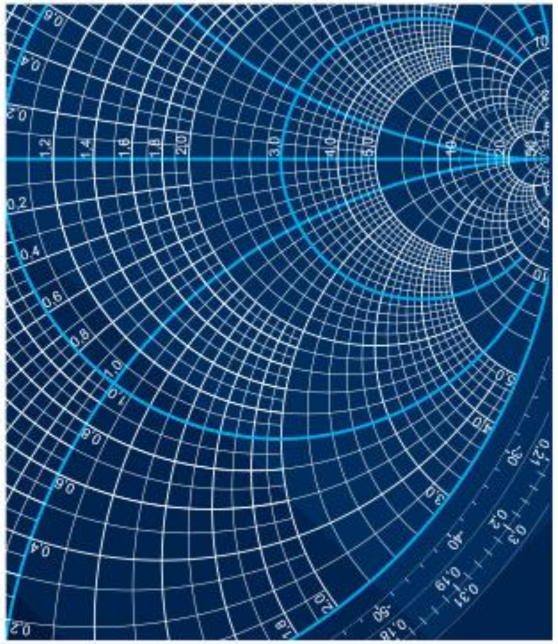
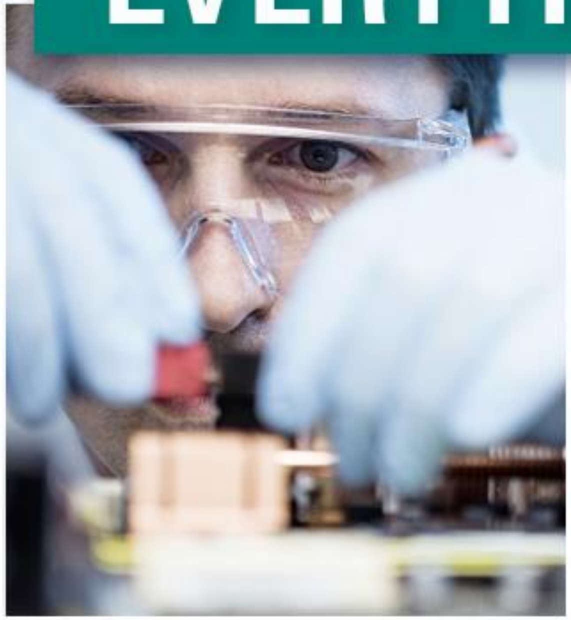


Measurement Techniques

Design Verification & Evaluation

EVERYTHING TEST

Instrument Selection & Optimization



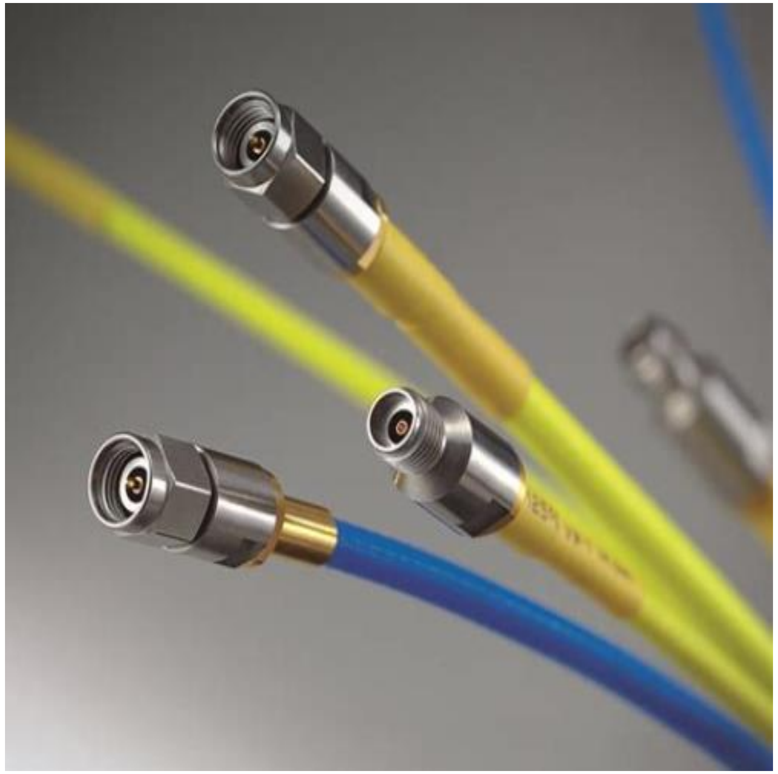
RF TEST:
Over the Air Fundamentals

Martin C Lim, Application Engineer

ROHDE&SCHWARZ

Make ideas real

What is an antenna



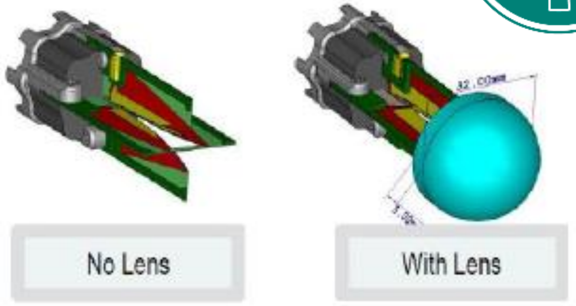
Antenna

Antennas are everywhere

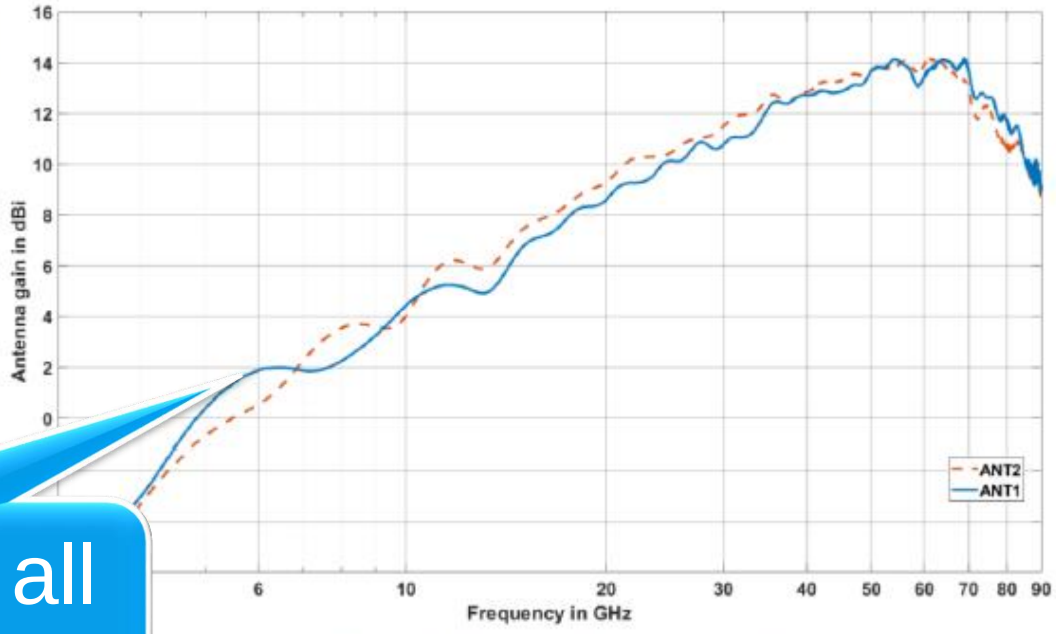
Cut the cord

Wideband Measurement Antenna

Patented low RCS dual-polarized Vivaldi antenna



Parameter	Value
Frequency range	4 - 87 GHz
VSWR	< 2.5
Gain	> 8 dBi from 20 GHz
Cross-polarization rejection	>20 d p to 40 GHz, >15 dB
Radar Cross Section (RCS)	-20 dBs : -8 dBsm)
Dimensions	76

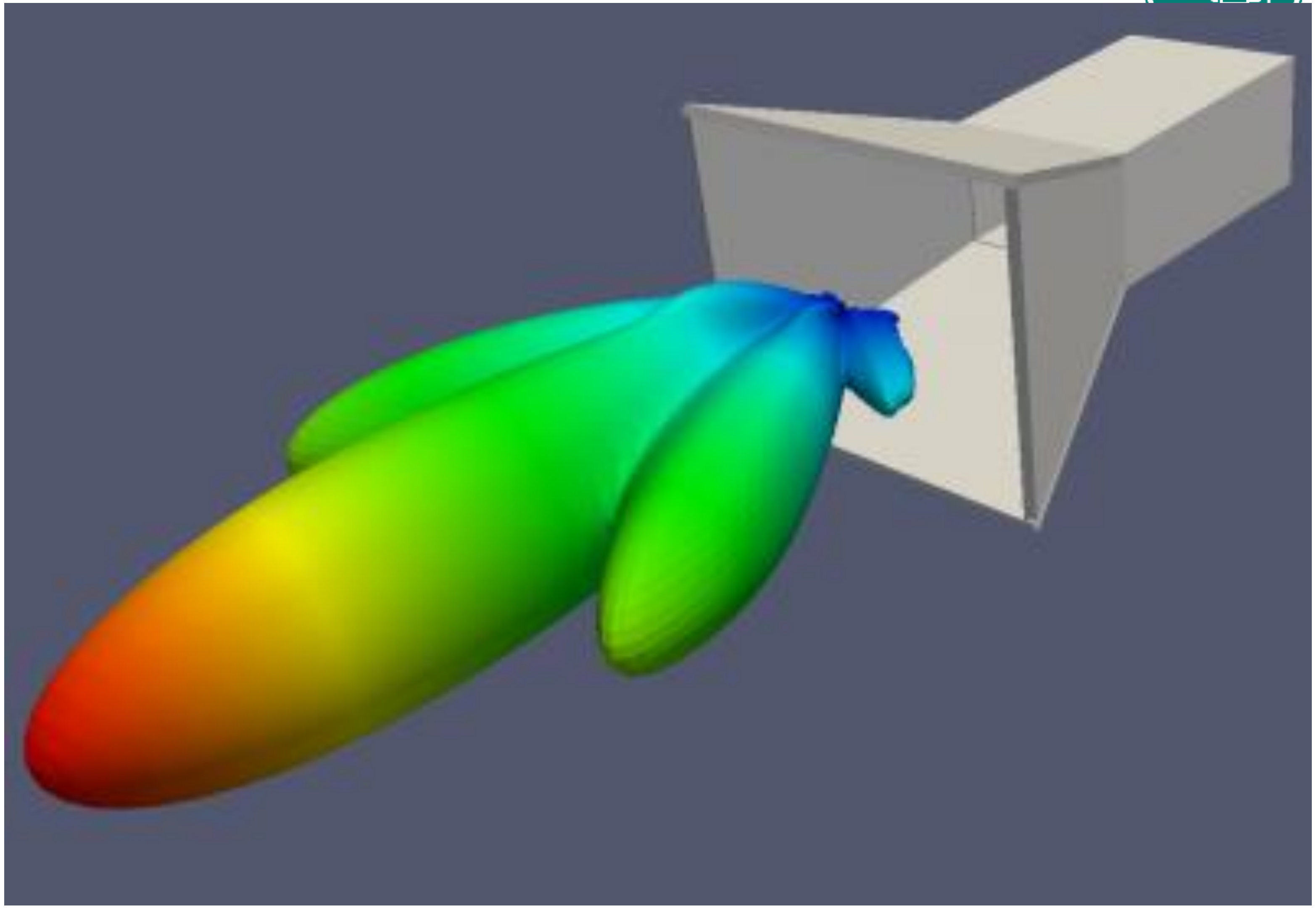


gain of the R&S®TC-TA85CP cross-polarized Vivaldi test antenna (meas.).

What does this all mean?

Agenda

- ▶ Antennas
  - – Types
  - – Specifications
- ▶ Chambers
- ▶ Measurements

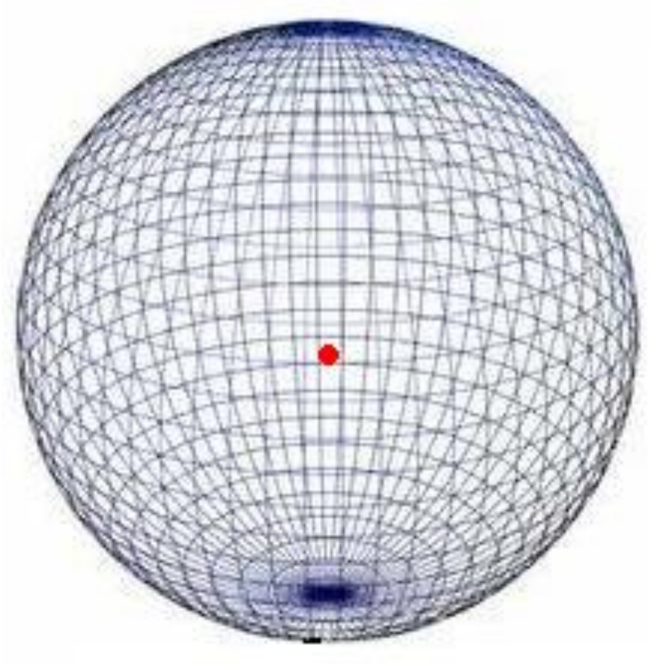


Antennas

V · T · E	Antenna types [hide]
Isotropic	Isotropic radiator
Omnidirectional	Batwing antenna · Biconical antenna · Cage aerial · Choke ring antenna · Coaxial antenna · Crossed field antenna · Dielectric resonator antenna · Dipole antenna · Discone antenna · Folded unipole antenna · Franklin antenna · Ground-plane antenna · Halo antenna · Helical antenna · J-pole antenna · Mast radiator · Monopole antenna · Random wire antenna · Rubber ducky antenna · Turnstile antenna · T2FD antenna · T-antenna · Umbrella antenna · Whip antenna
Directional	Adcock antenna · AS-2259 Antenna · AWX antenna · Beverage antenna · Cantenna · Cassegrain antenna · Collinear antenna array · Conformal antenna · Corner reflector antenna · Curtain array · Dipole antenna · Folded inverted conformal antenna · Fractal antenna · G5RV antenna · Gizmotchy · Helical antenna · Horn antenna · Inverted-F antenna · Inverted vee antenna · Log-periodic antenna · Loop antenna · Microstrip antenna · Moxon antenna · Offset dish antenna · Patch antenna · Phased array · Planar array · Parabolic antenna · Plasma antenna · Quad antenna · Reflective array antenna · Regenerative loop antenna · Rhombic antenna · Sector antenna · Short backfire antenna · Sloper antenna · Slot antenna · Sterba antenna · Vivaldi antenna · WokFi · Yagi–Uda antenna
Application-specific	ALLISS · Corner reflector (passive) · Evolved antenna · Ground dipole · Reconfigurable antenna · Rectenna · Reference antenna · Spiral antenna · Wullenweber · Television antenna

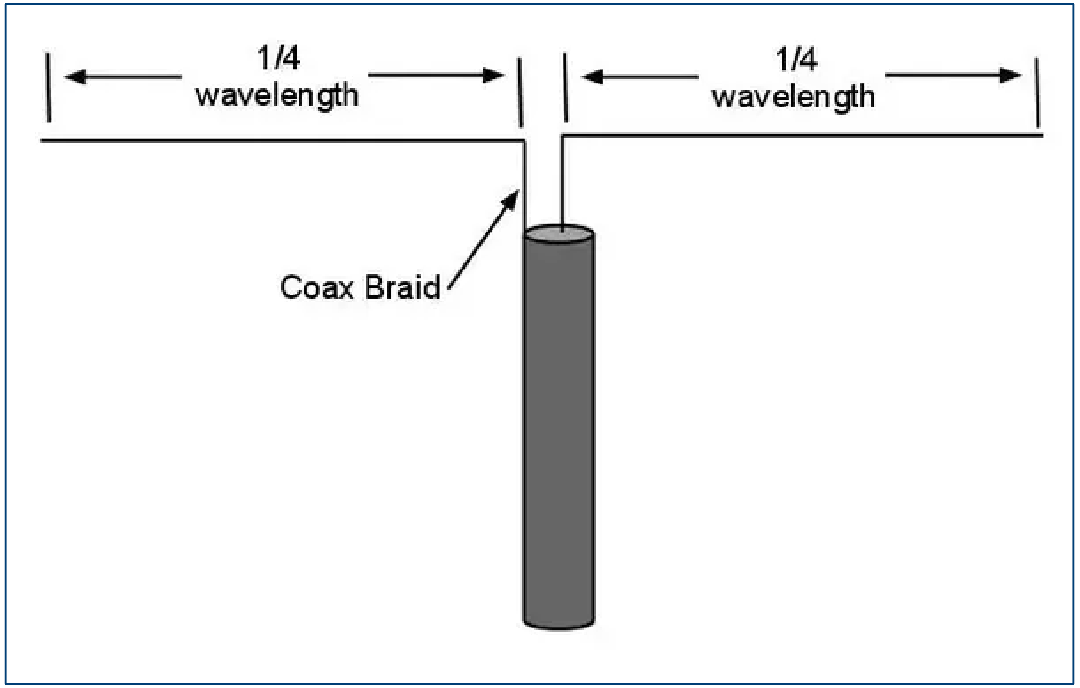
- There are quite a few antenna types
- We will discuss some common antennas

