Challenges and Techniques for Characterizing Antenna Systems for 5G

Dr. Taro Eichler
Technology Manager

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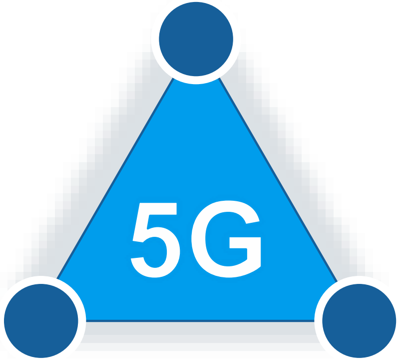
ROHDE&SCHWARZ

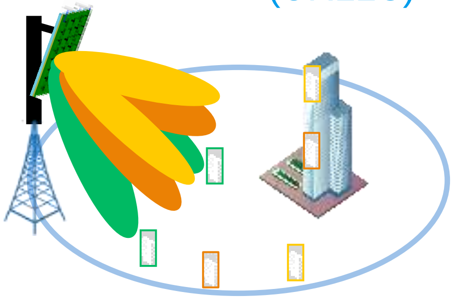
5G use cases and implications

enhanced Mobile Broadband (eMBB)



Ultra reliable & low Latency communication (URLLC)

massive Machine Type Communication (mMTC)



Increased Capacity, Increased OPEX

Capacity (bits/second) — Number of Channels

$$C = W\,N\,\log_2(1+SNR)$$

Signal BW (Hz) — Signal to Noise Ratio *(S/N)*

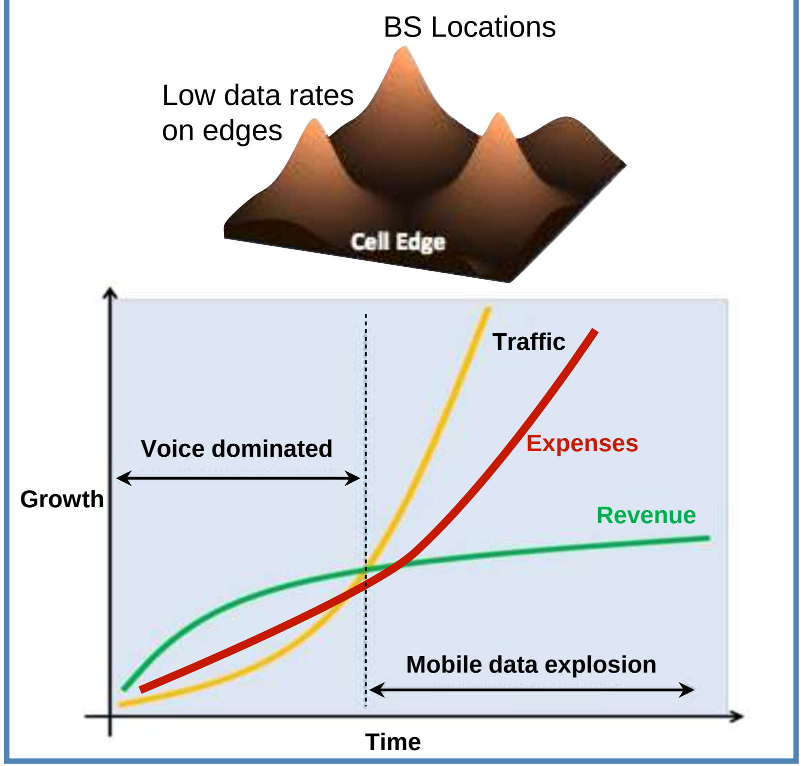
Solutions: mmWave & Massive MIMO

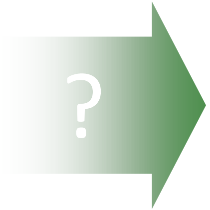
- Use additional frequency bands in **mmWave** spectrum (24 to 110 GHz) for increased **signal bandwidth** up to 2 GHz
- Increase **SNR** of 5G **waveforms** and multiple access
- Implement **Massive MIMO** with multiple **channels** and beamforming to improve SNR

Easiest ways to improve capacity: MIMO and Signal BW

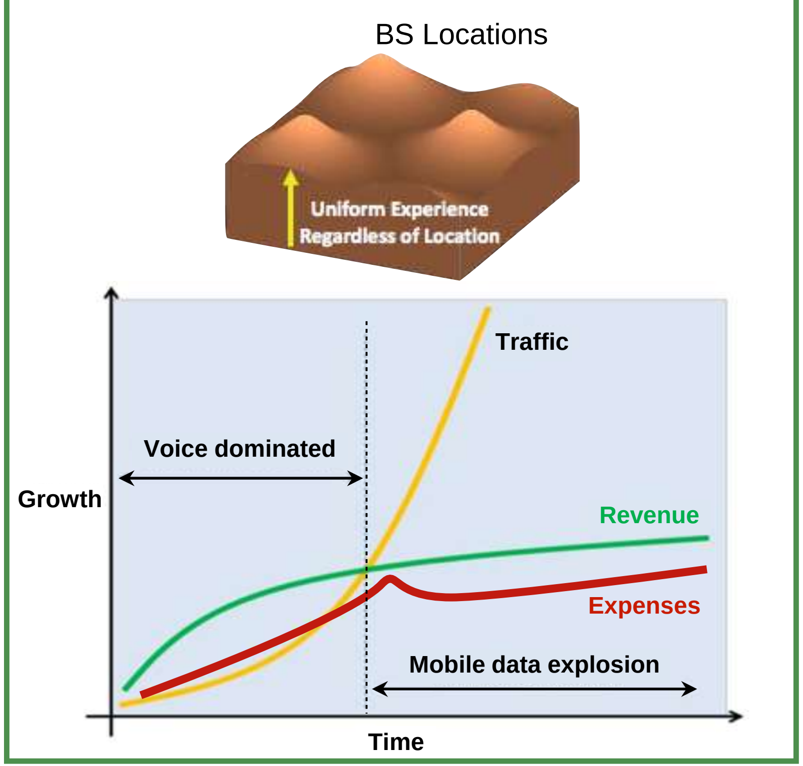
Massive MIMO increases capacity reducing expenses

Increased Capacity, Increased OPEX





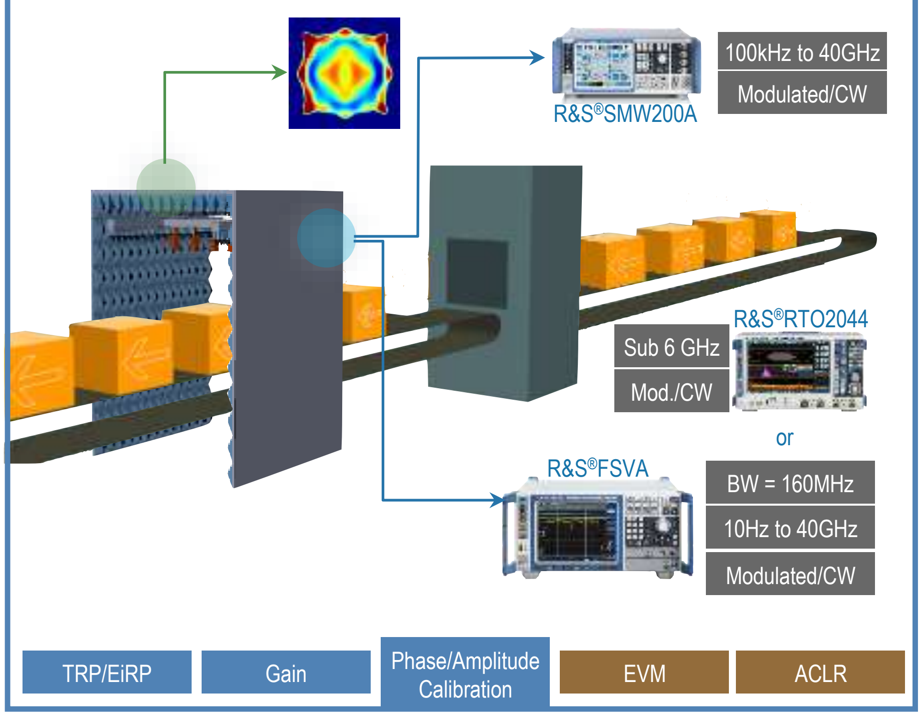
Optimal Network



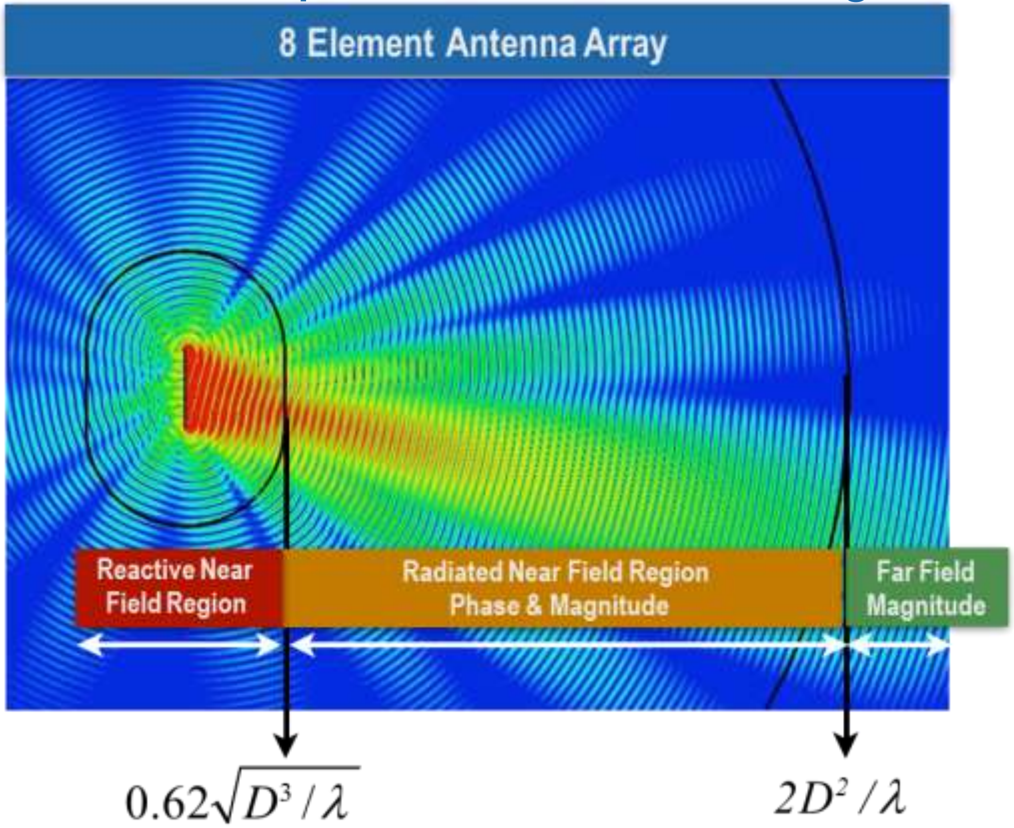
What are the Challenges?

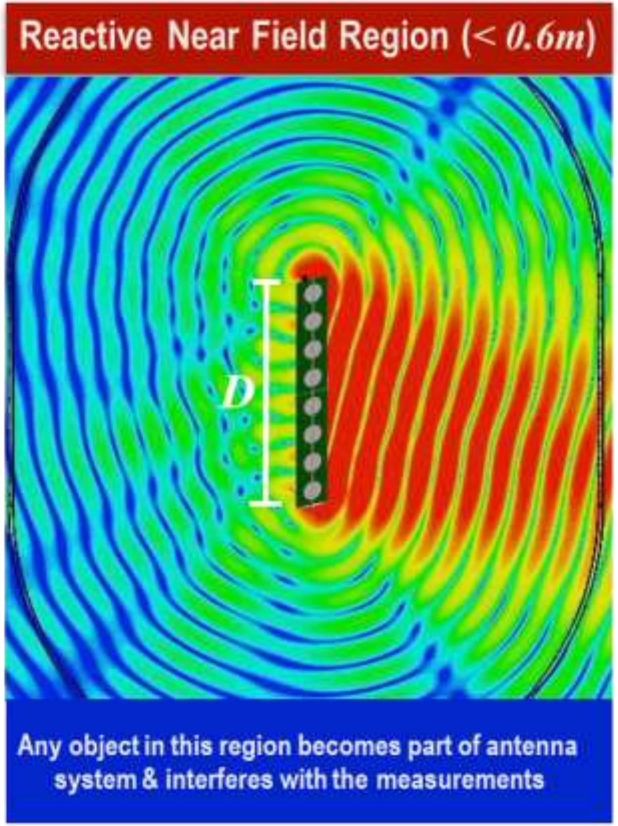
Problem: Measure 5G Massive MIMO Systems	
Challenge	64+ Integrated Transceivers
Challenge	128-256 Integrated Antennas
Challenge	Bi-directional measurements
Challenge	Transceiver & Antenna Performance
Challenge	No test ports
Customer	Speed, low-cost, and compact
Customer	Modulated and CW Waveforms
Customer	Antenna Phase Calibration
How	Cables? Too complex, no DUT access
How	Far-field? Huge chambers, high-cost
How	Near-field? Too slow
How	Something special this way comes….

