Challenges and Techniques for Characterizing Massive MIMO Antenna Systems for 5G

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ROHDE&SCHWARZ

Outline

Massive MIMO

How to increase spectral and energy efficiency ?

Beamforming MIMO

OTA Testing Technologies

Antenna Radiation Fields

Nearfield vs. Farfield Measurements

OTA Test Solutions:
- Spiral Scanner for Massive MIMO
- OTA Power Sensors

Channel sounding

Channel propagation measurements at mm-Waves

Channel measurements for Platooning below 6 GHz

5G Vision: A union of spectral & energy efficiency becomes reality


Ultra-Dense

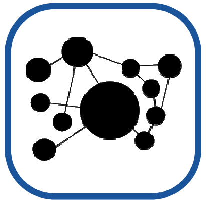

Broadband

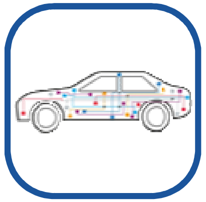

Broadcast


Mobility

Smart City Ecosystem


Public Safety


IoT


Automotive


E-Health

Radio: Spectral Efficiency

Advanced test equipment bridging between radio & virtualization

Virtualization: Energy Efficiency

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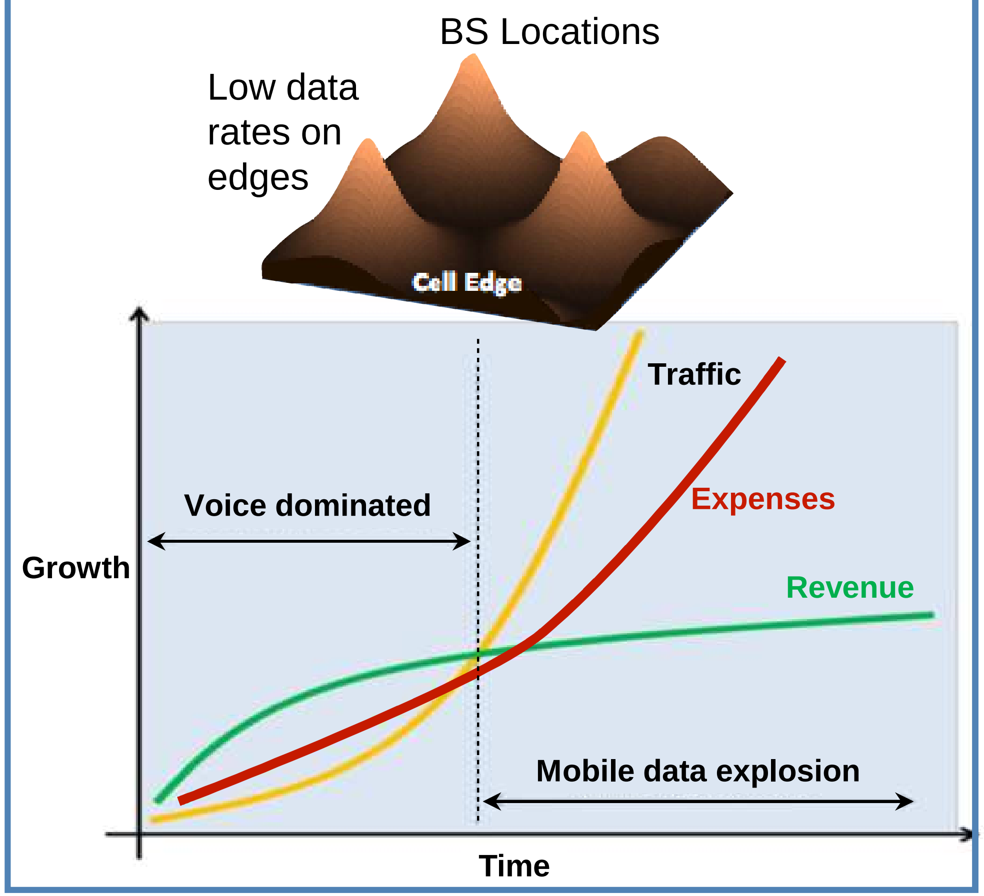
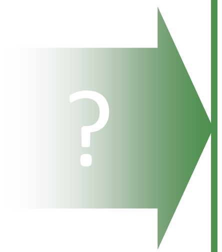
Both capacity and power consumption are critical for 5G success

Virtualization – Energy Efficiency

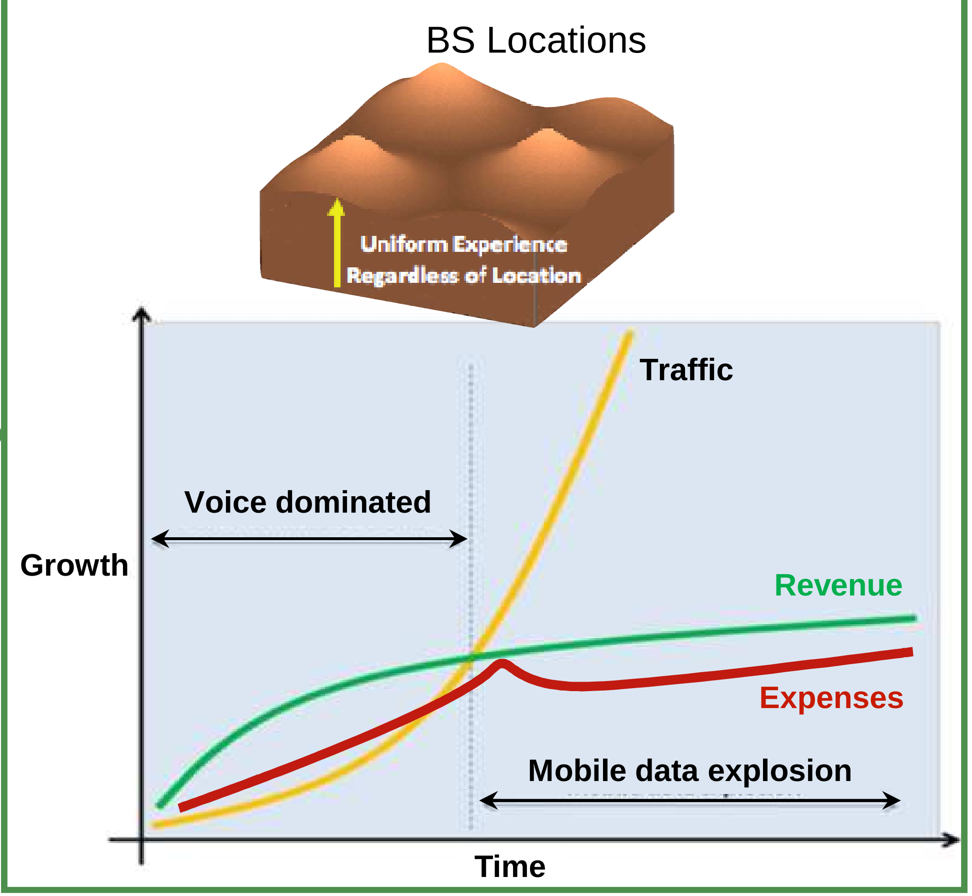
Why 5G?: Capacity vs. Revenue

Increased Capacity, Increased OPEX





Optimal Network



Drive profit by reducing the expenses (energy efficiency)

Why 5G?: Power Consumption

Cellular Network Energy Consumption (China)

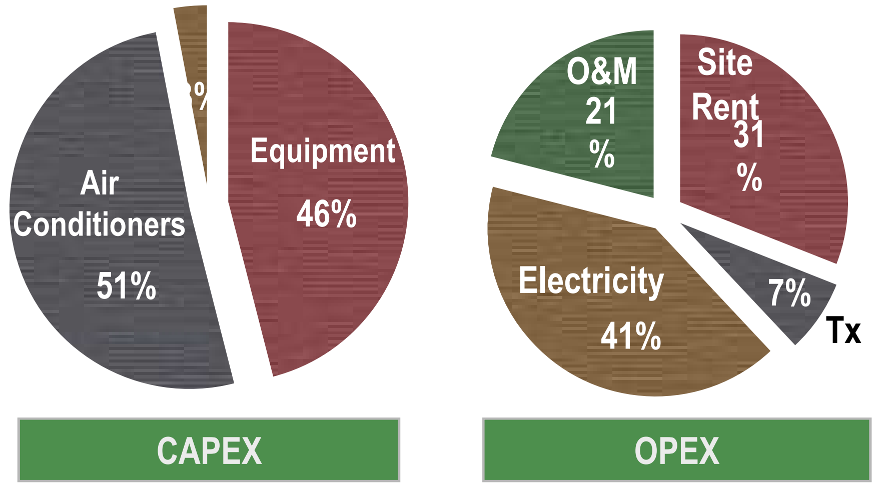
2G GSM
830,000 Basestations
80 GWH (96 KWH per BTx)

3G TD-SCDMA
350,000 Basestations
13 GWH (37 KWH per BTx)

WiFi Data Offloading
4.2 Million Access Points
2 GWH Power consumption

4G TD-LTE
800,000 Basestations
16 GWH (20 KWH per BTx)

Radio Access Network Energy Consumption

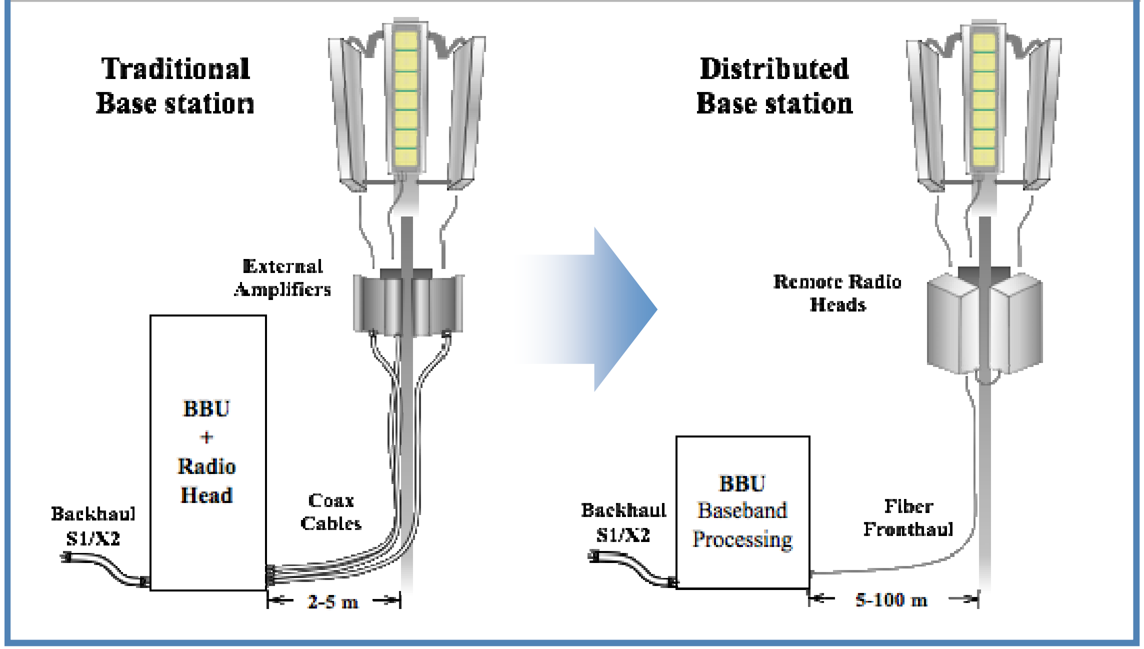


Biggest CAPEX/OPEX Expense is Air Conditioning

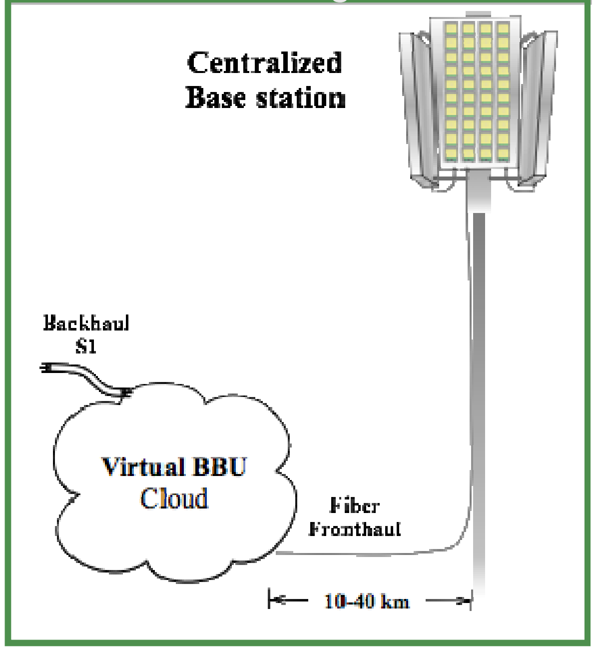
Example: China Mobile Network in 2014 consumed over 15 Billion KWH

