OVERCOMING MMWAVE DEVICE TESTING CHALLENGES FOR 5G NR

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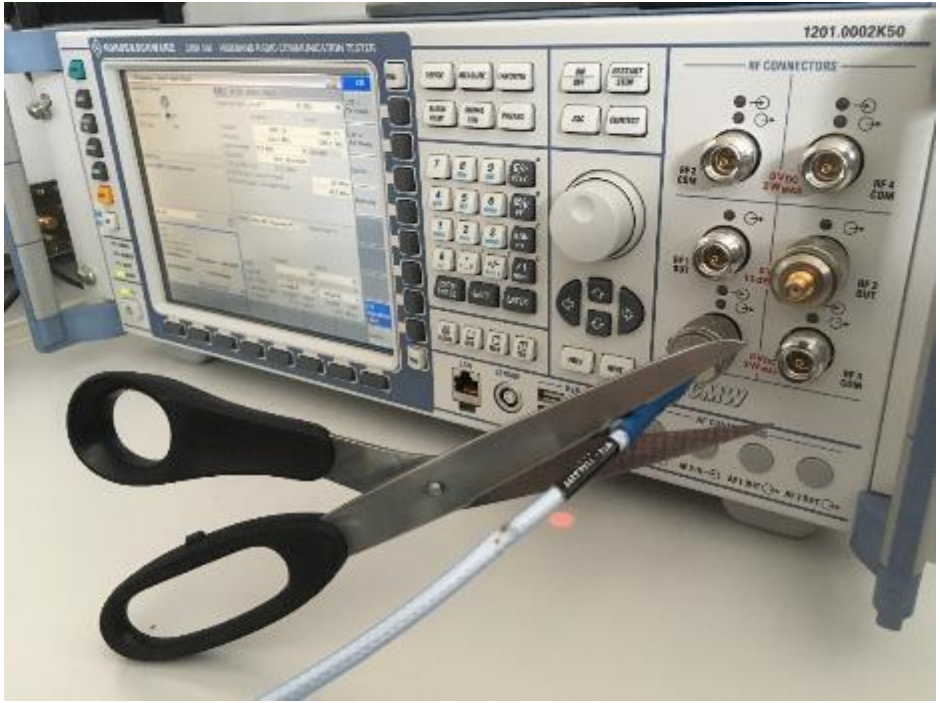
ROHDE&SCHWARZ
Make ideas real

TESTING OTA? – EASY, JUST CUT THE CORD…



…and replace it with an antenna…

WHY OTA TESTING?
STANDARDISATION VIEW

Conducted testing

Re-use LTE UE testing methodology

8 GHz

24 GHz

OTA measurements

in far field*

*Note: Alternative near field methods are not precluded

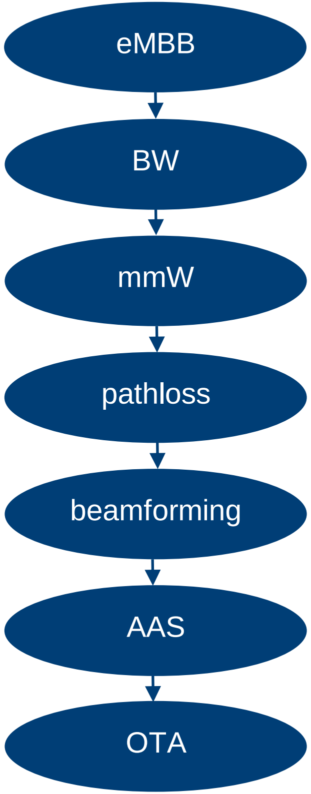
Only antenna performance test requires over the air (OTA)
[TRP, TIS, …]

Everything to be tested over the air (OTA)

Source: 3GPP TR 38.803 V2.0.0

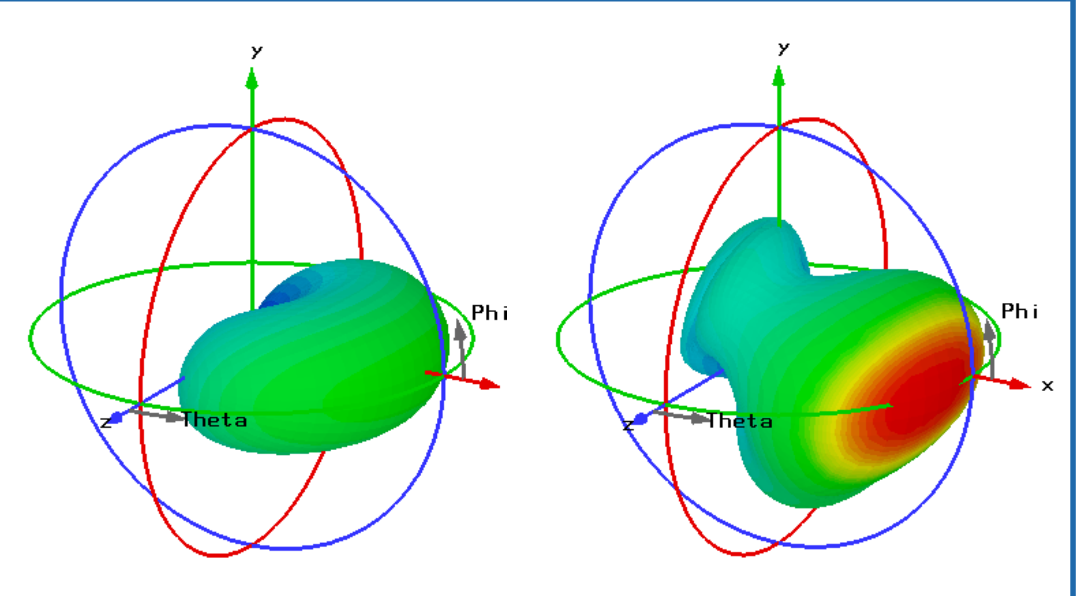
WHY OTA TESTING?
TECHNICAL BACKGROUND

- 5G NR addresses – besides others – eMBB (enhanced mobile broadband)
- eMBB means data rates of 20 Gbps
- Needs wide bandwidth (Shannon‘s law)
- Contiguous wide bandwidth available at high frequencies (mmW bands)
- High frequencies – high path loss
- Counter measure – beamforming techniques
- Beamforming needs active antenna arrays (AAS) with multiple phase steered antennas
- Phased arrays do not allow cable connections
- Testing can only be done wirelessly – over the air (OTA)



IT'S ALL ABOUT NO CABLES….IN 5G MMWAVE SYSTEMS

3D gain patterns of mmWave UE antenna

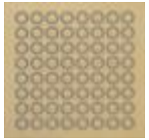


No measurement cable

With measurement cable

Antenna couples to all surrounding objects
Conductive measurements introduce large error

- ► Phased arrays do not allow connection through cables



  - Many antennas – many connectors
  - Cable influences antenna characteristics
  - Antenna becomes system relevant functionality with beamforming etc.

NEW CHALLENGES COMING UP WITH OTA TESTING

- Testing in OTA is not new
- So far below some GHz antenna performance tests only
- With 5G NR EVERYTHING has to be tested OTA
- Frequencies in the mmWave range

- Lots of new things to consider
  - Radiation pattern of the antenna
  - Field properties of the radiation
  - Near field vs. far field conditions
  - Quiet zone sizes
  - Chamber sizes
  - Positioners
  - …

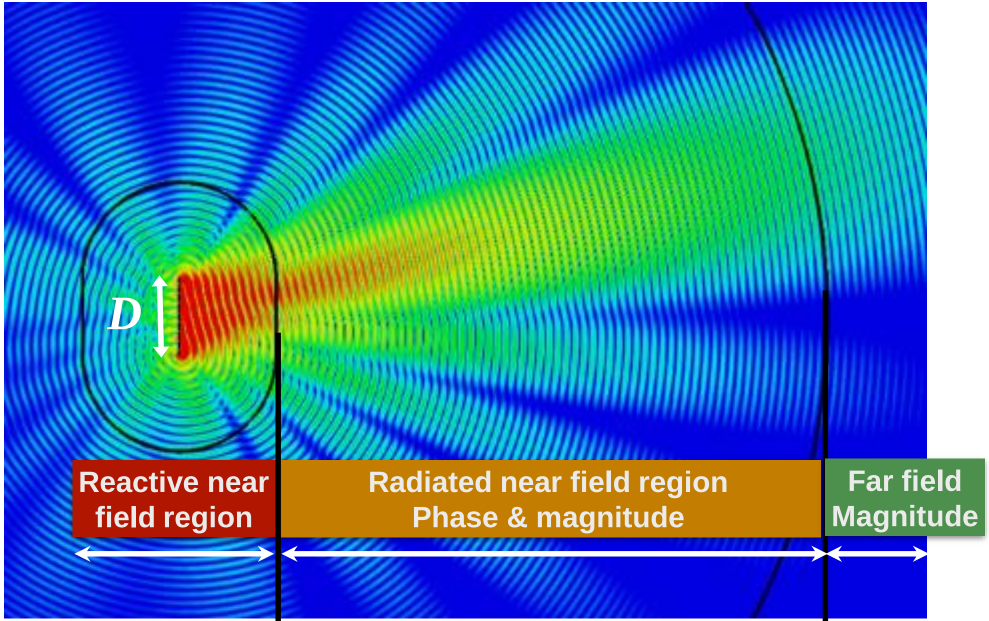
RADIATION PROPERTIES

- Each antenna or antenna element emits a multitude of spherical waves
- As the waves are travelling away from the antenna their energy locally decreases with the distance from the antenna as it distributes over an increasing sphere
- At a given point far enough away from the antenna the emitted wave looks plane within certain limits
  → this region is called the “quiet zone”
  - Compare with throwing a stone into water