The Dream: Compact, Fast, & Low-Cost 5G Measurements



Critical Properties of Electromagnetic Fields



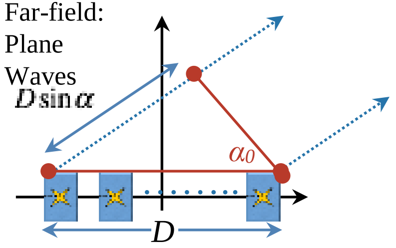


DUT Size vs Far Field Distance

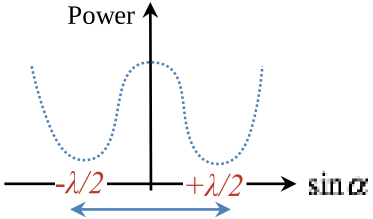
$$R_{FF} = \left(\frac{2D^2}{\lambda} \ or \ \frac{2\lambda}{BW^2}\right)$$

HPBW (radians)
Half-power beam width

DUT Size >>> Wavelength & Antenna Size (Boundary of Current Flow)



Interference Pattern



Null-to-null Beamwidth
$(\alpha_{min}) = 2\alpha_0$

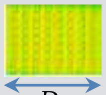
Far Field Distance (R_{FF})

$$\frac{\lambda}{2} = D\sin\alpha_0;\ \sin\alpha_0 = \frac{\lambda}{2D}$$

$$D = \lambda/\alpha_{min}$$

$$R_{FF} = \frac{2D^2}{\lambda} = \frac{2\lambda}{\alpha_{min}^2}$$

28GHz Example (λ = 10.7mm)



DUT

$D = 8.5cm$
$DUT = 50cm$

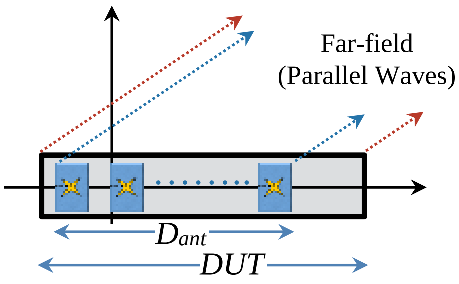
D

$\alpha_0 = 3.6^o \rightarrow \alpha_{min} = 7.2^o$

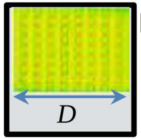
$$R_{DUT} = 46m$$

$$R_{FF} = R_D = \frac{2\lambda}{\alpha_{min}^2} = 1.35\text{m}$$

DUT Size >~ Wavelength or Antenna



2.8GHz Example (λ = 107mm)



DUT

$D = 70cm$
$DUT = 80cm$

D

$\alpha_0 = 3.8^o \rightarrow \alpha_{min} = 7.6^o$

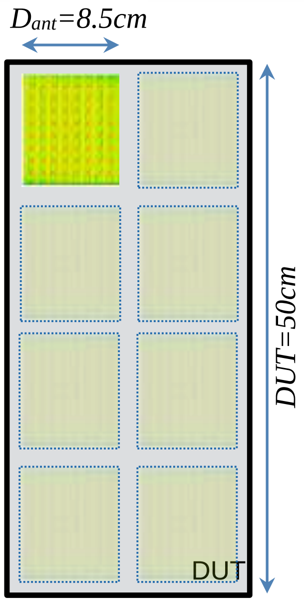
$$R_{FF} = R_{DUT} = \frac{2\lambda}{\alpha_{min}^2} = 11.9\text{m}$$

Chamber Size: Far-field or Near-field?

$$R_{FF} = \left(\frac{2D^2}{\lambda} \ or \ \frac{2\lambda}{BW^2}\right)$$

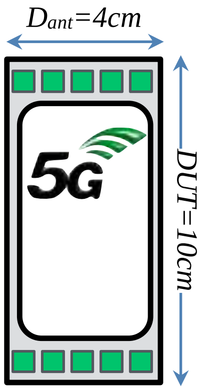
HPBW (radians)
Half-power beam width

Basestations: Subarray Measurements (D_{ant} << DUT)



28GHz Subarray (λ = 10.7mm, HPBW=7.2°)	
Criteria	**Far-field Distance**
$2\lambda/HPBW^2$	**1.35 meters**
28GHz Entire Base-station (HPBW=1.2°)	
$2D^2/\lambda$	**46 meters**

UEs: D_{ant} ~ DUT

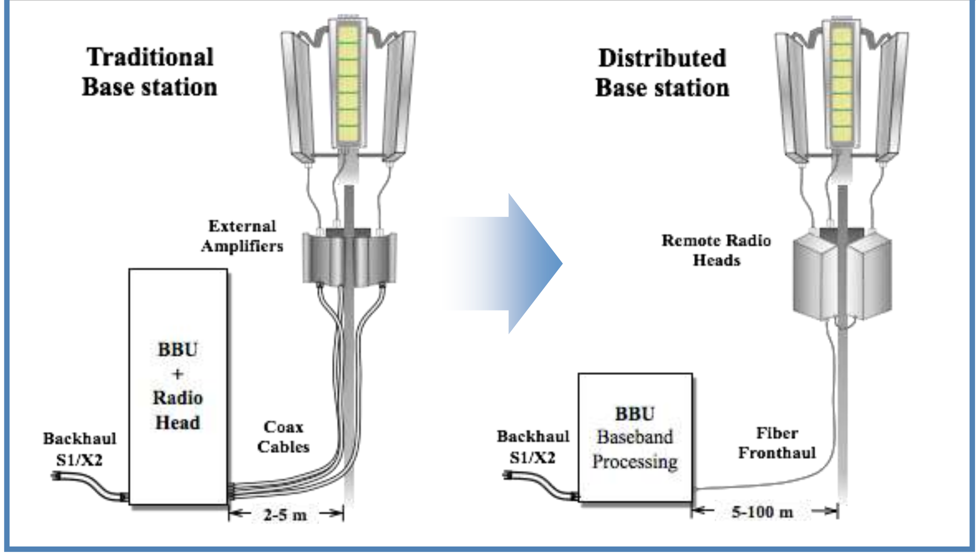


28GHz UE Subarray (HPBW=15°)	
Criteria	**Far-field Distance**
$2\lambda/HPBW^2$	**0.30 meters**
28GHz Entire UE	
$2D^2/\lambda$	**1.86 meters**

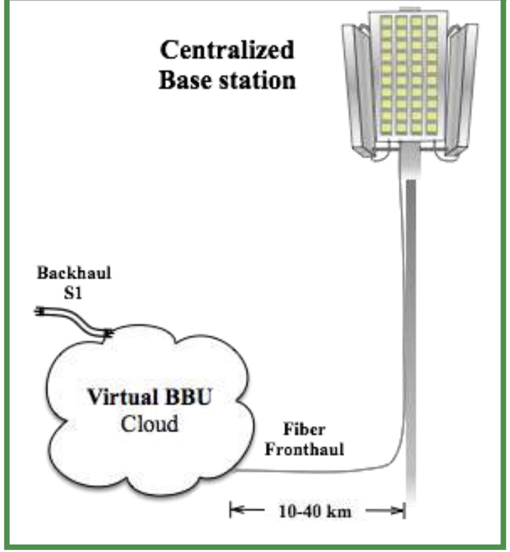
Far-field criteria is met for UE & Base-station Subarrays for R&S Chambers

Cellular Infrastructure Evolution to 5G

Passive Antennas & Separate Radio Transceivers



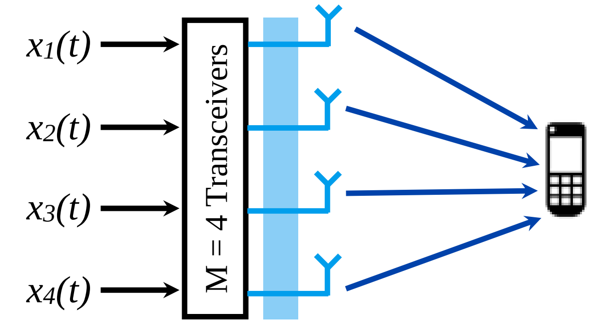
Active Antenna System
Antenna + Integrated TRx



Traditional: 1G & 2G	Distributed: 3G & 4G	Centralized: 4.5G & 5G
0.45 to 1.9 GHz	0.7 to 3.6 GHz	3.4 to 6 GHz & 20-60 GHz
8 dual-polarized antennas	8+ dual-polarized passive antennas	128-512 active antennas
Peak Data Rate: 114 kbps	Peak Data Rate: 150 Mbps	Peak Data Rate: 10 Gbps

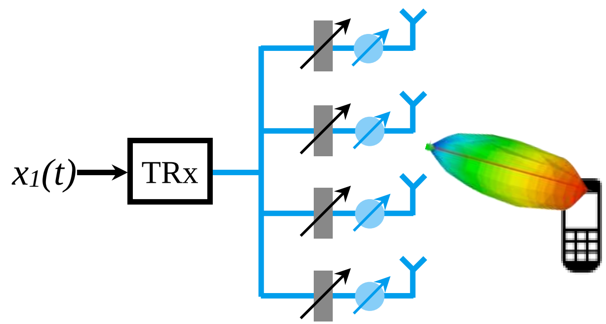
Massive MIMO = Beamforming + MIMO

MIMO Array: *M* Data Streams

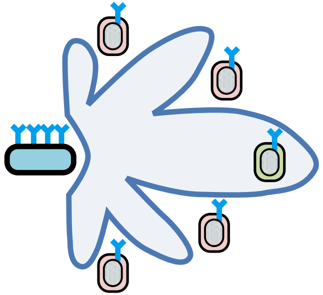


+

Beamforming Array: *1* Data Stream

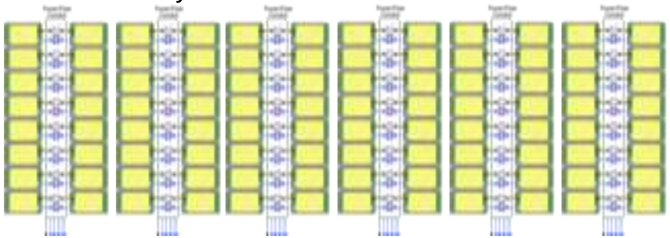


Massive MIMO: Combine Beamforming + MIMO = MU-MIMO with M antennas >> # of UEs

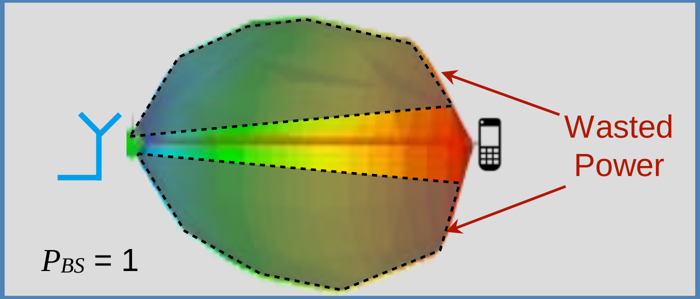


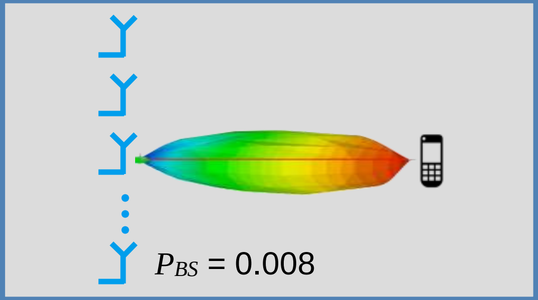
Multi User-MIMO
Increase SINR and capacity for each user
i.e. UE1: 16 ant BF with 16x2 MIMO
UE2: 32 ant BF with 8x2 MIMO

Massive arrays of 128-1024 active antenna elements



More Antennas: easiest way to improve energy efficiency





Number of Antennas = 1	
Number of BS Transmit Antennas	1
Normalized Output Power of Antennas	$P_{ant} = \frac{1}{M_t} = 1$
Normalized Output Power of Base Station	$P_{total} = \sum_{i=1}^{M_t} P_{ant}^{i} = 1$

