LITEPOINT
a Teradyne Company

Making High Performance 5G mmWave Over-the-air (OTA) Measurements

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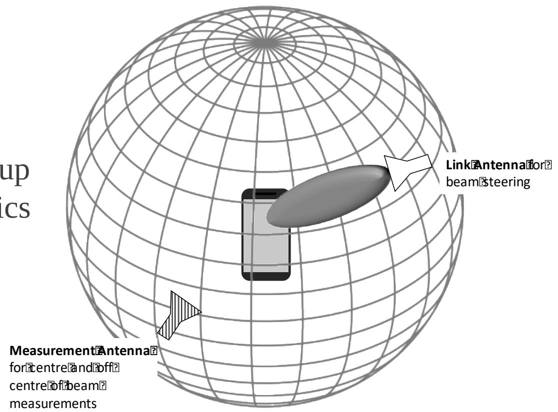
Outline

- 5G NR FR2 Test Method for UE RF Testing – DFF
- 5G NR FR2 Test Method for UE RF Testing – CATR
- 5G NR FR2 Test Equipment and Measurements

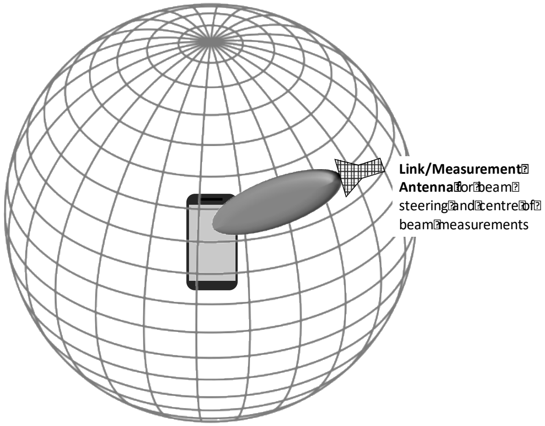
5G NR FR2 Test Methods

DFF measurement setup
of UE RF characteristics



- UE RF testing
  - Direct far field (DFF)
    - The DUT radiating aperture is D ≤ 5 cm
    - A manufacturer declaration on antenna array is needed (white box)
    - EIRP, TRP, EIS, EVM, spurious emissions and blocking metrics can be tested
  - Simplified Direct far field (DFF)
    - The measurement and the link antenna can be combined so that the single antenna is used to steer the beam and to perform UE RF measurements.
  - Indirect far field (IFF) method 1 (CATR)
  - Near field to far field transform (NFTF)

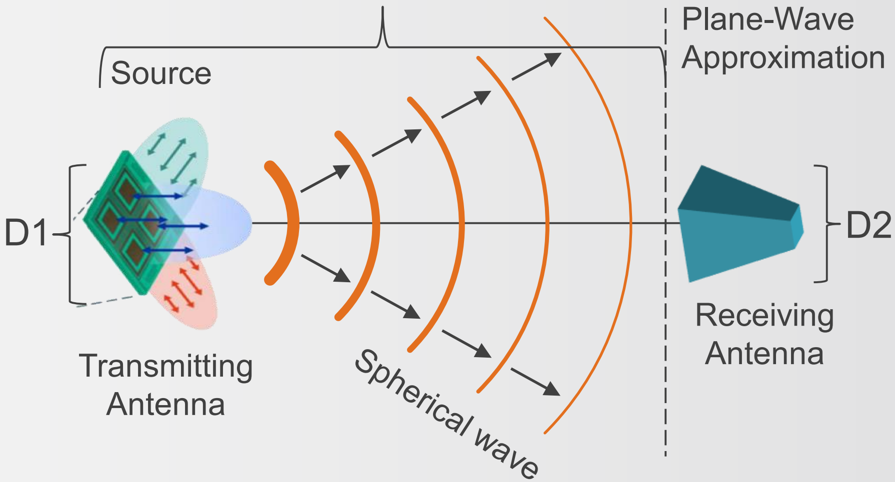
Centre of beam measurement
setup of UE RF characteristics



Far Field Criteria

It depends on the size of the antenna array and the application

R_{ff}, Far Field Region



The far-field region is at a distance R where the wave may be considered to be a plane wave

$$R_{ff} = \frac{2D^2}{\lambda}$$

Dx = Maximum effective size of the antenna

D = Max (D1, D2)

λ = Wavelength of the signal

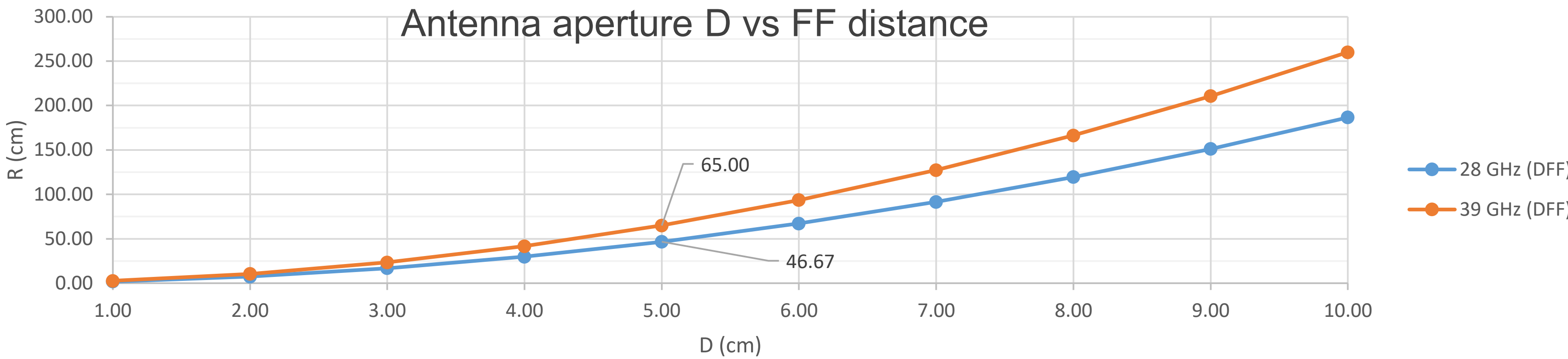
Examples for R_{ff} at 28 GHz and 39 GHz