- To increase the size of the quiet zone there are several options
  - Move further away from the antenna
  - Manipulate the field distribution
  - Use overlapping fields from multiple antennas
  - …

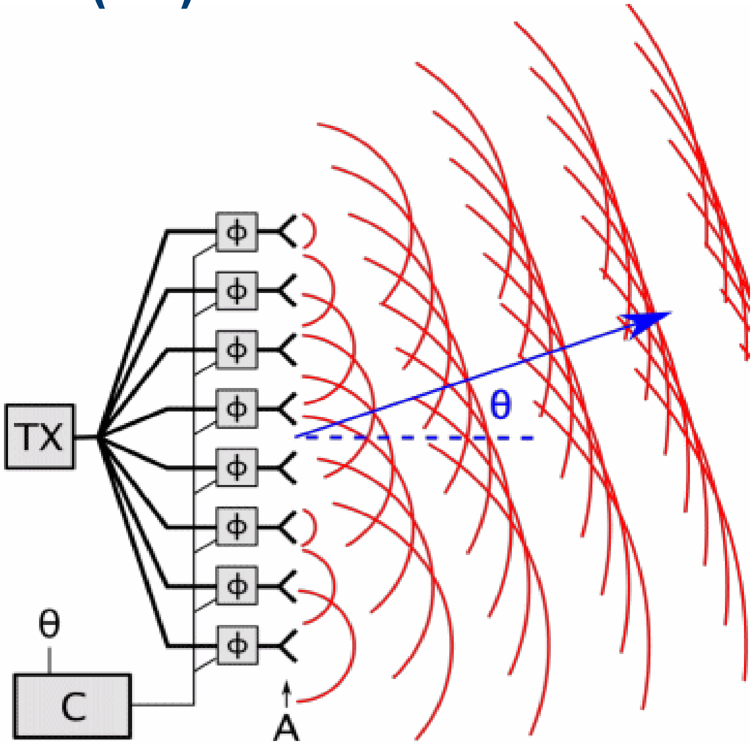
WHAT AND WHERE IS THE FAR-FIELD (FF)?

10 cm aperture size at 30 GHz



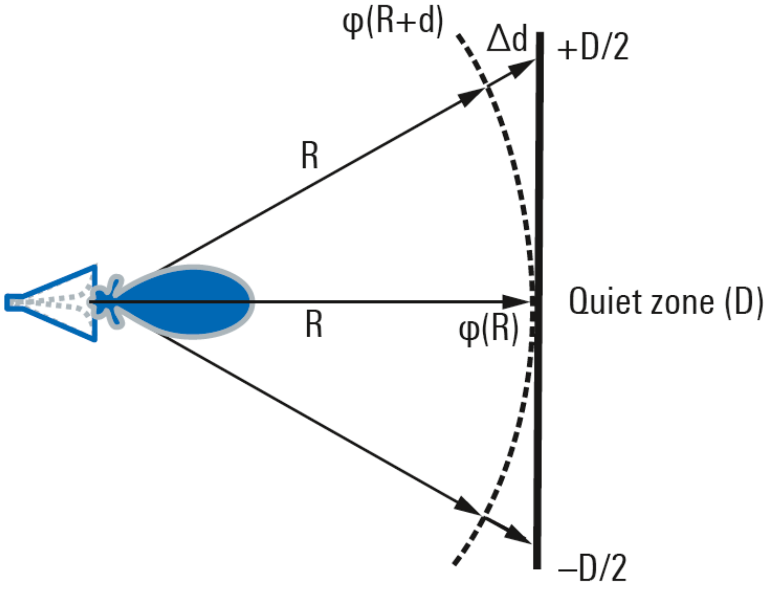
$$0.62\sqrt{\frac{D^3}{\lambda}}^{*} = 20\ cm \qquad \frac{2D^2}{\lambda} = 2\ m$$

* = formula commonly taken for radiators with D > $\frac{\lambda}{2}$



WHAT IS THE QUIET ZONE?

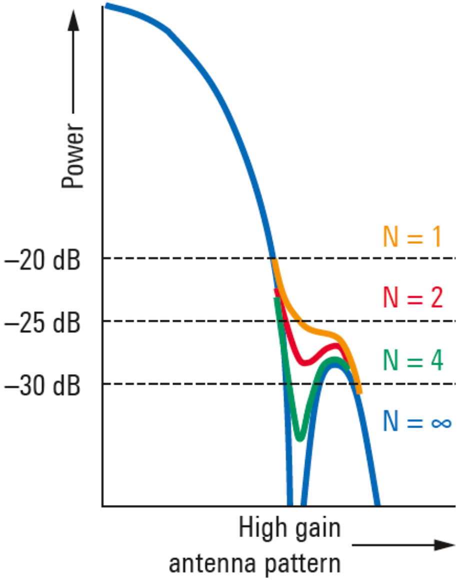
Definition of Fraunhofer distance



Quiet zone phase deviation and magnitude error

$$R_{FFmin} = \frac{ND^2}{\lambda}$$

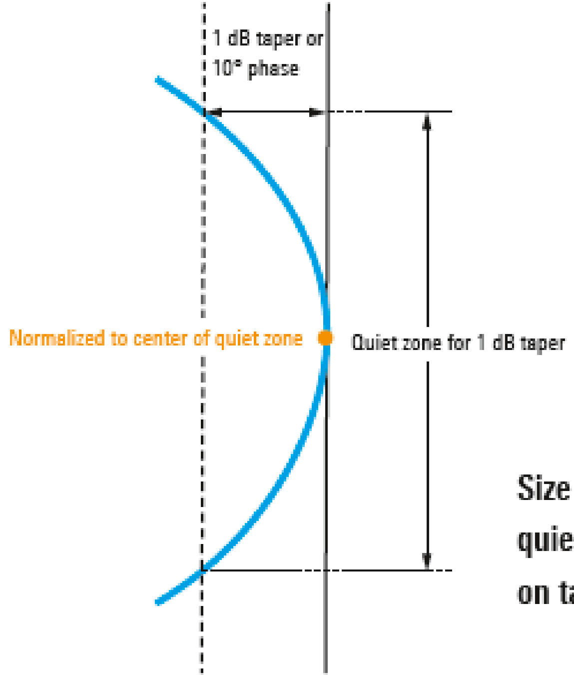
R_{FFmin} (N)	Phase deviation (φ)
D^2/λ	45°
$2D^2/\lambda$	22.5°
$4D^2/\lambda$	11.2°
$8D^2/\lambda$	5.6°



The Fraunhofer distance presents the best compromise between a compact test setup, acceptable phase deviation and measurable null

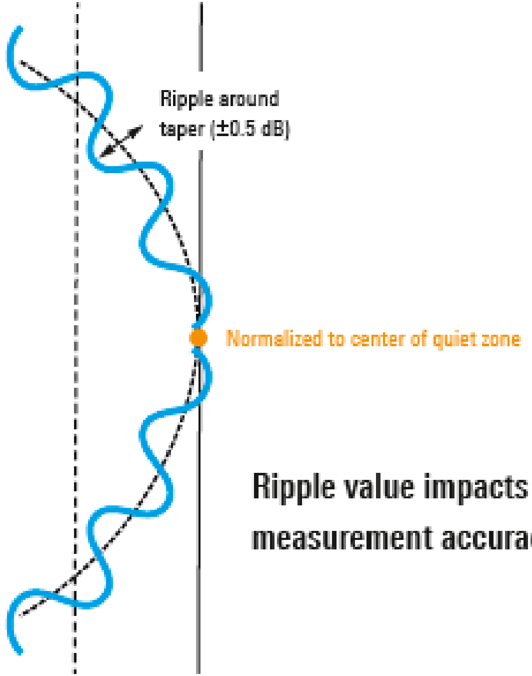
HOW GOOD IS THE QUIET ZONE?

Example of amplitude/phase taper



Size of achievable quiet zone depends on taper value.

Example of amplitude/phase ripple



Ripple value impacts measurement accuracy.