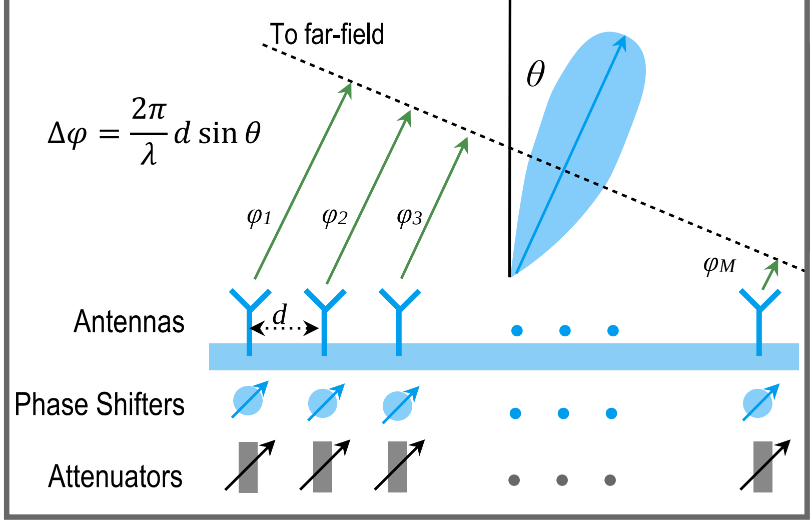
Number of UEs: 1 120 antennas per UE
120
$P_{ant} = \frac{1}{M_t^{2}}$
$P_{total} = \sum_{i=1}^{M_t} P_{ant}^{i} = 0.008$

Source: IEEE Signal Processing Magazine, Jan 2013

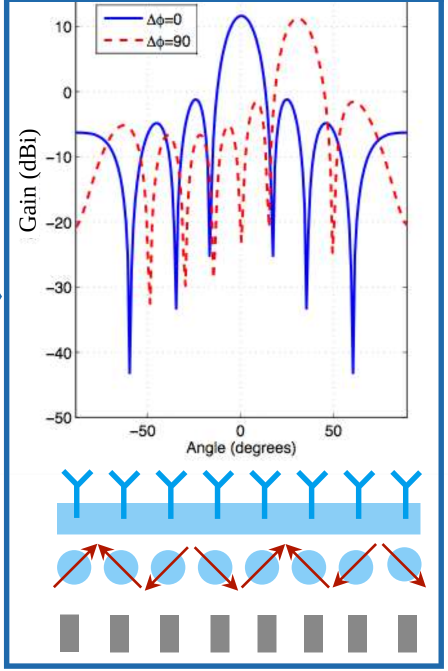
How to Steer Beams? 8 Element Dipole Array Example

Principle of Beamforming & Beamsteering

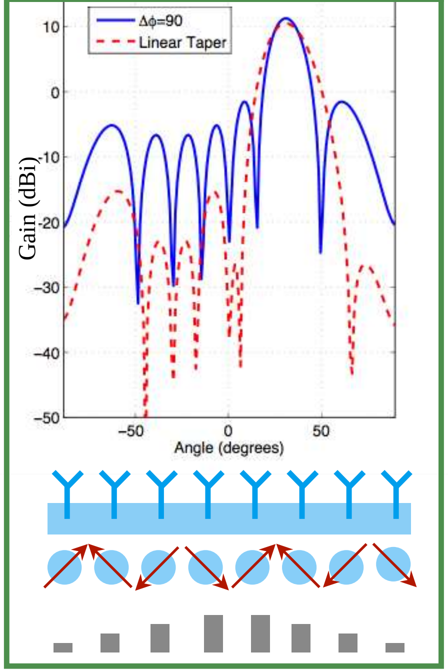
1. Fixed antenna spacing *d*
2. Choose direction *θ*
3. Set phase shifts *Δφ*



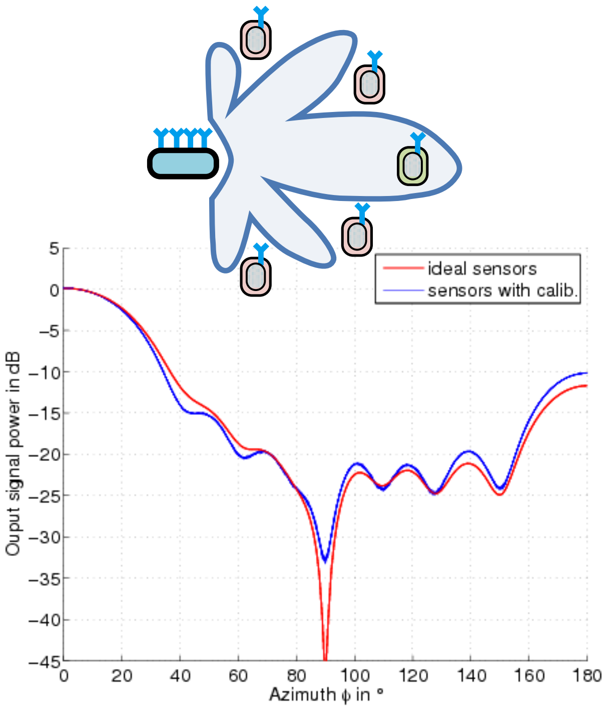
Beamsteering (Phase Shift)



Sidelobe Suppression



The "Real" Challenge with Phase: Tolerances

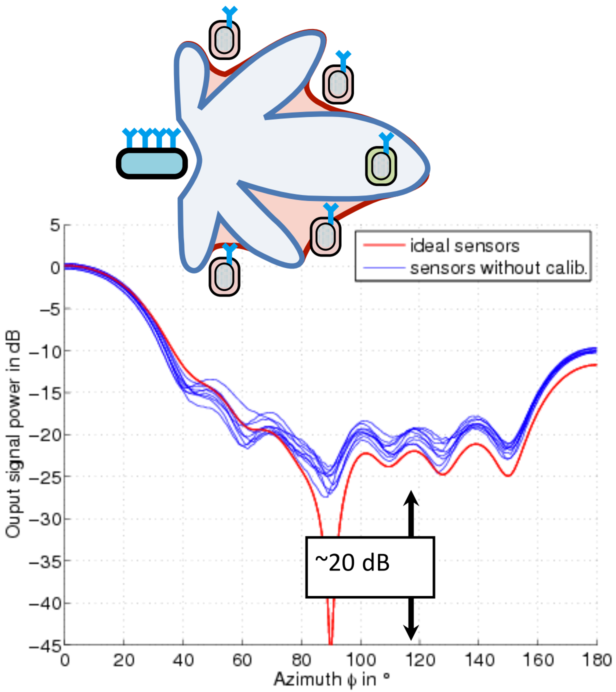


Comparison between ideal and calibrated

MU-MIMO

Multiple beams place nulls at other UEs:
Null-steering

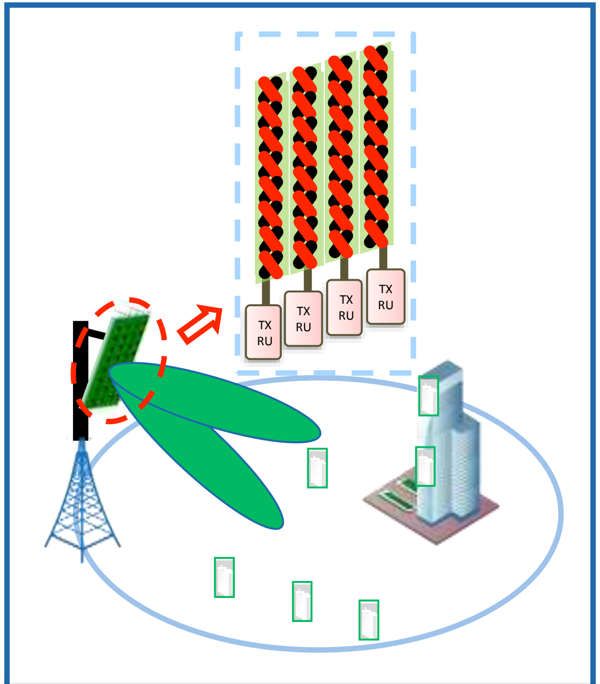
Require adaptive self-calibration in operation



Gerhard Doblinger, June 2010, Vienna University of Technology, Austria

Comparison between ideal and non-calibrated

2D vs 3D-MIMO: 1-axis vs 2-axis Beamsteering

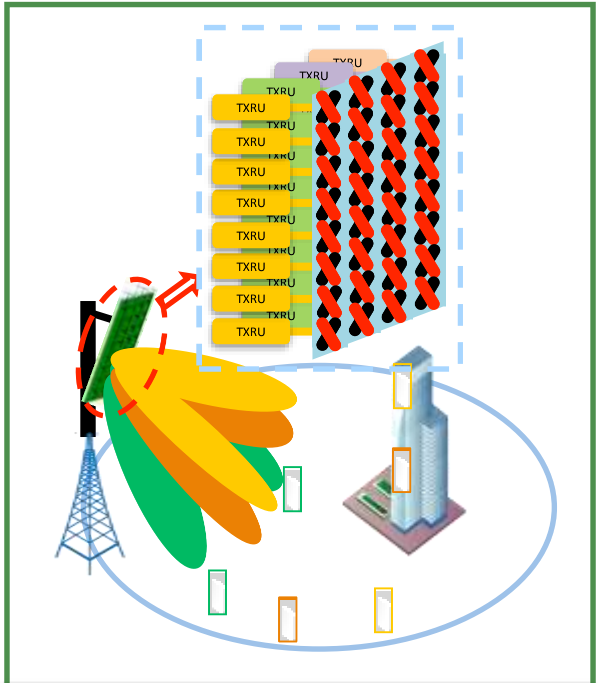


2D-MIMO: Switched Beams

Beam Power more focused

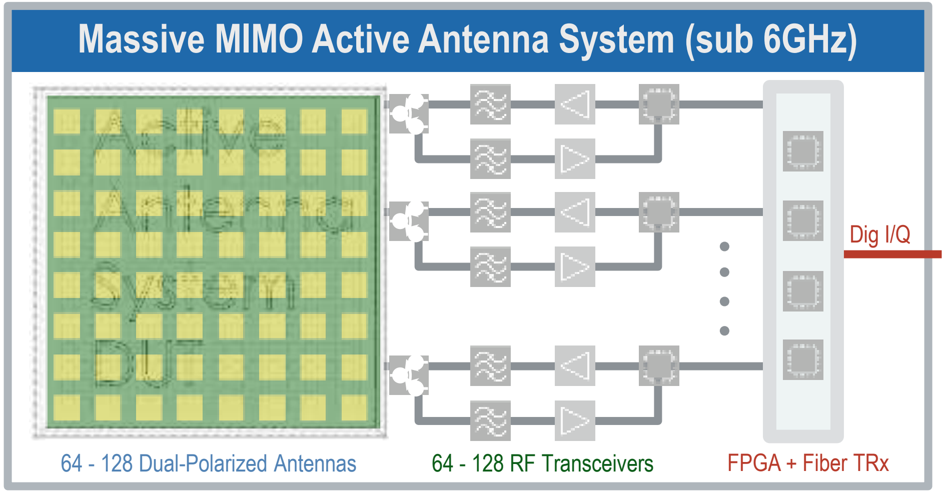
Beam Direction more accurate

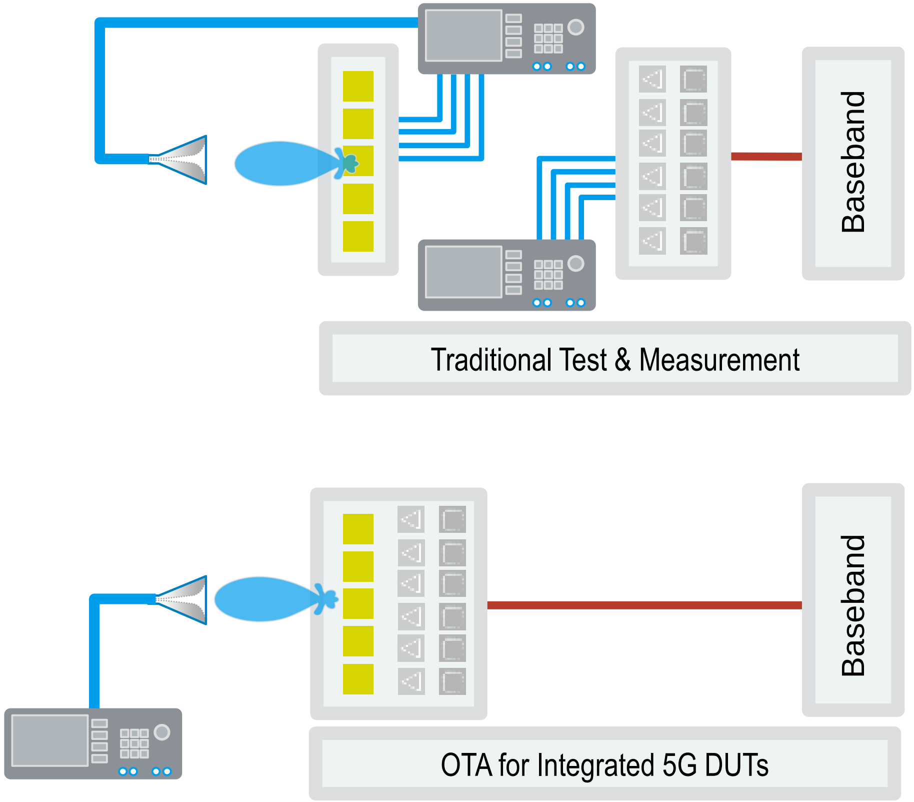
MU-MIMO required



3D-MIMO or FD-MIMO

Active Antennas Systems

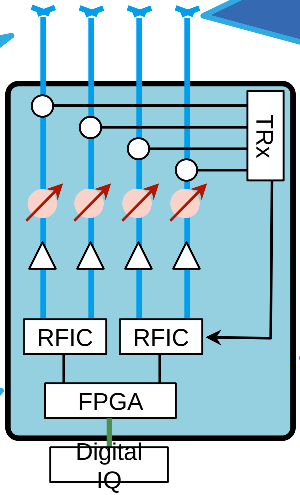


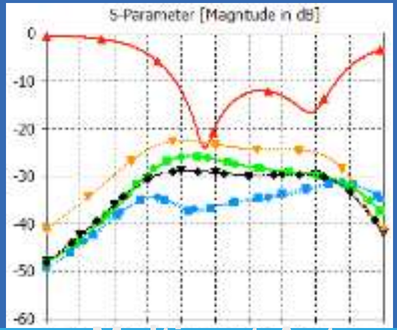


Measuring 5G mmWave & Massive MIMO Systems



OTA Gain, EiS, EiRP





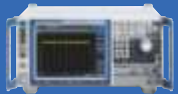
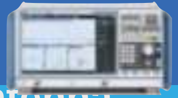
Measure mutual coupling S-Parameters