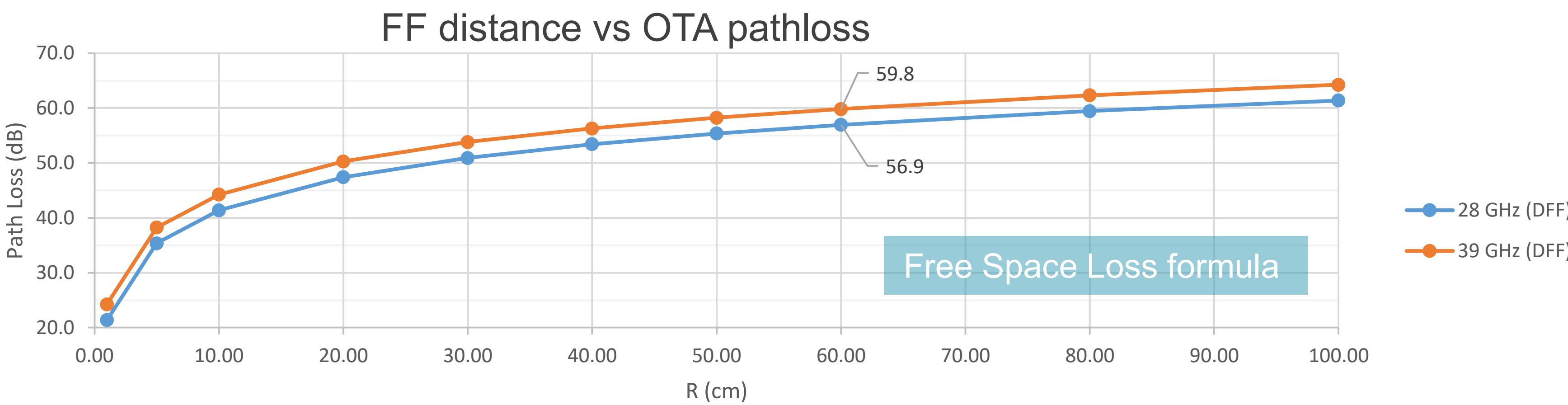
Freq (GHz): **28** Wavelength (mm): 10.7
Assume lambda/2 antenna size

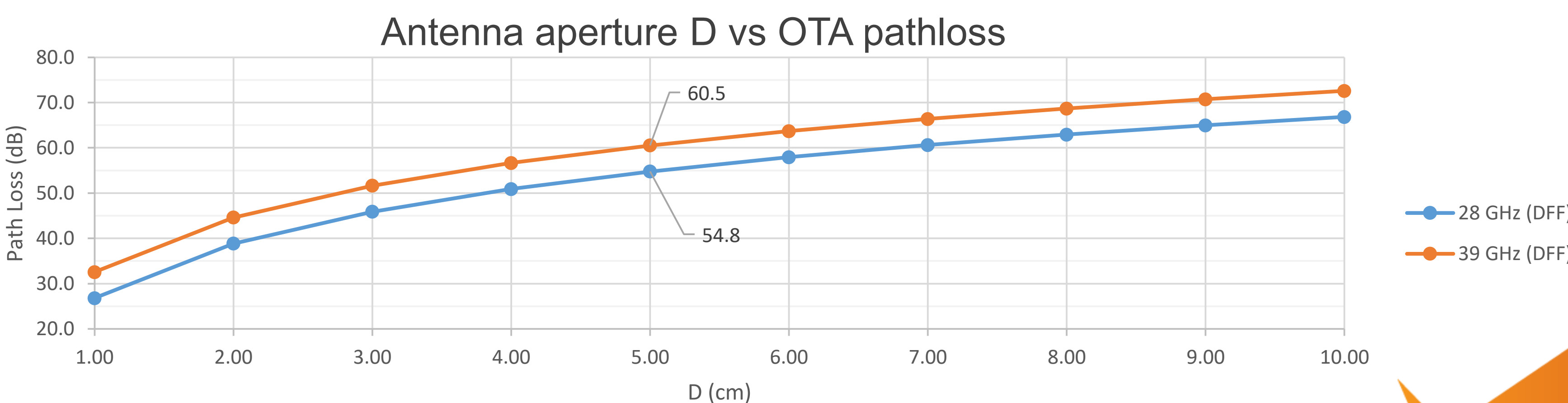
Antenna Array	2x2	3x3	4x4	5x5	6x6	7x7	8x8
Aperture D (mm)	15	23	30	38	45	53	61
Approx Far Field (cm)	5	10	18	27	39	53	69