REACTIVE NEAR FIELD – RADIATED NEAR FIELD – FAR FIELD

- Reactive near field close to the antenna
  - Every object couples with the antenna - influences the antenna pattern and performance

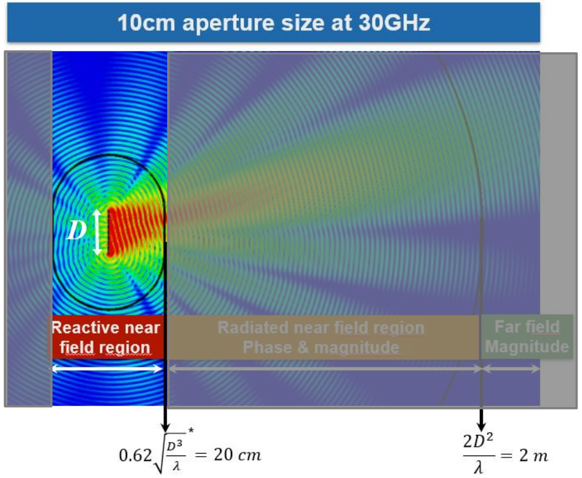
- Far field (beyond $\frac{2D^2}{\lambda}$) D = size of radiating aperture
  λ = wavelength
  - Field is considered as locally planar
  - RF measurements are easy - only magnitude measurements

- Radiated near field
  - Waves are not plane - measurements in magnitude and phase
  - Entire sphere has to be measured to understand field distribution
  - For transformation to far field
  - Typically use of a positioner
  - Measurement more complex and time consuming, setup more expensive

MEASUREMENTS THAT CAN BE PERFORMED IN THE REACTIVE NEAR FIELD

- No RF parametric measurements like EVM, ACLR etc.
- Stay away from the reactive near field
- Measurements would influence the result since antenna pattern is influenced

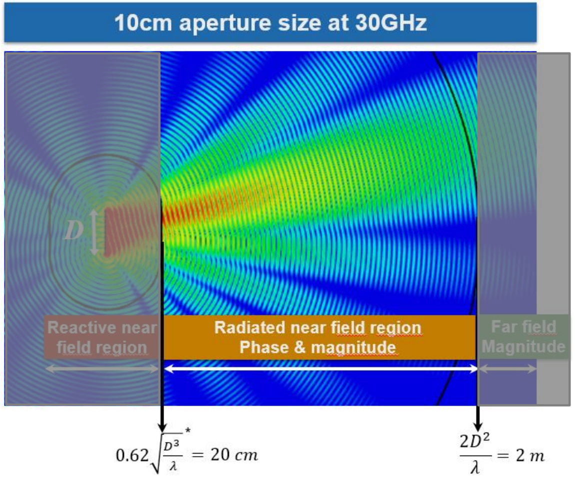
- Things like SAR measurements are performed here



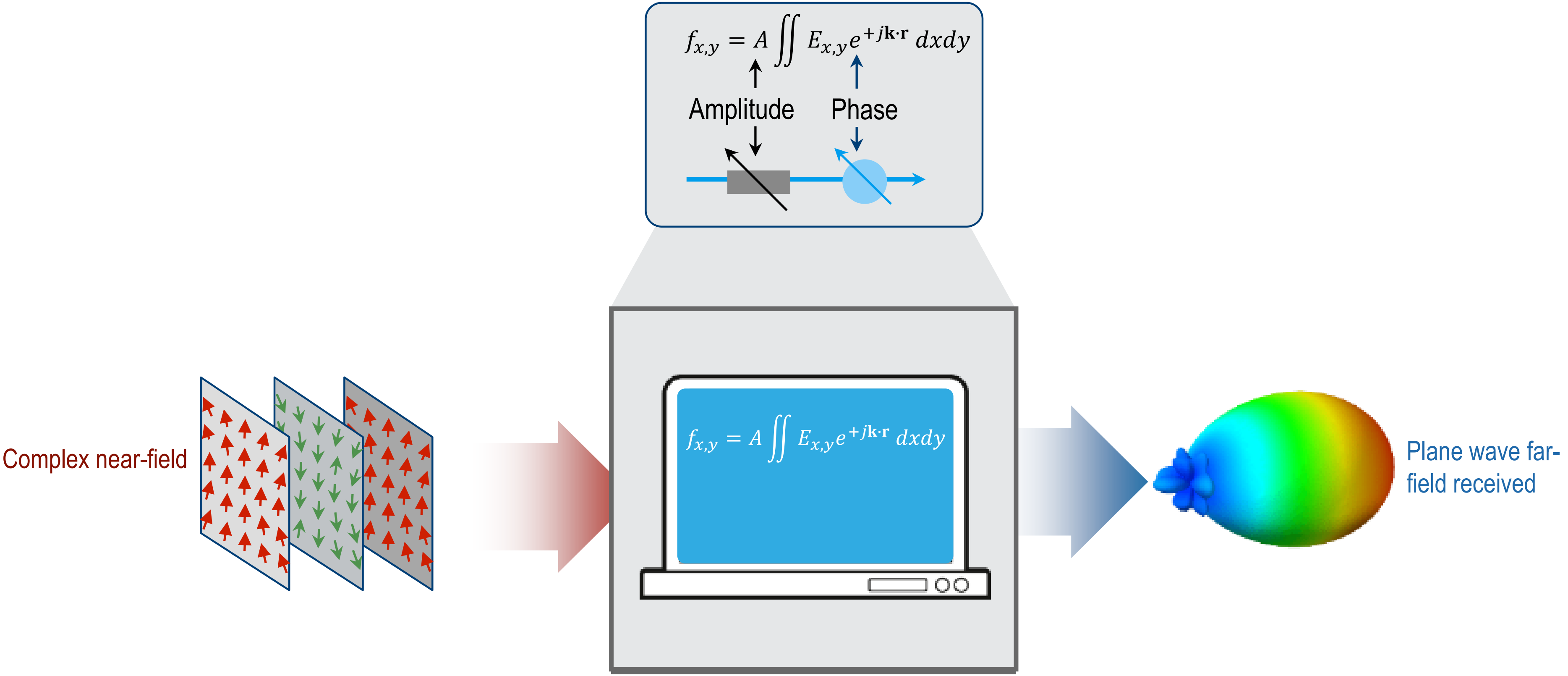
MEASUREMENTS THAT CAN BE PERFORMED IN THE RADIATED NEAR FIELD

- Spherical scan of the entire field in magnitude and phase
  - All field parameters are known
  - Mathematical transformation into the far field by using certain algorithms
  - All Tx measurements
  - Effort much higher than in far field
  - Space requirements are lower

- Directly in radiated near field (without far field transformation)
  - Only some certain parameters can be measured
    - TRP (total radiated power)
    - Peak EIRP (equivalent isotropic radiated power)
  - Measurement uncertainties higher than in far field

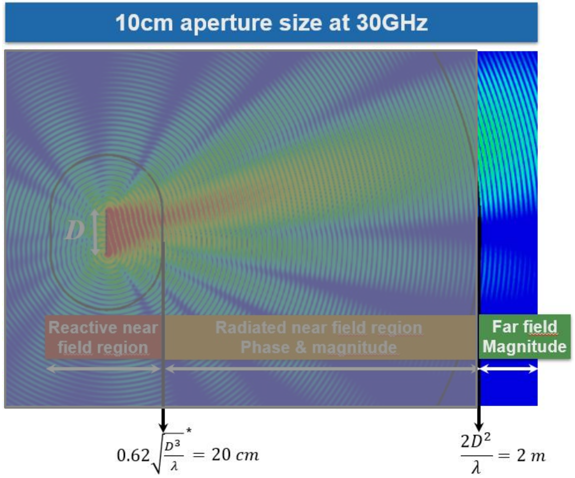


TRANSFORMING NF TO FF BY SOFTWARE ALGORITHM

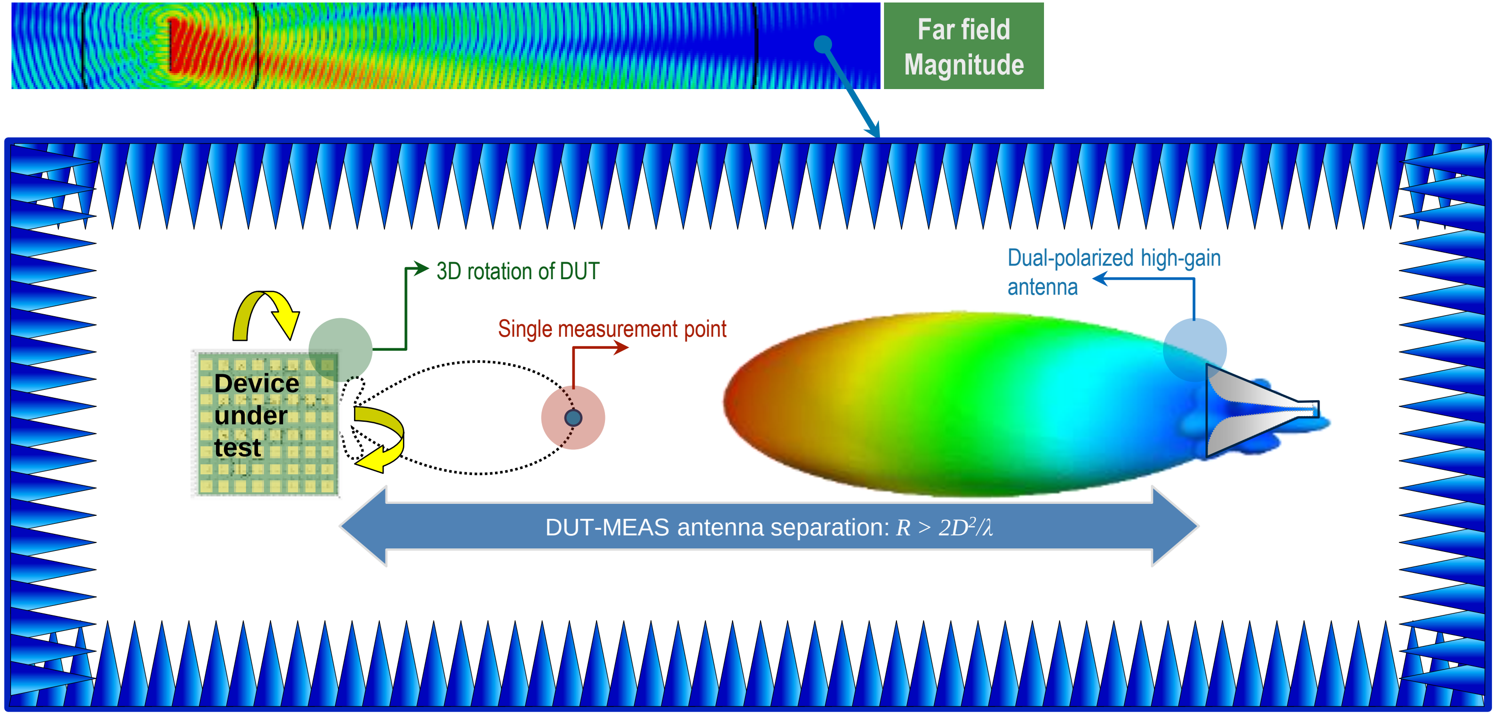


MEASUREMENTS THAT CAN BE PERFORMED IN THE FAR FIELD

- Measurements in the far field
  - Comparably easy
  - Every RF measurement can be performed
    - EiRP/EiS (effective isotropic radiated power/sensitivity)
    - In-Beam measurements for R&D and production
    - EVM, ACLR, SEM, OBW, BLER etc.
  - Far away from antenna
    - Additional challenge –
      path loss typically high for direct far field
    - Space requirements can become massive
      dependent on DUT size and frequency used