Multiport Antenna Array Measurements



Element/System OTA EVM, ACLR



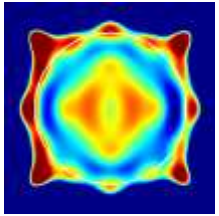
Production TRx & Antenna Calibration

5G OTA Measurement Systems

Far field Measurement (Magnitude)

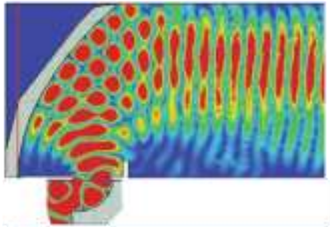
Far field Chamber

NEW



Near field Chamber

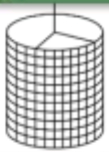
Compact Range



Near Field Measurement (Phase + Magnitude)

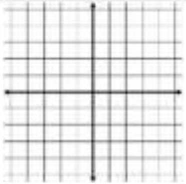
Surface Scan

- Arbitrary
- Cylindrical



- Spherical/Spiral

- Planar
  - Rectangular

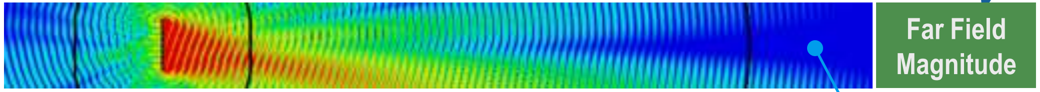


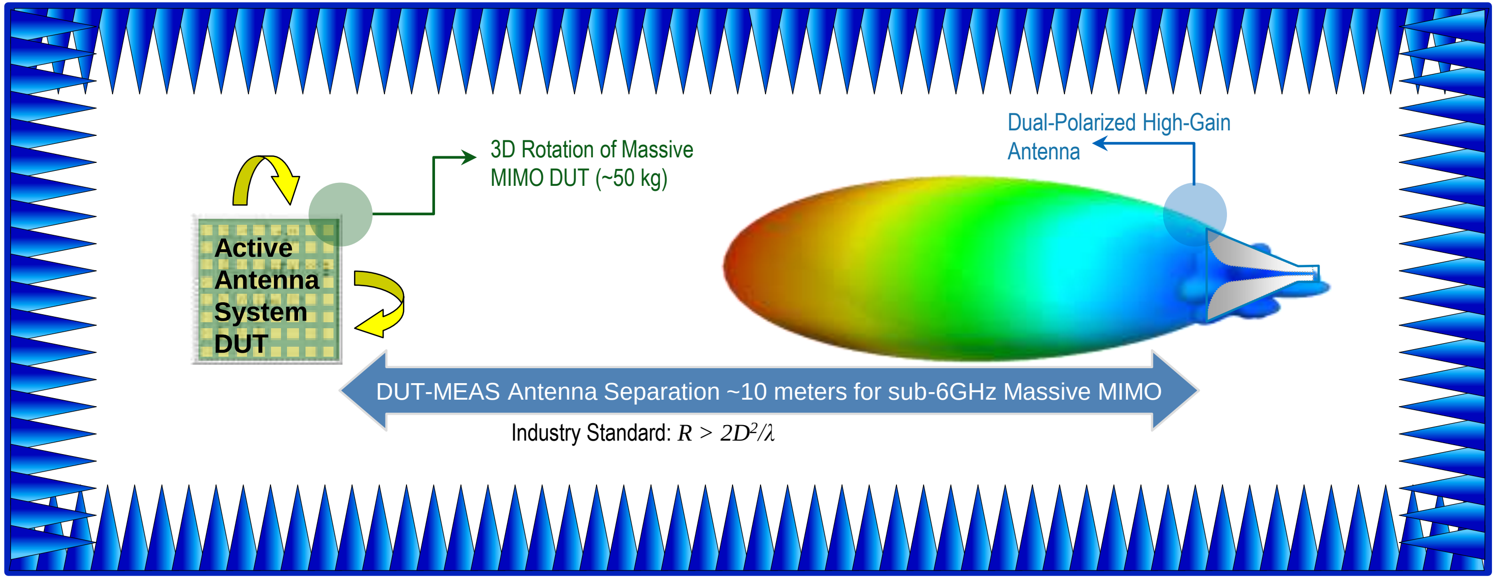
  - Bi-Polar

Chamber Type	Range Length
Far Field	$> D^2/\lambda$
MPAC	$> D^2/\lambda$
Near Field	$< D^2/\lambda$
CATR	2D to 4D
Ideal	closer

Chamber Type	Measurement Time (EVM)
Far Field	1 second
Near Field	10-15 minutes
CATR	1 second
Ideal	1 second