Freq (GHz): **39** Wavelength (mm): 7.7
Assume lambda/2 antenna size

Antenna Array	2x2	3x3	4x4	5x5	6x6	7x7	8x8
Aperture D (mm)	11	16	22	27	33	38	44
Approx Far Field (cm)	4	7	13	20	28	38	50


Antenna aperture D vs FF distance
R (cm)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
D (cm)
65.00
46.67
28 GHz (DFF)
39 GHz (DFF)


FF distance vs OTA pathloss
Path Loss (dB)
70.0
60.0
50.0
40.0
30.0
20.0
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
R (cm)
59.8
56.9
Free Space Loss formula
28 GHz (DFF)
39 GHz (DFF)


Antenna aperture D vs OTA pathloss
Path Loss (dB)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
D (cm)
60.5
54.8
28 GHz (DFF)
39 GHz (DFF)

LitePoint DFF Chamber

Compact mmWave OTA Test Chamber for Design Validation Testing

- Designed for 24” far field distance (~600 mm) in 1 axis
- 2-axis device positioner option
- 0.1 degree resolution
- Outer dimensions:
  1205 mm H x 975 mm W x 765 mm D
- Temperature control enabled with an external Thermo-stream unit

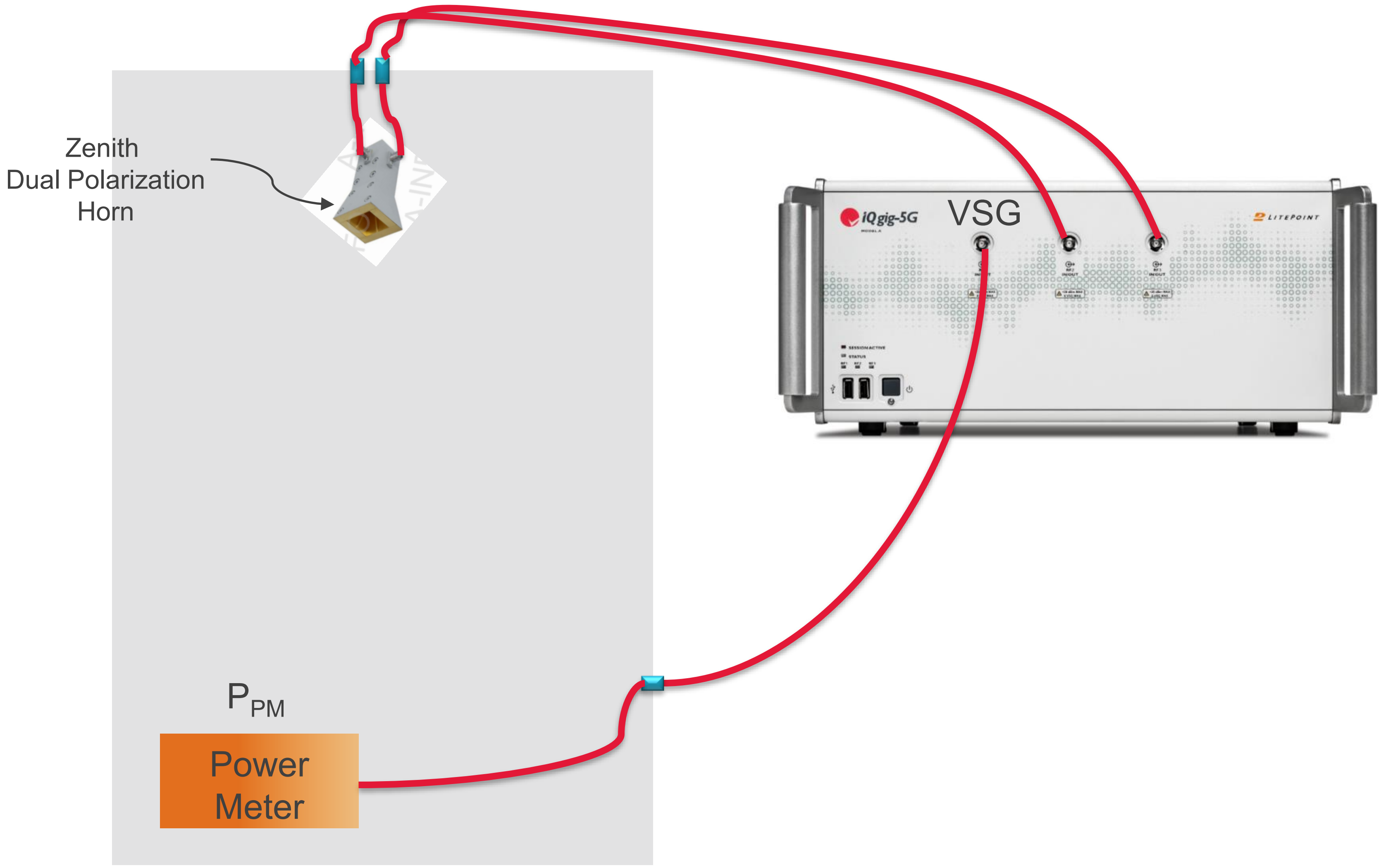
Calibration Measurement Procedure

- The calibration measurement is done by using a **reference calibration antenna** with known gain values. For the calibration measurement, the reference antenna is placed in the centre of the quiet zone.
- The calibration process **determines the composite loss** of the entire transmission and receiver chain path gains and losses
- The calibration measurement is repeated for each measurement path (**two orthogonal polarizations**).

