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Smart antenna systems for future 6G wireless communications

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29 June 2021

Center for Wireless Technology Eindhoven

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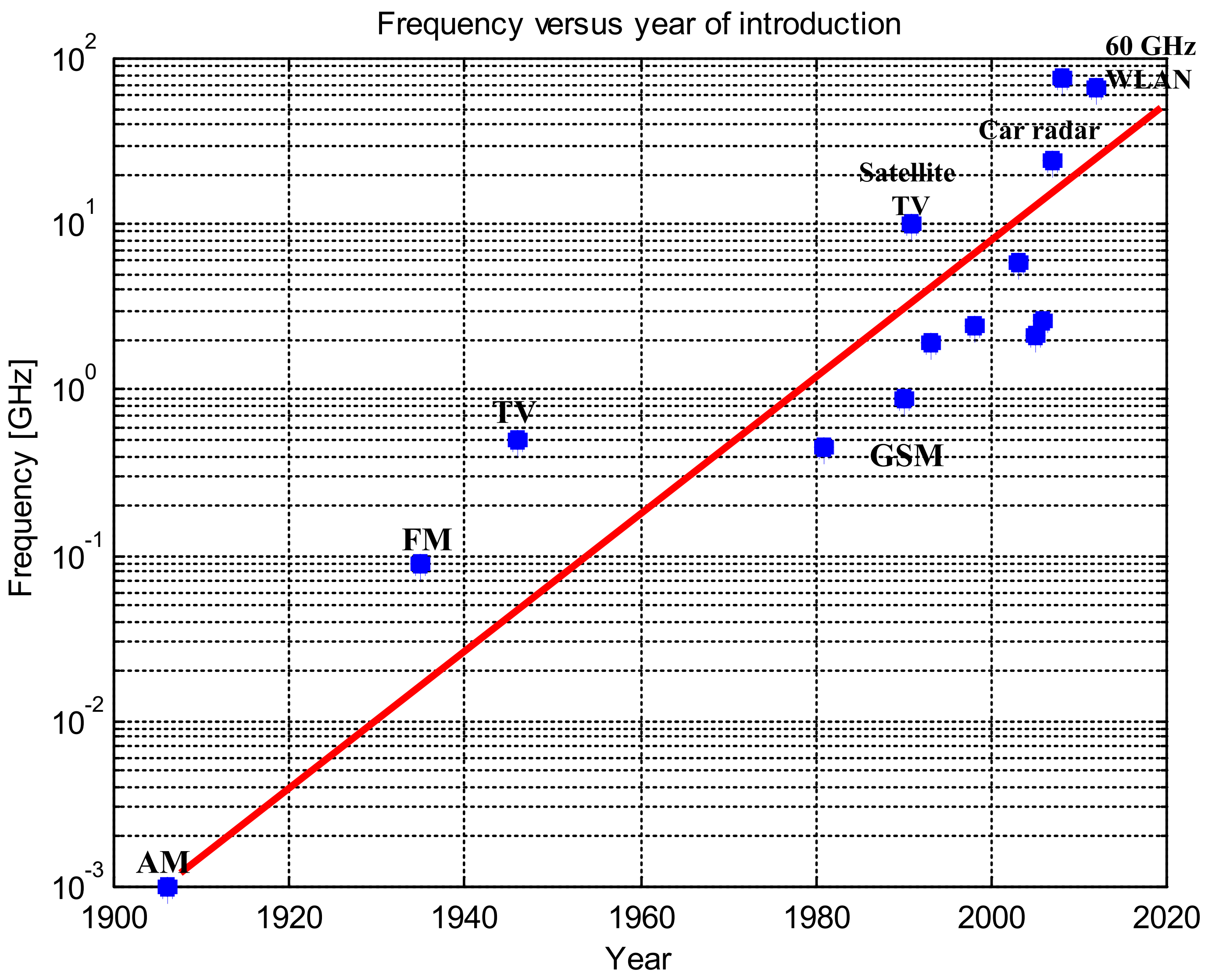
Content

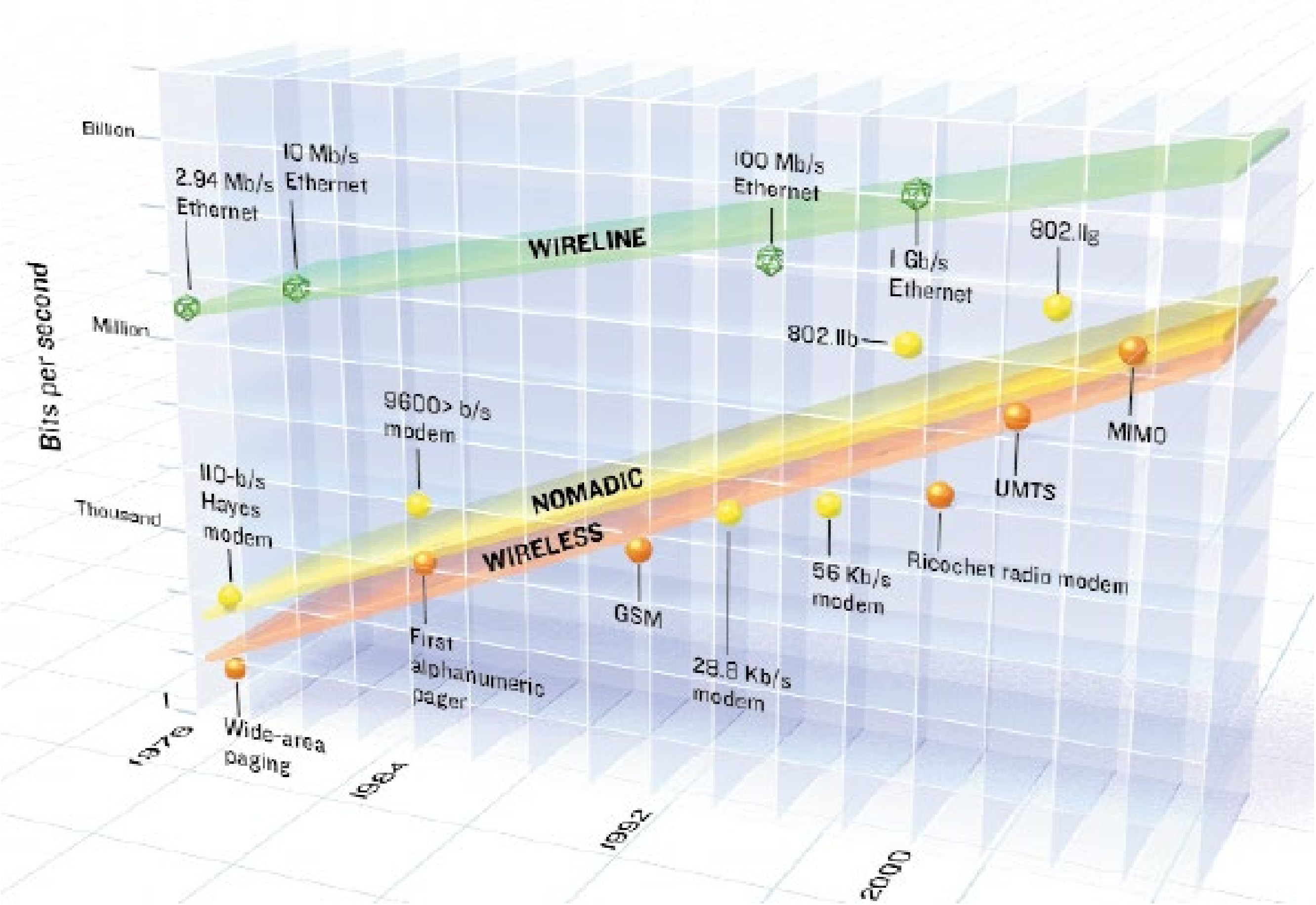
- Trends in wireless communication
- Why do we need smart antennas?
- Overview research activities 5G New Radio
- Outlook towards 6G

Trends in Wireless communications

Trend 1: Increase of operational frequency



Trend 2: Increase in bandwidth:Edholm's Law

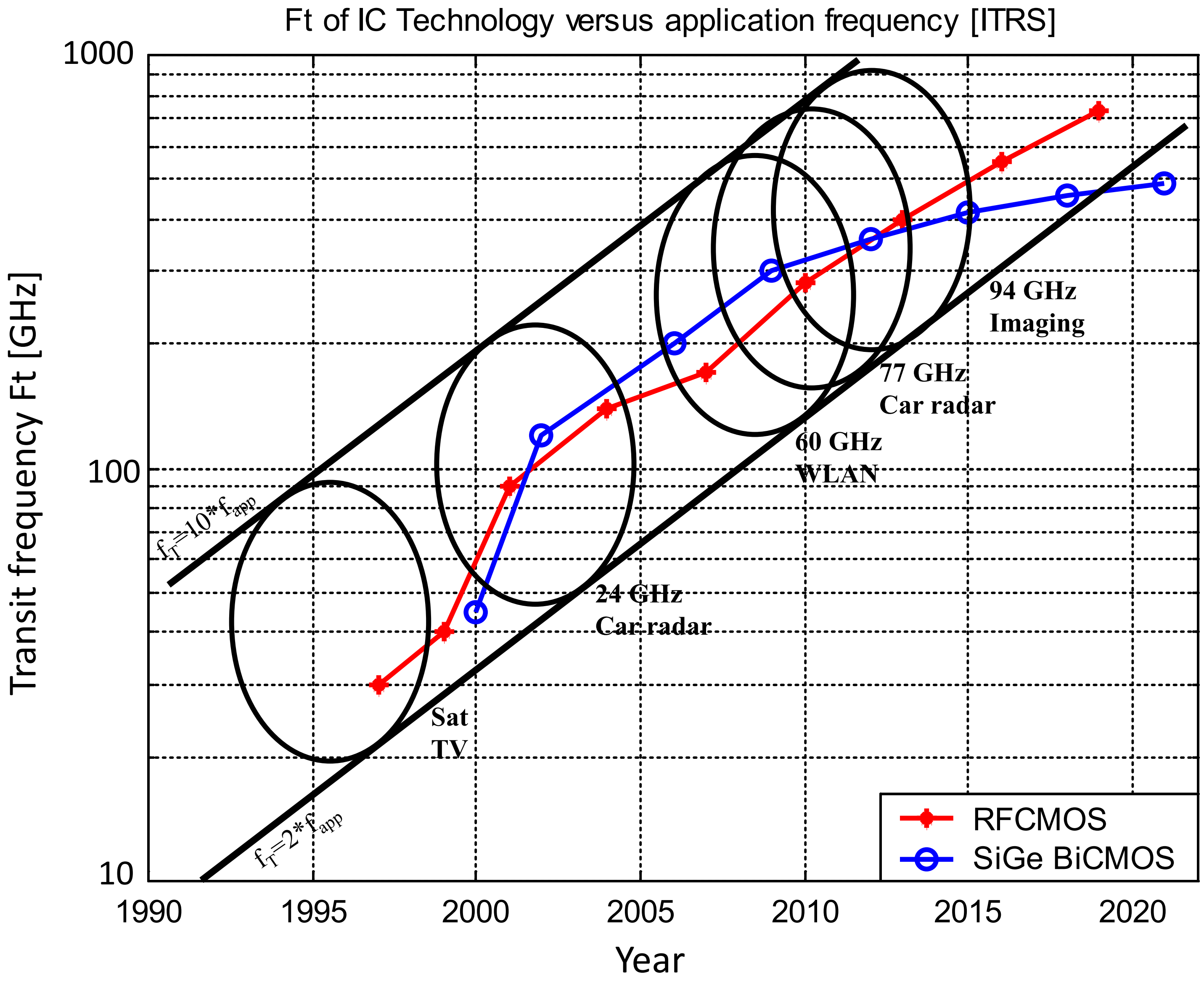


Wireless growing faster than wired

Required Bandwidth/datarate doubles each 18 months

Source: IEEE spectrum, 2004

Trend 3: Improved performance sililcon Technologies



Evolution of wireless standards

1G	2G	3G	4G	5G	6G
The foundation of mobile telephony	Mobile telephony for everone	The foundation of mobile broadband	Mobile broadband enhanced	Embracing a networked society	Enabling a smart sustainable society
~1980	~1990	~2000	~2010	~2020	~2030
1st GENERATION wireless network	2nd GENERATION wireless network	3rd GENERATION wireless network	4th GENERATION wireless network	5th GENERAT… wireles…	…ENERATION …etwork
• Basic Voice service • Analog Based Protocols	• Designed for voice • First digital standards (GSM,CDMA)	• Designed for voice and data • First mobile broadband • Voice through circuit & Data-Packet Switching	• Designed Primarily for Data • IP based protocol • True Mobile broadband.		…ve …d
2.4 Kbps	*64 Kbps*	*2 Mbps*	*100 Mbps*	*10 Gbps*	*1 Tbps*