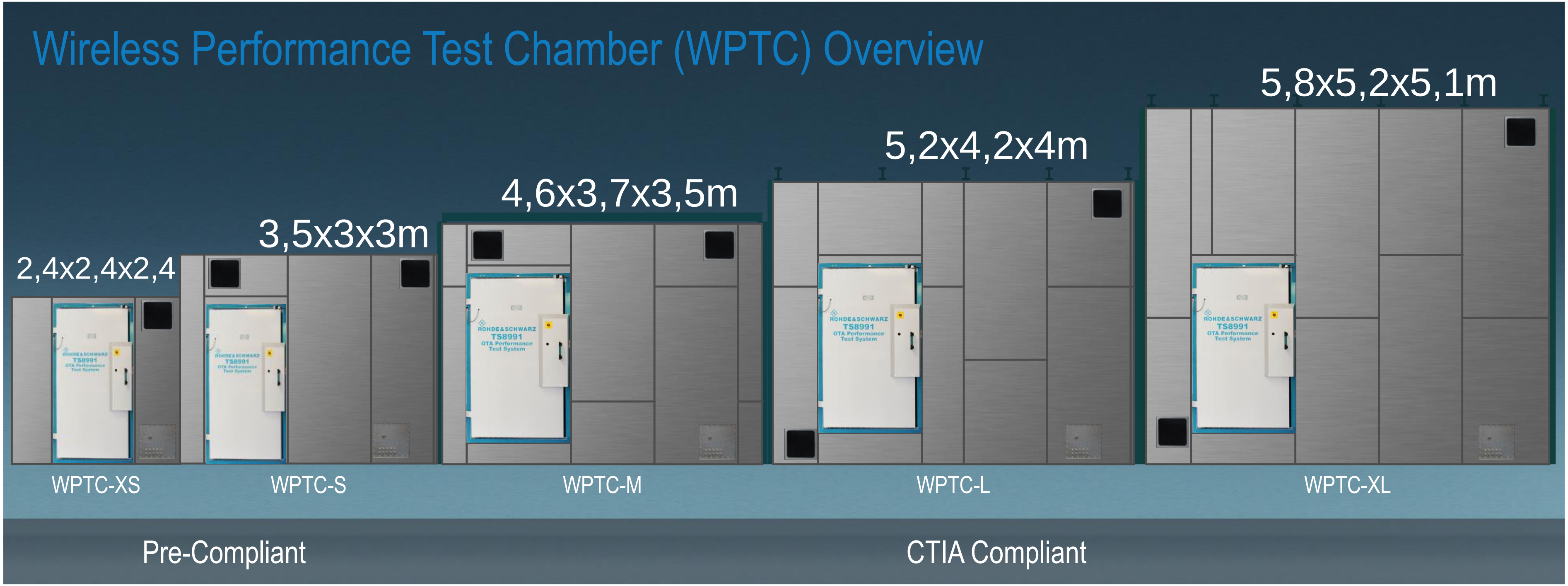
DIRECT FAR FIELD



WIRELESS PERFORMANCE TEST CHAMBERS FOR MMWAVE

Far-field: 5G UE/CPE Test

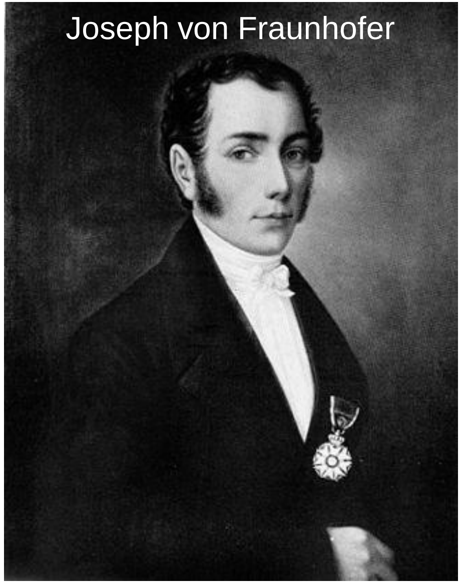
Far-field: 5G Basestation Test



QUIET ZONE SIZE

- ► How big of a quiet zone is required in far field?
- ► Depends on frequency and size of radiating aperture
  - – Fraunhofer distance $\frac{2D^2}{\lambda}$

D = size of radiating aperture
λ = wavelength



* 6. März 1787 in Straubing
† 7. Juni 1826 in München

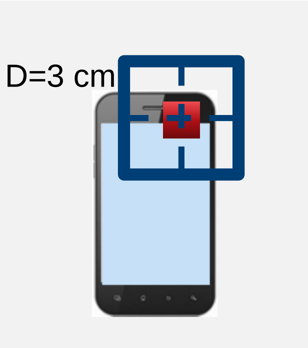
WHAT SIZE OF A QUIET ZONE (QZ) IS NEEDED?

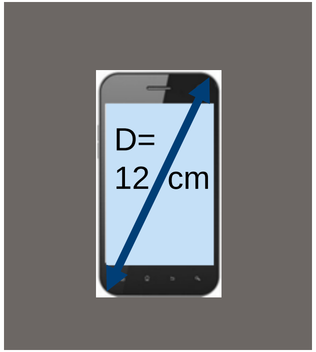
- Size and position of the antenna known
  - This size can be taken as D
  - White box testing – device is a “white box” for the user since position of the antenna is known

e.g. QZ size 3 cm; 30 GHz → λ = 1cm ; $\frac{2D^2}{\lambda}$ far field distance 18 cm

- Size and/or position of the antenna is unknown
  - Entire DUT maximum distance to be considered as D
  - Black box testing - device is a “black box” for the user

e.g. QZ size 12 cm; 30 GHz → λ = 1 cm; $\frac{2D^2}{\lambda}$ far field distance 2.9 m



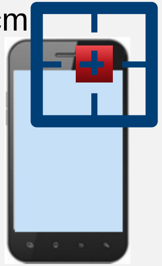


D = size of radiating aperture
λ = wavelength

HOW BIG OF A CHAMBER IS REQUIRED FOR DIRECT FAR FIELD?

Quiet zone size (white box)

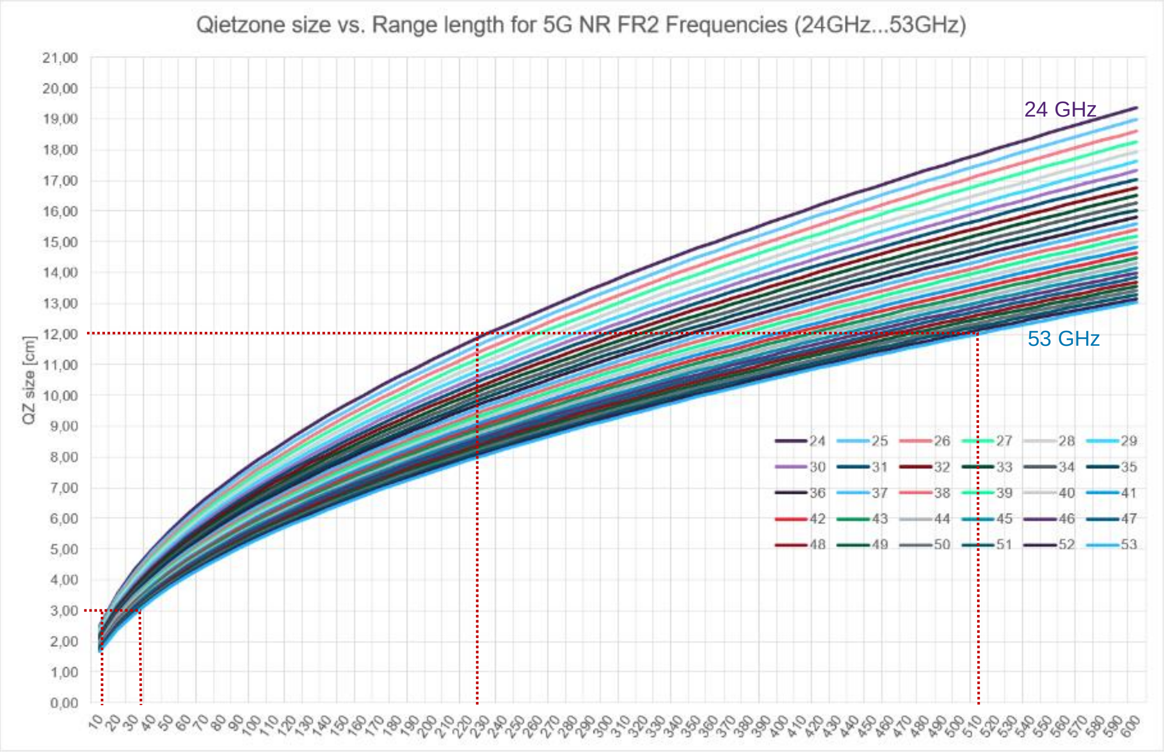
D=3 cm



Chamber size < 0.5 m

Quiet zone size (black box)

Chamber size ~ 3 m…6 m



HOW TO REDUCE THE FAR FIELD DISTANCE?