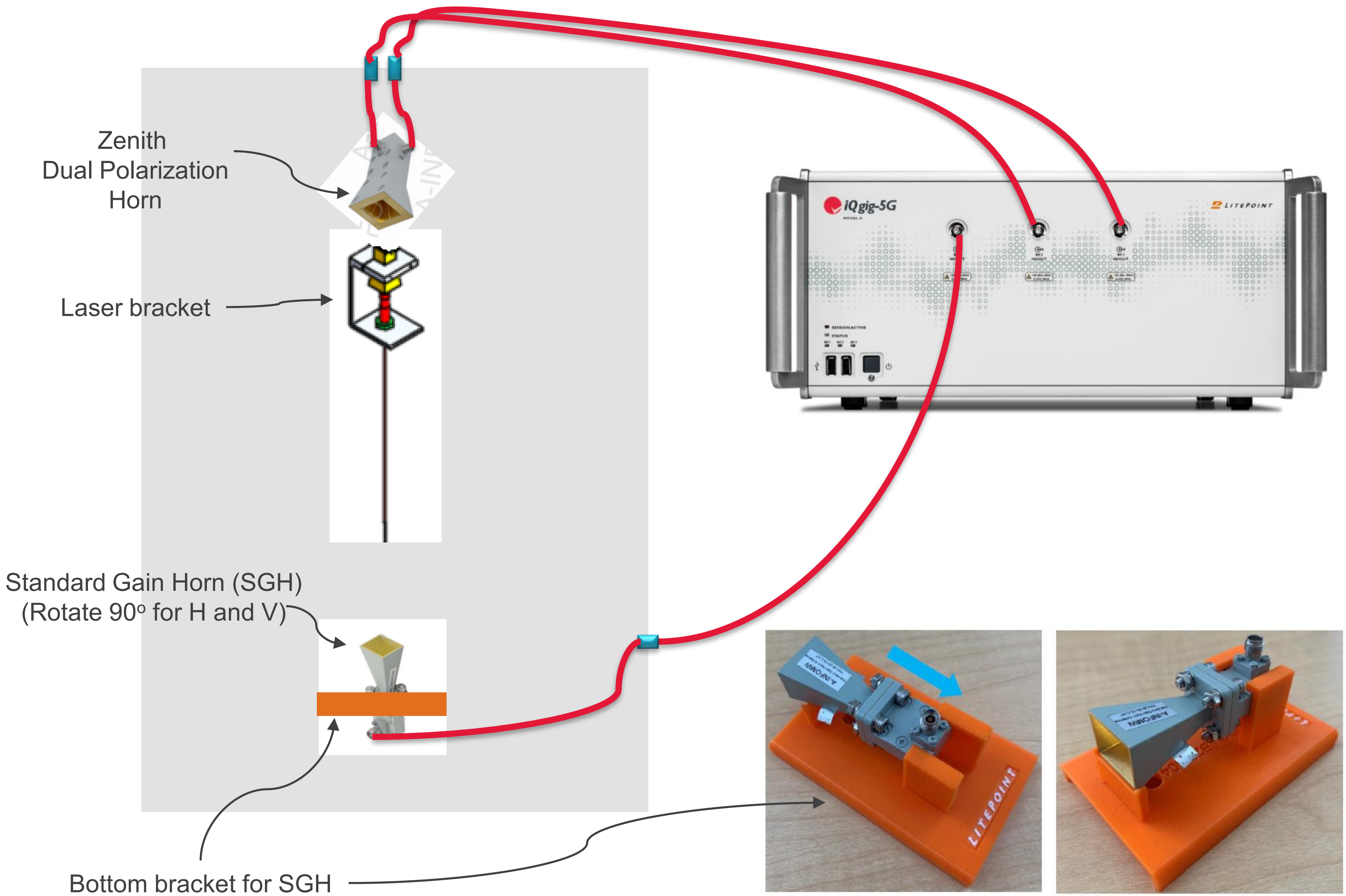
LitePoint Calibration Kit

1. **Digital Level**
2. **Standard gain horn (SGH)**
3. **Bottom bracket for SGH**
4. **Laser bracket**
5. **Two cables**