Cellular Infrastructure Evolution to 5G

Passive Antennas & Separate Radio Transceivers

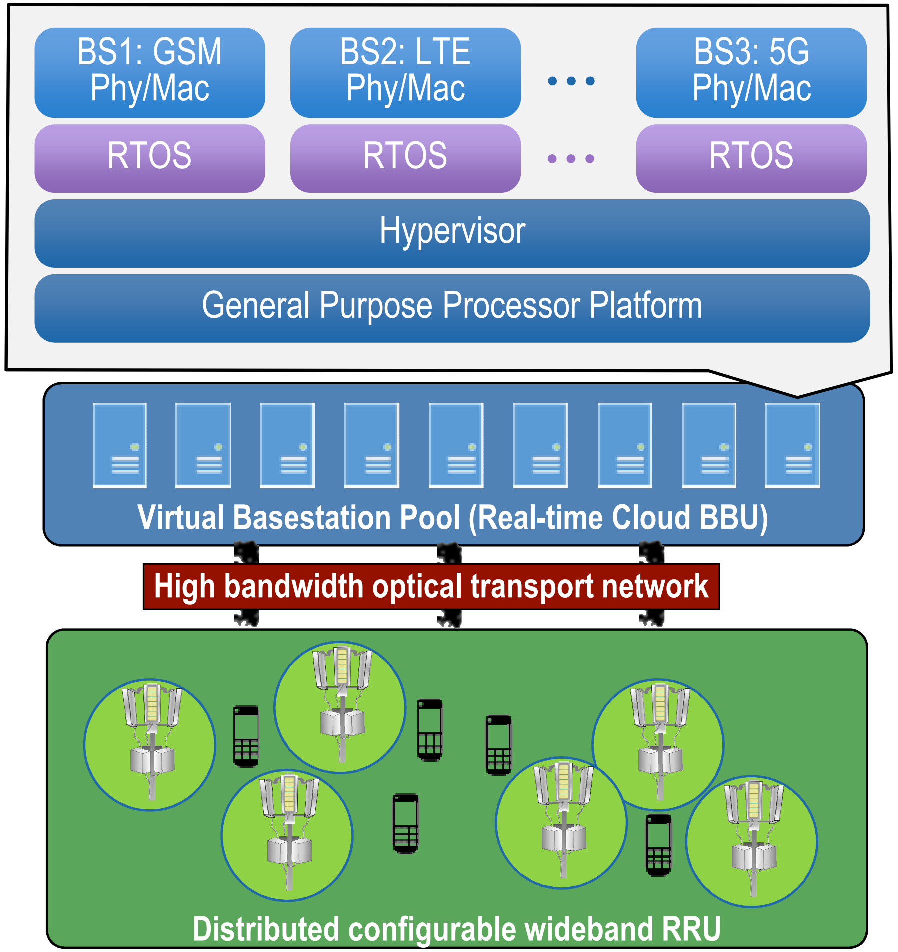


Active Antenna System
Antenna + Integrated TRx



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

Energy Efficiency: C-RAN & Network Virtualization



Centralized Control/Processing
- Centralized processing resource pool that can support 10~1000 cells

Collaborative Radio
- Multi-cell Joint scheduling and processing

Real-Time Cloud
- Target to Open IT platform
- Consolidate the processing resource into a Cloud
- Flexible multi-standard operation and migration

Clean System Target
- Less power consuming
- Lower OPEX
- Fast system roll-out

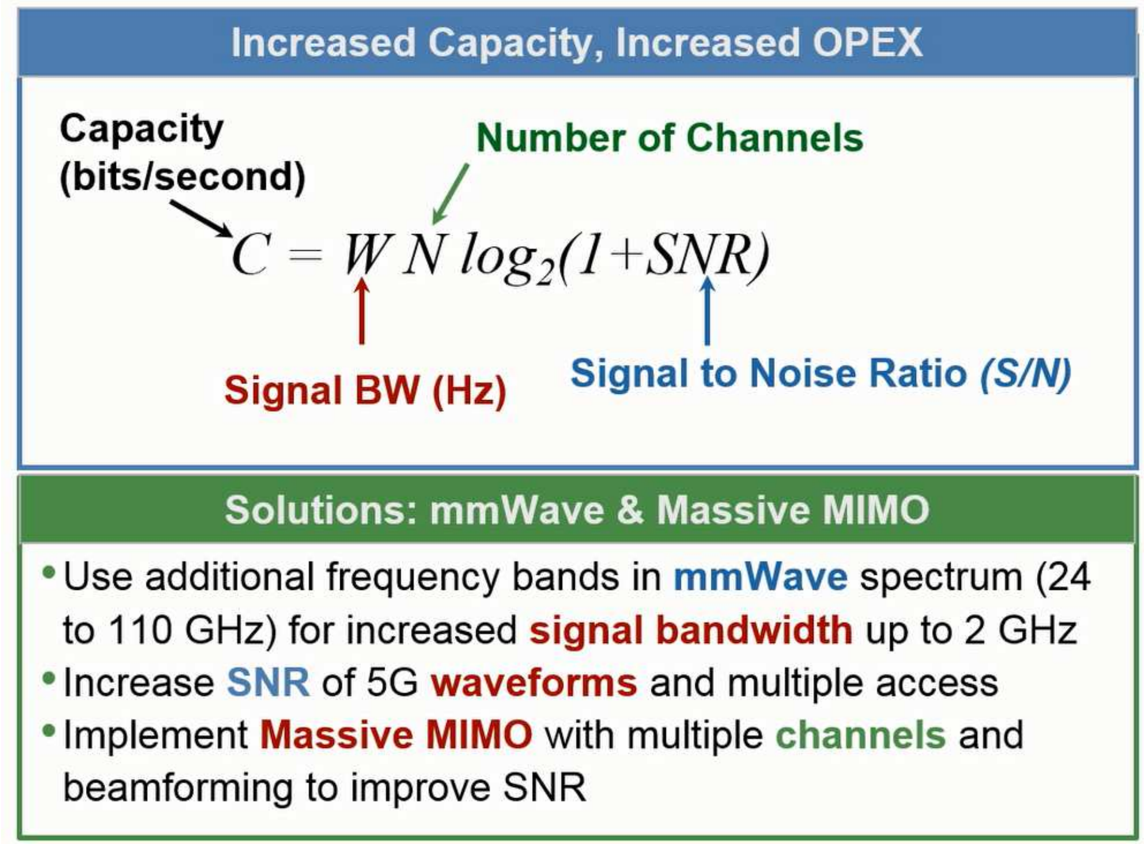
-15% Capital Costs
-50% Operating Costs
-70% Power Consumption

Architecture	Equipment	Air Con	Switching	Battery	Transmission	Total
Traditional	0.65 kW	***2.0 kW***	0.2 kW	0.2 kW	0.2 kW	3.25 kW
Cloud Radio	0.55 kW	***0.1 kW***	0.2 kW	0.1kW	0.2 kW	1.15 kW

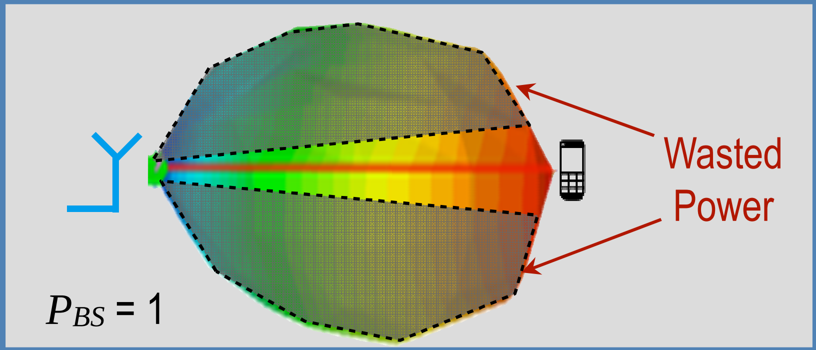
CMRI, "C-RAN: The Road Towards Green RAN," Dec. 2013

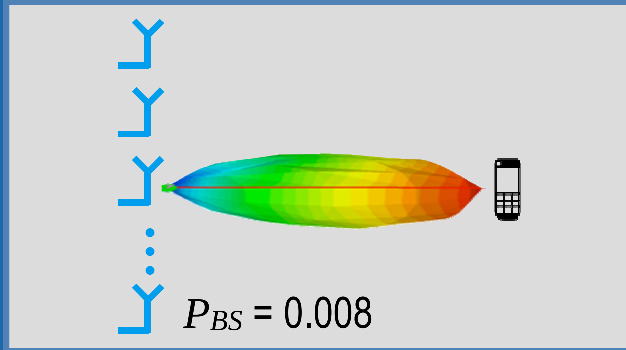
Spectral Efficiency:
Massive MIMO / Beamforming

Spectral efficiency: Why MIMO ?



Energy Efficiency: Why Massive?