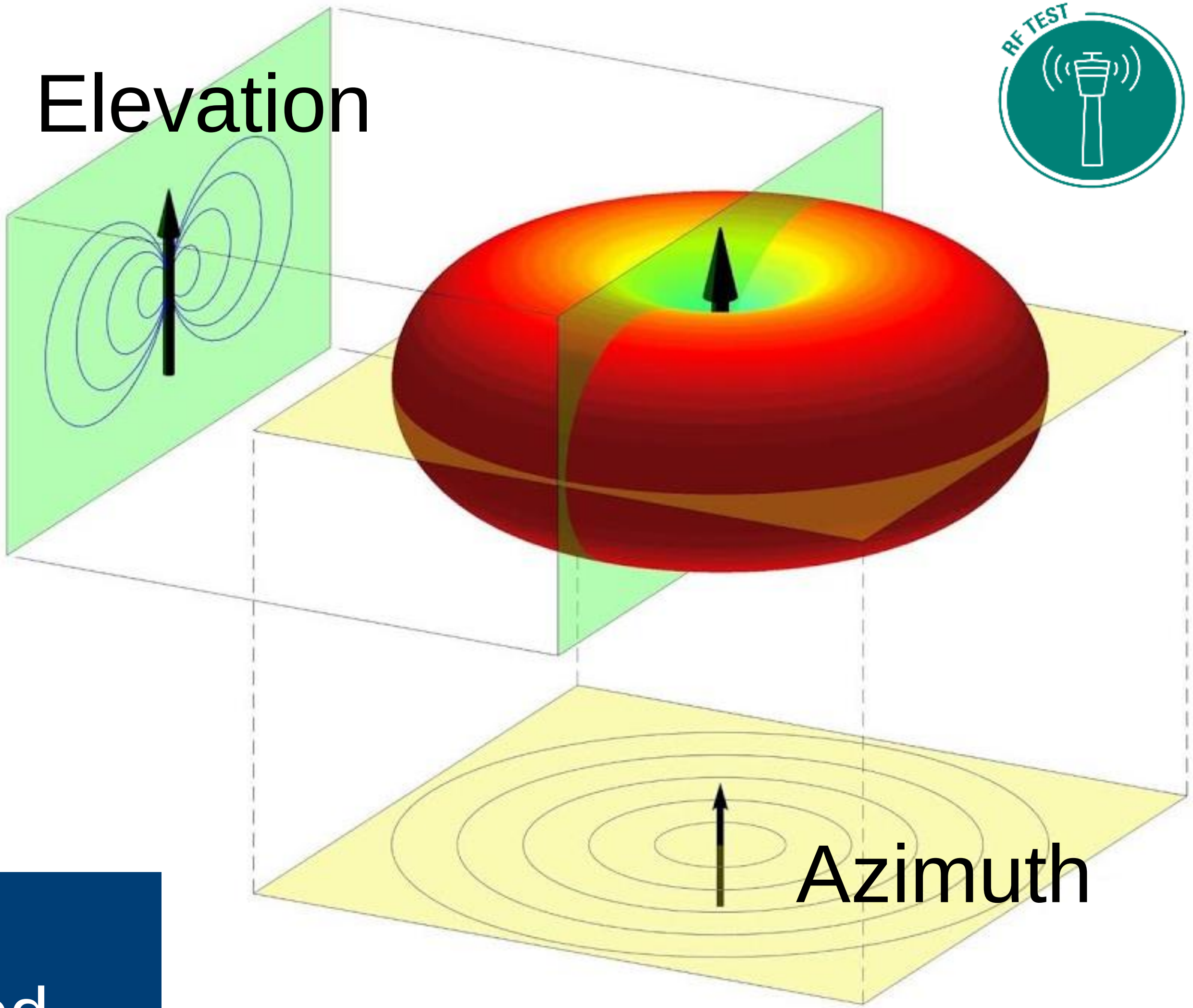
Isotropic Antenna



- Theoretical Antenna
- Radiates equally in all directions
- Antenna gain 1dB
- Antenna gain is relative to isotropic antenna
  - dBi, decibels over isotropic

Dipole Antenna



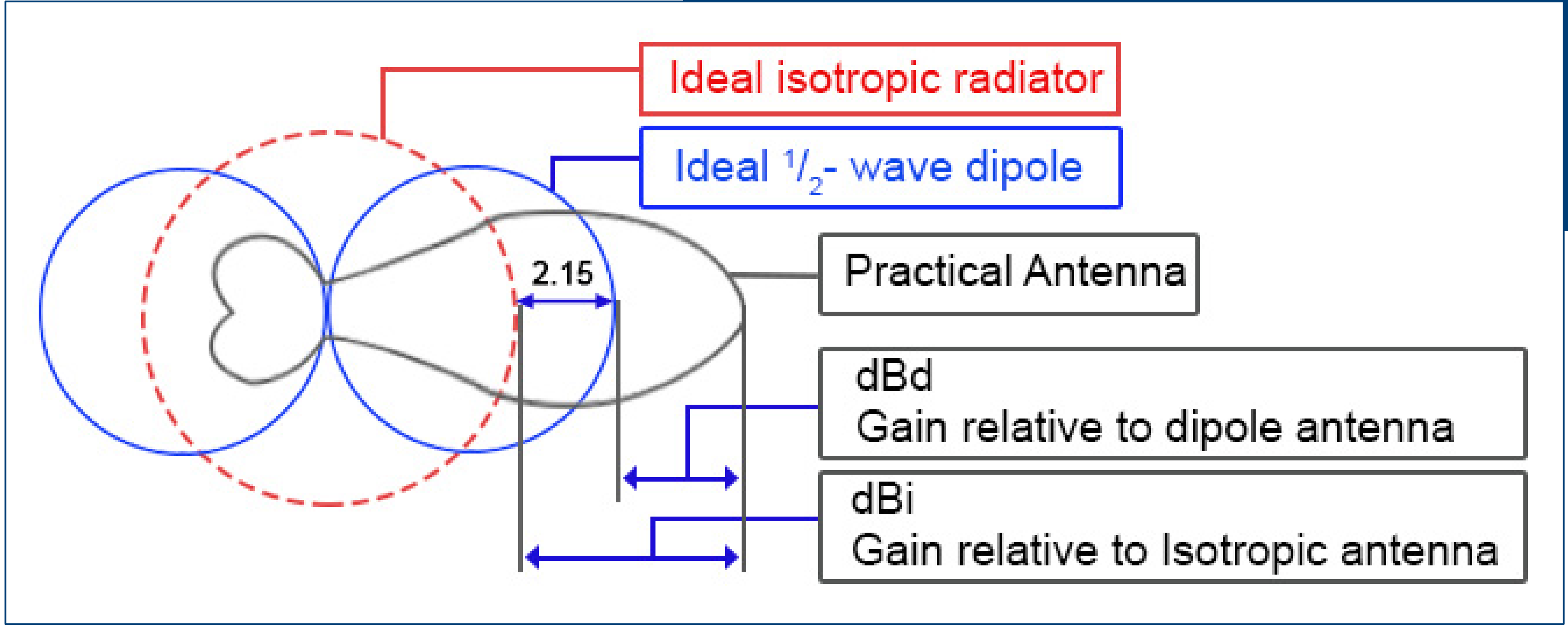


Advantages

- Easy to make & well understood
- Uniform Azimuth Pattern

Dipole Antenna

- Gain Measurements
  - dBd, decibels over dipole
  - 0 dBd is defined as 2.15 dBi
  - dBi = dBd + 2.15



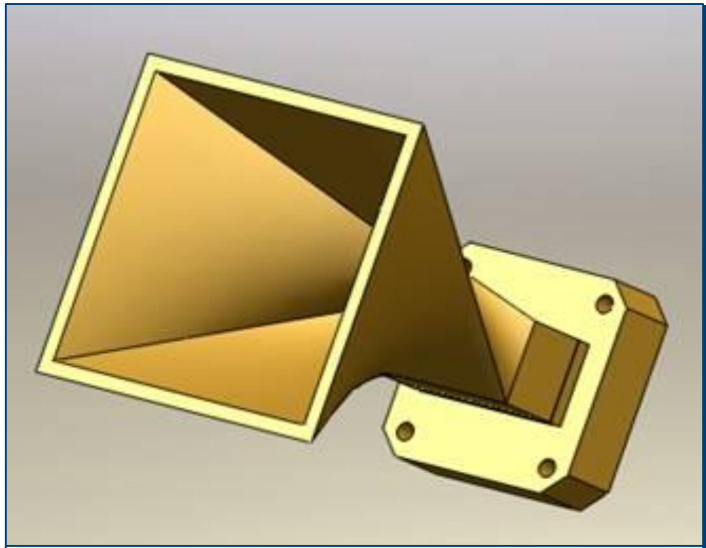
Source: https://www.softwright.com/

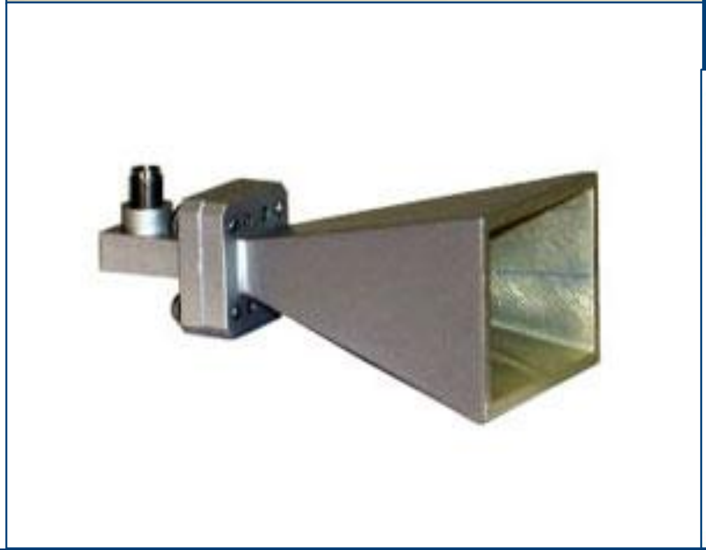
Waveguide

- Advantage:
  - Low loss
  - Completely shielded
  - High power handling

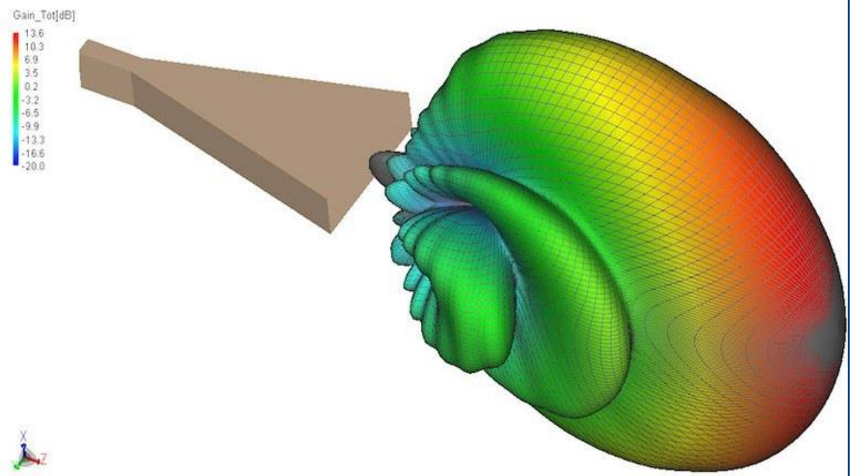
Source: https://www.medicaldesignandoutsourcing.com/

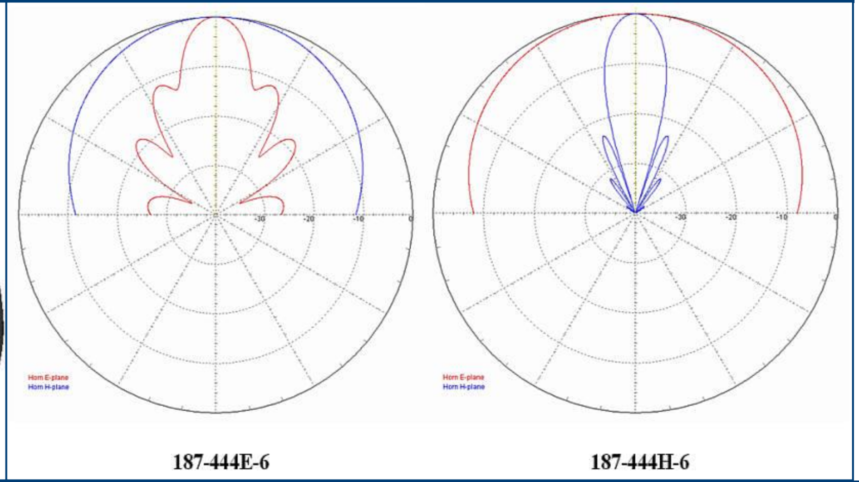
Horn Antenna



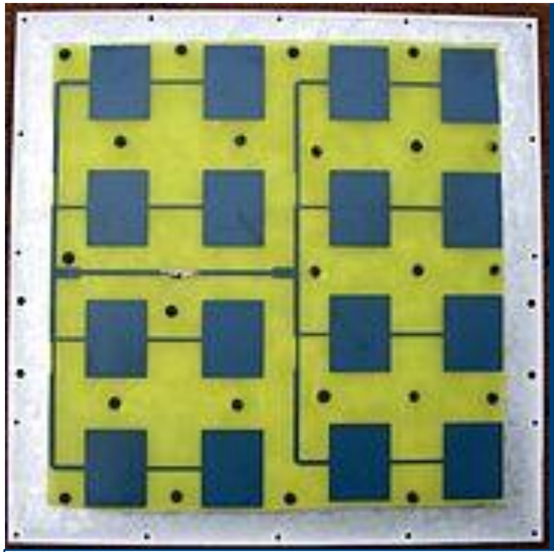


- Flaring metal waveguide shaped like a horn
- Advantage:
  - Low loss, directivity ≈ gain
  - Moderate directivity
  - Low VSWR
  - Broad bandwidth

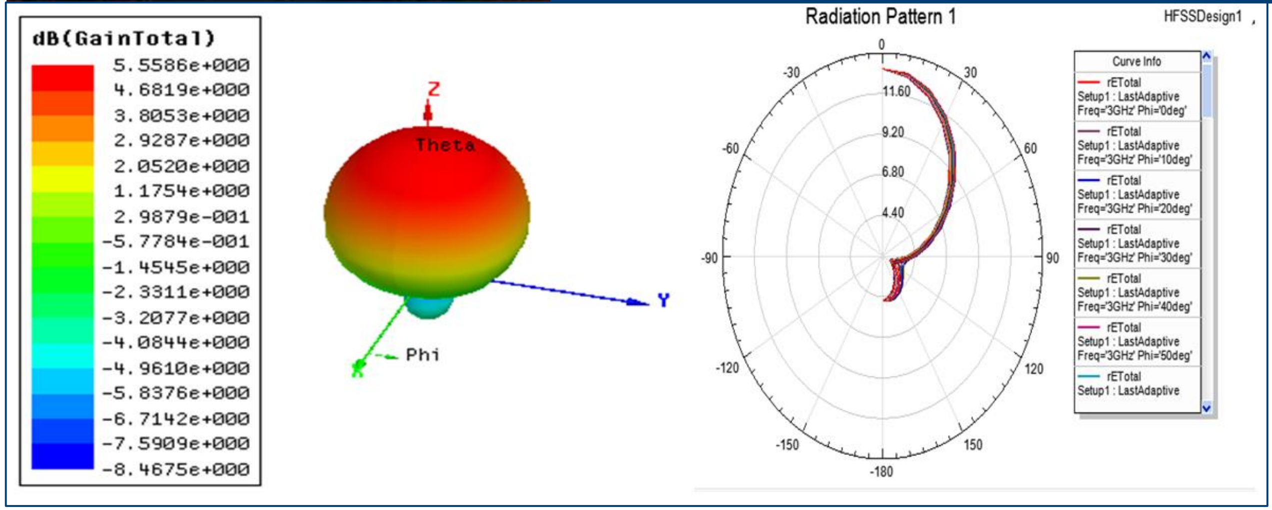


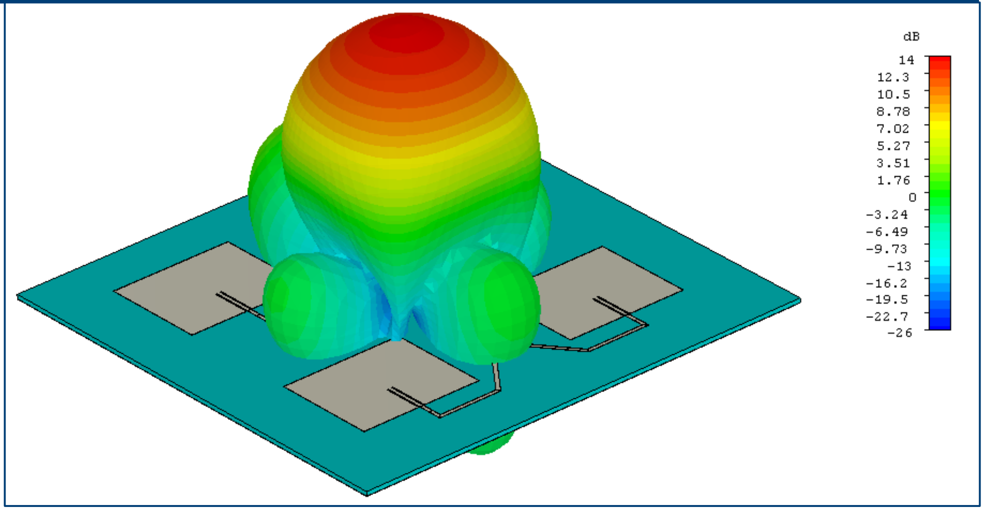


Patch Antenna



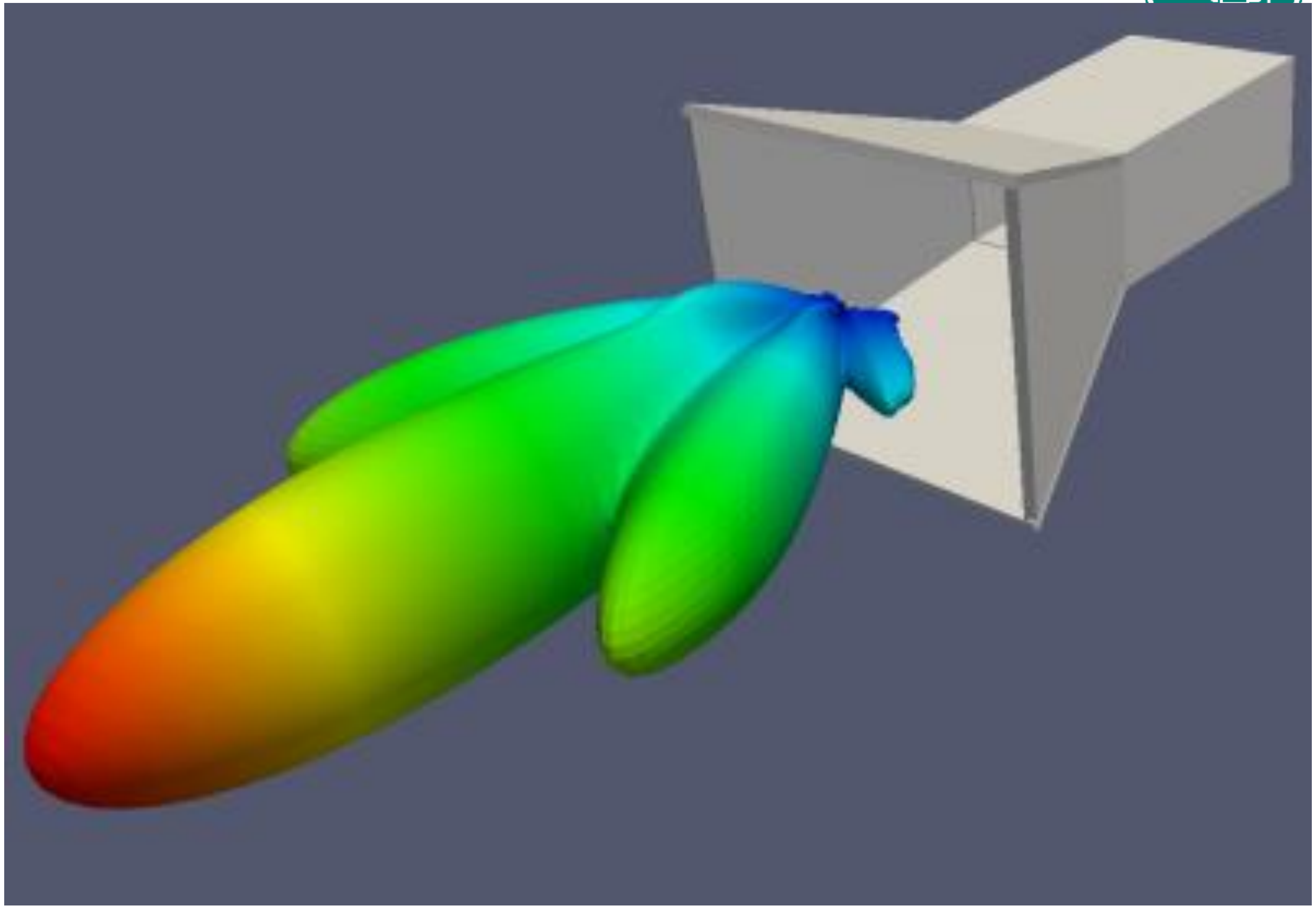
- Antenna consisting of metal sheets over a ground plane.
- Similar to dipole with gain of 6–9 dBi.
- Their easy fabrication using PCB techniques have made them popular in modern wireless devices.
- Often combined into arrays.



