# 5G NR – OTA test & measurement aspects standards & regulations

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# New spectrum for mobile communications: cm and mm waves

| 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 |

| ITU band | Range | ITU band | Range |
|---|---|---|---|
| X | 8 – 12 GHz | Q | 33 – 50 GHz |
| Ku | 12 – 18 GHz | U | 40 – 60 GHz |
| K | 18 – 27 GHz | V | 50 – 75 GHz |
| Ka | 27 – 40 GHz | E | 60 – 90 GHz |

*Free Space Path Loss*

$$* FSPL = 20log\left(\frac{4\pi}{\lambda}\right)$$

Source: ITU: Recommendation ITU-R V.431-7: Nomenclature of the Frequency and Wavelength Bands Used in Telecommunications

# Sample 3GPP sub 6 and mmW NR bands

- The prefix “n” is used for any NR bands
- The following numbers are assigned to each of the new NR bands:
  - NR frequency range 1:

| | UL | DL | Duplexing mode |
|---|---|---|---|
| n77 | 3.3 - 4.2 GHz | 3.3 - 4.2 GHz | TDD |
| n78 | 3.3 - 3.8 GHz | 3.3 - 3.8 GHz | TDD |
| n79 | 4.4 - 5.0 GHz | 4.4 - 5.0 GHz | TDD |
| n80 | 1710 - 1785 MHz | N/A | SUL |
| n81 | 880 - 915 MHz | N/A | SUL |
| n82 | 832 - 862 MHz | N/A | SUL |
| n83 | 703 - 748 MHz | N/A | SUL |

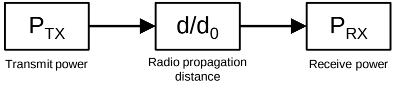
  - NR frequency range 2:

| | UL | DL | Duplexing mode |
|---|---|---|---|
| n257 | 26.5 –29.5 GHz | 26.5 –29.5 GHz | TDD |
| n258 | 24.25 – 27.5 GHz | 24.25 – 27.5 GHz | TDD |
| n259 | 31.8 – 33.4 GHz | 31.8 – 33.4 GHz | TDD |

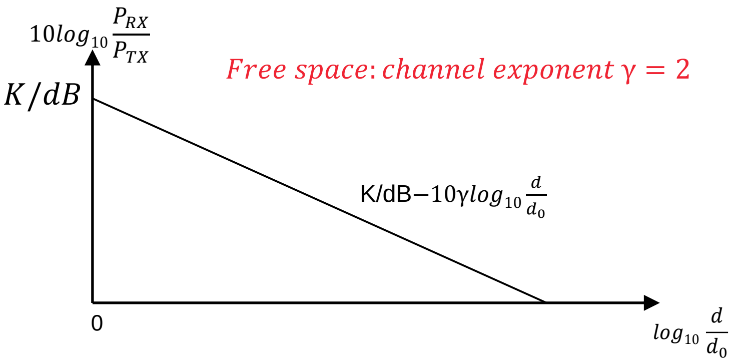
Source: 3GPP RAN4#84 Tdoc R4-1709181

# Beamforming to combat increased path loss

## Path loss model for real propagation environments




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

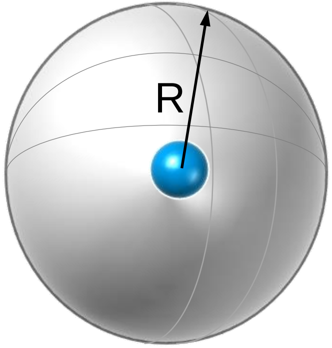



| Frequency | 2 GHz | 28 GHz | 39 GHz | 60 GHz | 73 GHz |
|---|---|---|---|---|---|
| Path-loss (d = 1m) | 41.4 dB | 61.4 dB | 64.3 dB | 68.0 dB | 69.7 dB |

20dB additional pathloss between FR1 and FR2

$$P_{RX} = P_{TX}\underbrace{G_{TX}G_{RX}}_{\text{Antenna gain}}\underbrace{\left(\frac{\lambda}{4\pi R}\right)^2}_{\text{path loss}}$$

$$P_{RX} = P_{TX}G_{TX}G_{RX}\left(\frac{\lambda^2}{4\pi}\right)\left(\frac{1}{\underbrace{4\pi R^2}_{\text{Spherical Surface}}}\right)$$




Isotropic Antenna

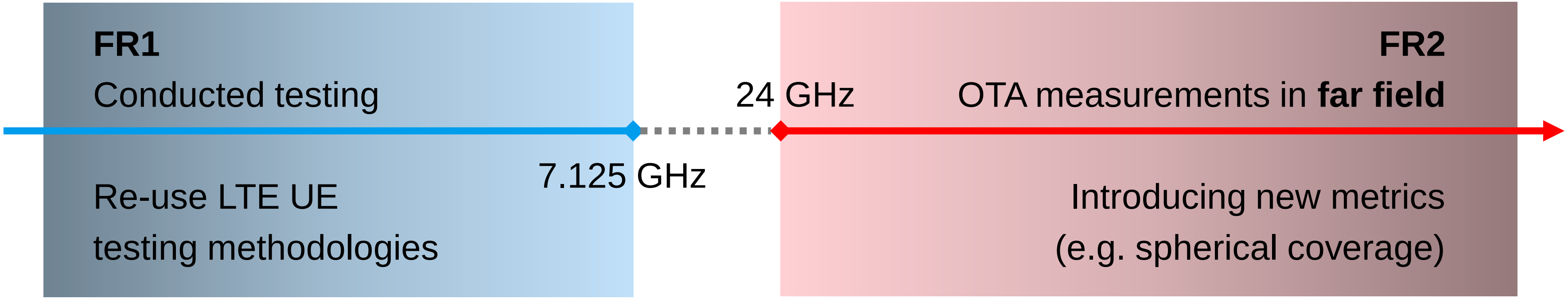
It‘s no loss, it‘s the dilution of the radiated power intensity with increasing distance from source.

# 5G - Frequency Ranges and 3GPP OTA testing recommendation

Two basic frequency ranges (FR1 and FR2) are used in 3GPP specifications, since cm-/mm-wave spectrum behaves differently in nature.

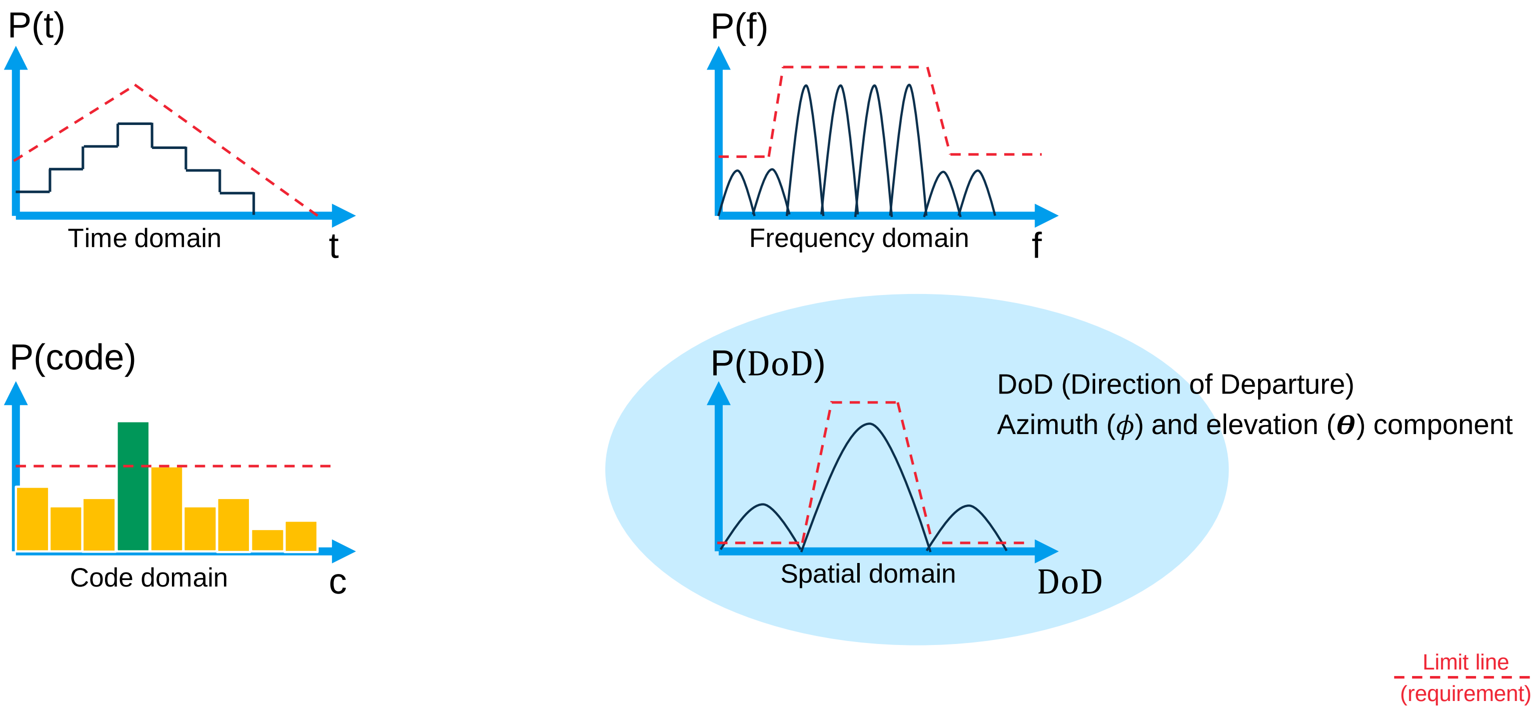
| Frequency range | Range covered in 3GPP Rel.15 |
|---|---|
| FR1 | 450 MHz – 6000 MHz |
| FR2 | 24250 MHz – 52600 MHz |

Extended to 410 .. 7125 MHz (RAN#82)



# Over the air testing adds another measurement domain: space

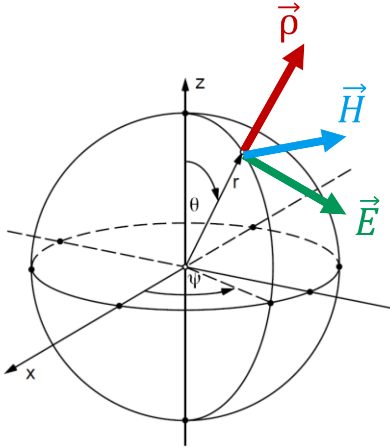
## Example: Power vs. time, frequency, code domain, **DoD**



# Antenna radiation characteristic: Hertz Dipole

Isotropic radiator reference:

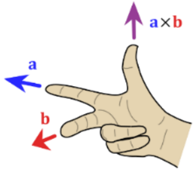
Constant power density $|\overrightarrow{\rho}|_i = const$ (W/m²)



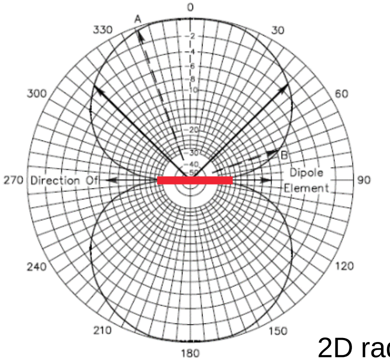

Poynting vector

$$\vec{\rho} = \vec{E} \times \vec{H}$$

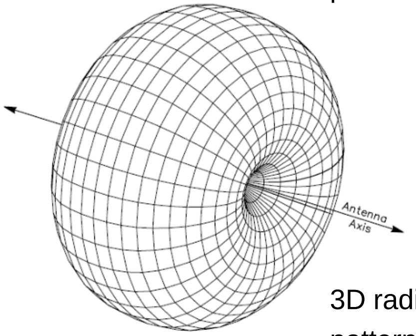
Remember the „right-hand rule“




Max power density $|\overrightarrow{\rho}|_{max}$




2D radiation pattern („cut“)




3D radiation pattern

Maximum gain

$$G = \frac{|\overrightarrow{\rho}|_{max}}{|\overrightarrow{\rho}|_i} = 1{,}76 \text{ dBi}$$

Total radiated power:

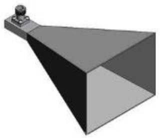
$TRP = \eta \cdot P_{feed}$

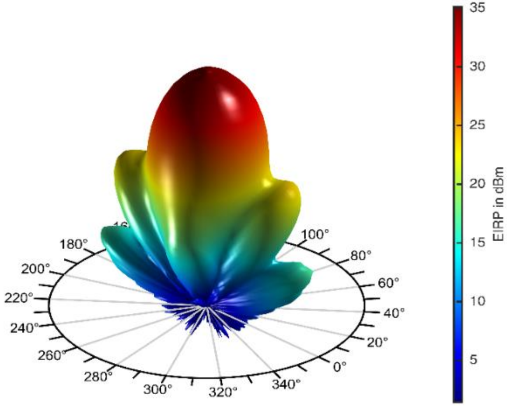
**Equivalent Isotropic Radiated Power:**

$$EIRP = G \cdot P_{feed}$$

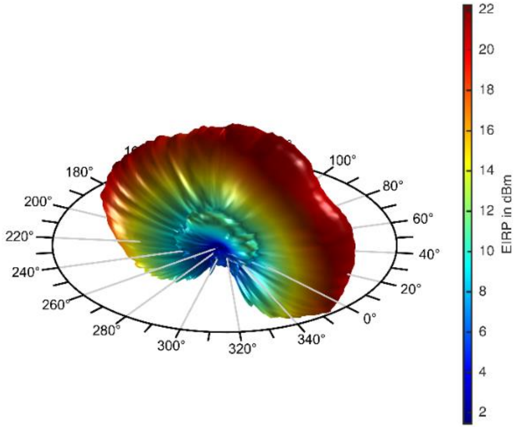
The SI unit of the Poynting vector is **W/m²**, i.e. it describes a directional energy transfer per unit time and per unit area. It’s called radiated energy flux or radiated power density.

