5G OTA RF testing

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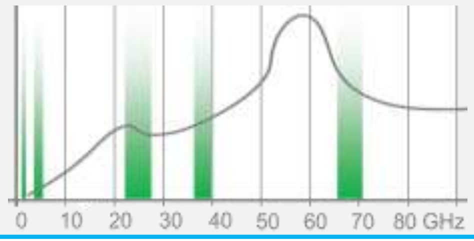
FCC 5G Spectrum Auction: 24/28 GHz

- **03.06.2019**: The **FCC** released the names of companies that won licenses in the recently completed auction of spectrum suitable for 5G deployments in the 24 GHz and 28 GHz millimeter wave bands
- The biggest 5G millimeter wave auction winners: **AT&T, T-Mobile, Verizon**, Windstream, Starry and U.S. Cellular
- Two auctions combined raised a total of about **$2.7 billion**.
- Millimeter wave spectrum also can support high speeds for fixed wireless service: hence the participation of companies such as Starry and Windstream that are likely to use the spectrum for fixed services.

5G Key Technology Components

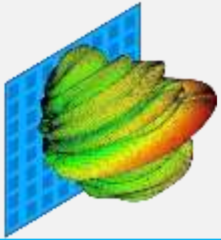
NR builds on four main pillars

New Spectrum



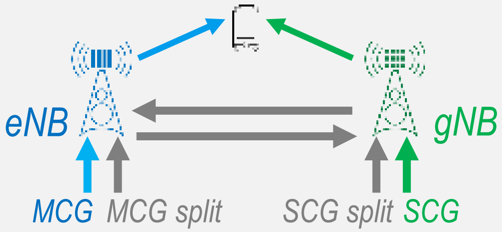
- < 1GHz
- ~ 3.5 GHz
- ~ 26/28/39 GHz

Massive MIMO & Beamforming



- Hybrid beamforming
- > 6GHz also UE is expected to apply beam steering

Multi-Connectivity



Initially based on Dual Connectivity with E-UTRA as master

Network flexibility - virtualization

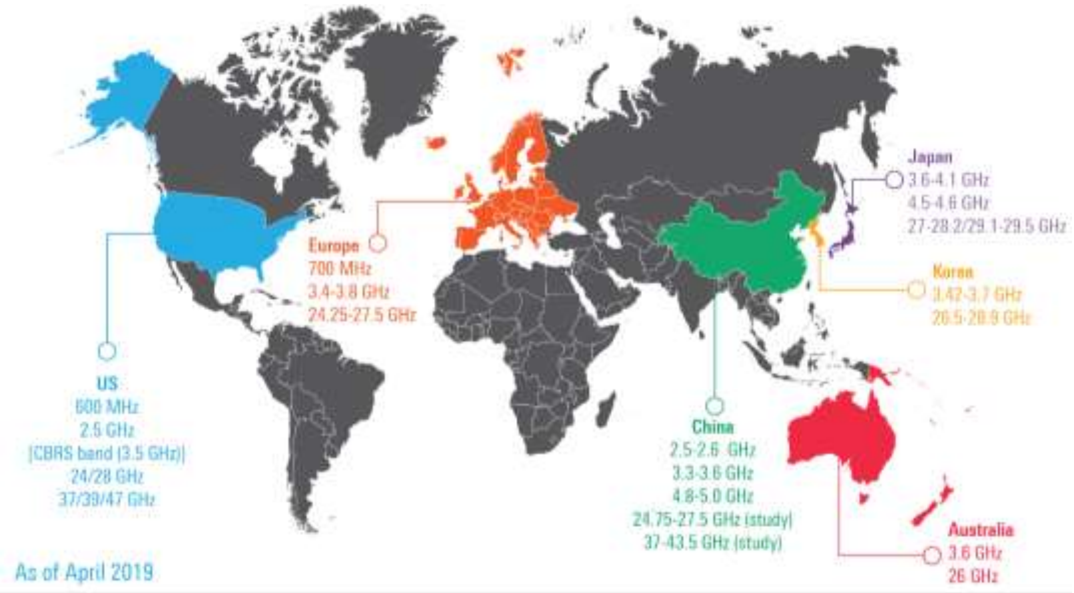
- Flexible physical layer numerology
- Network Slicing
- NFV/SDN

Frequency trends for 5G

NR frequency range 1 reserved numbers 65-256		
	Downlink	Uplink
…	…	…
n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz
n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz
n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz
…	…	…

NR frequency range 2 Reserved numbers 257-512		
	Downlink	Uplink
n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz
n259	n/a	n/a
n260	37 – 40 GHz	37 – 40 GHz

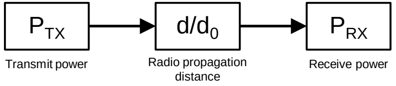
The prefix “n” is used for any NR bands



Frequency bands	**Frequency range**	**Wavelength range λ**	$1\ m\ distance\ FSPL^{*}$
UHF Ultra High Frequency	300 MHz – 3 GHz	10 – 1 dm	22 dB – 42 dB
SHF Super High Frequency	3 GHz – 30 GHz	10 – 1 cm	42 dB – 62 dB
EHF Extra High Frequency	30 GHz – 300 GHz	10 – 1 mm	62 dB – 82 dB

Beamforming to combat increased path loss

Path loss model for real propagation environments



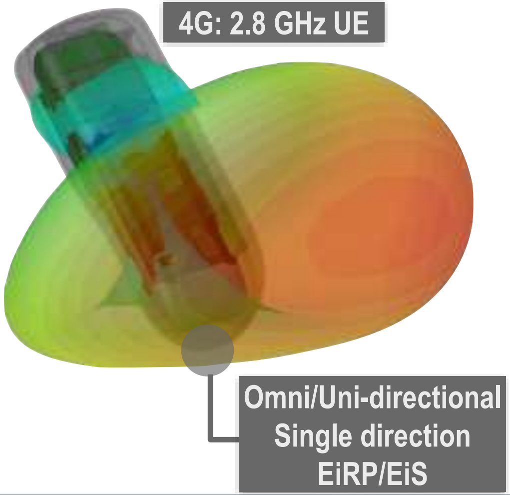
$$P_{RX} = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi R}\right)^2$$