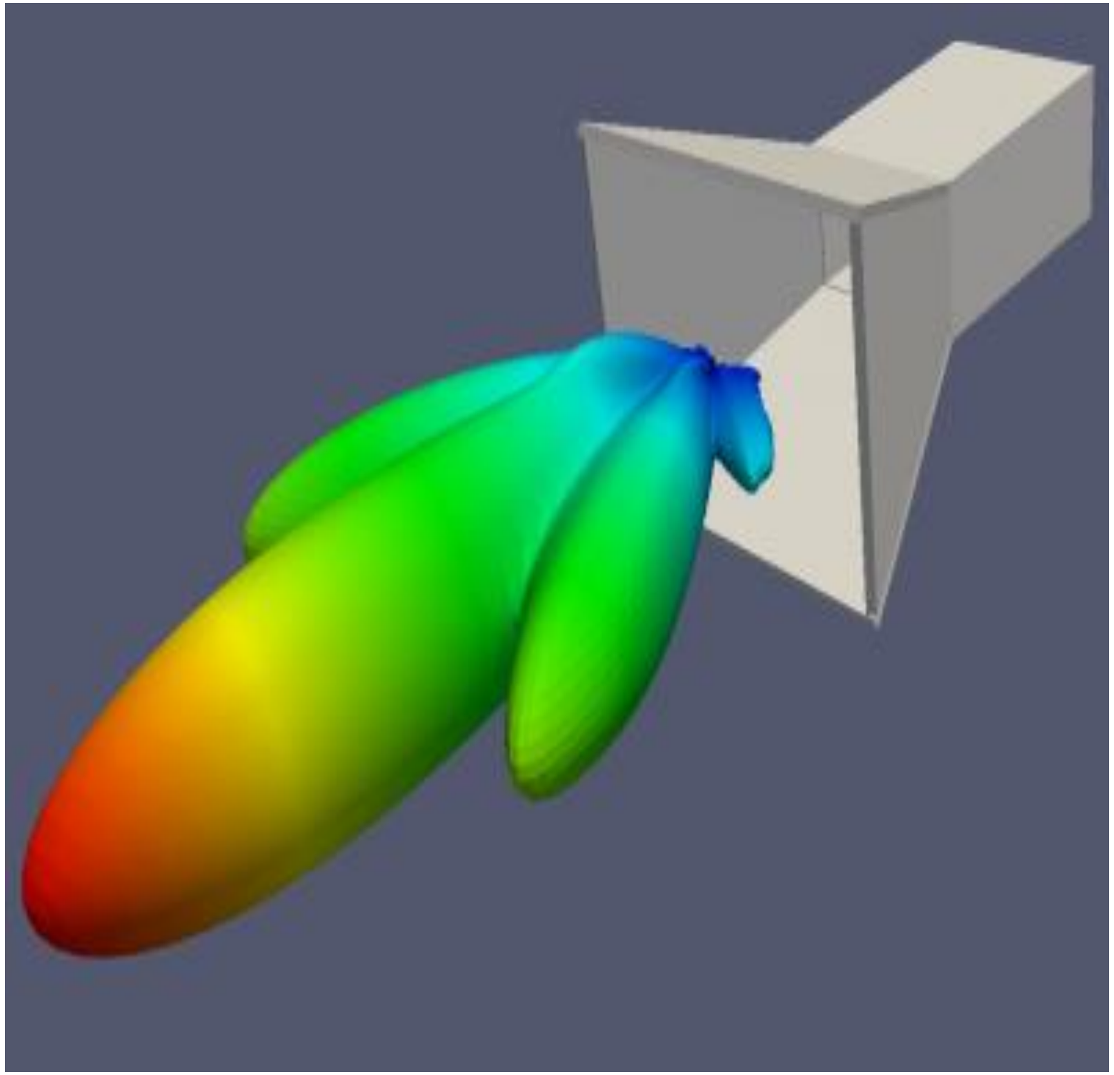


Agenda

- ▶ Antennas
  - – Types
  - – Specifications
- ▶ Chambers
- ▶ Measurements



Important Antenna Characteristics



- Antenna Parameters:
  - Frequency/ Bandwidth
  - Radiation Pattern
    - Side Lobe Levels
    - Beam Width
  - Directivity
  - Efficiency
  - Gain
  - Polarization

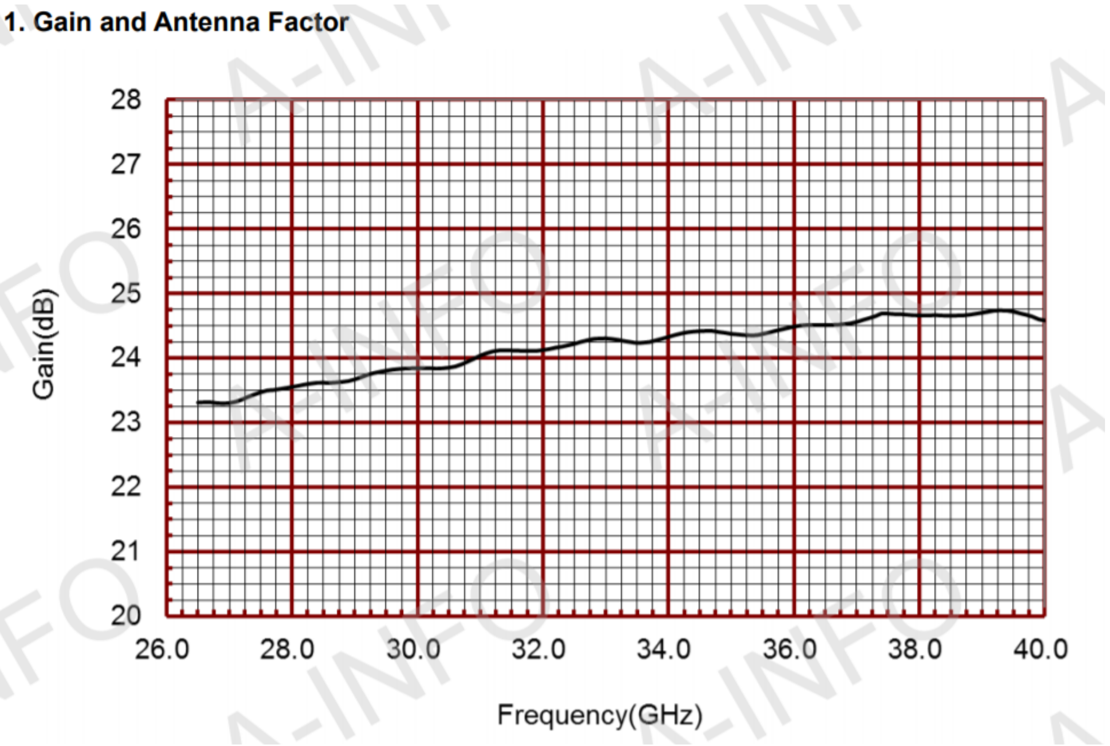
Frequency & Bandwidth

- Definition: BW; range of frequencies over which an antenna can properly transmit, or receive energy

- Voltage Standing Wave Ratio (VSWR) is a key factor in determining an antenna's BW

- Antennas can radiate outside of their defined bandwidth, but performance can drop significantly.

- Pattern shape typically has minimal change when operating within the antenna's BW.

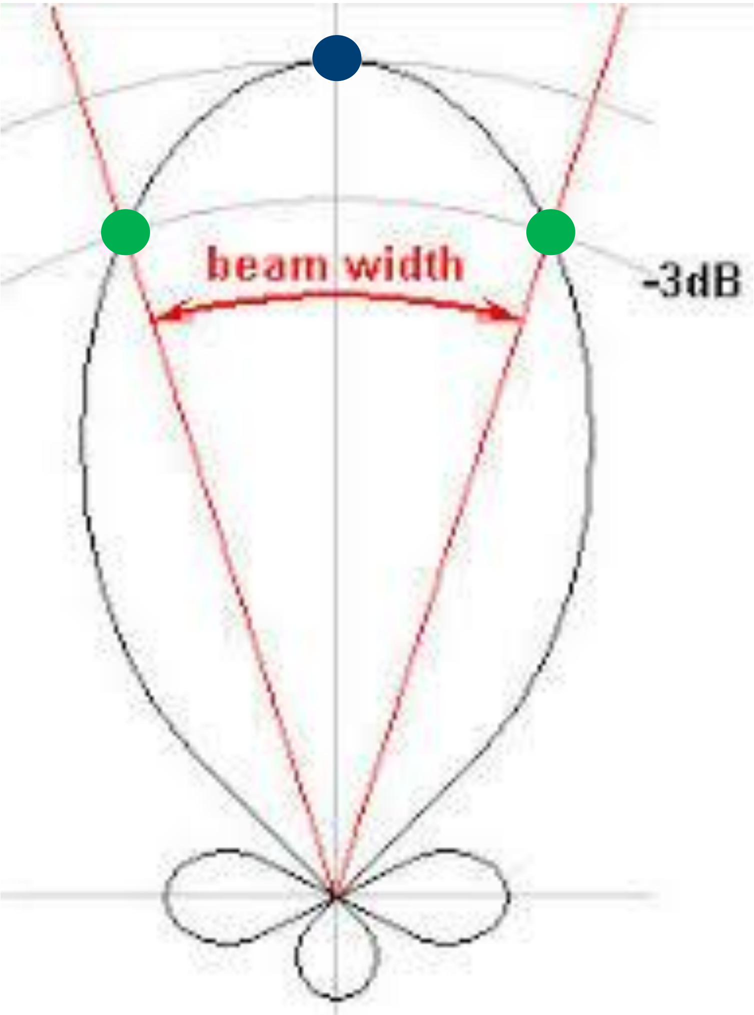


Main Lobe Beam Width

Half-Power Beam Width or 3 dB Beam Width

Definition: HPBW=k*$\frac{\lambda}{d}$; angular separation in which the radiated power is reduced by half from the main beam.

- k is a factor (in degrees) that depends on shape of the antenna aperture
- λ: wavelength, c/frequency
- d: antenna aperture, meters



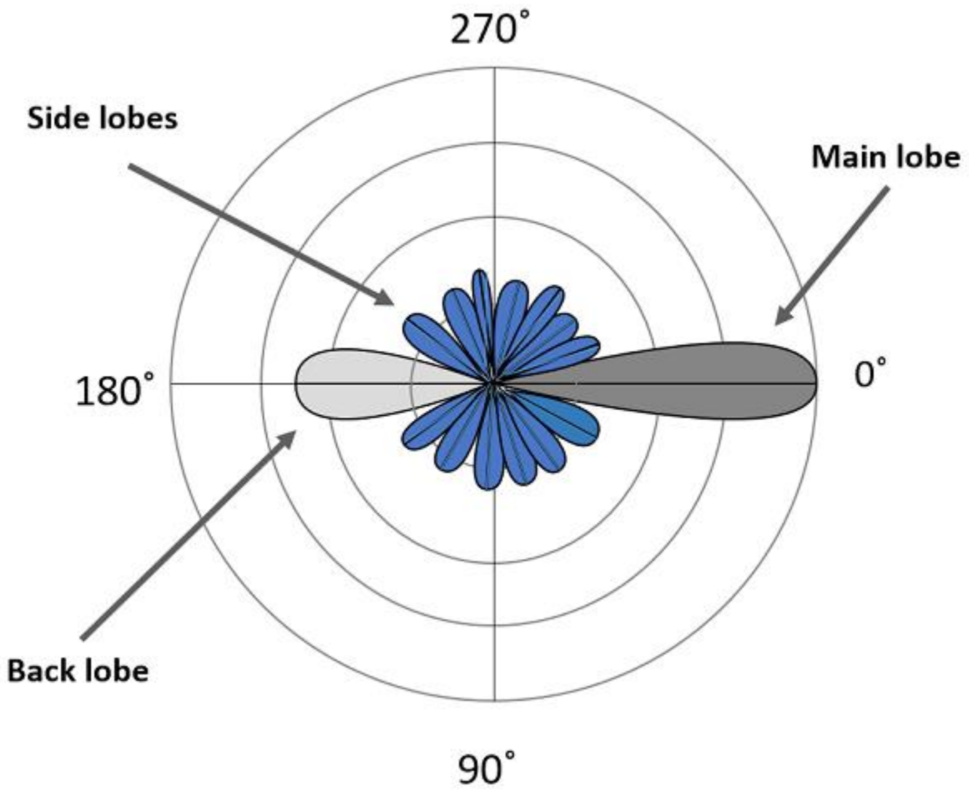
Sidelobe Level

Sidelobes

- ► Generally smaller, unwanted beams in some direction away from the main beam.
- ► Sidelobes cannot always be eliminated.

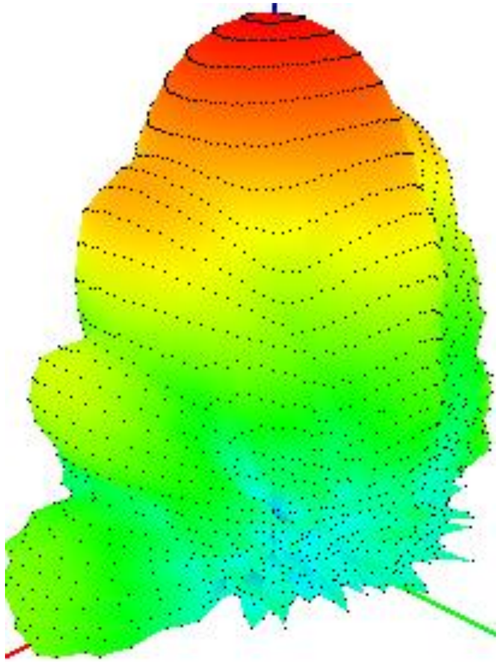
Definition: SLL= $\frac{|\max value\ of\ side\ lobe|}{|\max value\ of\ main\ lobe|}$;

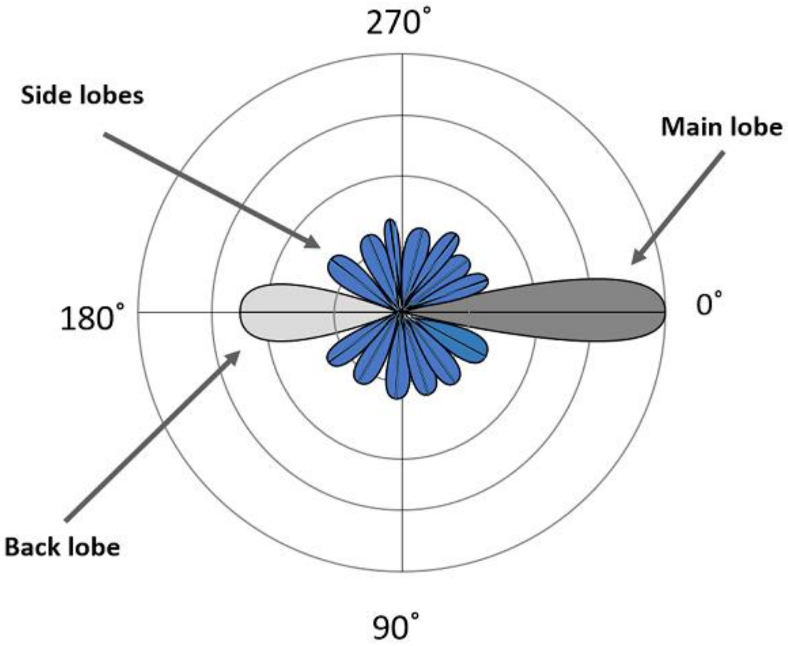
- ► maximum value of the sidelobes with respect to the main lobe



Source: https://en.wikipedia.org/wiki/Main_lobe

Radiation Pattern





- Definition: F(θ,ϕ); angular variation of radiation
- Radiation pattern is essentially a map of the measured power (either transmit or receive)
- Pattern shows: main, side, and back lobes
- Can be plotted in 2D and 3D coordinate systems

Source: https://en.wikipedia.org/wiki/Main_lobe

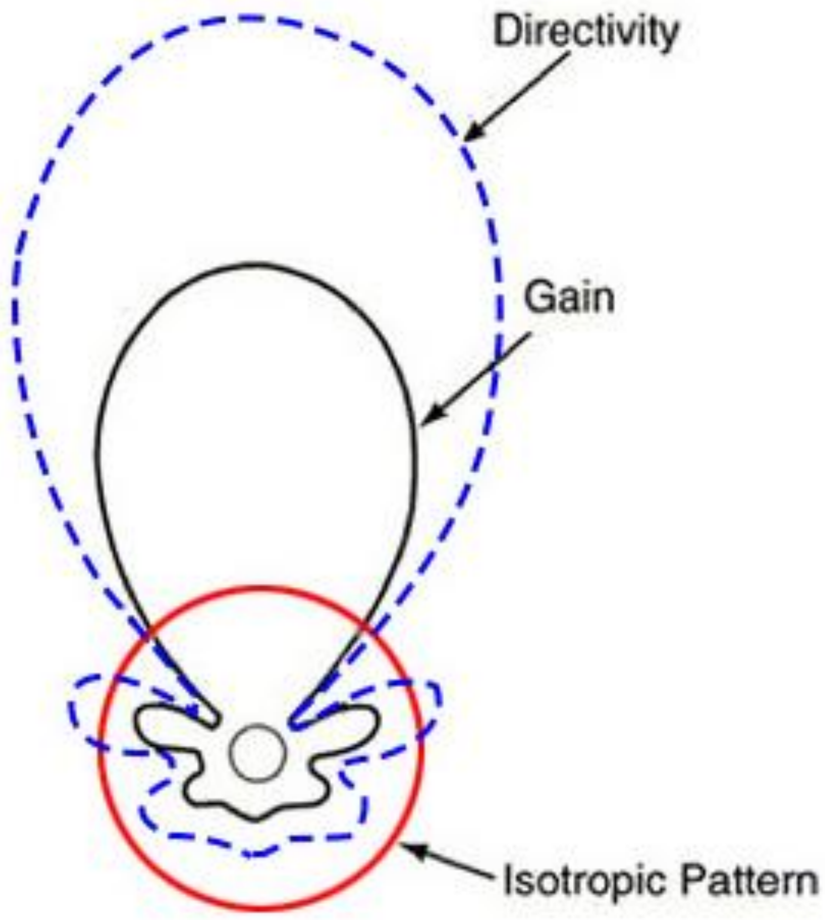
Directivity

- Definition: $D = \frac{P(\theta,\phi)_{max}}{P(\theta,\phi)_{av}}$; ratio of power density in direction of max power

- Directivity is a quantity that defines the antenna's ability to concentrate power in a given direction.