Massive MIMO: Far-Field Measurement System

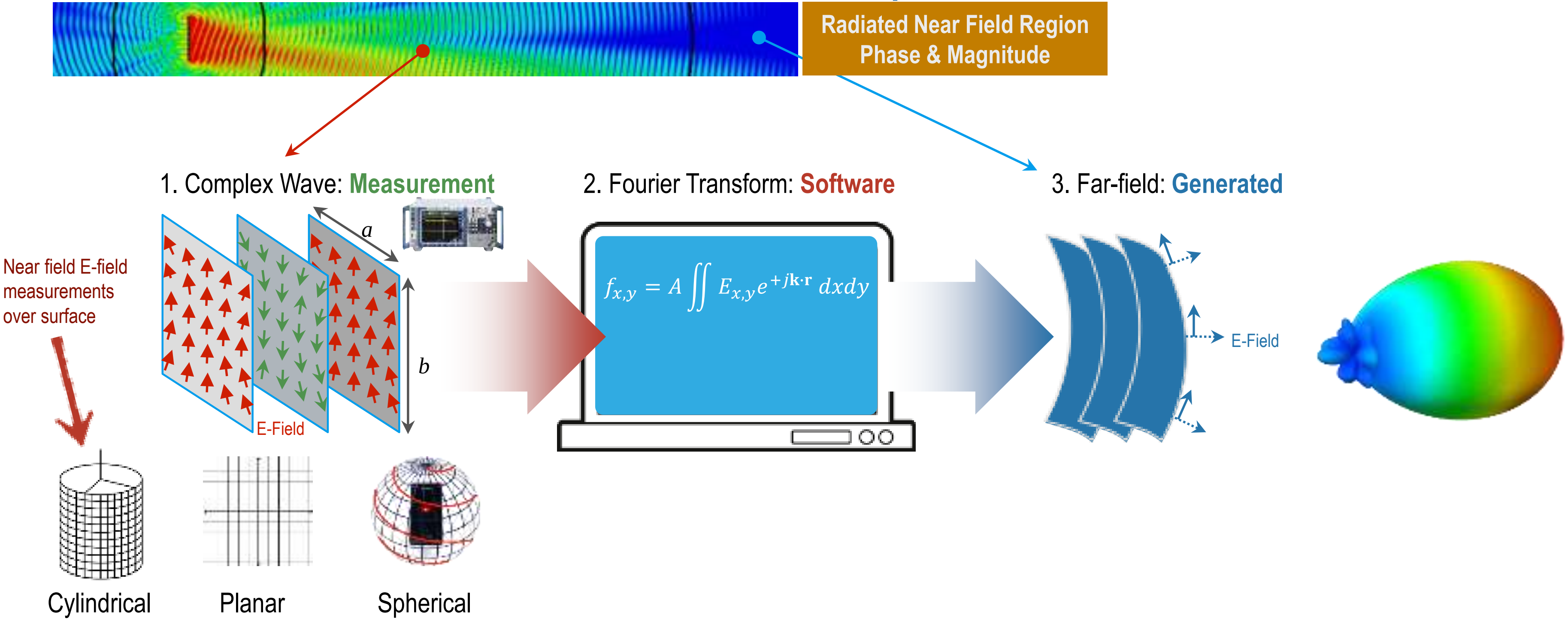




Passive Measurements

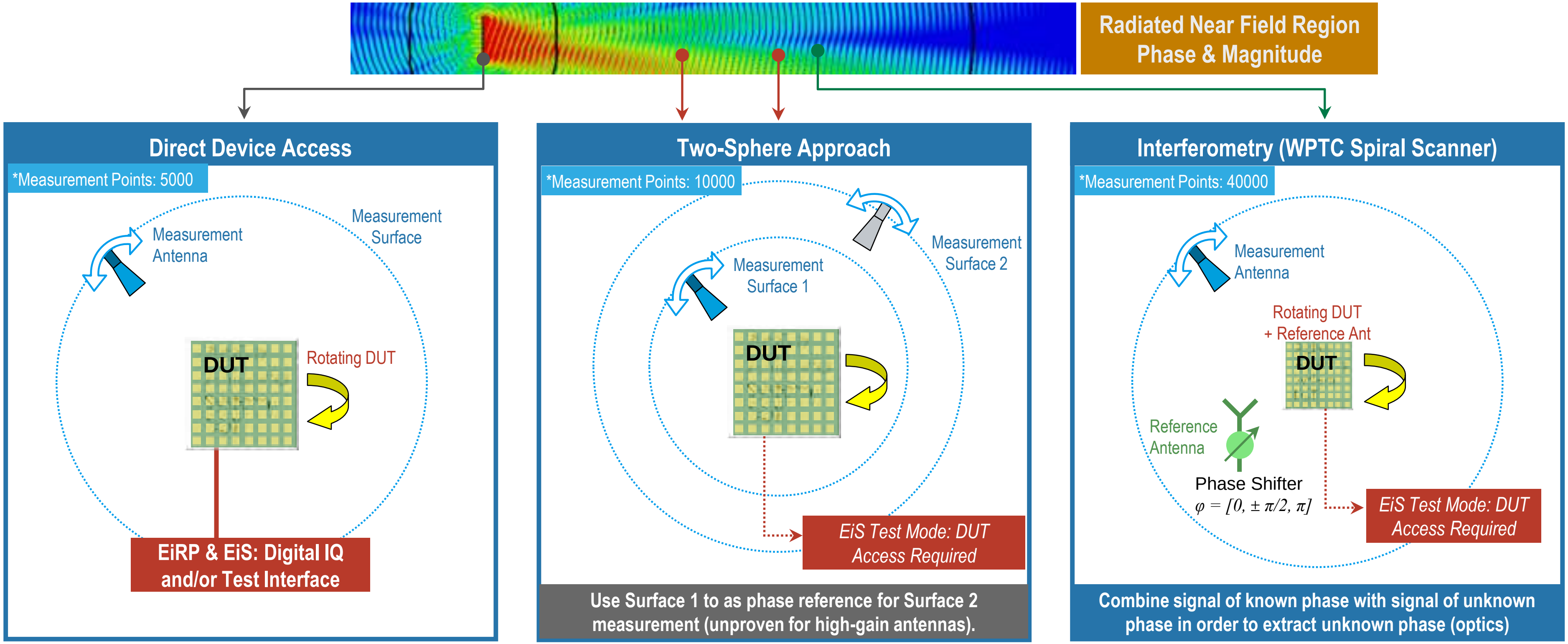
Active Measurements

Near Field to Far Field Transform Steps



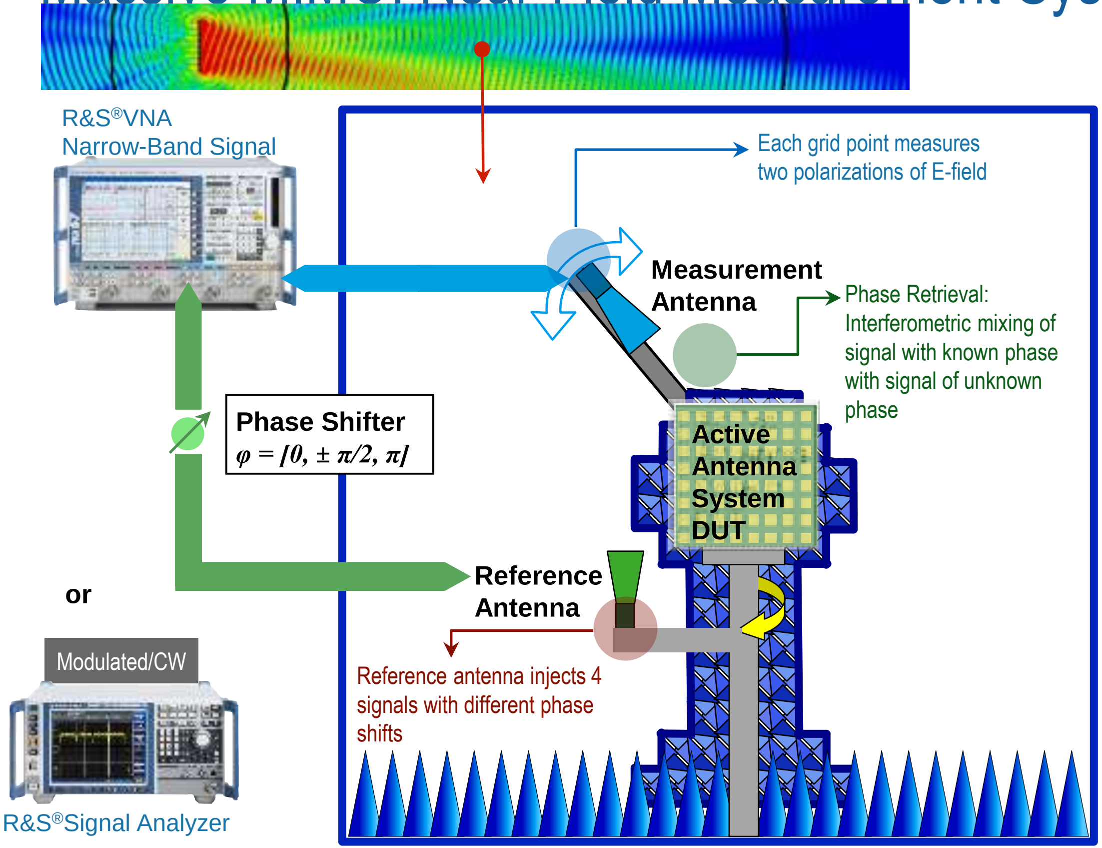
How to measure the phase for Massive MIMO DUT with no test ports?

Near-field Systems: Phase Retrieval



*Measurement Points: Assume 5° spacing in φ and θ

Massive MIMO: Near-Field Measurement System

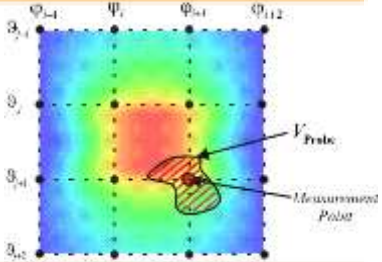


4 phase measurements per grid point
1000's of points
+
NF2FF transformation
2 minutes per frequency

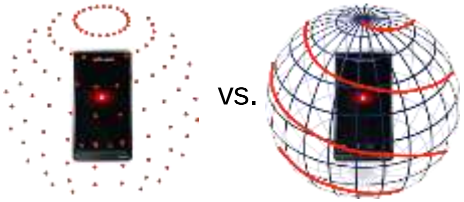
Near-field to Far-field Transformation – FIAFTA

Features

Equivalent Sources



Probe Compensation

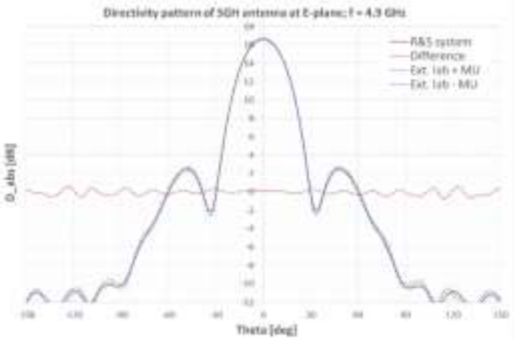


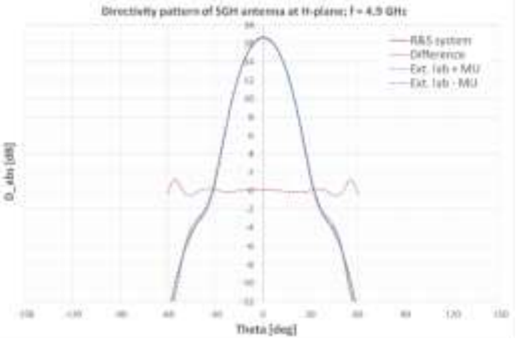
220 minutes

6 minutes

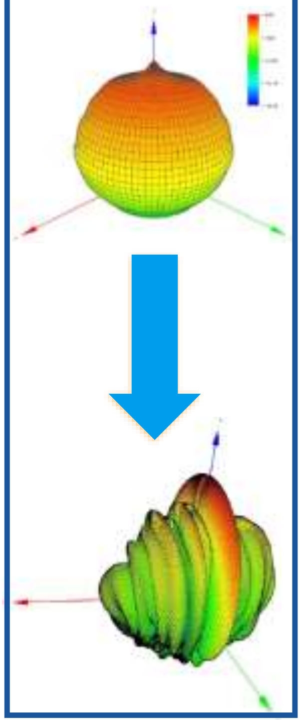
Arbitrary Grids

Performance Comparison



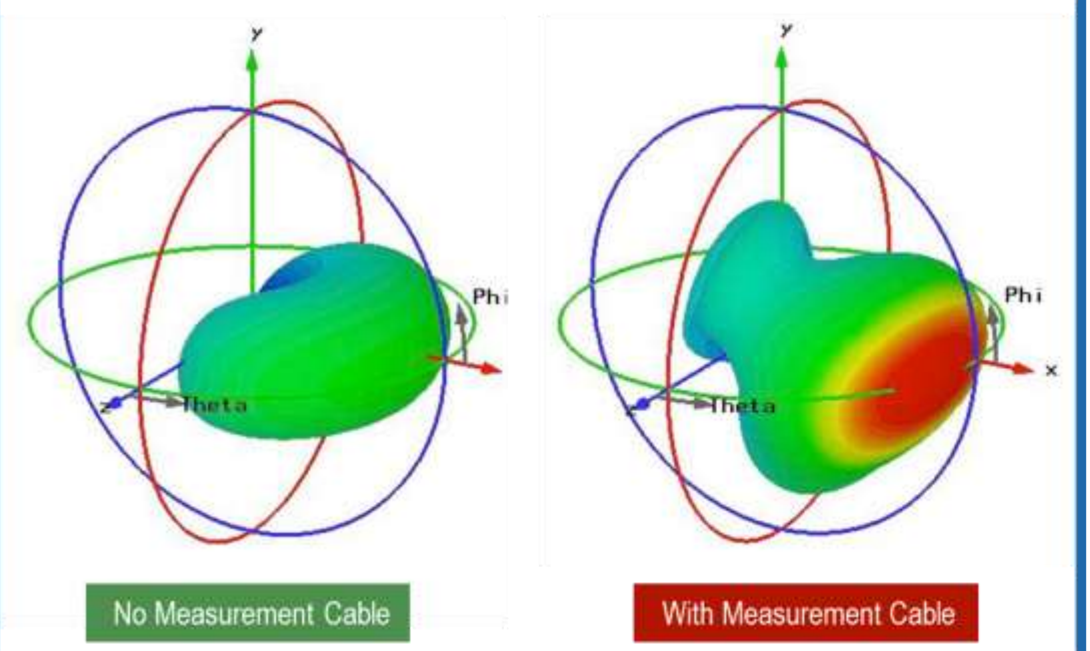


Transformation

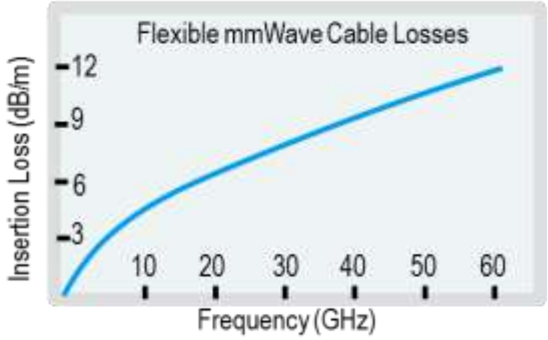


It's all about the cables in 5G mmWave Systems

3D Gain Patterns of mmWave UE antenna

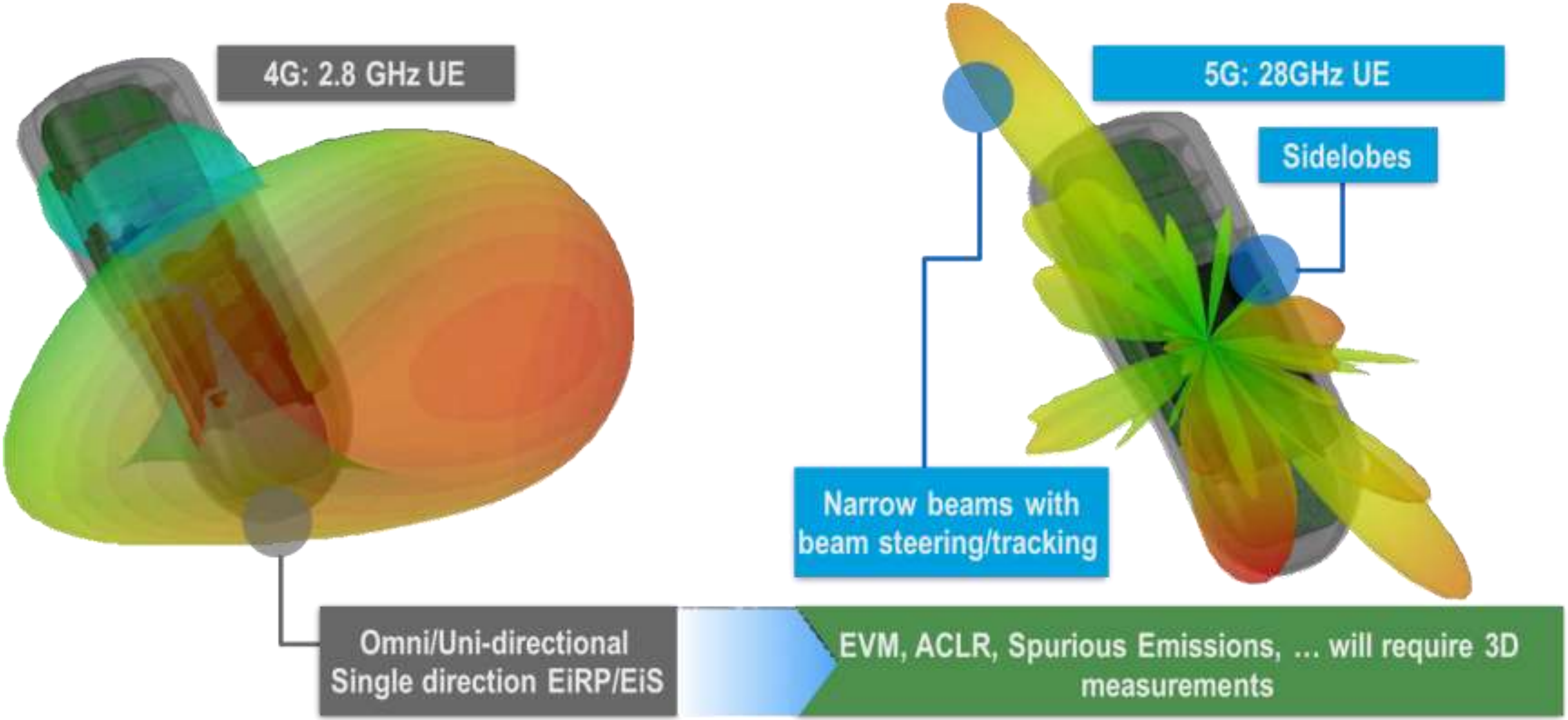


Antenna couples to all surrounding objects
Conductive measurements introduce large error



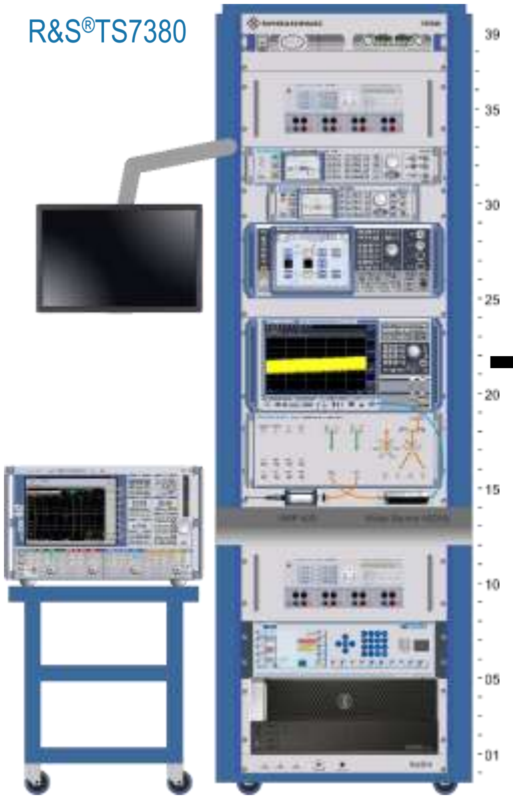
High Precision & Low-loss cable
70 GHz: > $1000 USD/meter

How to measure EiRP for mmWave UEs?