Calibrating an OTA Chamber Setup

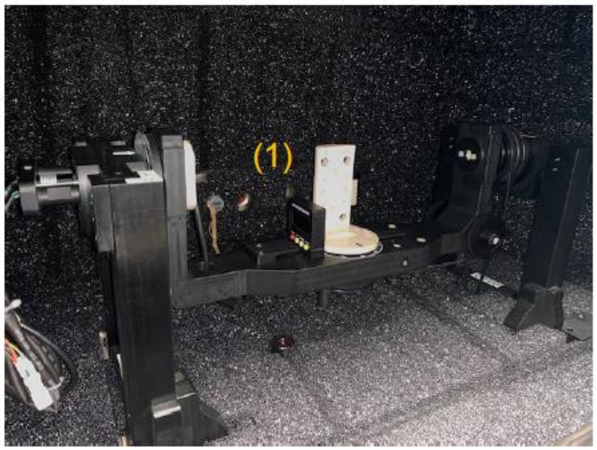


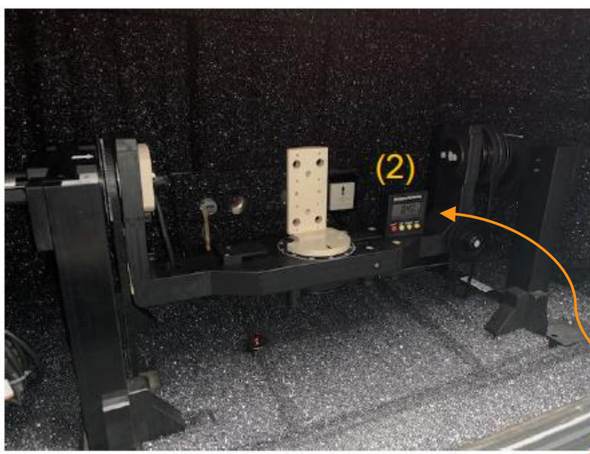
Calibrating an OTA Chamber Setup



Calibrating an OTA Chamber Setup

Positioner Alignment

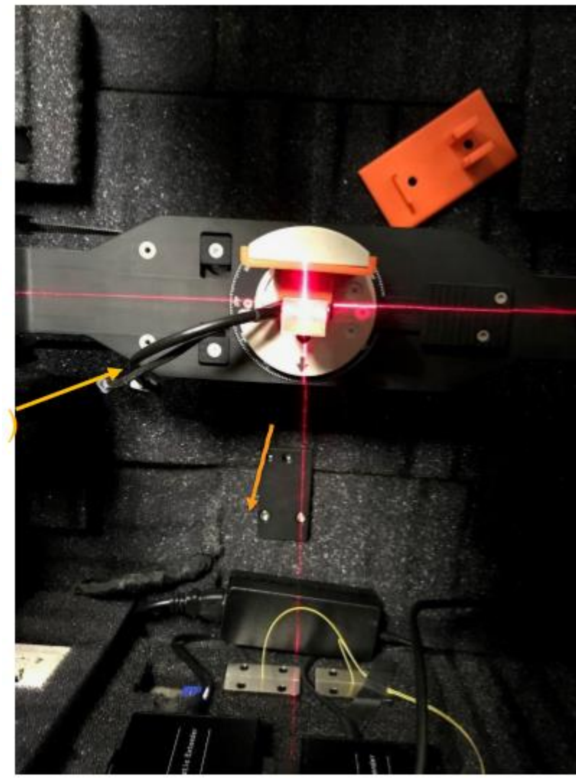




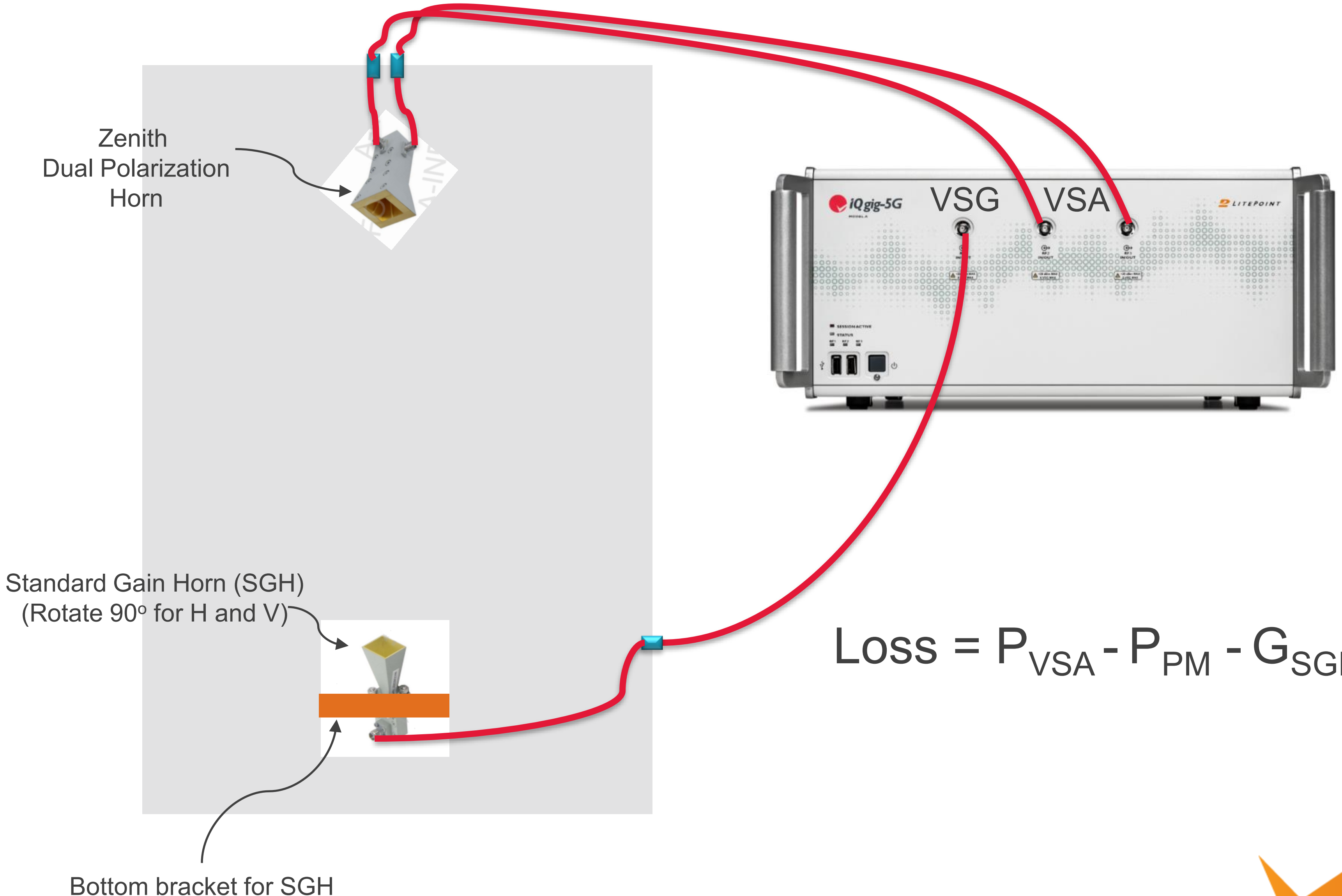
Digital Level

Zenith Horn Parallelism

Zenith Horn Alignment

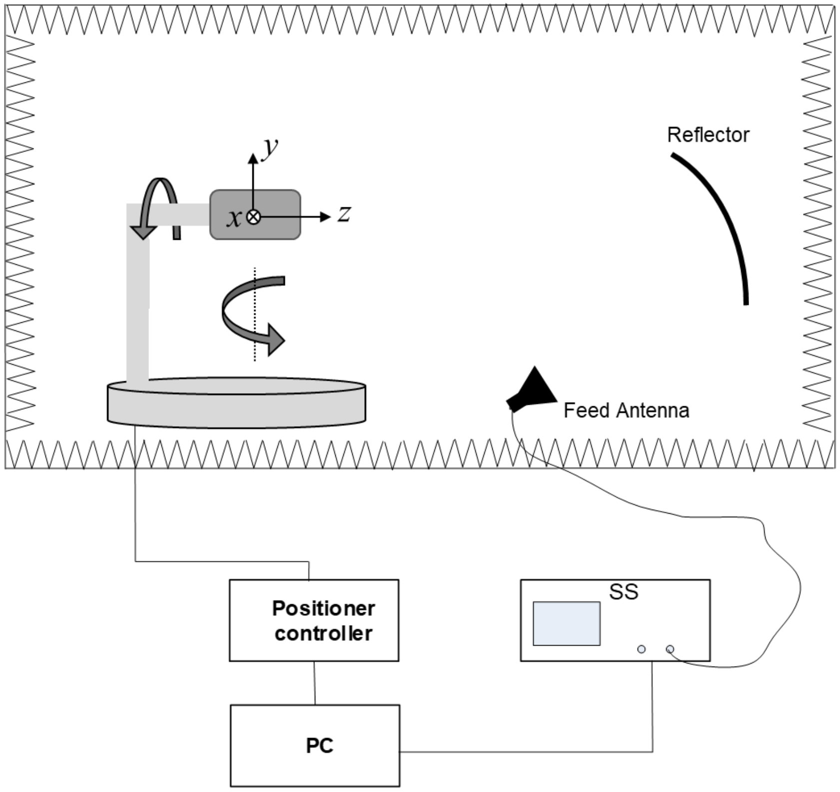


Calibrating an OTA Chamber Setup



$$Loss = P_{VSA} - P_{PM} - G_{SGH}$$