Compare with Edholms law: factor 2 more BW in 1.5 year 2^(10/1.5)=101

Need for more capacity drives us towards

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The use of higher frequencies enabling “smart antennas”

- Exponential growth of semiconductor content
- Intelligence moves from central office towards the antenna

More computing and network communication required

- More complex digital chips with advanced CMOS (Moore’s law)
- More-than-Moore (e.g. integrated photonics and quantum computing)

Relevance of 5G/6G for NL/EU

Technology point of view

Key enabling technologies for 5G/6G and EU position

Advanced silicon CMOS

- EU semicon companies use fabless model with supply from mainly from TSMC (Taiwan)
- EU doing good job in manufacturing equipment (e.g. super-star ASML)

Specialized semiconductor technologies

- EU has good position in analog and high-frequency technologies such as BiCMOS and III-V technologies

Emerging technologies, e.g. Photonics and Quantum

- From academic (low TRL level) point of view EU has leading position but to scale-up towards actual products we need a strong long-term strategy.

Opportunities for EU towards 6G

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Use strong position EU in

- Telecommunication industry
- Automotive industry
- Specialized semiconductor components

Facilitate building European eco-systems and complete value chains

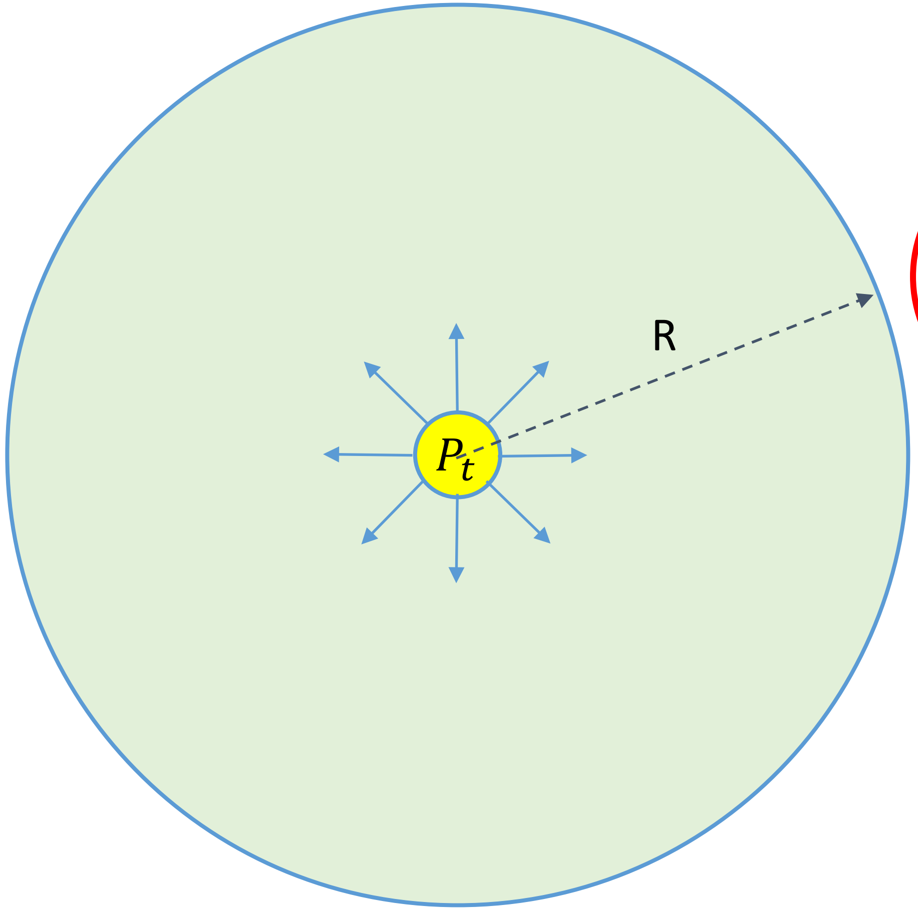
- Scale up of emerging/special technologies (Photonics/Quantum/BiCMOS)
- EU-based manufacturing of advanced CMOS

Define a joint EU 6G Living-lab (Dutch: “proeftuin”)

- Place(s) where technology meets new applications.

Why do we need Smart Antennas?

Spherical wave expansion
from point source

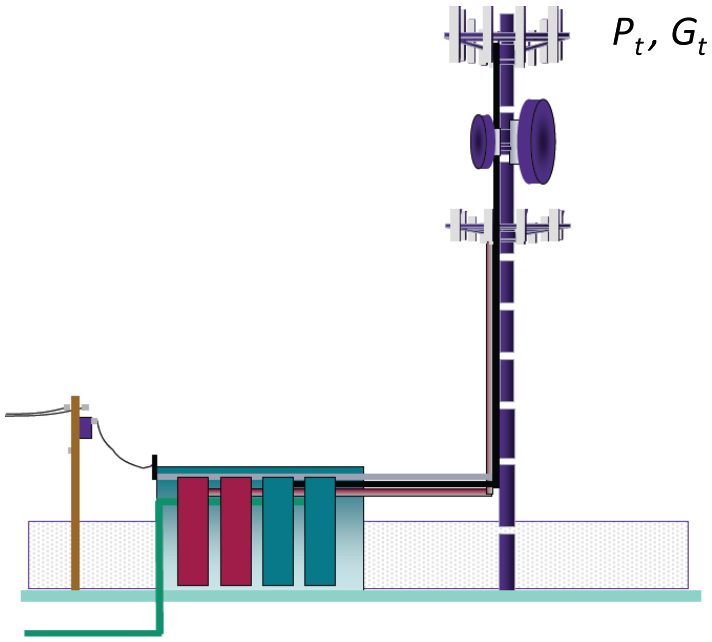


$$S = \frac{P_t}{4\pi R^2}\,[\mathrm{W/m^2}]$$ Power density at distance R

No frequency dependence!

P_t: total radiated power

Downlink, Link Budget



R

P_r, A_e

A_e is frequency dependent!

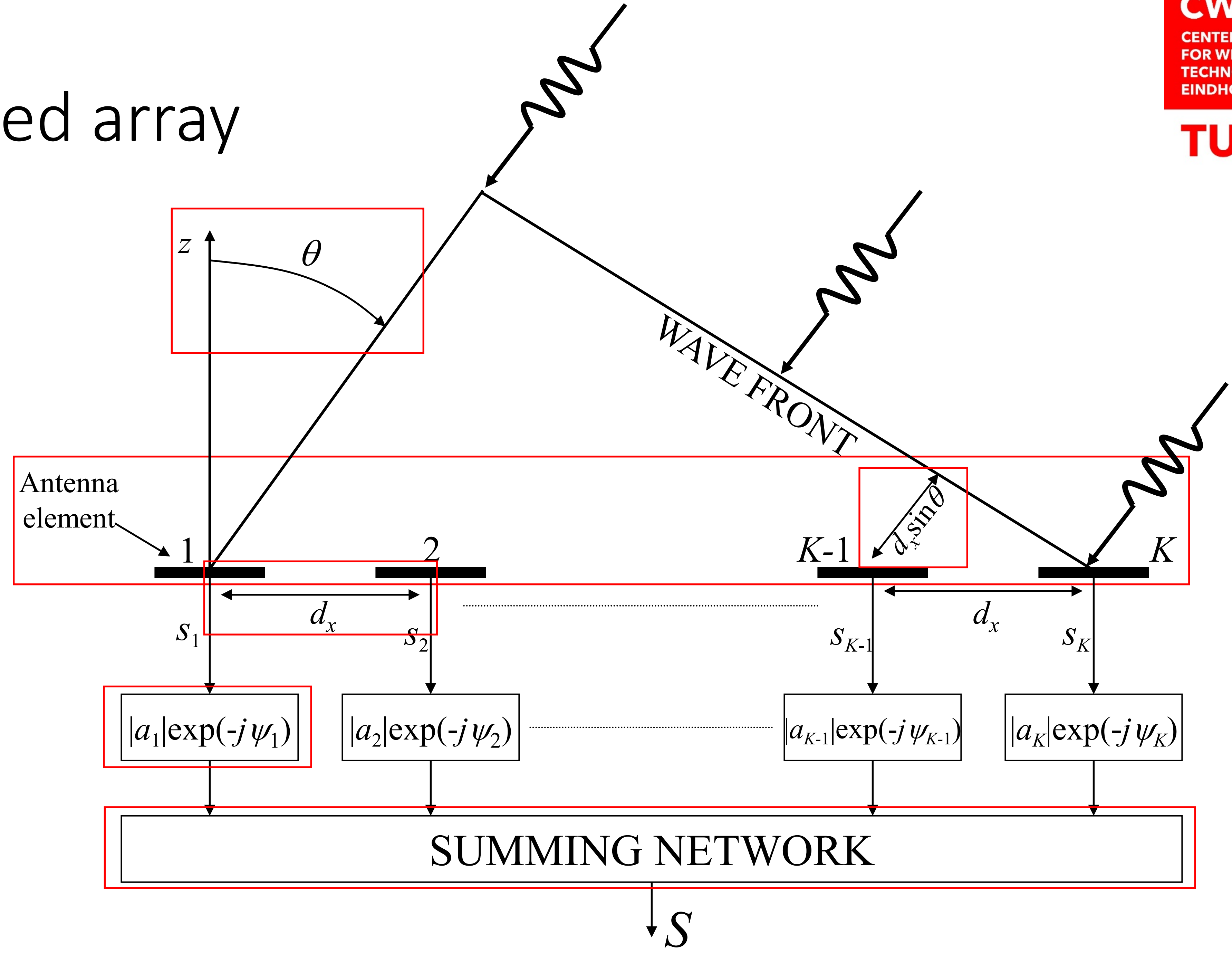
$\lambda_0 = c/f_0$

$$P_r = \frac{P_t G_t A_e}{4\pi R^2} = \frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 R^2} \Rightarrow R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}}$$