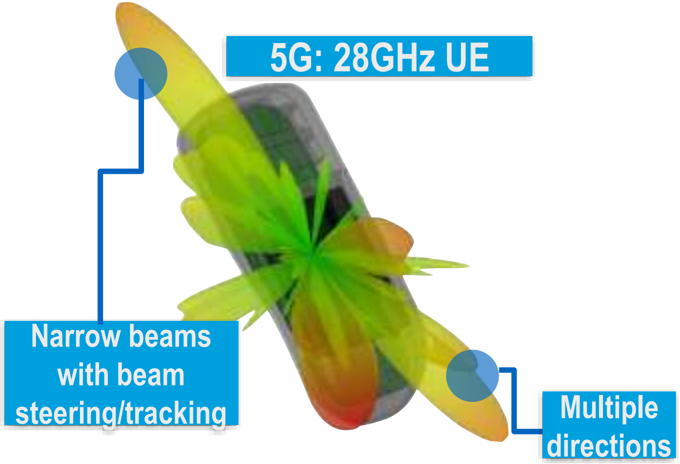
Antenna gain

path loss

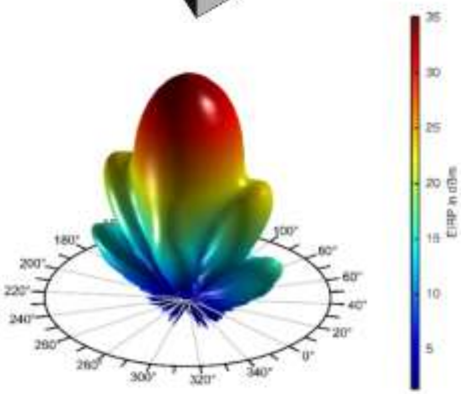
Friis equation: $\frac{P_{RX}}{P_{TX}} = G_{TX}G_{RX}\left(\frac{\lambda}{4\pi d}\right)^{\gamma} = K\left(\frac{d}{d_0}\right)^{-\gamma}$

Frequency	2 GHz	28 GHz	39 GHz	60 GHz	73 GHz
Path-loss (d = 1m)	41.4 dB	61.4 dB	64.3 dB	68.0 dB	69.7 dB

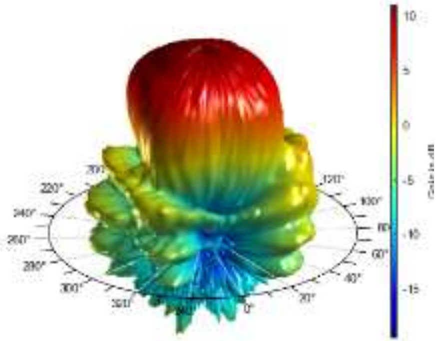




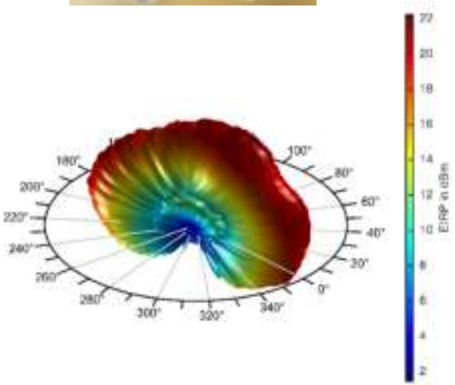
Directive antenna samples @ 28 GHz



Standard Gain Horn Antenna
IB measurements



R&S Vivaldi antenna
IB and OOB measurements



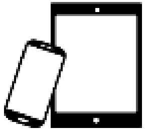
4x1 printed antenna array

Measurement antenna

DUT antenna

From lab to the field

Early development stage → **Prototyping** → **Reference designs and final devices**



Stage: **R&D** → **Integration** → **Production**

Measurements:

R&D
- *Simulations*
- *Passive testing*
- *gain, directivity, efficiency, beam width, 3D/2D pattern,*

Integration
- *Active testing: reference unknown. TRP, EIRP, efficiency, 3D/2D pattern, TIS, EIS, EVM, ACLR, BER*
- *Multiple active antenna arrays: no constant pattern*
- *No Tx and Rx reciprocity*

Production
- *Transmitter tests*
- *Receiver tests*
- *Conformance*

Transmitter and receiver testing needs

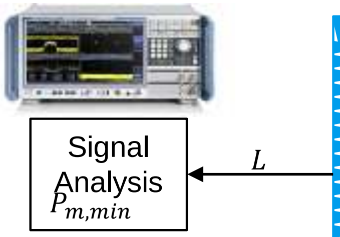
Transmitter RF testing needs

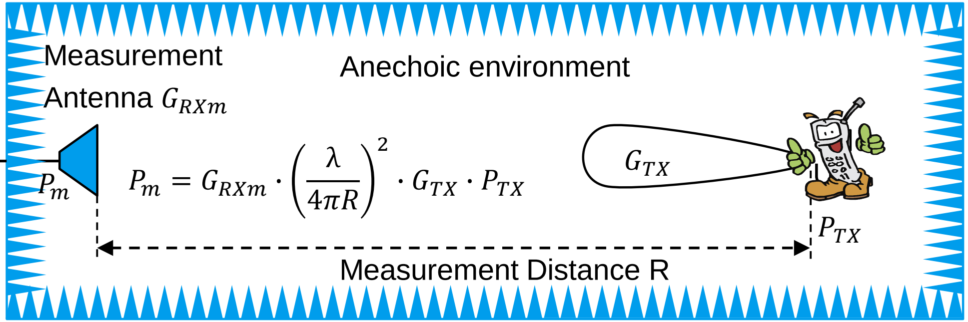
- Frequency accuracy and stability (regulatory)
- Transmitter min and max power (regulatory)
- Transmitter inband and out of band emissions (regulatory)
- Transmitter signal (modulation) quality: OBW, ACLR, EVM, spectral flatness

Receiver RF testing needs

- Reference sensitivity
- Selectivity (ACS, blocking, intererence, intermodulation)
- Demodulation performance (fading and multipath conditions)
- RRM related parameters: RSRP and RSRQ

- Example: Signal quality measurements (EVM)
- Link budget constraints





$$P_m - L - P_{m,min} > SNR_{min}$$

3GPP Terminology

- *Where is the far field?*
- *White box vs black box approach*
- *Quiet zone*
- *DFF vs IFF*