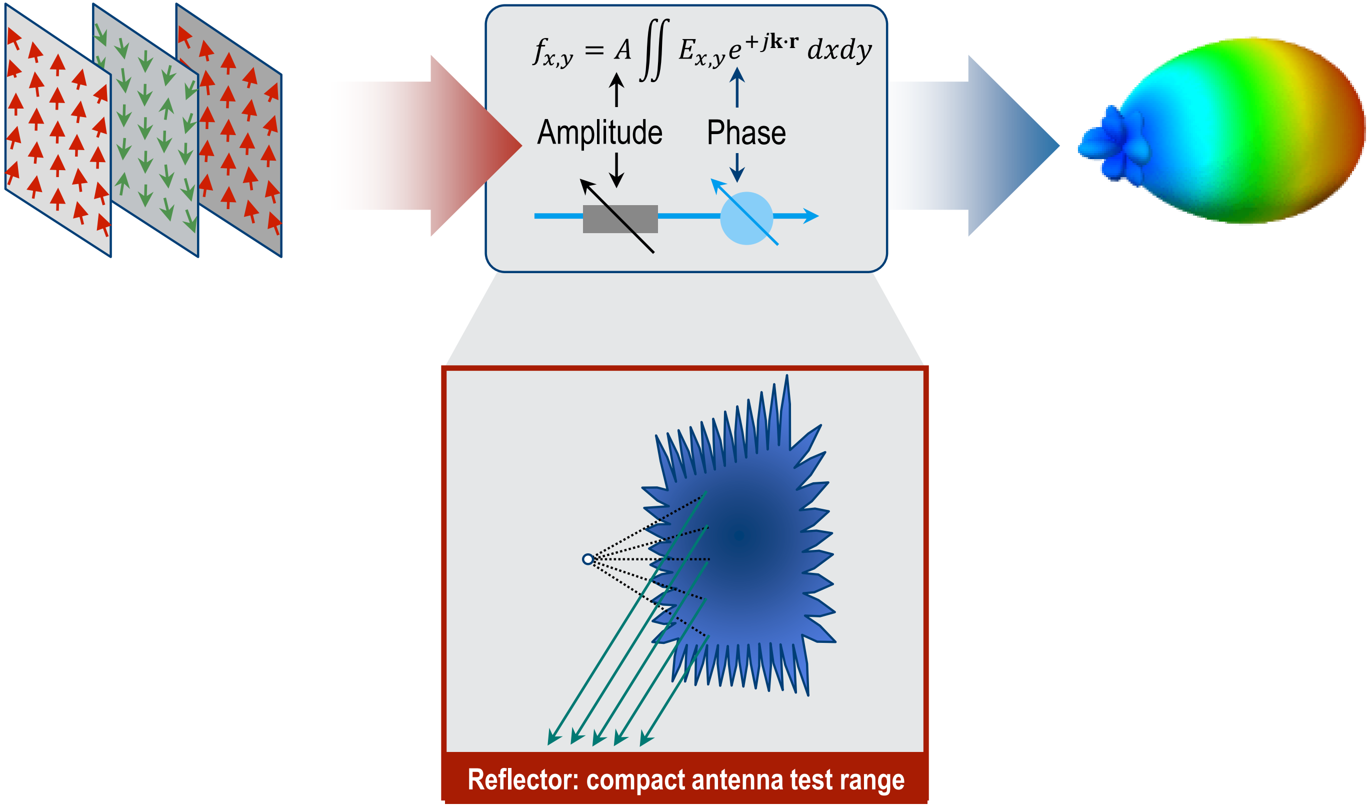
- Indirect far field methods
  - To overcome challenge of high path loss in far field

- CATR (compact antenna test range)
  - Performs transformation of fields to far field conditions using hardware
  - Leads to far field conditions in much smaller chamber size
  - Typically bigger quiet zone than direct far field

- Same measurements as in far field

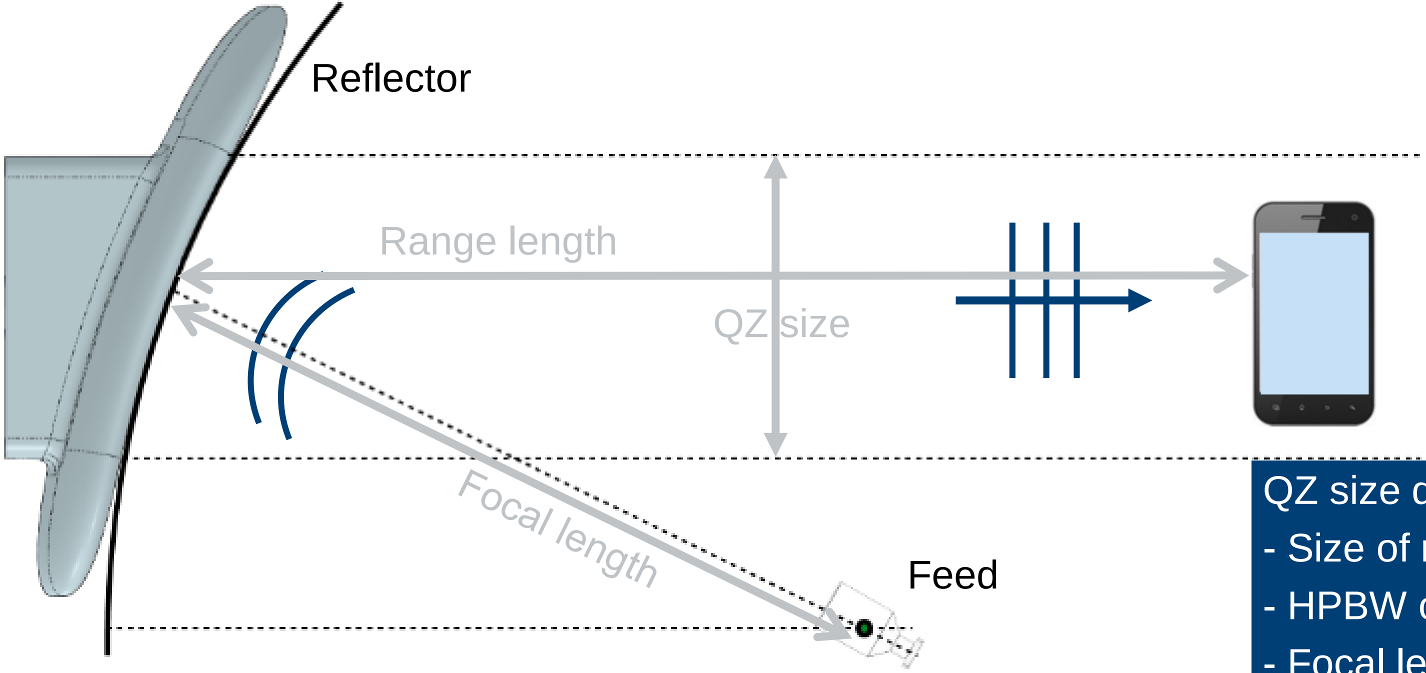
TRANSFORMING NF TO FF BY HARDWARE (CATR)