Overview Smart antenna research 5G-New Radio Infrastructure

www.silika-project.eu

Linear phased array



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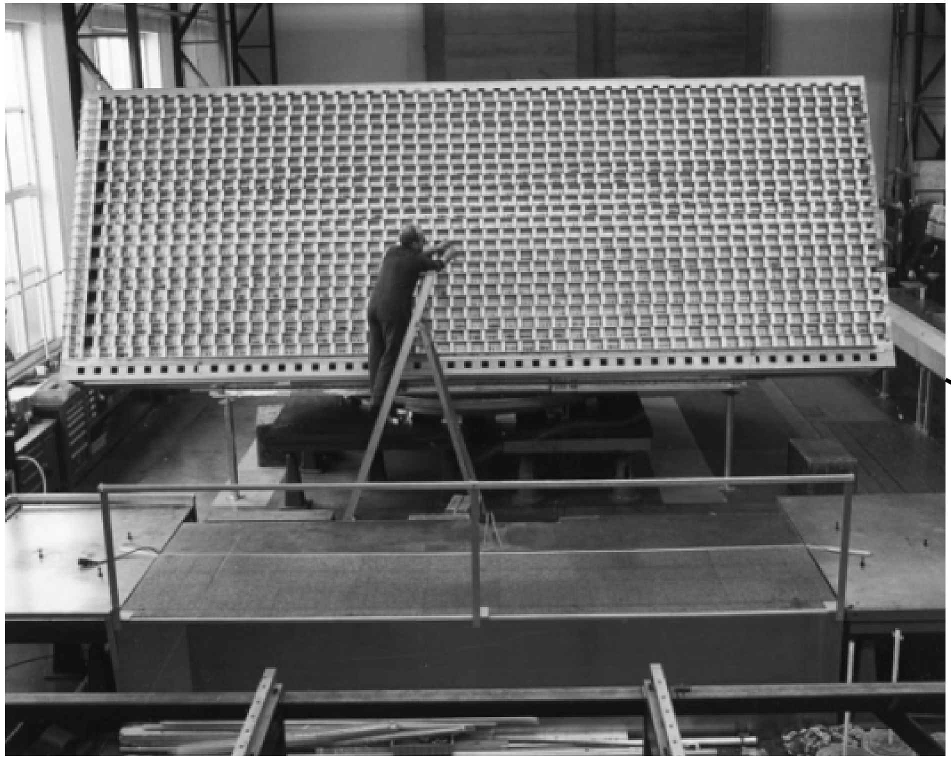
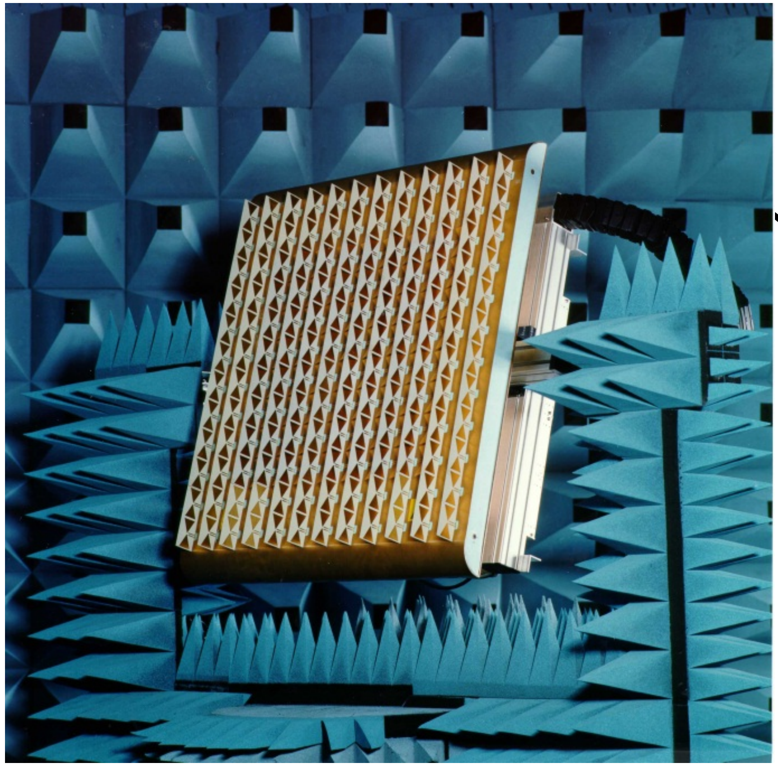
History of phased-arrays (1)



[1] M.C. Van Beurden, A.B. Smolders, IEEE Trans. AP, 2002, pp.1266-1273

History of phased-arrays (2)

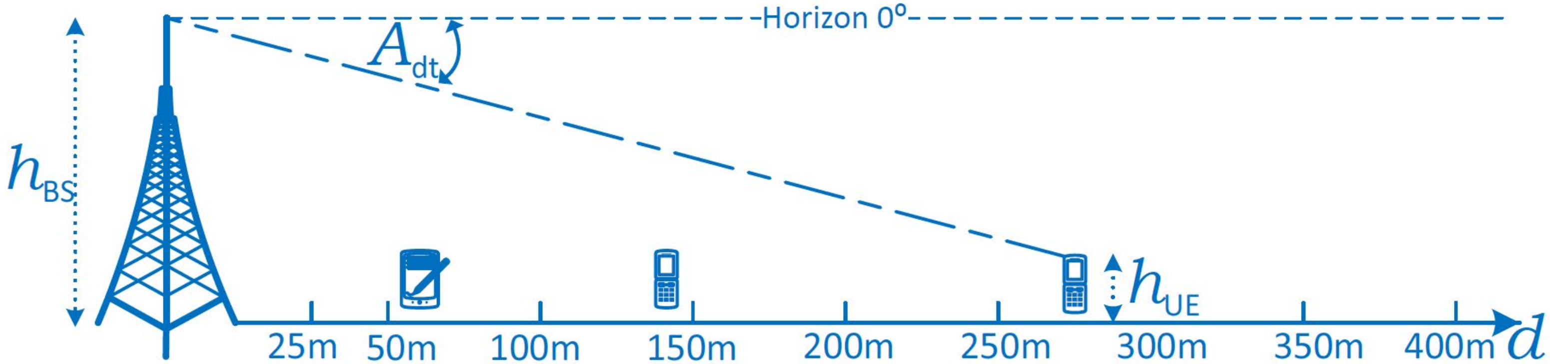
SKA Radio astronomy

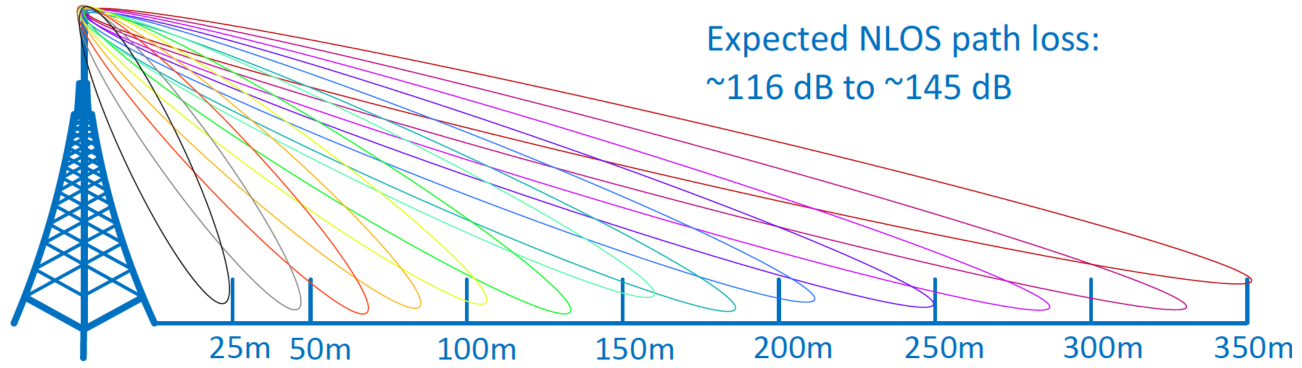


[1] SKA, www.astron.nl
[2] A.B. Smolders, G.Hampson, IEEE AP Magazine, 2002

Base station cell at mm-waves (28.5 GHz)

Scenario: Urban environment





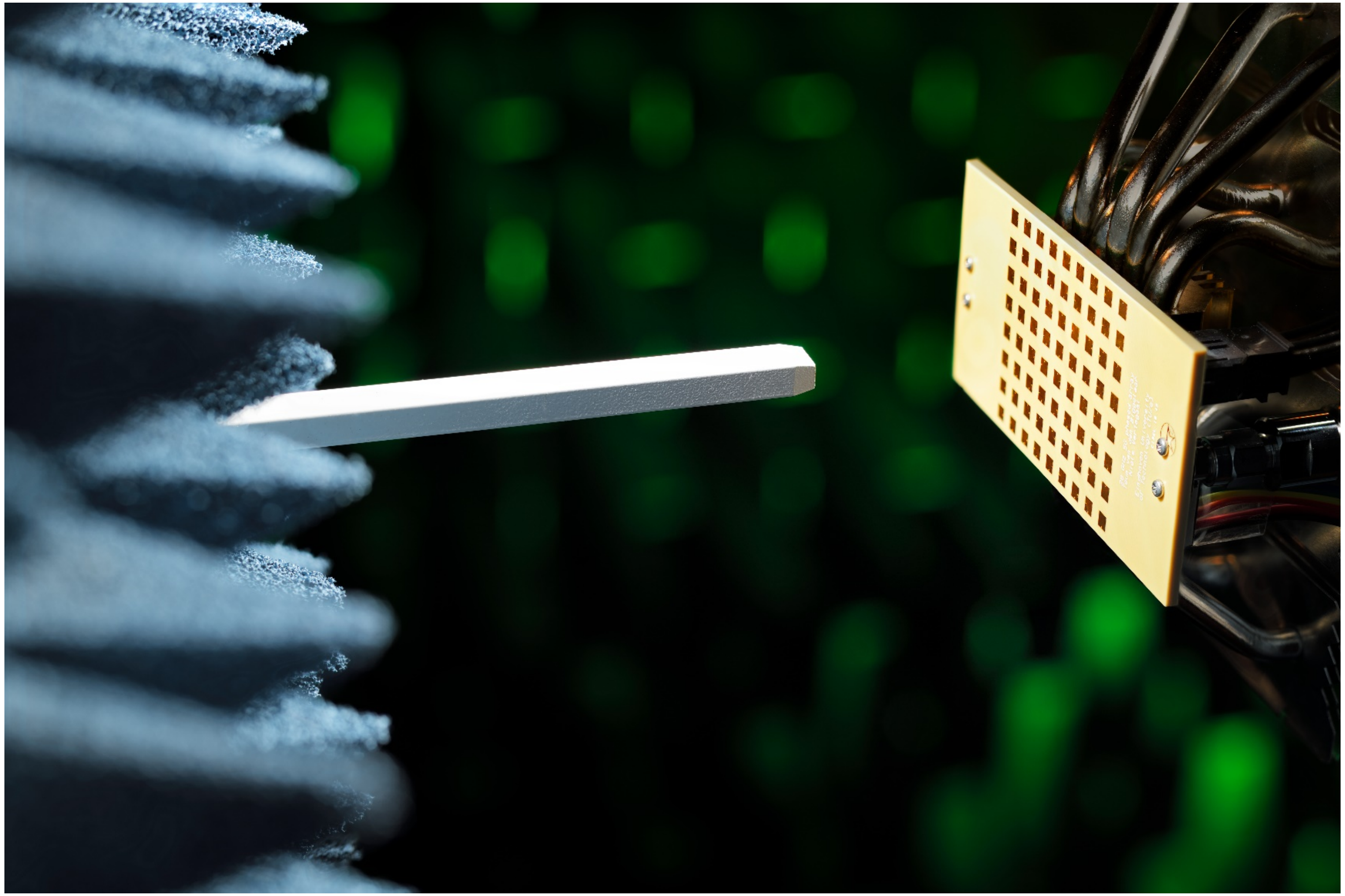
Expected NLOS path loss:
~116 dB to ~145 dB