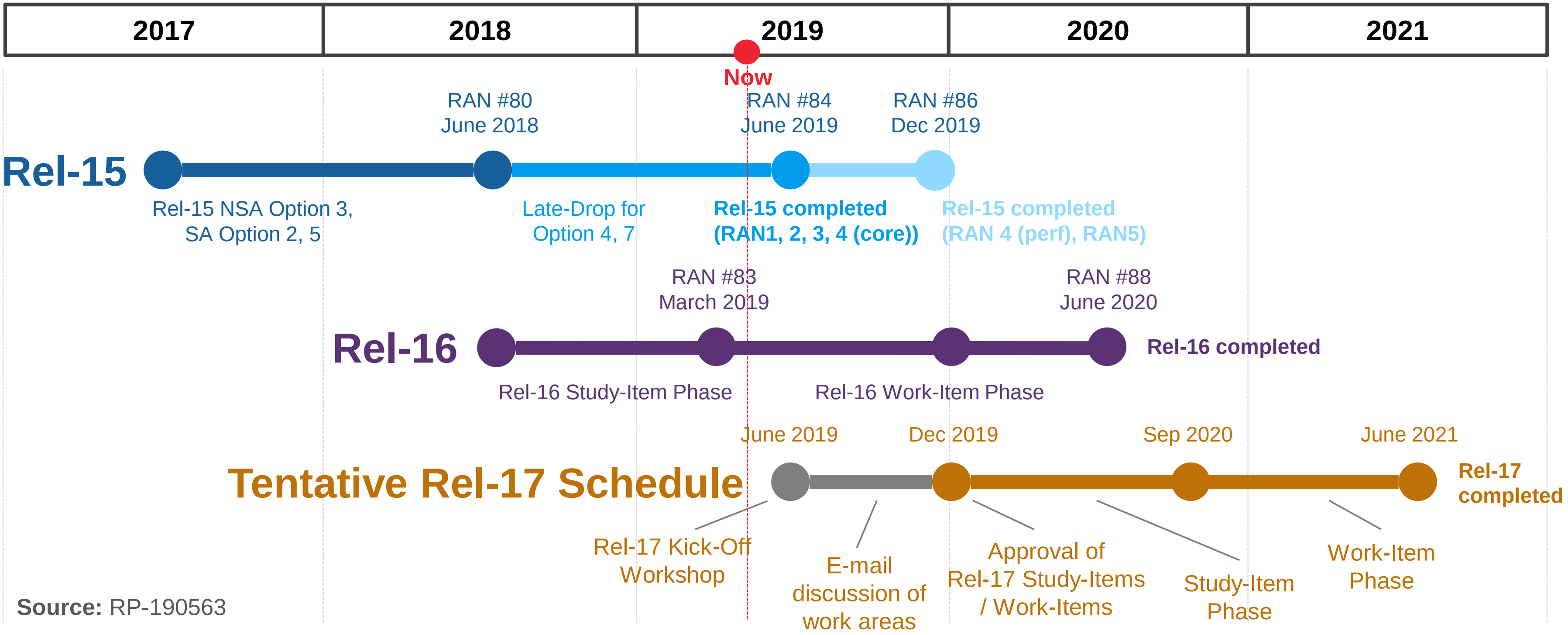
3GPP RAN NR Standardization Overview

Status after 3GPP RAN #83 (April 2019)

Rel-15 NR specs for 5G

Rel-16 NR specs for V2x, satellite etc

Rel-17 future trends tbd



Source: RP-190563

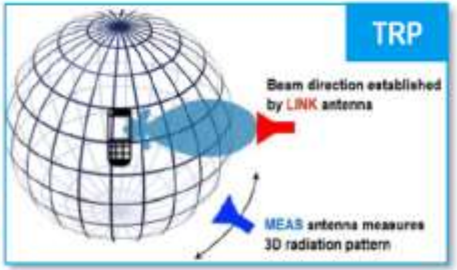
3GPP conformance testing

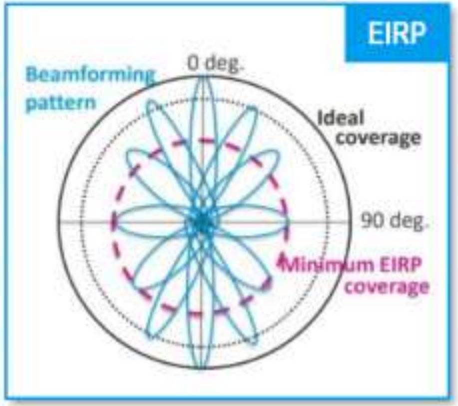
3GPP NR Specifications	
Series	**Title**
38.1xx	RF test spec.
38.2xx	Layer 1
38.3xx	Layer 2 / 3
38.4xx	Core netw.
38.5xx	**UE conf.**
37.324	LTE and NR
37.340	NR multi-conn.

RF 38.521

- **Tx in-band**
- **Tx spurious**
- **Rx in-band**
- **Rx blocking**
- **Demod**
- **Mobility**
- **Reporting**

RRM 38.533

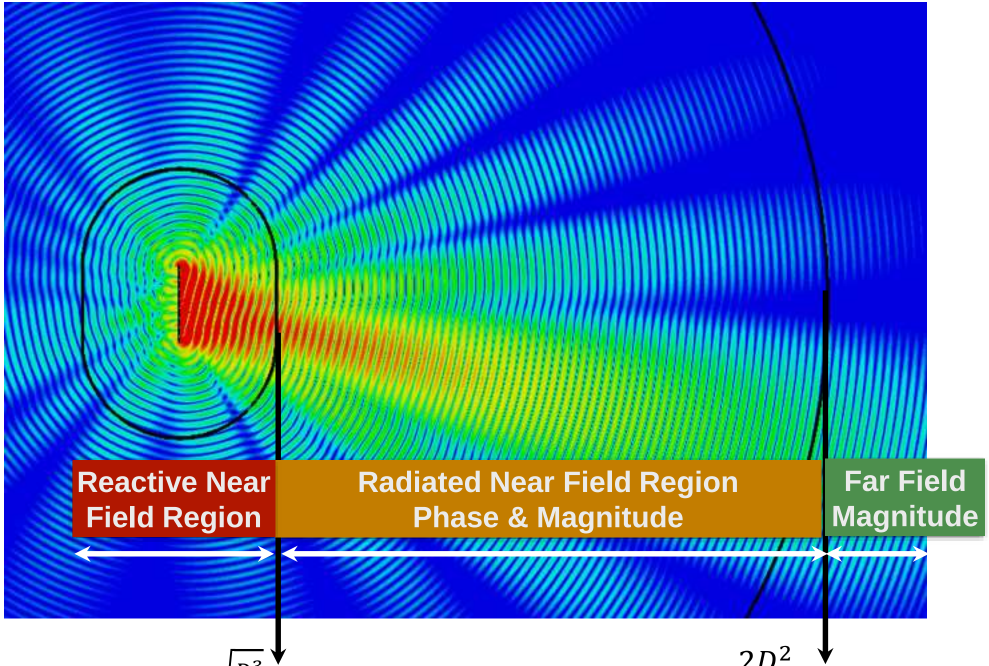




TC	Test	Metric
6.2.1	Max Tx Power	TRP @ BP
6.3.1	Min Tx Power	EIRP
6.3.2	Off Power	TRP
6.3.3	On/Off Time Mask	Beam Peak
6.4.1	Frequency Error	Beam Peak
6.4.2.1	Carrier Leakage	Beam Peak
6.4.2.2	EVM	Beam Peak
6.4.2.4	Spectral Flatness	Beam Peak
6.5.3.1	OBW	TRP
6.5.2	SEM	TRP
6.5.3.2.4	ACLR	TRP
6.5.3.2	Spurious Emissions	TRP
7.3	Ref. Sensitivity	EIS CDF
7.4	Max Input Level	Beam Peak
7.5	ACS	Beam Peak
7.6.1	In-Band Blocking	Beam Peak
7.6.2	Out of Band Blocking	Beam Peak
7.9	Rx Spur. Emissions	TRP

Where is the Far-field?