Complex near-field wave generated



Plane wave far-field received

POSSIBILITIES TO SHRINK THE CHAMBER SIZE – INDIRECT FAR FIELD

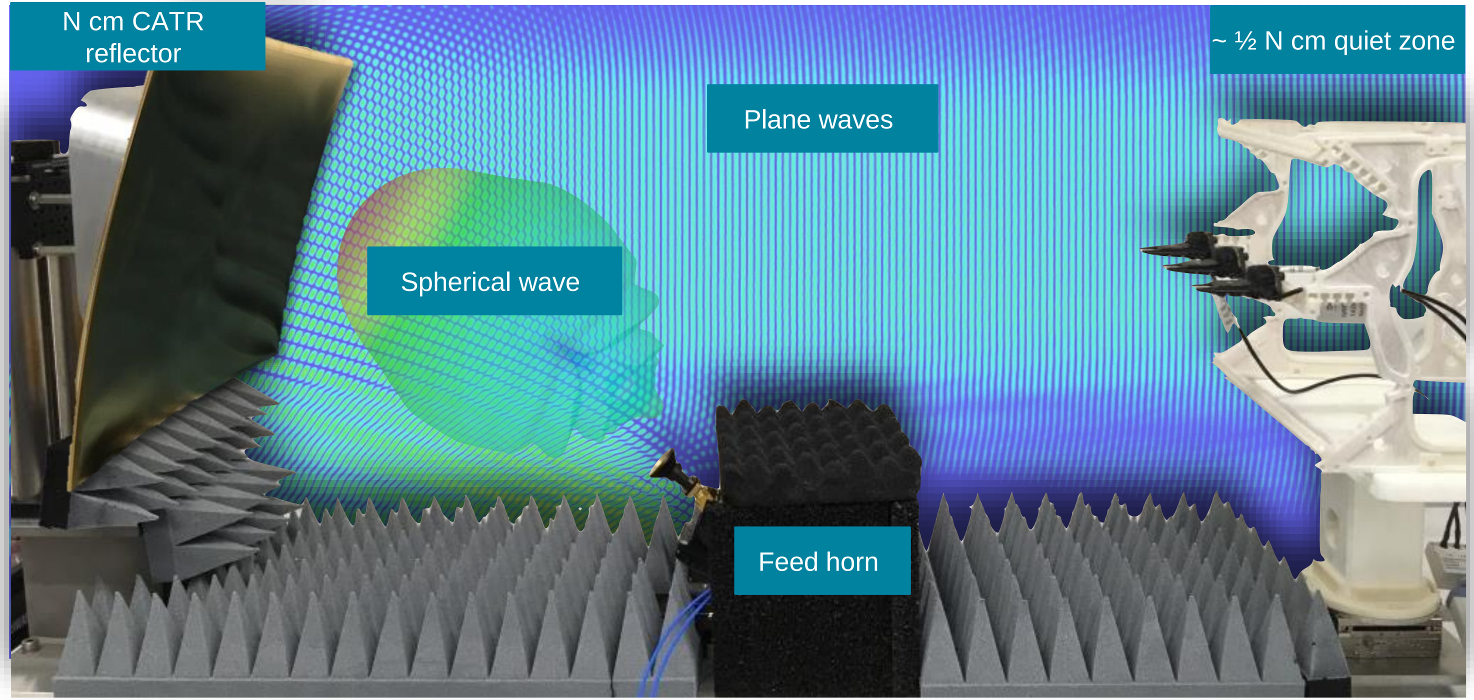


QZ size depends on

- Size of reflector
- HPBW of feed antenna
- Focal length

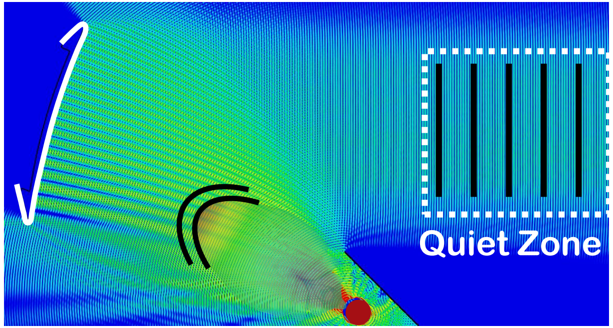
No direct relation between chamber size and QZ size

CATR – COMPACT ANTENNA TEST RANGE



CATR IS BI-DIRECTIONAL

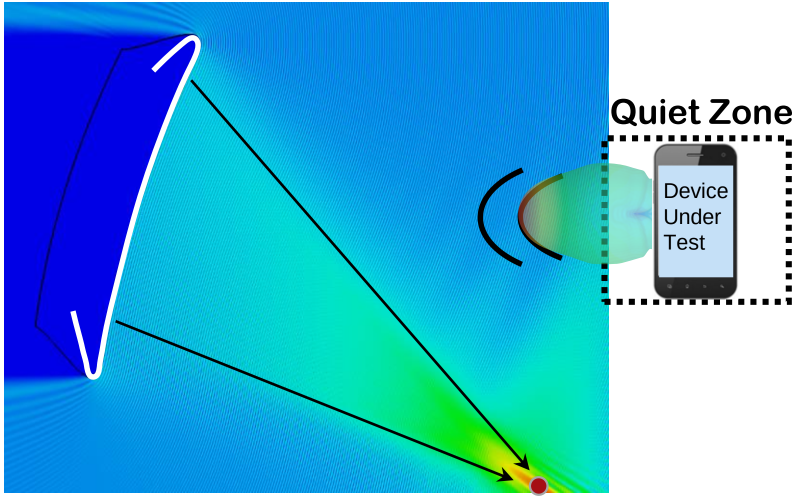
Forward: DUT Receives



From: Reflector Focal Point (Feed)
To: Reflector and DUT Quiet Zone

Reflector **transforms** spherical field from focal point (feed antenna) into a **planar wave** in front of reflector to quiet zone

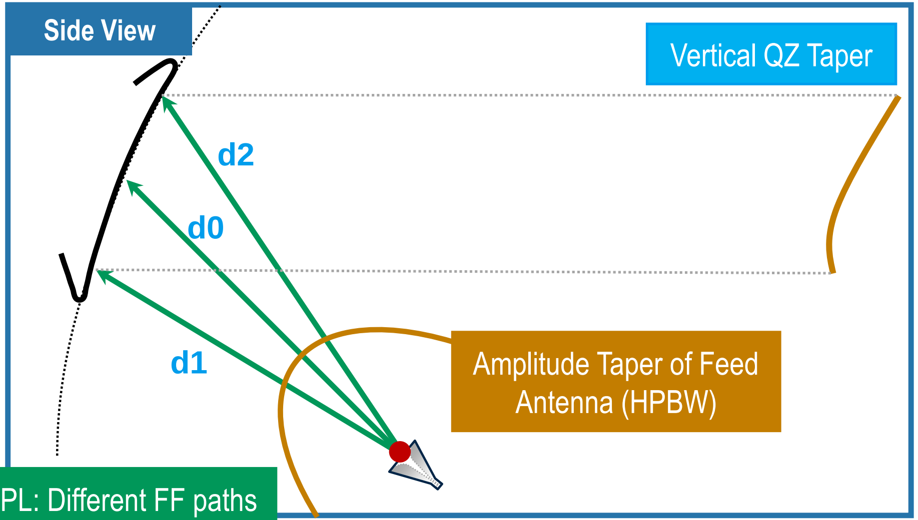
Reverse: DUT Transmits

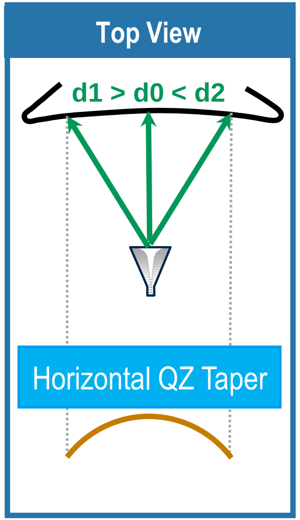


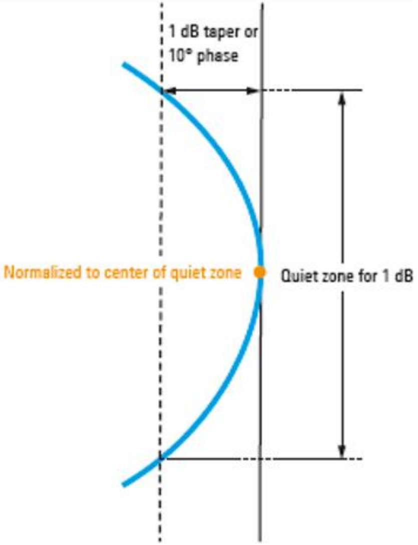
From: DUT Quiet Zone
To: Reflector Focal Point (Feed)

Reflector is a **spatial filter** that extracts the **planar components** of the spherical wave from DUT and focuses them at the focal point (feed antenna)

PATH LOSS IN CATR SYSTEMS







FSPL: Different FF paths to upper and lower portions of reflector

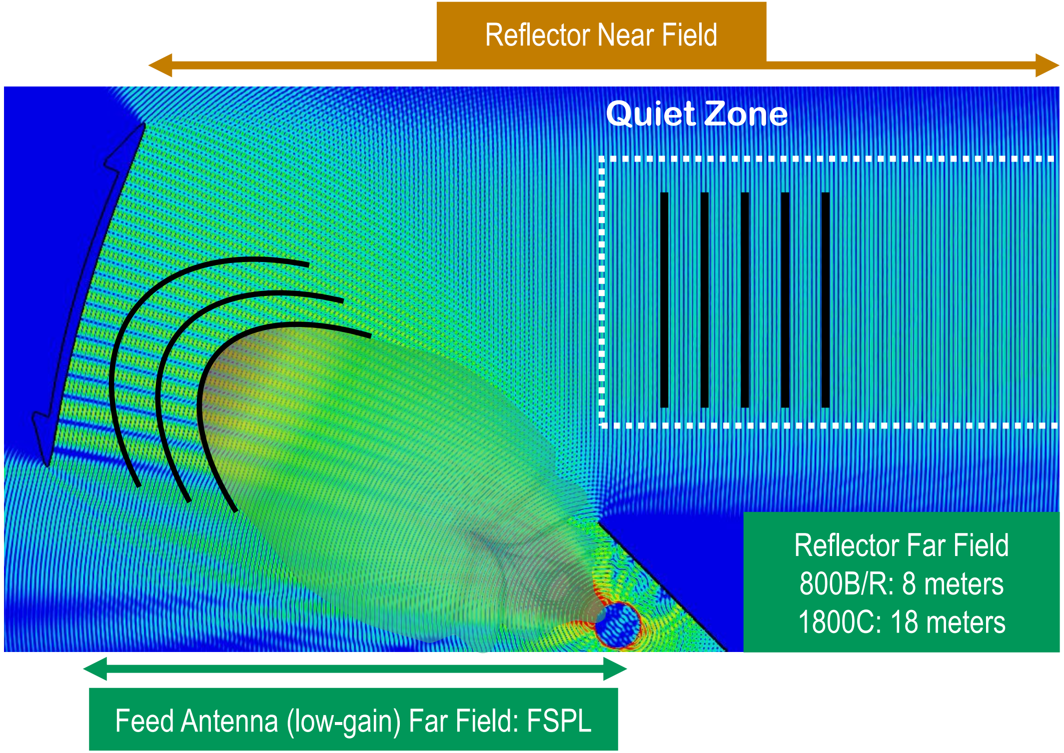
$$FSPL = 20\log_{10}(d) - 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r$$