# Directive antenna samples @ 28 GHz

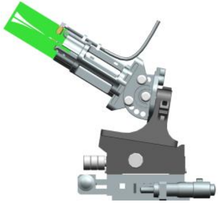


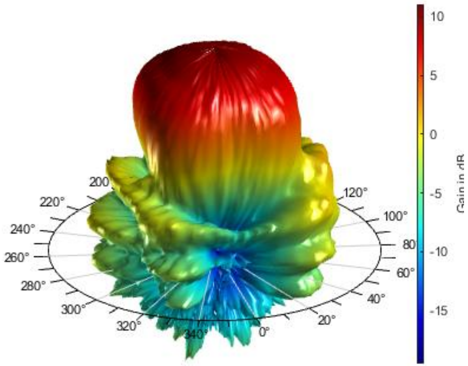



Standard Gain
Horn Antenna




4x1 printed
antenna array

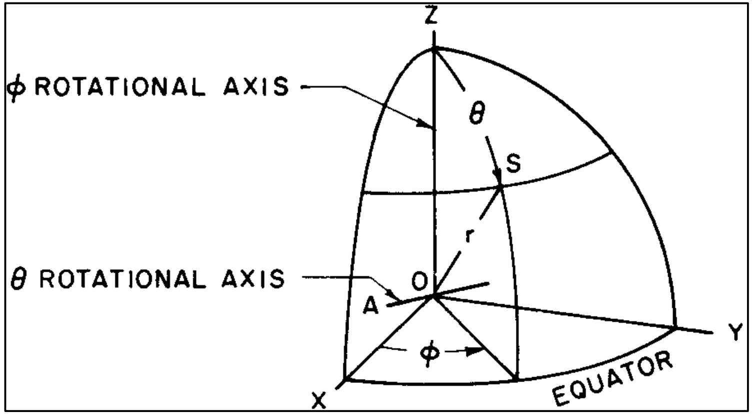




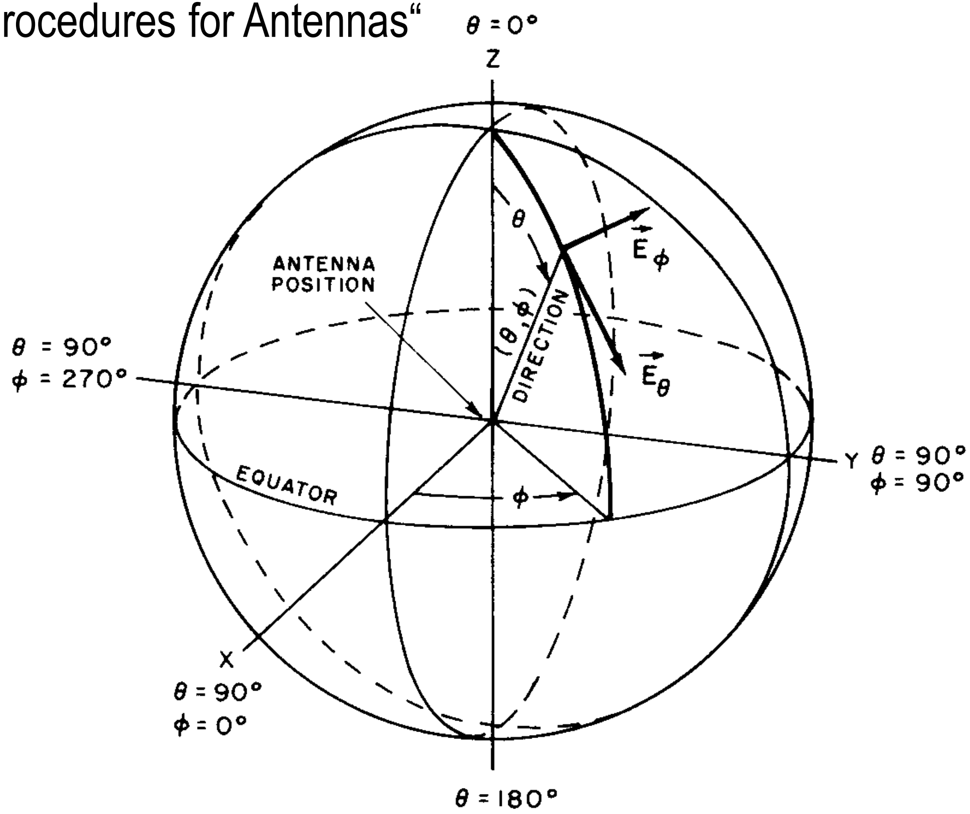

R&S Vivaldi
antenna

# Standard Spherical Coordinate System for Antenna Measurements

ANSI/IEEE Std 149-1979 „IEEE Standard Test Procedures for Antennas“



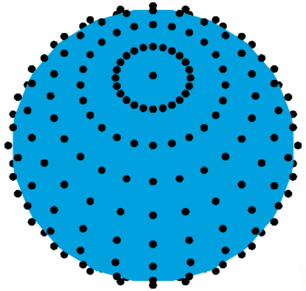

Orthogonal axes of an antenna positioner

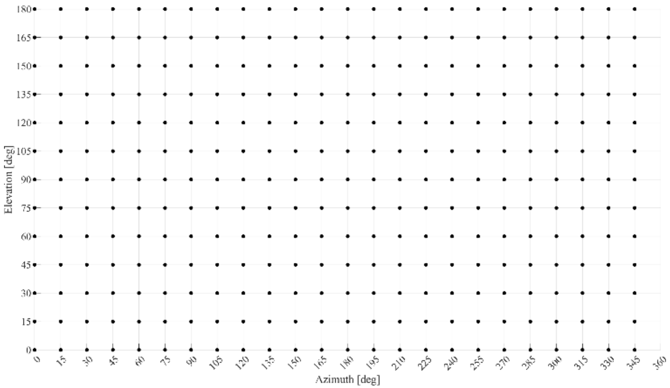


# Grid types

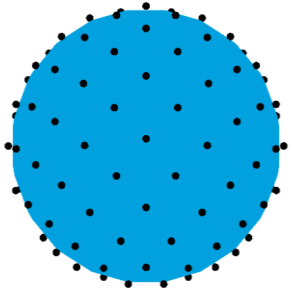
Constant step size

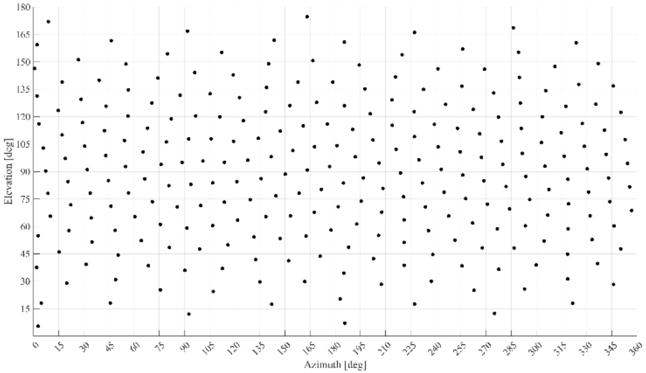
ΔΘ, ΔΦ





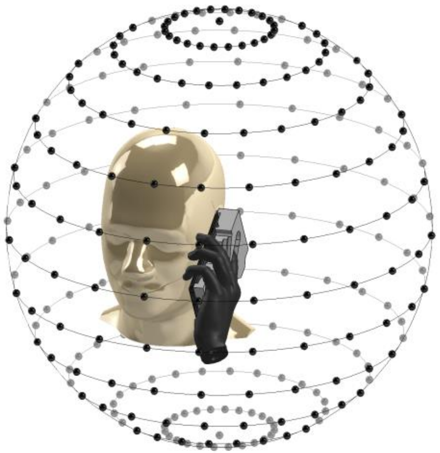

Constant density

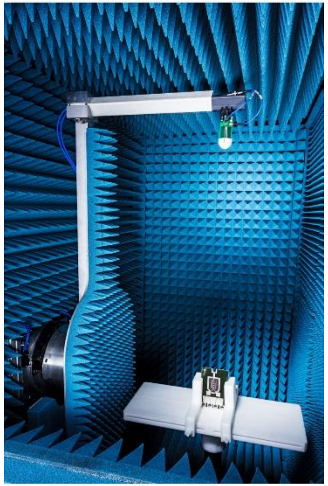




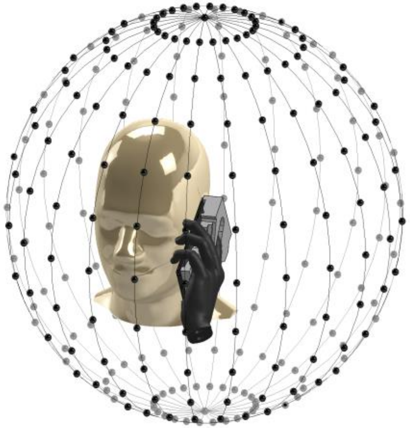
# Spherical scan systems

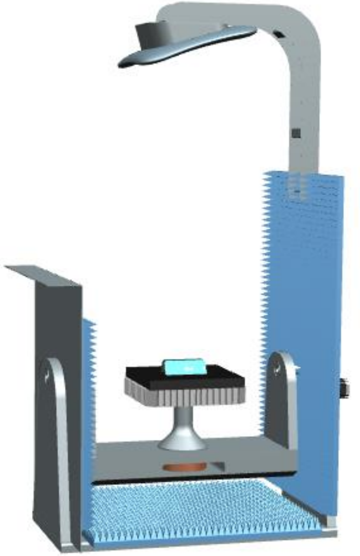
**Conical cut** = Distributed Axis
e.g. R&S®ATS1000 or R&S®WPTC





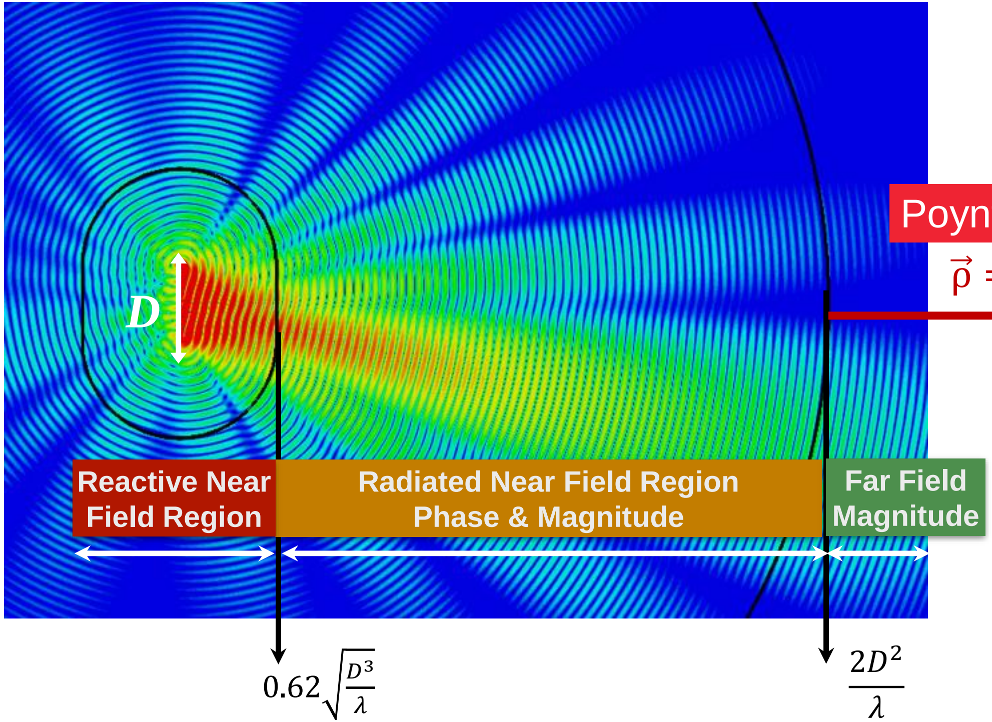
**Great circle cut** = Combined Axis
e.g. R&S®ATS1800C





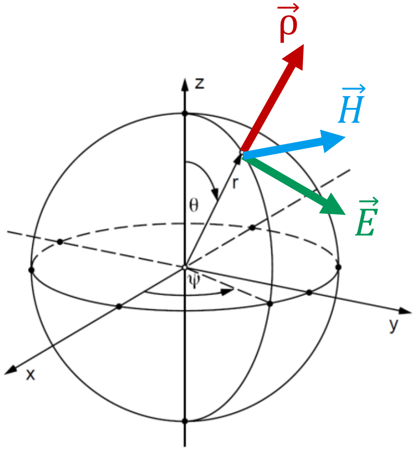
# What and where is the Far-field (FF) ?

D = Radiating Aperture Size




Poynting vector

$\vec{\rho} = \vec{E} \times \vec{H}$




**Free space far field conditions:**

- $\vec{E}$ and $\vec{H}$ orthogonal and connected by $Z_{F0}=120\pi\ \Omega$ (free space impedance)
- Only radial component of $\vec{\rho} = \vec{E} \times \vec{H}$ relevant

# Reactive near field – radiated near field – far field

D = size of radiating aperture
$\lambda$ = wavelength

- In the reactive near field close to the antenna every object couples with the antenna and influences the antenna pattern and performance

- In the far field (beyond $\frac{2D^2}{\lambda}$) the field is considered as locally planar and RF measurements are easy since only magnitude measurements on the electric field are required

- Between these two point is the radiated near field where the waves are not yet plane and hence measurements need to be performed in magnitude and phase
- Also the entire sphere has to be measured in the radiated near field in order to understand the field distribution and be able to transform this to far field. Typically a positioner is used for this
- This makes measurement in the radiated near field more complex and time consuming and the 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 the antenna pattern is influenced

- Things like SAR measurements are performed here

# Measurements that can be performed in the radiated near field

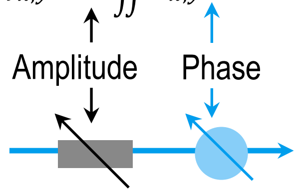
- If a spherical scan of the entire field in magnitude and phase is performed in radiated near field all field parameters are known and can then be mathematically transformed into the far field by using certain algorithms
- With this all Tx measurements can also be performed in the radiated near field, however the effort is much higher than in far field, but on the other hand the space requirements are lower

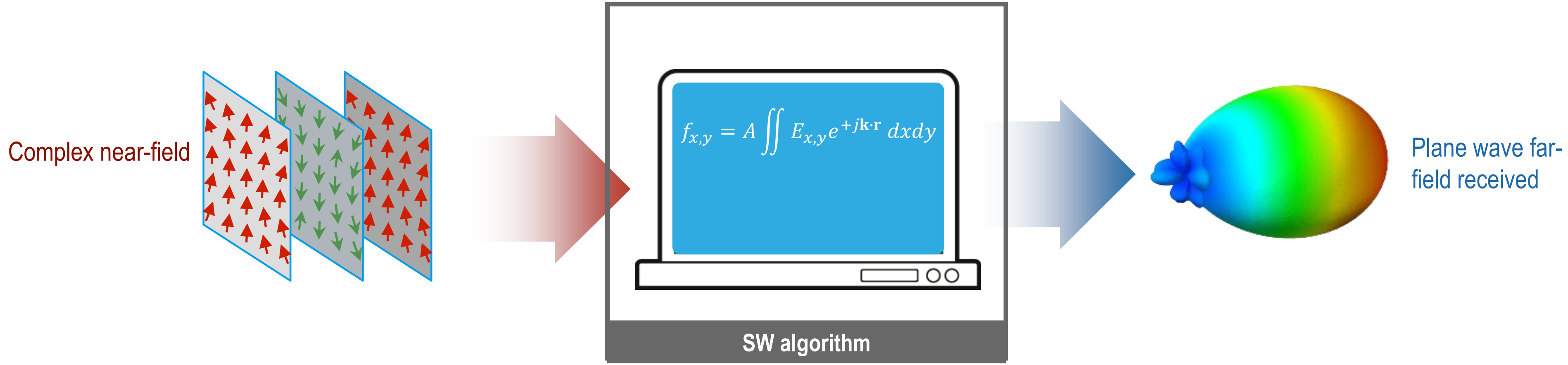
- Directly in the radiated near field (without far field transformation) only some certain parameters can be measured such as
  - TRP (Total Radiated Power)
  - Peak EIRP (Equivalent Isotropic Radiated Power)
  - ACLR
- Measurement uncertainties are higher than in far field

- The controversy is if you can test EVM in radiated near field
- No receiver measurements possible in the radiated near field!

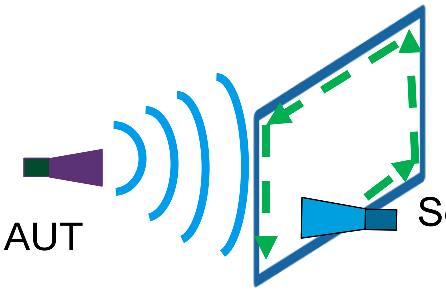
# Solution transforming NF to FF by Software algorithm

$$f_{x,y} = A \iint E_{x,y} e^{+j\mathbf{k}\cdot\mathbf{r}}\, dxdy$$

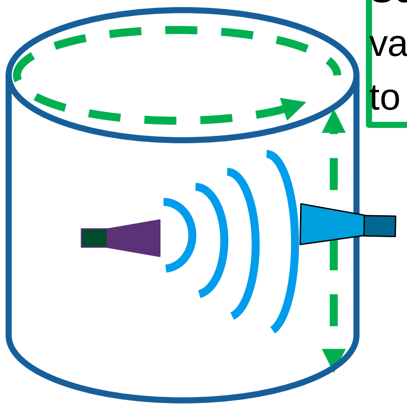


# OTA aspects: near field



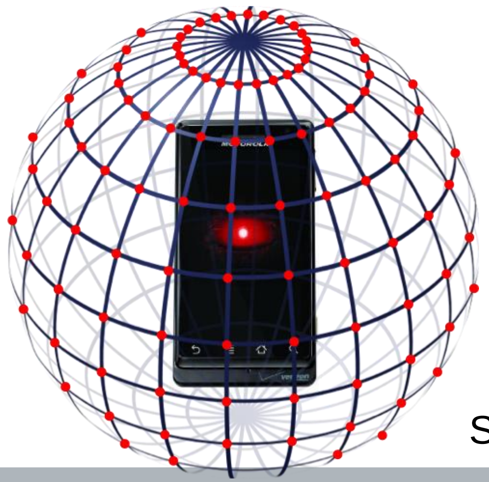

Planar scan



Scanning at various positions to build a surface S

Cylindrical scan

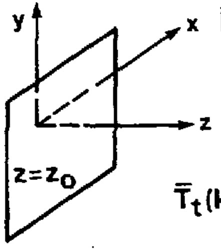
Integrate E and H along a surface given
=> Scanning with „ideal dipole“ along a surface



Spherical scan

# OTA aspects: near field – the maths behind

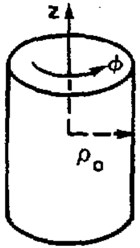
**PLANAR**




$$\bar{E}_t(x,y,z) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \bar{T}_t(k_x,k_y)e^{i\gamma z}e^{ik_x x}e^{ik_y y}\,dk_x dk_y$$

$$\bar{T}_t(k_x,k_y) = \frac{e^{-i\gamma z_0}}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \bar{E}_t(x,y,z_0)e^{-ik_x x}e^{-ik_y y}\,dxdy$$

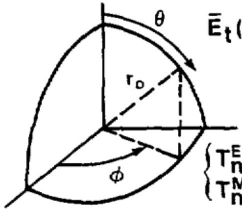
**CYLINDRICAL**




$$\bar{E}_t(\rho,\phi,z) = \frac{1}{2\pi}\sum_{m=-\infty}^{\infty}\int_{-\infty}^{\infty}\left\{\bar{\bar{H}}_m(\gamma,\rho)\cdot\bar{T}_m(\gamma)\right\}e^{im\phi}e^{i\gamma z}\,d\gamma$$

$$\bar{T}_m(\gamma) = \frac{1}{2\pi}\bar{\bar{H}}_m^{-1}(\gamma,\rho_0)\cdot\int_{-\infty}^{\infty}\int_{0}^{2\pi}\bar{E}_t(\rho_0,\phi,z)e^{-im\phi}e^{-i\gamma z}\,d\phi dz$$

**SPHERICAL**




$$\bar{E}_t(r,\phi,\theta) = \sum_{n=1}^{\infty}\sum_{m=-n}^{n}\left[T^E_{nm}h_n^{(1)}(kr)\bar{M}_{nm}(\theta) + T^M_{nm}g_n^{(1)}(kr)\bar{N}_{nm}(\theta)\right]e^{im\phi}$$

$$\begin{Bmatrix} T^E_{nm} \\ T^M_{nm} \end{Bmatrix} = \begin{Bmatrix} -h_n^{(1)}(kr_0)^{-1} \\ g_n^{(1)}(kr_0)^{-1} \end{Bmatrix}\int_0^{\pi}\int_0^{2\pi}\begin{Bmatrix} \bar{N}_{nm}(\theta) \\ \bar{M}_{nm}(\theta) \end{Bmatrix}\cdot\hat{r}\times\bar{E}(r_0,\phi,\theta)e^{-im\phi}\sin\theta\;d\phi d\theta$$

An Overview of Near-Field Antenna Measurements
ARTHUR D. YAGHJW

# Near-field to Far-field Transformation – FIAFTA

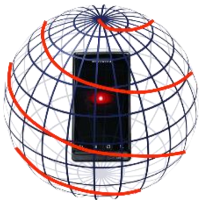
## Features

### High precision positioner

angular resolution 0.1°

NF-FF transformation

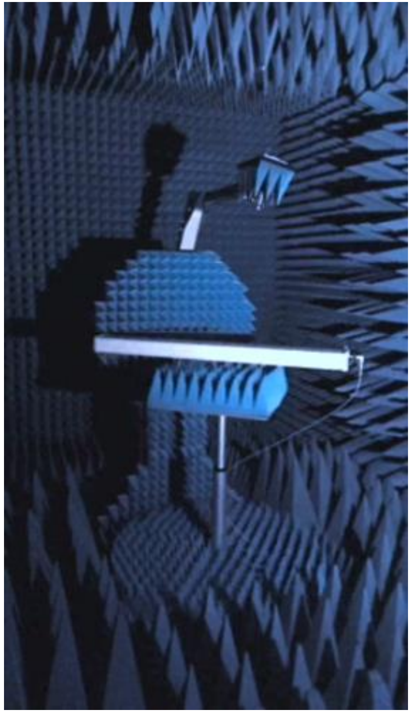
### Fast Spiral Scan



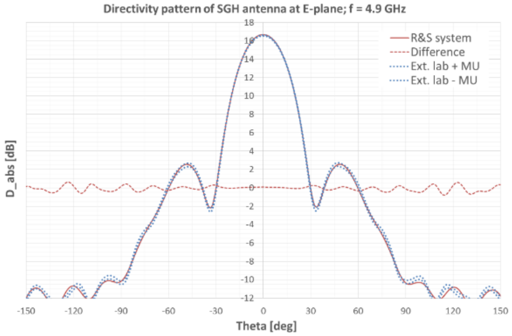
vs.

