RavenStar™ Active Antenna RU

One Aperture, One Solution: Wideband Active Antenna Performance Across 600 MHz to 7 GHz

ISART - August 13th, 2026

Disclaimer

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Agenda

- Battelle Overview
- O-RAN architecture
- Array Overview
- Planewave Testing
- RavenStar testing and results

- At >$13B in annual revenue, Battelle is the world's largest nonprofit research & development organization
- Business pillars: Contract Research, Laboratory Management, STEM Education
- Serving Health & Consumer; Environment & Infrastructure; Global & National Security, and Laboratory Management
- Our Mission: to translate scientific discovery and technology advances into societal benefits
- 501(c)3 charitable trust formed in 1923 by the will of Gordon Battelle to conduct R&D for the benefit of humankind
- Percentage of profit reinvested in science, technology, education, philanthropy

Decades of innovation having an impact today

1929
Battelle Established

1929
Aluminum Foil

1939
Armor Plating

1949
Nautilus

1959
Xerography

1965
Universal Product Code

1974
Compact Discs

1987
PIRI

1991
Battelle Technologies in Desert Strom

2001
RareCyte

2006
STEM Education

2008
Bio-Based Plasticizer

2011
Battelle HeatCoat™

2012
Battelle LS10™ Liquid Bottle Scanner

2013
Resource Effective Bio-Identification System (REBS)

2014
Battelle NeuroLife®

2014
Battelle DeviceSecure®
Battelle Exact ID®

2015
Battelle DroneDefender™
Battelle CANProtect™

2020
Battelle RAICS™
COVID-19 Diagnostics and Vaccines; CCDS™

2021
Biosecurity & Pandemic Preparedness

2023
RavenStar™

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History of RavenStar™

- Battelle funded
- DoD funded
- DoC funded

Design for Manufacturing (DFM) to Enable Commercial Deployment

Aperture / Digital Interface Physics Proven in Lab

Improved Fieldable Design for ISR and 5G

ORAN / ultra-wideband massive MIMO, digitally steered radio unit

Development of Multi-mission RavenStar™ Systems for Federal Customers

5G N77 Small Cell

2012-2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

IR&D

1st Lab Design
800 MHz-5 GHz

1st DFM
700 MHz-6 GHz

Prototype
700 MHz-9 GHz

Ku POC
100 MHz-20GHz

5G Panel
600 MHz-7.125 GHz

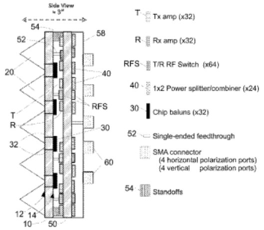
5G NSA
Dual Band Small Cell

TDD / FDD

TRL / MRL+ / COTs

Battelle begins to advance a new antenna

Battelle demonstrates novel features are possible



Battelle files patents on significantly improved design and architecture

Battelle begins to expose RavenStar™ tech to 5G community

Prove function in real environment

Product dev roadmap launched to drive RavenStar™ 5&6G product portfolio

Successful independent assessment of over the air end-end connectivity at VT ARC Range

Long duration 5G test in Santa Rita, AZ proves components and architecture function in permanent outdoor fixture

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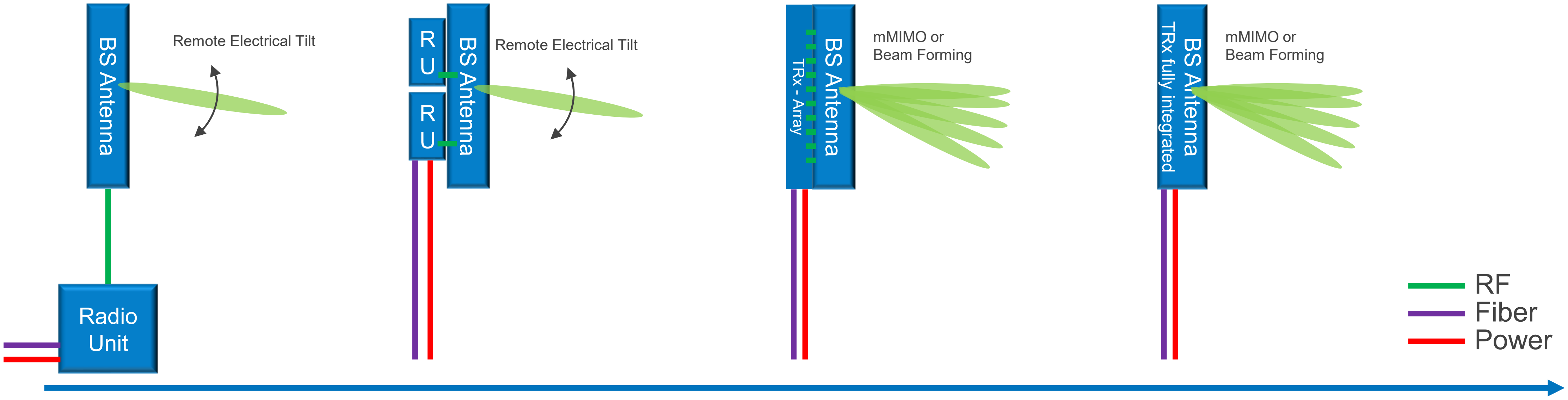
The evolution of base station antennas



Huge variety of multi-band configurations

Short RF connection on active part → enhanced RF performance; Passive ports still available

AAS only; limited number of bands; Internal RF ports for testing

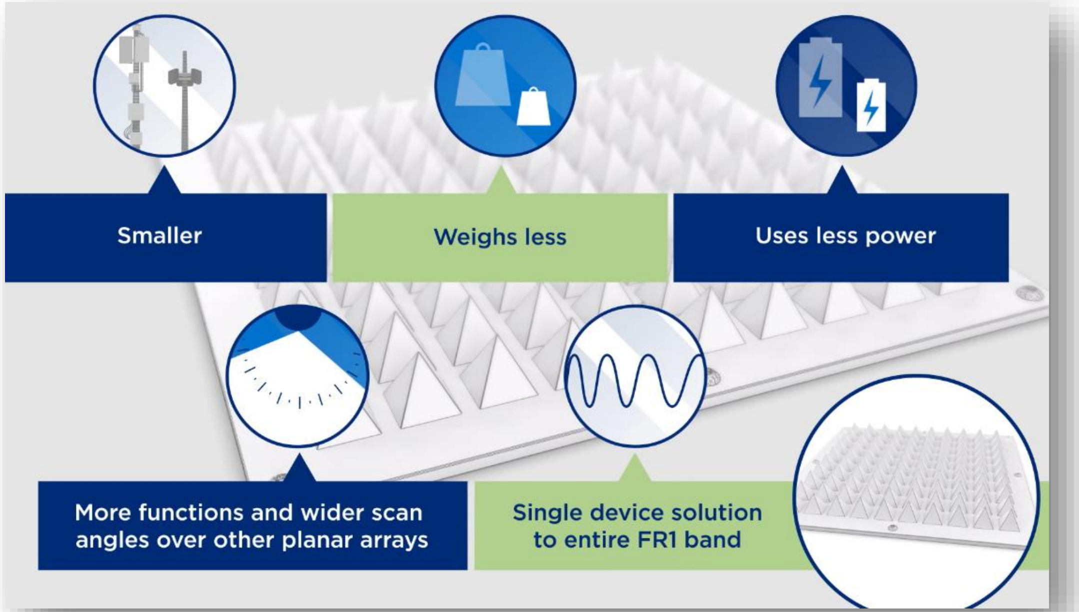
No accessible RF connectors for testing

Slide Credit: Rohde & Schwarz

RavenStar™ Advantages for Telecommunications

Unique antenna design enables critical benefits

- Serve the entire **FR1 frequency spectrum** (600-7G) with one unit
- Place Antenna **elements close together without self-interference problems**; exquisite beam forming and interference mitigation in a compact form factor:
  - **2-4x more data** through same amount of spectrum
  - Dramatic improvement in uplink speeds
  - Improved range
- Serve both **Frequency Division Duplexing and Time Division Duplexing on the same unit** (Not possible with any other radio unit)