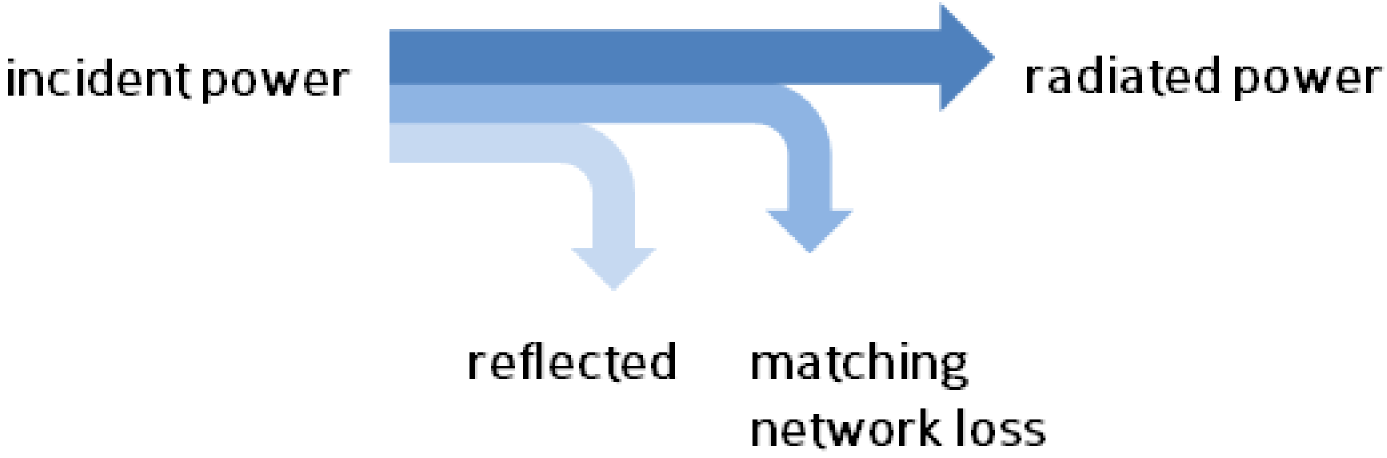
- A characteristic of the radiation pattern for an ideal (lossless) antenna.

- Typically, when dealing with directivity, we are concerned with the D_{MAX} (i.e. in the direction of maximum directivity).



Source: https://www.everythingrf.com/community/what-is-antenna-directivity

Efficiency



- ► Ideal antennas have no ohmic losses.
- ► Real antennas inherently have reflected power and mismatches
- ► Radiated power < input power.

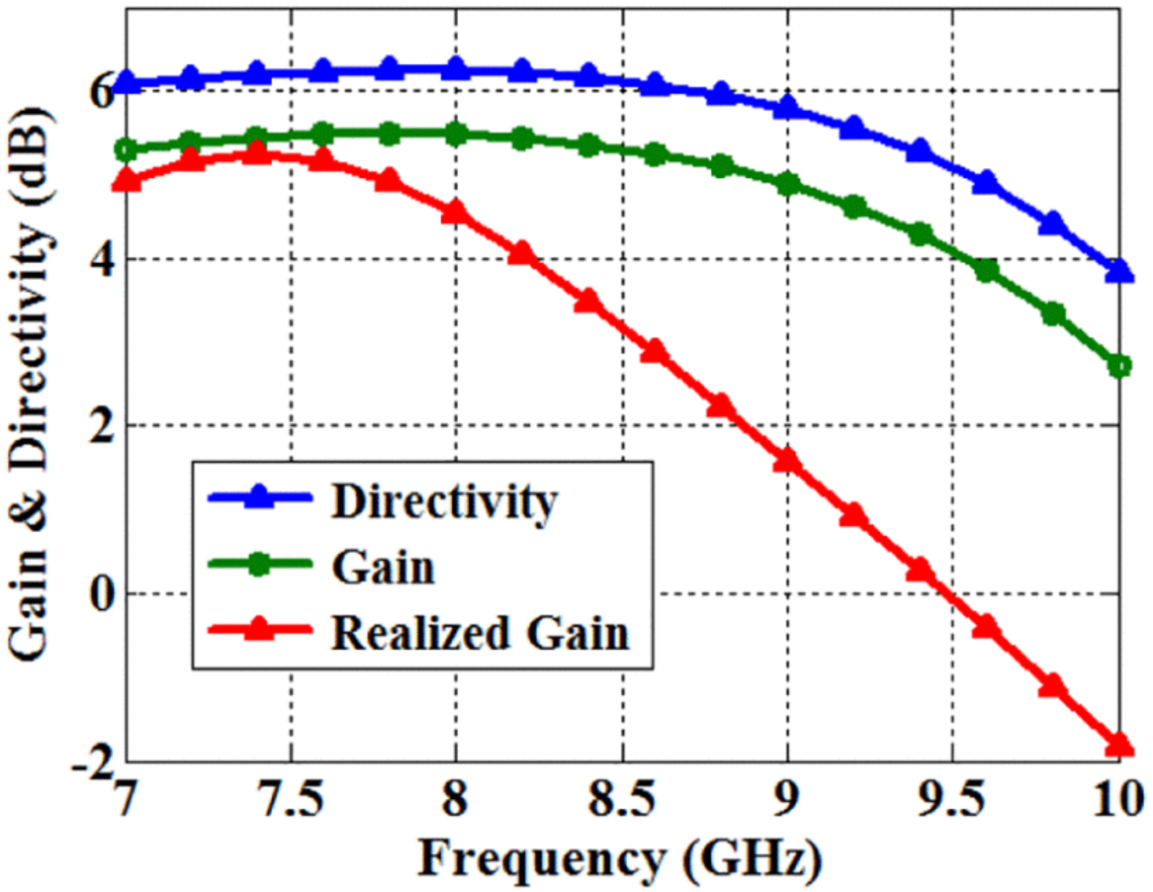
- ► Definition: $\varepsilon = \frac{P_{Out}}{P_{In}}$; ratio of output power to input power

Antenna Gain

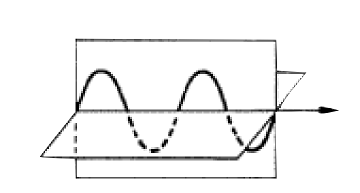
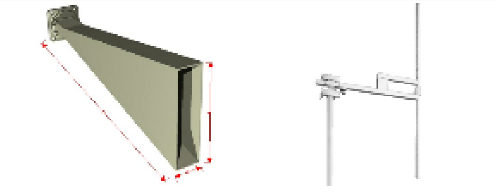
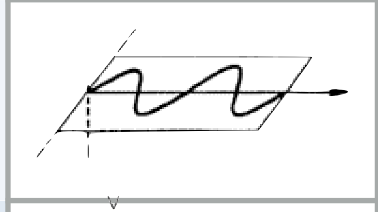
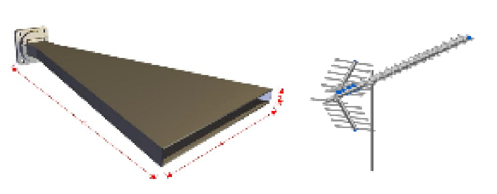
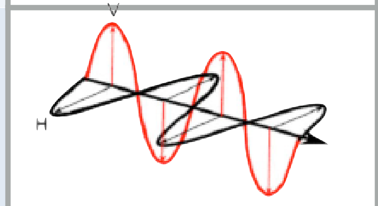
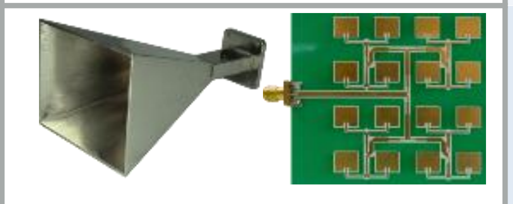
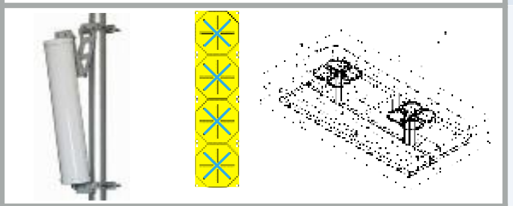
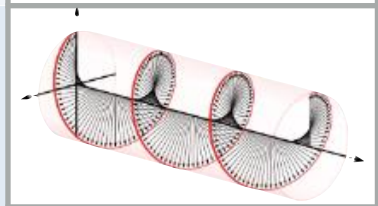
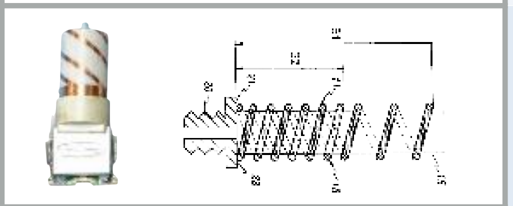
IEEE Gain
- Antenna Efficiency

Realized Gain
- Antenna Efficiency + Mismatch (S11)

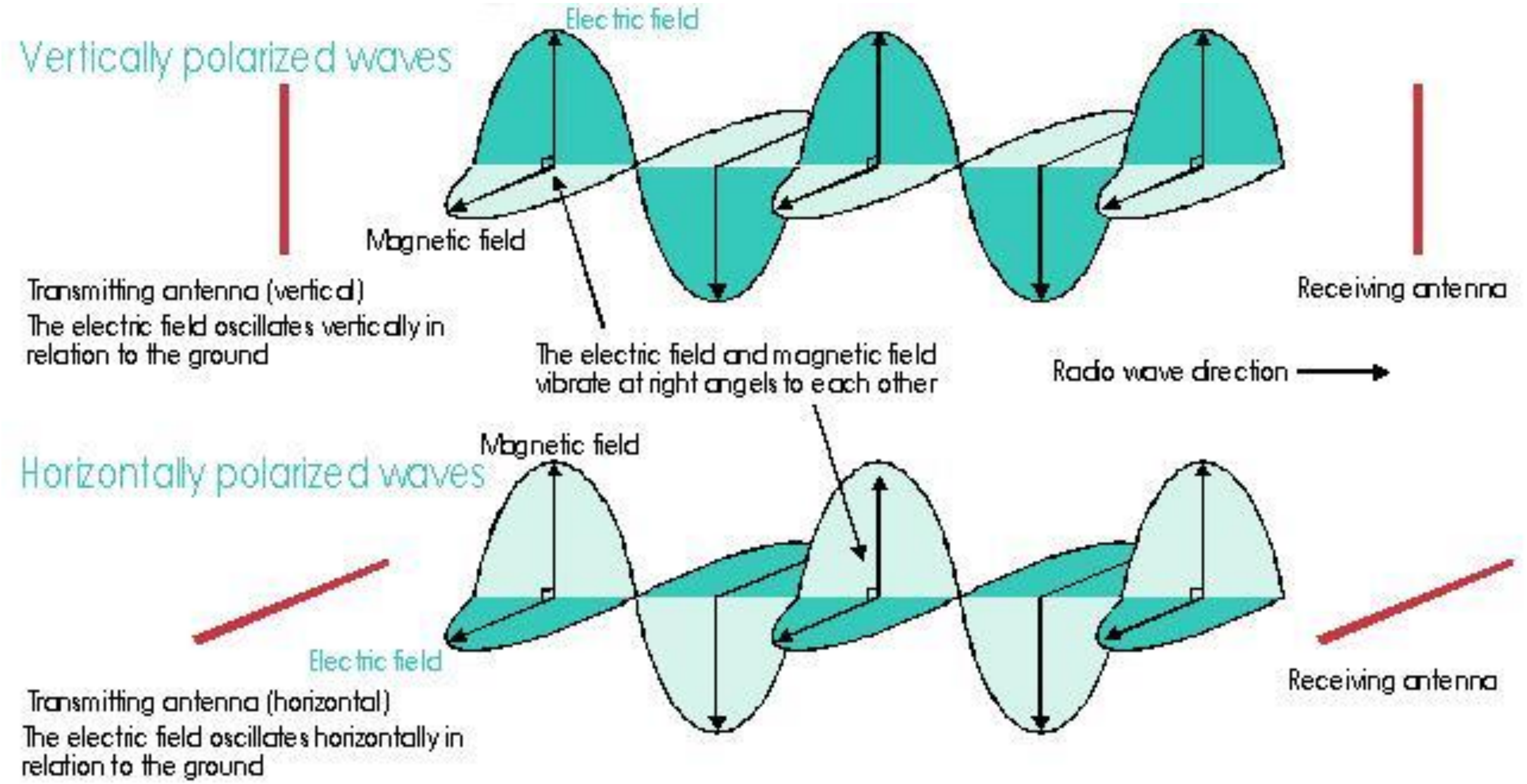
Realized Gain < IEEE Gain



Antenna Polarization

Polarization	Antenna	EM Wave	Examples	Notes
Vertical	*Dipoles, Monopoles, Horns*			*Used for early wireless communications (paging) and radio*
Horizontal	*Dipoles, Monopoles, Horns*			*Used mostly for yagi antennas (television)*
Dual (V+H)	*Horn, reflectors, patches*			*Combine two polarizations in one antenna*
Co/Cross	*Dipoles, Patches*			*Used for wireless basestations since reduces cancellation due to ground and buildings*
Circularly	*Helixes, Patches*			*Used for satellite to ground applications since CP can penetrate atmosphere*