Base Station (50cm) 8 element array at 28 GHz



$0.62\sqrt{\frac{D^3}{\lambda}}$

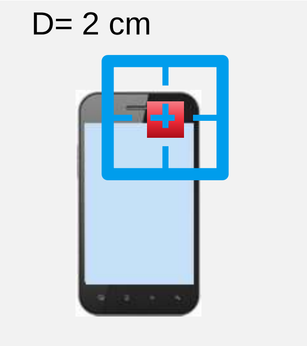
$\frac{2D^2}{\lambda} = 46m$

- 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

White box vs. black box testing

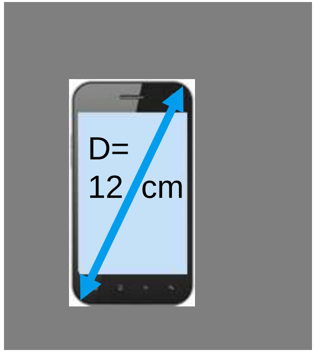
White box

- 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 know
- Example @ 30GHz
  - λ = 1cm
  - D= 2cm
  - Far field distance: $\frac{2D^2}{\lambda}$ 8cm



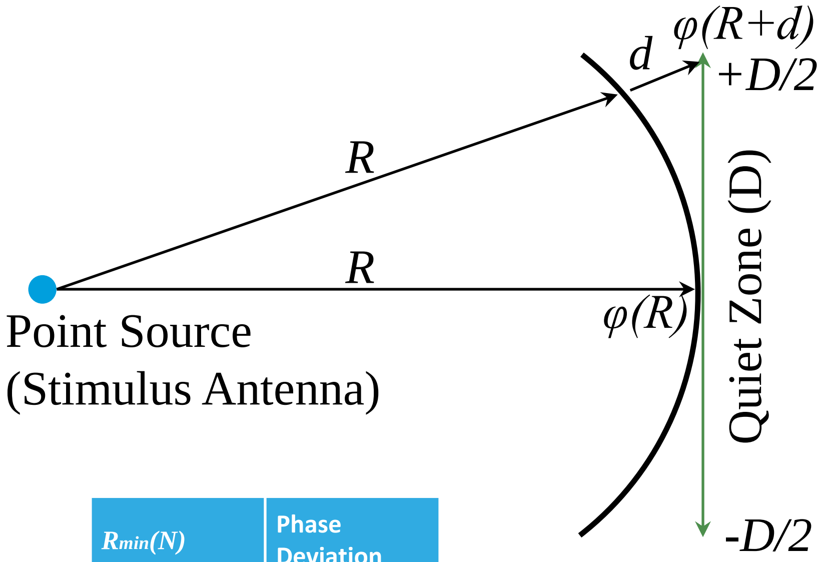
Black box

- 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
- Example @ 30GHz
  - λ = 1cm
  - D= 12cm
  - Far field distance: $\frac{2D^2}{\lambda}$ 2.9 m



What and where is the Quiet zone ?

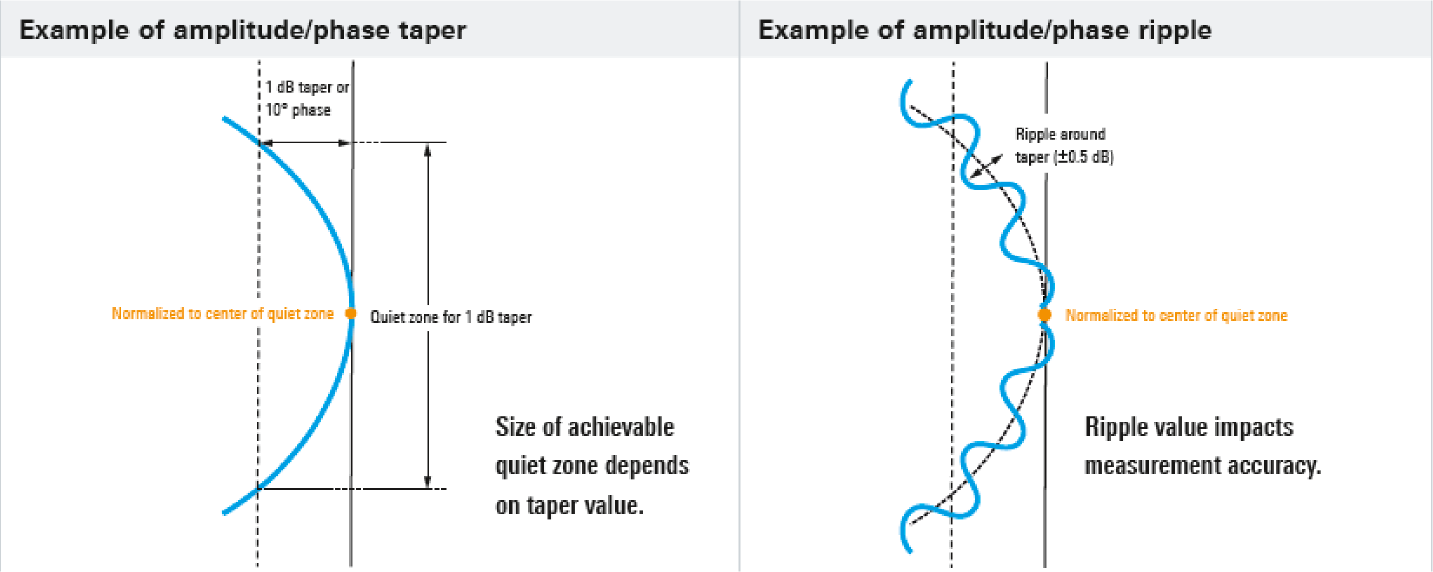
- For all types of chambers, the quiet zone (QZ) defines the area in which deviation of the amplitude and phase from the plane wave criteria is limited
- Inside the quiet zone for a given test range, plane waves are assumed.
- The quality of the QZ must be established by measurements in both amplitude and phase over the area the QZ encompasses.
  - Amplitude: x dB deviation
  - Phase. Maximum 22.5°
- Quiet zone size determines the DUT size



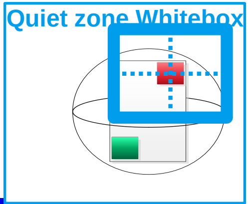
$R_{min}(N)$	Phase Deviation
D^2/λ	45 degrees
$2D^2/\lambda$	22.5 degrees
$4D^2/\lambda$	11.2 degrees
$8D^2/\lambda$	5.6 degrees

How "quiet" is it in the quiet zone?