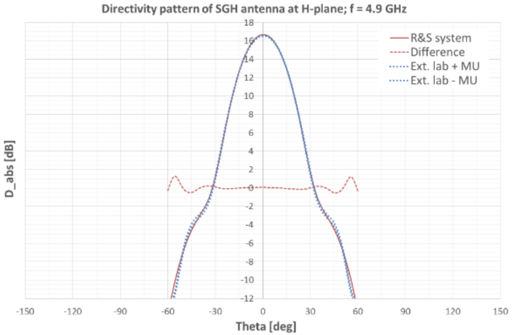
6 minutes

220 minutes

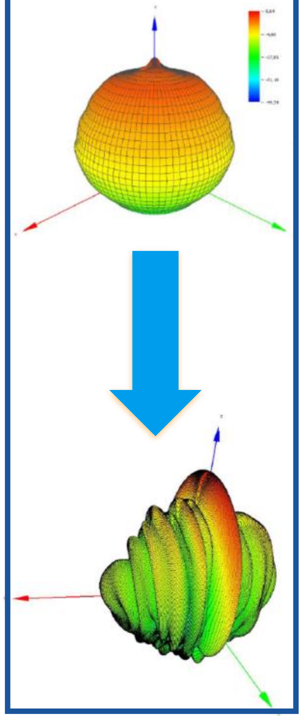


## Performance Comparison




## Transformation



# Measurements that can be performed in the far field

- Measurements in the far field are comparably easy
- Every RF measurement can be performed in the far field for example
  - TX measurements like EiRP/ TRP
  - RX measurements like EiS (Effective isotropic Radiated Power/Sensitivity)
  - In beam measurements for R&D and Production
  - EVM, ACLR, SEM, OBW, BLER etc.

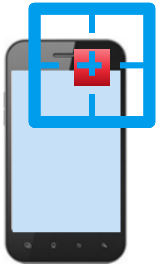
- Since the far field is far away from the emitting antenna the path loss is typically high for direct far field measurements which is an additional challenge

# How big of a chamber is required for direct far field?

- Quiet zone size (black box)

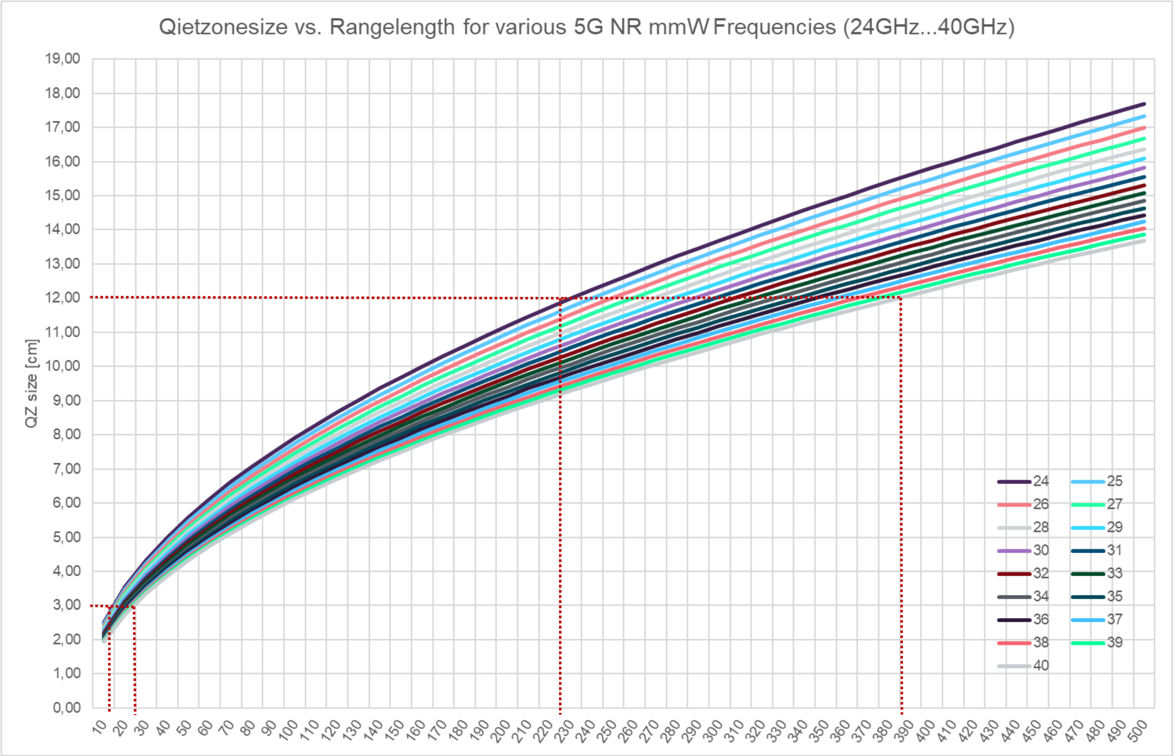

- Chamber size 3 m…5 m

- Quiet zone size (white box)

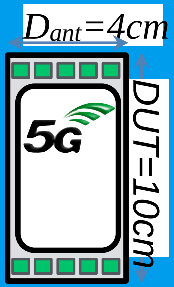


D= 3 cm

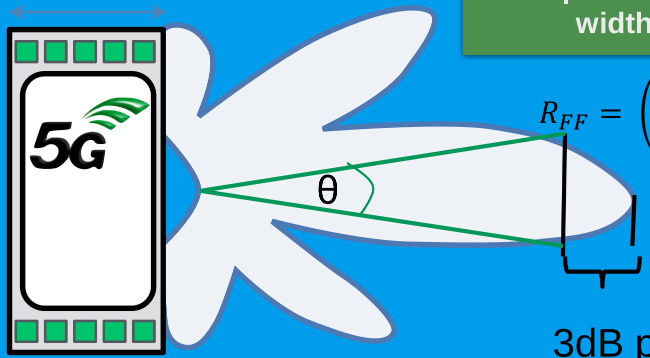
- Chamber size 0.5 m



# What is the Far-field distance? 2 additional methods




| 28GHz UE Subarray (HPBW=15°) | |
|---|---|
| **Criteria** | **Far-field Distance** |
| $2\lambda/HPBW^2$ | **0.30 meters** |
| 28GHz Entire UE | |
| $2D^2/\lambda$ | **1.86 meters** |




**HPBW (radians) Half-power beam width**

$$R_{FF} = \left( \frac{2D^2}{\lambda} \ or \ \frac{2\lambda}{HPBW^2} \right)$$

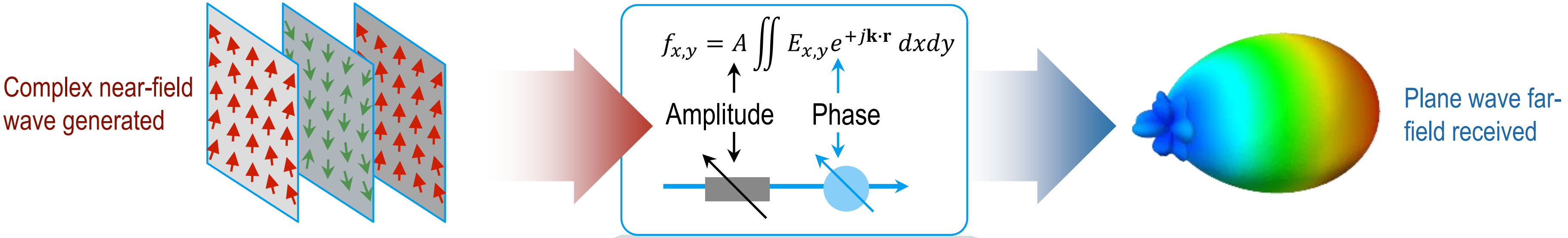
3dB power difference

$$R_{ffD} = \lambda \left(\frac{\pi D}{\lambda}\right)^{0.8633} \left[ 0.1673 \left(\frac{\pi D}{\lambda}\right)^{0.8633} + 0.1632 \right]$$

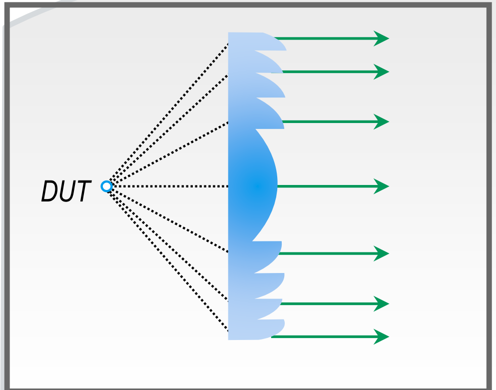
15 cm DUT @ 24 GHz
FHD = 3.6 m
RffD = 1.14 m

Consideration only in peak beam direction allows to re-consider FF distances: APEMC 2018 [Derat, « 5G antenna characterization in the far-field – How close can far-field be? »] - based on spherical wave expansion

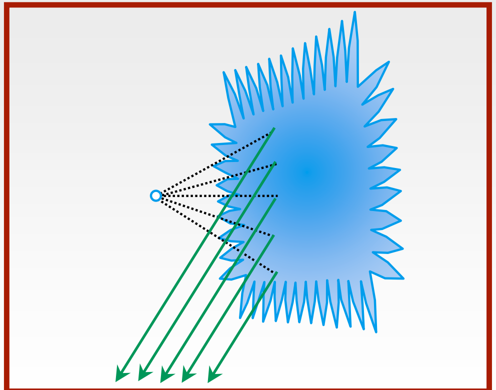
# Far-field in Near-field Systems: Hardware Fourier Transforms



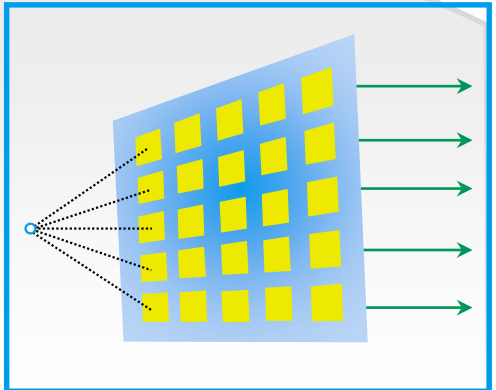

Holographic techniques




Fresnel Lens (Fourier Optics)



Reflector: Compact Antenna Test Range

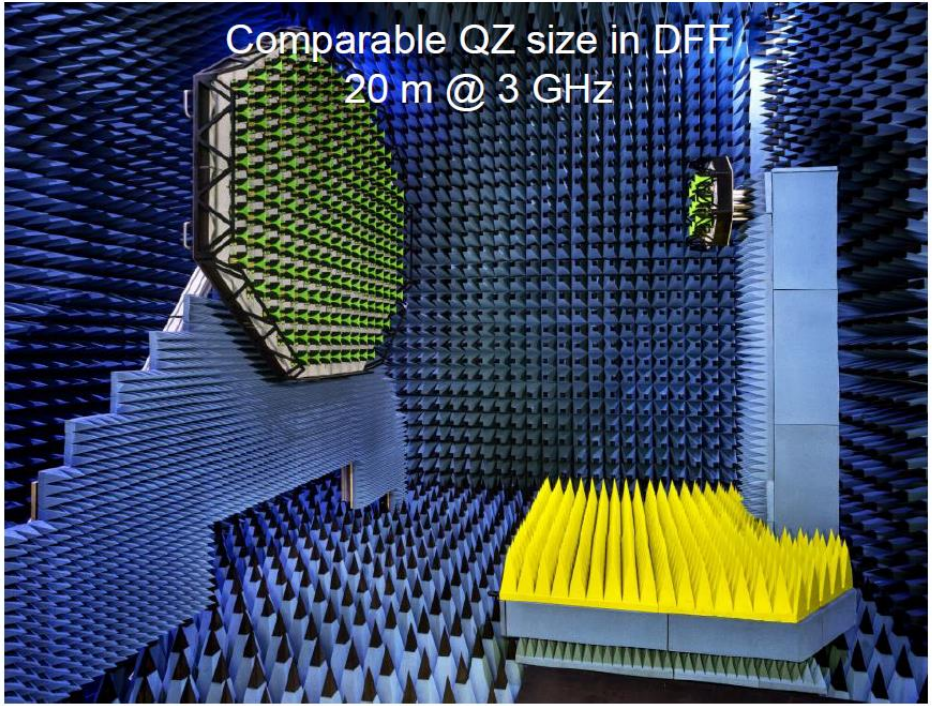


Array: Plane Wave Convertor

# Sub 6 GHz compact approach: Plane Wave Synthesis

## To test sub 6 GHz Base Station Adaptive Antenna Systems (AAS)

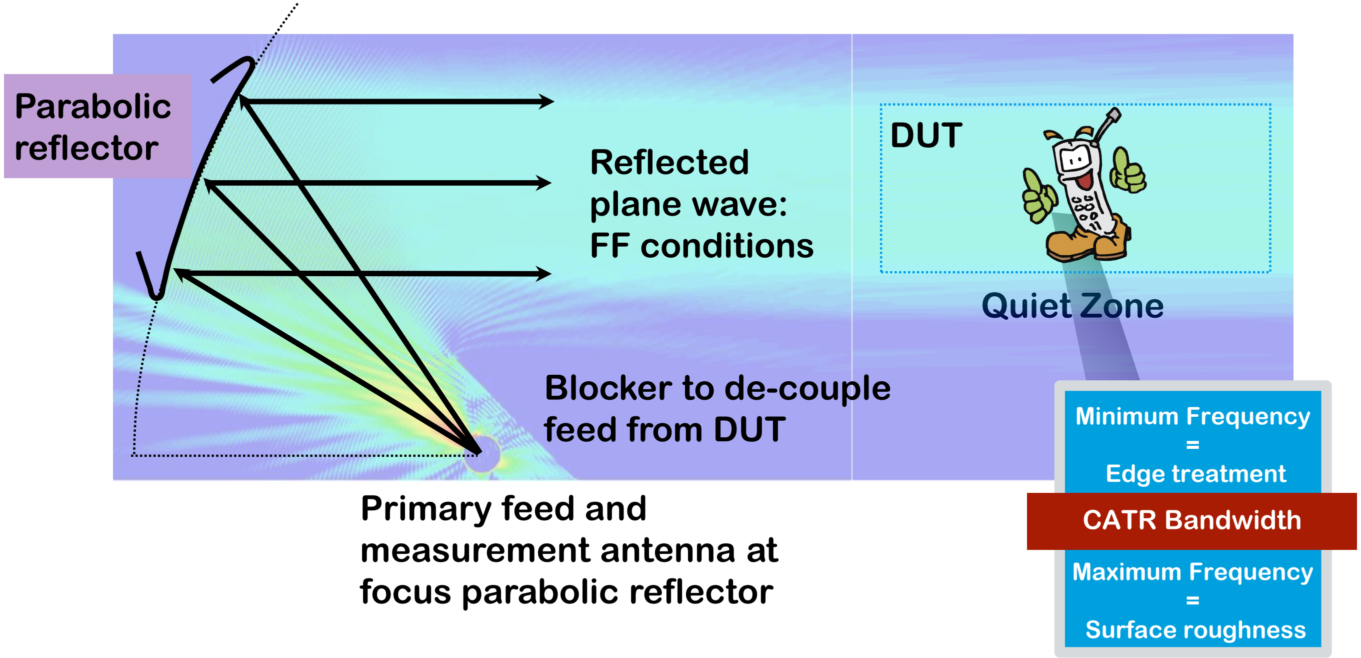
- Signal distributes to 156 Vivaldi antennas through phase shifters and attenuators
- The fields generated by the antennas combine in the target region to generate a plane-wave front (reciprocal device)
- 1 m spherical quiet zone (QZ) at 1.5 m distance
- Frequency range FR1




R&S®PWC200 Plane Wave Converter

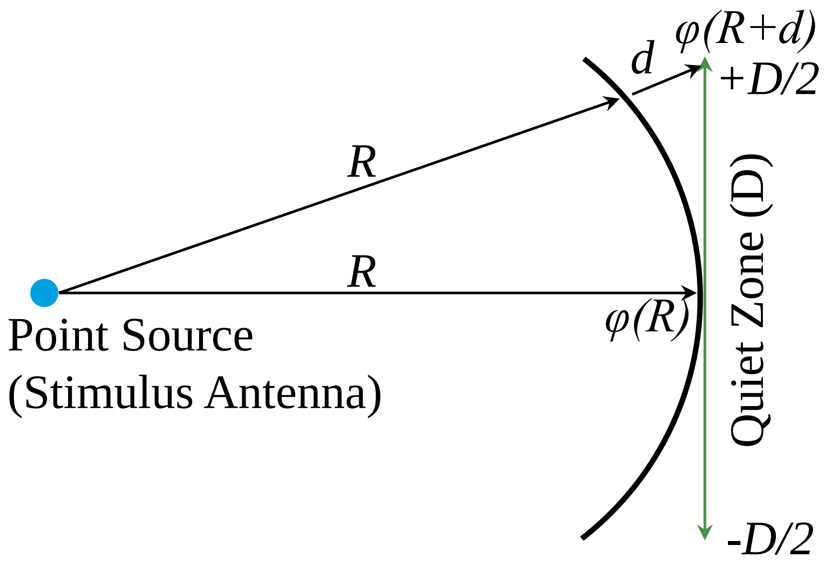
# 3GPP NR OTA RF test setup … and the winner is …