Antenna Polarization

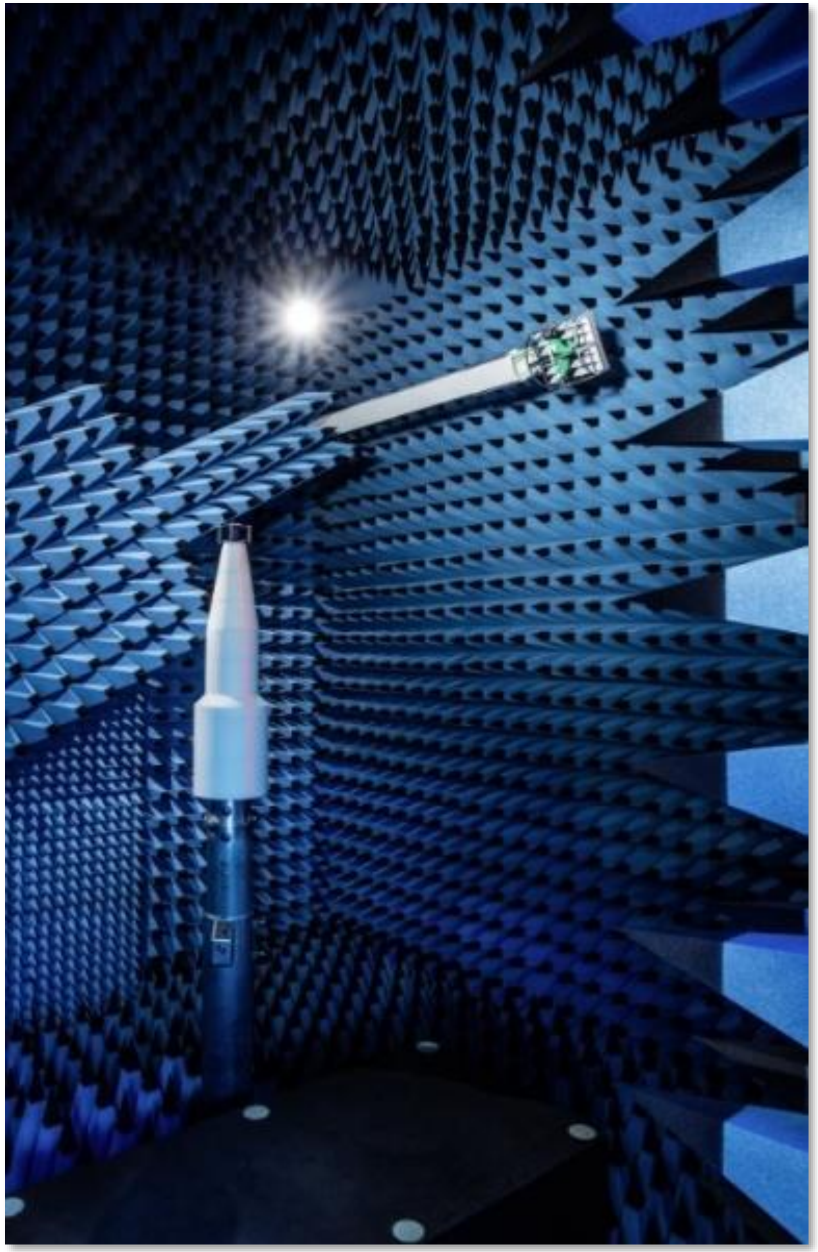


Source: https://www.cdt-up.eng.cam.ac.uk/

COMPANY RESTRICTED

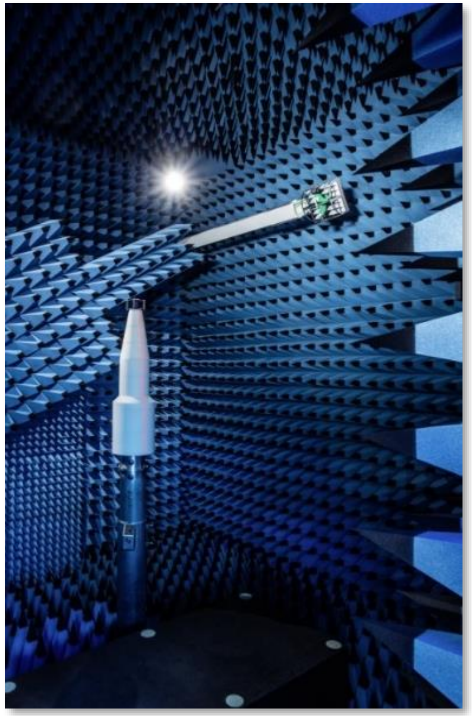
Agenda

- ► Antennas
- ► Chambers
- ► Measurements



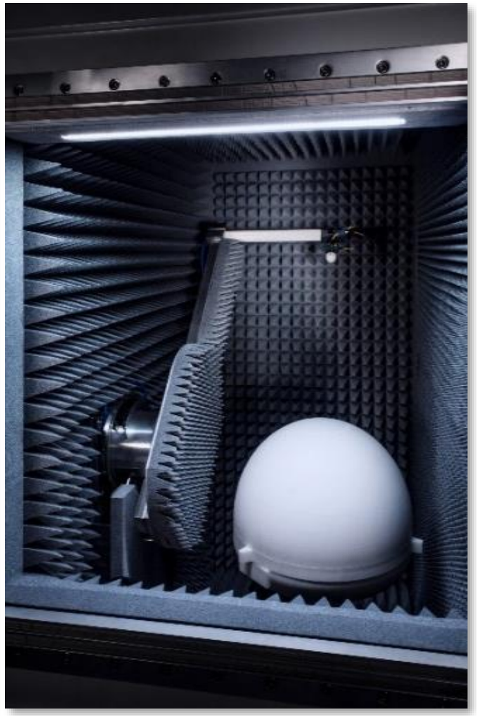
5G OTA range – mmW capable solutions

UE & BS R&D
- Most broadband
- Highest flexibility



WPTC

FR2 chip and antenna R&D
- Fast, accurate, compact
- 3-D thermal testing

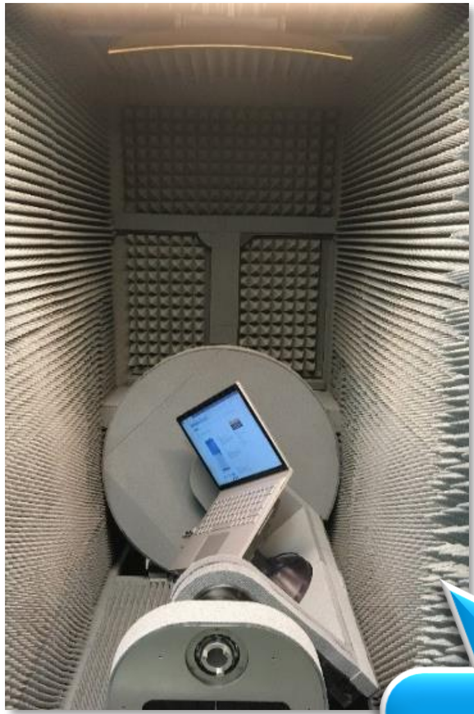


ATS1000

FR2 UE / small cells R&D
- 20 cm QZ
- Cost efficient

ATS800B/R

FR2 UE / small cells compliance
- 30 cm QZ
- RFCT, RRM



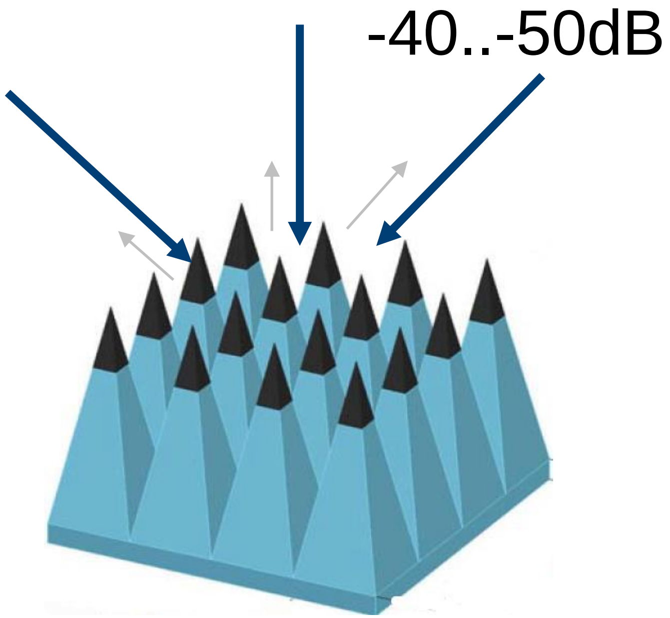
ATS1800C

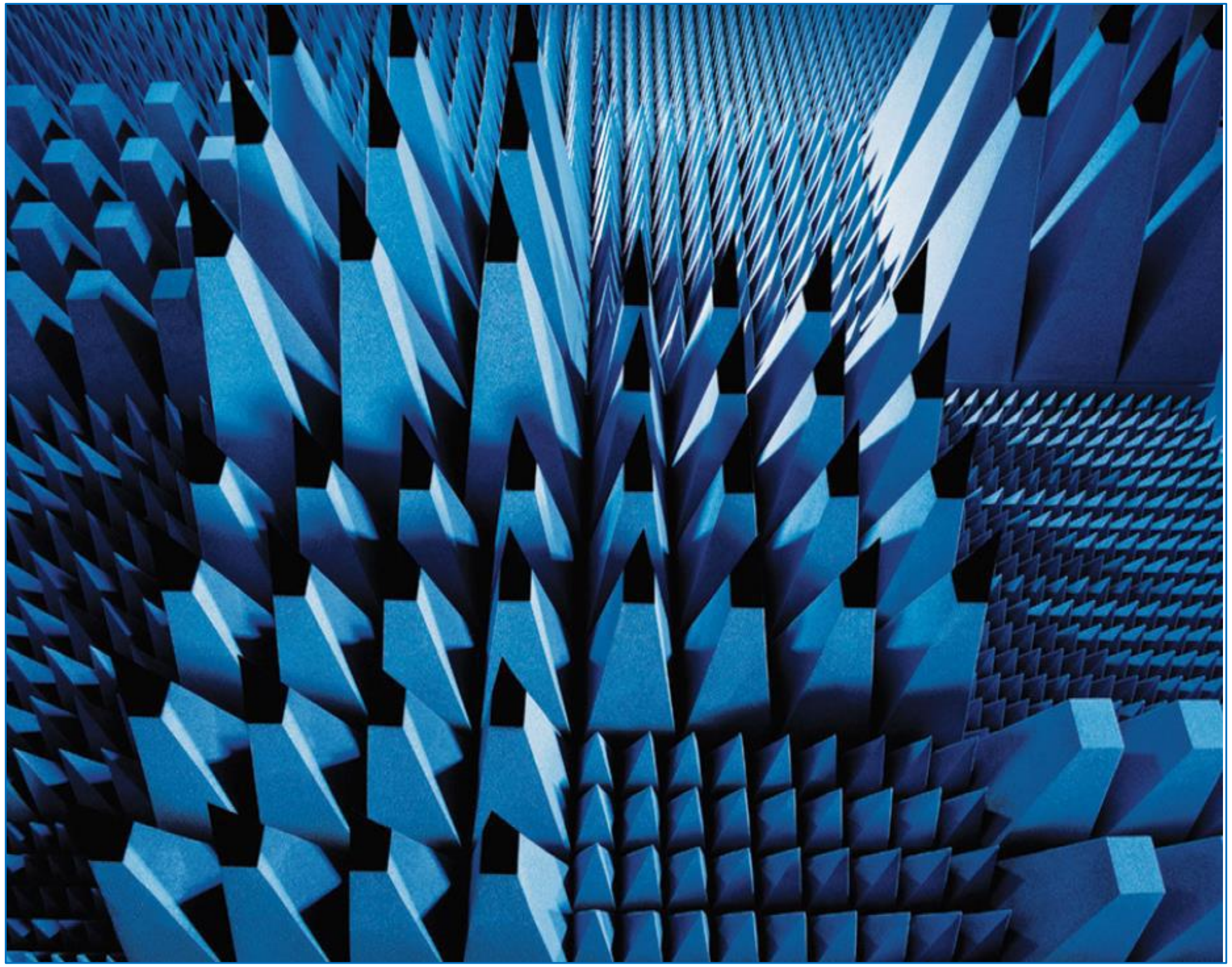
UE / small cells prod. / benchtop
- Flexible test capability
- Can be rack-integrated

Which do I choose?

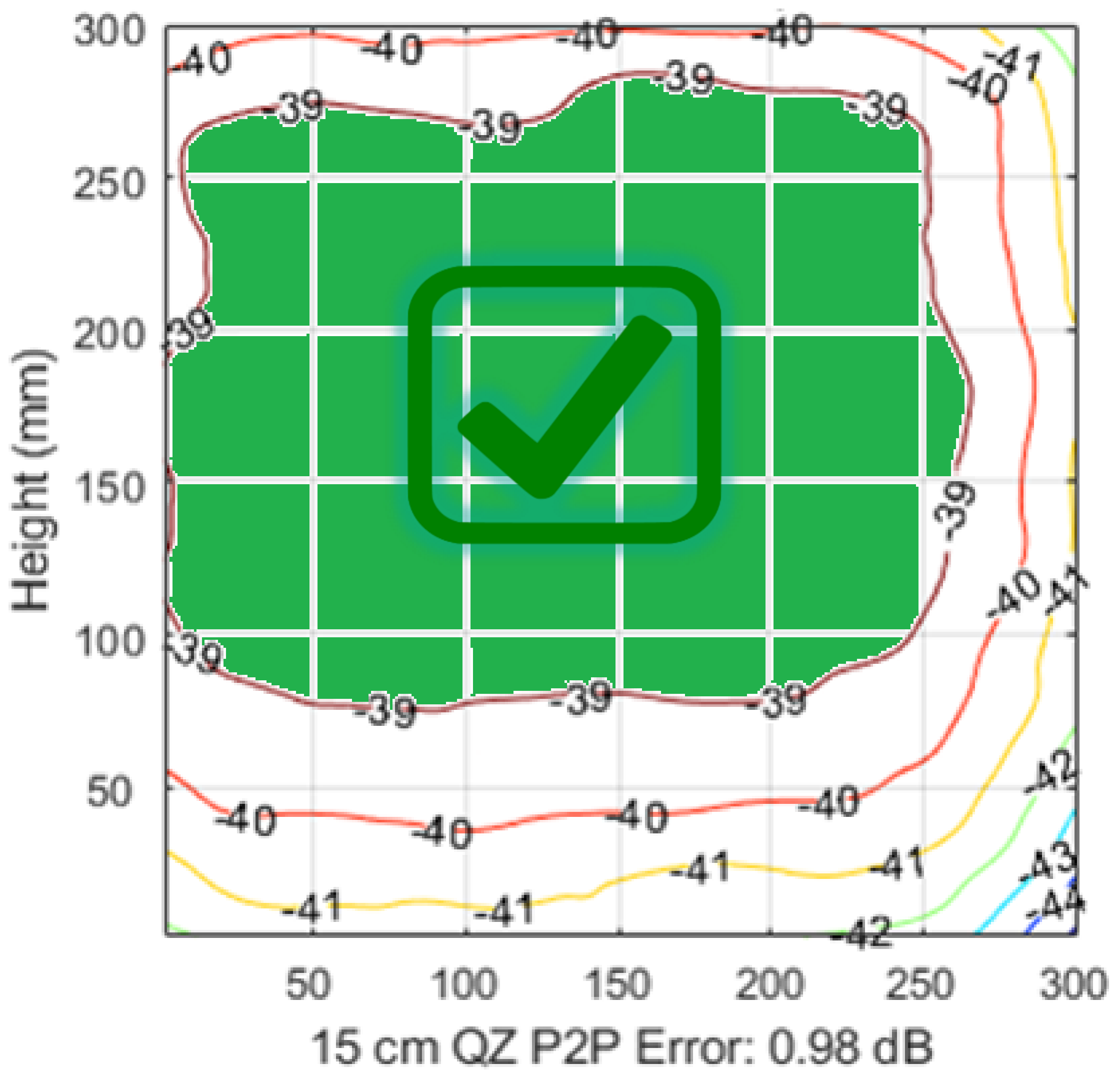
Pyramidal Absorbers

- Carbon loaded
- Made of urethane foam
- Highest absorption for normal incidence





Quiet Zone Measurement

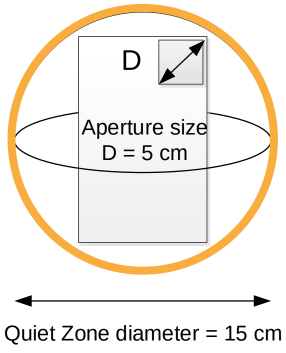


Quiet Zone: UE antenna configurations

Most important Configuration = for Smartphones

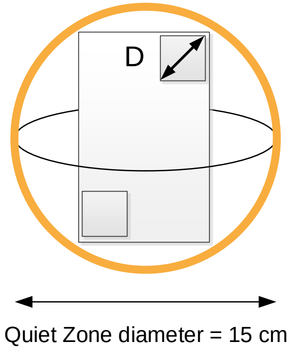
UE antenna config. 1

Single aperture, D = 5 cm



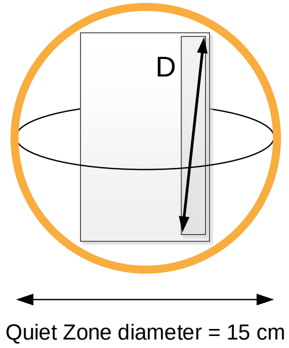
UE antenna config. 2

Multiple, non-coherent apertures, D = 5 cm



UE antenna config. 3

Larger apertures, D = 15 cm

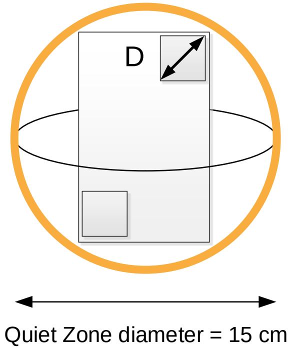


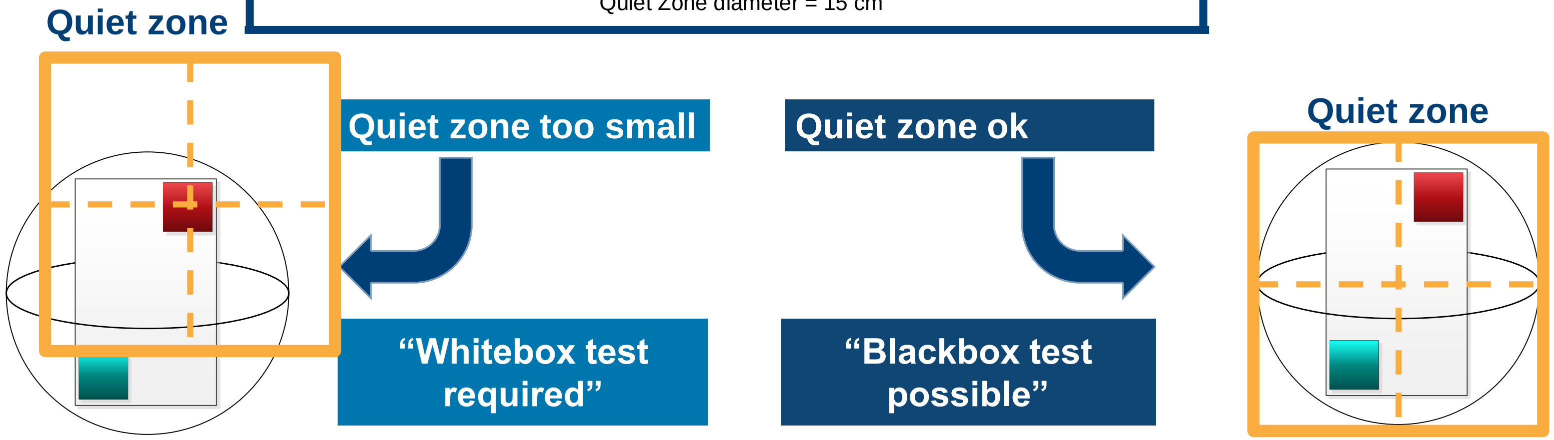
Quiet Zone: UE antenna configurations

Most important Configuration = for Smartphones

UE antenna config. 2

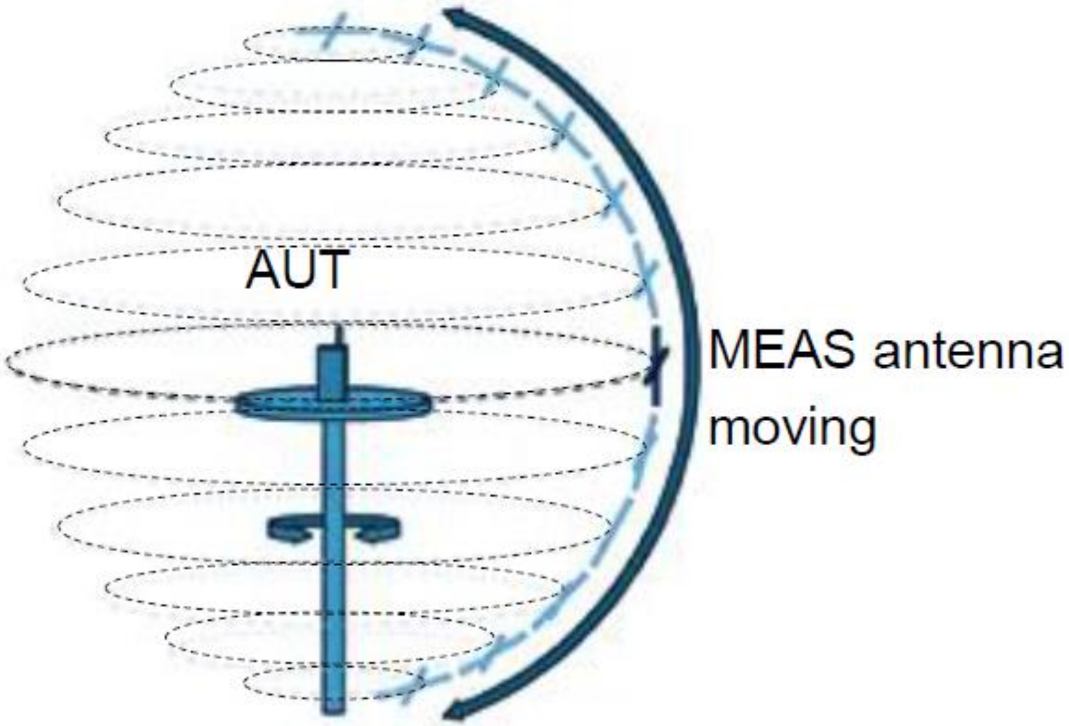
Multiple, non-coherent apertures, D = 5 cm



