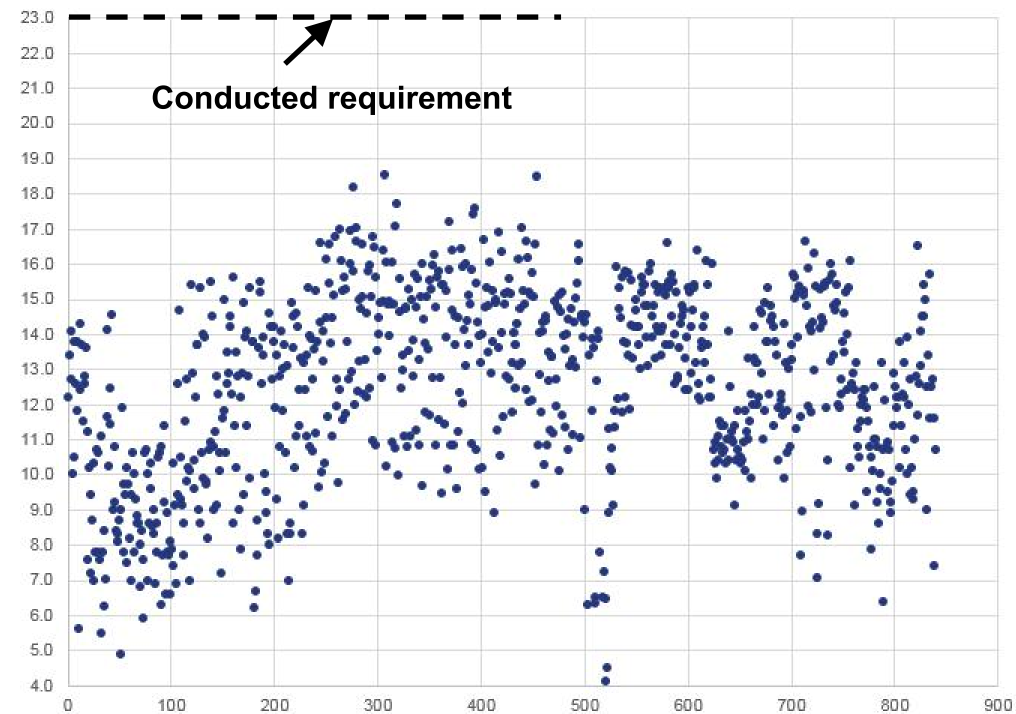
Massive MIMO T&M Challenges

- Measurement metrics
  - Not fully defined
  - System performance versus component performance (antenna, RF, baseband)
  - Performance in field versus performance in lab room
  - Performance in OTA versus performance in conducted
- Test method
  - Scalable, cost effective and fast test massive MIMO system
  - Test and calibration challenge due to active components
  - Over the air test
  - Virtual field test in the labs
- Test speed
  - Finer spatial resolution due to high directivity
  - Test coverage for different directions
- Change of test interface
  - Integration of RF frontend with antenna → no RF interface for test, OTA needed
  - New proprietary baseband interface -> Can this be used for test?