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RavenStar™ Discards The Assumption In Antenna Design That Electronics Are Large And Expensive

Ultra Wideband array + Open Standards for Digital I/Q + COTS RF µElec. = Compact **General Purpose** Array

- We have created the first **Software Defined Active Antenna Unit**
  - Utilize COTS multi-channel, wideband systems on chip/module for 5G MIMO arrays, pushing down the $/channel
- Provide **General Purpose Capability** vs the Application Specific Solutions used today
  - Analogy: Provide the microprocessor in a world made of application specific integrated circuits
  - Doing so involves making trades in performance, size, and power

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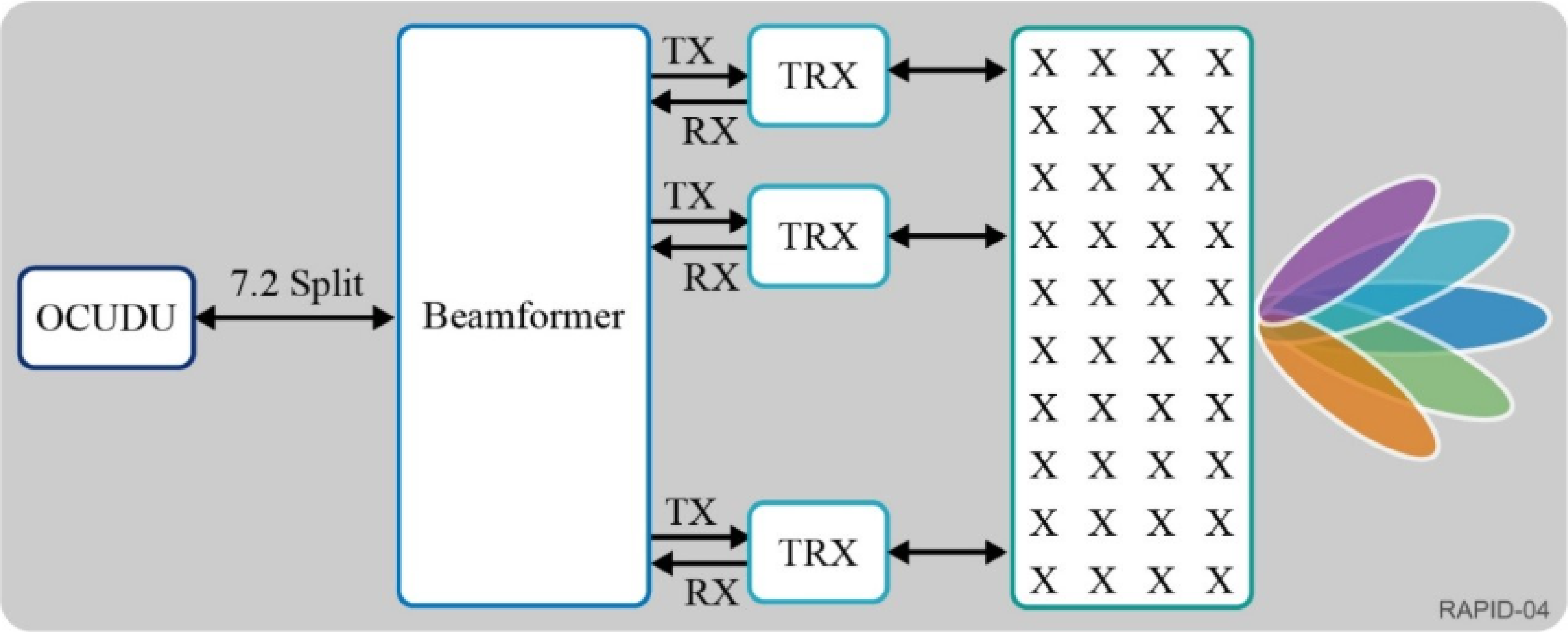
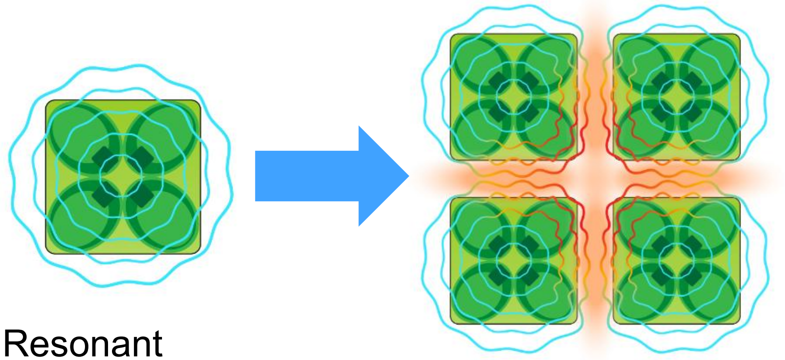
Basic Architecture



Battelle's RavenStar™ technology redefines the assumptions in antenna array design

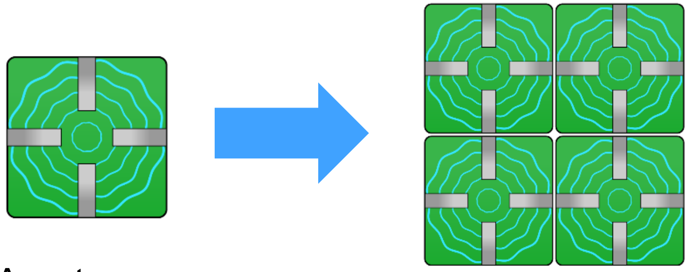
Traditional Antenna



Resonant
- Narrowband
- Interacts with fields around it

Arrays Reduce Performance
- Low packing density
- De-tunes array losing efficiency
- Power and Antenna count are coupled

Patented RavenStar Antenna



Aperture
- Wideband
- Interacts with fields through it

Arrays Increase Performance
- High packing density
- Improves gain and noise
- Decouples Antenna count and power