5G NR FR2 Test Methods



- UE RF testing
  - Direct far field (DFF)
  - Simplified Direct far field (DFF)
  - Indirect far field (IFF) method 1 (CATR)

    The total test volume is a cylinder with diameter d and height h.

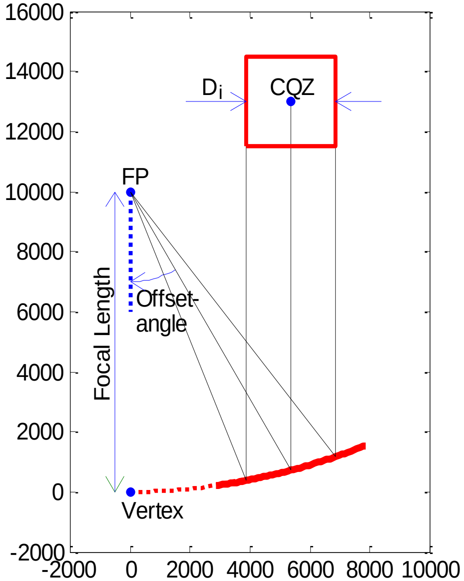
    DUT must fit within the total test volume for the entire duration of the test.

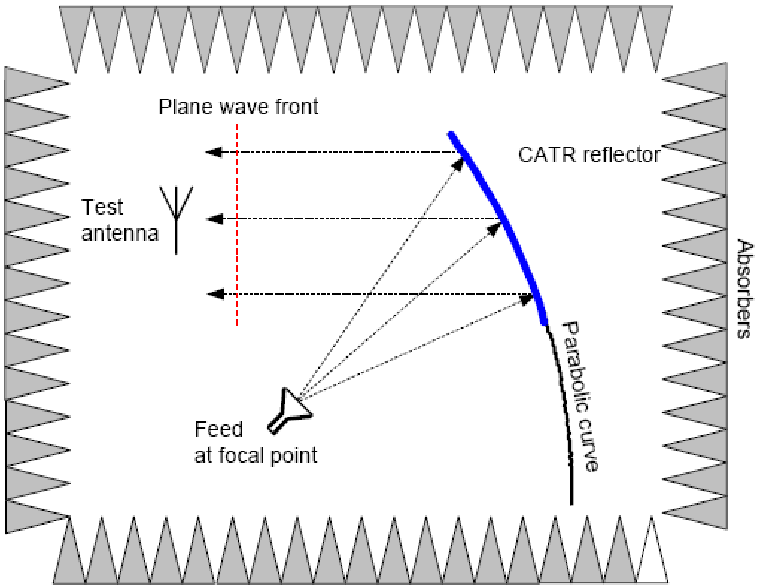
    EIRP, TRP, EIS, EVM, spurious emissions and blocking metrics can be tested.