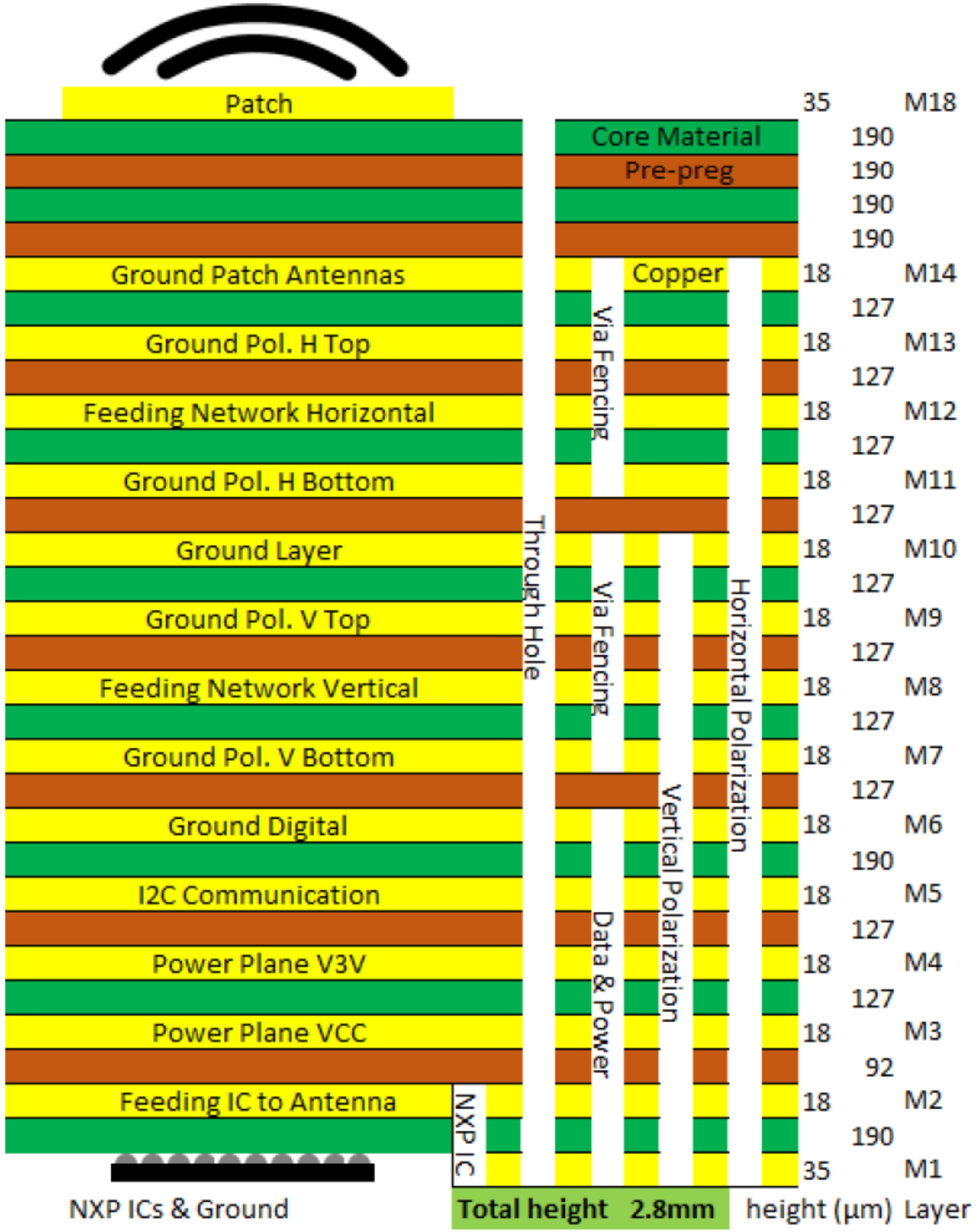
Base station concepts

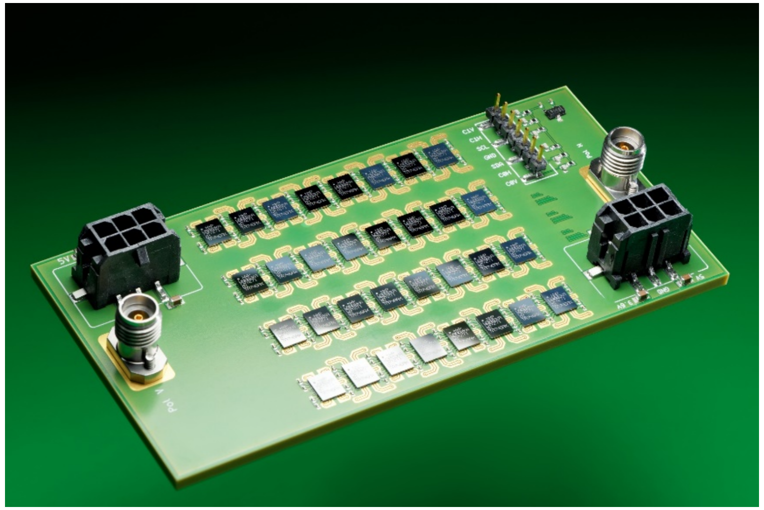
- Dense arrays
  - ++ Wide-scan, full beam control, massive MIMO
  - - - Expensive, power hungry, cooling problem (W/cm^2)
- Sparse arrays
  - ++ Reduced mutual coupling, better thermal management (W/m^2)
  - - - Grating lobes could occur, large in size
- Focal-plane arrays
  - ++ High gain from reflector, limited number of active elements
  - - - limited scan, 3D mechanical structure.

Dense Arrays

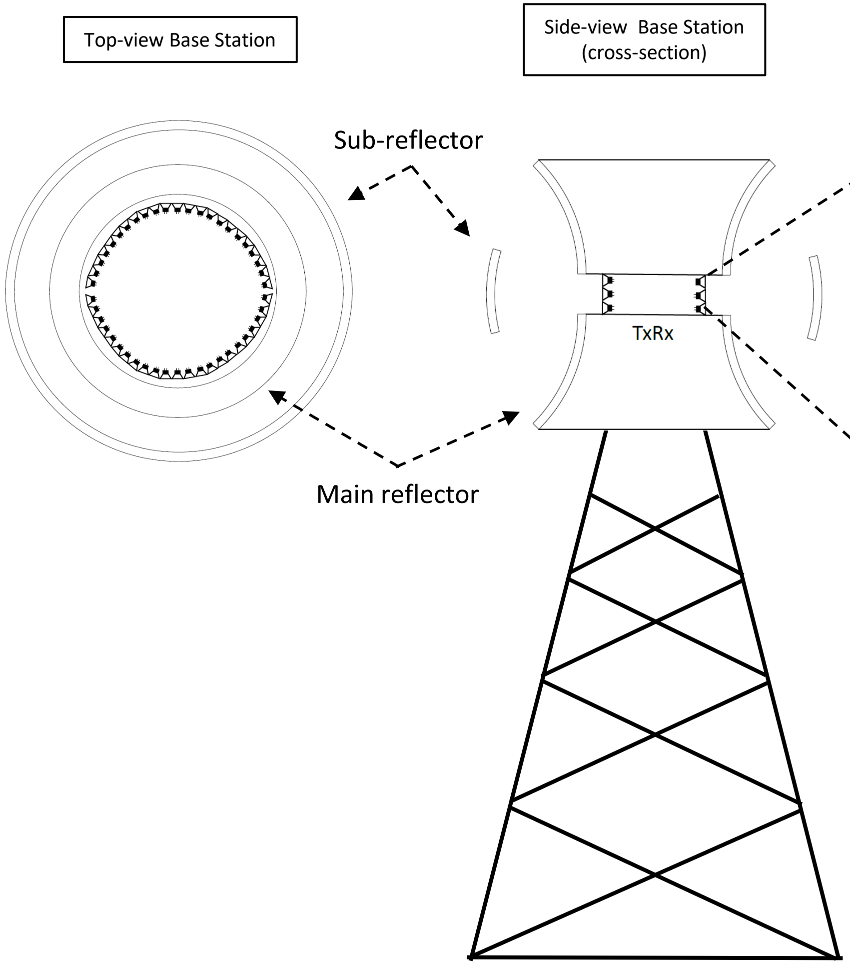
28 GHz dual-polarized active array with BiCMOS ICs

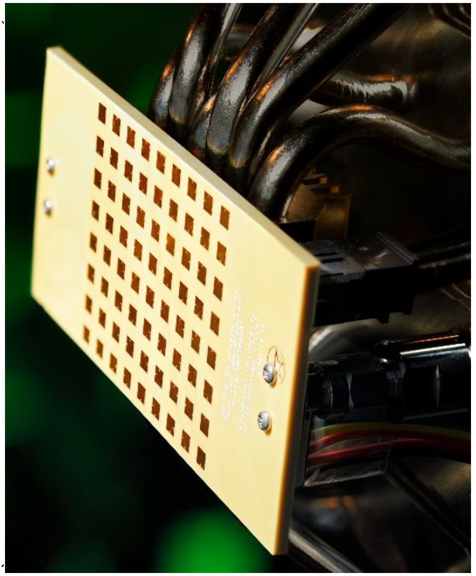



Patch
Core Material
Pre-preg
Ground Patch Antennas
Copper
Ground Pol. H Top
Feeding Network Horizontal
Ground Pol. H Bottom
Ground Layer
Ground Pol. V Top
Feeding Network Vertical
Ground Pol. V Bottom
Ground Digital
I2C Communication
Power Plane V3V
Power Plane VCC
Feeding IC to Antenna
NXP ICs & Ground
Through Hole
Via Fencing
Via Fencing
Data & Power
Vertical Polarization
Horizontal Polarization
NXP IC
Total height 2.8mm
height (μm)
Layer
35 M18
190
190
190
190
18 M14
127
18 M13
127
18 M12
127
18 M11
127
18 M10
127
18 M9
127
18 M8
127
18 M7
127
18 M6
190
18 M5
127
18 M4
127
18 M3
92
18 M2
190
35 M1