False Assumptions

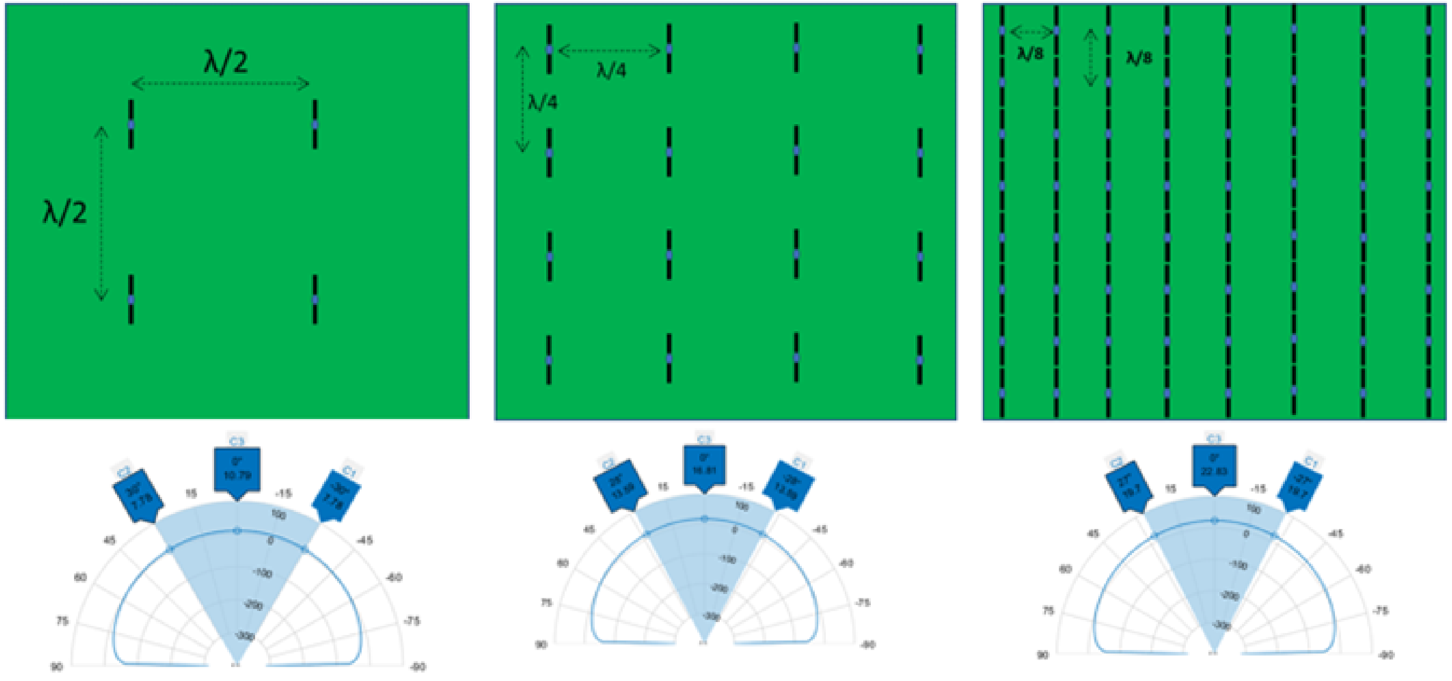
- True Multiband active arrays >30% bandwidth are unviable
- Low Band, sub 1GHz arrays can't exist
- Radios and antennas are a commoditized, race to the bottom

The New Reality

- Multiband active arrays with >160% bandwidth are affordable
- Array cost and performance gains exist in all bands
- Innovation in the RF-Air interface enables the market & use case expansion that 5G has failed to bring

Antenna Gain vs Array Density

Comparison of Gain Performance vs Array Density
(Array Size Remains Constant)



2x2; λ/2 Separation	
Gain (dBi):	10.8
HPBW (deg):	60
# Radiators:	4

4x4; λ/4 Separation	
Gain (dBi):	16.81
HPBW (deg):	56
# Radiators:	16

8x8; λ/8 Separation	
Gain (dBi):	22.83
HPBW (deg):	54
# Radiators:	64

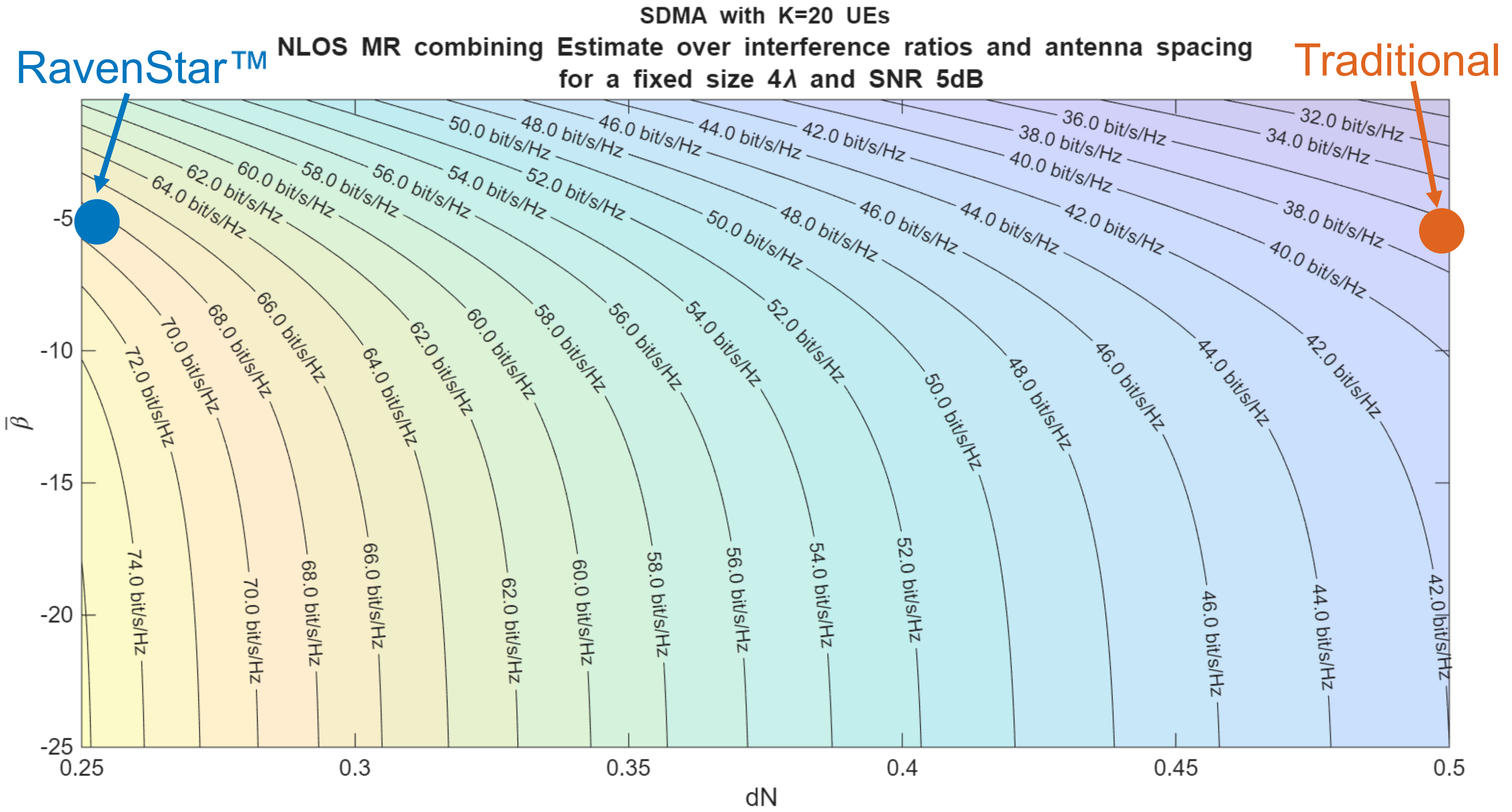
Battelle's RavenStar™ Redefines What is Possible

Lower bound of spectral efficiency assuming maximum ratio combining:

$$SE_0^{NLOS} \geq \log_2\left(1 + \frac{M-1}{\overline{\beta} + \frac{1}{SNR_0}}\right) = \log_2\left(1 + \frac{\left(\frac{N}{dN}\right)^2 - 1}{\overline{\beta} + \frac{1}{4\pi dN^2 \frac{\rho}{\sigma^2}}}\right)$$

Traditional	RavenStar™
dN – Element Spacing	$\overline{\beta}$ – Intercell Interference
N – total aperture area	ρ – Transmit power
M – Antenna Count	σ^2 – Noise power

- Spectral Efficiency increases as dN decreases, with higher impact at higher interference levels (greater $\overline{\beta}$)
- Traditional array design presume the spacing of the antennas to be fixed at $\lambda/2$, or greater limiting a number of elements M in a given array size N