Step 1: Replace mmWave cable from DUT with OTA

R&S®TS7380



Dual-Pol Antenna

R&S®ATS1000

Radiated Tests (previously done conducted)

Optimized system design with dedicated signal conditioning HW

Design and level analysis for each test

Verified performance based on test experience

System calibration routine for high accuracy

Special: Antenna Tests with ATS1000

EiRP/TRP/Gain Pattern (2D/3D)

Special: Radiated Phase Calibration

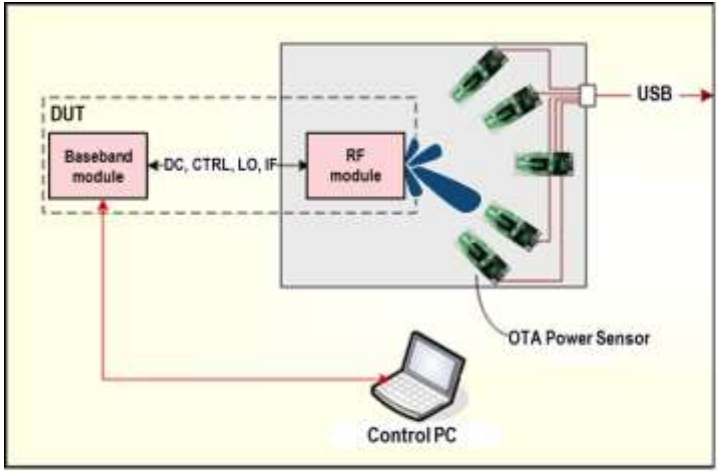
R&S algorithm with phase demodulation by Signal Analyzer FSW allows accurate phase measurements between antennas

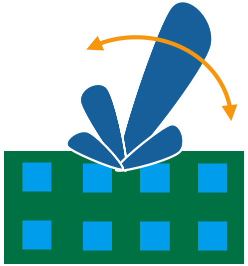
RF Test	Radiated and conducted
Rx	**Pout** **Gain** **RSB** **P1dB** **Flatness** **Noise figure** **IP3** **EVM**
Tx	**Pout** **Emissions** **Carrier Suppression** **RSB** **Flatness** **ACLR** **EVM** **EIRP** **TRP / antenna pattern** **Phase Shifter accuracy**
...	...

Antenna Array Beamsteering
Magnitude Only

mmWave DUTs will not have antenna connectors

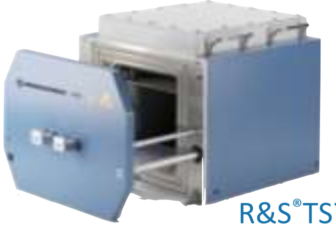
OTA Measurements will be mandatory for production





RF antenna array

Measurement Equipment



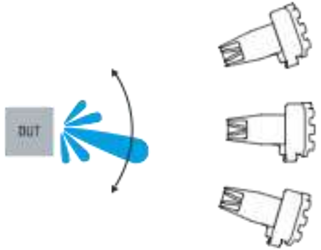
R&S®TS7124

Shielded chamber (TS7124)

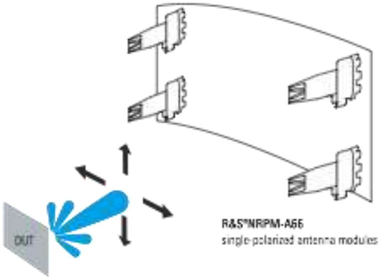
R&S®NRPM

Vivaldi Probe 28-77 GHz

Measurement Scenarios

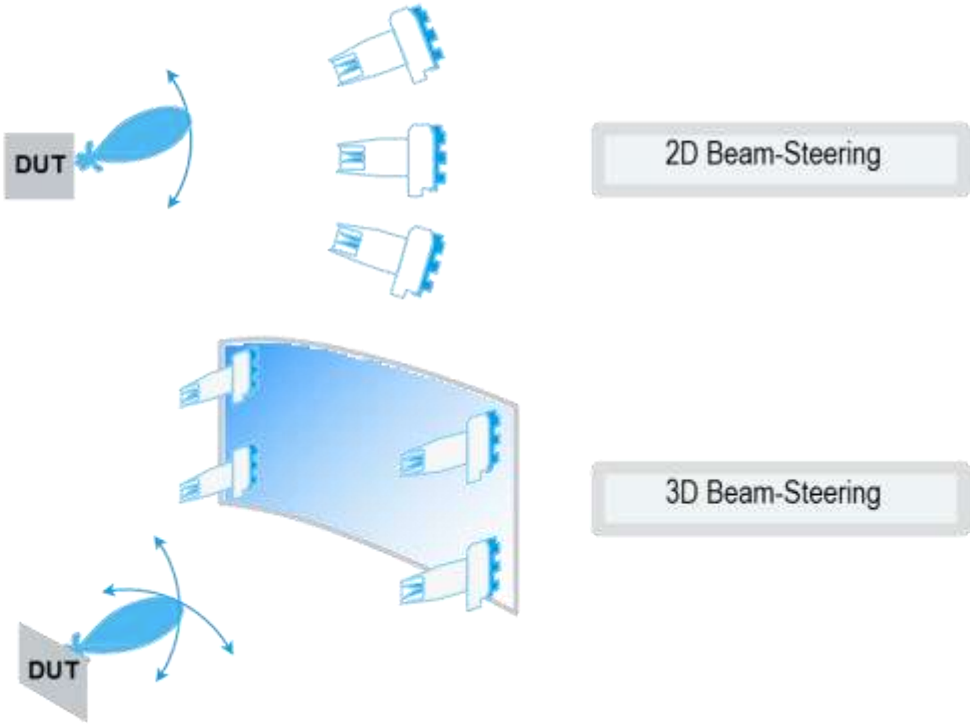


2D Beam-Steering

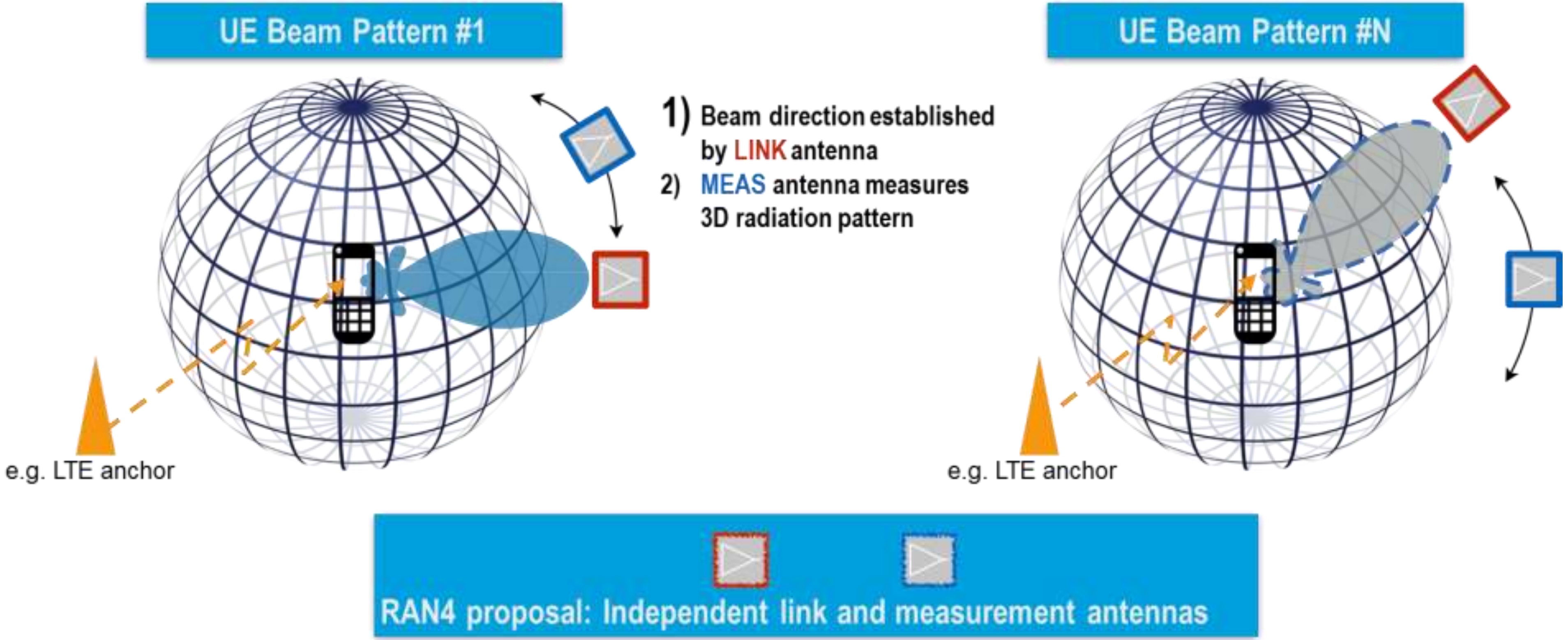


3D Beam-Steering

Step 2: Remove all mmWave cables in OTA

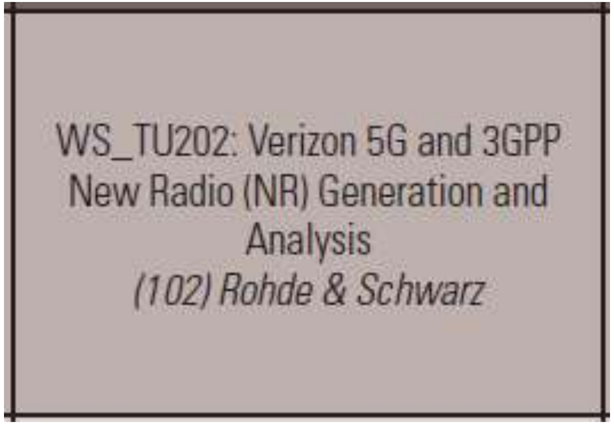


3D Measurements at 5G mmWave: 28 GHz



Signal generation and analysis benchmark performance

- When using the test instruments to measure the EVM of such a 5G signal at 28 GHz, measurement results are below 1 % across a 10 dB power sweep.



[Rohde & Schwarz supports 5G signal generation and analysis based on Verizon 5G open trial specifications]

R&S 5G OTA Product Matrix

Far-field speed
+
Near-field
Size

	CTIA OTA: TS8991/WPTC	OTA R&D: WPTC Spiral Scanner	OTA R&D and Production: ATS1000	OTA R&D: DST 200	OTA Production: NRPM OTA Power Sensors	*Coming soon in 2018 for Massive MIMO Production*
	0.4 to 18 GHz	0.4 to 40 GHz	0.4 to 90 GHz	0.4 to 40 GHz	28-75 GHz	Far-field speed + Near-field Size EVM, EiS, EiRP, Gain, Antenna calibration, …
	250x250x220 cm	250x250x220 cm	85x100x180 cm	77x76x70 cm	45x40x48 cm	
	Near & Far	Near & Far	Near & Far	Far Field (UEs)	Near & Far	
	Modulated/CW	Modulated/CW	Modulated/CW	Modulated/CW	Modulated/CW	
	EiRP, EiS, Gain, EVM, …	EiRP, EiS, Gain, EVM, …	EiRP, EiS, Gain, EVM, …	EiRP, EiS, Gain, EVM, …	EiRP at single points	
Availability	Available for purchase	Available for purchase	Available for purchase in Q3 2017	Available for Purchase	Available for Purchase	

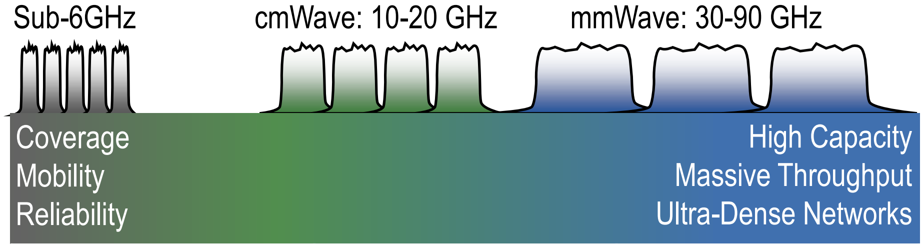
5G channel modeling and measurements

ROHDE&SCHWARZ

Why mm-Waves for 5G ?