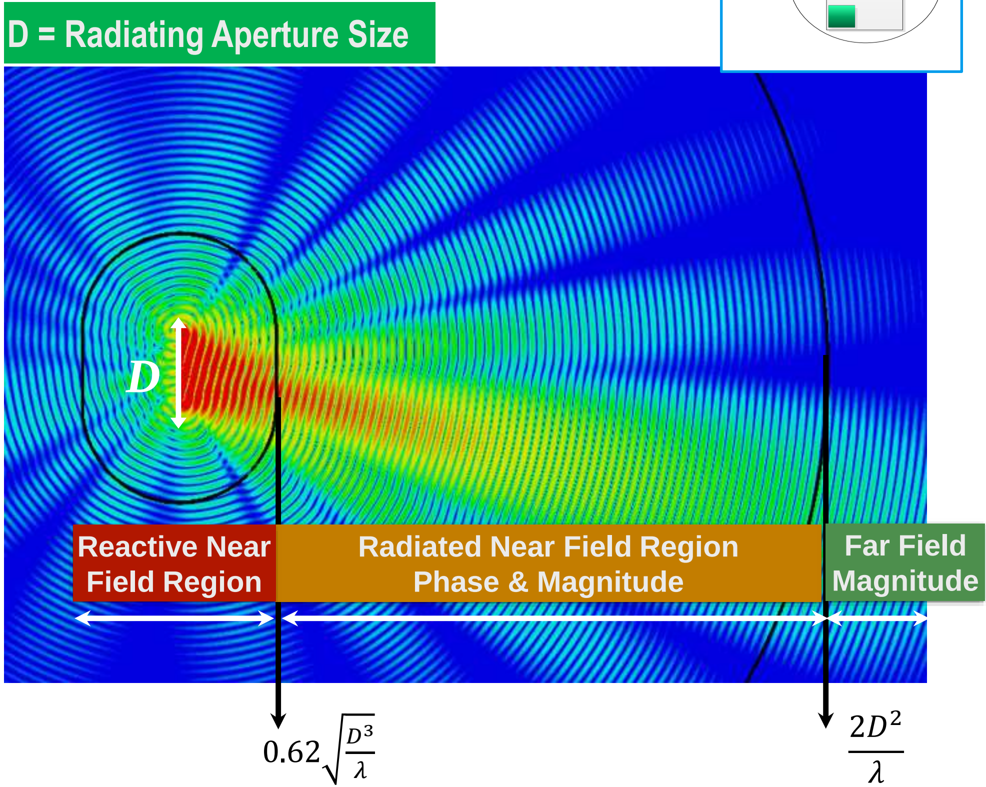
- The quietness of the quiet zone is defined by:
  - Amplitude Taper: caused mainly by the antenna pattern of the feed antenna
  - Amplitude Ripple: caused by imperfections in the reflector



DFF: direct far field

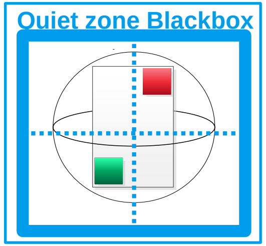


- All common antenna properties are defined in far field region
- Per IEEE definition, FF is the region where the field of the antenna is essentially independent of the distance from a point in the antenna region
- In FF, free space and plane waves are assumed
- Free space: no reflections-> need for a chamber
- FF distance: Fraunhofer distance $r \geq \frac{2D^2}{\lambda}$
- No special post processing steps are required to measure the antenna parameters
- Whitebox approach



IFF Indirect far field

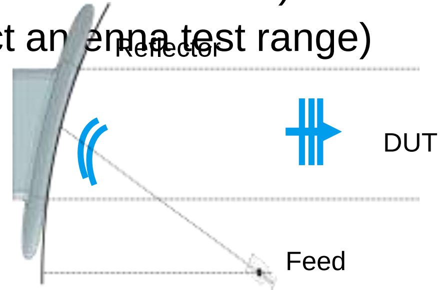
- A solution for far field condition in smaller distance than the Fraunhofer distance
- Use of adittional HW
- To differentiate direct FF test ranges from smaller setups with FF conditions, the term indirect far field (IFF) is used.
- Reduce the space requirement
- When having a bandwidth limited setup
- Blackbox approach



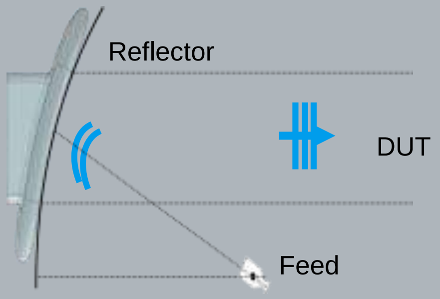
Techniques to reduce the far field distance

1. Transformation to far field conditions using SW
   - Fourier transformations: non real time

2. Transformation to far field conditions using HW
   - Using PWC (plane wave conversions)
   - Using CATR (compact antenna test range) technology



CATR technology
- Frequency
- Surface roughness
- Edge treatment



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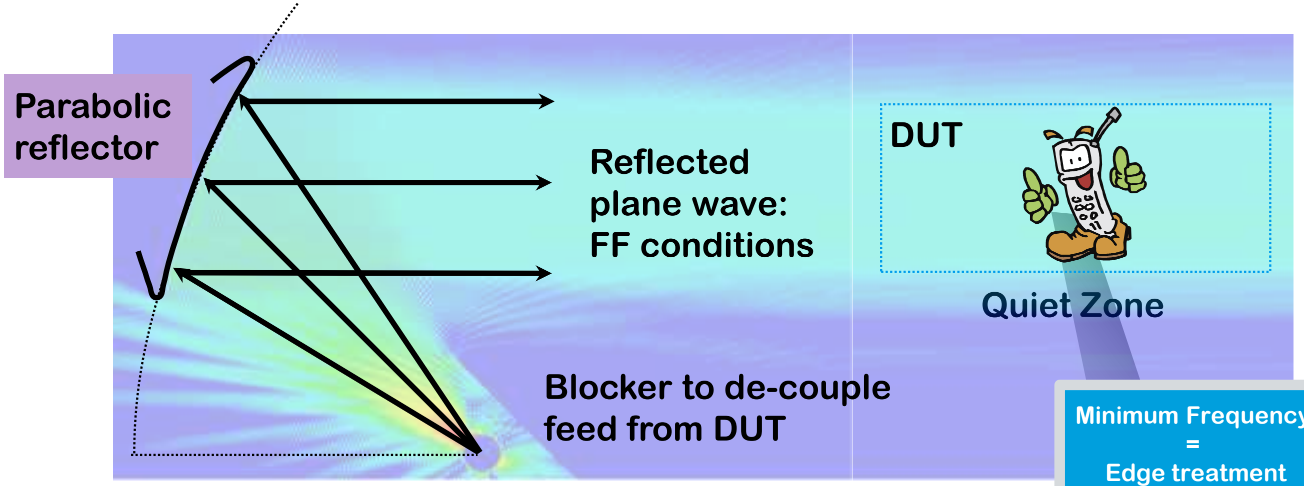
3GPP NR OTA RF test setup Compact Antenna Test Range (CATR)