## CATR: Compact Antenna Test Range




R&S®ATS1800C

# What and where is the Quiet zone ?

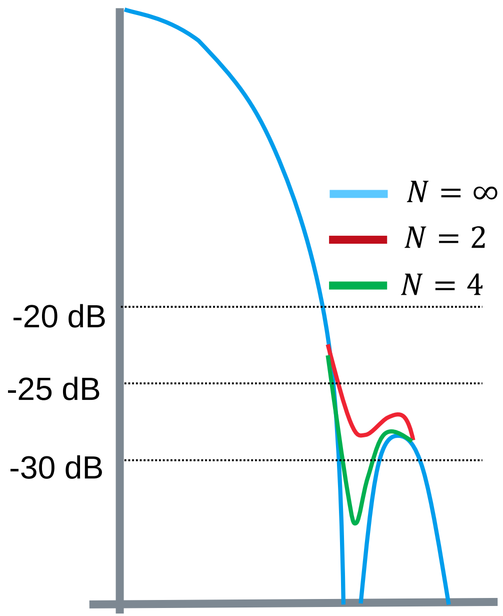



**Quiet zone size determines the DUT size**

## Quiet Zone Phase Deviation vs. Measurement Error

$$R_{min} = \frac{\pi D^2}{4\lambda\Delta\varphi_{max}} = \frac{ND^2}{\lambda}$$

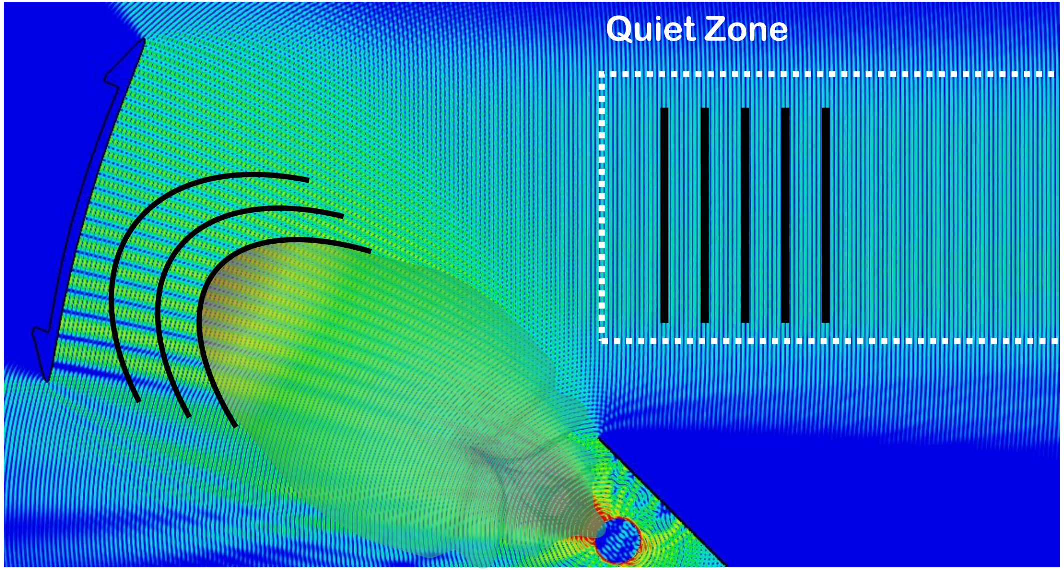
| $R_{min}(N)$ | Phase Deviation |
|---|---|
| $D^2/\lambda$ | 45 degrees |
| $2D^2/\lambda$ | 22.5 degrees |
| $4D^2/\lambda$ | 11.2 degrees |
| $8D^2/\lambda$ | 5.6 degrees |




High Gain Antenna Pattern

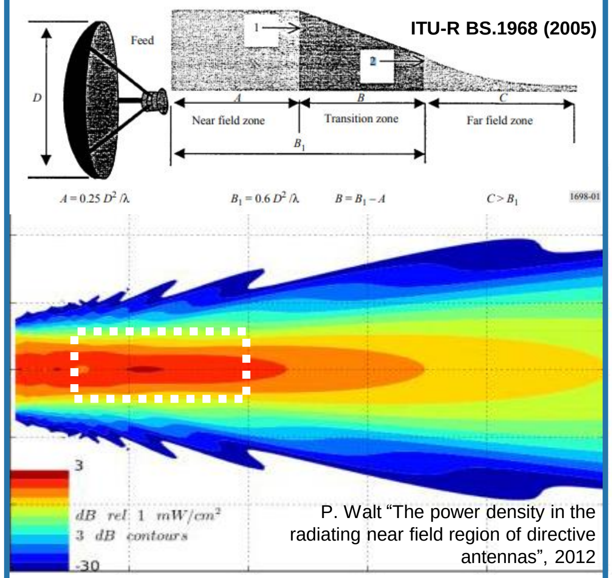
# CATR Path Loss

Reflector Near Field




Feed Antenna (low-gain) Far Field: FSPL

## Parabolic Reflector Power Density

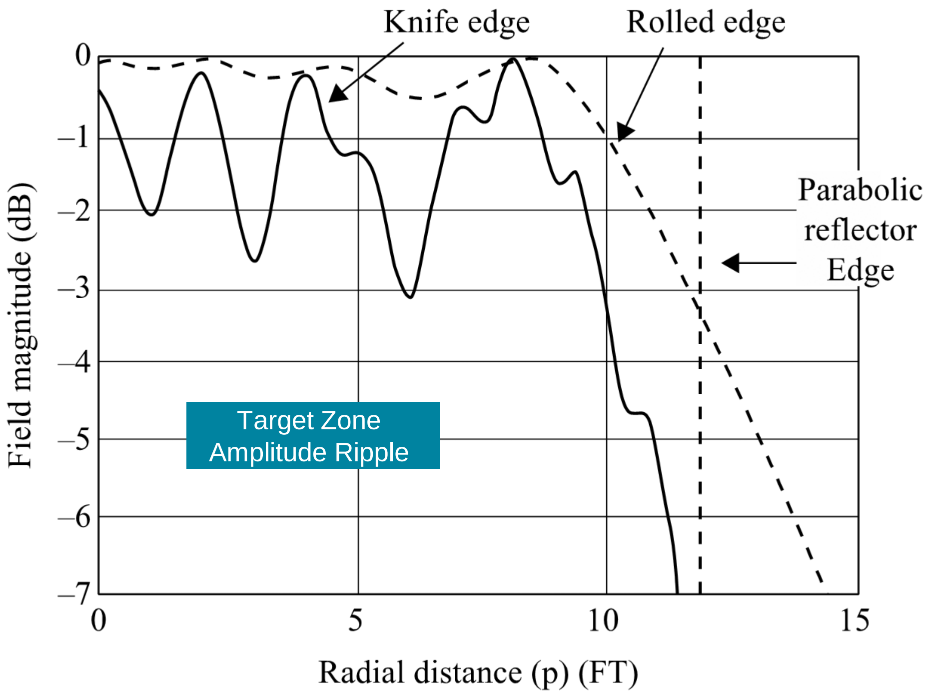



P. Walt "The power density in the radiating near field region of directive antennas", 2012

Power Density is constant up to: $0.6D^2/\lambda$
1800C (D = 30cm): 5.4 meters

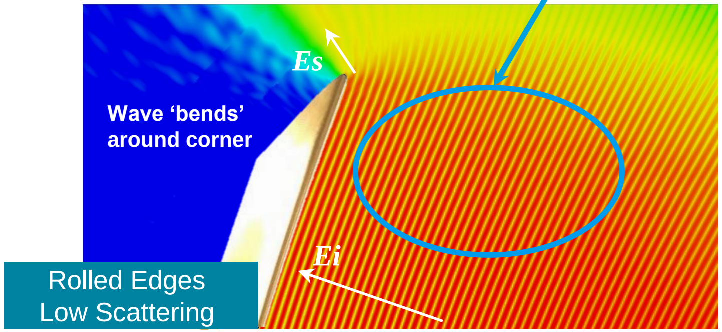
No Path Loss from Reflector to DUT

# CATR basics: Quiet Zone Quality

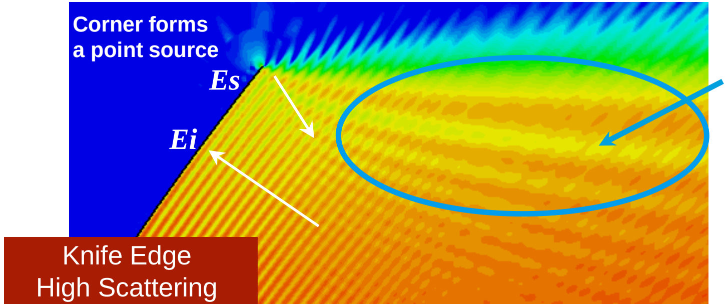



Source: W. Burnside “Curved Edge Modification of Compact Range Reflector”, IEEE 1987

No scattering of energy back into quiet zone




***Ei***: Initial EM field (from feed horn)

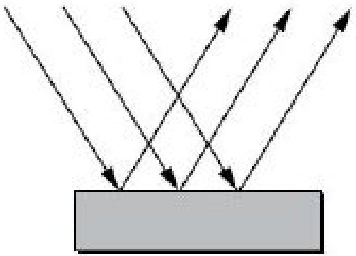



High scattering of energy into quiet zone

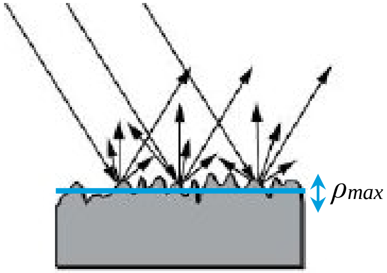
***Es***: Scattered EM field (from edges)

# CATR reflector errors: surface roughness

Surface Roughness < $\lambda$/100, i.e. determines CATR **upper frequency bound**!



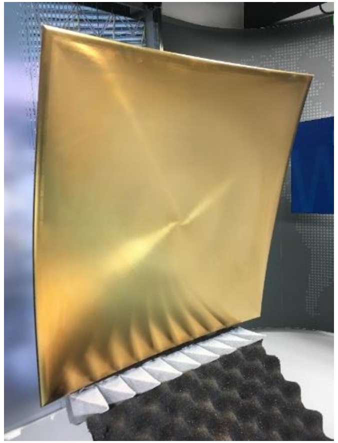
Ideal




Actual

Maximum Surface Deviation

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

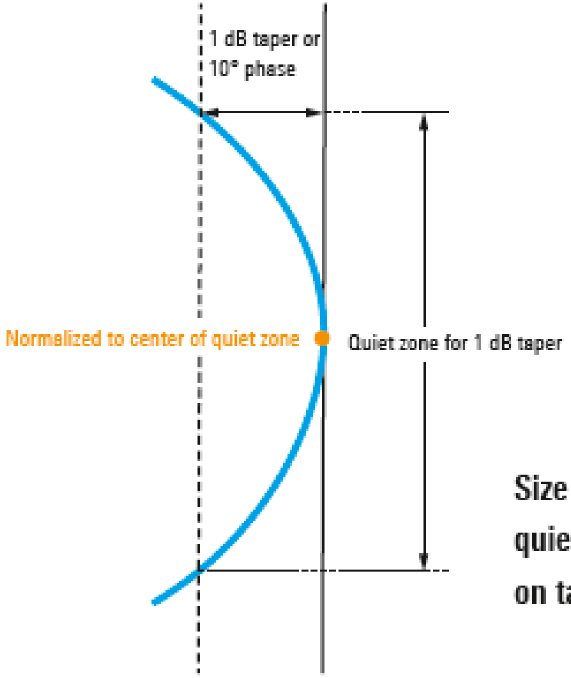


| Maximum Frequency | Required surface Roughness (microns) |
|---|---|
| 28 GHz | 75 |
| 43 GHz (in band) | 49 |
| 87 GHz (spurious emissions) | 24 |
| 220 GHz (FCC 5th Harmonic) | < 1 |

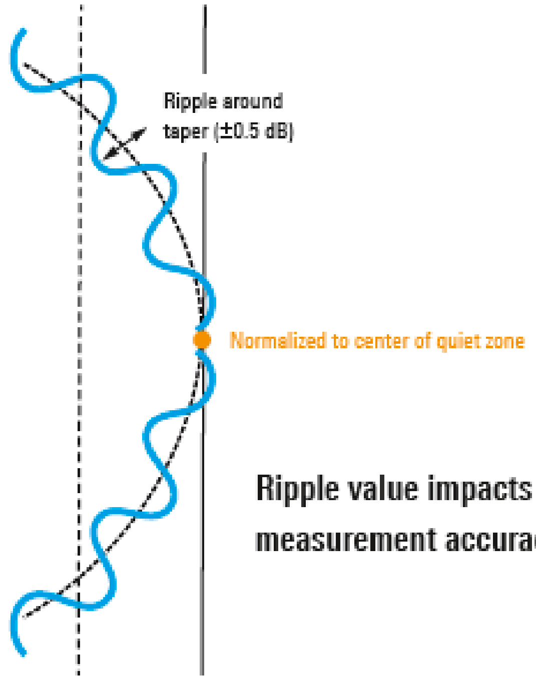
Accuracy vs. complexity & price

# How good is the quiet zone?

| Example of amplitude/phase taper | Example of amplitude/phase ripple |
|---|---|



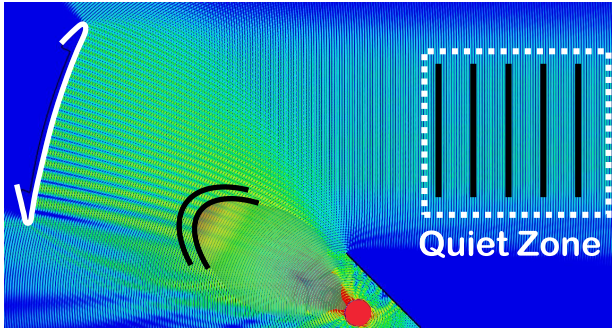

Size of achievable quiet zone depends on taper value.




Ripple value impacts measurement accuracy.

# CATR is a Bi-directional Device

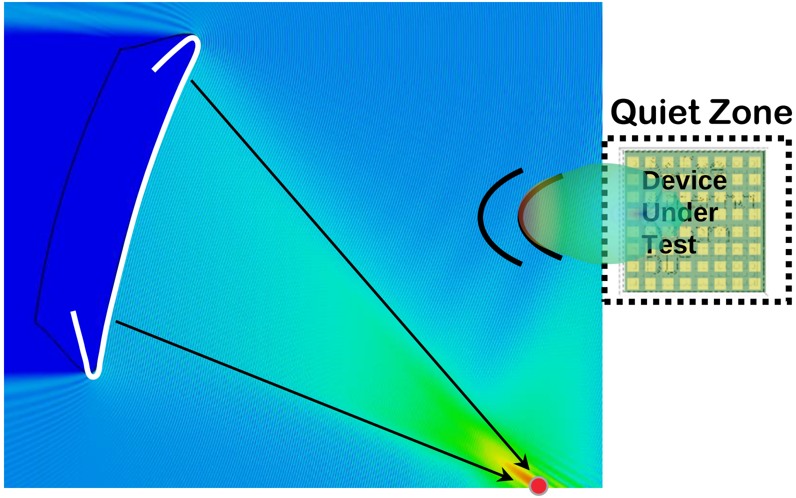
Forward: DUT Rx




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 Tx

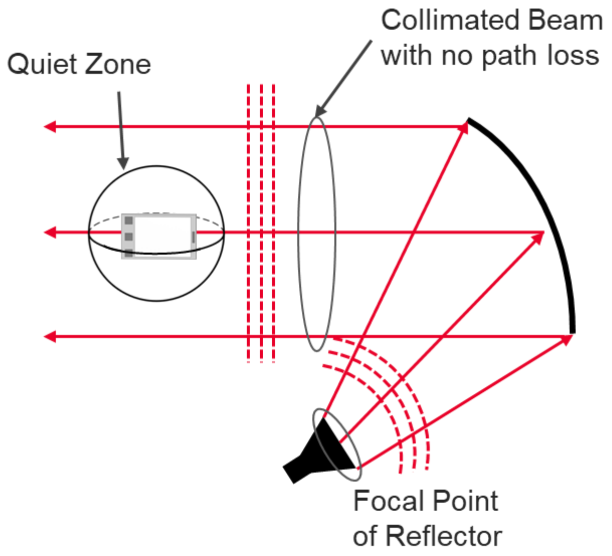



From: DUT Quiet Zone
To: Reflector Focal Point (Feed)

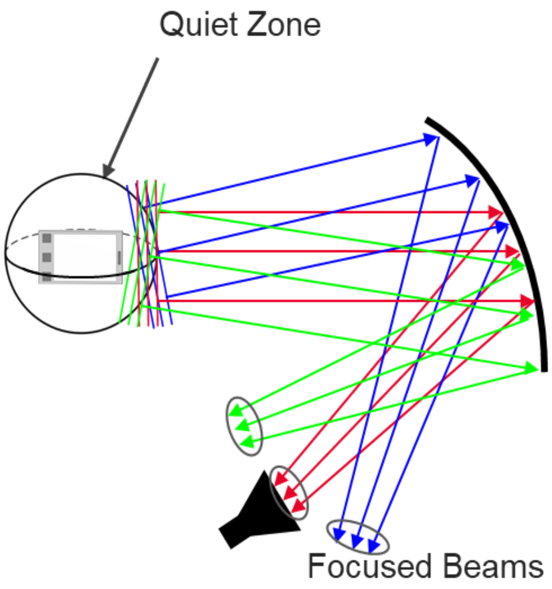
**Reflector is a spatial filter that extracts the planar components of the spherical feed and focuses them at the focal point (feed antenna)**