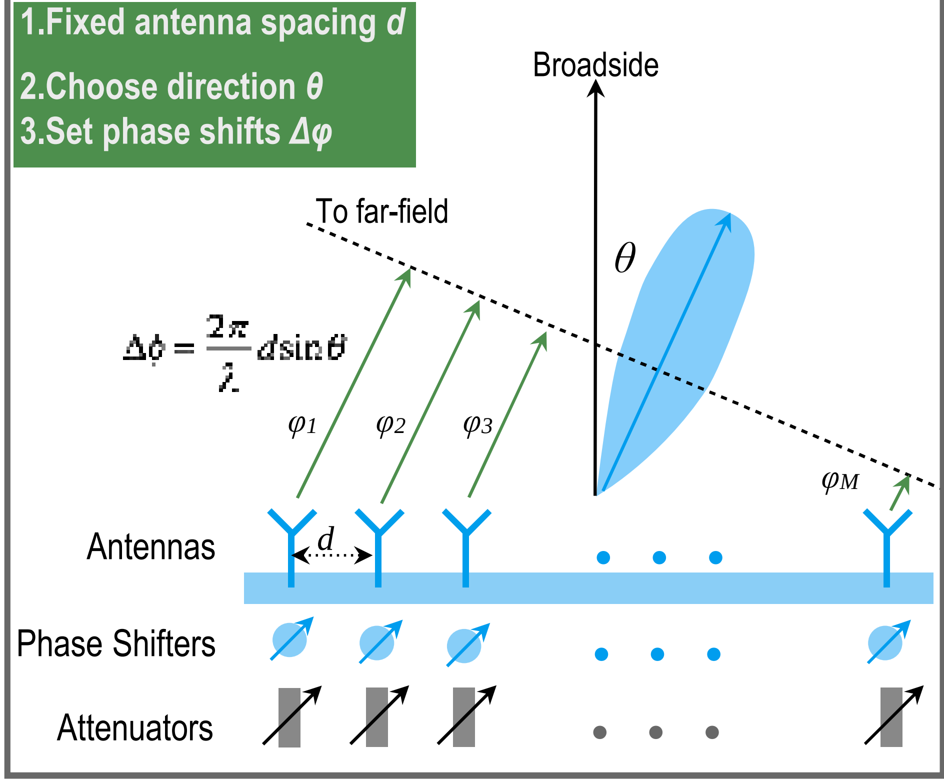
	Number of Antennas = 1	Number of UEs: 1 120 antennas per UE
Number of BS Transmit Antennas	1	120
Normalized Output Power of Antennas	$P_{ant} = \frac{1}{M_t} = 1$	$P_{ant} = \frac{1}{M_t^2}$
Normalized Output Power of Base Station	$P_{total} = \sum_{i=1}^{M_t} P_{ant}^i = 1$	$P_{total} = \sum_{i=1}^{M_t} P_{ant}^i = 0.008$

Source: IEEE Signal Processing Magazine, Jan 2013

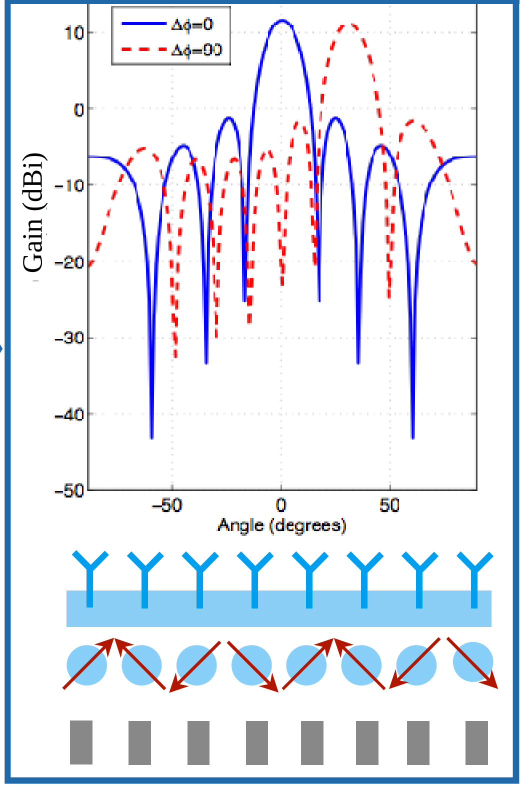
How to Steer Beams? 8 Element Dipole Array Example

Principle of Beamforming & Beamsteering

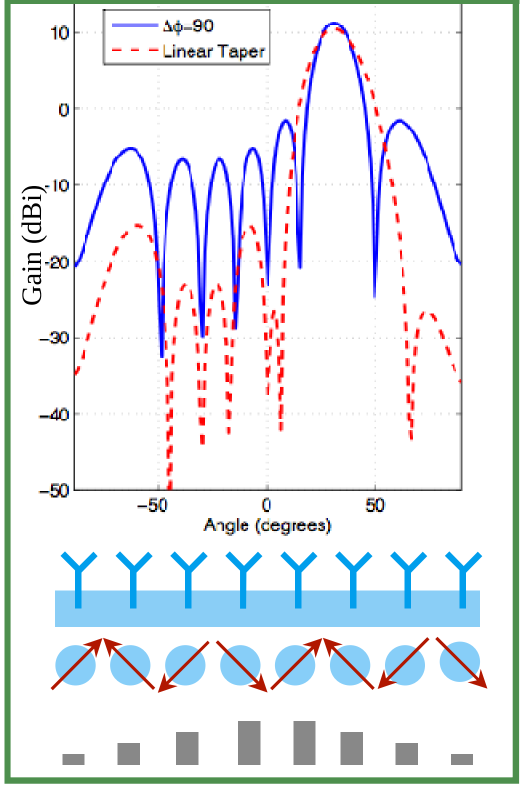
1. Fixed antenna spacing *d*
2. Choose direction *θ*
3. Set phase shifts *Δφ*



Beamsteering (Phase Shift)

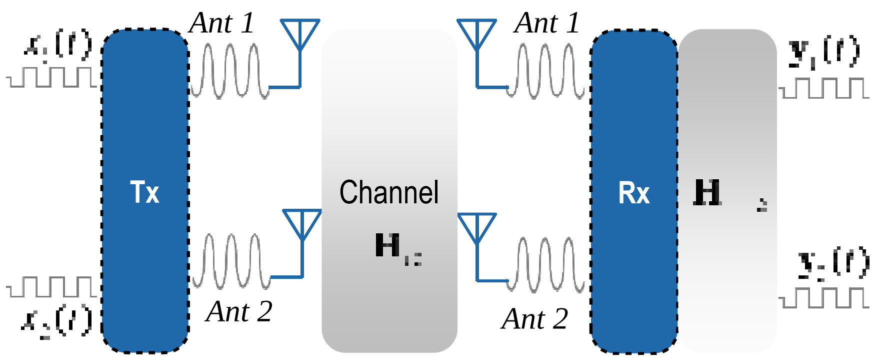


Sidelobe Suppression



System Perspective: From MIMO to MU-MIMO

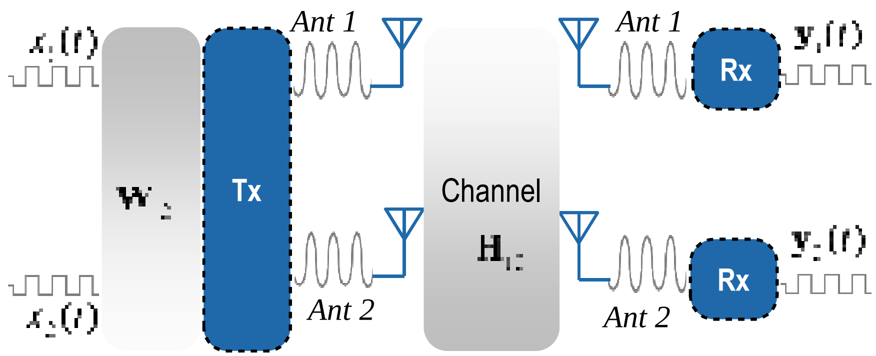
Single User MIMO



1. Tx transmits multiplexed data streams with pilot signals
2. Rx determines channel matrix H from pilot signals
3. Rx calculates inverse channel matrix to recover data

Complexity at Receiver (UE)

Multi-User MIMO



$$\mathbf{W}_{12} = \mathbf{H}^{*}_{12}\left(\mathbf{H}_{12}\mathbf{H}^{*}_{12}\right)^{-1}$$

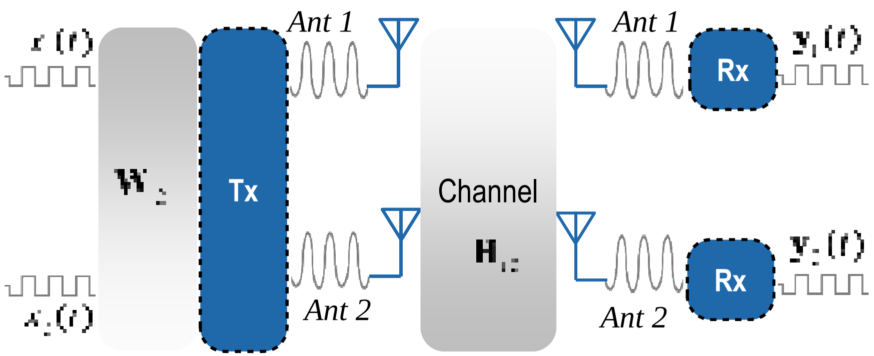
$\mathbf{H}^*$: complex conjugate

1. Tx precodes with weights based on inverse channel matrix with multiplexed data streams
2. Rx receives in-phase waves from Tx
3. Interference is out-of-phase

Complexity at Transmitter (Basestation)

System Perspective: From MU-MIMO to Massive MIMO

Multi-User MIMO: Homogenous Requirements



Zero interference at receiver

$$y = x + n$$

$$W_2 = H_{12}^H \left(H_{12} H_{12}^H \right)^{-1}$$

Same SINR for every user
Power constraints

Limited interference at receiver

$$W_2 = H_{12}^H \left(H_{12} H_{12}^H + \alpha I \right)^{-1}$$

$$\alpha = \text{UEs} / \text{Power}$$

Same SINR for every user
No power constraints

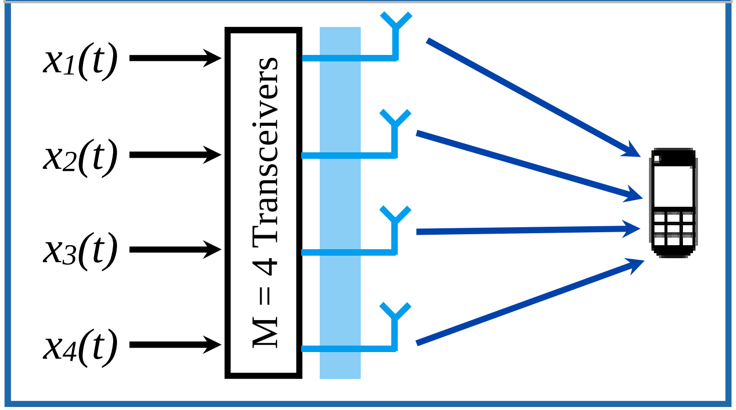
Different users require different data rates

Massive MIMO:
Heterogeneous Requirements Problem:
Power transmitted to one user changes SINR to all users

Therefore, must use beamforming where beamforming vectors & power weights are jointly optimized

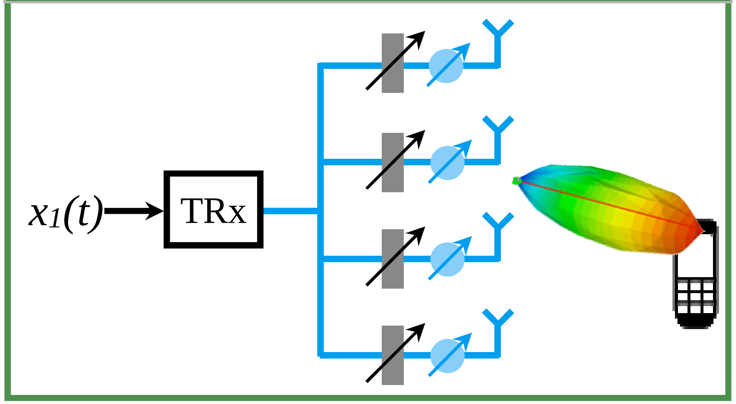
Hardware Perspective: Massive MIMO = Beamforming + MIMO