CATR: Compact Antenna Test Range



Primary feed and measurement antenna at focus parabolic reflector

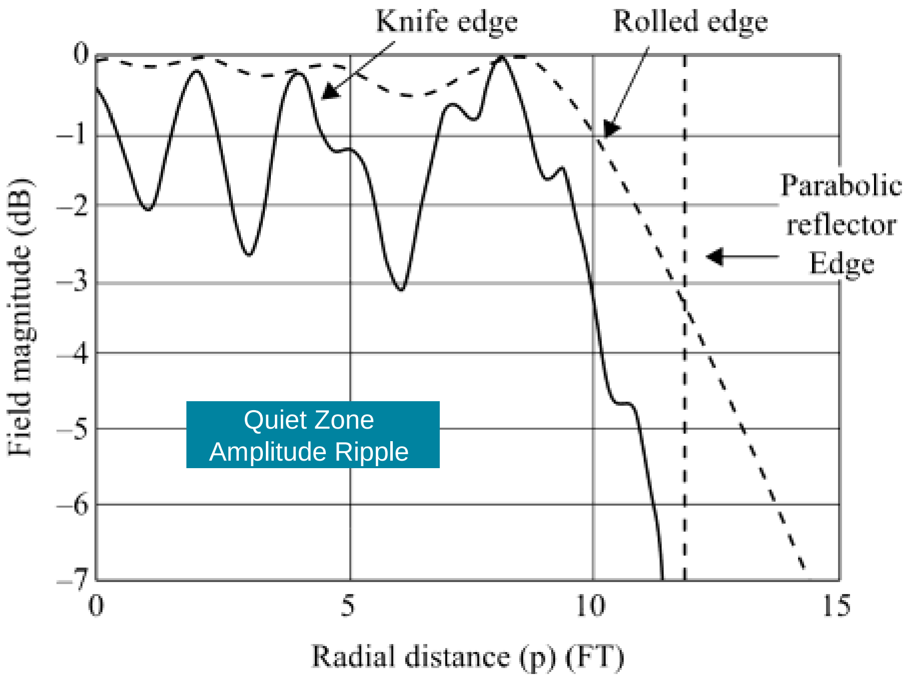
Minimum Frequency = Edge treatment

CATR Bandwidth

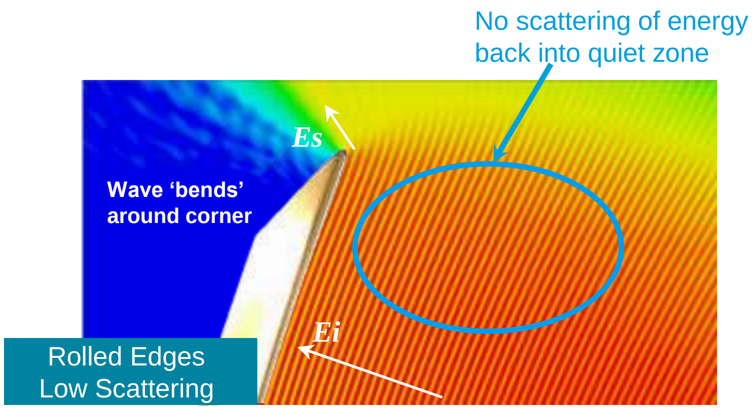
Maximum Frequency = Surface roughness

R&S®ATS1800C

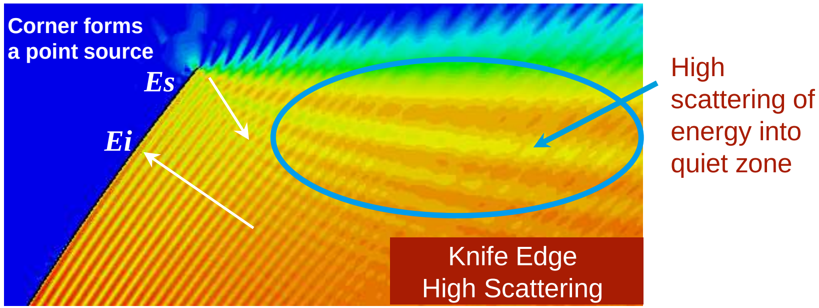
CATR reflector errors (1): edge treatment



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

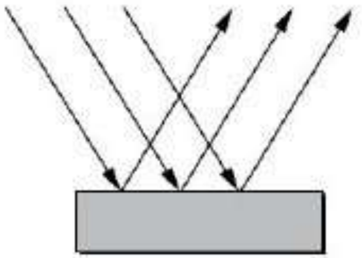


Ei: Initial EM field (from feed horn)

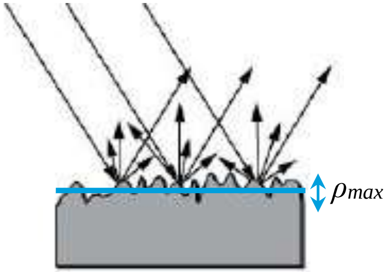


Es: Scattered EM field (from edges)