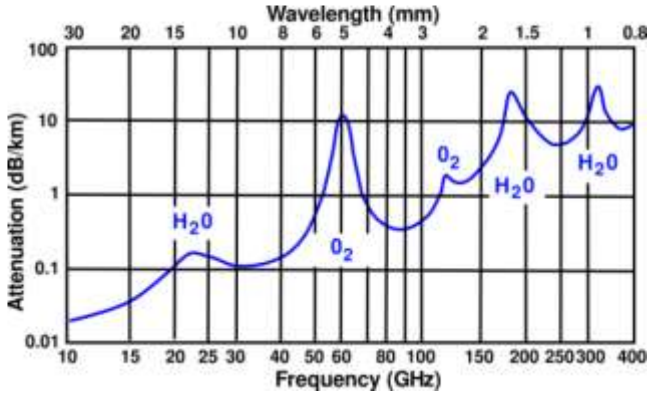
Conclusion WRC-15 on 5G frequency candidates

- Considered frequency ranges and bands for 5G at cm- and mm-Waves:
  - 24.25 to 27.5 GHz
  - 31.8 to 33.4 GHz
  - 37.0 to 43.5 GHz
  - 45.4 to 50.2 GHz
  - 50.4 to 52.6 GHz
  - 66 to 76 GHz
  - 81 to 86 GHz.



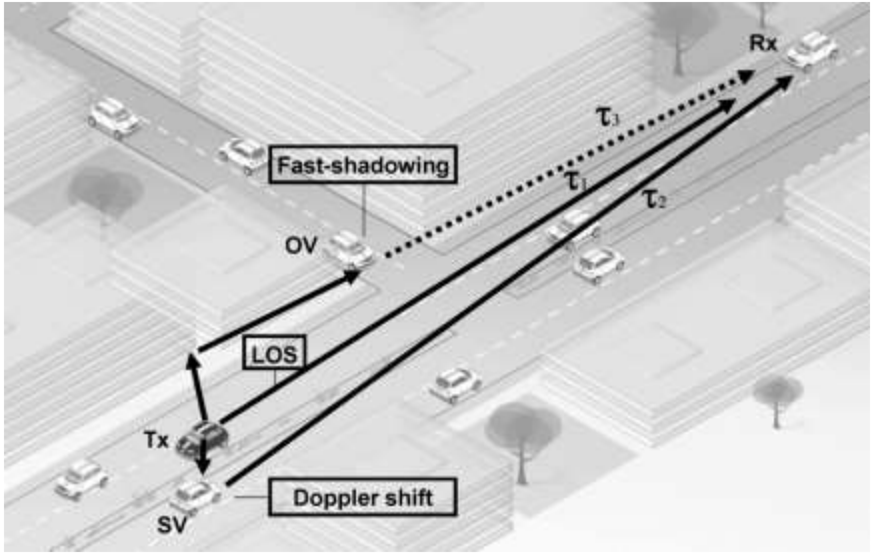
Carrier BW	*n* x 20 MHz	*n* x 100 MHz	1-2 GHz
Cell Size	Macro	Small	Ultra-small
Waveform	Multi-Carrier (OFDM)	Multi-Carrier (OFDM)	Multi-Crrier? Single Carrier?

- 27.5 to 29.5 GHz band is not listed, but is still expected to play an important role for anticipated 5G deployments.



Total available bandwidth for mm-waves: **30 GHz**

Theoretical review: multipath propagation



Channel impulse response CIR is a theoretical measure to describe the wave propagation: Idea is to excite the channel with a Dirac impulse and to measure the arrivals of that impulse at the receiver. Due to multipath each pulse response is attenuated, delayed and phase shifted.

$$h(\tau,t)=\sum_{i=0}^{L-1} a_i(t)\, e^{j\phi_i(t)}\, \delta(\tau-\tau_i)$$

path attenuation | path phase | path delay

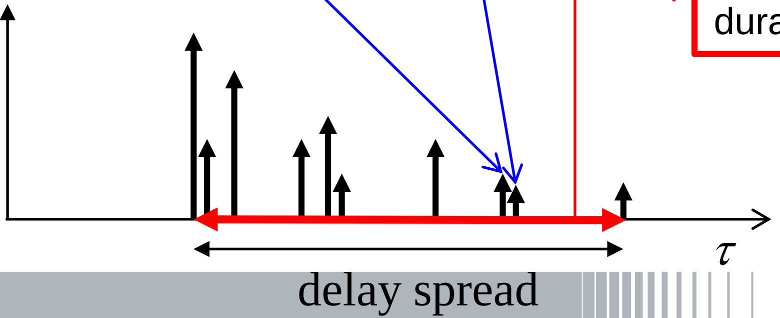
Separability of MPC

τ_{RES}

Identify each MPC.

$$\tau_{RES} \approx \frac{1}{B}$$

Minimum measurement duration

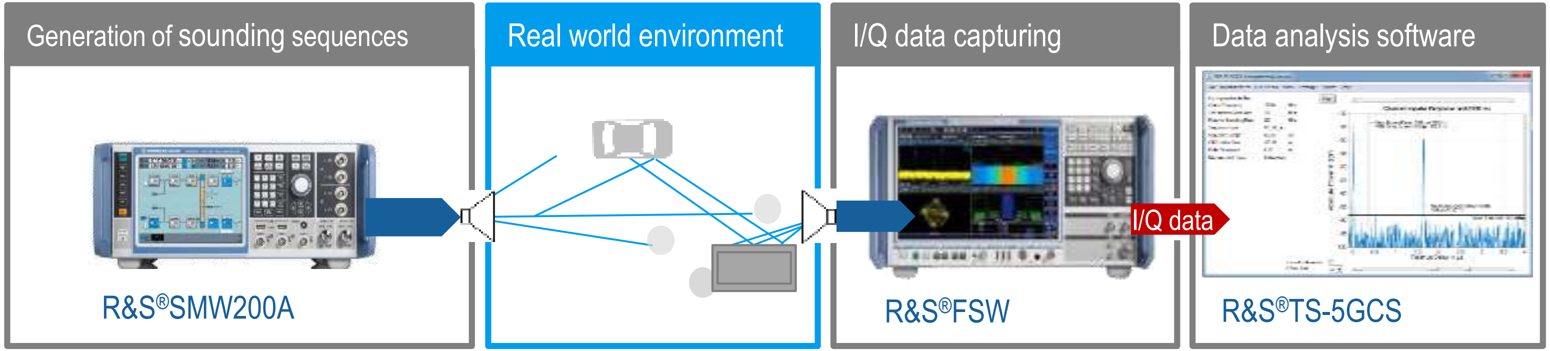


Setup for Channel Propagation Measurements

Channel Impulse Response in the time domain

Channel Sounding Solution

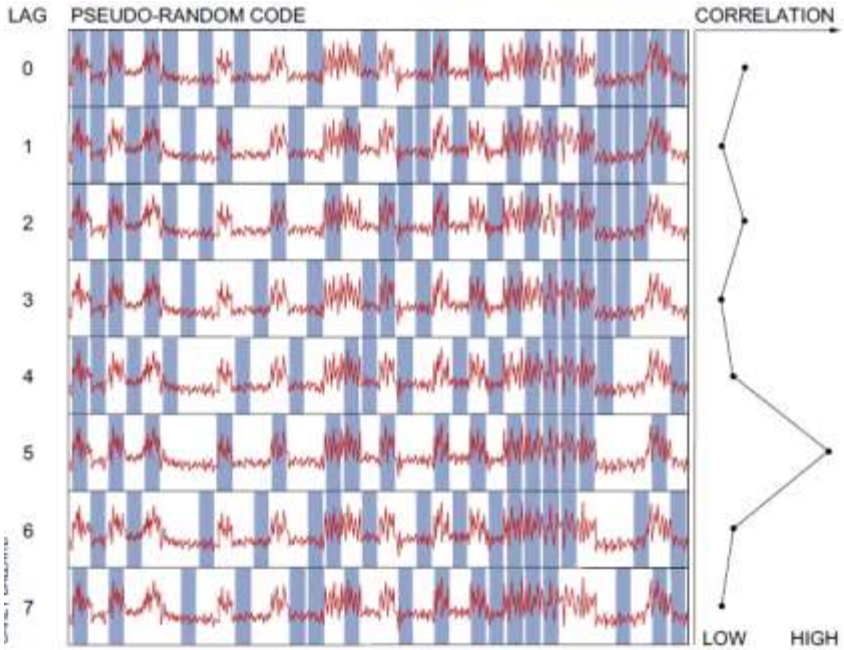
Channel sounding is a process that allows a radio channel to be characterized by decomposing the radio propagation path into its individual multipath components.

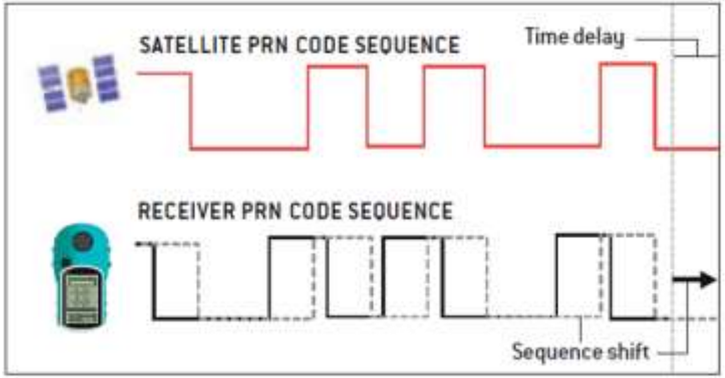


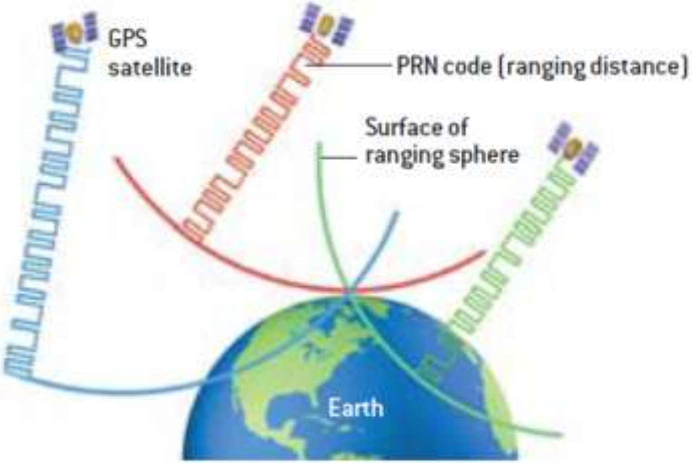
- fast measurement in time domain
- support for in- and outdoor sounding
- very high dynamic range
- Time and frequency reference

Correlation for time delay measurement

Analogy to GPS (each satellite distinctive PRN “song”)