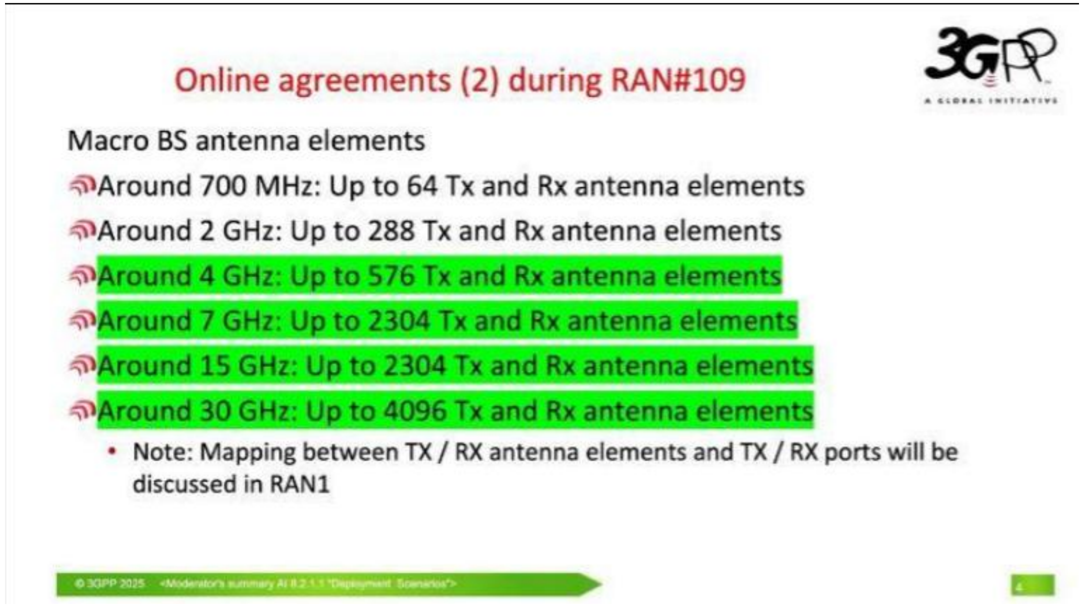


Oversampled Array Geometry uniquely suited for applications in dense, high interference environments, offering >2x Spectral efficiency

6G will primarily be Active Antenna Units

Active Antenna Units provide these benefits

- Significant improvements in capacity and range
- Optimizing coverage area and capacity reduces energy consumption
- Simpler Installation; only fiber and power
- Digital pointing and control
  - AI-RAN can control the physical layer
  - Reduce or eliminate truck rolls
- More efficient
  - PAs and LNAs at the antenna



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Why OTA testing became necessary

- Radiated testing and TS 38.141-2 was primarily thought of as a FR2 need:
  - Transceivers are integrated into active antenna systems
  - Traditional conducted RF test ports may be limited or unavailable
  - Antenna and radio metrics must be verified over the air
- However, the need is real as FR1 moves to AAUs in mass and FR3 development progresses
- Typical OTA needs include:
  - Gain, Pattern, EIRP, Rx Sensitivity, EVM, ACLR, SEM

Conducted AAU testing

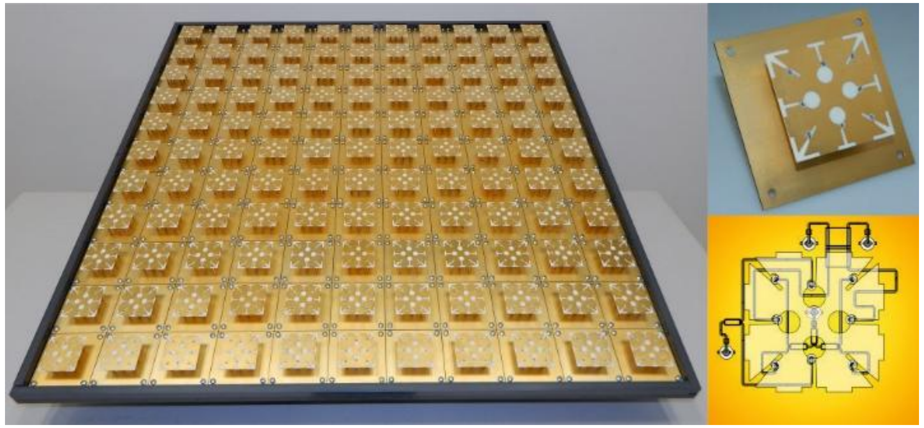


Photo from University of Hannover

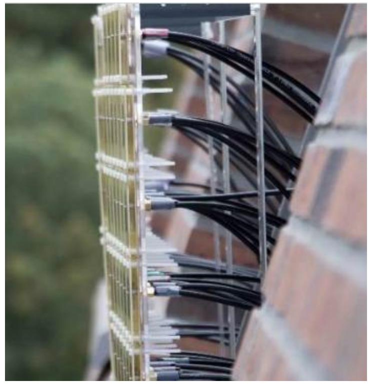


Photo from Ku Leuven

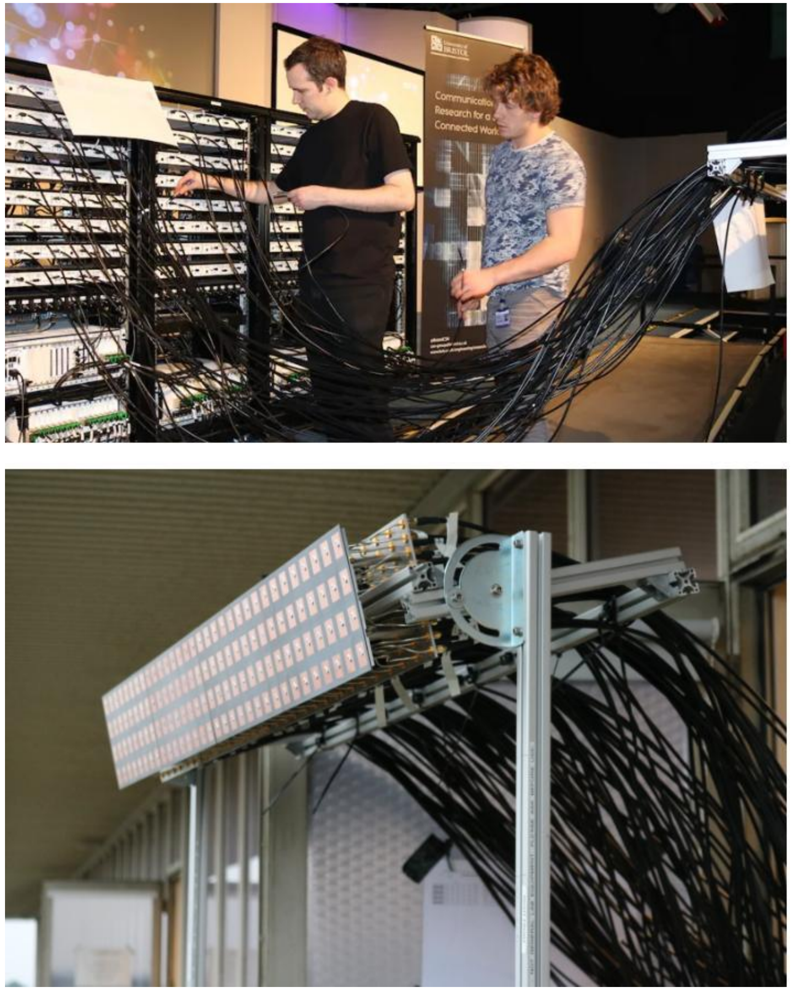
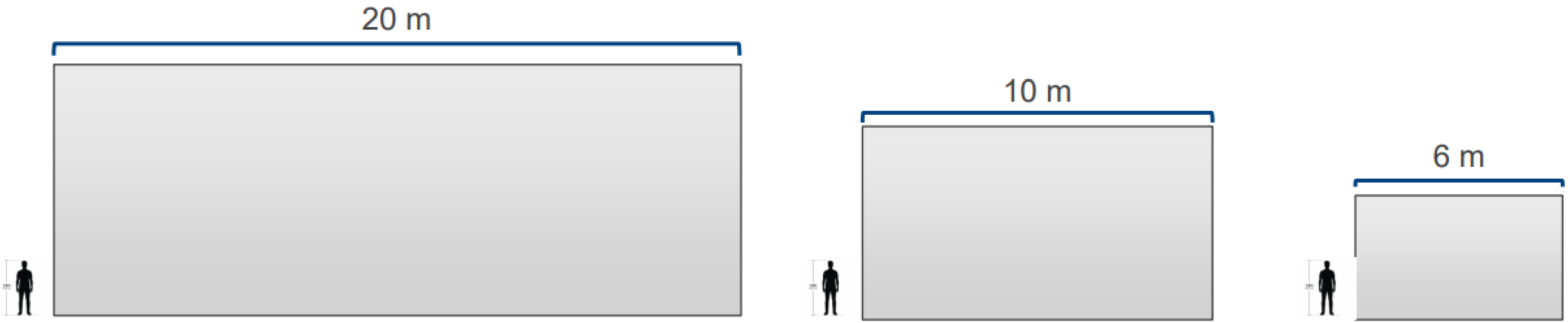