OTA and Cable Conducted Test Difference

R4-1706093 TRP/TRS joint band passing rate worksheet

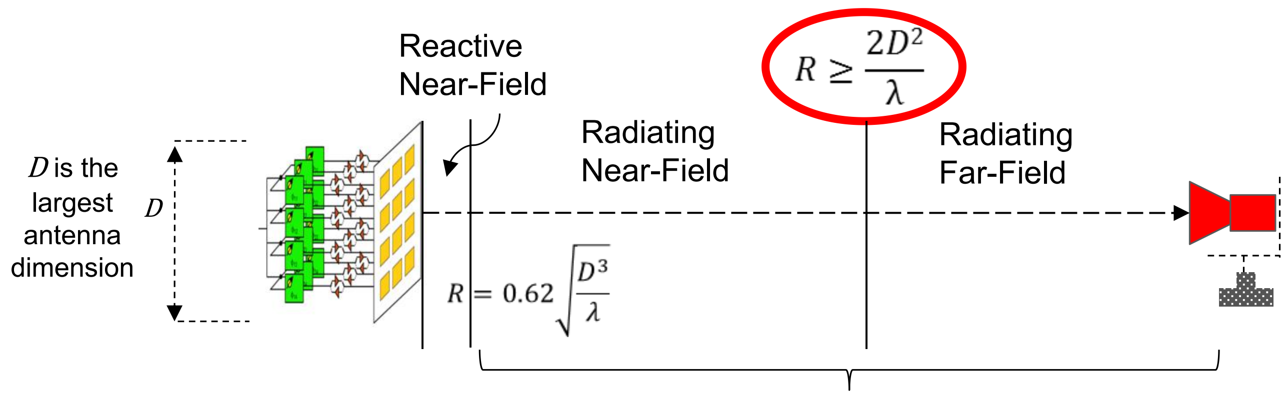
- 3GPP RAN WG4 is currently analyzing a data set of 840 TRP measurements on 198 devices over 21 bands
- The plot shows all 840 results for the beside head hand (BHH) use case averaged over 6 measurements (low/mid/high channel, left and right)
- The best was 18.4 dBm and the worse was 4.1 dBm, average of 12.4 dBm
- The lowest individual result was 1 dBm
- All phones pass the 23 dBm ± 2 dB conducted requirement



Massive MIMO T&M Challenge and OTA Solutions

Quick Refresher – Near Field and Far Field

Know the Difference



Most OTA measurement systems operate in these two regions

$R \geq \frac{2D^2}{\lambda}$

- Is a useful rule of thumb
- Is not a 'hard' transition
- May vary with wideband modulated signals

How Far is the Far-Field?

A Quick Look

D (cm)	Frequency (GHz)	Near/far boundary (m)
5	28	0.5
10	28	1.9
15	28	4.2
20	28	7.5
25	28	11.7
30	28	16.8

Looks OK… (D = 5–10 cm)

Getting big! (D = 15–30 cm)

- Far-Field measurements can imply large chambers – not very practical.
- Do I need to measure in the Far-Field anyway?
- Is there an alternative?

What OTA Tests Do I Need to Make?

Start with the basics…

Antenna Measurements
Antenna Array Pattern
Equivalent Isotropic Radiated Power (EIRP)
Total Radiated Power (TRP)
Equivalent Isotropic Sensitivity (EIS)

RF Test (Transmit)	RF Test (Receive)
EVM	Sensitivity level
ACLR	Dynamic Range
Spurious Emissions	Adjacent Channel Sensitivity
SEM	Blocking
Intermodulation	Band selection

Plus:

Over the Air Calibration of the DUT

- Phase & Gain Calibration of each Transmitter/Receiver Element

RF Conformance Testing

What has been defined so far?

Base Station Test Environment

Leverage low-frequency test methods for RF measurements
- Far-Field Anechoic
- CATR
- 'One-Dimension' CATR (Plane wave synthesis)
- Near-Field

Base Station Measurements

- EIRP and EIS (3GPP Release.13)

Tx Measurement Metrics

AAS BS requirement		OTA requirement type	Coverage range	Notes
Base station output power	Output power accuracy for EIRP	Directional requirement	OTA peak directions set	Output power accuracy for EIRP requirement is already included as a core requirement in TS 37.105.
	Output power accuracy for TRP	TRP	n/a	
Output power dynamics		Directional requirement	OTA peak directions set	
Transmit ON/OFF power		FFS	FFS	
Frequency Error		Directional requirement	OTA coverage range	
Time Alignment Error		Directional requirement	OTA coverage range	
Modulation Quality (EVM)		Directional requirement	OTA coverage range	
Unwanted emissions		TRP	n/a	
Adjacent Channel Leakage Radio (ACLR)		TRP	n/a	
Transmitter intermodulation		FFS	FFS	
...		...	...	