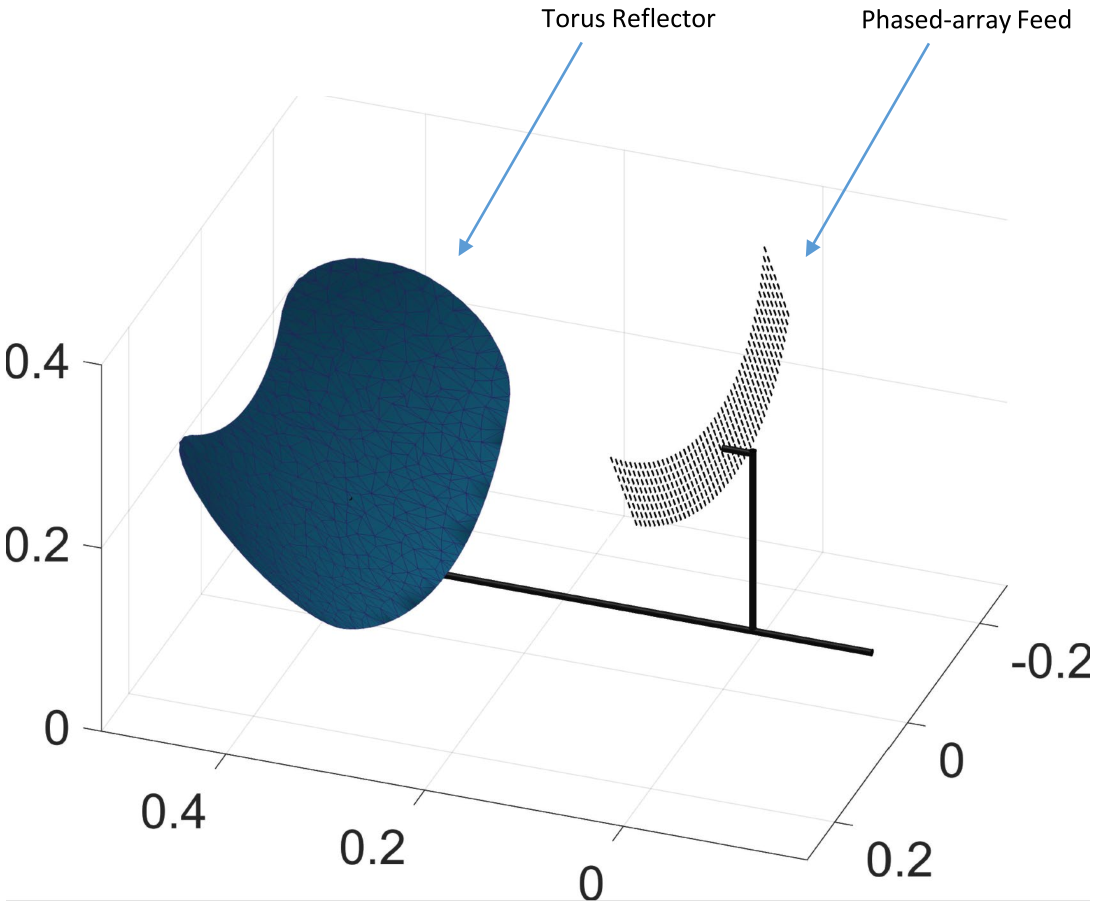
Focal-Plane Arrays

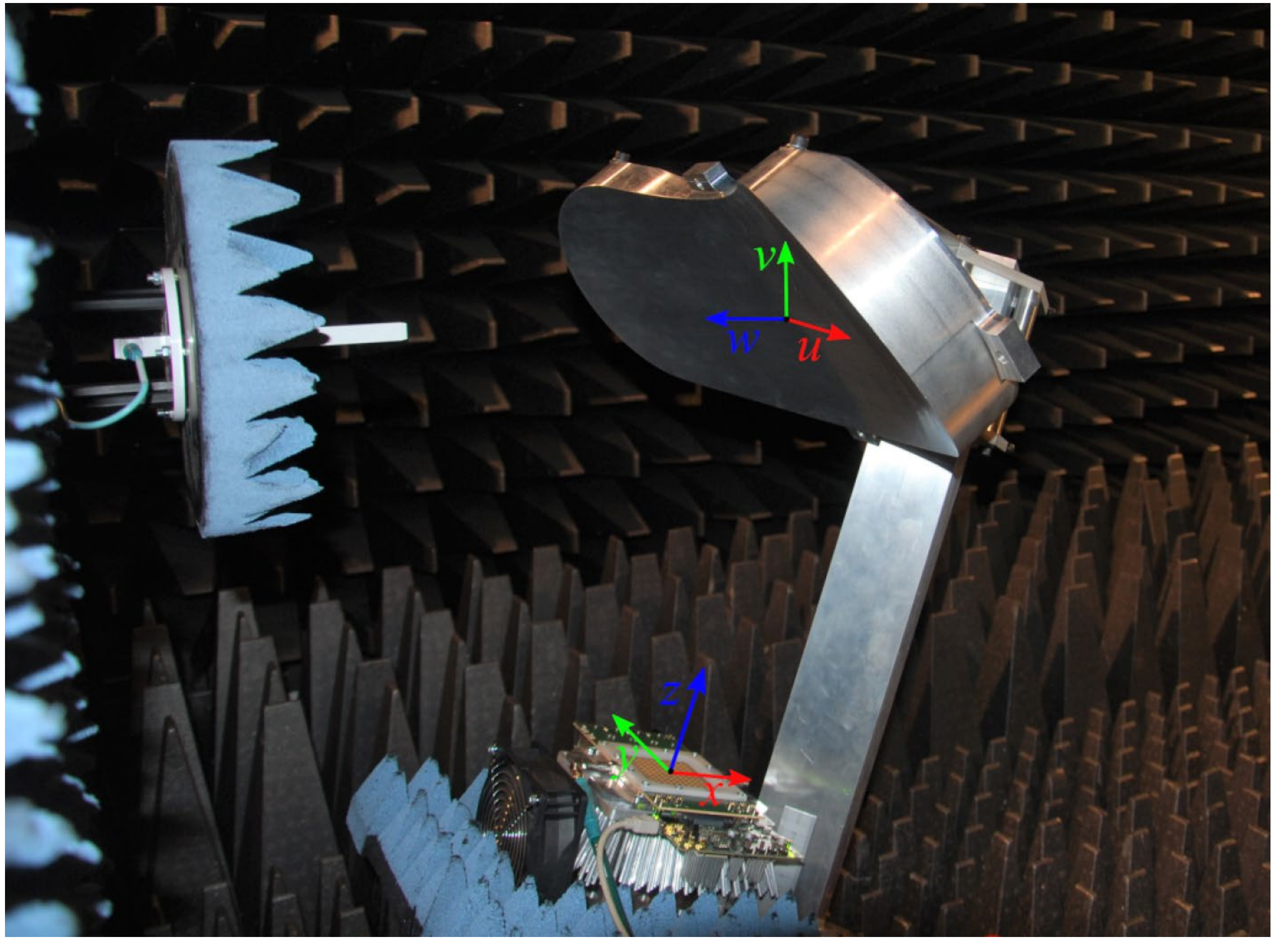




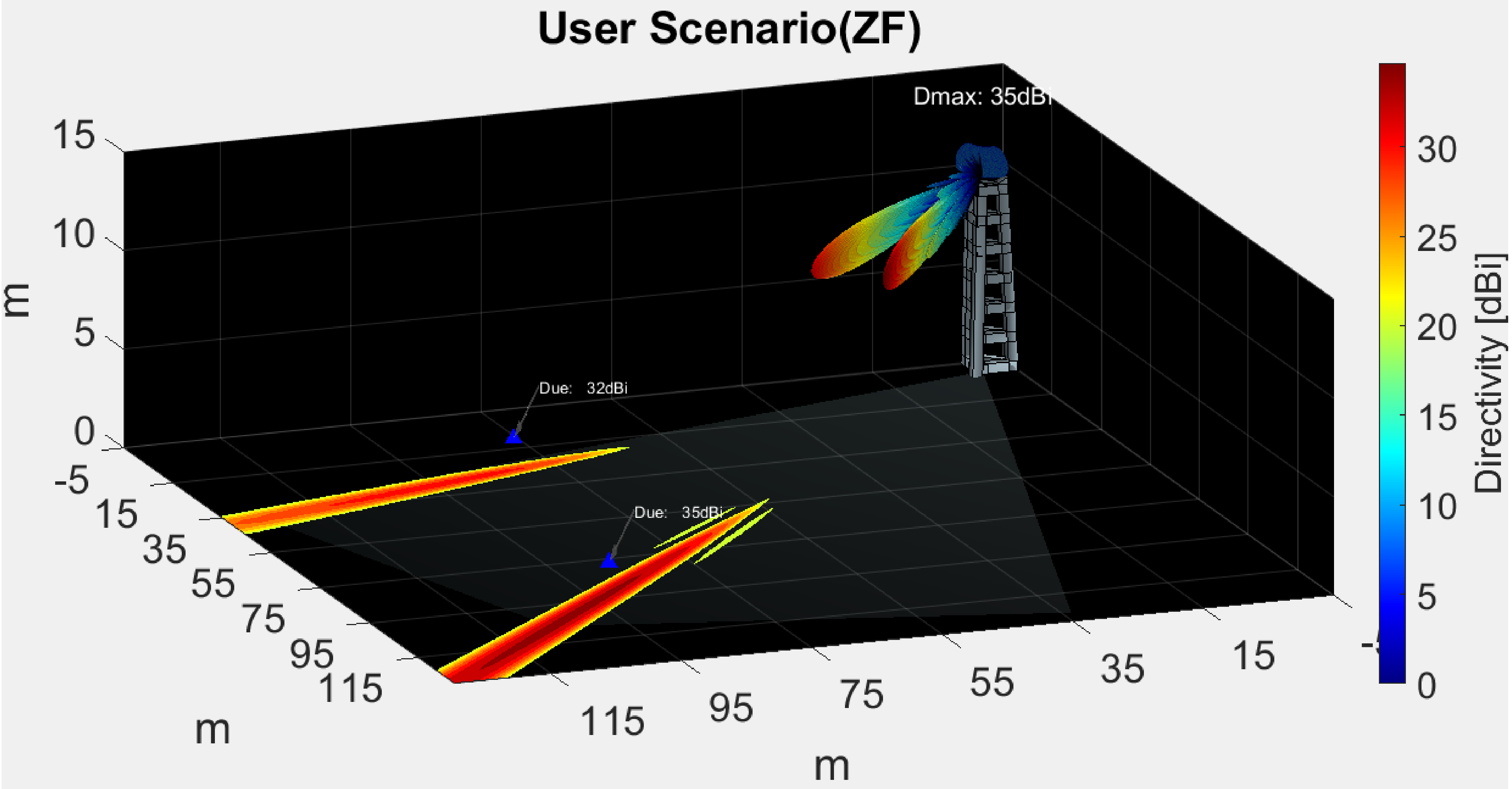
Focal-Plane Arrays

Torus wide-scan reflector operating at 28 GHz





System-level verification of concepts



Sparse arrays using highly-directive antennas

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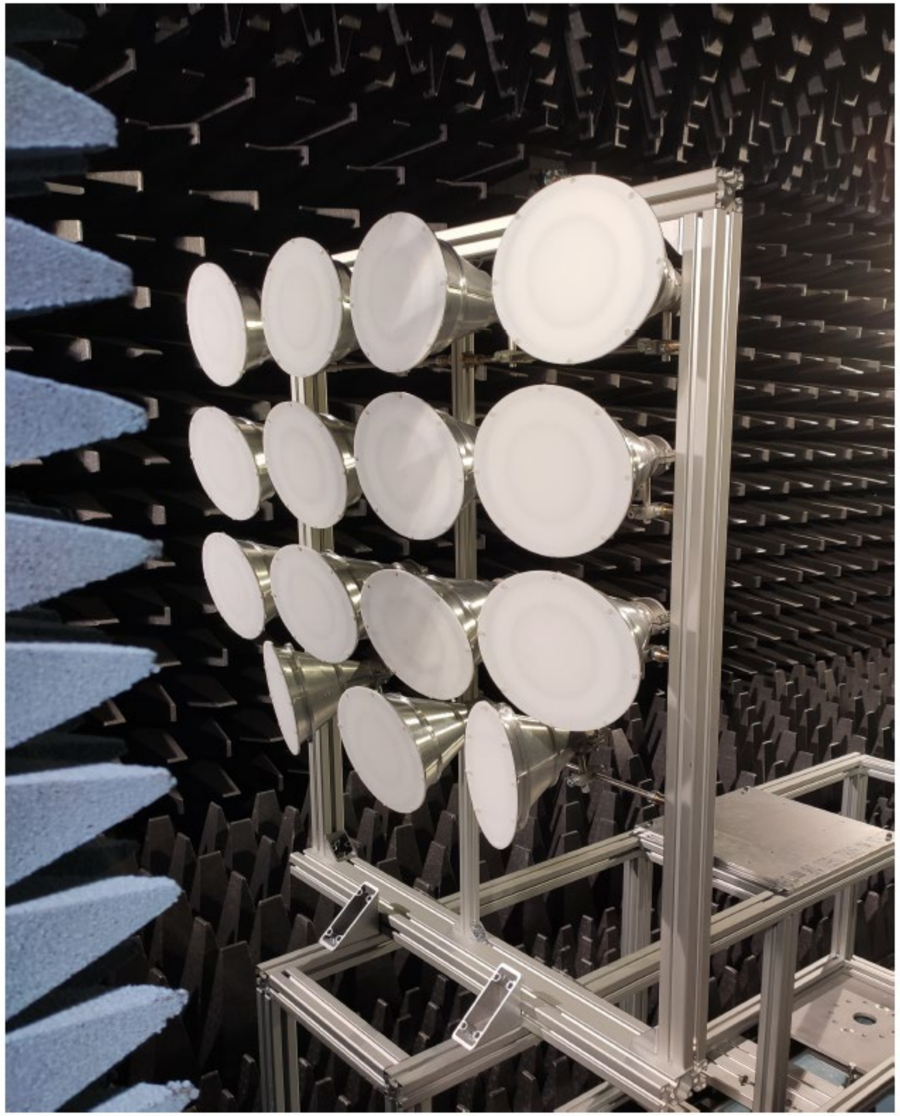
Dual polarized lens-horn antenna
n257 band (26.5-29.5 GHz)