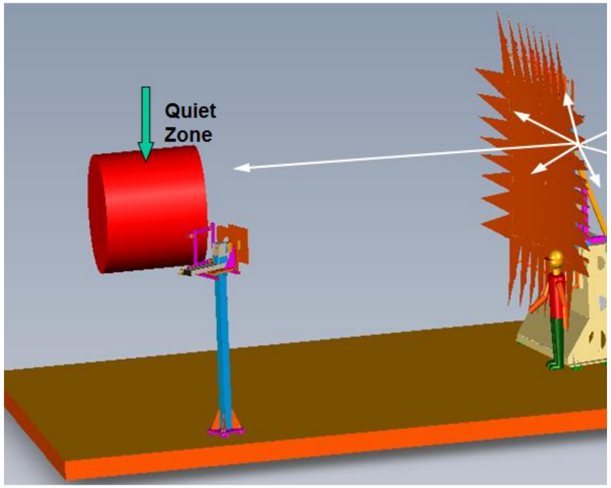
    No manufacturer declaration is needed (black box)
  - Near field to far field transform (NFTF)

CATR Principle

- A CATR (Compact Antenna Test Range) is a system in which the spherical wave is transformed in plane wave within the desired quiet zone (QZ).
  - The plane wavefront (uniform amplitude and phase) is guaranteed in a certain cylinder volume