Rx Measurement Metrics

AAS BS requirement	OTA requirement type	Coverage range	Notes
Minimum EIS	Single direction		
Dynamic range			
In-band selectivity and blocking			
Out-of-band blocking			
Receiver spurious emissions	TRP		
Receiver intermodulation			
In-channel selectivity			

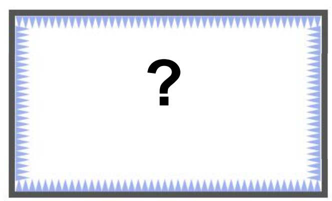
3GPP TR37.843 AAS Radiated Performance Requirements Release 15 ver.0.4.0

Base Station Demod/RRM Test

Base Station Demod Test

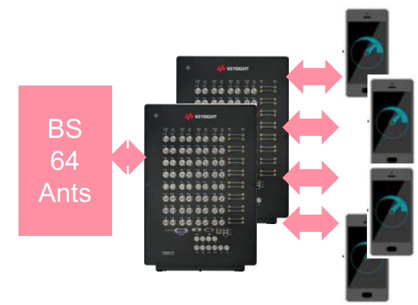
Today:
- Cable conducted test with channel emulator and non-spatial channel models

Tomorrow (OTA):
- Not yet defined
- 3D Spatial Field?

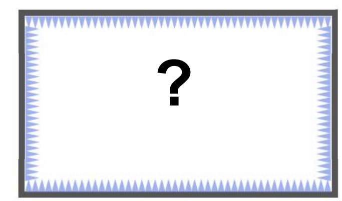


Base Station RRM Test

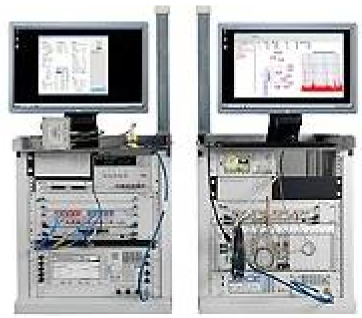
Today:
- Spatial channel model
- Cabled connection
- Channel emulator used



Tomorrow (OTA):
- Not yet defined
- 3D Spatial field
- Many UEs



Multi-user Performance Test

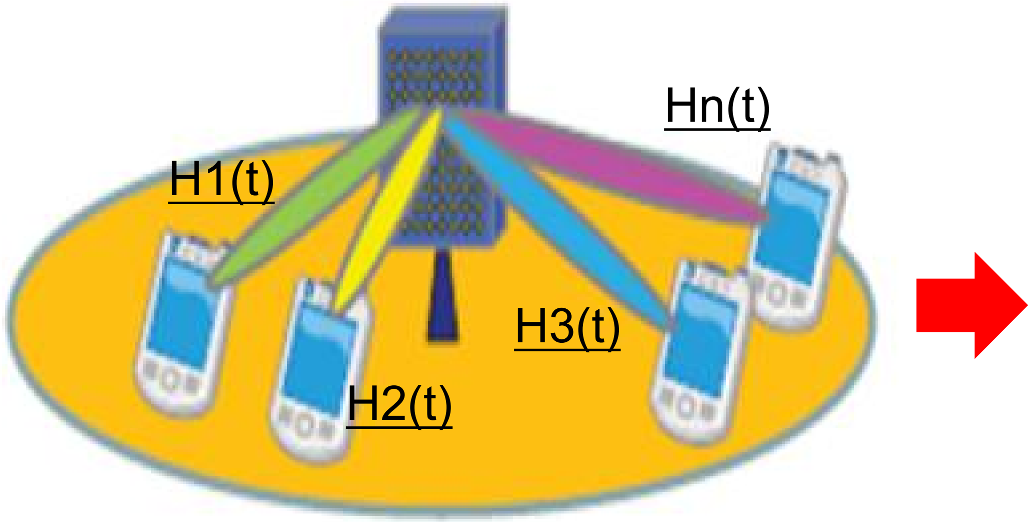


Virtual in field test

(playback of measured channel data or measured channel model)