MIMO Array: *M* Data Streams

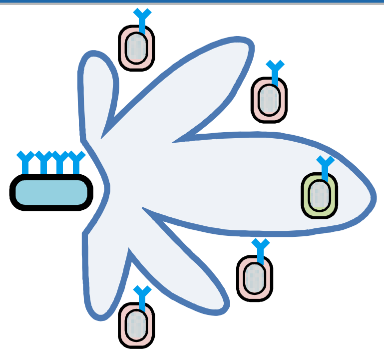


+

Beamforming Array: *1* Data Stream



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



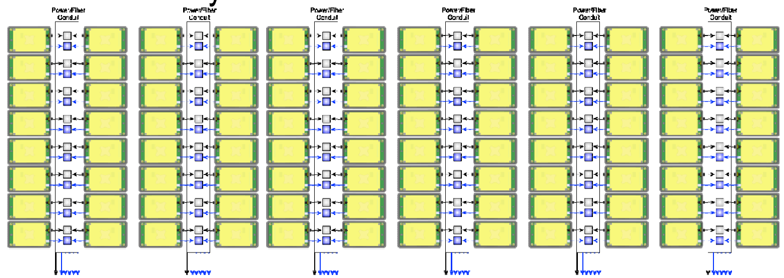
Multi User-MIMO

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



Background on over-the-air (OTA) testing technologies

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Beamforming
MIMO

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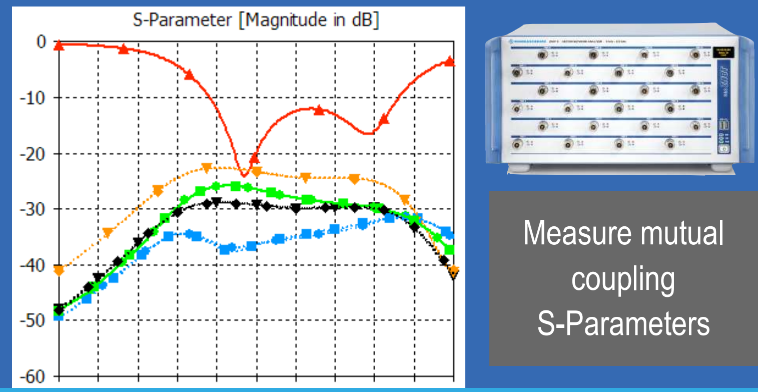
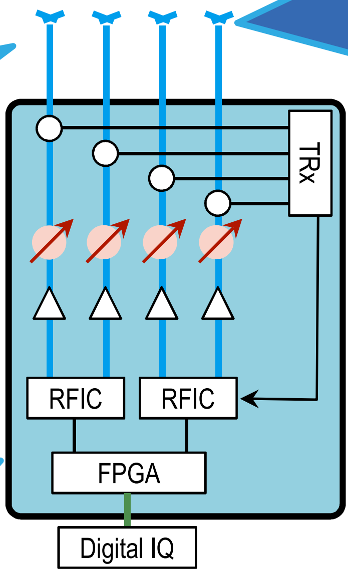
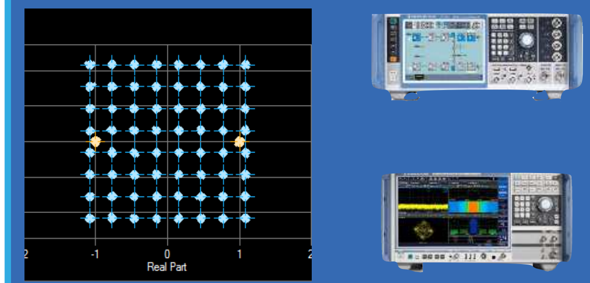
Measuring 5G mmWave & Massive MIMO Systems

OTA Gain, EiS, EiRP



Multiport Antenna Array Measurements





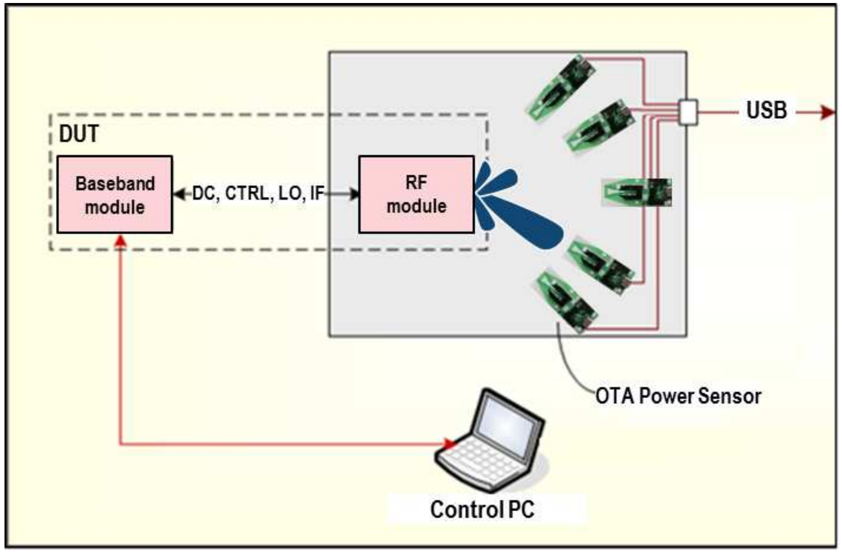
Element/System OTA EVM, ACLR

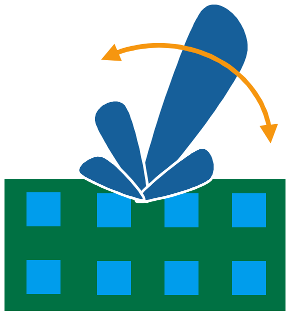
Production TRx & Antenna Calibration

Antenna Array Beamsteering
Magnitude Only

mmWave DUTs will not have antenna connectors

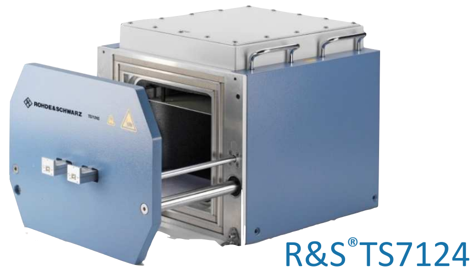
OTA Measurements will be mandatory for production





RF antenna array

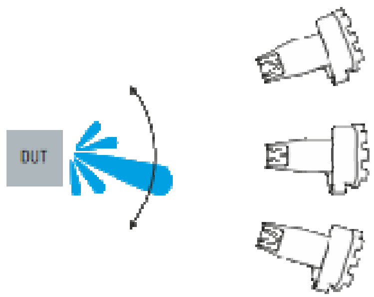
Measurement Equipment

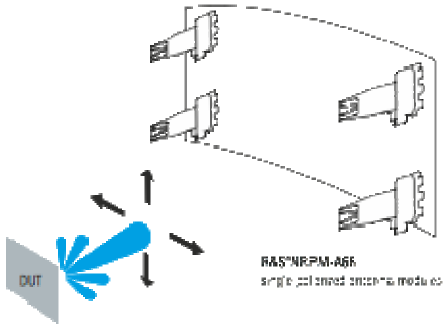


Shielded chamber (TS7124)

Vivaldi Probe 28-77 GHz

Measurement Scenarios





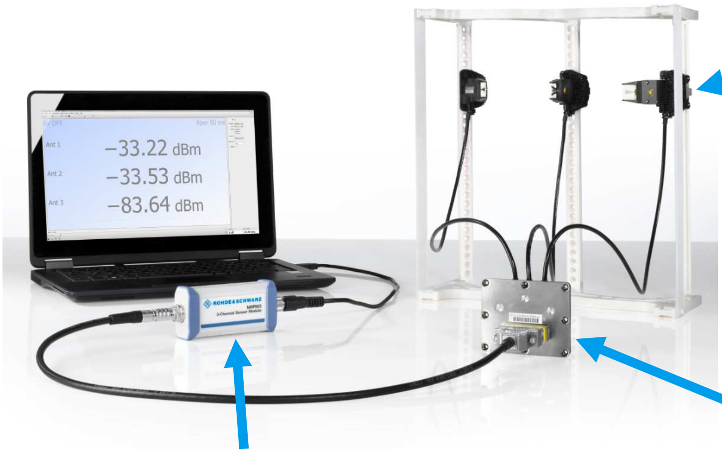
2D Beam-Steering

3D Beam-Steering

mmWave & 802.11ad test setup in the TS7124

- TS7124 shielded chamber+multiple OTA Power sensors
- OTA power sensor: Vivaldi antenna with integrated diode detector
  No compensation of mmWave cable loss required
- Frequency range 27.5 GHz to 75 GHz
- Power measurements