Photo from University of Bristol

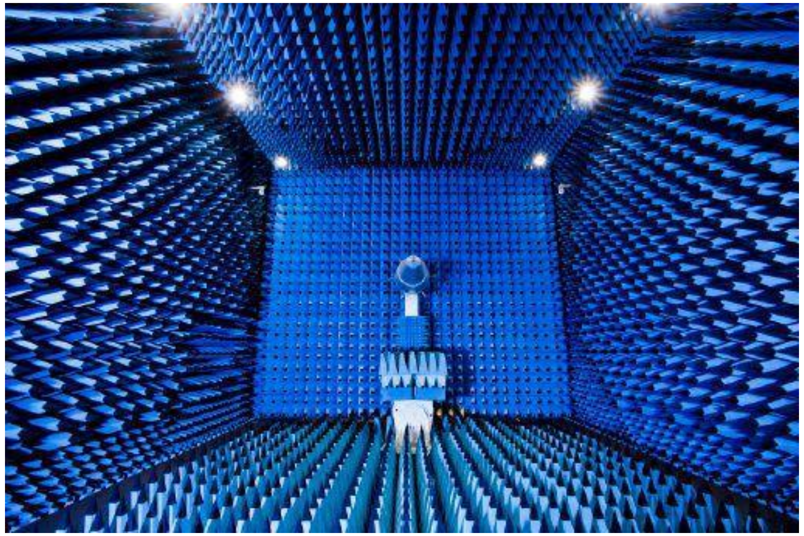
Practical Comparison: Direct Far Field vs CATR vs Plane Wave Synthesis

- Direct Far Field: true FF by distance; simplest concept; largest chamber footprint
- CATR: reflector creates quiet zone; established method; medium to large footprint and significant reflector burden at FR1
- Plane Wave Synthesis: phased array synthesizes quiet zone; compact setup; requires calibration and transfer synthesis



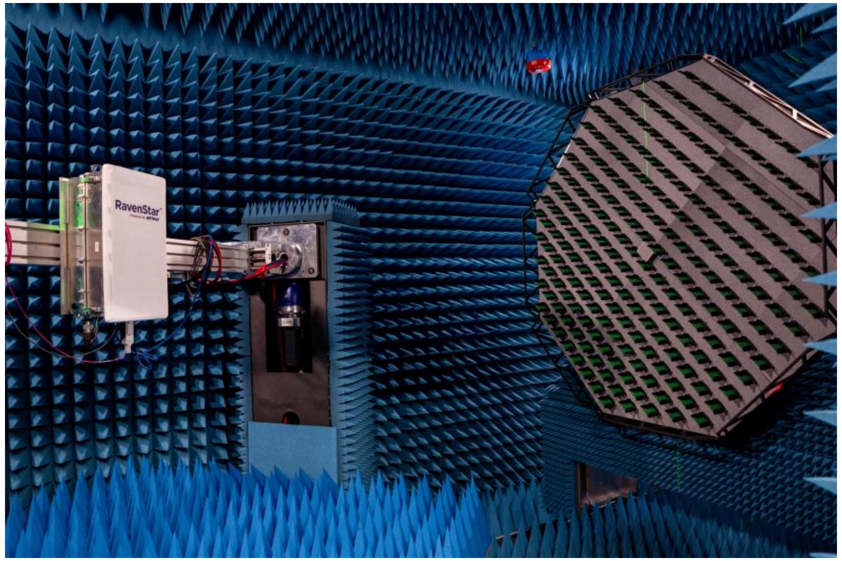
Slide Credit: Rohde & Schwarz

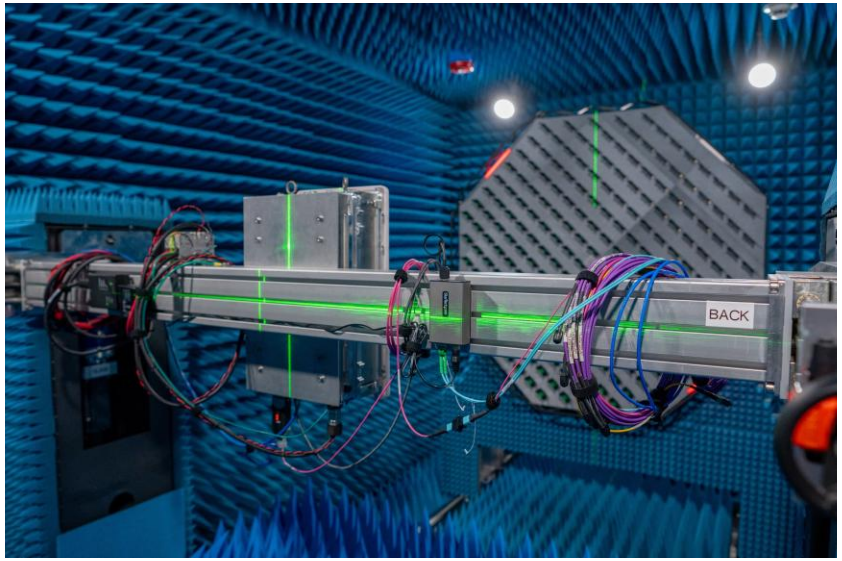
Examples of OTA Chambers



Farfield Range

Compact Range





Plane Wave Converter

Measurement Types and Test Requirements

Tx Directional	Rx Directional	TRP (In-band or OOB)	Co-location
EIRP accuracy (Max EIRP)	Sensitivity	Output Power	Tx OFF power
Output power dynamics	Dynamic Range	ACLR	In-band Unwanted Emissions
Frequency Error	Adjacent Channel Selectivity	Spectrum Emission Mask	Intermodulation
EVM	In-band blocking	In-band Unwanted Emissions	In-band blocking
Time Alignment Error	Receiver Intermodulation	Spurious Emissions (Tx and Rx)	
Occupied Bandwidth	In-channel Selectivity		
OFF power	Out of Band Blocking		