Fresnel-lens

Elliptical horn

Coax-to-waveguide adapter



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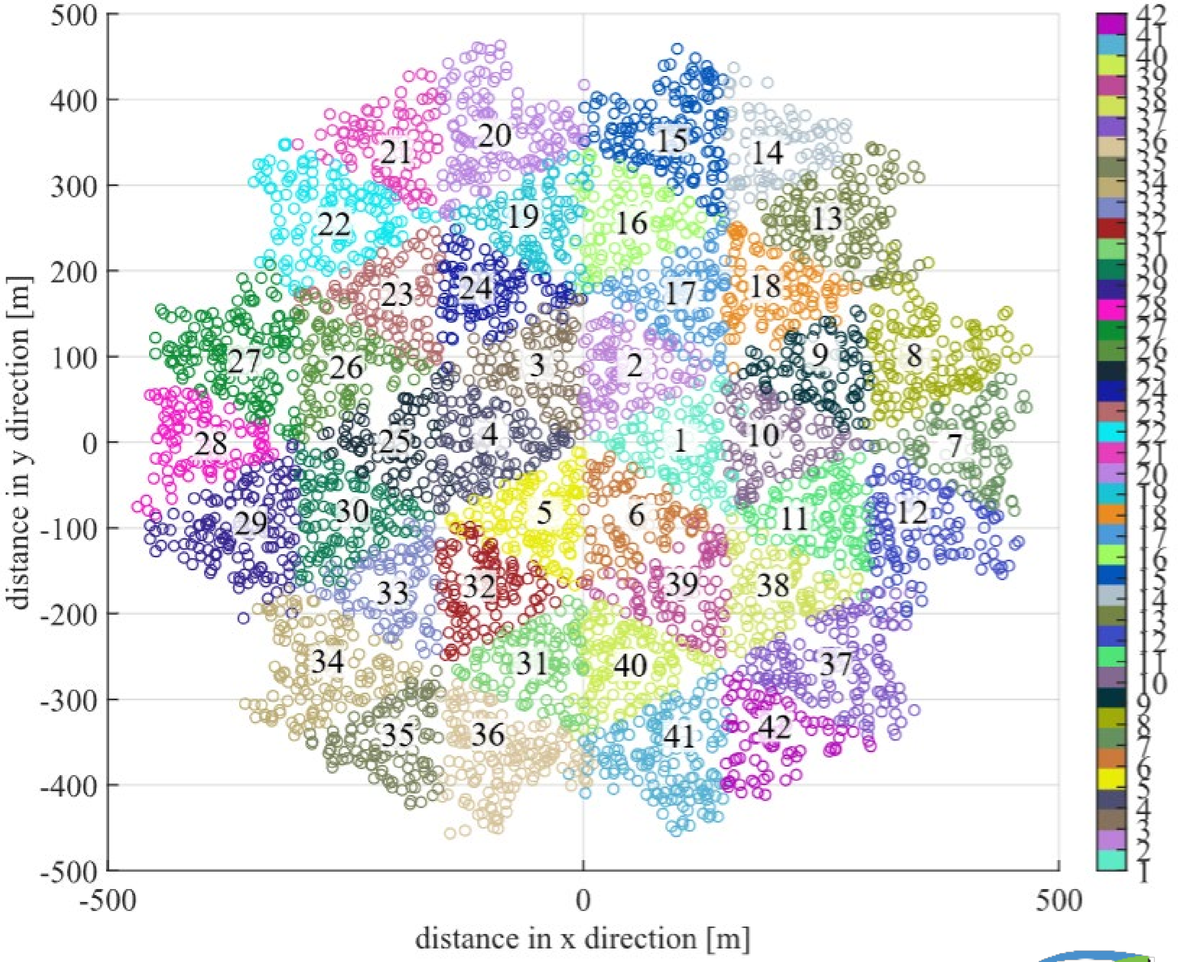

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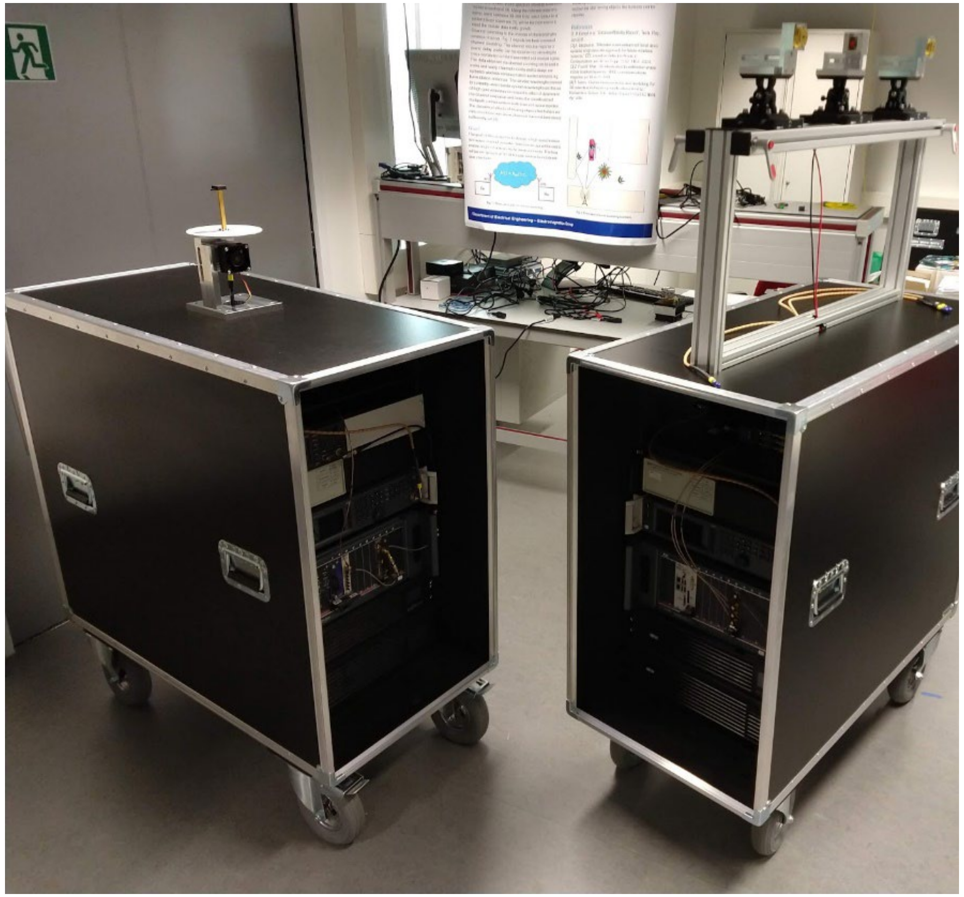
Millimeter-Wave Channel Sounding

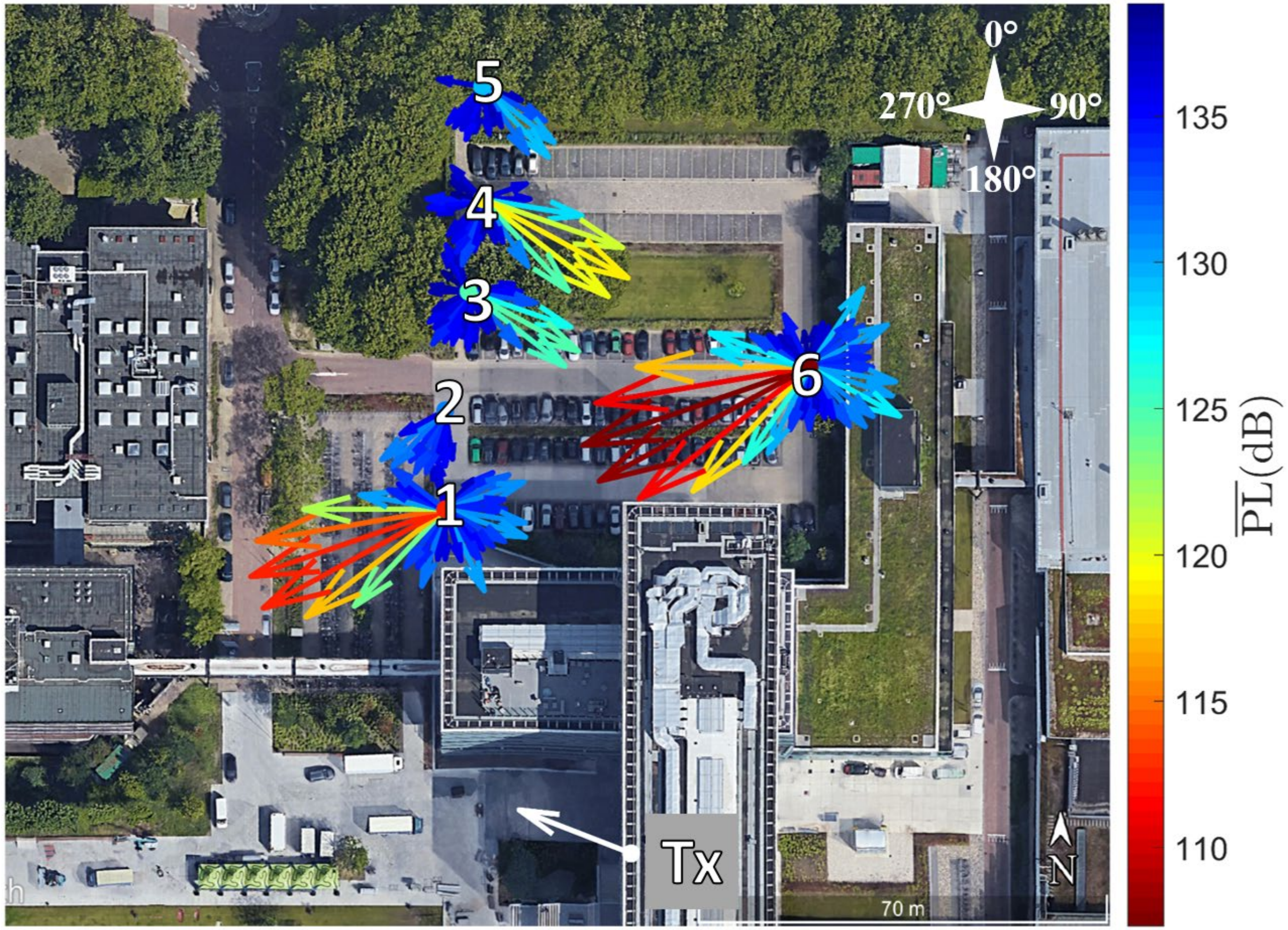


Typical Performance:

- Three Tx channels at 49 dBm EIRP
- One omnidirectional receiver
- Unambiguous range: 3km
- Range resolution: 0.1m
- Dynamic Range: 20dB
- Max. speed: ~50km/h
- Speed resolution: ~2km/h
- Measurement interval: 0.2s