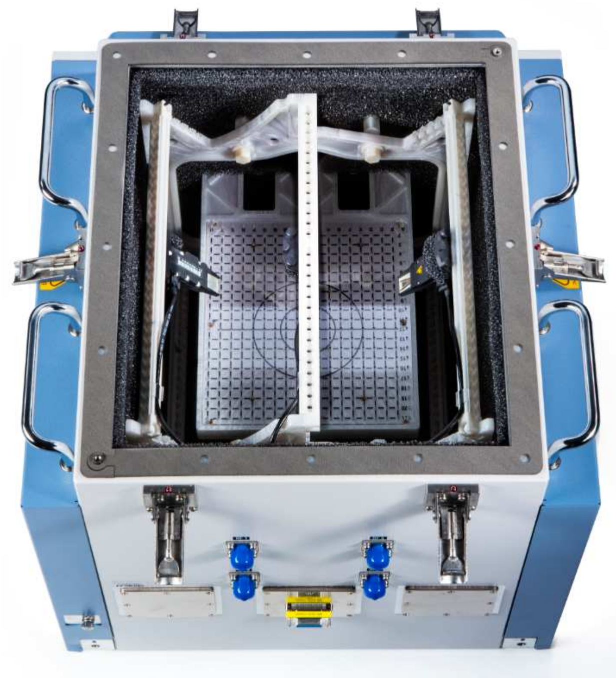
Monitoring PC with Power Viewer Plus



NRPM-A66 Antenna module

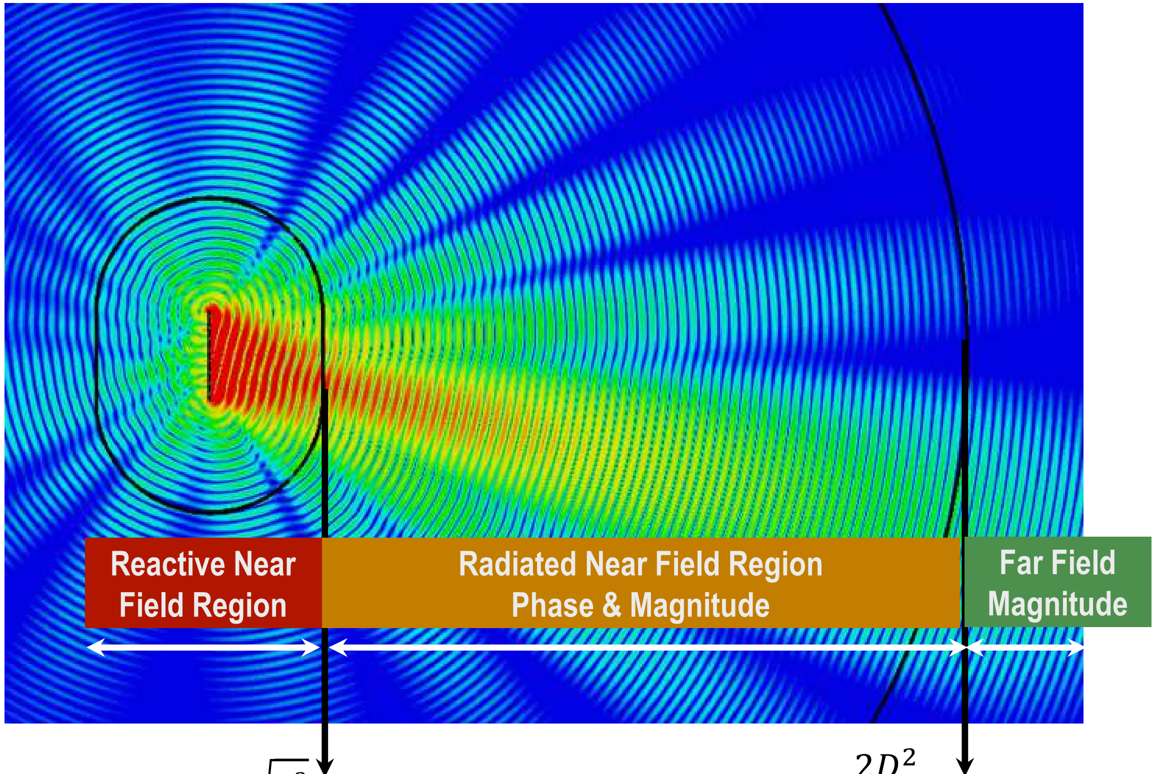
NRPM-ZD3 Interface to TS7124

NRPM3 3 channel power sensor



Fundamental Properties: Electromagnetic Fields

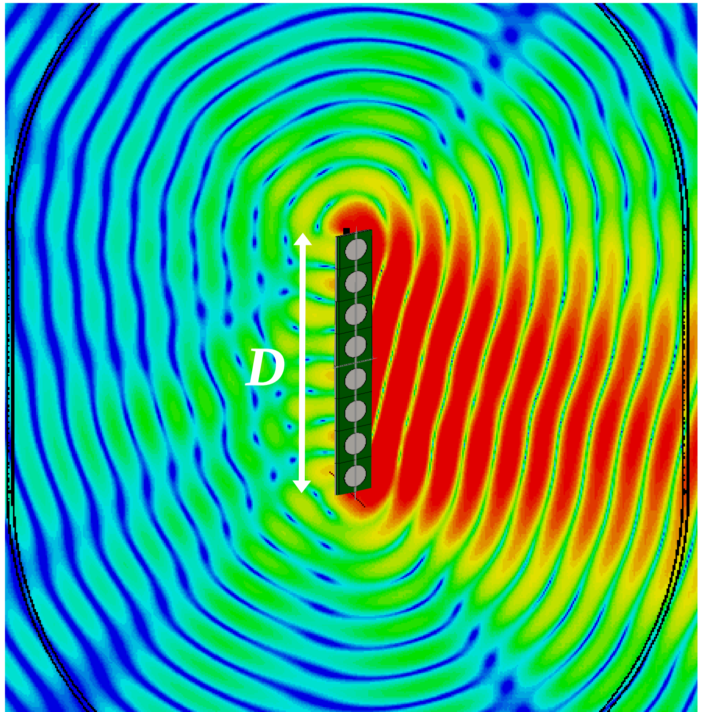
Basestation 8 Element Array at 2.7 GHz



$0.62\sqrt{\frac{D^3}{\lambda}} = 0.6\ \text{m}$

$\frac{2D^2}{\lambda} = 4.5\ m$

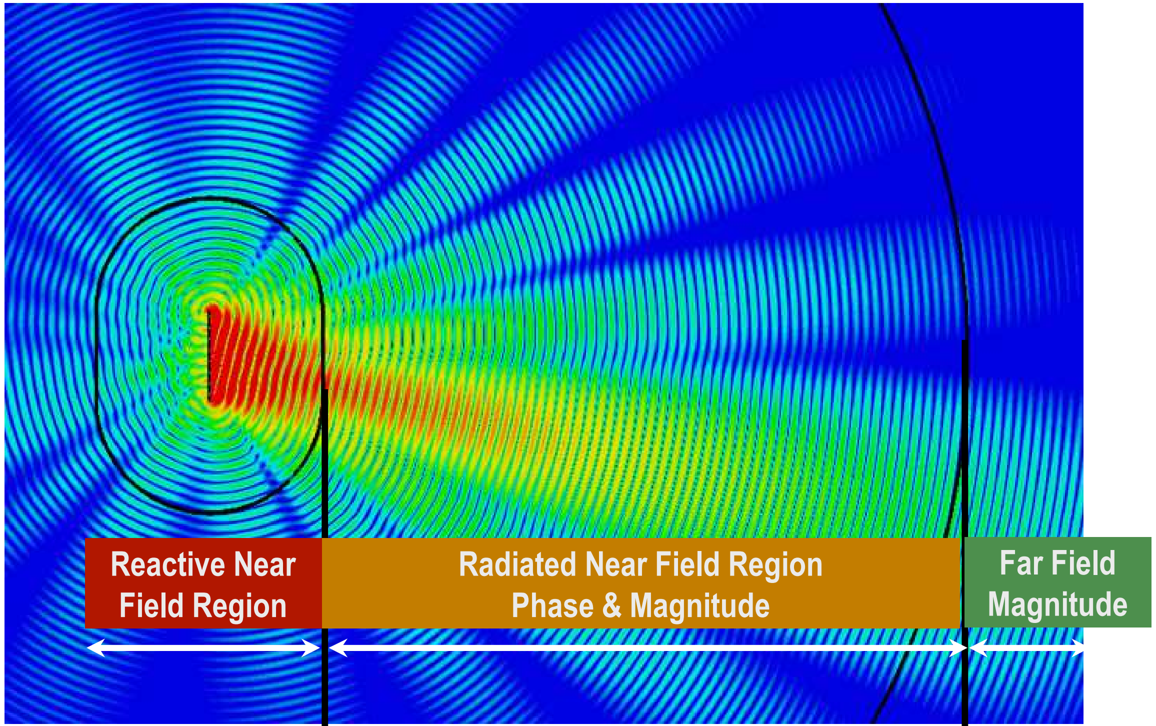
Reactive Near Field Region ($< 0.6m$)



Any object in this region becomes part of antenna system & interferes with the measurements

Fundamental Properties: Electromagnetic Fields

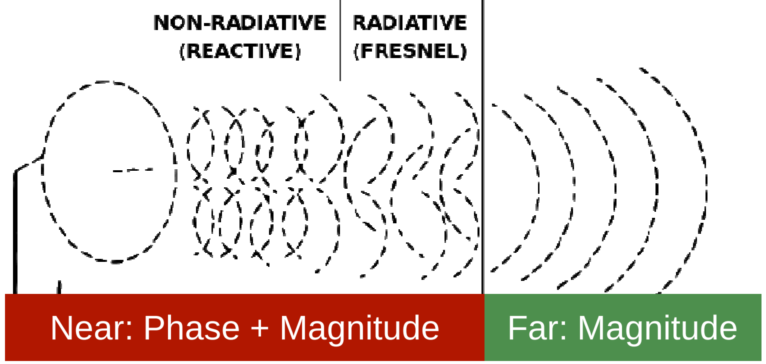
Basestation 8 Element Array at 2.7 GHz



$$0.62\sqrt{\frac{D^3}{\lambda}} = 0.6\text{ m}$$

$$\frac{2D^2}{\lambda} = 4.5\ m$$

Far-field vs. Near-field



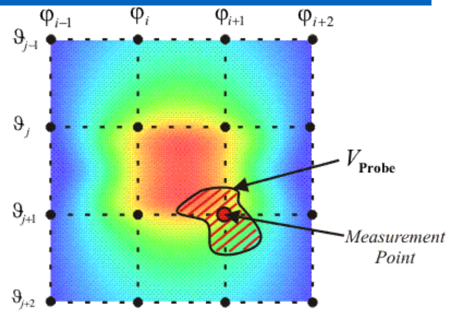
Required Chamber Size for Far-field

AUT Size (D)	Frequency	Chamber Size
0.5 meters	6 GHz	10 meters
0.5 meters	30 GHz	50 meters
1.0 meter	6 GHz	40 meters

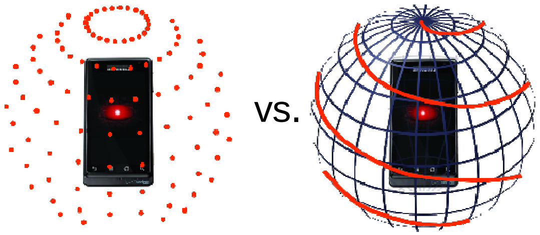
Near-field to Far-field Transformation – FIAFTA