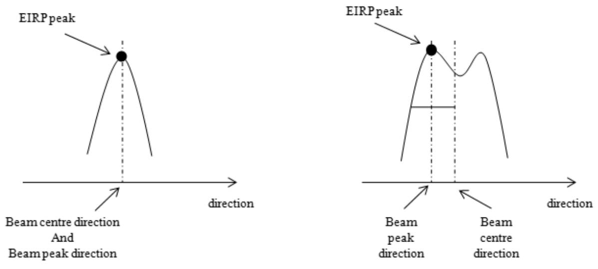


Figure 6.2.2-1: Example of *beam direction pair*

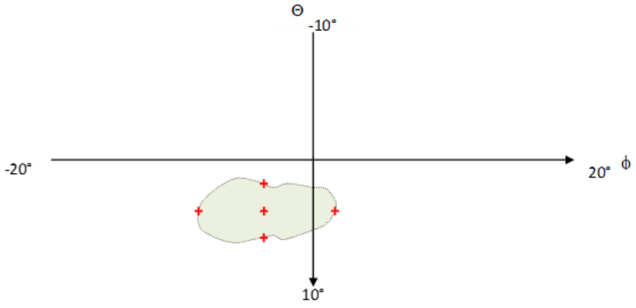


Figure 6.2.3-1: OSDD without target redirection capability

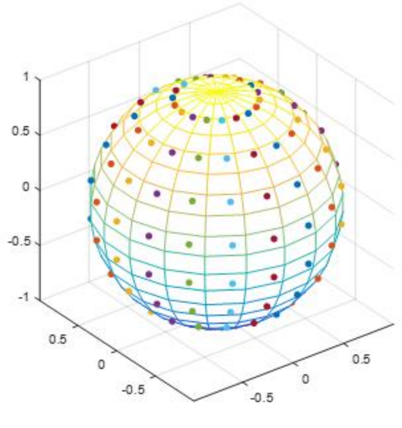
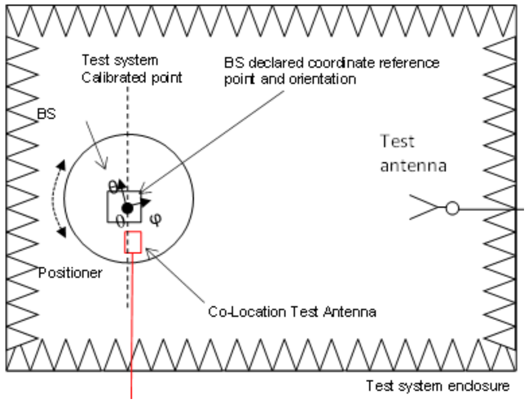


Figure 6.3.4.1-1: Spherical equal angle sampling grid



Source: 3GPP TS 38.141-2

Slide Credit: Rohde & Schwarz

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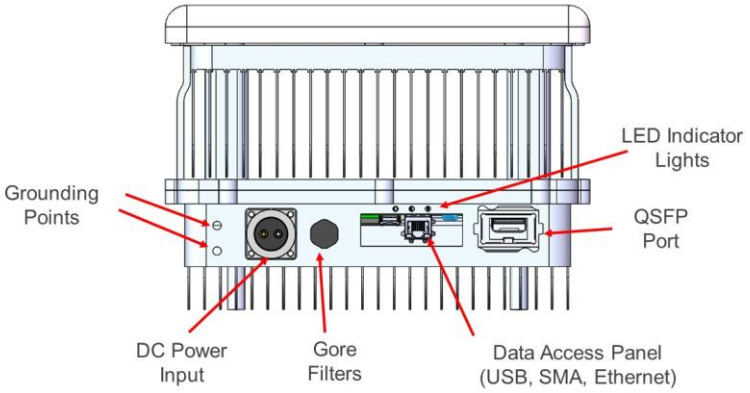
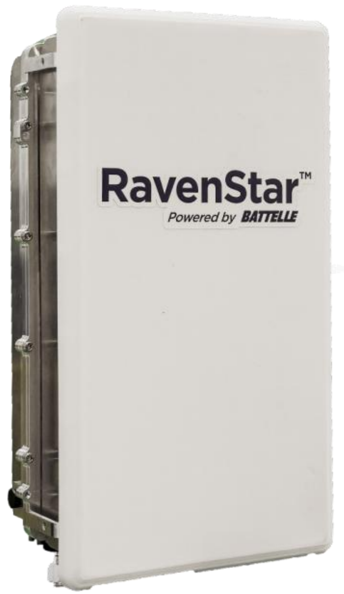
RavenStar n77 RU Testing





Testing requirements

- Multiple bandwidths (10 MHz, 20 MHz … 100 MHz)
- Multiple frequencies
- Multiple beams
- Power levels – CBRS, Licensed bands
- Modulation QPSK … 256 QAM

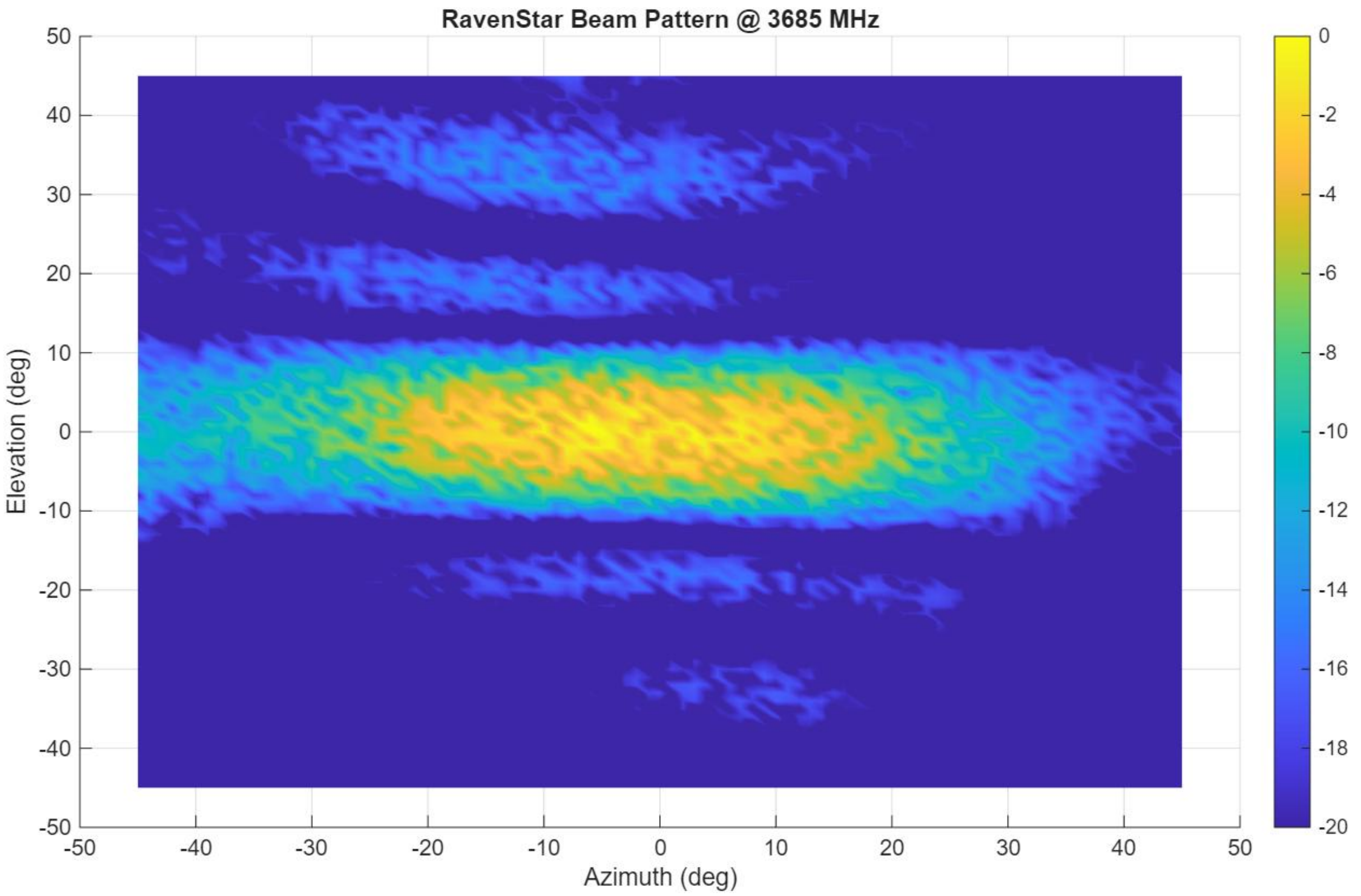
- Volume: 20.4 L
- Dimensions: 460mm x 180mm x 250mm (18" x 7" x 10")
- Nominal weight: 12.5 kg (27.5 lbs)