# Summary: CATR testing principles (Indirect Far Field, IFF)

RX working princple




TX working princple



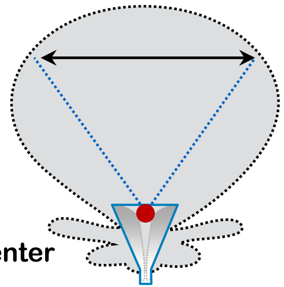

Source: CTIA 5G Millimeter-Wave OTA Test Plan

# CATR Feed Antennas

**Requirements for Ideal CATR Feed**

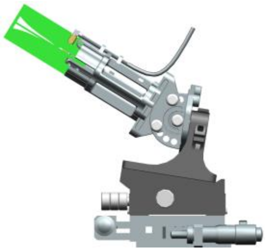
**HPBW > 50 degrees**

**Dual Polarized**
- **Same Pattern**
- **XPOL < 30-40 dB**



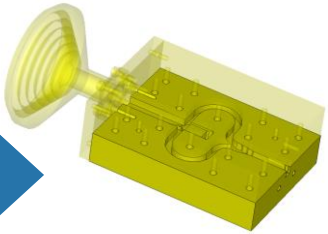
**● Constant Phase Center**
- **Polarization**
- **Frequency**

Non-Ideal Wide-Band



| Vivaldi Antenna |
|---|
| Dual Polarized |
| Frequency: 20-87 GHz |
| HPBW: 50-10 degrees |
| XPOL: 20-30 dB |

Ideal Band-Limited



| Circular WG Horn with OMT |
|---|
| Dual Polarized WR28 (OMT) |
| Frequency: 23-44 GHz |
| HPBW: 50 degrees |
| XPOL: 40 dB |

# OTA measurement result analysis options

## Transmitter: EIRP (θ, Φ)

- $EIRP(\theta,\Phi) = G_{TX}(\theta,\Phi) \cdot P_{Tx}$
- **Single direction measurement**
  - Maximum gain ► Beam peak
  - Modulation quality
- **Full sphere integral metric**
  - Total radiated power: TRP
- **Statistical analysis**
  - Spherical coverage

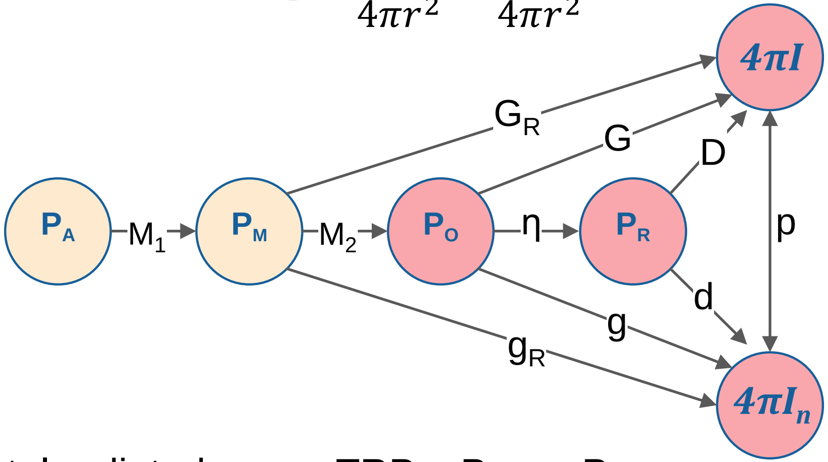
## Receiver: EIS (θ, Φ)

- $EIS_{Level}(\theta,\Phi) = f(G_{RX}(\theta,\Phi), SNR_{QAM})$
- **Single direction measurement**
  - Maximum sensitivity ► beam peak
  - Selectivity, blocking
  - Demodulation quality
- **Full sphere integral metric**
  - Total isotropic/radiated sensitivity: TIS, TRS
- **Statistical analysis**
  - Spherical coverage
- **UE reported values:** RSRP, RSRQ (RRM)

# Gain and directivity flowchart

## IEEE Std 145-2013 Definitions of Terms for Antennas

$$I = \frac{GP_0}{4\pi r^2} = \frac{EIRP}{4\pi r^2}$$




$P_A$ = power available from the generator
$P_M$ = power to matched transmission line
$P_O$ = power accepted by the antenna (feed power)
$P_R$ = power radiated by the antenna
I = radiation intensity (power flux)
η = radiation efficiency
$G_R$ = realized gain
G = (isotropic) gain
D = Directivity
$M_1$ = impedance mismatch 1
$M_2$ = impedance mismatch 2
$I_n$ = partial radiation intensity (i.e. per polarization)
$g_R$ = partial realized gain
g = partial gain
d = partial directivity
p = polarization efficiency
EIRP = Equivalent Isotropic Radiated Power

e.g. Total radiated power TRP = $P_R = \eta \cdot P_0$

$$G(dBi) = 10 log_{10} \frac{I_{max}}{I_{isotropic}}$$

Assumption: An antenna is a passive, linear, reciprocal device

# TRP integral

$r \cdot sin\theta \cdot d\phi$

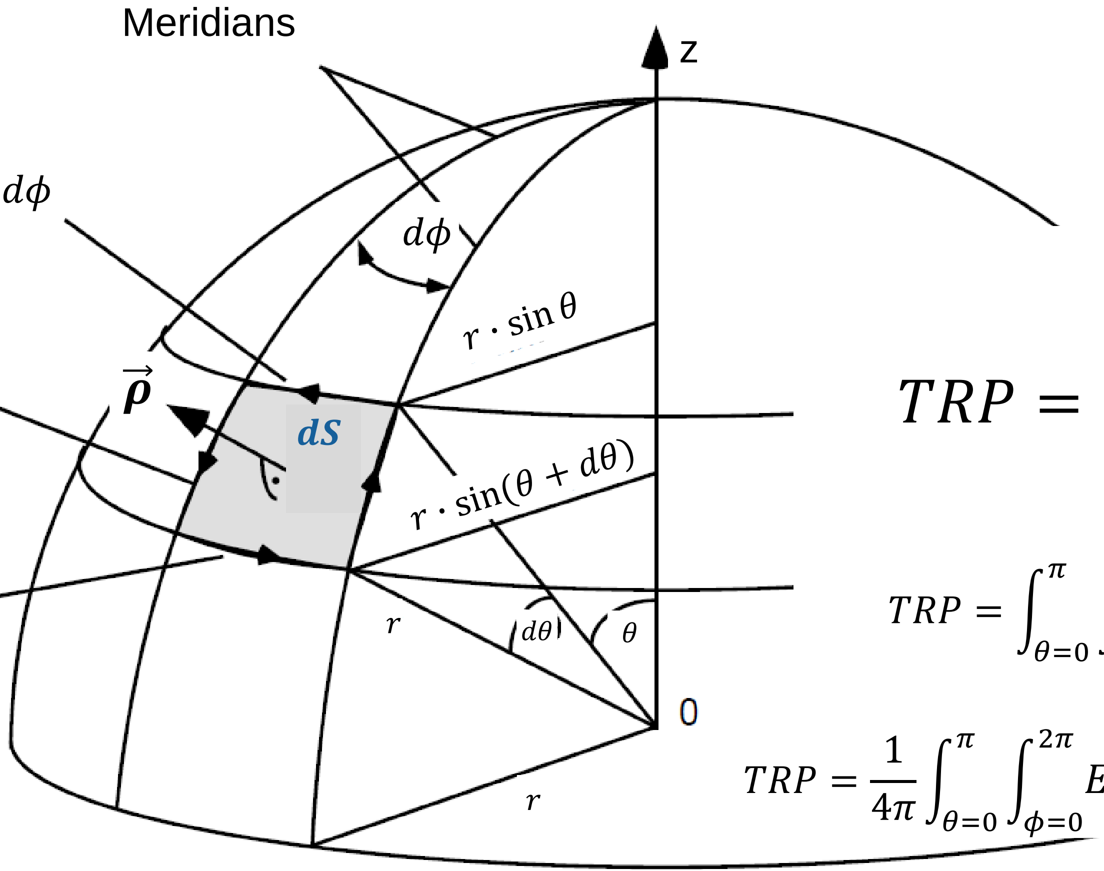
$\Downarrow$

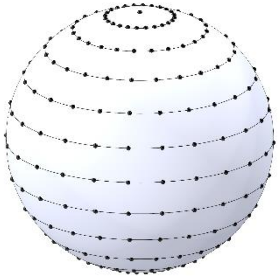
$\boldsymbol{dS = r^2 sin\theta d\theta d\phi}$

$\Uparrow$

$r \cdot d\theta$

$r \cdot \sin(\theta + d\theta) \cdot d\phi$



$$TRP = \iint_S |\vec{\rho}\,| \boldsymbol{dS}$$

$\Downarrow$

$$TRP = \int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi} |\vec{\rho}\,| \boldsymbol{r^2 sin\theta d\theta d\phi}$$

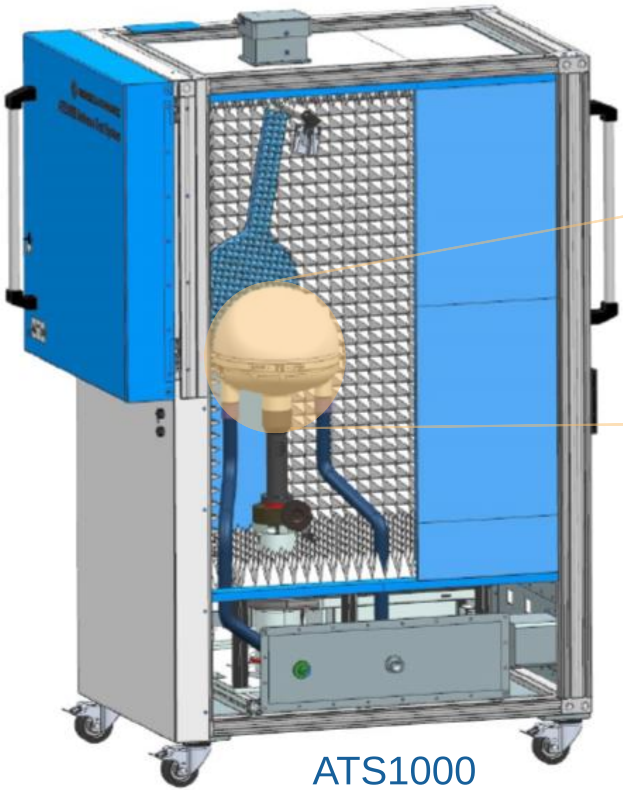
$\Downarrow$

$$TRP = \frac{1}{4\pi}\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi} EIRP(\theta,\phi) \boldsymbol{sin\theta d\theta d\phi}$$

# 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
- Dynamic behavioiur: transmit power control algorithms

# OTA test in extreme climatic conditions



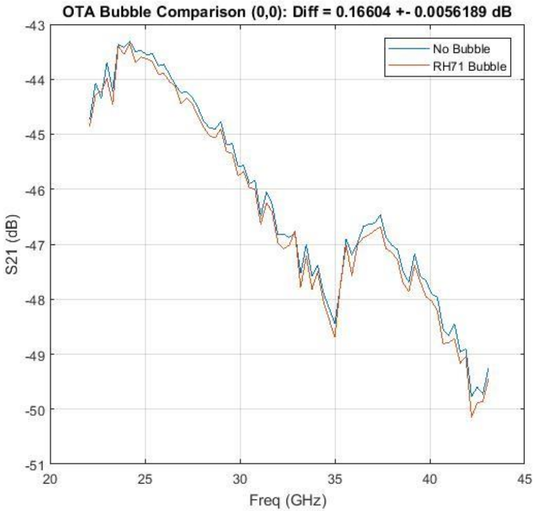
ATS1000

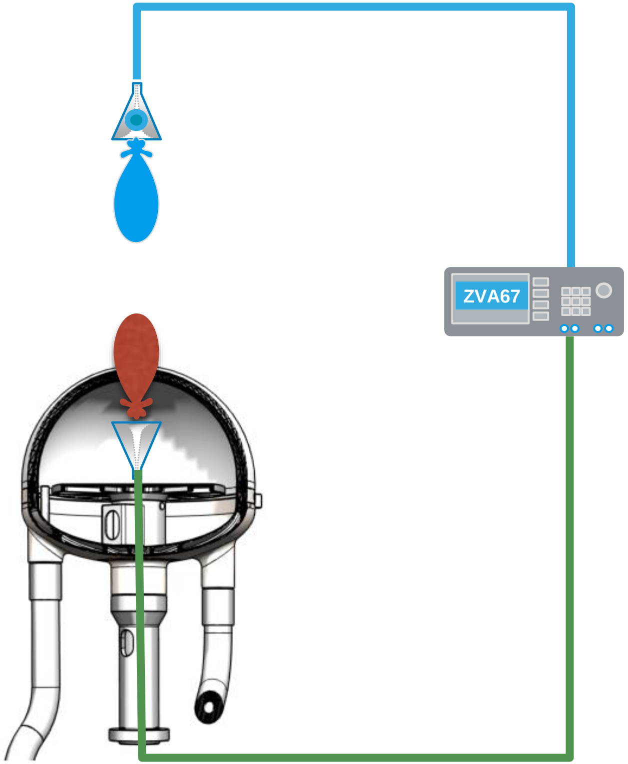

- Minimized influence on DUT radiation
- Temperature tests from -20°C to +85°C

Thermal stream

# ATS-TEMP: RF influence

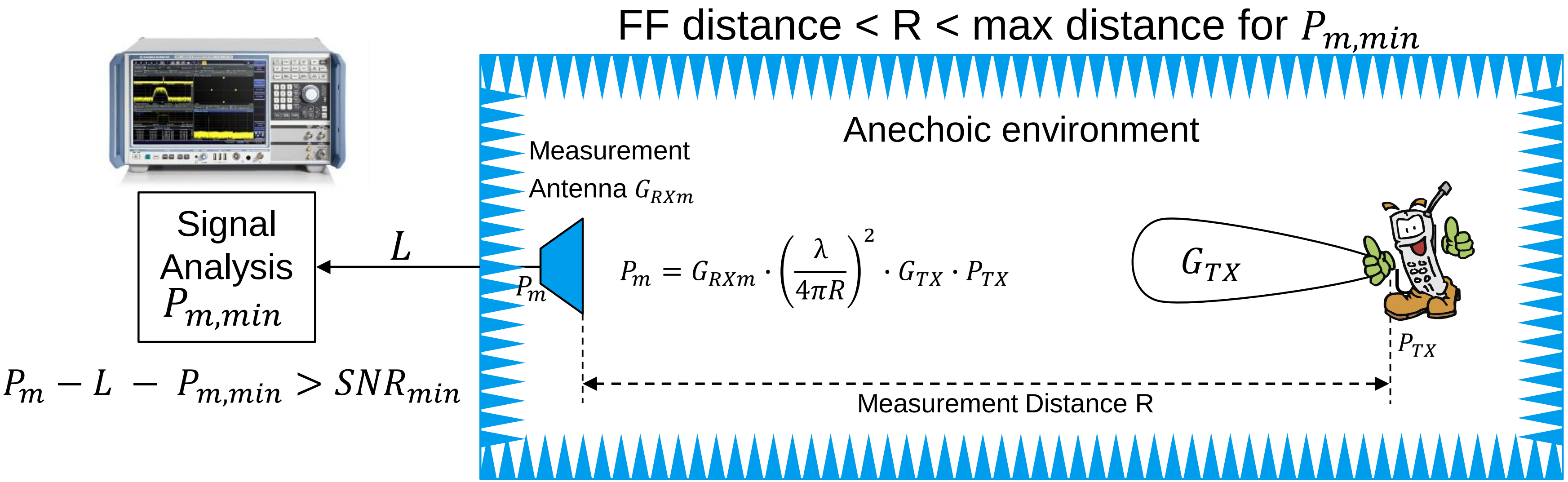
- ATS-TEMP dome material: Rohacell
- Rohacell´s permittivity is close to air´s
- Minimized influence on DUT radiation
- Influence in amplitude is >0,2 dB@28 GHz



# OTA TX measurement link budget constraints

## Example: Signal quality measurements (e.g. EVM)




L = cable and mismatch loss between measurement antenna and measurement receiver

# UE spherical coverage requirements: $N^{th}$ percentile

The „percentile“ indicates that a certain percentage falls below that percentile.

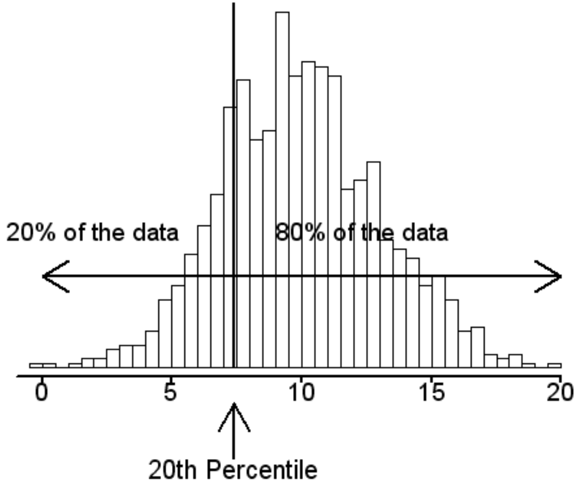



**Table 6.2.1.3-3: UE spherical coverage for power class 3**

| Operating band | Min EIRP at 50th%-tile CDF (dBm) |
|---|---|
| n257 | [11.5] |
| n258 | [11.5] |
| n260 | [8] |
| n261 | [11.5] |
| NOTE 1: Minimum EIRP at 50 %-tile CDF is defined as the lower limit without tolerance | |

**Example n260**

Take k EIRP measurements over the full sphere around the UE.