R. Schulpen et al., "5G Millimeter-Wave NLOS Coverage Using Specular Building Reflections," EuCAP2020

Millimeter-Wave Channel Sounding

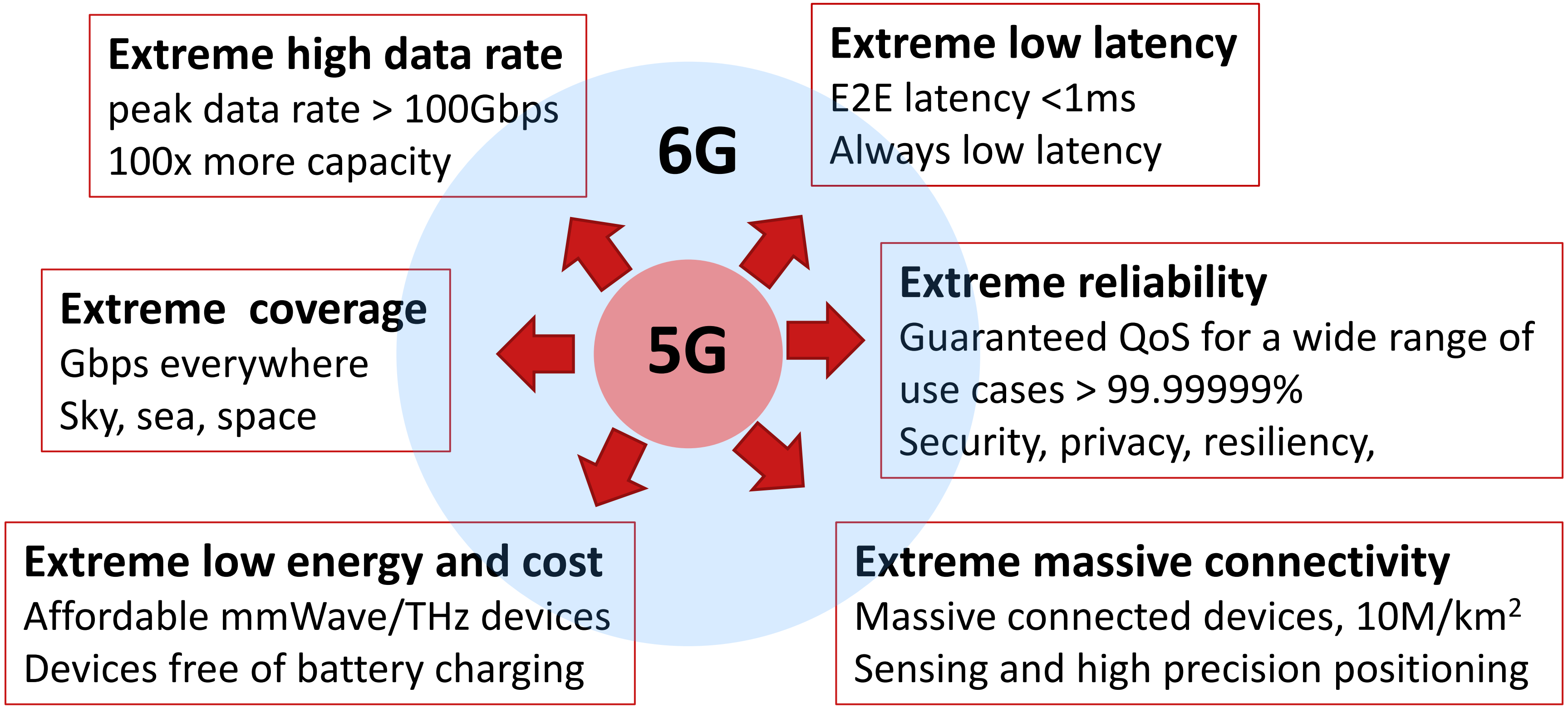


R. Schulpen et al., "5G Millimeter-Wave NLOS Coverage Using Specular Building Reflections," EuCAP2020

Outlook towards 6G

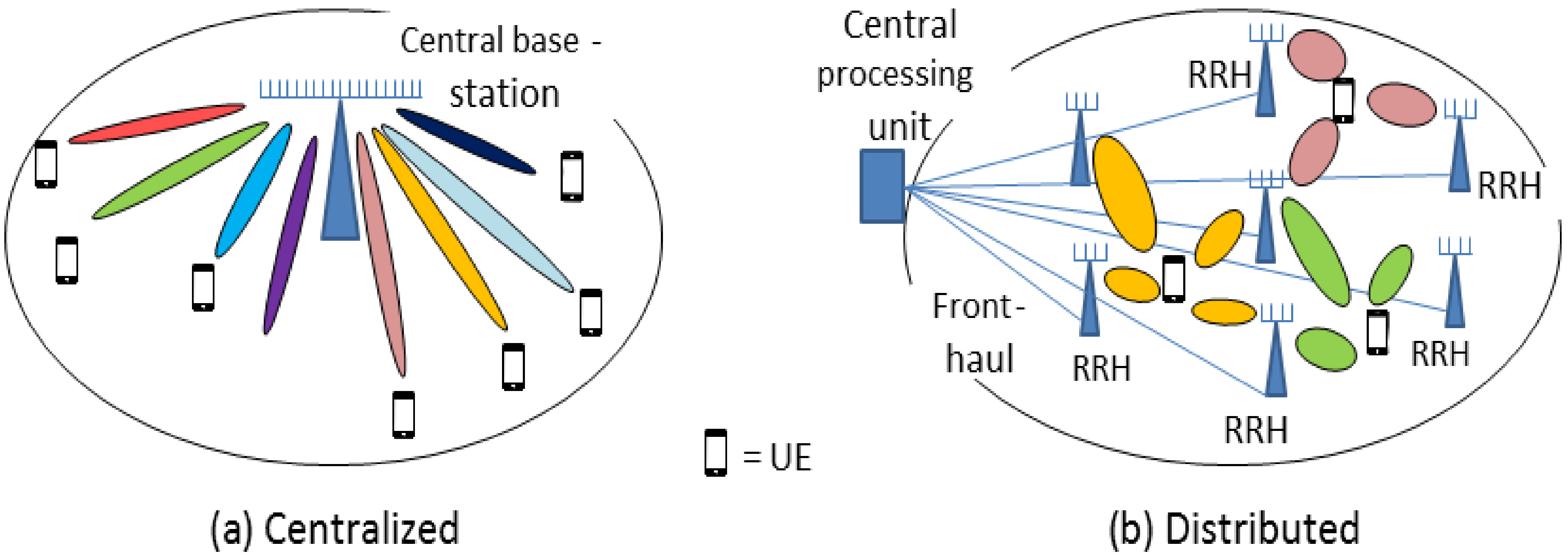
System and Requirements

Requirements for 6G

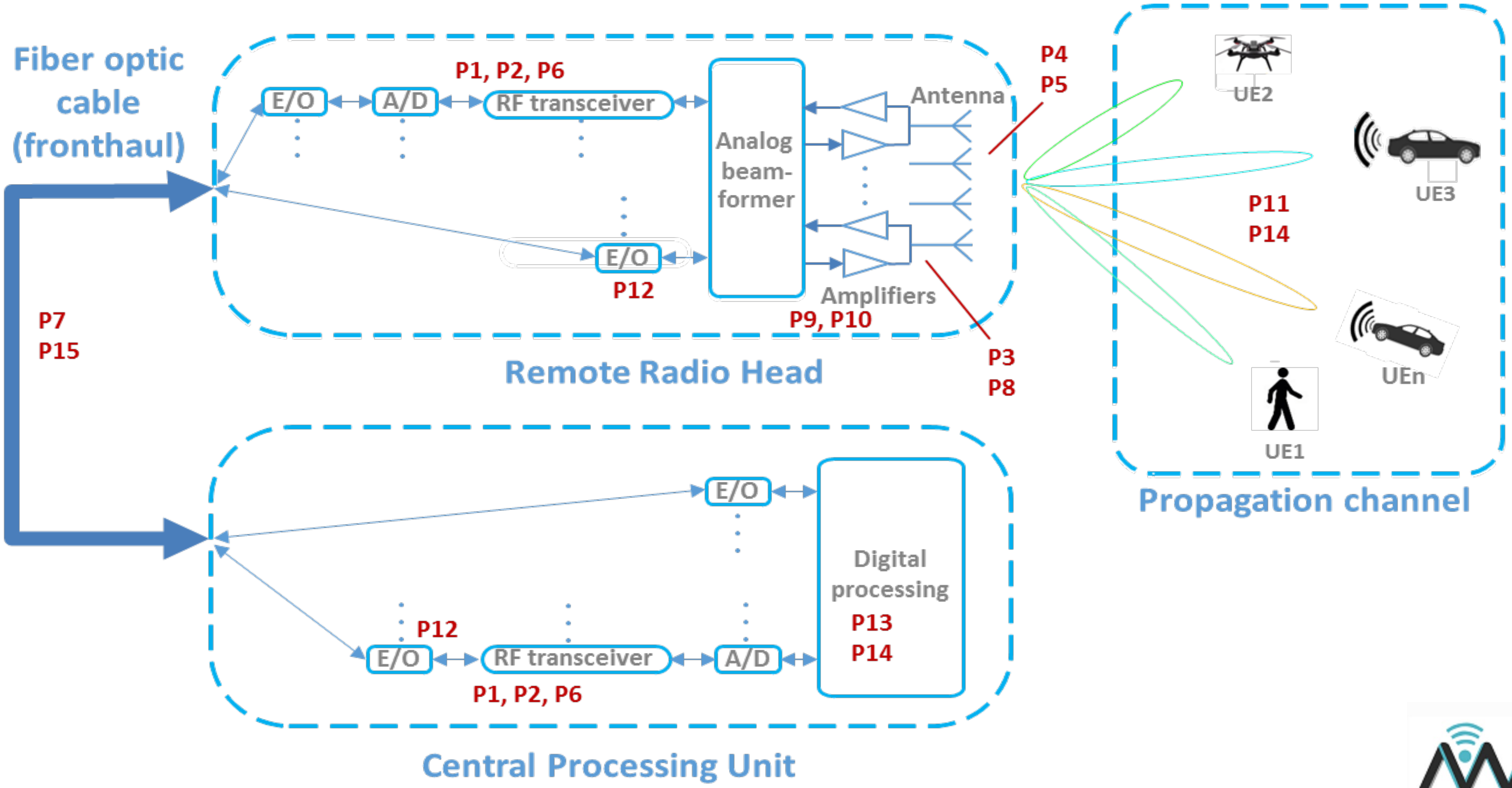


Source: 5G Evolution and 6G, NTT DOCOMO, 2020

Distributed Massive MIMO



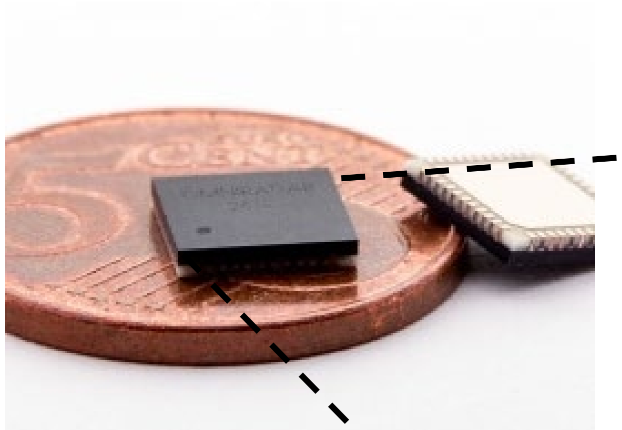
MyWave – Project Overview

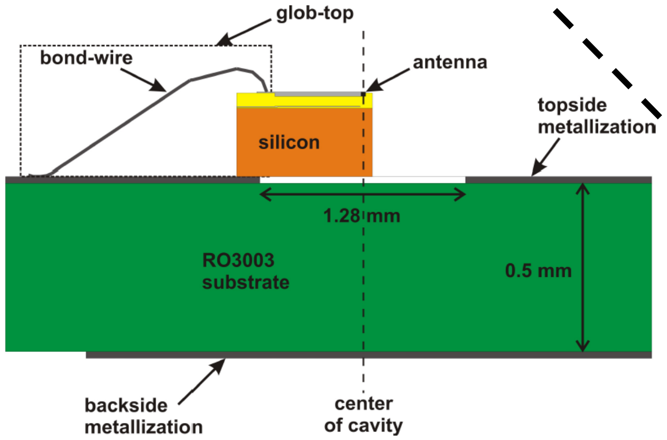


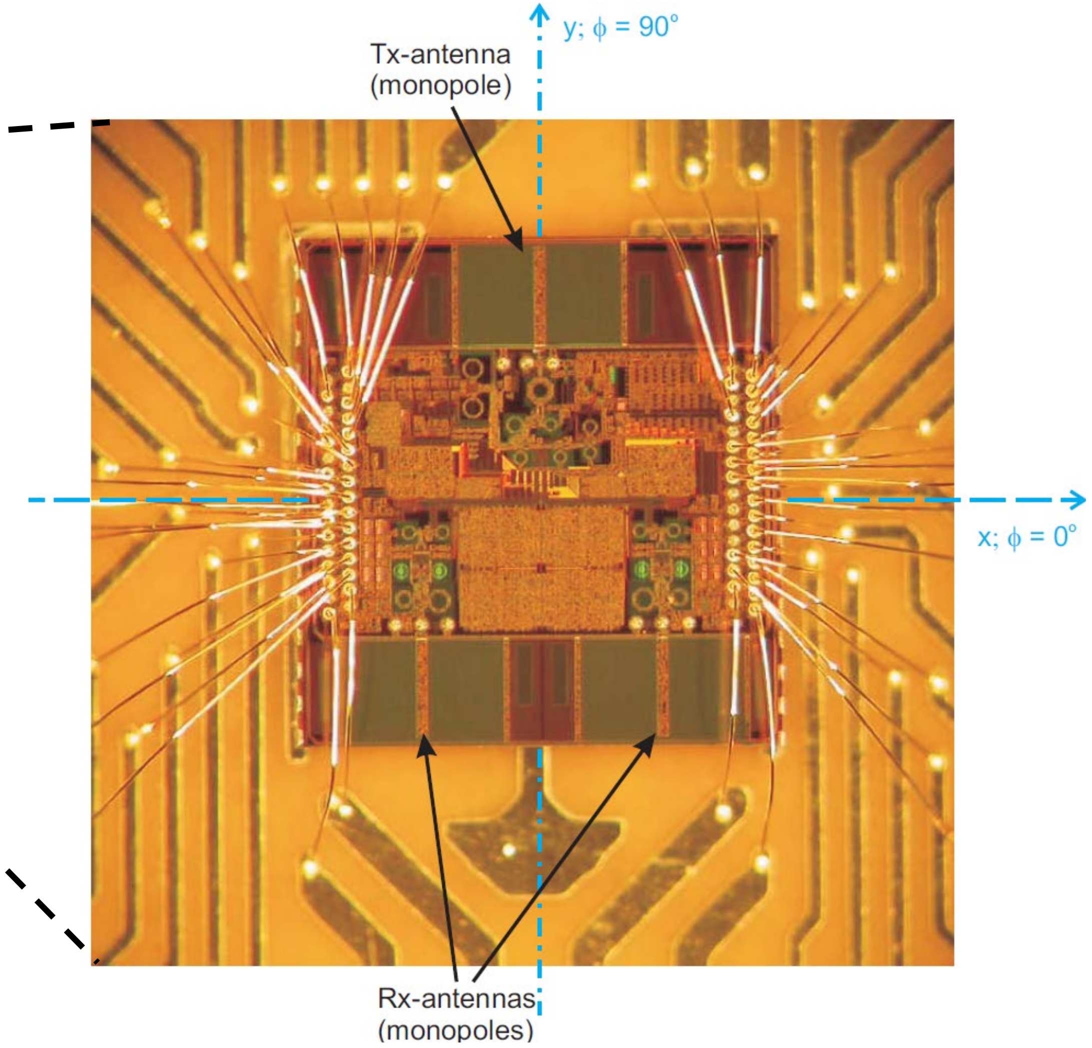
Outlook towards 6G

Antenna Integration Technologies

Single-chip 60 GHz FMCW radar



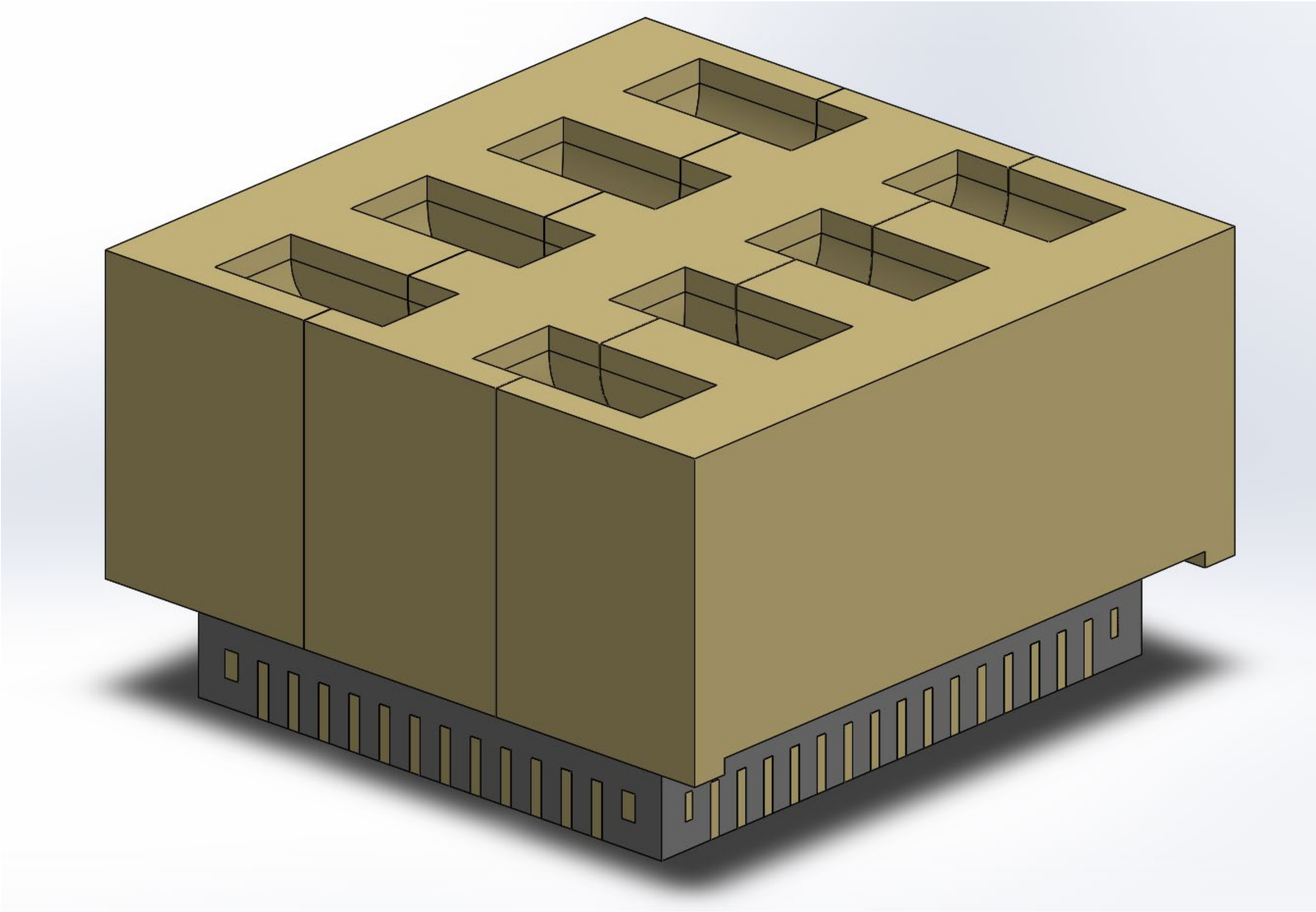