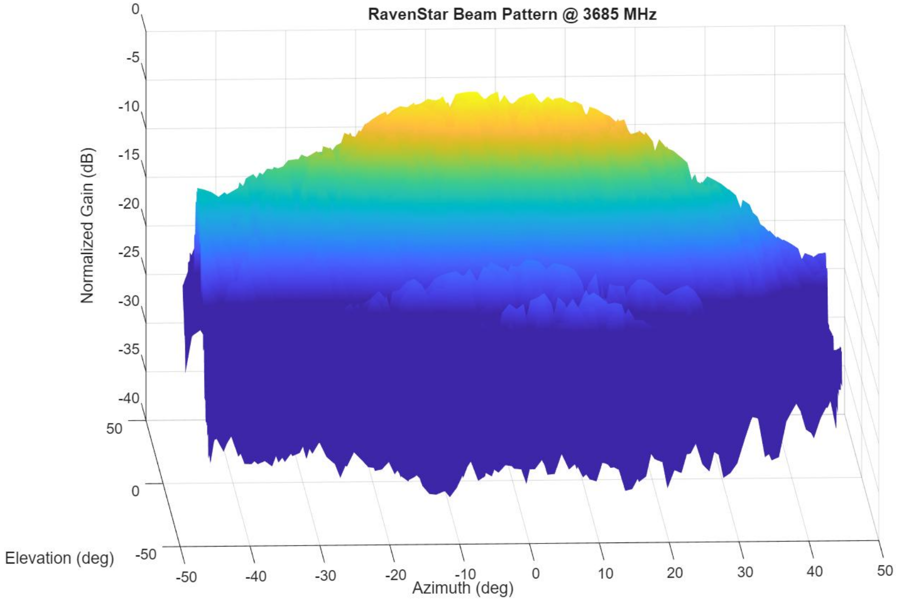
Battelle Development Lab

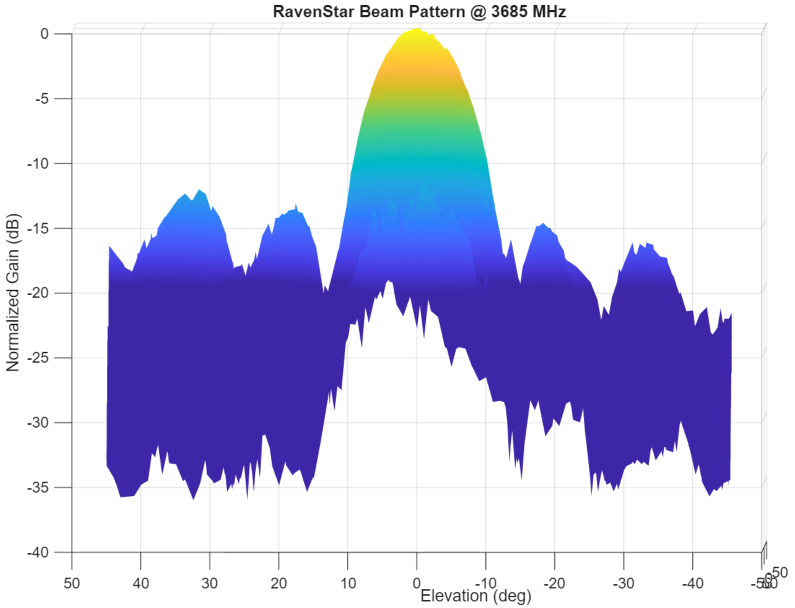
RavenStar development

- Chamber integrated into HW/SW development lab
- Quick iterations for SW and HW changes
- Prototype development