Features

Equivalent Sources



Probe Compensation

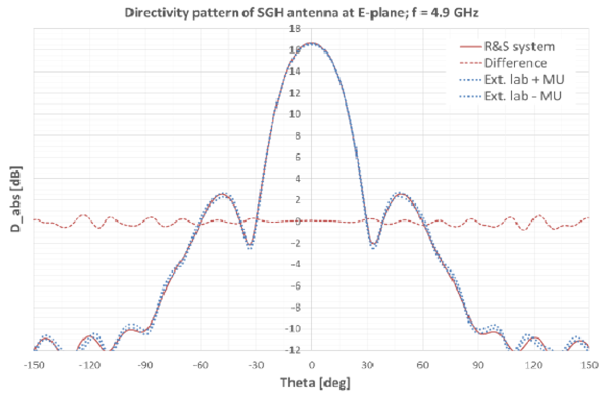


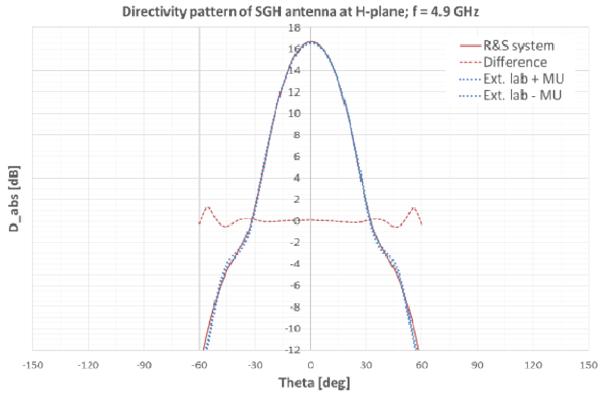
220 minutes

6 minutes

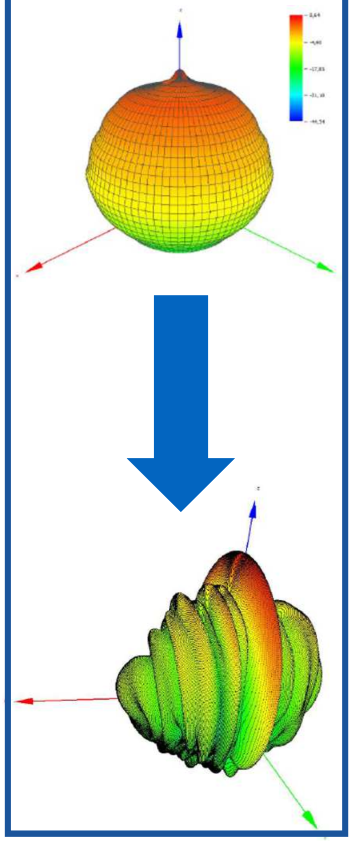
Arbitrary Grids

Performance Comparison





Transformation



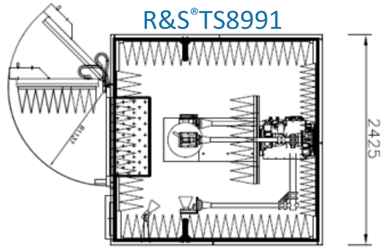
R&S Antenna Test Solutions Summary

Massive MIMO

R&S®TS8991

CTIA Radiation Patterns

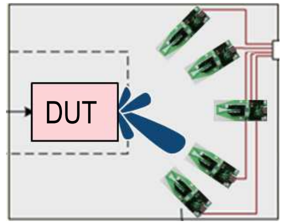
R&S®TS8991



R&S®FSV

R&S®NRP

mmWave Beamsteering

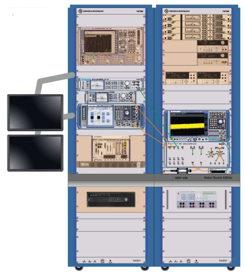


R&S®NRPM

R&S®NRPM-A66

RF Conformance

R&S®TS7380

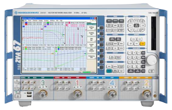


R&S®ATS1000

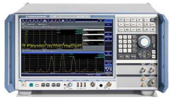
mmWave

R&S®ATS1000

R&S®ZVA

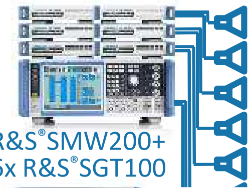


R&S®FSW

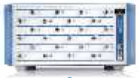


R&S®SMW200A

Multiport Testing



R&S®SMW200+
6x R&S®SGT100



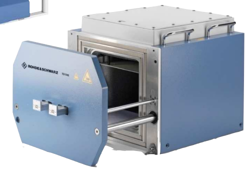
R&S®ZNBT

- Phase-coherent RF generation
- Multi-port VNA for Active Return Loss

Production & Benchtop

R&S®DST200

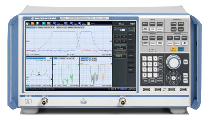
R&S®TS7124



R&S®RTO

R&S®FSV/FSP

R&S®ZVC/D



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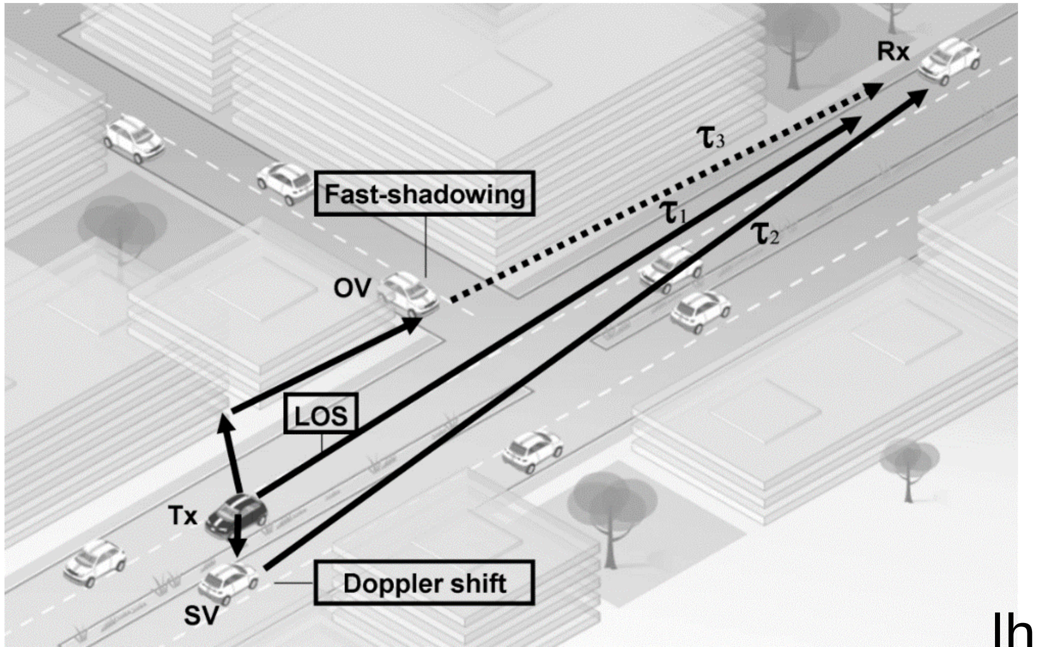
Theoretical review: multipath propagation

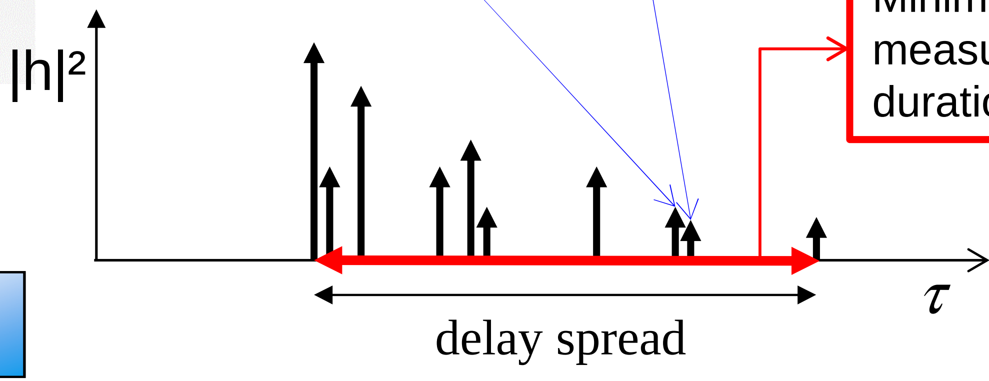


Channel impulse response CIR is a theoretical measure to describe the wave propagation: Idea is to excite the channel with a Dirac impulse and to measure the arrivals of that impulse at the receiver. Due to multipath each pulse response is attenuated, delayed and phase shifted.

required resolution to identify each multipath component:

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

Minimum measurement duration



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

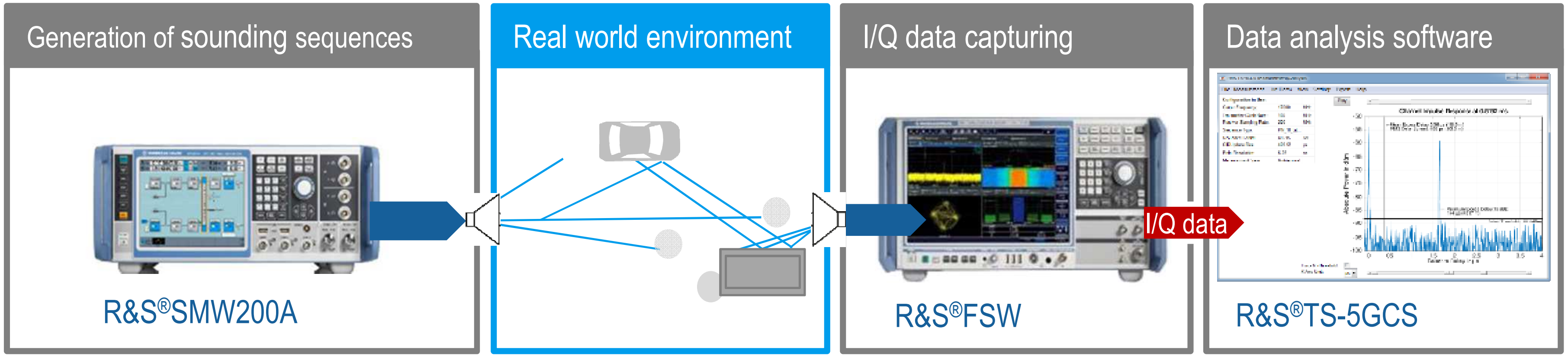
path attenuation | path phase | path delay

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.

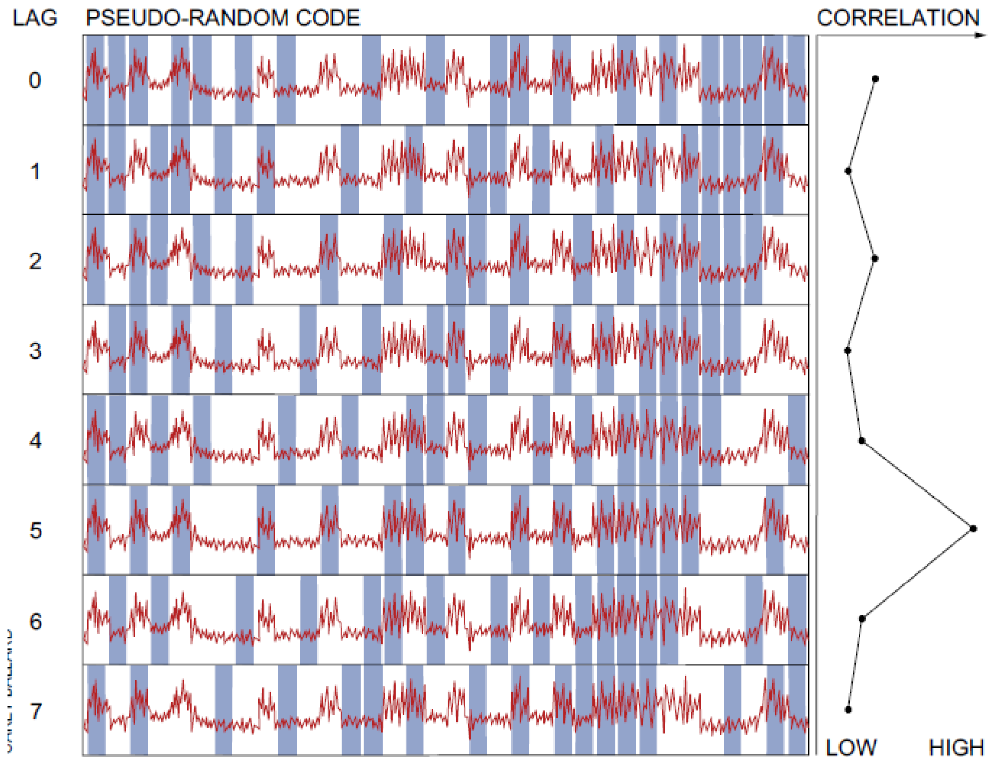


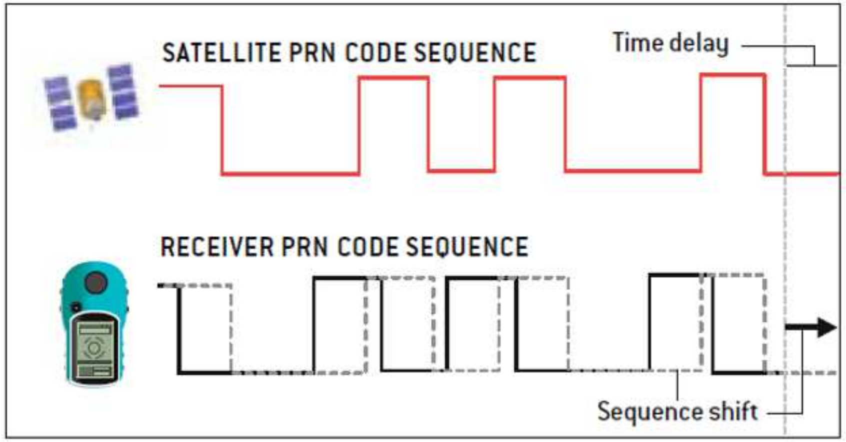
- fast measurement in time domain
- support for in- and outdoor sounding
- very high dynamic range
- Time and frequency reference