End-to-end performance test

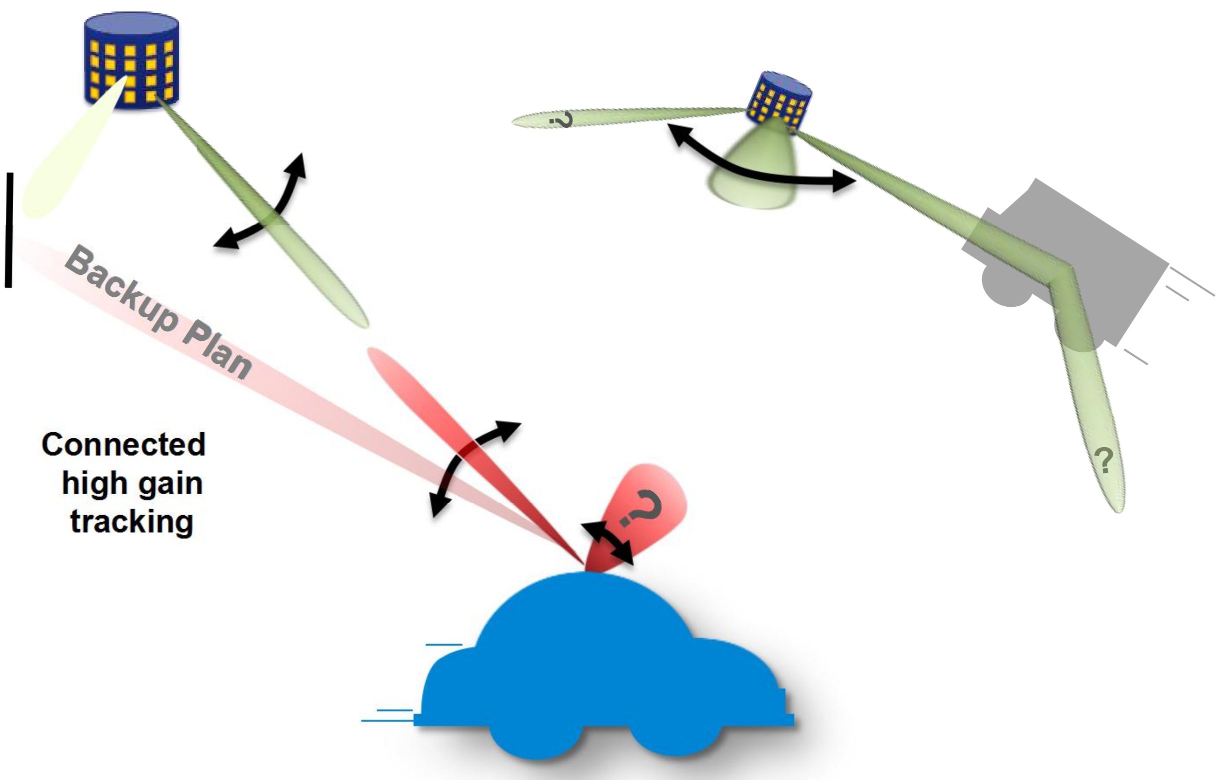
(standard spatial channel models)



- Spatial channel models for each UE and Base station link
- Bi-directional spatial channel emulation for each link
- Multiple UEs
- OTA environment's test zone supports the base station size