B. Adela; P.van Zeijl; U. Johannsen; A. B. Smolders "On-chip Antenna Integration for Millimeter-wave Single-chip FMCW Radar, Providing High Efficiency and Isolation" IEEE Transactions on Antennas and Propagation Year: 2016.

Low loss transition: Integrated waveguides

Antenna-in-Plastic-Package (AiPP)



Outlook towards 6G

Test and characterization facilities

Integrated antenna test-facility at TU/e

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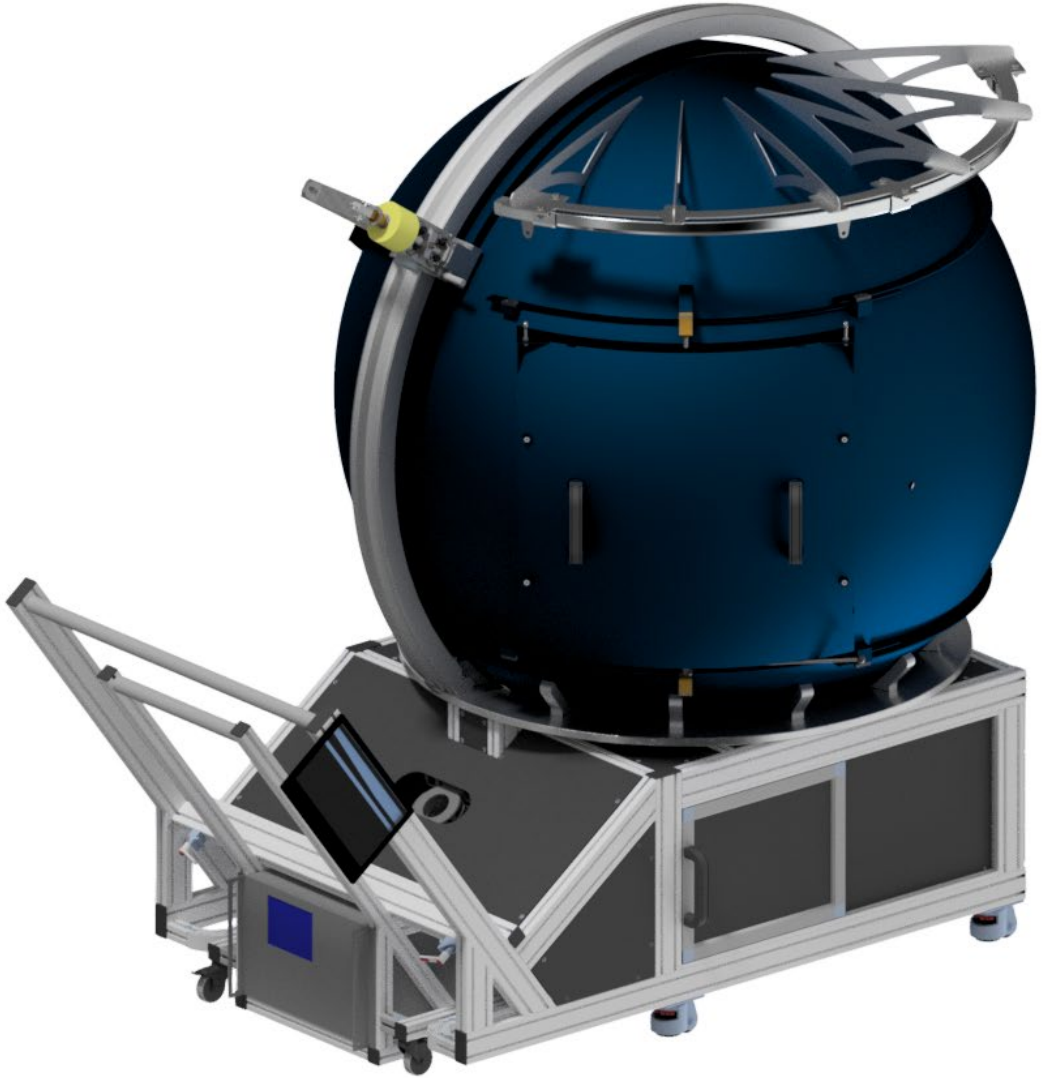
2021 Version (6G)



ANTENNEX

Summary

- 6G will use mm-wave frequencies up to 100 GHz and beyond
- Distributed Massive-MIMO
- Highly integrated antenna concepts are required
  - Existing concepts are too power hungry and far to expensive
  - Aperture sharing
- Measurement of integrated antennas is research topic

Thank you !

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Back-up