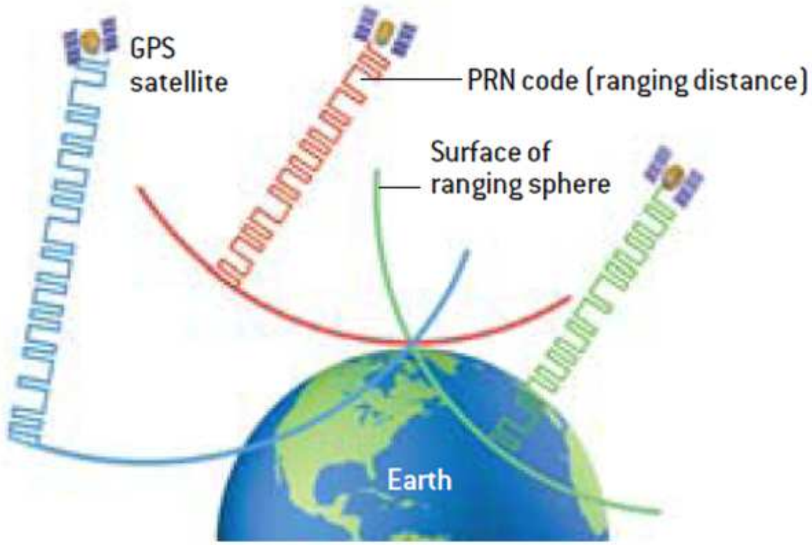
ROHDE&SCHWARZ

Correlation for time delay measurement

Analogy to GPS (each satellite distinctive PRN "song")

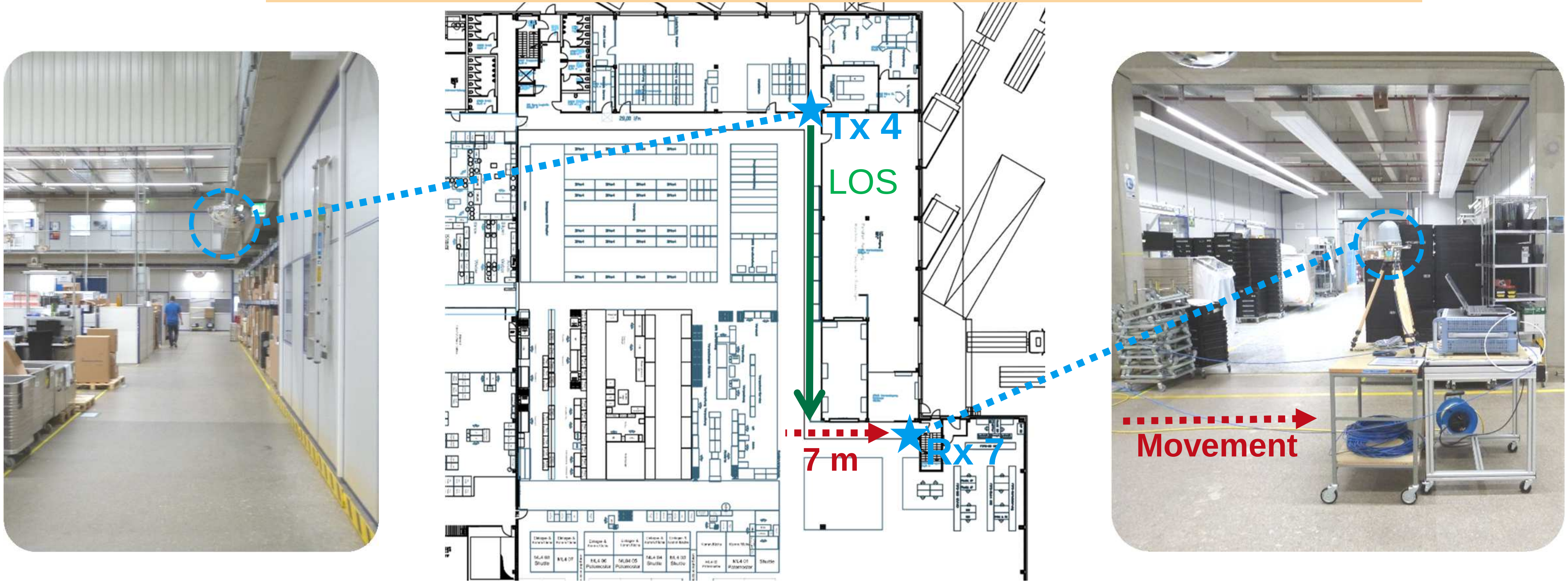






Industry 4.0: R&S conducted own channel sounding campaigns in industrial surrounding

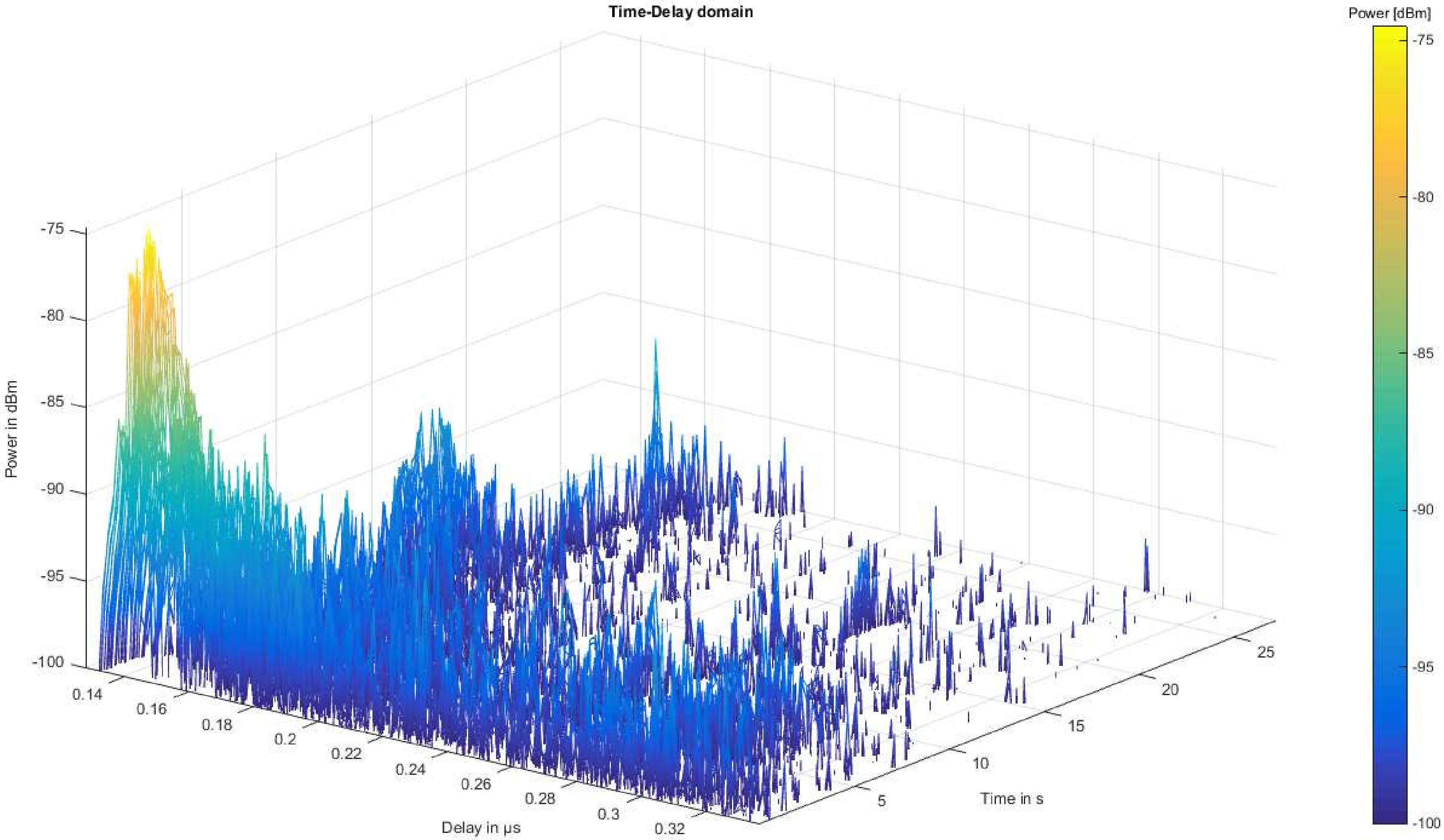
At first: LOS , then Rx is moved around a corner → corner effect