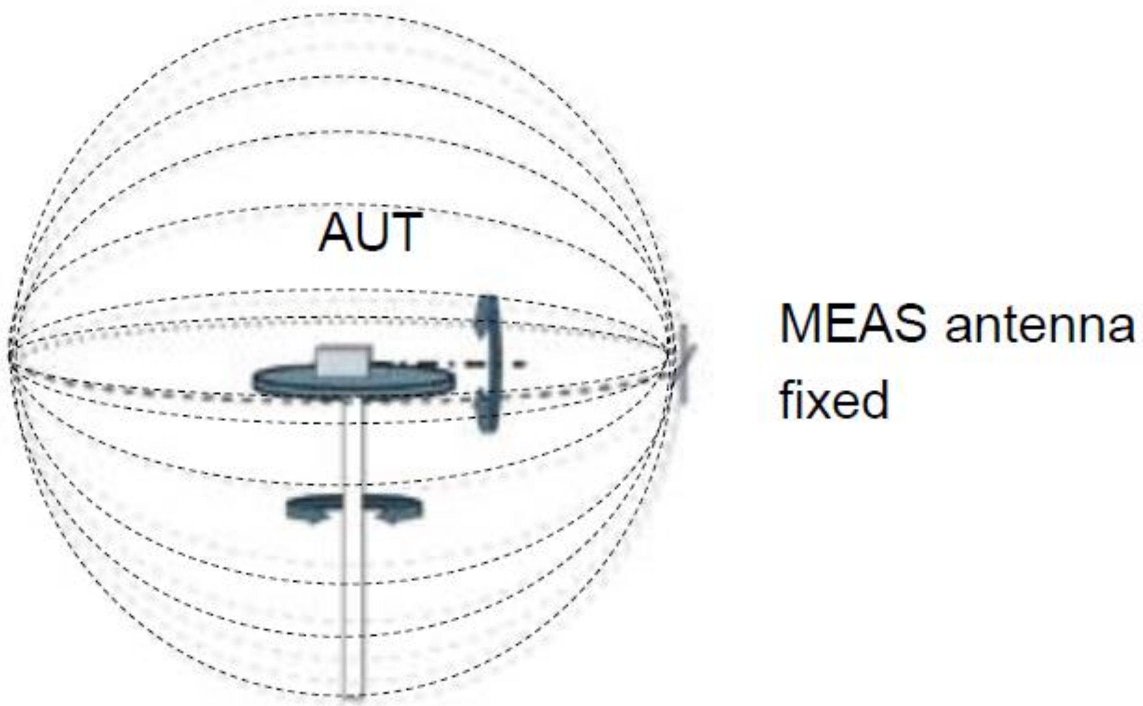


OTA Chamber Positioners: 3D Pattern

Conical cut = distributed axis

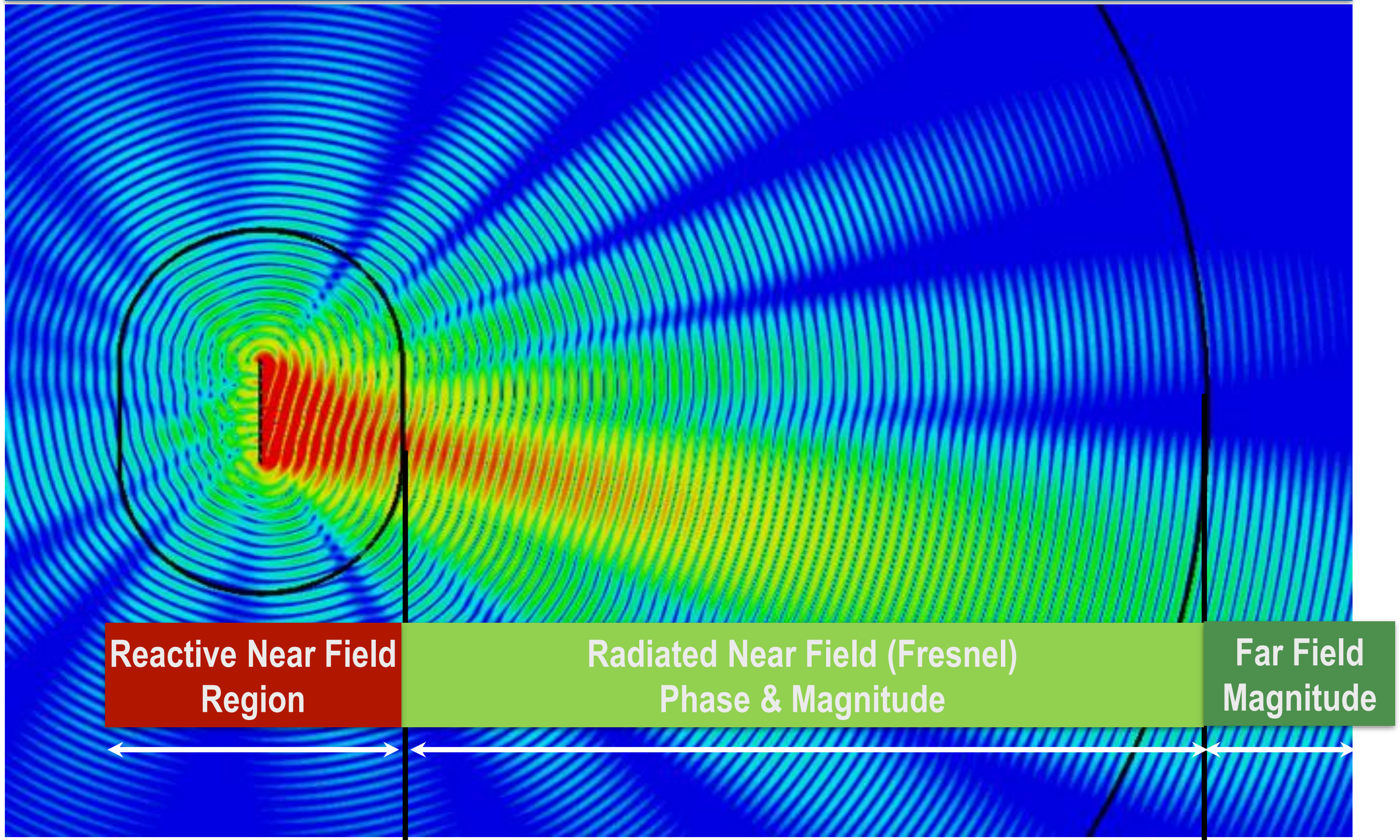


Great-circle cut = combined axis



Electromagnetic Fields: Near or Far?

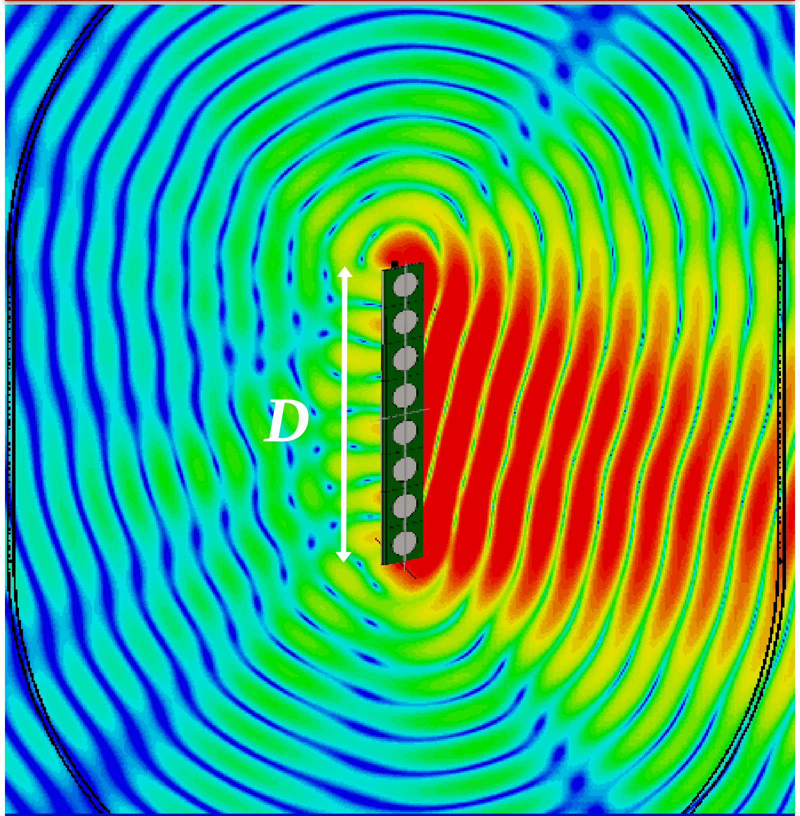
8 Element Antenna Array



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

$$R_{FF} = 2D^2/\lambda$$

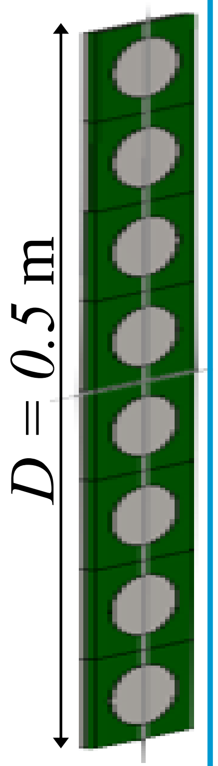
Reactive Near Field Region



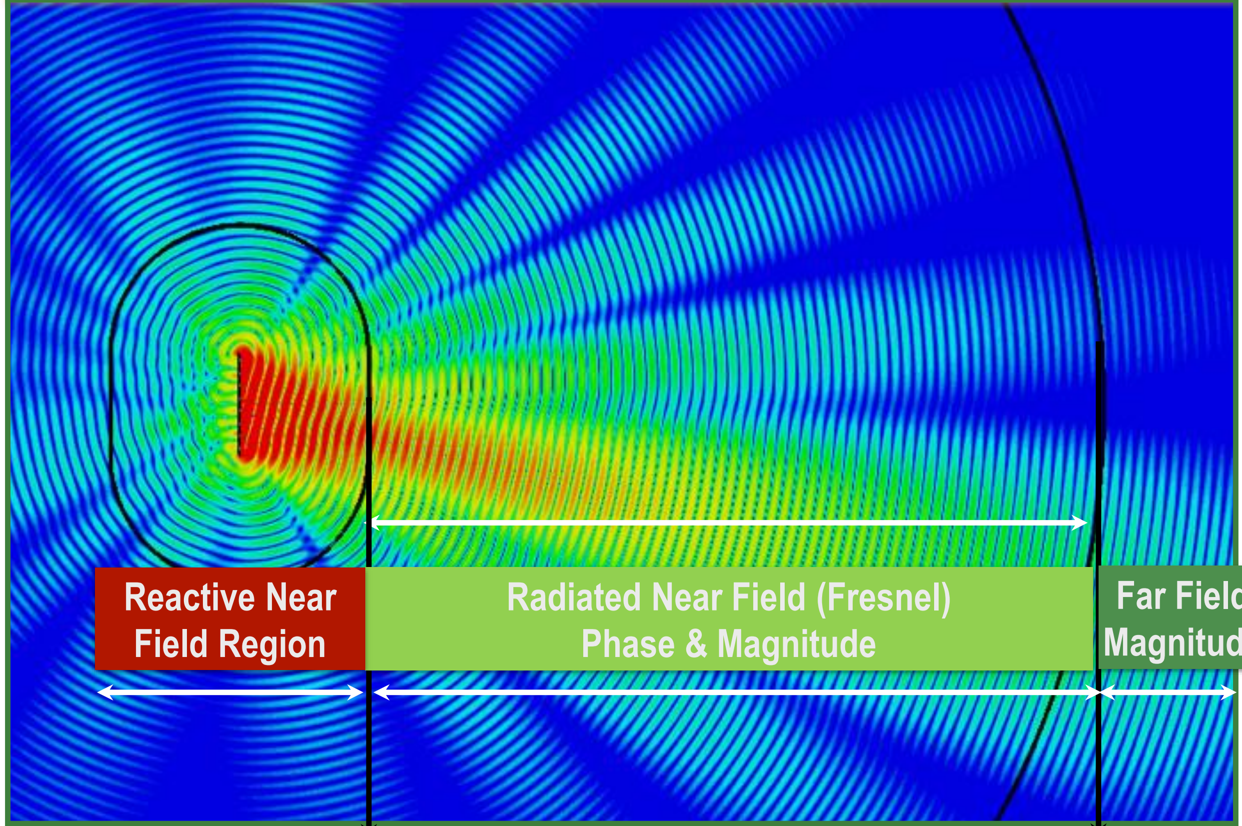
Any object in this region becomes part of antenna system & interferes with the measurements

Field Regions

AUT



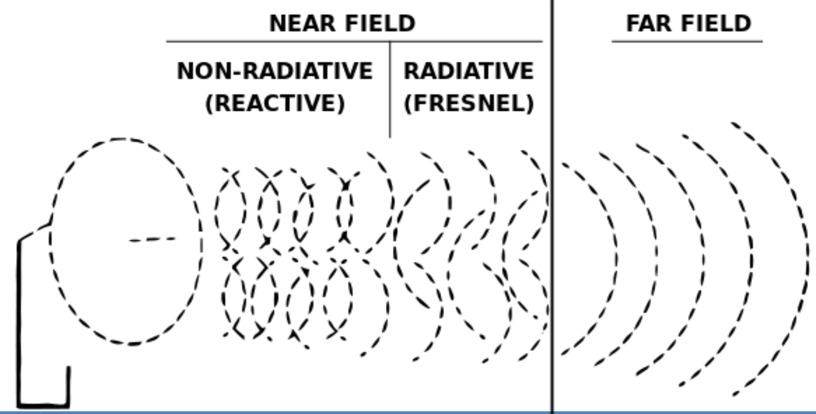
8 Element Antenna Array at 2.69 GHz



$$0.62\sqrt{D^3/\lambda} = 0.6 \text{ m}$$

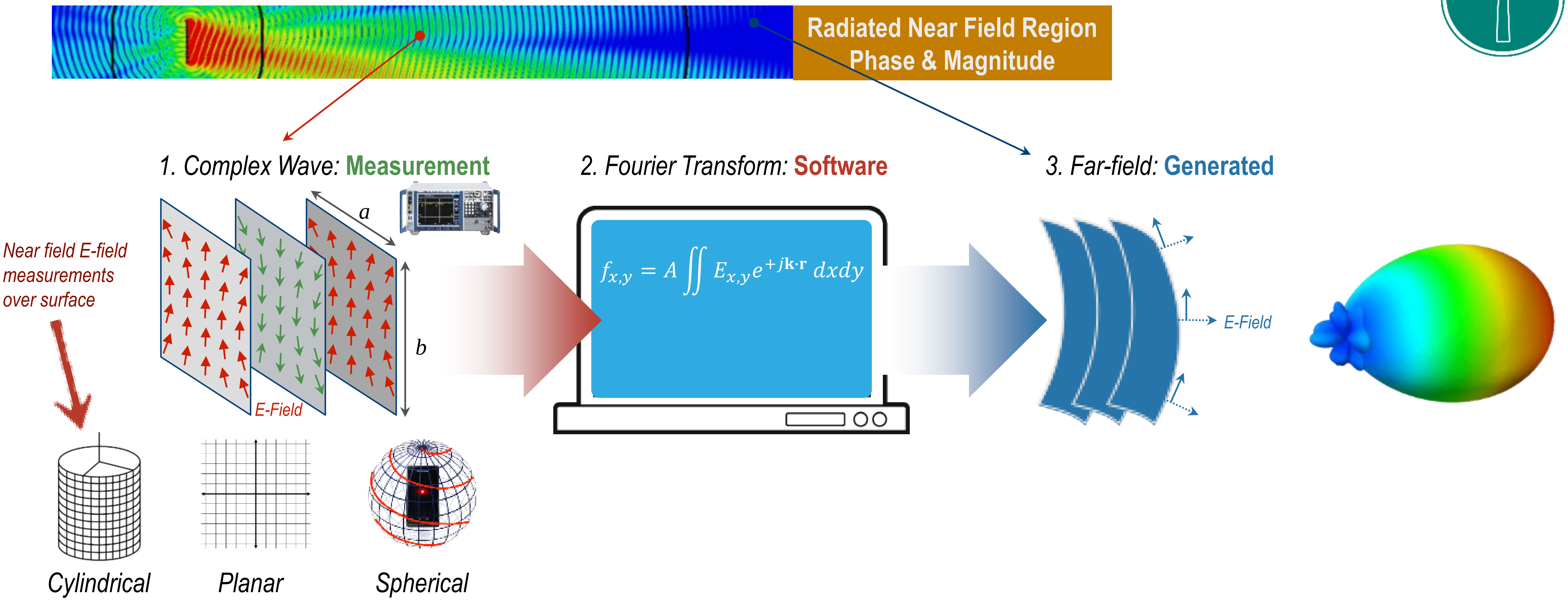
$$2D^2/\lambda = 4.1 \text{ m}$$

Far Field Plane Wave Generation

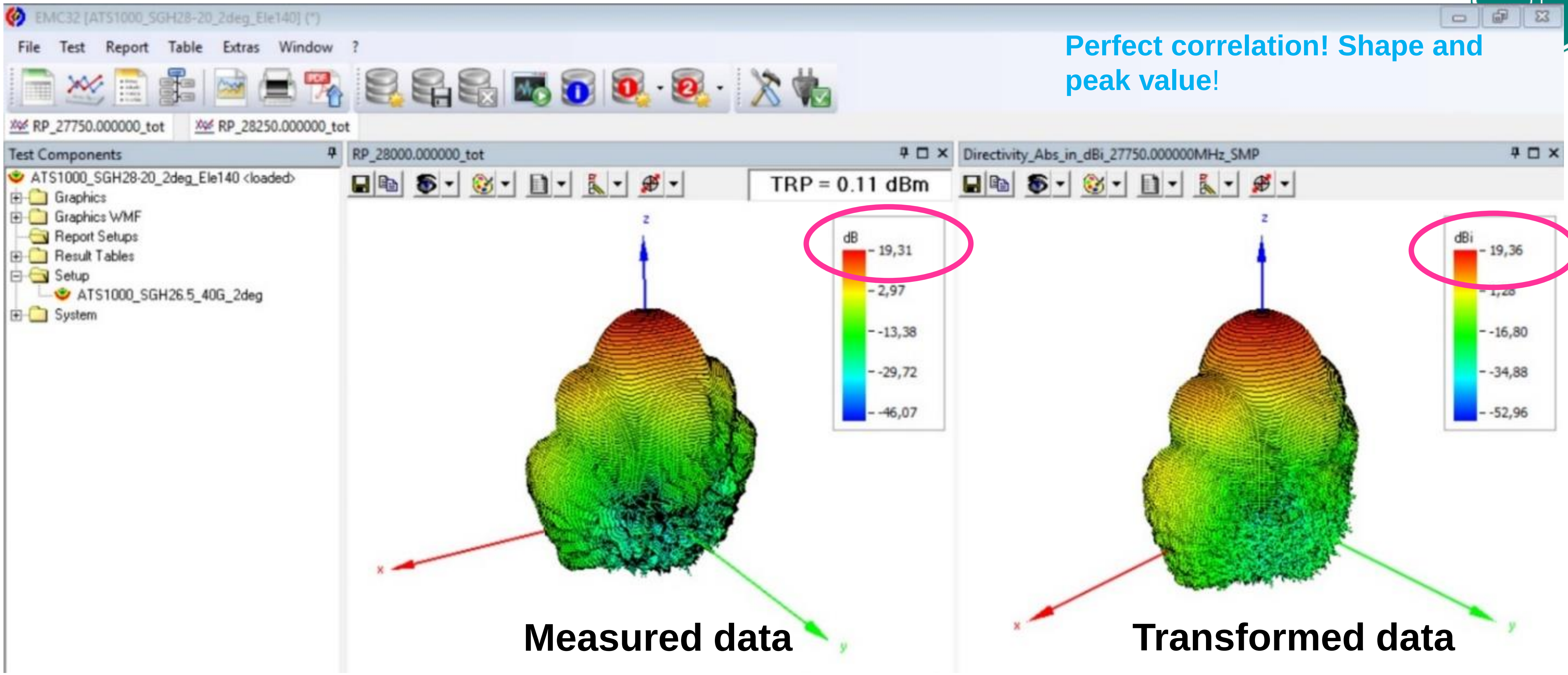


Required Chamber Size		
AUT Size	Frequency (c/λ)	FF Chamber Size
0.5 meters	*6 GHz*	*10 meters*
0.5 meters	*30 GHz*	*50 meters*
1.0 meter	*6 GHz*	*40 meters*

Near Field to Far Field Transform Steps



NF vs FF Transformation



Perfect correlation! Shape and peak value!