CATR reflector errors (2): surface roughness



Ideal

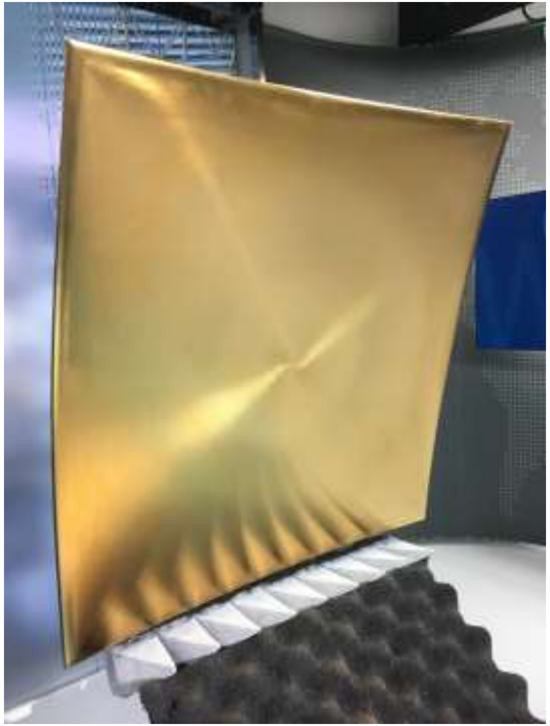


Actual

Maximum Surface Deviation

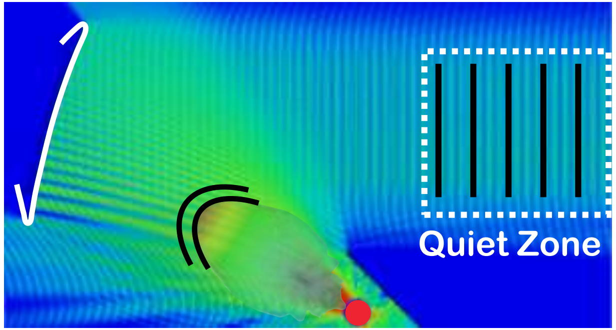
$\rho_{max} = 0.007\,\lambda$

Maximum Frequency	Surface Deviation (microns)
28 GHz	75
43 GHz (in band)	**49**
87 GHz (spurious emissions)	24



CATR is a Bi-directional Device

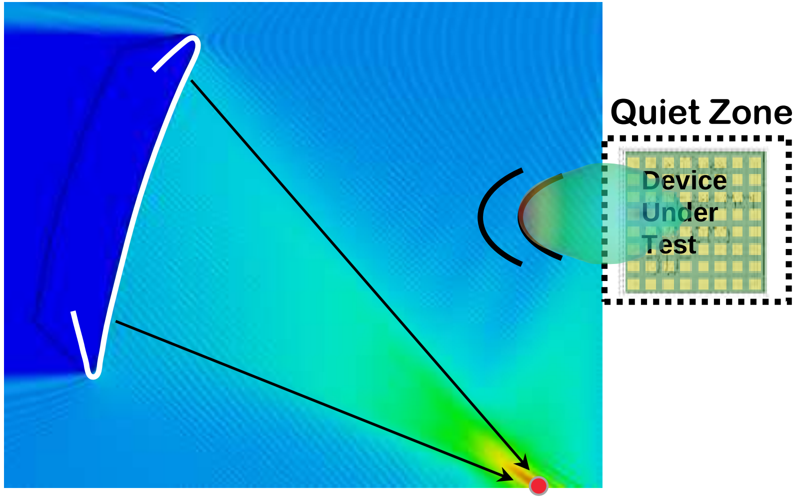
Forward: DUT Receives



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

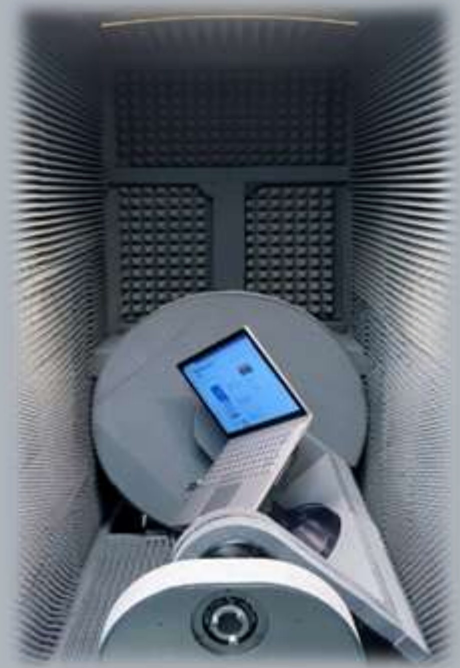
Reverse: DUT Transmits



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

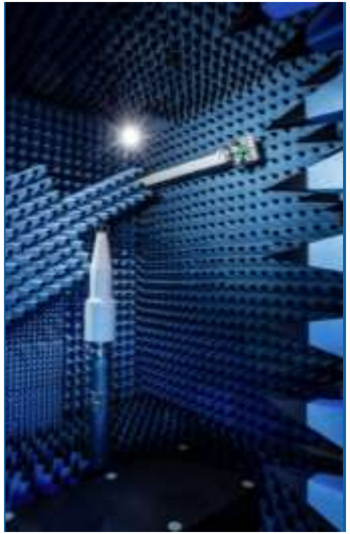
Reflector is a spatial filter that extracts the planar components of the spherical wave from DUT and focuses them at the focal point (feed antenna)

R&S OTA systems portfolio



R&S 5G NR OTA Solutions

Antenna Design
- Most Broadband
- Flexible system
- FR1&FR2 R&D



WPTC

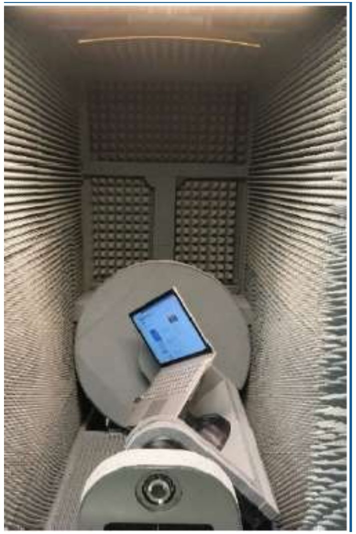
Early Stage R&D
- Fast Test Speed
- Climate Test
- FR2 chip and antenna