Positions:
Tx4 Rx7

Frequency:
5.8 GHz

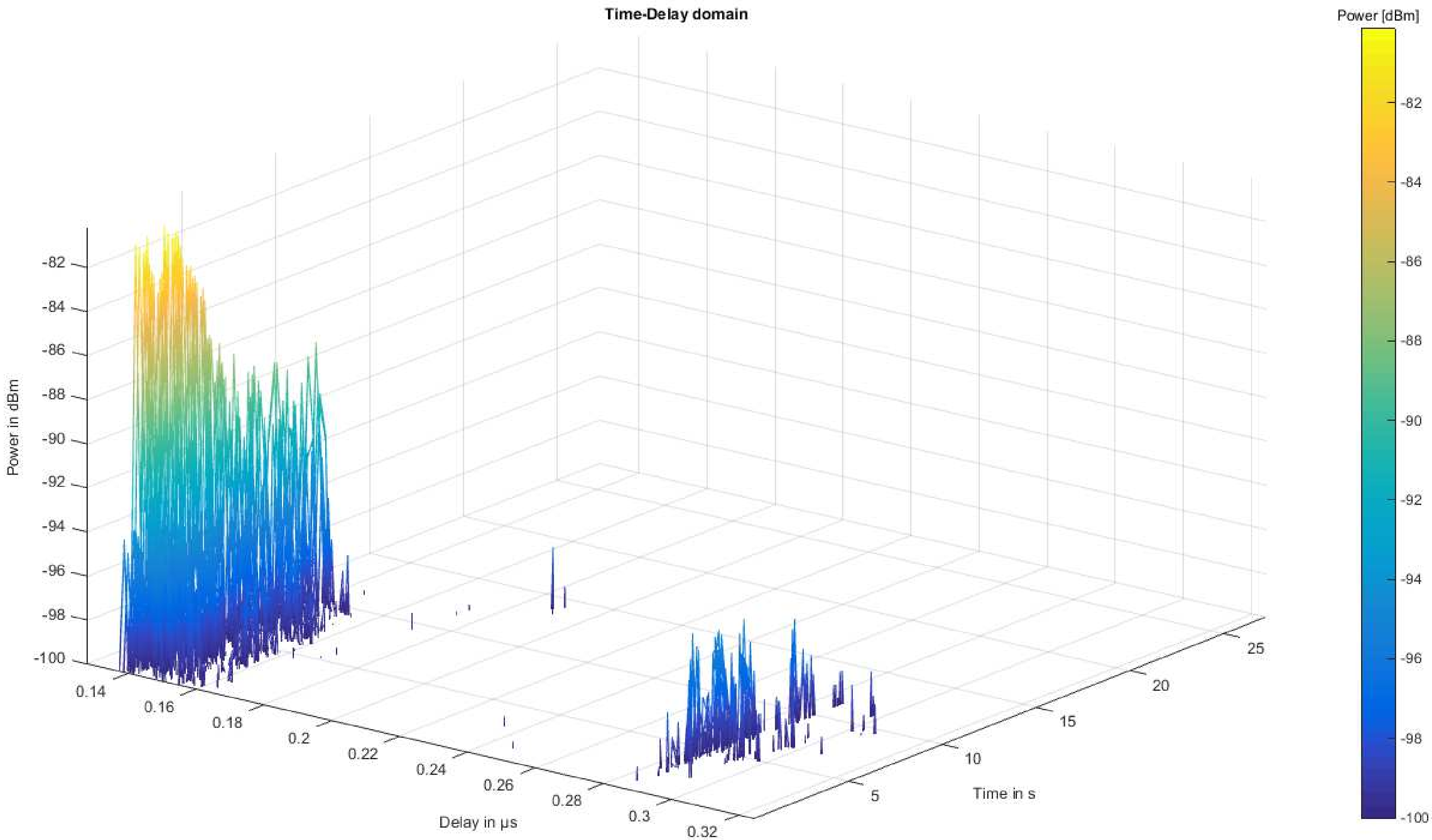
Bandwidth:
500 MHz



Positions:
Tx4 Rx7

Frequency:
38 GHz

Bandwidth:
500 MHz



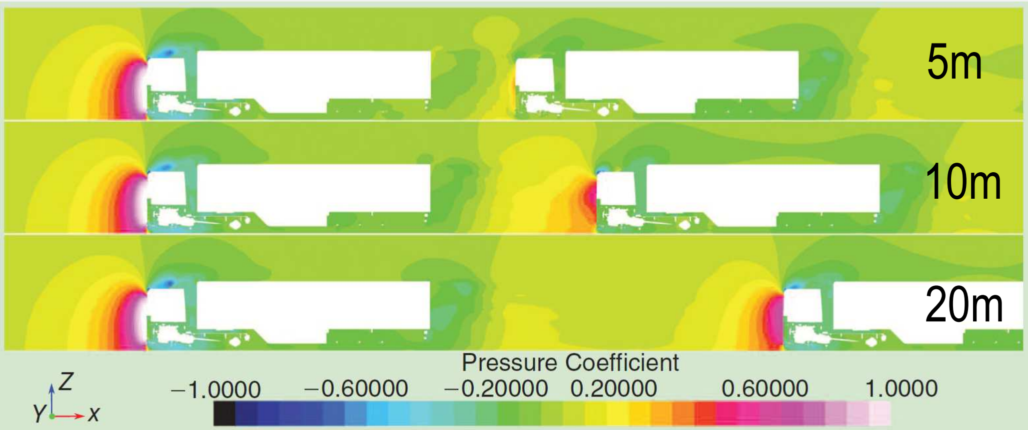
Platooning

„road train“ with „electronic link“ to reduce aerodynamic drag and thus fuel consumption

Platooning: A cooperative method to enhance safety and efficiency

Technologies: radar, stereometric camera, V2X

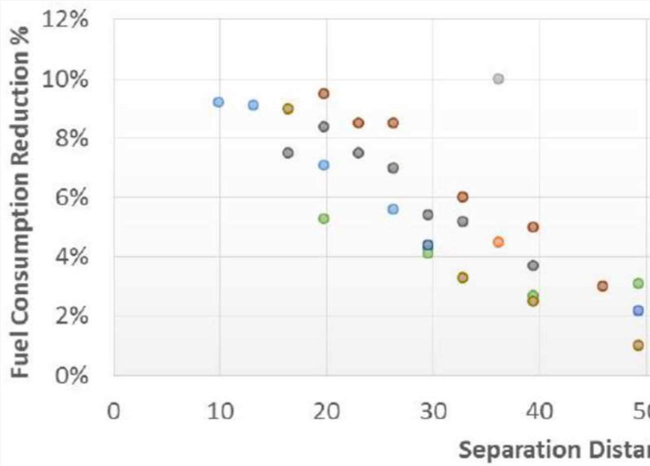
Aerodynamics (pressure coefficient)



The pressure field for a two-vehicle platoon with a spacing of 5, 10, and 20 m. The pressure coefficient represents a scaled deviation from the nominal air pressure.

Reference: *A. Alam et. al. "Heavy-Duty Vehicle Platooning for Sustainable Freight Transportation",* In: IEEE Control Systems Magazine, Dec 2015

Fuel Consumption Reduction



Fuel savings:

4-5% at 10 m distance

8-9% at 3-6 m distance

Values vary for other References (up to 20% for 2nd truck on test track)

Reference: 2016 North American Council for Freight Efficiency *CONFIDENCE REPORT: Two-Truck Platooning*

⇒ The distance is crucial for fuel reduction (even 1-2m if possible)

⇒ 5G URLLC

3GPP 5G Standardization: RAN#74 (Dec 2016)

Platooning: a 5G use case

NR: New Radio
SA: Standalone
NSA: Non Standalone

TR 22.886, December 2016:

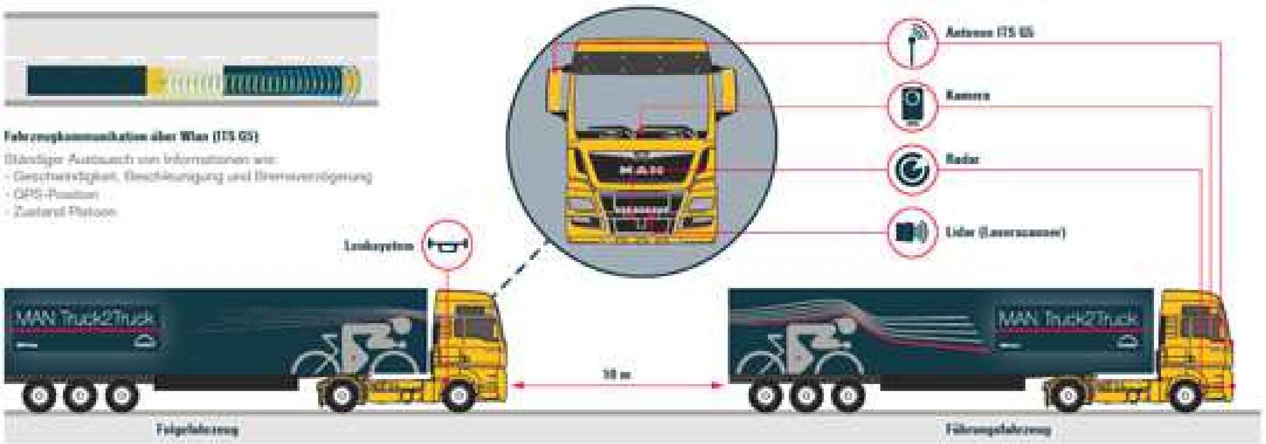
- safe platooning requires reliable wireless communication
- current discussion in 3GPP towards 5G involves long-term development (eV2X) including automated driving

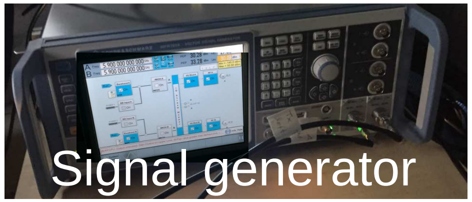
- TR 22.886 V15.0.0 (2016-12)
- Technical Specification Group Services and System Aspects
- Study on enhancement of 3GPP support for 5G eV2X Services
- Important use case “Information exchange within platoon”

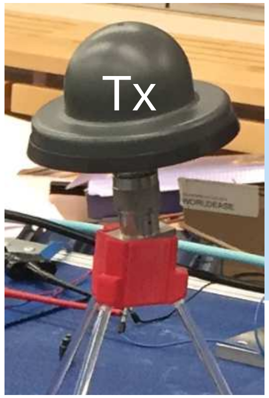
- complementary technologies: 11p, LTE-V

V2X Channel Propagation Measurements at 5.9 GHz (24.11.2016)

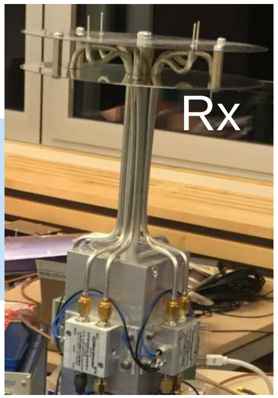
MAN Truck2Truck (Project RoadArt / Platoon)







2x8 MIMO
channel
measurement



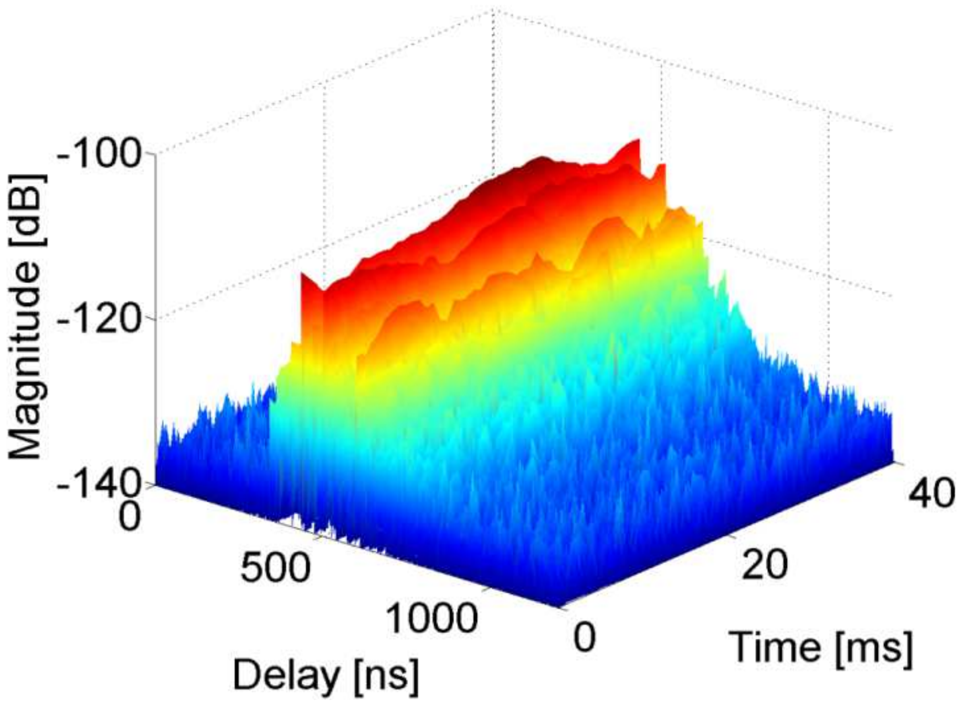
Fraunhofer
Heinrich-Hertz-Institut

V2X Channel Propagation Measurements at 5.9 GHz

Various drive Scenarios (highway, intersection, roundabout, tunnel) with 3 trucks

Tunnel Scenario

Typical CIR measurement between moving vehicles



Tunnel scenario

- Direct outcome of measurement
- Line-Of-Sight Path (LOS) and reflected components (multipath contributions: MPC)
- Channel length: 1µs
- Large-scale fading of MPCs due to RX movement

Thank you for your attention !