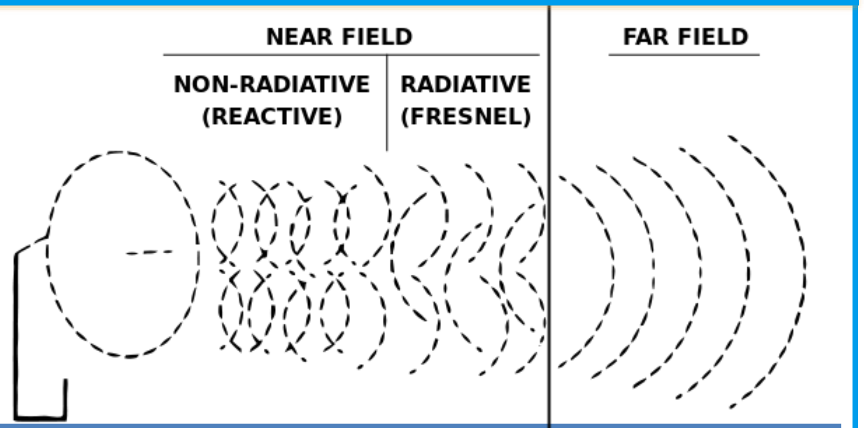
Measured data

Transformed data

ROHDE&SCHWARZ

Still in Near field?

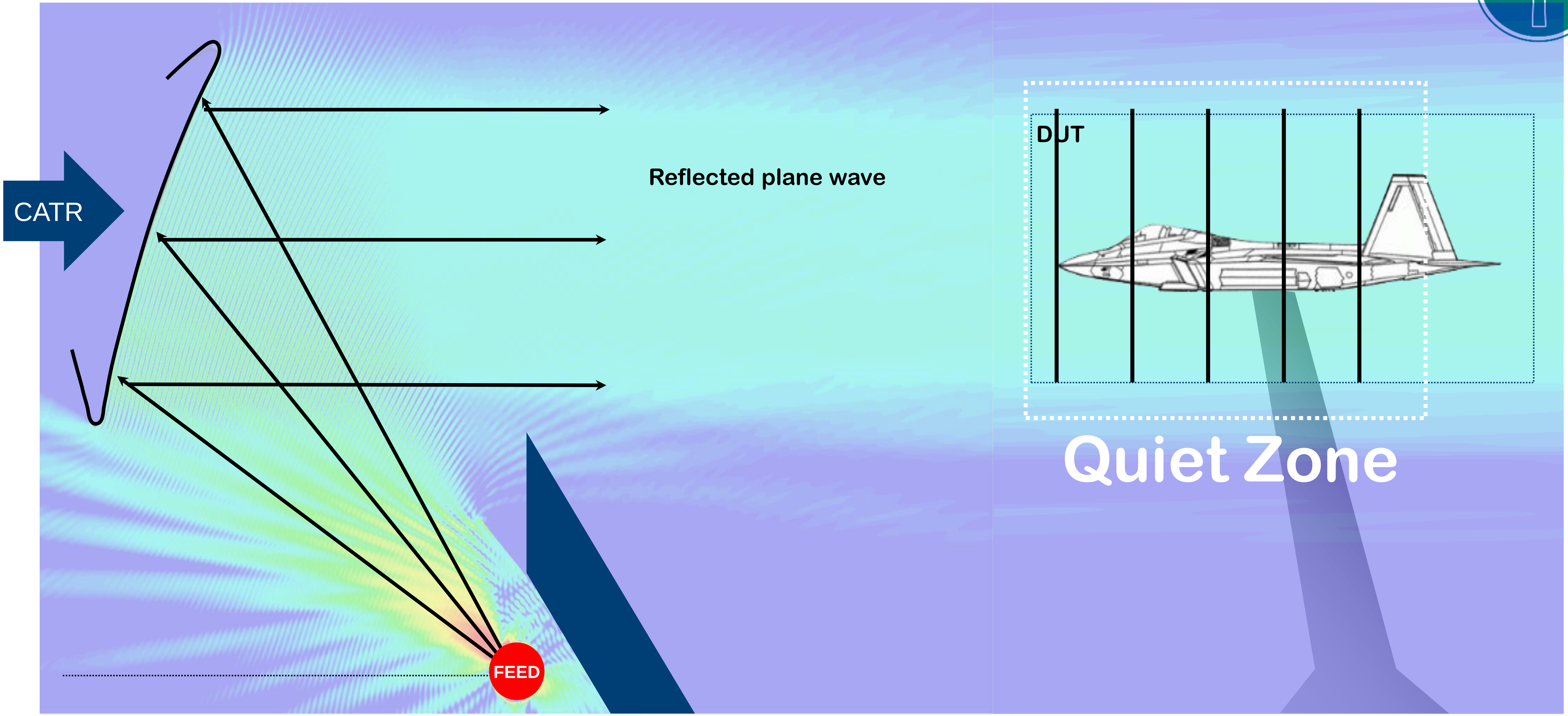
Far Field Plane Wave Generation



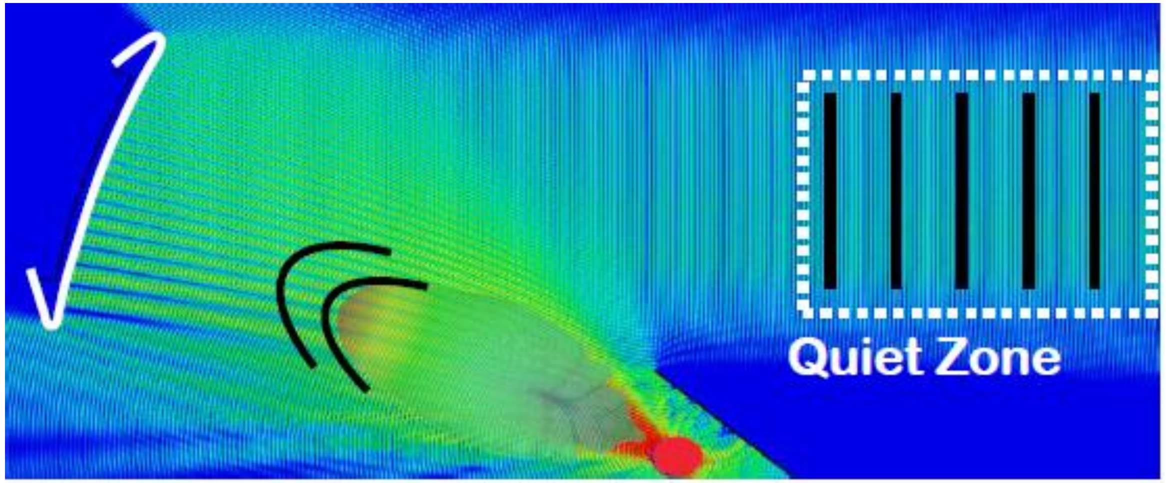
Required Chamber Size		
AUT Size	Frequency (c/λ)	FF Chamber Size
0.5 meters	*6 GHz*	*10 meters*
0.5 meters	*30 GHz*	*50 meters*
1.0 meter	*6 GHz*	*[illegible]ters*

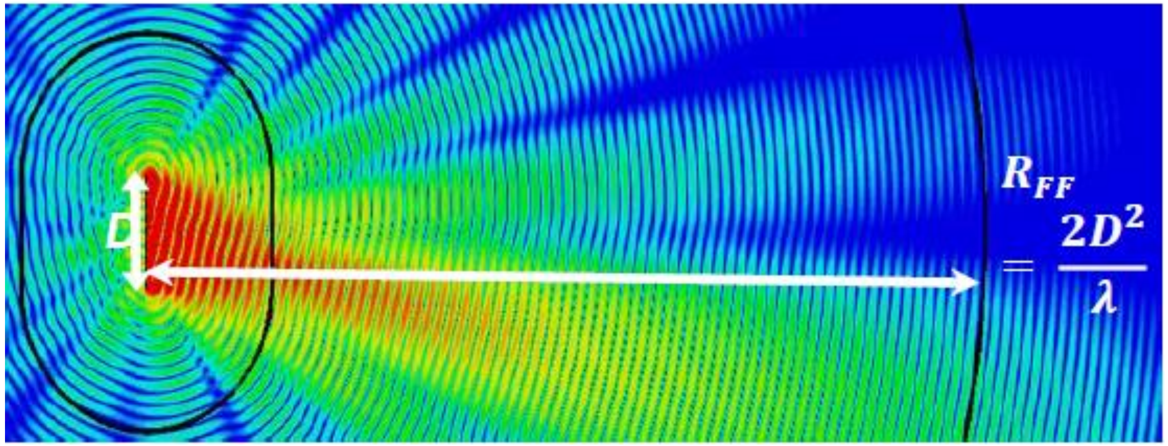
- Move farther
- Or....CATR

Compact Antenna Test Range, CATR?



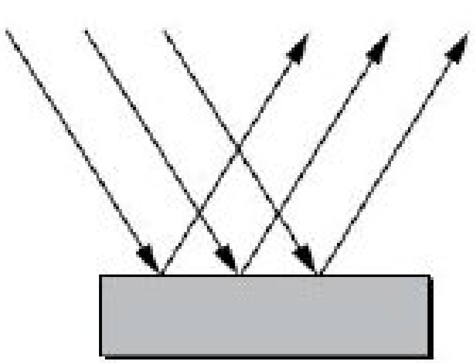
Direct Far Field (DFF) vs CATR Comparison

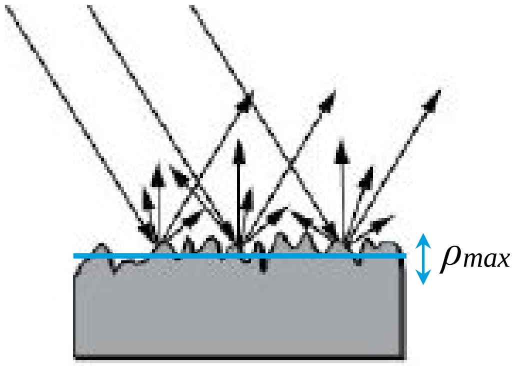




28GHz 20cm Quiet Zone	DFF	CATR
Distance feed to reflector	-	0.7 m
Distance to AUT	7.5 m	1.2 m
Path loss	79 dB	58 dB
Length of cables	> 8 m	~ 2 m
Cable loss	> 20 dB	~ 5 dB
Size/cost of chamber	**high**	**moderate**

CATR reflector errors (2): surface roughness

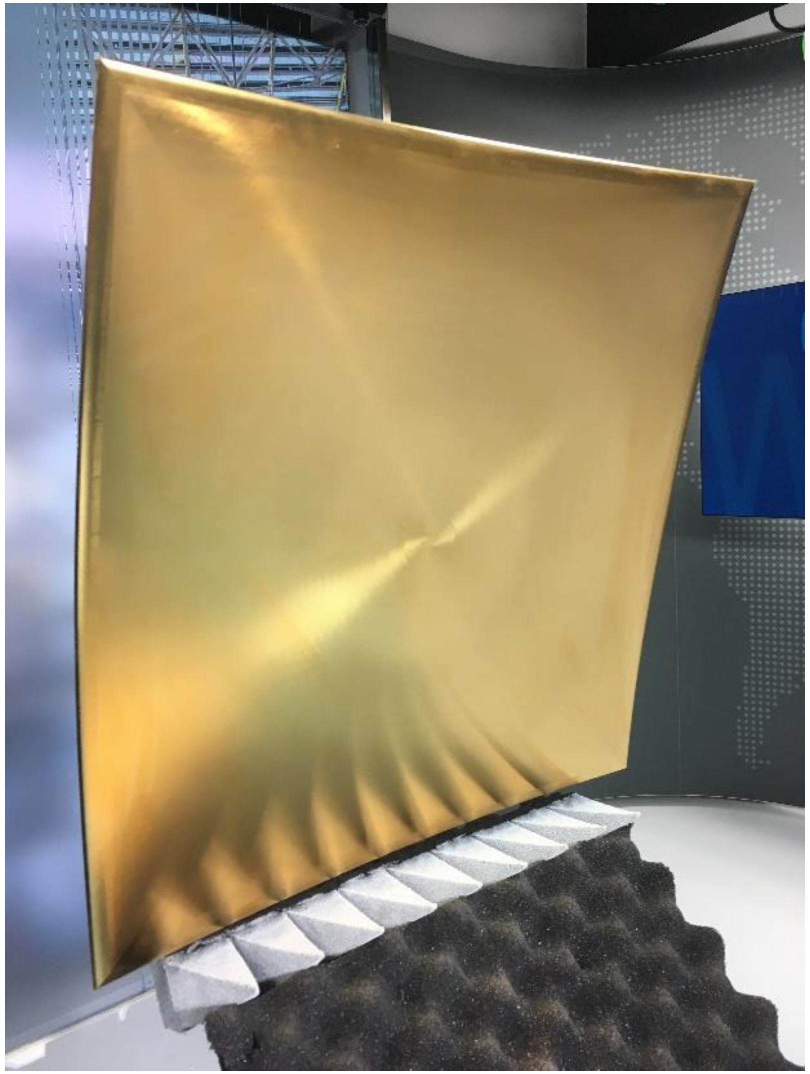




Maximum Surface Deviation

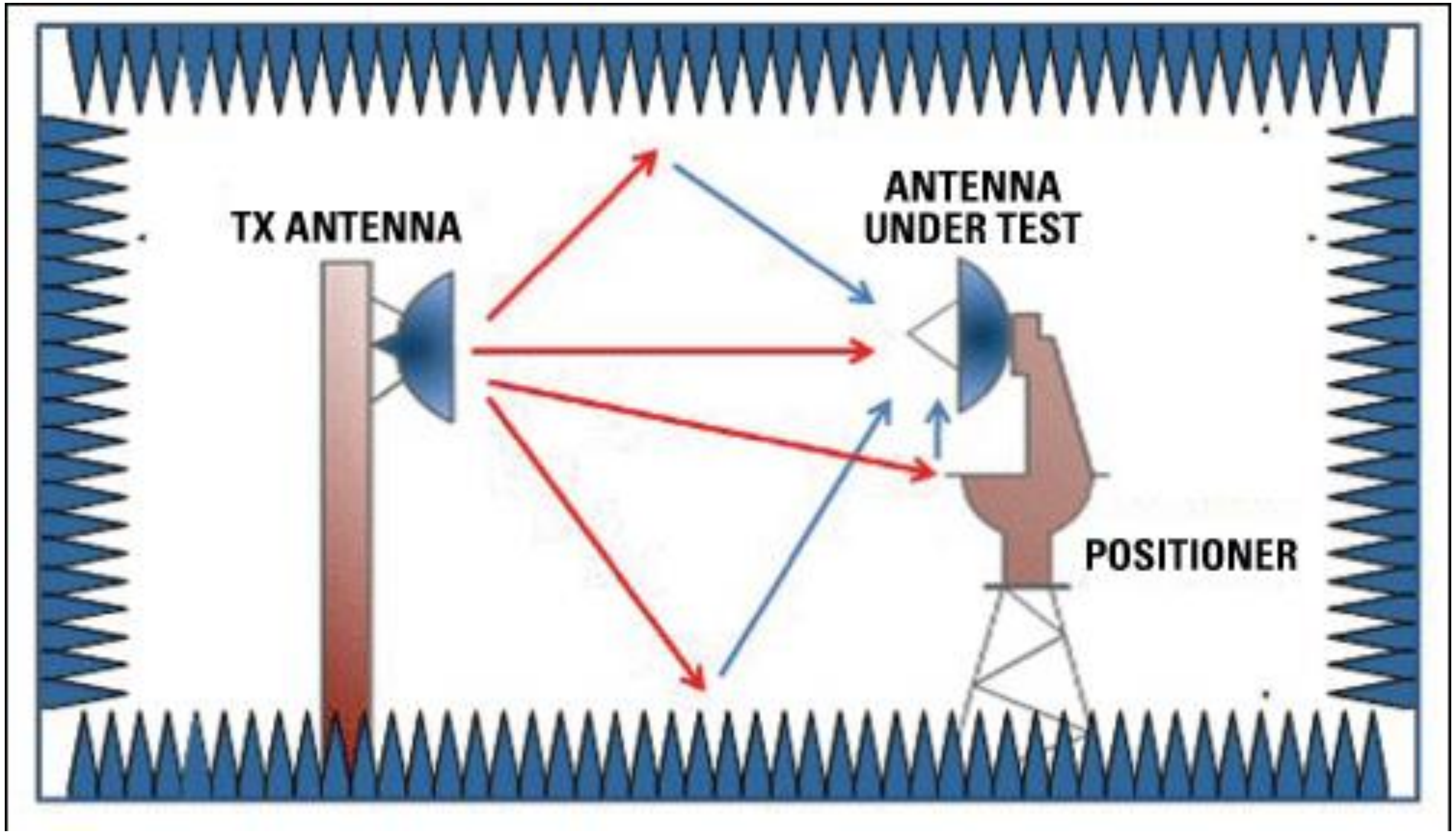
$\rho_{max} = 0.007\,\lambda$

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



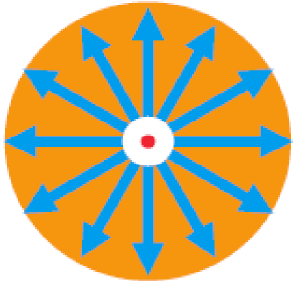
Agenda

- ▶ Antennas
- ▶ Chambers
- ▶ Measurements



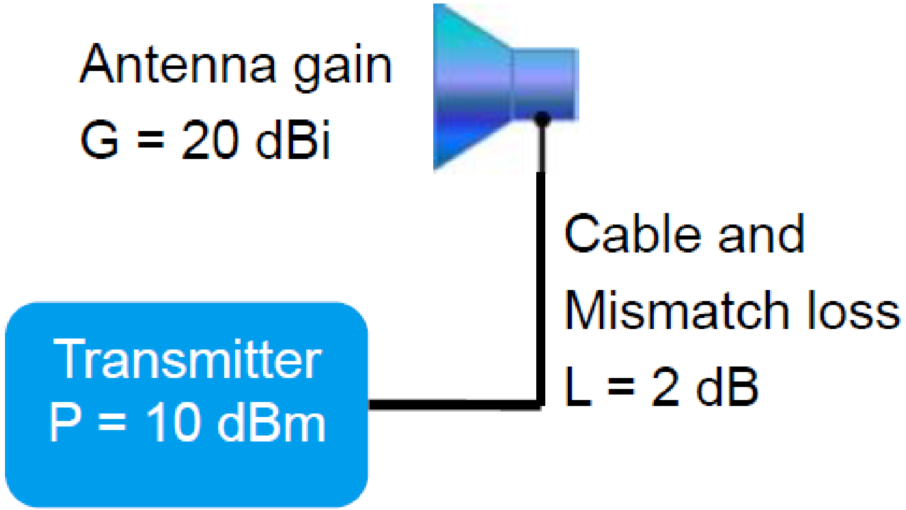
Equivalent isotropic radiated power, EIRP

- Loss-free isotropic radiator (G = 0 dBi) fed with P = 10 dBm TX power



  - EIRP = P + G = 10 dBm

- Directive antenna connected to a transmitter



  - EIRP = P(dBm) – L(dB) + G(dBi) = 28 dBm

Total Radiated Power, TRP

$$TRP = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} EIRP\,(\vartheta,\varphi)\sin\vartheta\, d\vartheta\, d\varphi = \frac{1}{4\pi}\sum_{i=1}^{N_\vartheta -1}\sum_{j=1}^{N_\varphi -1} EIRP(\vartheta_i,\varphi_j)\ \sin\vartheta_i\ \Delta\vartheta\,\Delta\varphi$$

Measure EIRP at this point

+

Measure EIRP at this point

+

Measure EIRP at this point

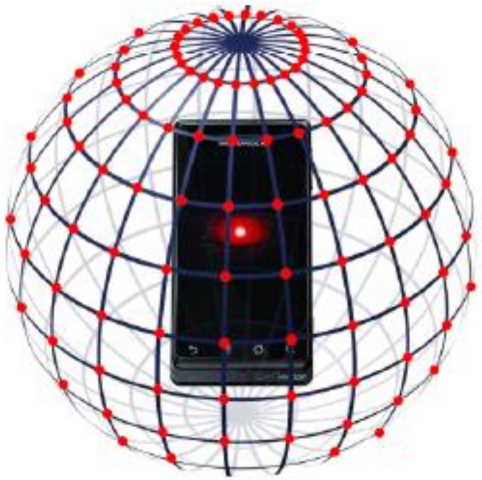
+

..