Spatial Domain Optimization

Mobility and the Challenge of Directional Antennas



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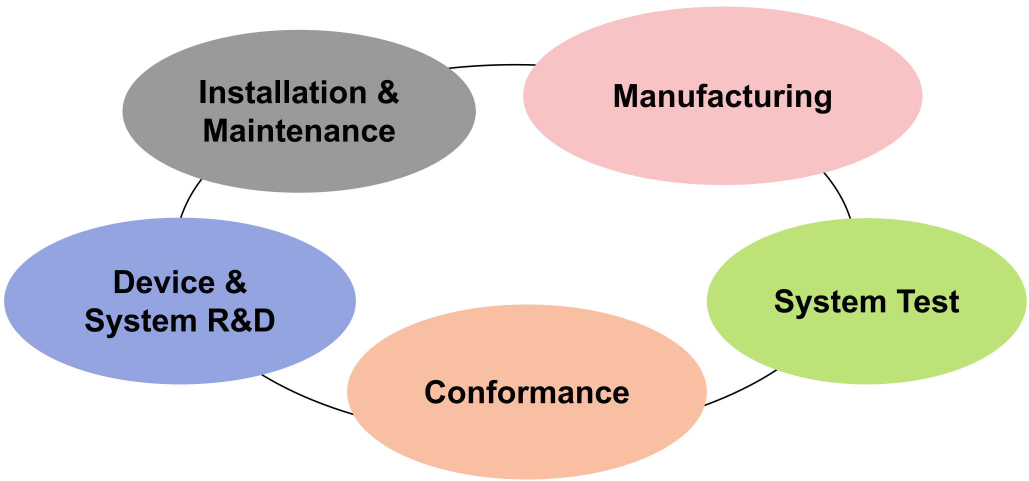
The Test Lifecycle

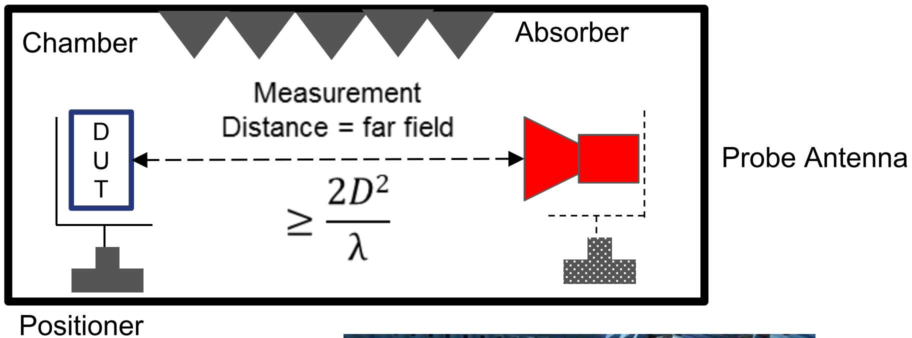
Widely varying test requirements

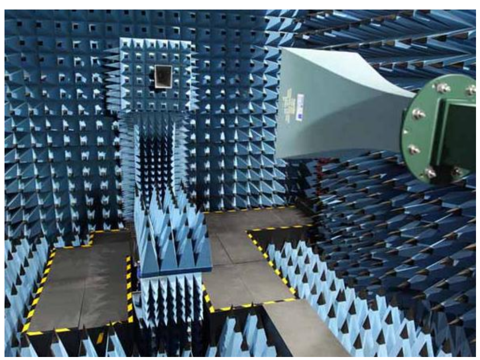


Test needs vary - There is no ‘One-Size-Fits-All’ OTA Test Solution

Far-Field Measurement

Direct Far-Field



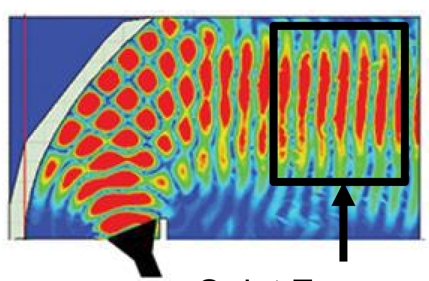


- ✓ ‘Real-world’ DUT environment
- ✓ Antenna Beam pattern characterization
- ✓ EIRP/TRP and EIS measurements
- ✓ Beamforming/Beamsteering Validation
- ✓ RF Parametric Tests (if S/N high enough)
- ✓ Can fit blocking sources
- ✓ Relatively easy to reconfigure
- ✓ Support multi-user spatial channel emulation