The spherical coverage requirement is fulfilled when at least 50% of the EIRP measurements are ≥ 8 dBm.

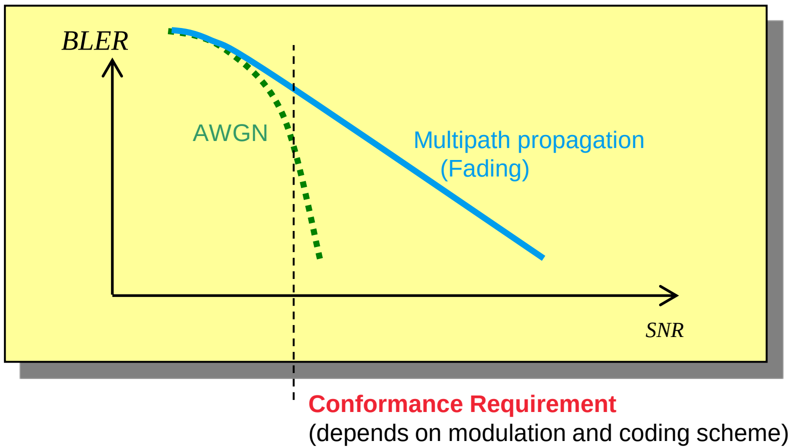
# Receiver testing needs

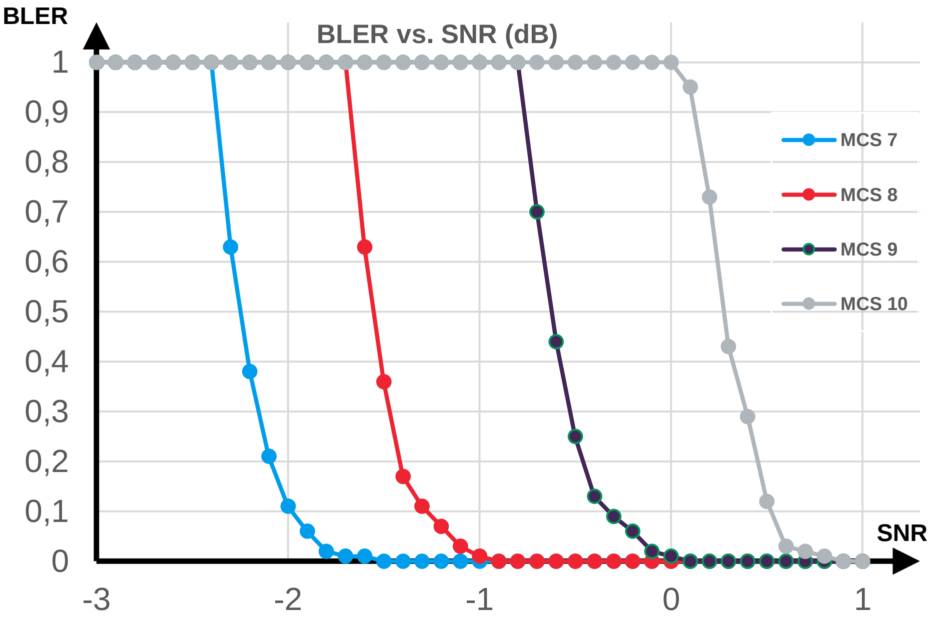
- Reference sensitivity
- Selectivity (ACS, blocking, intermodulation  …)
- Demodulation performance (fading and multipath conditions)
- RRM related parameters: RSRP and RSRQ

# Receiver Performance Conformance Testing

- Block Error Rate BLER or throughput R @ reference level + AWGN + (optional) multipath propagation

BLER and throughput correspondence: $$R = (1 - \mathrm{BLER})\frac{\mathrm{BitsPerBlock}}{\mathrm{TxTimePerBlock}}.$$



# Reference sensitivity determination

Receiver output noise power („noise floor“)

$$\mathrm{P_{noise}} = 10\,\mathrm{lg}(\mathrm{k} \cdot \mathrm{T} \cdot \mathrm{BW} \cdot \mathrm{NF}) = -174\,\frac{\mathrm{dBm}}{\mathrm{Hz}} + 10\mathrm{lg}\,\mathrm{BW} + \mathrm{NF_{dB}}$$

*k = Boltzmann constant (1.38 · 10-23 J/K), T = System temperature (typical assumption is 290 Kelvin “room temperature”)*
*BW = signal bandwidth, NF = noise figure of receiver (8 – 12 dB)*
*lg(x) represents the common logarithm, i.e. logarithm with base 10.*

Receiver reference sensitivity (REFSENS)

$$\mathrm{P_{REFSENS}} = \mathrm{P_{noise}} - \mathrm{G_{antenna}} + IL + \mathrm{SNR_{min}}(MCS)$$

*G = total receive antenna gain*
*IL = implementation loss (e.g. impact of form factor, case material etc.)*
*SNRmin = minimum required SNR for minimum MCS (modulation and coding scheme performance*

EIS is the directional REFSENS(θ,Φ)

# Reference sensitivity according to 3GPP

$NF$ = UE Noise Figure
$SNR$ = SNR target (depends on MCS)
$IL$ = Implementation Loss (depends e.g. on form factor)

Defined in peak EIS direction, i.e. assuming maximum receive antenna and diversity gain!

$$P_{rsens} = 10\lg(kT) + 10\lg(max.RXBW) + NF - G_{RX} - G_{div} + SNR + IL$$

Example (100 MHz BW, QPSK1/3):

$$P_{rsens,100MHz} = -174\frac{dBm}{Hz} + 80\ dB + (10)dB - (6)dB - 3dB + 1dB + (8)dB$$

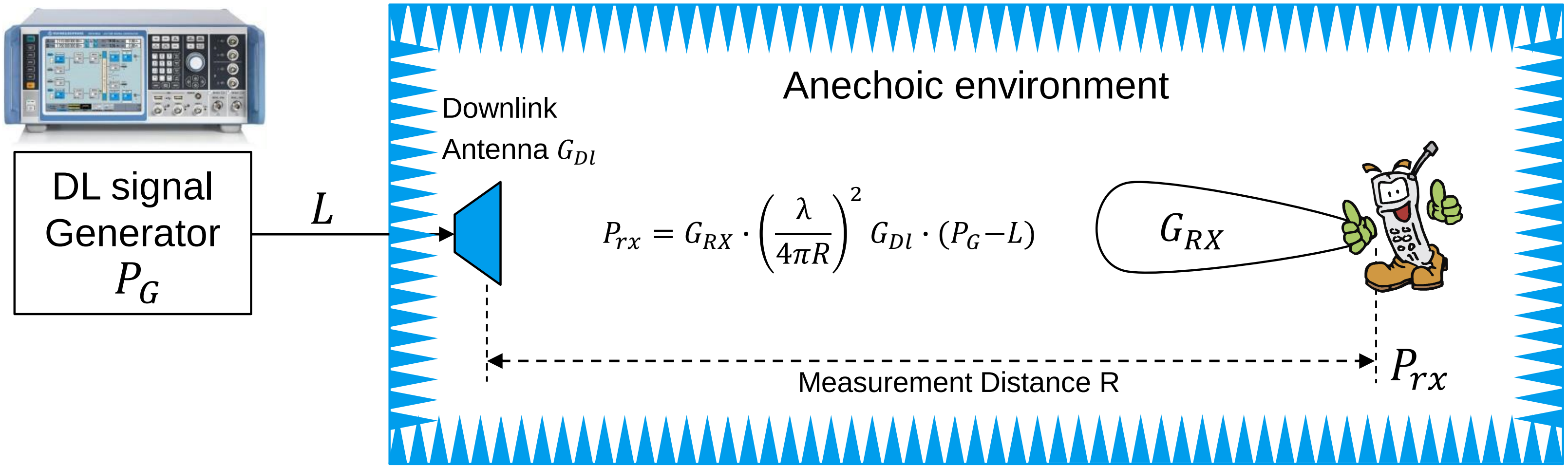
This would allow a free field coverage range of approx. 400 m for a 30dBm transmitter @ 28 GHz !

Source: RAN4 Tdocs R4-1801788 and R4-1804589

# OTA RX measurement link budget constraints

## Example: Demodulation quality measurements

FF distance < R < max distance for $P_{rsens}$




$P_{rx} > P_{rsens}$

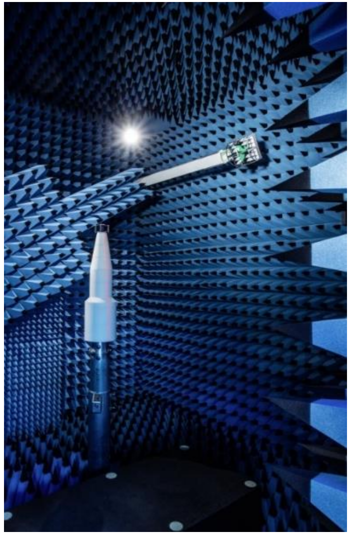
**Create quasi „conducted“ test conditions**

L = cable and mismatch loss between downlink signal generator and downlink antenna

# 5G OTA range for UE testing

### UE FR1 CTIA & FR2 R&D

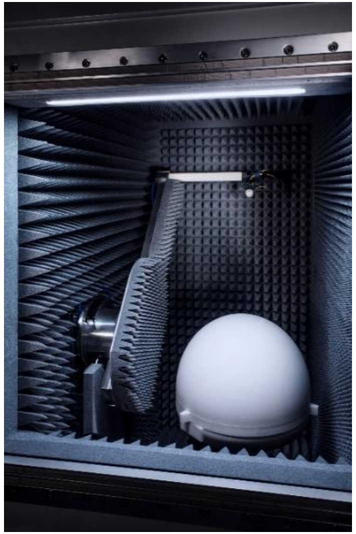
- Most broadband
- Highest flexibility



**WPTC**

### FR2 chip and antenna R&D

- Fast, accurate, compact
- 3-D thermal testing



**ATS1000**

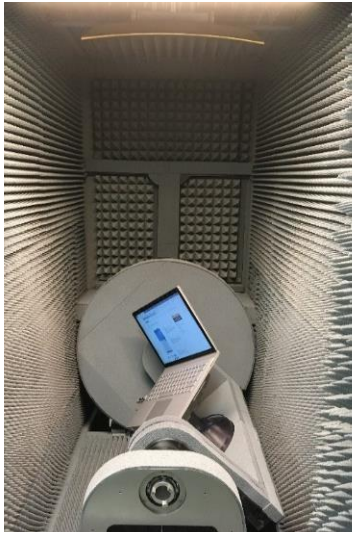
### FR2 UE R&D

- 20 cm QZ
- Cost efficient
- Can be rack-integrated

**ATS800**

### FR2 UE conformance & CTIA

- 30 cm QZ
- RFCT, PCT, RRM



**ATS1800C**

### FR2 production & R&D

- Flexible test capability
- Can be rack-integrated

**CMQ200/500**

# The world of regulation and standardisation

International Electrotechnical Commission

CISPR

# Full scope of test needs for radio communication devices

Regulator requirements (ITU-R, FCC, CEPT, …)

Regional industry (e.g. CTIA)

Global Industry Requirements (e.g. GCF)

National Safety Regulations

etc.

„House standards“ (manufacturers own requirements)

Standards Requirements

**Pool of Test Parameters**

CCA

Receiver Saturation

DFS

Blocking

(Radiated) Spurious Emissions

AFA

Polite Channel access

Adjacent Channel Selectivity (ACS)

Spectrum Emission Mask (SEM)

Co-existence Testing

Out-of-Band Emissions

LBT

Transmit Power Control (TPC)

Duty Cycle

**Adaptivity**

Intermodulation by Transmitter

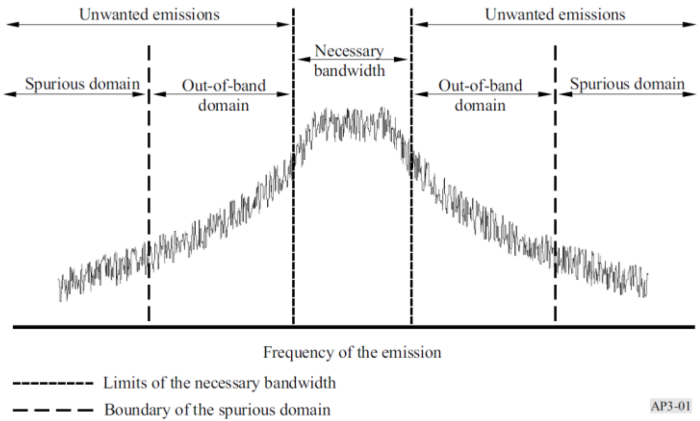
Intermodulation by Receiver

…. and more

# ITU-R – Unwanted emissions regulation

- ITU-R SM.329 provides options for different categories of limits for unwanted emissions in the spurious domain
- ITU-R SM.1539 and Appendix 3 of the ITU Radio Regulations deal with variation of the boundary between the out-of-band and spurious domains, other than the specific 250% of the Necessary Bandwidth from the center frequency of the emission
- Appendix 3 of the ITU Radio Regulations contains general spurious emissions limits, with the time scales for their implementation
- Receivers may also radiate spurious components from the antenna, which are presently not covered by Recommendation ITU-R SM.329

**Out-of-band and spurious domains**




| Service category in accordance with Article 1, or equipment type[15] | Attenuation (dB) below the power supplied to the antenna transmission line |
|---|---|
| All services except those services quoted below: | 43 + 10 log ($P$), or 70 dBc, whichever is less stringent |

**Values for frequency separation between the centre frequency and the boundary of the spurious domain**

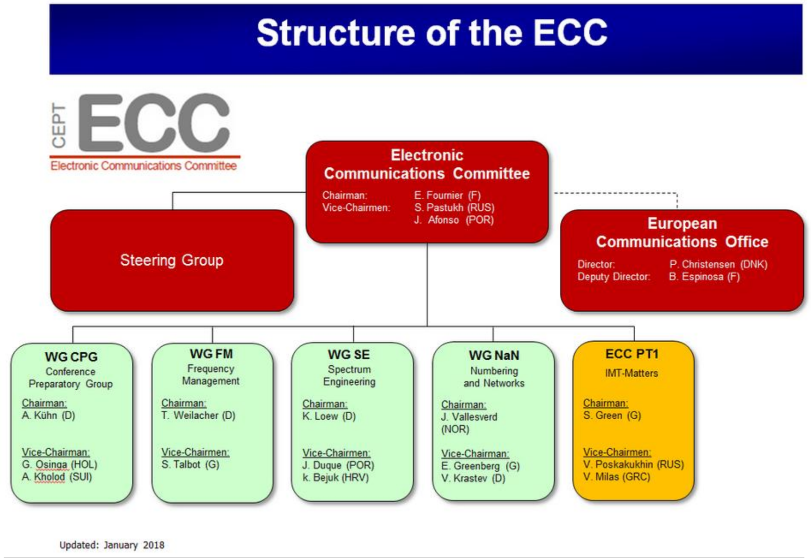
| Frequency range | Narrow-band case | | Normal separation | Wideband case | |
|---|---|---|---|---|---|
| | for $B_N$ < | Separation | | for $B_N$> | Separation |
| 9 kHz < $f_c$ ≤ 150 kHz | 250 Hz | 625 Hz | 2.5 $B_N$ | 10 kHz | 1.5 $B_N$ + 10 kHz |
| 150 kHz < $f_c$ ≤ 30 MHz | 4 kHz | 10 kHz | 2.5 $B_N$ | 100 kHz | 1.5 $B_N$ + 100 kHz |
| 30 MHz < $f_c$ ≤ 1 GHz | 25 kHz | 62.5 kHz | 2.5 $B_N$ | 10 MHz | 1.5 $B_N$ + 10 MHz |
| 1 GHz < $f_c$ ≤ 3 GHz | 100 kHz | 250 kHz | 2.5 $B_N$ | 50 MHz | 1.5 $B_N$ + 50 MHz |
| 3 GHz < $f_c$ ≤ 10 GHz | 100 kHz | 250 kHz | 2.5 $B_N$ | 100 MHz | 1.5 $B_N$ + 100 MHz |
| 10 GHz < $f_c$ ≤ 15 GHz | 300 kHz | 750 kHz | 2.5 $B_N$ | 250 MHz | 1.5 $B_N$ + 250 MHz |
| 15 GHz < $f_c$ ≤ 26 GHz | 500 kHz | 1.25 MHz | 2.5 $B_N$ | 500 MHz | 1.5 $B_N$ + 500 MHz |
| $f_c$ > 26 GHz | 1 MHz | 2.5 MHz | 2.5 $B_N$ | 500 MHz | 1.5 $B_N$ + 500 MHz |

NOTE – In Table 1, $f_c$ is the centre frequency of the emission and $B_N$ is the necessary bandwidth. If the assigned frequency band of the emissions extends across two frequency ranges, then the values corresponding to the higher frequency range shall be used for determining the boundary.