d1 < d0 < d2

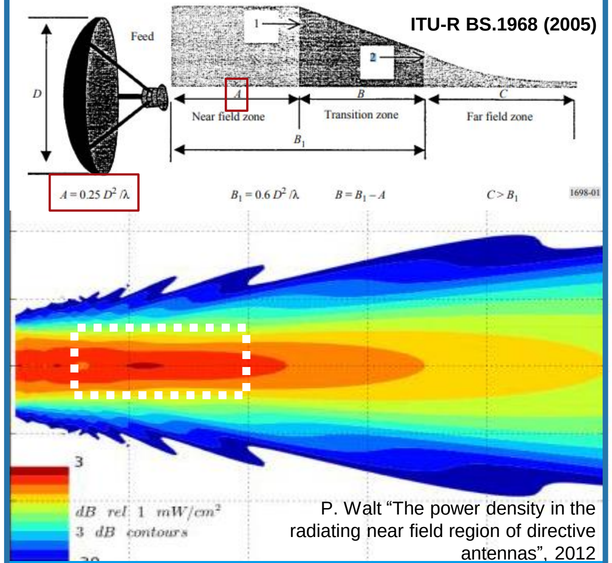
frequency

Free Space Path Loss: from Feed to Reflector

PATH LOSS IN CATR SYSTEMS



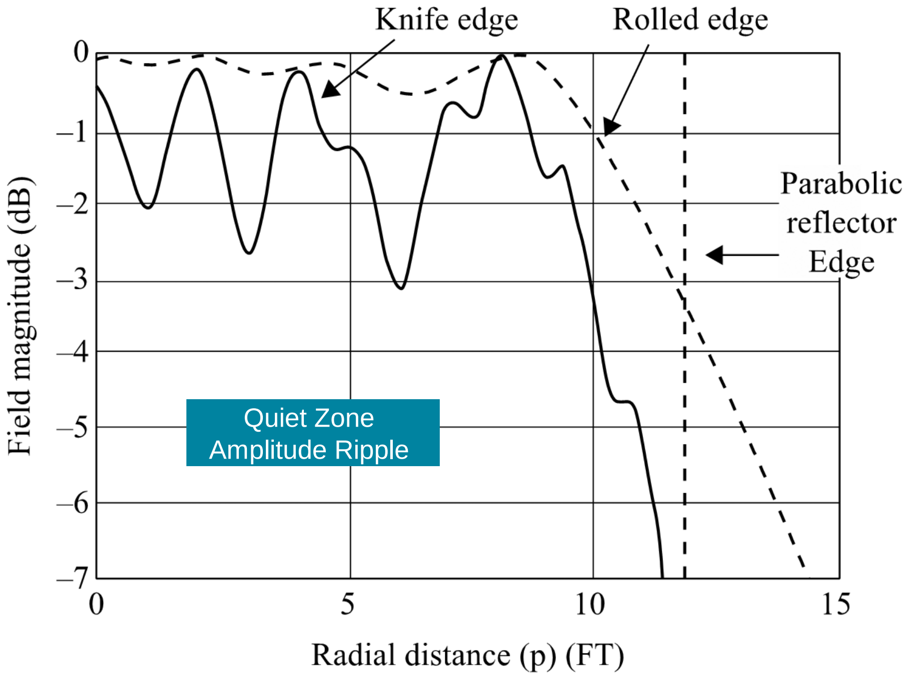
Parabolic Reflector Power Density



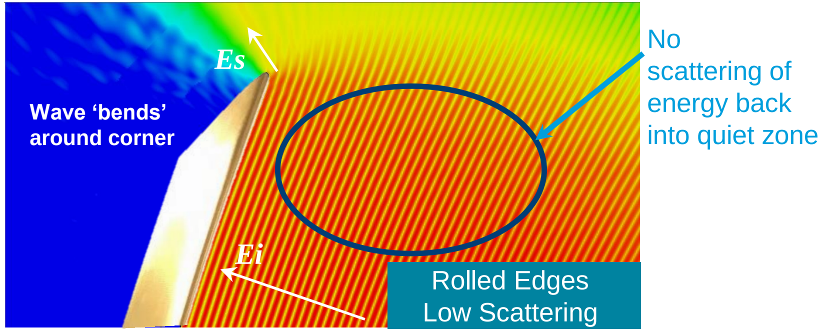
Power Density is constant up to: $0.25D^2/\lambda$
800B/R (D = 20cm): 1 meter @30GHz
1800C (D = 30cm): 2.25 meters @30GHz

No Path Loss from Reflector to DUT

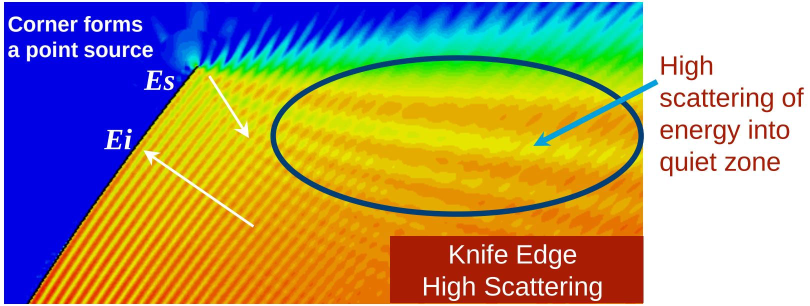
CATR REFLECTOR EDGE TREATMENT (LOW FREQUENCY)



W. Burnside "Curved Edge Modification of Compact Range Reflector", IEEE 1987

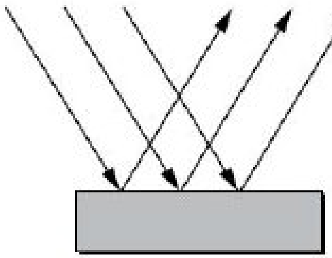


Ei: Initial EM field (from feed horn)

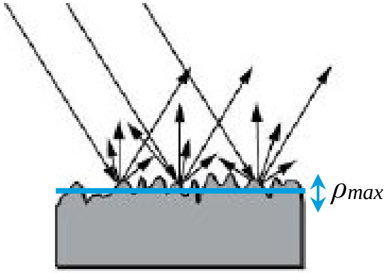


Es: Scattered EM field (from edges)

CATR REFLECTOR SURFACE ROUGHNESS (HIGH FREQUENCY)

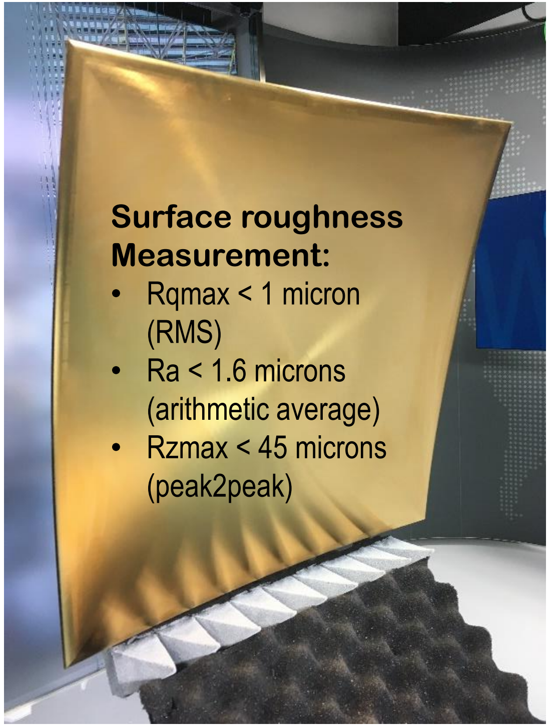


Ideal

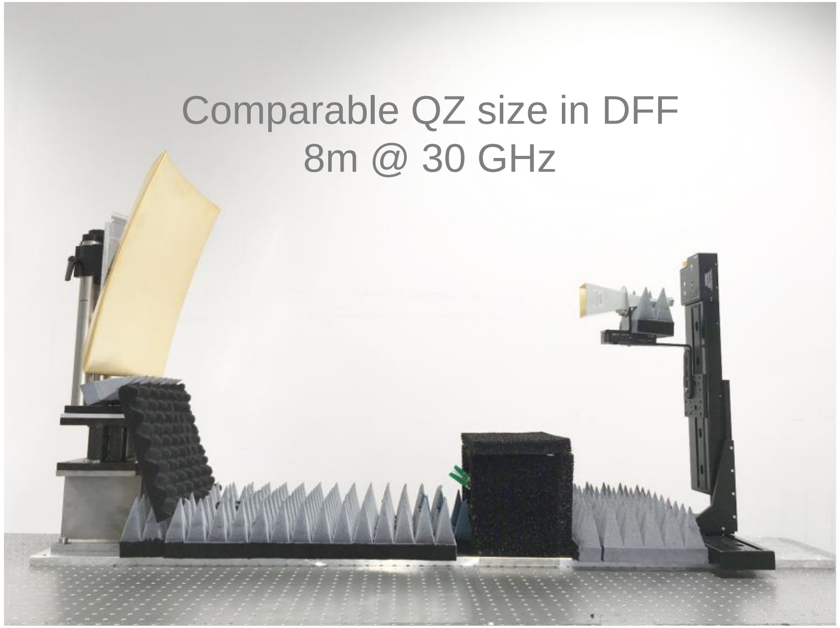


Actual

Maximum Frequency	Surface Roughness (microns)
28 GHz	75
43 GHz (in band)	49
87 GHz (spurious emissions)	24
220 GHz (FCC 5th Harmonic)	< 1