- × Can be very large
- × Large chambers can be very expensive (construction/installation)
- × High to very high path loss

Far-Field Measurement

Compact Ranges

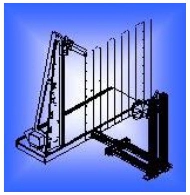


- ✓ Smaller footprint than Far-Field
- ✓ Lower path loss
- ✓ Antenna Beam pattern characterization
- ✓ EIRP/TRP and EIS measurements
- ✓ Beamforming/Beamsteering Validation
- ✓ RF Parametric Tests
- ✓ Reasonable speed of test

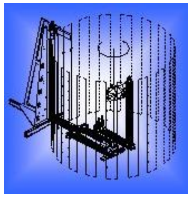
- × Large chambers can be very expensive (construction/installation)
- × Can't fit blocking sources
- × Can't emulate multi-user spatial channel

Near Field Measurement

Scanning Systems



Planar (x-y)
- Good for high-gain antennas
- Relatively fast



Cylindrical
- Good for both high and low gain antennas
- Medium fast

Spherical
- Good for low-gain antennas
- Spherical-spiral (Sphiral) faster

✓ Relatively small

✓ Antenna Beam pattern characterization – CW only

✓ EIRP/TRP and EIS measurements – for AAS at least

✓ RF Parametric Tests

✓ Low path loss

× Antenna measurements require transformation algorithms to Far-Field – currently can only be done for CW

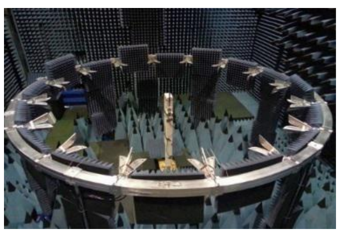
× Can't fit blocking sources

× Can't emulate multi-user spatial channel

Near Field Measurement

Multi-probe Systems

MVG StarLab
- Extended to mmW
- Best suited to UEs



MPAC
- Multiprobe Anechoic Chamber for UE MIMO OTA, <6GHz
- Costly
- Test zone at mmW too small to be practical

GTS Rayzone
- Radiated two-stage system with multiprobe Anechoic Chamber for UE MIMO OTA, <6GHz
- Test zone at mmW too small to be practical

✓ Faster test speed

✓ Antenna Beam pattern characterization – CW only

✓ EIRP/TRP and EIS measurements – for AAS at least

✓ Beamforming/Beamsteering Validation

× Antenna measurements require transformation algorithms to Far-Field – currently can only be done for CW

× Test zone becomes really small at mmW

× Multi-user spatial emulation with nearfield effect

KEYSIGHT TECHNOLOGIES

Manufacturing Test
The Playground for Innovation?

- Cost of Test will need to drop significantly compared with 4G today.

- OTA test in manufacturing demands **<u>Innovative Solutions</u>** (throughput, cost, footprint)