Source: ITU Radio Regulations 2016 Appendix 3

# CEPT/ECC

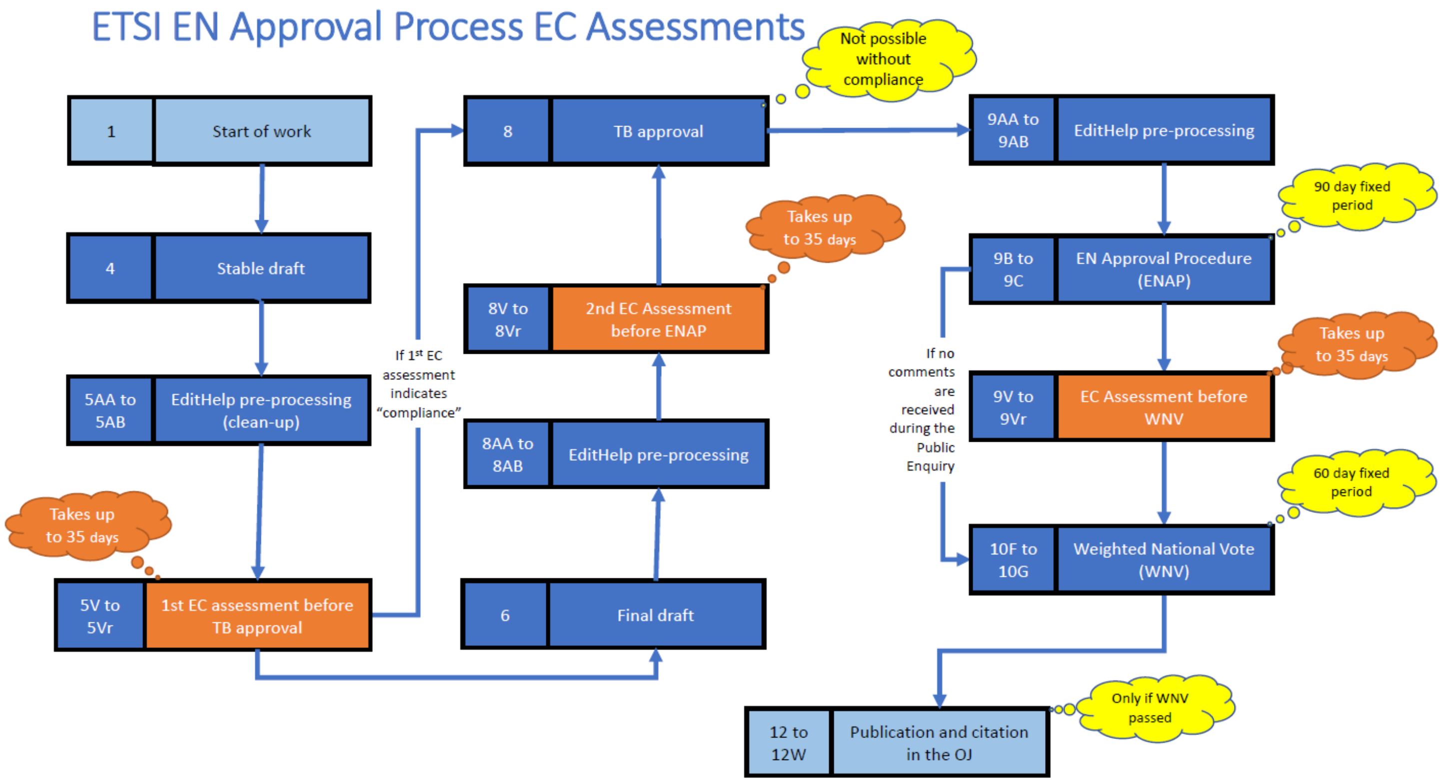
- The **ECC** (Electronic Communications Committee) is the leading expert group within CEPT responsible for developing common policies and regulations in electronic communications and related applications for Europe and harmonising spectrum use.
- **WG SE** (Spectrum Engineering ) is responsible for developing technical guidelines and sharing and compatibility arrangements for radio spectrum use by various radio communications services using the same or different frequency bands respectively.
  - **SE 21** is taking care of **spurious emissions**.
  - **SE 24** is looking after **short range devices**, incl. ITS.
- **WG FM** (Frequency Management ) is responsible for developing strategies, plans and implementation advice for the management of the radio spectrum.
- **WG CPG** (Conference Preparatory Group ) is responsible for developing briefs, studies, and European Common Proposals (ECPs) for the World Radiocommunication Conference.
- **ECC PT1** (Project Team 1) is responsible for mobile (IMT) issues, incl. compatibility studies, band plans, development and review of ECC deliverables and for the preparation of CEPT positions on WRC-19 agenda




- **WG NaN** (Numbering and Networks) is responsible for developing policies in numbering, naming and addressing and advising on technical regulatory matters to promote and support telecom innovation and competition.

Source: www.cept.org

# Revised Approval Process for European Harmonised Standards



# Federal Communications Commission (FCC)

## Electronic Code of Federal Regulations

e-CFR data is current as of **October 12, 2018**

| Title | Volume | Chapter | Browse Parts | Regulatory Entity |
|---|---|---|---|---|
| **Title 47 Telecommunication** | 1 | I | 0-19 | FEDERAL COMMUNICATIONS COMMISSION |
| | 2 | | 20-39 | |
| | 3 | | 40-69 | |
| | 4 | | 70-79 | |
| | 5 | | 80-199 | |
| | | II | 200-299 | OFFICE OF SCIENCE AND TECHNOLOGY POLICY AND NATIONAL SECURITY COUNCIL |
| | | III | 300-399 | NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, DEPARTMENT OF COMMERCE |
| | | IV | 400-499 | NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, DEPARTMENT OF COMMERCE, AND NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION, DEPARTMENT OF TRANSPORTATION |
| | | V | 500-599 | THE FIRST RESPONDER NETWORK AUTHORITY (Parts 500-599) |

The **F**ederal **C**ommunications **C**ommission's (FCC) telecommunication rules and regulations are located in **Title 47** of the **C**ode of **F**ederal **R**egulations (CFR).

The official rules are published and maintained by the **G**overnment **P**rinting **O**ffice (GPO) in the Federal Register.

# IEEE / ANSI standard C63.26


IEEE STANDARDS ASSOCIATION ◆IEEE

American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services

C63®

Accredited Standards Committee C63®—Electromagnetic Compatibility

Accredited by the
American National Standards Institute

## Transmitter requirements only !

- Frequency range
- RF output power
- Modulation characteristics
- Occupied bandwidth
- Radiated emissions
- Frequency stability
- Unwanted (out-of-band and spurious) **conducted** measurements

Procedures on TRP compliance for out-of-band and spurious emissions are currently discussed at **C63.26 mmWave JTG** !

# RED: Radio Equipment Directive

## 2014/53/EU: mandatory since June 2017

Transmitter Performance

This chapter is classic.

Radio Equipment Directive

Art. 3.2

Efficient Use of Spectrum

Receiver Performance New

This chapter is new

- Frequency accurracy/stability
- Transmit power
- ACLR
- Inband emissions
- Out of band emissions
- Spurious emissions
- Modulation quality
- Duty cycle
- …

**Harmonised Standards**
e.g. EN 301 908, EN 301 893,
EN 303 413, EN 303 340, etc.

- Dynamic range
- Sensitivity
- Adjacent channel selectivity
- Co-channel rejection
- Intermodulation rejection
- Blocking
- Spurious response
- …

# European Harmonised Standards following closely 3GPP

ETSI EN 301 908-13 V11.1.2 (2017-07)


IMT cellular networks;
Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; = RED
Part 13: Evolved Universal Terrestrial Radio Access (E-UTRA) User Equipment (UE)

**Transmitter** max/min output power, spectral emission mask, Adjacent channel leakage (ACLR), spurious emissions

**Receiver** reference sensitivity, adjacent channel selectivity (ACS), blocking, spurious response/emissions, Intermodulation

**Basis:**
ETSI 136 521-1 = 3GPP TS 36.521-1
(E-UTRA UE conformance testing)

Today: Conducted measurements only

Under preparation:
Adding radiated measurements (TRP, TRS)
Responsible working group: ETSI MSG TFES
Problem: No 3GPP limits available !

# ETSI MSG TFES

ETSI Technical Committee **Mobile Standards Group** (MSG) continues to update the HS required by the RED for the IMT family (incl. WCDMA, LTE, NR), to take account of the new specifications in 3GPP Releases. This work is undertaken in co-operation with ETSI TC ERM in the **Task Force for European Standards** (TFES).

- Relevant deliverables: **ETSI EN 301 908**
  - Part 2 "UTRA FDD User Equipment (UE)“, i.e. WCDMA/UMTS
  - Part 13 "E-UTRA User Equipment (UE)“, i.e. LTE
- **Initiated work items on 5G:**
  - **ETSI EN 301 908 - Part 24**

    "New Radio (NR) Base Stations (BS)“, Planned citation in the OJ August 2021
  - **ETSI EN 301 908 - Part 25**

    "New Radio (NR) User Equipment (UE)“, Planned citation in the OJ September 2021

# CTIA test plans and ongoing 5G activities

- **CTIA OTA Test Plan Version 3.8 (does not cover 5G yet)**
  - Published Sept 2018 and to become mandatory by Jan 2019. AVRD* is still not available.
  - Next test plan **version 3.9 shall include NR FR1** as new RAT for TRP/TIS, i.e. frequency range extension up to 6 GHz.
  - Note: CTIA certification testing includes Phantom heads and hands !

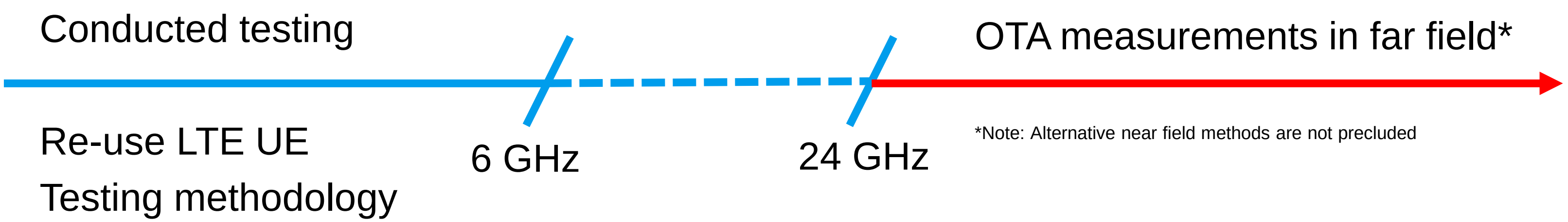
- **CTIA – 5G mmW OTA subworking group**
  - Most of the discussions and progress is an extension of the work at 3GPP RAN4.
  - Targetting only bands n260 and n261, using 100MHz BW
  - Free Space is the first priority (hand only phantoms expected later)
  - **Target is to have a Test Plan for 5G mmWave by Q3'2019**

*AVRD = Assessment & Validations Requirements Document

# 5G NR conformance testing according to 3GPP

ROHDE&SCHWARZ

# 3GPP TR 38.803 NR Testability




## 10.2.3 Test Interface

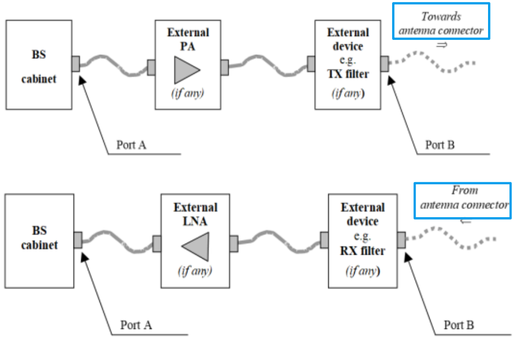
A Test Interface (TI) is needed for certain control and measurement functions. Detailed functions and implementation of the TI are TBD

Source: 3GPP TR 38.803 V2.0.0

# Base station types defined in 3GPP TS 38.141

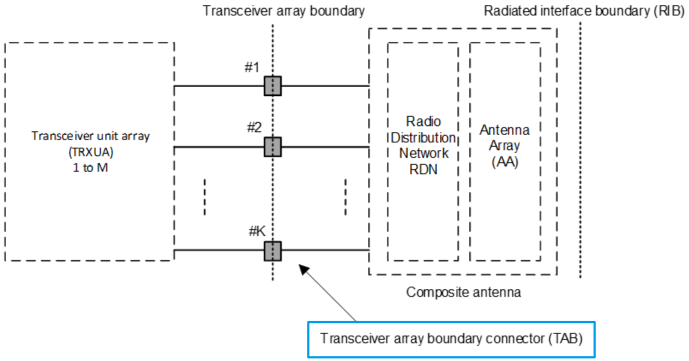
## Conducted

- BS type 1-C transmitter/receiver interface



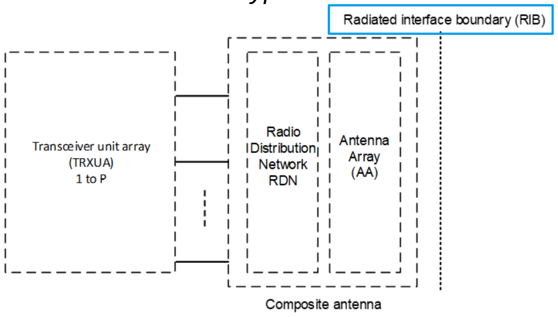

## Hybrid

- General architecture of *BS type 1-H*




## OTA

- General architecture of *BS type 1-O* and *BS type 2-O*




**BS type 1-C:** NR base station operating at FR1 with requirements set consisting only of conducted requirements defined at individual ***antenna connectors***

**BS type 1-H:** NR base station operating at FR1 with a requirement set consisting of conducted requirements defined at individual ***TAB connectors*** and OTA requirements defined at RIB

**BS type 1-O:** NR base station operating at FR1 with a requirement set consisting only of OTA requirements defined at the **RIB**

**BS type 2-O:** NR base station operating at FR2 with a requirement set consisting only of OTA requirements defined at the **RIB**

**Source: 3GPP TS 38.141-1/-2 V15.0.0**

# Test models

- NR FR1 test models needed for BS type 1-C, BS type 1-H and BS type 1-O
- NR FR2 test models needed for BS type 2-O

| Test model | Measurement |
|---|---|
| NR-FR1-TM1.1<br>NR-FR2-TM1.1 | BS output power |
| | TAE (Time Alignment Error) |
| | Occupied bandwidth |
| | ACLR |
| | Operating band unwanted emissions |
| | Transmitter spurious emissions |
| | Transmitter intermodulation |
| NR-FR1-TM1.2 | ACLR |
| | Operating band unwanted emissions |
| NR-FR1-TM2<br>NR-FR2-TM2 | Total power dynamic range (lower OFDM symbol power limit at min power) |
| | EVM of single 64QAM PRB allocation (at min power) |
| | Frequency error (at min power) |
| NR-FR1-TM2a | EVM of single 256QAM PRB allocation (at min power) |
| | Frequency error (at min power) |

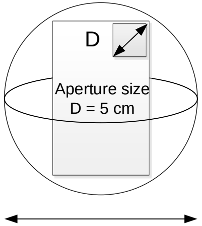
| Test model | Measurement |
|---|---|
| NR-FR1-TM3.1<br>NR-FR2-TM3.1 | Total power dynamic range (upper OFDM symbol power limit at max power with all 64QAM PRBs allocated) |
| | Frequency error |
| | EVM for 64QAM modulation (at max power) |
| NR-FR1-TM3.1a | Total power dynamic range (upper OFDM symbol power limit at max power with all 256QAM PRBs allocated) |
| | Frequency error |
| | EVM for 256QAM modulation (at max power) |
| NR-FR1-TM3.2 | Frequency error |
| | EVM for 16QAM modulation |
| | Frequency error (at min power) |
| NR-FR1-TM3.3 | Frequency error |
| | EVM for QPSK modulation |

# 3GPP: three UE categories specified for RF mmW

**Most important category = for Smartphones**

## UE Category 1

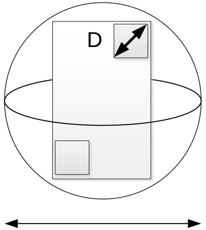
**Single aperture, D = 5 cm**




Quiet Zone diameter = 15 cm

## UE Category 2

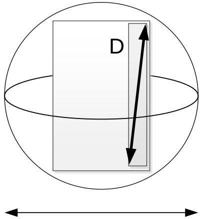
**Multiple, non-coherent apertures, D = 5 cm**




Quiet Zone diameter = 15 cm

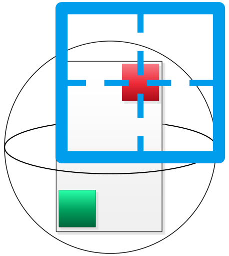
## UE Category 3

**Larger apertures, D = 15 cm**




Quiet Zone diameter = 15 cm

**Quiet zone**



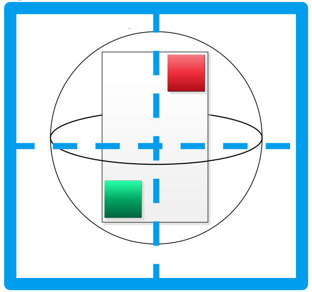
**Quiet zone too small**

**"Whitebox test required"**

**Quiet zone ok**

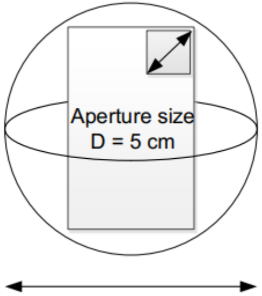
**"Blackbox test possible"**

**Quiet zone**



# UE Category 1

Applicabilty to single aperture,
D = 5 cm

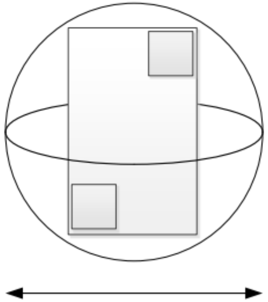



Quiet Zone diameter = 15 cm

- A DUT with <u>single</u> radiating aperture
  - The aperture has max dimension of D = 5 cm
  - The aperture can be placed anywhere within the QZ
- In this situation, the following requirement on test zone quality applies:
  - A magnitude requirement on test zone quality is sufficient.