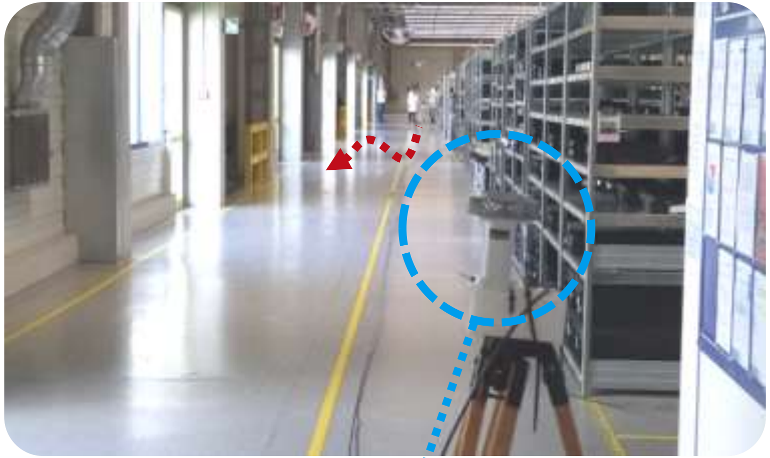






Scenario: Street in Factory Hall, Moving People

Setup Description



Scenario: Street in Factory Hall with Moving People

approx. 68 m LOS

Positions:
Tx2 Rx5

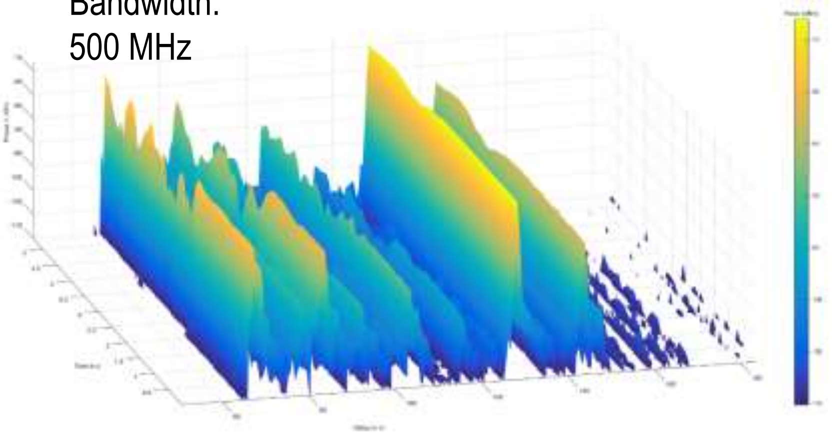
Frequency:
5.8 GHz

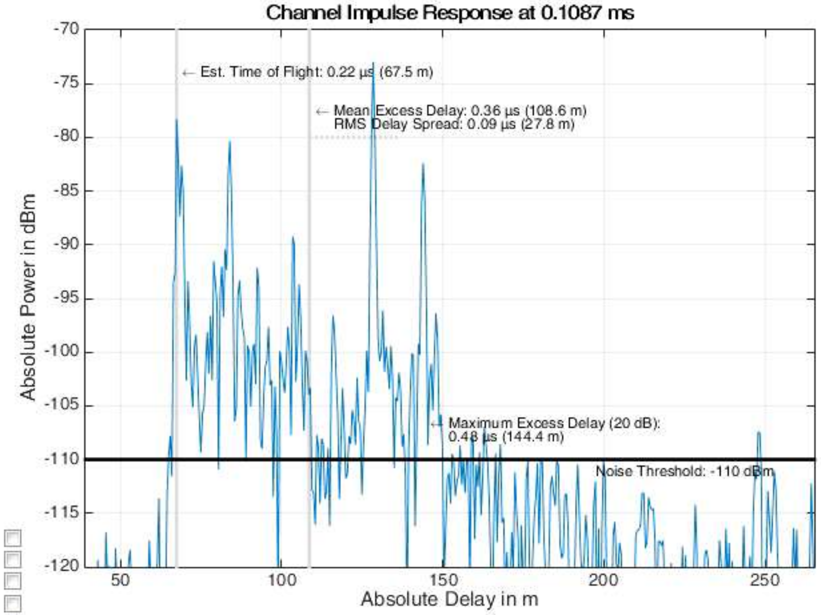
Bandwidth:
500 MHz

Configuration in Use:

Center Frequency:	5800 MHz
Transmitter Clock Rate:	600 MHz
Receiver Sampling Rate:	600 MHz
CIR Update Rate:	109.22 µs
Echo Resolution:	1.6667 ns
Sequence Length:	65535 Sa
Sequence Type:	FZC_16_bit.mat
Measurement Type:	Captured Triggere...

Play

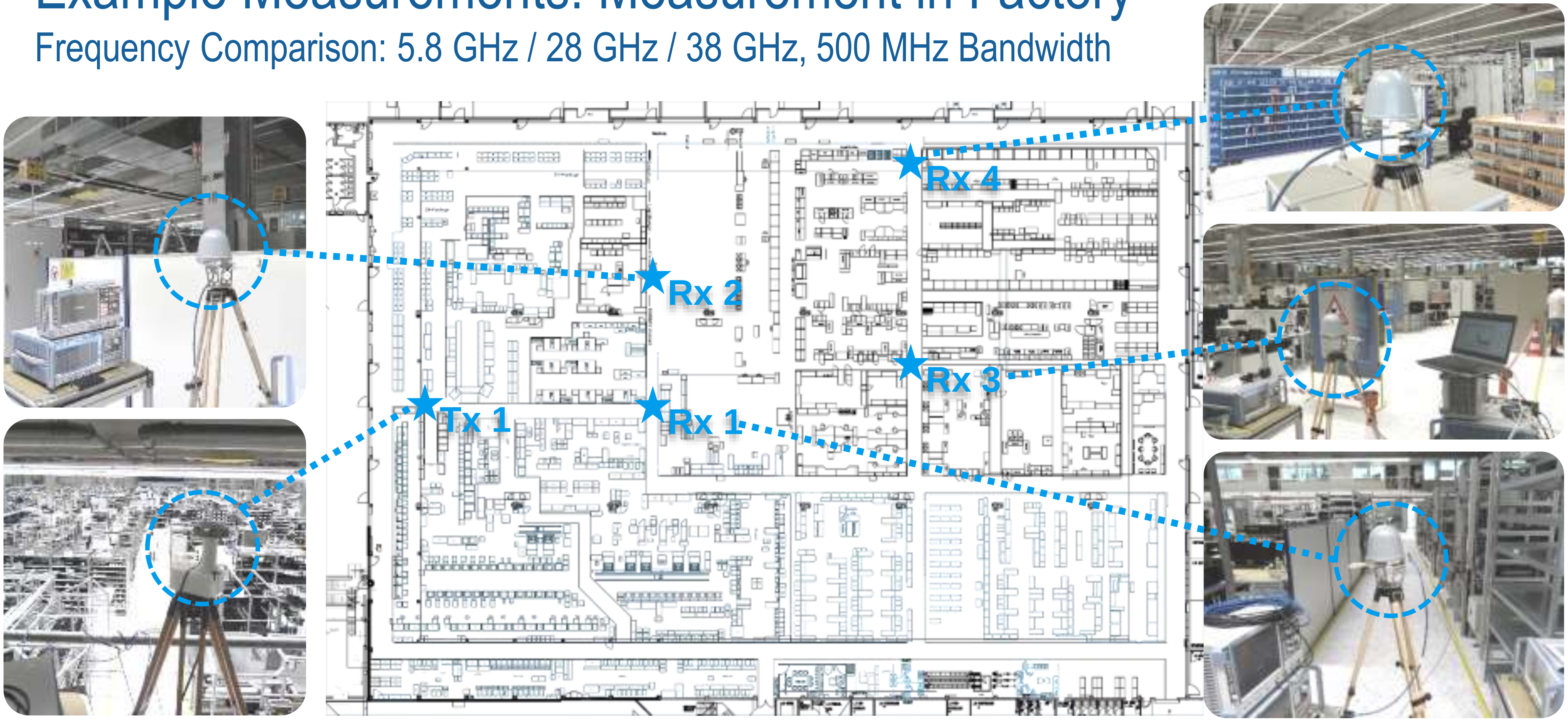




Path Loss:
Data Cursor:
Hide Text in Diagram:
Hold Y-Axis:
Force Noise Thresh.: ☑
X-Axis Unit: m

Example Measurements: Measurement in Factory

Frequency Comparison: 5.8 GHz / 28 GHz / 38 GHz, 500 MHz Bandwidth

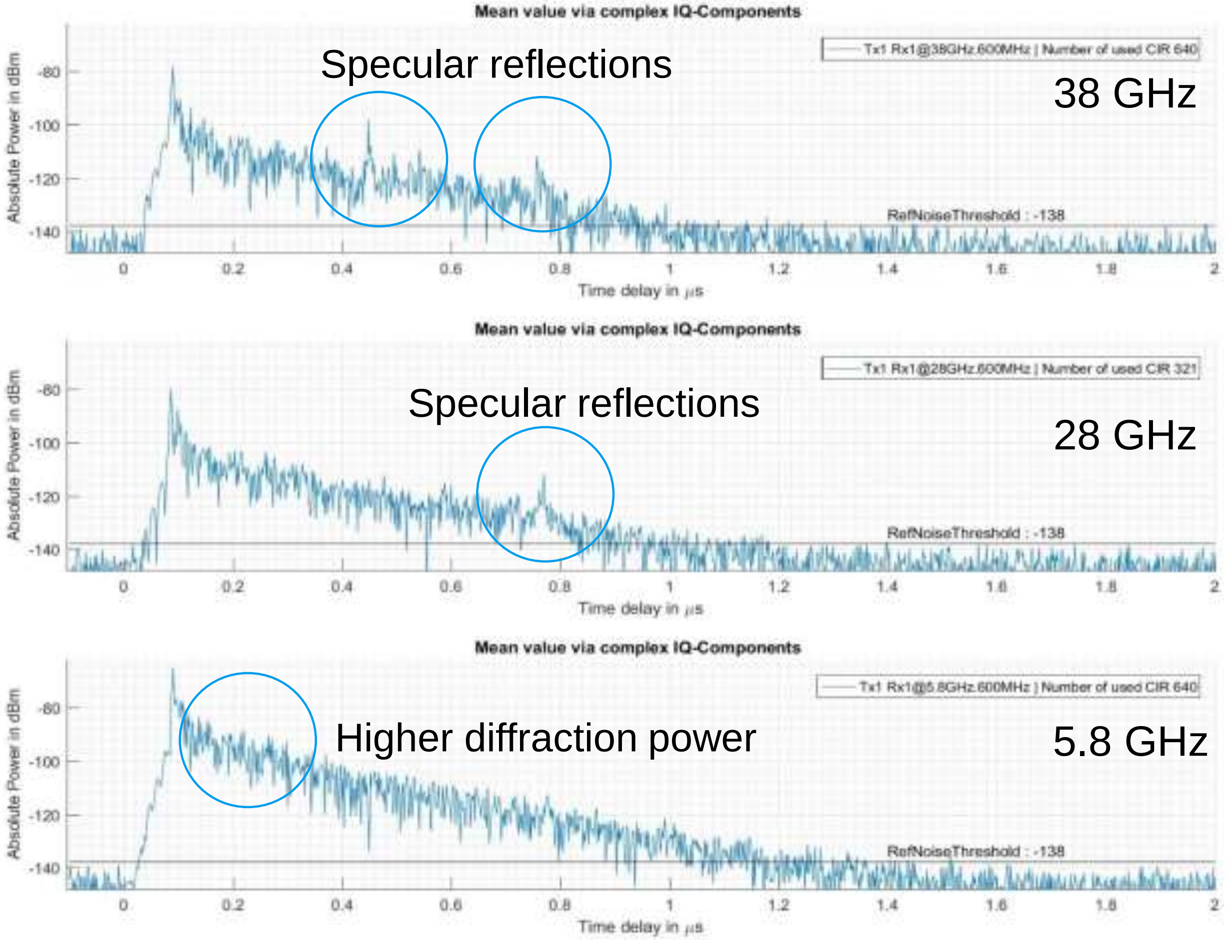


Example Measurements in Factory

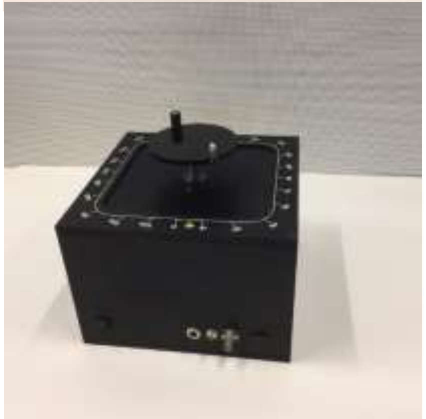
Position:
Tx1 Rx1 (LOS)

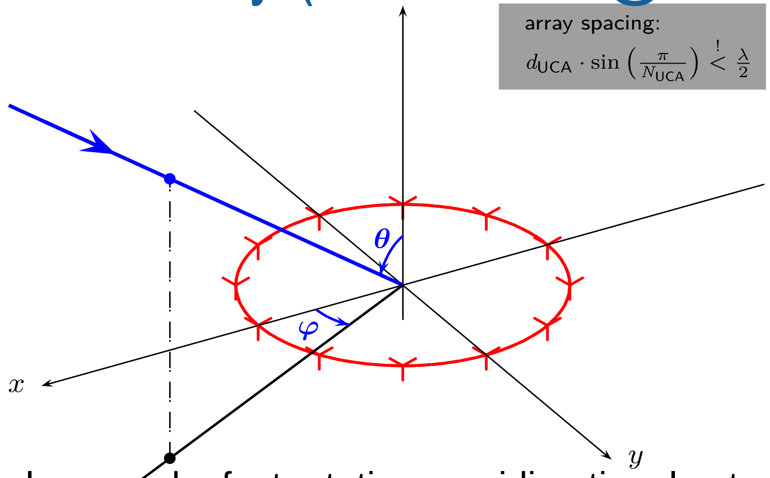
Frequencies:
38 GHz,
28 GHz,
5.8 GHz

Bandwidth:
500 MHz



DoA Measurement: Circular virtual array (HHI / R&S @ Globecom)





- Virtual circular array by fast rotating omnidirectional antenna
- Design suitable for lower frequencies up to 110 GHz
- Alignment of rotation and measurements by HHI Synchronomat
- Very fast acquisition within several ms
- Working Prototype

Publication:
Hung-Anh Nguyen, Wilhelm Keusgen, and Taro Eichler
"Instantaneous Direction of Arrival Measurements in Mobile Radio Channels Using Virtual Circular Array Antennas", In: Global Communications Conference (GLOBECOM), 2016 IEEE

Thank you for your attention !

お客様窓口

受付時間：9:00～18:00
（土、日、祭日を除く）
※Fax、E-mailは24時間受け付け

お問い合わせ先

Tel：　0120-190-722（東京）
Fax：　03-5925-1285（東京）
E-mail：　Technical-Support.Japan@rohde-schwarz.com
Web：　http://www.rohde-schwarz.co.jp