Normalized user beam pattern

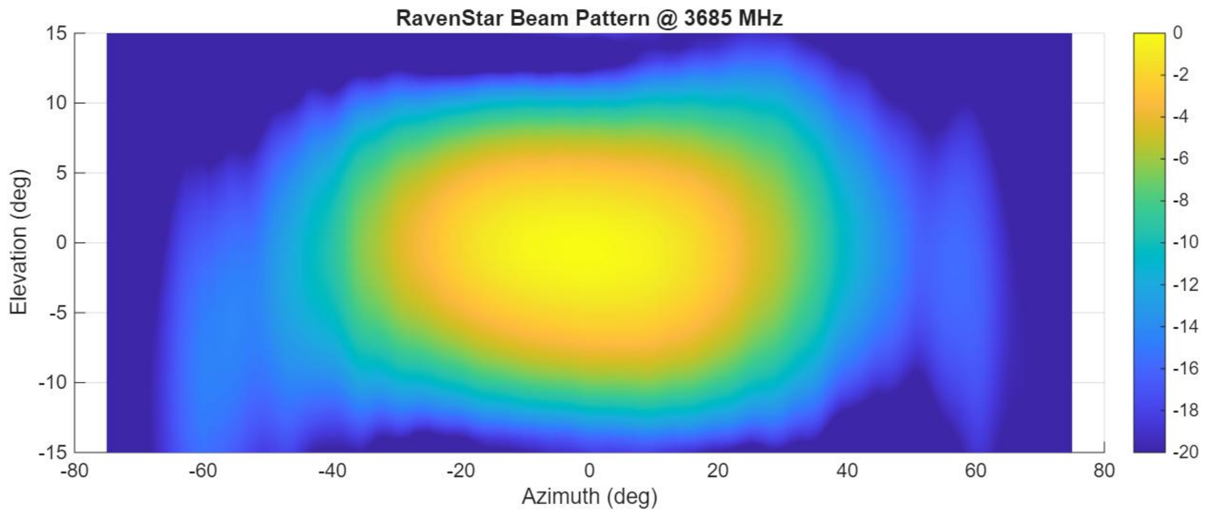




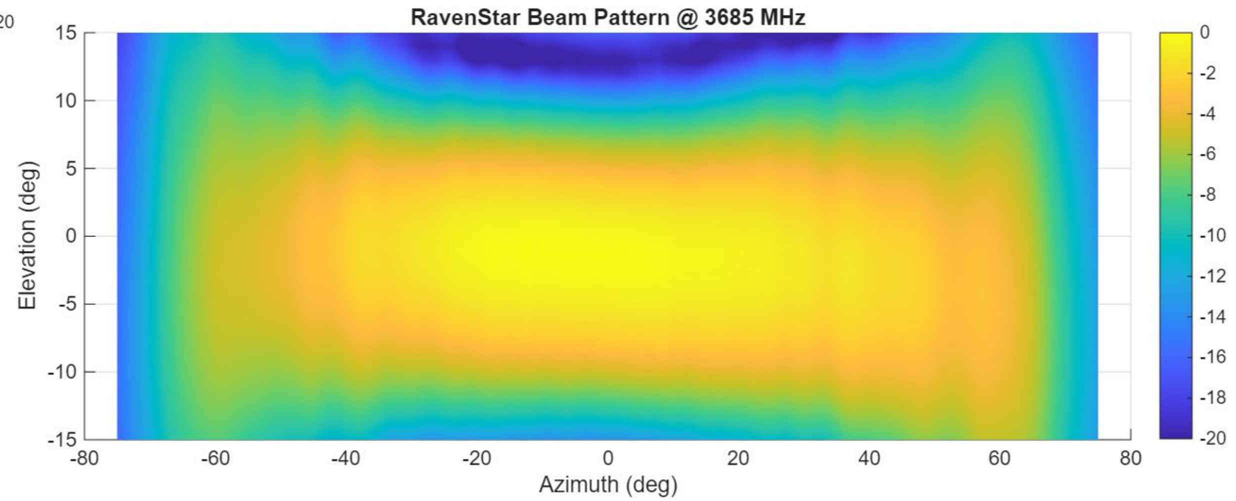


Peak gain is 17dBi
*Preproduction Beam calibration process used

User and Broadcast beam patterns

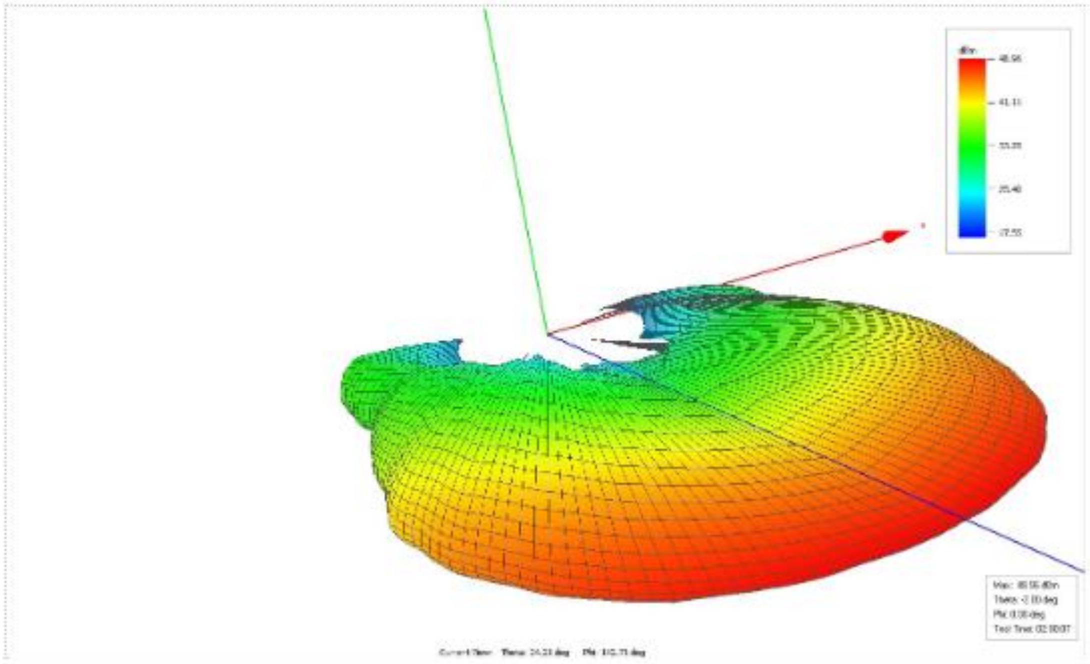


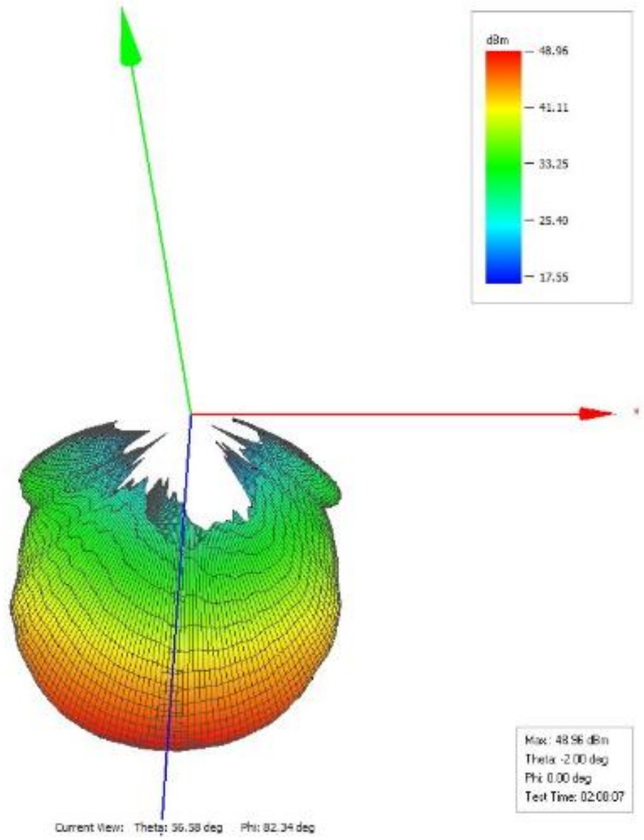
Tight User Beam



Spread Broadcast Beam

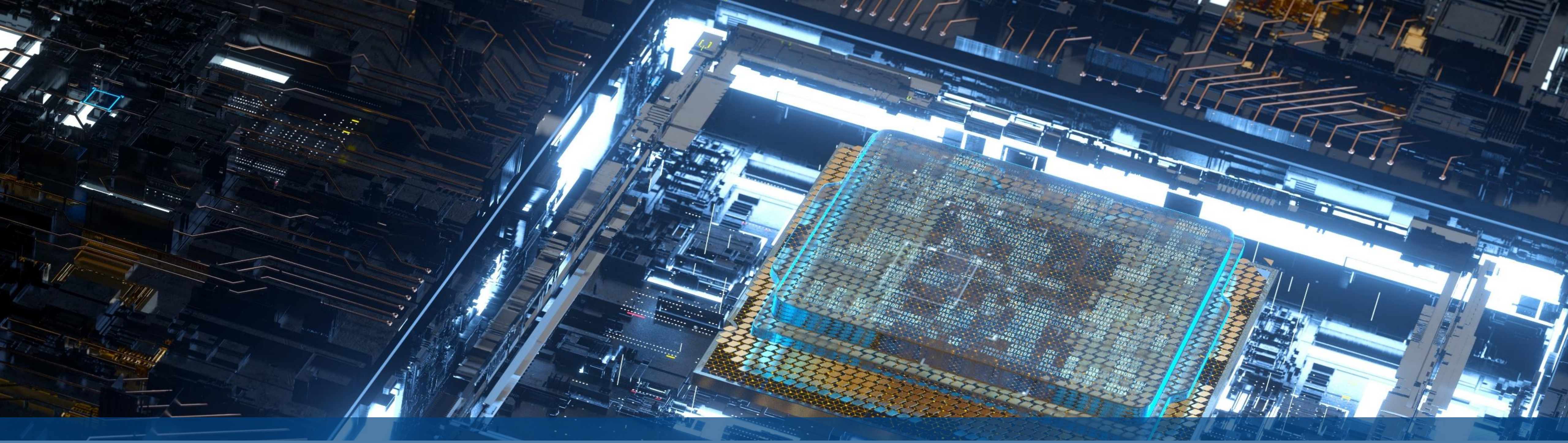
3D beam patterns





Summary

- OTA testing is critical for accurately characterizing active antenna units
- Anechoic chamber enables repeatable test configurations for development and certification
- Expanding test scope to include interference mitigation and capacity measurements
- MNO field testing of n77 small cell early 2027



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It can be done

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