+

..

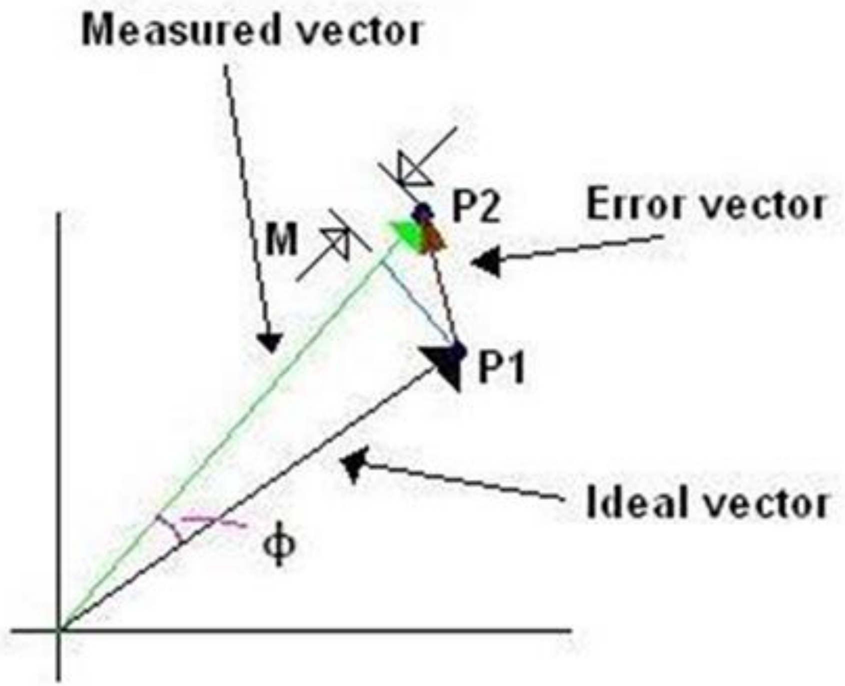
= TRP

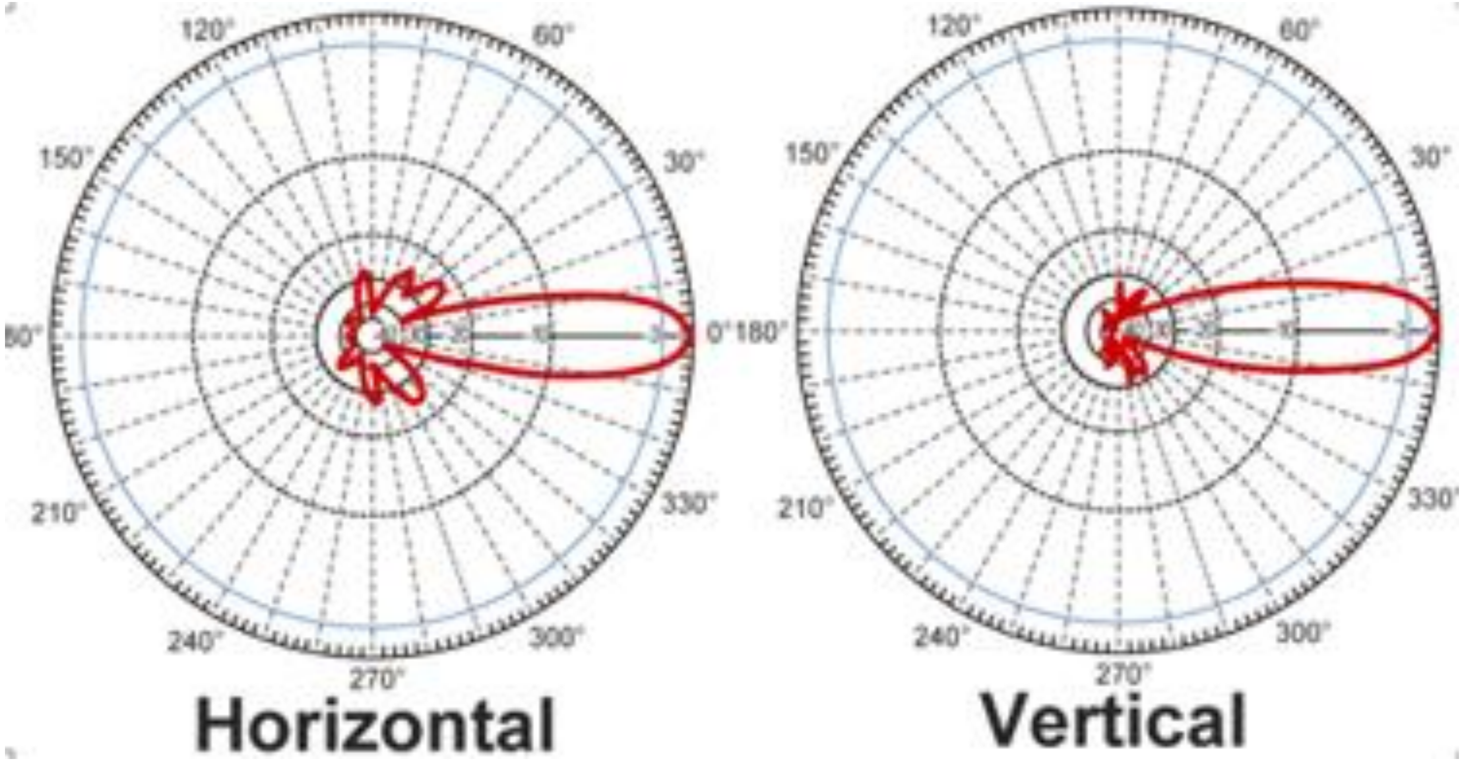


Equally spaced Increments of ϑ and φ

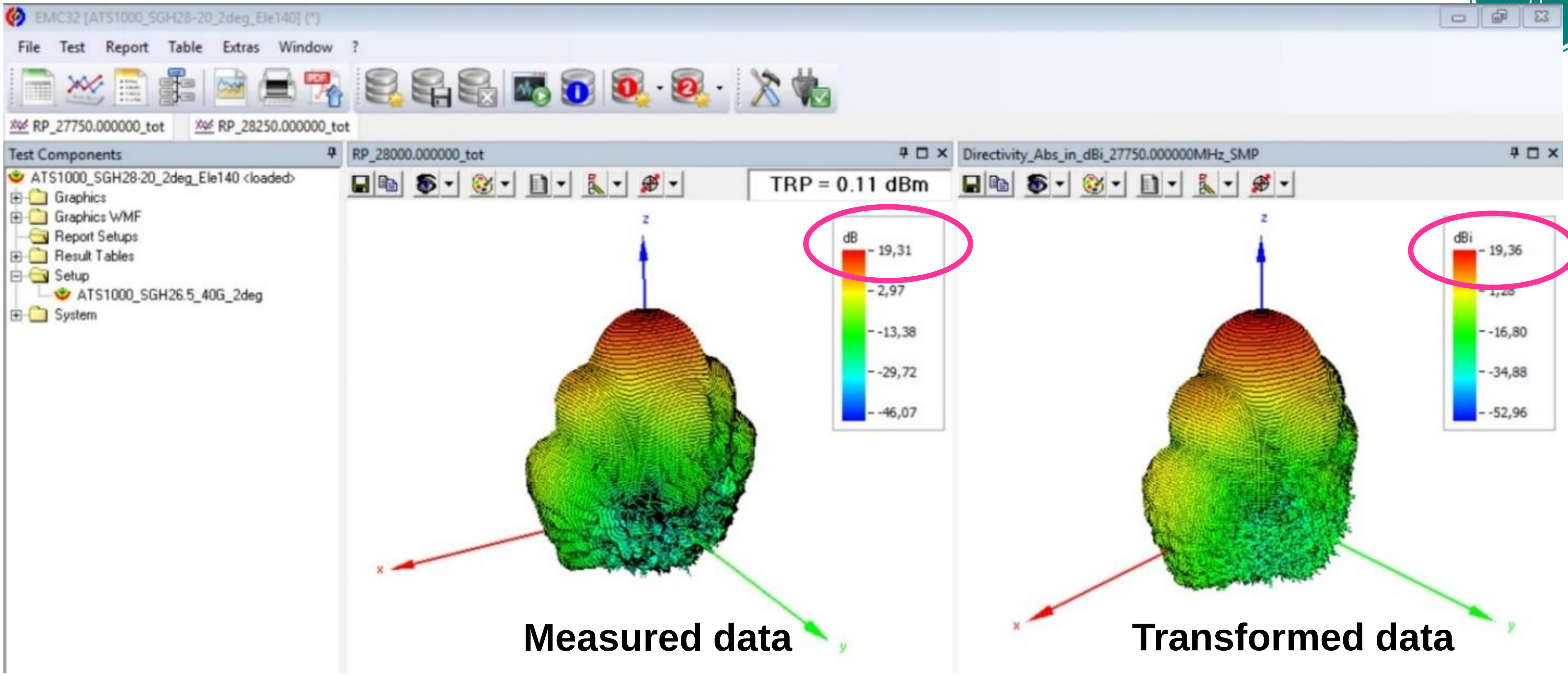
sin ϑ weighting

2D Antenna Pattern, EVM





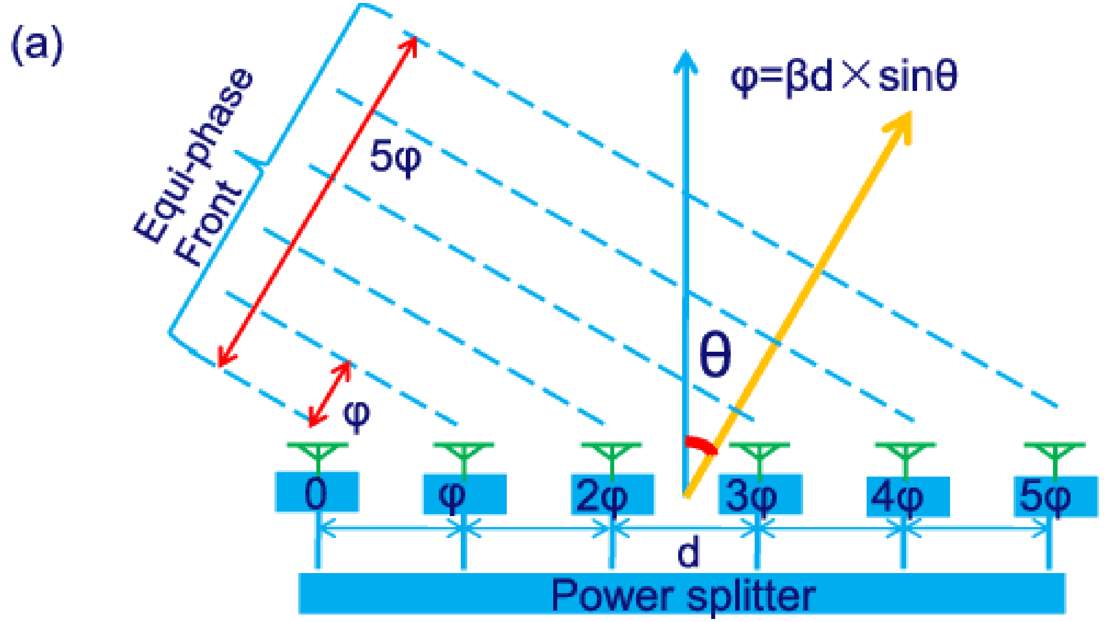
3D Antenna Pattern, Power

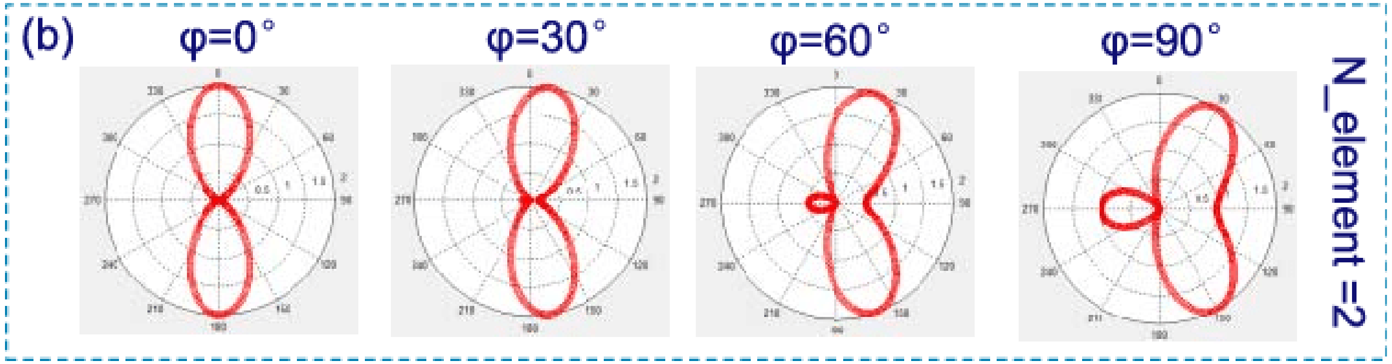


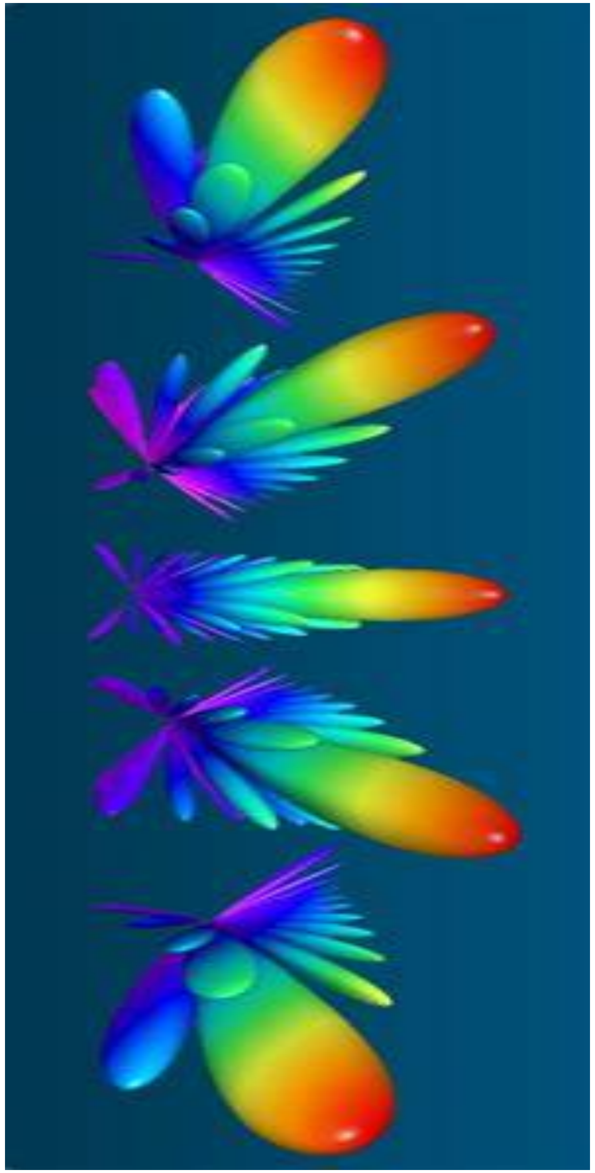
Measured data

Transformed data

Beam Steering





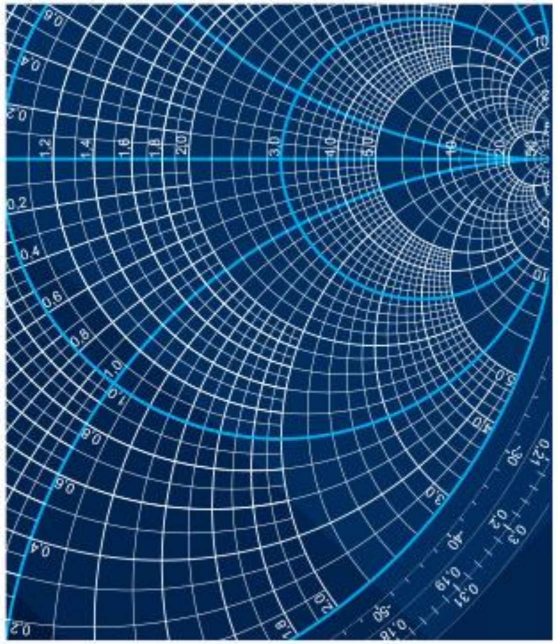


Additional Resources

- Rohde & Schwarz, Demystifying over-the-air (OTA) testing - White paper
- 5G – System calibration basics for over-the-air (OTA) testing (video)
- 5G – Calibrating OTA test systems using gain transfer method (video)
- Rohde & Schwarz, 5G NR OTA Base Station Transmitter Tests, App Note
- Rohde & Schwarz, 5G NR OTA Base Station Receiver Tests, App Note

SUMMARY / Q&A

- Antennas
- Chambers
- Measurements



Measurement Techniques

Design Verification & Evaluation

EVERYTHING TEST

Instrument Selection & Optimization