ATS1000

R&D Callbox
- 20 cm QZ
- Rack-Integrable
- FR2 R&D

ATS800R/B

RF Conformance
- 30 cm QZ
- CTIA
- FR2



ATS1800

mmW Production
- Flexible test capacity
- High automation
- FR2

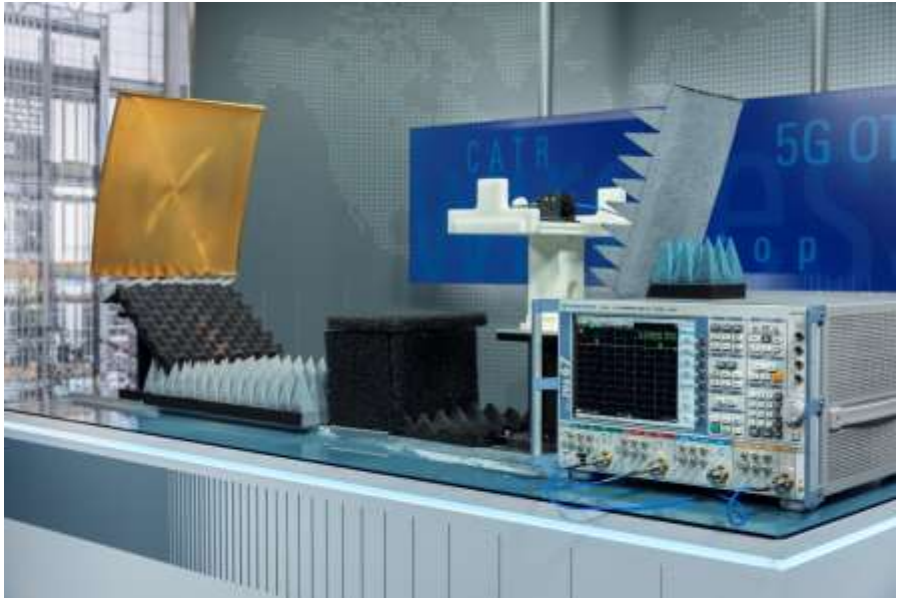
CMQ

ATS1000: DFF for extreme temperature testing

DFF solution for OTA testing

- Customer target group: chipset and mobile phone manufacturer R&D teams
- Frequency range: 12-90 GHz
- Quiet zone: D 7 cm
- Dimensions: Dimensions: 90x150x210 cm
- Maximum DUT size: 20x20 cm Reflector Full set of absorbers
- Wide band feed antenna
- Extreme temperature testing: -40°C to 85°C
- Fukk 3D pattern in super fast speed

*ATS800***B***: **Benchtop** *CATR test setup*



Benchtop R&D OTA solution

- Customer target group: basic antenna R&D teams, educational customers
- Frequency range: 20-50 GHz
- Quiet zone: D 20 cm
- Dimensions: 120x60x80cm
- Maximum DUT size: 40x40 cm (laptop)
- Reflector <1um surface roughness
- 2D positioner
- Basic set of absorbers
- Wide band feed antenna
- Shipped in unmounted parts

*ATS800***R***: CATR* **Rack-***Mounted Test Chamber*

Rack solution for OTA testing

- Customer target group: chipset and mobile phone manufacturer R&D teams
- Frequency range: 20-50 GHz
- Quiet zone: D 20 cm
- Dimensions: 80x100x210 cm (rack)
- Maximum DUT size: 40x40 cm (laptop)
- Reflector <1um surface roughness
- 14 HE space für instruments: CMX, ZVA etc
- Full set of absorbers
- Wide band feed antenna
- Shipped in pre mounted parts

ATS1800C: CATR OTA conformance solution

CATR Conformance solution

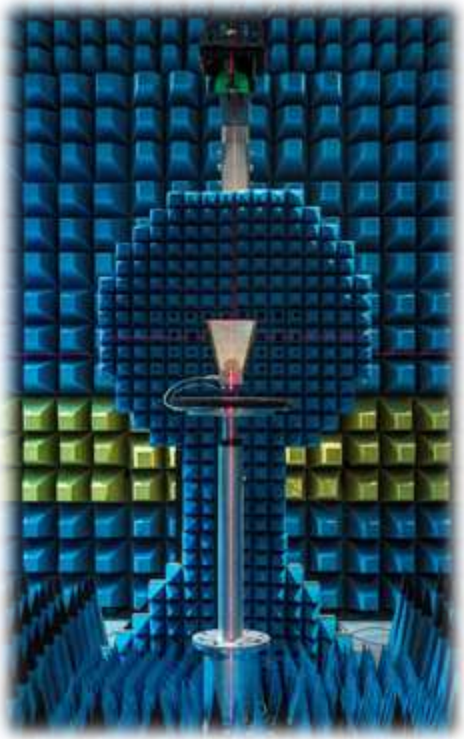
- Customer target group: 3GPP conformance
- Frequency range: 18-87GHz
- Quiet zone: D 30 cm
- Dimensions: 90x150x210 cm
- Maximum DUT size: 40x40 cm (laptop)
- Reflector <1um surface roughness
- 3D great circle cut positioner
- Wide band feed antenna
- Planned CTIA FR2 compliance: optional phantom hands and head

ATSx series overview

	ATS800B	ATS800R	ATS1000	ATS1800
			 	
Application	Benchtop R&D	R&D	R&D +preconformance	Conformance
Testing Approach	Black box	Black box	White box	Black box
Main frequency range	20-50 GHz	20-50GHz	18-87 GHz	18-87 GHz
Quiet zone (@1 dB amplitude taper)	D 20 cm	D 20 cm	D 7 cm	D 30 cm
Automation/Positioner	2D positioner	In development	3D conical cut	3D great circle cut

Overcoming 5G OTA challenges

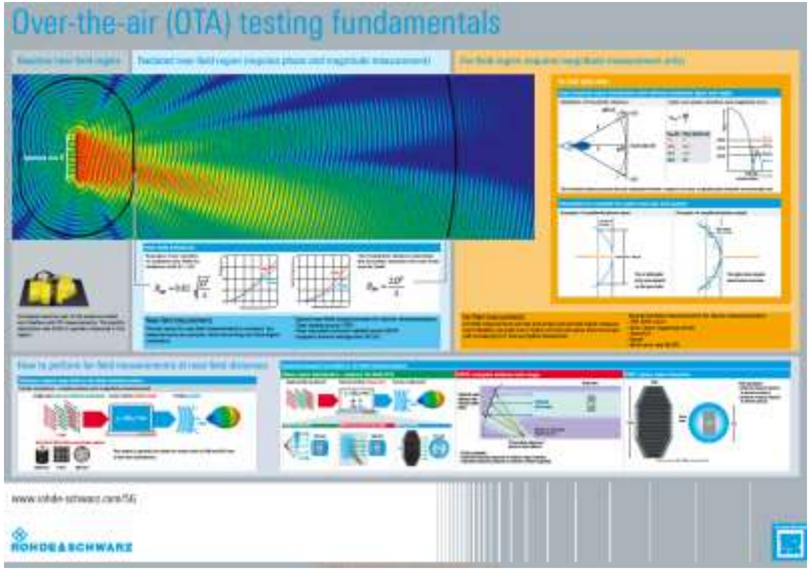
- Everything goes OTA
  - Most transceiver and antenna performance metrics must be assessed over-the-air (OTA)
  - No RF test port
  - Dynamic range and uncertainty become critical
  - Beamforming on both user equipment (UE) and BS sides to mitigate propagation losses
  - Completely integrated modem, RF and antenna solutions
- Higher frequencies: 28, 39, 60, 200 GHz…
  - Spurios emission testing
- Lack of experience – a lot of open questions, e.g.
  - How to calibrate mmW antenna arrays
  - FF (far field) vs IFF (indirect far field) conditions



Available material @ www.rohde-schwarz.com

- Poster: OTA testing fundamentals

www.rohde-Schwarz.com/OTA-poster



- White paper: Demystifying over-the-air (OTA) testing– important antennaparameters, test system setup and calibration

www.rohde-Schwarz.com/whitepaper-ota

… or just ask R&S Portugal to find the right solution for your OTA testing needs!


"If you want to go fast, go alone.
If you want to go far, go together!"
African proverb