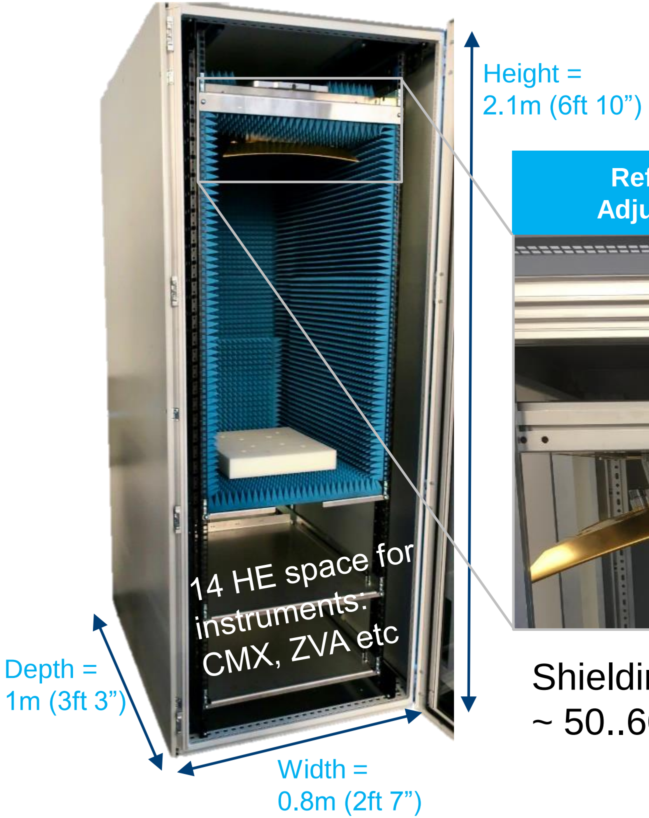
ATS800B – CATR BENCHTOP TEST SETUP

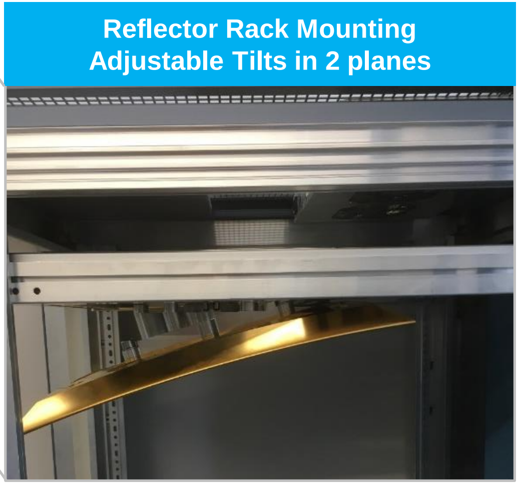


No shielding

- Application: basic antenna R&D, education
- Quiet zone: D 20 cm
- Dimensions: 120x60x80 cm
- Maximum DUT size: 40x40 cm (laptop)
- Reflector <1um surface roughness
- Optional 2D positioner
- Wide band feed antenna

ATS800R – CATR RACK-MOUNTED TEST CHAMBER





Shielding efficiency
~ 50..60dB

- Application: chipset and mobile phone R&D
- Quiet zone: D 20 cm
- Dimensions: 80x100x210 cm (rack)
- Maximum DUT size: 40x40 cm (laptop)
- Reflector <1um surface roughness
- 3D Azimuth over Elevation positioner (opt.)
- Wide band feed antenna

ATS1800C FULL CONFORMANCE/COMPLIANCE TESTING

- Application: 3GPP conformance
- Quiet zone: D 30 cm
- Dimensions: 90x150x210 cm
- Maximum DUT size: 40x40 cm (laptop)
- Reflector <1um surface roughness
- 3D Azimuth over Elevation positioner
- Wide band feed antenna

OTA TEST IN EXTREME TEMPERATURE CONDITIONS

- Active antenna arrays
  - Amplifiers and phase shifters for beam forming and beam steering
  - Temperature sensitive
  - Accuracy in forming beams influenced by operation temperature

  → OTA tests in different temperature conditions

- Temperature tests in OTA chamber is difficult
  - Volume of air to be heated or cooled is big - takes a long time to reach stable temperature
  - Absorbers and positioning motors do not like very high or very low temperatures

- Thermal solution avoiding these problems
  - Climate bubble installed inside OTA chamber
  - Climate controlled by an external thermal stream

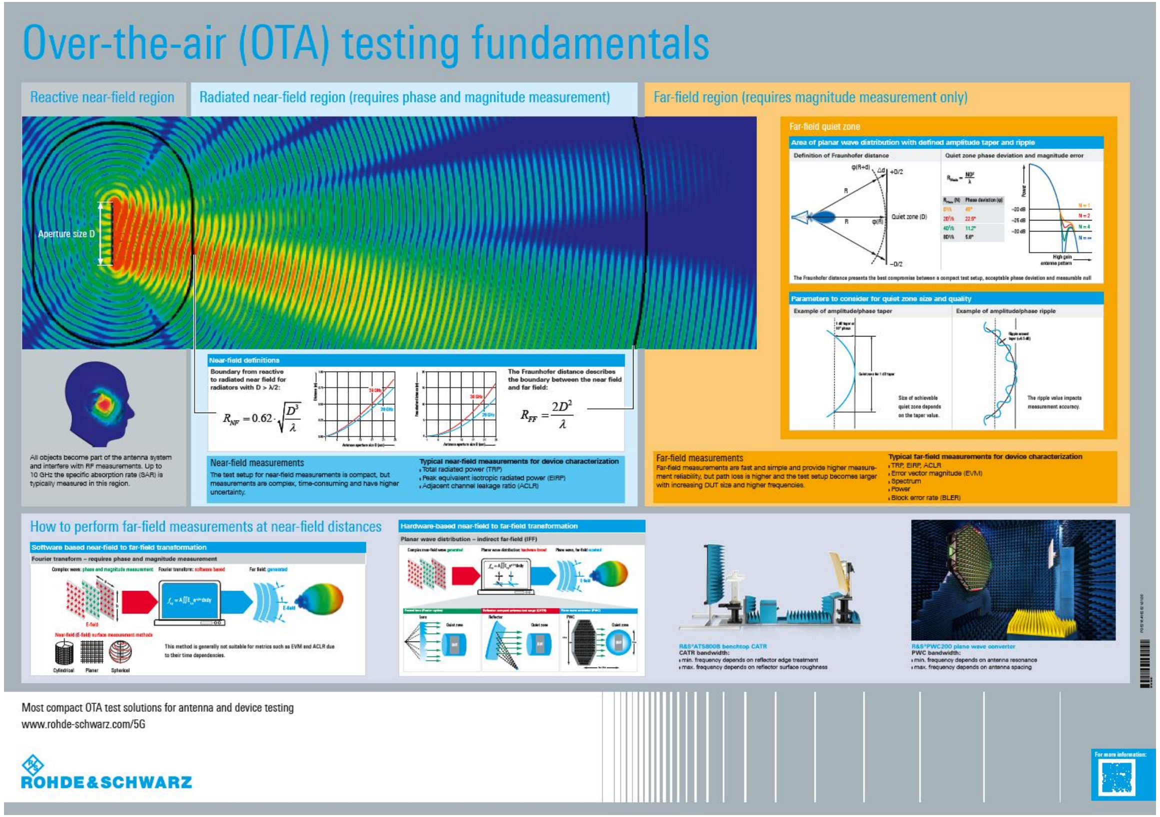
FULL 3-D OTA SOLUTION FOR EXTREME CONDITIONS

- Full spherical measurement under controlled temperature condition from -40°C to +85°C
- 100°K temp change within approx. 10 minutes
(-40…+60 / +85…-15)

R&S OTA FR2 SOLUTIONS OVERVIEW

	WPTC	ATS1000	CMQ200	ATS800B	ATS800R	ATS1800C
						
Dim. (WxDxH) [m]	5.2 x 4.3 x 4.1 (L)	0.9 x 1.5 x 2	0.45 x 0.7 x 0.6	1.2 x 0.6 x 0.8	0.8 x 1 x 2.3	0.9 x 1.5 x 2
Application	R&D antenna measurements CTIA	R&D antenna measurements	Production device/components	R&D academia, research institutes	R&D pre-conformance (RF, PQA)	R&D pre-conformance Conformance (RF, RRM 1AoA)
Approach	White box DFF/NF	White box DFF/NF	White box DFF	Black box CATR	Black box CATR	Black box CATR
Freq. range	0.4 to 90 GHz	10 to 87 GHz	20 to 75 GHz	10 to 87 GHz	10 to 87 GHz	6 to 90 GHz
Quiet zone	Ø 7 cm @ 40 GHz	Ø 4 cm @ 40 GHz	Ø 2 cm @ 40 GHz	20 cm @ 40 GHz	20 cm @ 40 GHz	30 cm @ 40 GHz
Positioner	3D conical cut	3D conical cut	1D	2D positioner (optional)	3D Az over El (optional)	3D Az over El
DUT size	Up to 1 m	20 cm x 20 cm	25 cm x 25 cm	40 cm x 40 cm	40 cm x 40 cm	Ø 45 cm
DUT weight	Up to 100 kg	20 kg	1 kg	2.5 kg	5 kg (w/o pos.)	8 kg

OTA TESTING FUNDAMENTALS POSTER



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