Small

Scalable

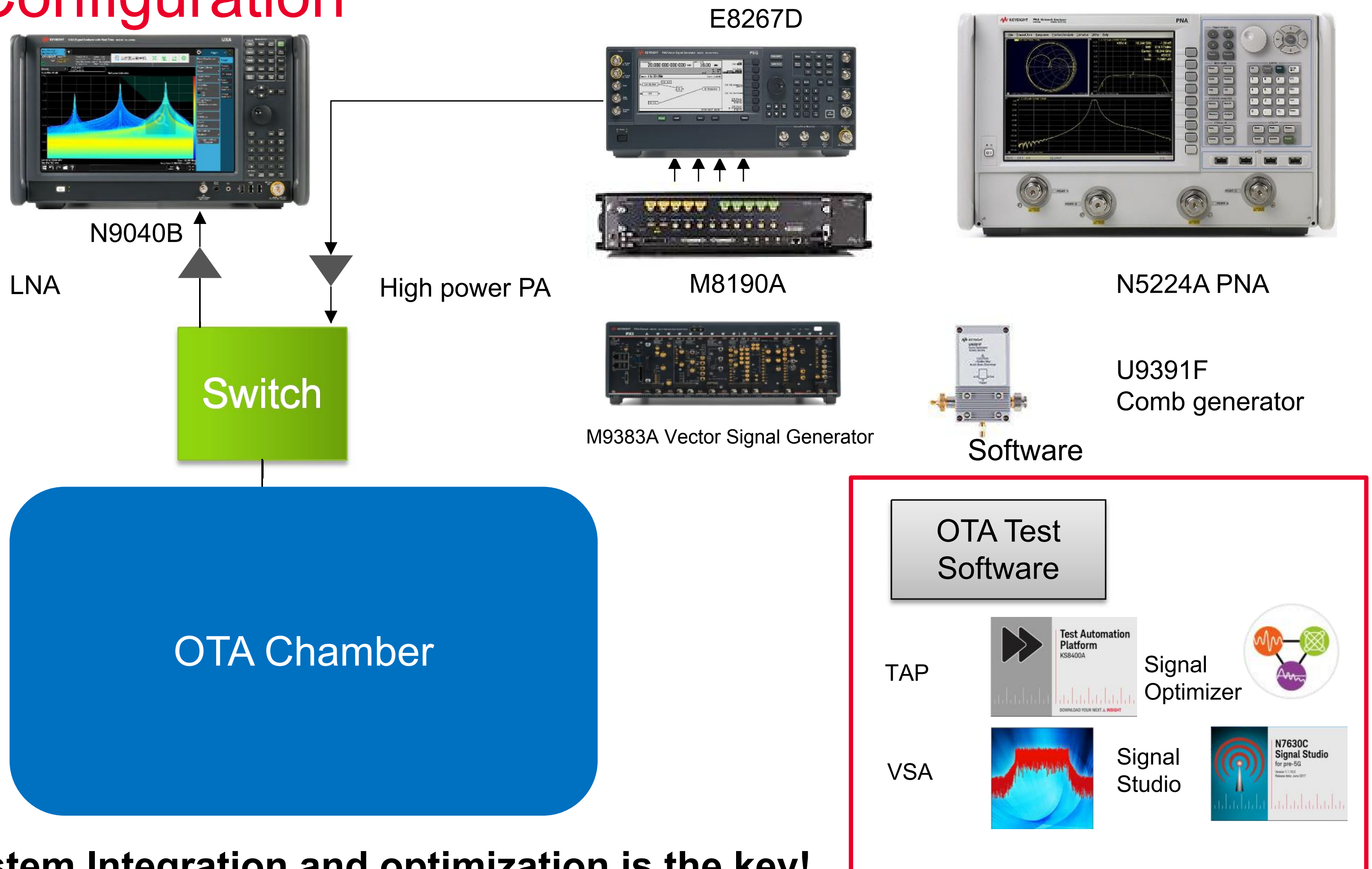
Ultra-fast

Repeatable

Summary of the new OTA Measurement Challenges

- OTA environment selection is one big challenge facing massive MIMO OTA test
- OTA RF parameter measurement results in new challenges not addressed in previous OTA test methods
- Beamforming (high directivity antenna) OTA test brings new challenges not fully addressed in previous OTA test methods
- Massive MIMO multi-user OTA test needs new test method
- Link budget and test speed are important OTA system factors

Massive MIMO RF Performance OTA System Configuration



System Integration and optimization is the key!
AAS measurement and calibration methods are the key!

Summary

- Massive MIMO requires different OTA test solutions
  - RF calibration and performance test
  - Functional test
  - System performance
- The OTA system requirements vary depending on the test need and the lifecycle
- Keysight are working on the different OTA test solutions to address the test needs and challenges
- Come to discuss with us on your OTA test needs and Keysight solution details under Confidential Disclosure Agreement

Questions?

Thank you!