# UE Category 2

Applicabilty to multiple
non-coherent apertures, D = 5 cm

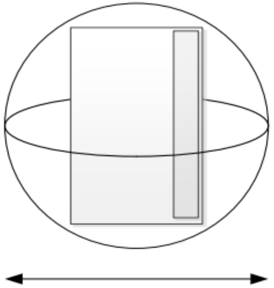


Quiet Zone diameter = 15 cm

- A DUT with <u>multiple</u> <u>non-coherent</u> radiating apertures
  - Each aperture has max dimension of D = 5 cm
  - Each aperture has its own independent receiver chain
  - Apertures can be placed anywhere within the QZ
- In this situation, the following requirement on test zone quality applies:
  - A magnitude requirement on test zone quality is sufficient

# UE Category 3

Applicabilty to single aperture,
D = 15 cm



Quiet Zone diameter = 15 cm

- A DUT with a single coherent radiating aperture
  - The aperture has max dimension of D = 15 cm
  - The aperture can be placed anywhere within the QZ
- In this situation, the following requirement on test zone quality applies:
  - A magnitude <u>and</u> phase requirement on test zone quality is sufficient

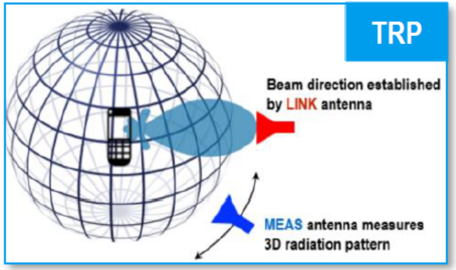
# 3GPP conformance testing

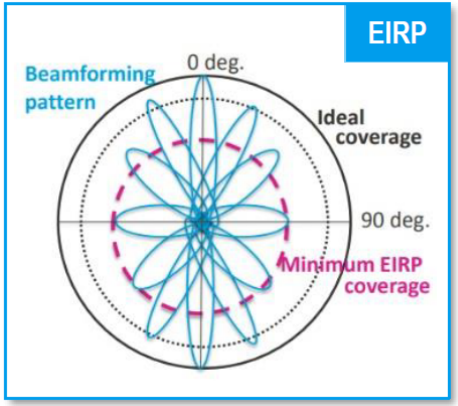
| 3GPP NR Specifications | |
|---|---|
| Series | Title |
| 38.1xx | RF test spec. |
| 38.2xx | Layer 1 |
| 38.3xx | Layer 2 / 3 |
| 38.4xx | Core netw. |
| **38.5xx** | **UE conf.** |
| 37.324 | LTE and NR |
| 37.340 | NR multi-conn. |

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 |

# OTA testing for sub-6GHz

## Metrics

- Below 6GHz, Over-The-Air means “only” radiated performance:
  - **T**otal **R**adiated **P**ower is an spatially average of EIRP measurements
  - **T**otal **I**sotropic **S**ensitivity is an spatially average of EIS measurements
  - **I**ntermediate **C**hannel **D**egradation, is a measurement relative to TIS to evaluate all the channels between Low, Mid and High channels within the band
  - **Desense:** desensitization of the Wi-Fi radio when the Cellular radio is operating (and vice versa)

# OTA testing for sub-6GHz

## CTIA Test Plans

- CTIA Test Plan for **Wireless Device Over-the-Air Performance**
  - It covers cellular wireless technologies deployed in the US: GSM, WCDMA, LTE (including CA, LAA, Cat-M1…), CDMA, A-GNSS and BT
  - SISO OTA performance = TRP, TIS, ICD.
  - Human phantoms standarization is one of the key activities

- CTIA Test Plan for **2×2 Downlink MIMO and Transmit Diversity** Over-the-Air Performance
  - Currently only applicable for LTE (FDD and TDD), based on a noise-controlled environment (Throughput vs. SIR)

- CTIA Test Plan for **Wireless Large-Form-Factor** Device Over-the-Air Performance
  - Extension of the OTA Test Plan for devices bigger than 30cm diameter, using Reverberation Chamber as the main methodology.

- CTIA/Wi-Fi Alliance Test Plan for RF Performance Evaluation of **Wi-Fi Mobile Converged Devices**
  - Shared test plan between CTIA and WFA for the OTA performance of devices including both Cellular and Wi-Fi transmitters.
  - Most important Test Case is the Desense between cellular and Wi-Fi, and viceversa.

- Several others, like LTE CA Interoperability, Battery Life, Speech performance, and many others.

# OTA testing for sub-6GHz

## Positioning and phantoms

- **FS** = Free Space

- **BHHL** = Beside Head and Hand Left Side (Head and Hand Phantom)
- **BHHR** = Beside Head and Hand Right Side (Head and Hand Phantom)

- **HL** = Hand Left (Hand Phantom Only)
- **HR** = Hand Right (Hand Phantom Only)

- **WL** = Wrist-Worn Left
- **WR** = Wrist-Worn Right

FIGURE A-9 HEAD AND HAND CONFIGURATION (A) WITH AND (B) WITHOUT MASK SPACER (RIGHT), (C) WITH AND (D) WITHOUT MASK SPACER (LEFT)

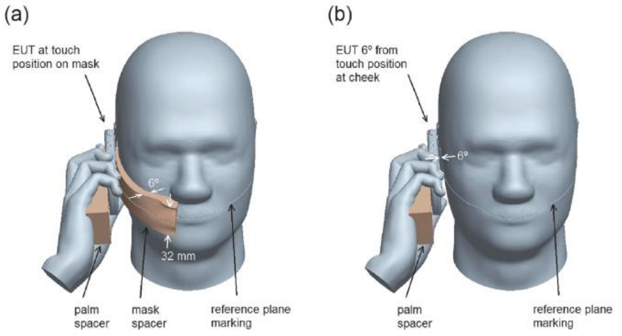



FIGURE A-17 WIDE GRIP HAND PHANTOM CONTACT POINTS

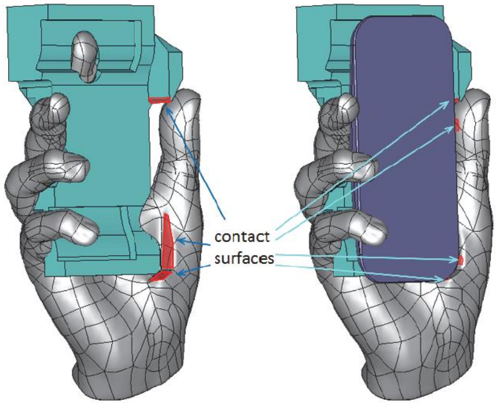
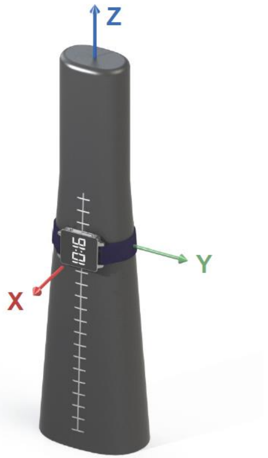


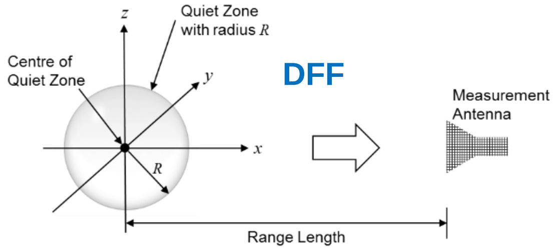

FIGURE Q-2 CARTESIAN COORDINATE SYSTEM FOR FOREARM PHANTOM

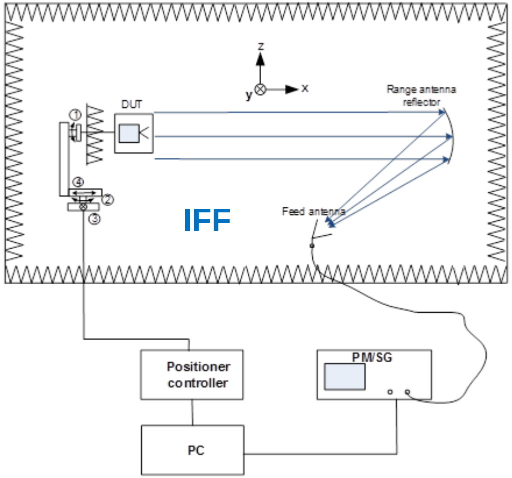


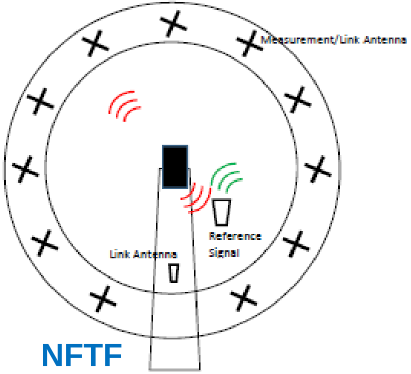
# Conformance testing for mmWave

## Methodologies for **RF**

- Currently there are 3 accepted methodologies for RF Conformance testing, all of them ensuring Far Field conditions for testing:
  - Direct Far Field (DFF)
  - Indirect Far Field (IFF), a.k.a. CATR
  - Near field to far field transform (NFTF)
- The applicability for each of them is mainly based on the number, size and position of all the arrays within the DUT.
- The Quiet Zone size, that limits the maximum size of the DUT, depends on the specific implementation.



# Conformance testing for mmWave

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  - Near field to far field transform (NFTF)
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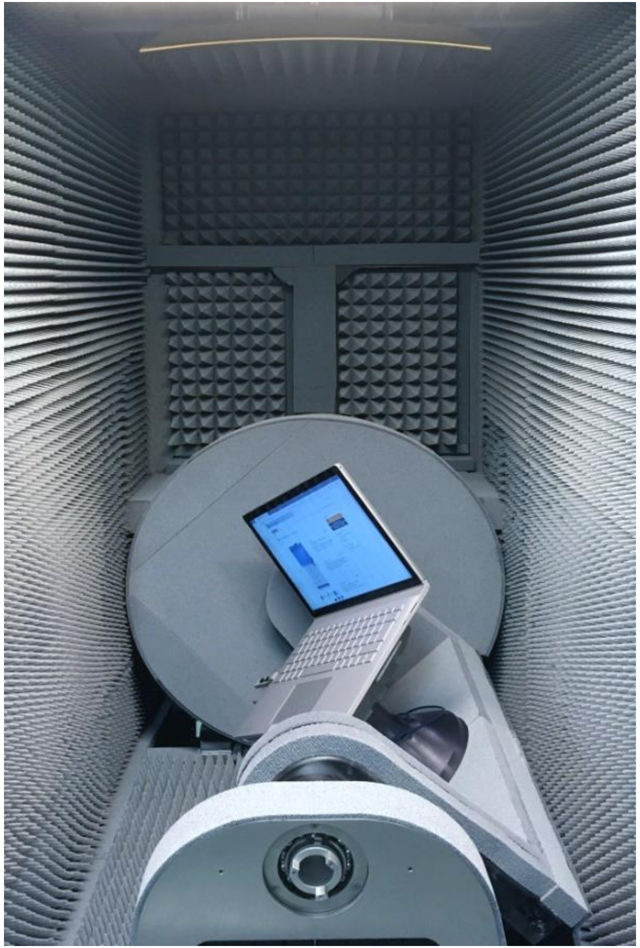
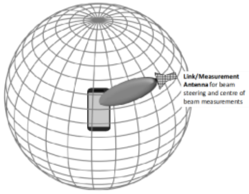
- The Quiet Zone size, that limits the maximum size of the DUT, depends on the specific implementation.



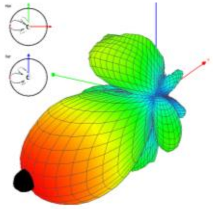
# Conformance testing for mmWave

## Test Cases for **RF**

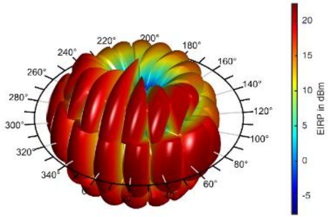
| Test Case | Spatial requirement |
|---|---|
| Tx Max Output Power | EIRP on **main beam** |
| MPR and A-MPR | EIRP on **main beam** |
| Configured Tx Power | EIRP on **main beam** |
| Min Output Power | EIRP on **main beam** |
| ON/OFF time mask | EIRP on **main beam** |
| Power Control | EIRP on **main beam** |
| Freq Error | **Main beam** |
| EVM | **Main beam** |
| Carrier leakage | **Main beam** |
| In-band emissions | **Main beam** |
| Occupied BW | **Main Beam** |
| Reference Sensitivity | EIS on **main beam** |
| Max Input level | EIS on **main beam** |
| Adjacent Channel Selectivity (ACS) | EIS + **Blocker** on **main beam** |
| In-band blocking | EIS + **Blocker** on **main beam** |
| | |
| Spurious response | *TBD* |
| Receiver Image | *TBD* |




3D positioning is only required to accurately find the main beam



3D pattern (or scan) is required

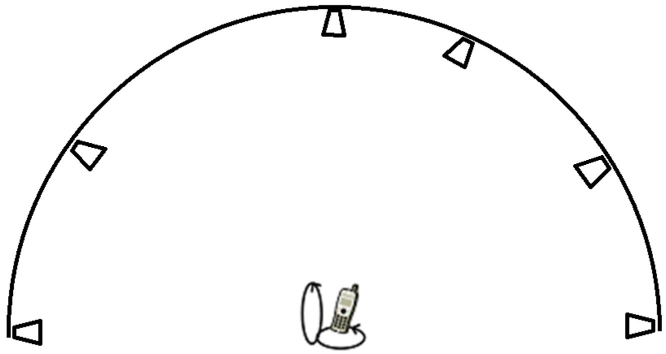



| Test Case | Spatial requirement |
|---|---|
| Tx Max Output Power | **TRP** & **Spherical Coverage** |
| Tx OFF power | **TRP** |
| Spectrum Emission Mask | **TRP** |
| ACLR | **TRP** |
| Spurious emissions | **TRP** |
| Reference Sensitivity | **Spherical Coverage** |
| Rx Spurious Emissions | **TRP** |
| | |
| Beam correspondence | *TBD* |

# Conformance testing for mmWave

## Methodologies and Test Cases for **RRM**

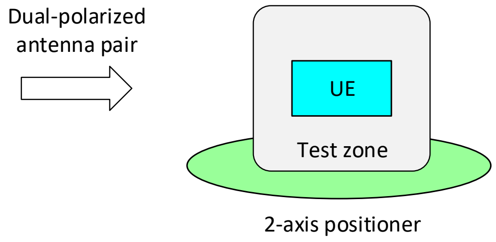
- **R**adio **R**esource **M**anagement
- Setup shall be capable of establishing an OTA link between the DUT and a number of emulated gNB sources.
  - $N_{MAX\_AoAs}$ = 2 and the setup shall enable a relative angular relationships between the active probes: 30°, 60°, 90°, 120° and 150°.
  - Currently, Far Field conditions are required for RRM and DFF is considered as baseline with the corresponding applicability agreed for RF.
  - Reference point for metrics and calibration is centre of QZ for DFF approach.



- Typical test cases for RRM:
  - Cell selection, re-selection and connection
  - UE tx Timing, timer accuracy…
  - Radio link monitoring, link interruption, link recovery…
  - Cell identification, reporting requirements…

# Conformance testing for mmWave

## Methodologies and Test Cases for **Demod**




- Only one AoA is emulated with a dual-polarised connection to enable a Rank 2 transmission (i.e. MIMO 2x2 on polarization diversity).
- Fading conditions are modelled as Tapped Delay Line (TDL).
- The minimum measurement distance R is defined according to the following formula:

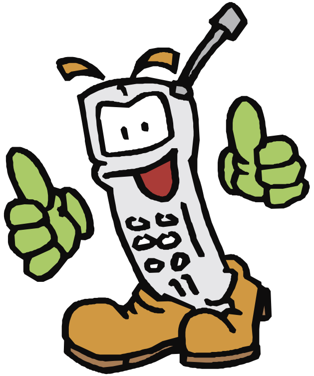
$$R > 0.62\sqrt{\frac{D^3}{\lambda}}$$

- where D is the DUT radiating aperture, and λ is the wavelength.

- Reference point is defined as center of rotation axis, being that the center of QZ for DFF/IFF.

- Test cases for Demod:
  - Absolute PDSCH throughput
  - Block-error rate performance for different DL physical channels (e.g. PDCCH)
  - CSI statistics (e.g. CQI accuracy, throughput ratio for different CSI or test settings, etc.)
  - All of them done under different scenarios: modulation, SNR, propagation conditions…

# Testing a NR UE in OTA environment



- UE is an „active antenna“ ► Reference signal is „unknown“
- UE contains multiple active antenna arrays ► no constant pattern
- Different Tx and Rx antenna arrays ► No Tx and Rx reciprocity
- No CW but modulated (wideband) signal analysis
- Phase center of antenna under test unkown ► Black box testing

- More than RF parameter testing needs:
  - Demodulation performance ► OTA multipath emulation
  - RRM ► OTA multiple angle of arrival simulation
  - Protocol ► Ideal OTA radio link conditions
  - Other features (e.g. LBS etc.) ► Introducting other radio technology OTA signals

# Conclusion on OTA testing

- It is mandatory today for CTIA certification in USA
- It will become mandatory for 3G and 4G certification according to RED in Europe
- It is the only option for 5G NR FR2

➢ Test & Measurement becomes wireless, too!

# Summary: What do we need to test OTA NR ?

- Anechoic environment providing the right measurement distance and sufficient QZ size
- High speed, resolution and accuracy Positioning systems providing sufficient support for DUTs (incl. Laptops) and optional phantoms (head and hands)
- Measurement / Stimulus antennas providing the right frequency range (inband, out-of-band), gain and bandwidth
- Best quality T&M instruments (e.g. sensitivity, dynamic range, modulation quality, phase noise, …) and RF system components (e.g. cables, filters, switches, …) to ensure **reliabilty**
- System calibration process to ensure **traceability**
- Test automation to ensure **repeatability**
- Optional temperature control for extreme test conditions (ETC)

- … or just ask Rohde&Schwarz to find the right solution for your OTA testing needs!

# Thank you for your attention!