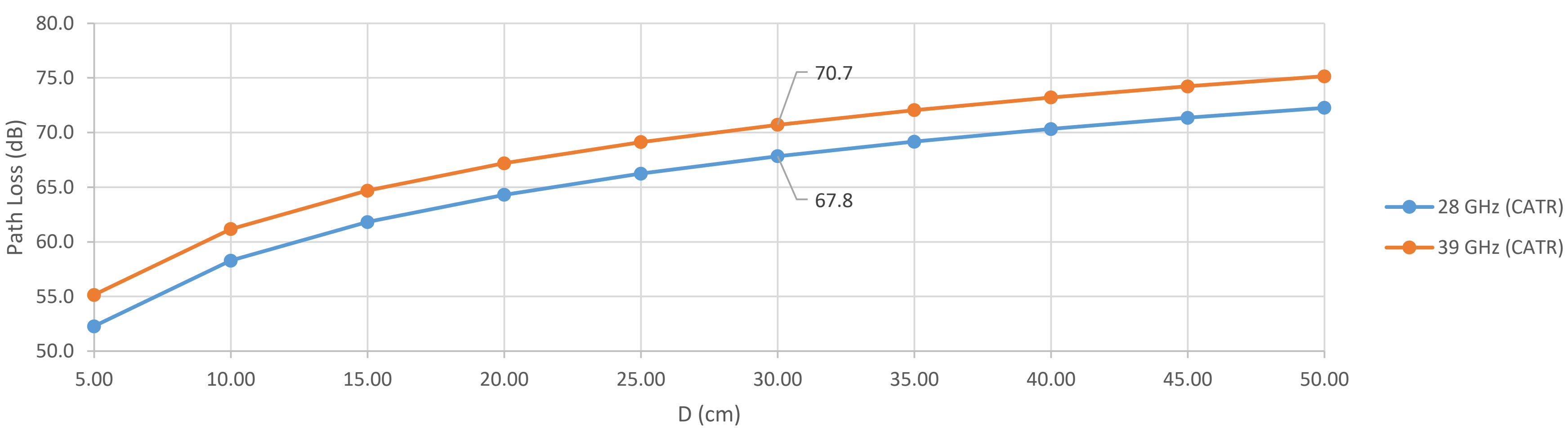






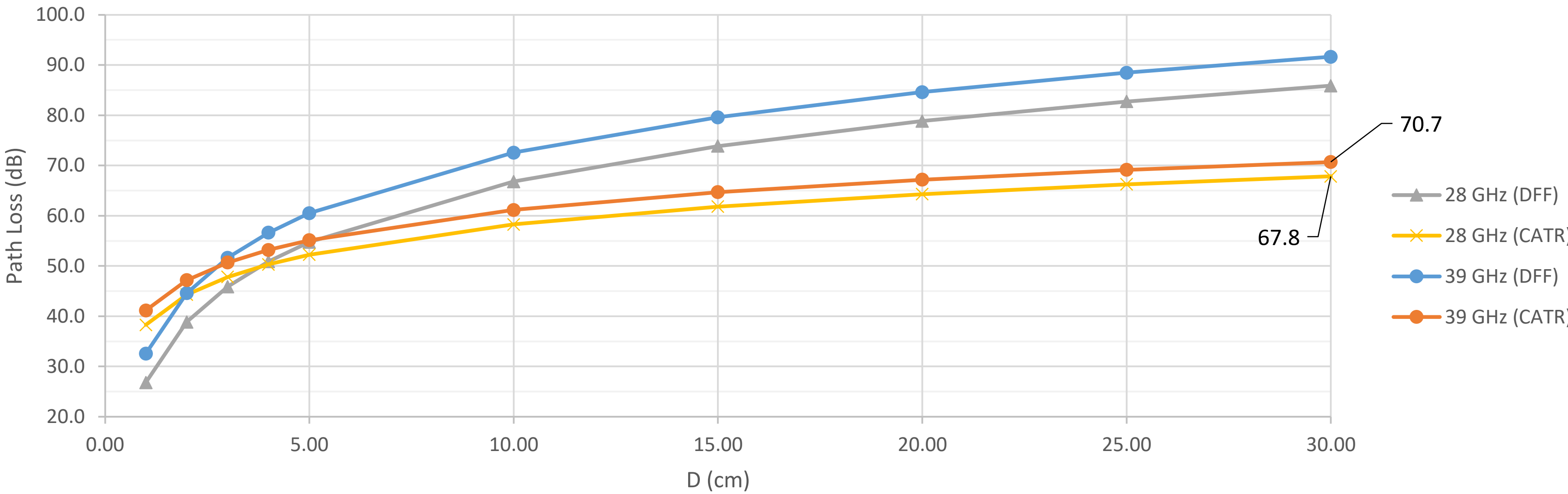
Far Field Criteria

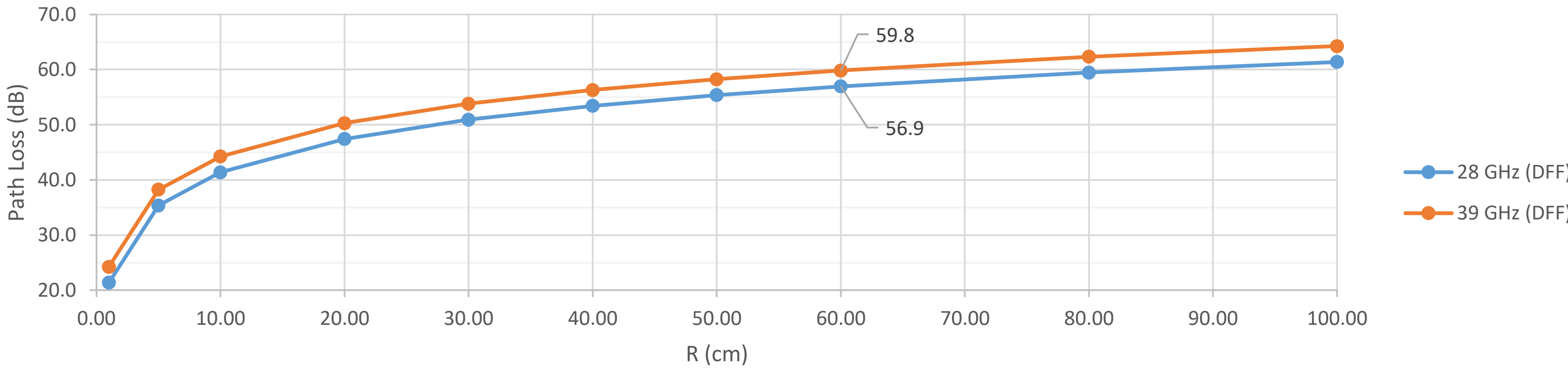
- For CATR, the FF distance is seen as the focal length, distance between the feed and reflector for a CATR, which can be calculated as shown below (as a rule of thumb although it can vary depending on system implementation):
  - D = x [m]
  - size of reflector = 2*D
  - R = focal length = 3.5*size of reflector = 3.5*(2*D) = 7*D



DFF vs CATR

When D < 5cm, Path Loss of DFF and CATR test method is similar
When D > 5cm, Path Loss of CATR is getting better than DFF

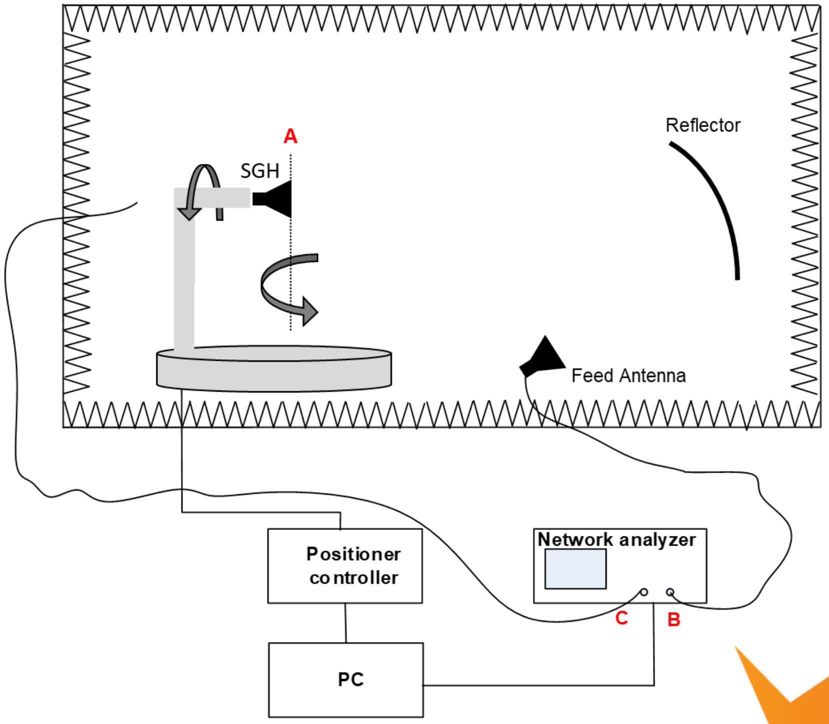




If we compare 60 cm reflector CATR and 60 cm distance DFF,
actually path loss of 60 cm distance DFF is 10 dB better than 60 cm reflector CATR

Calibration Measurement Procedure

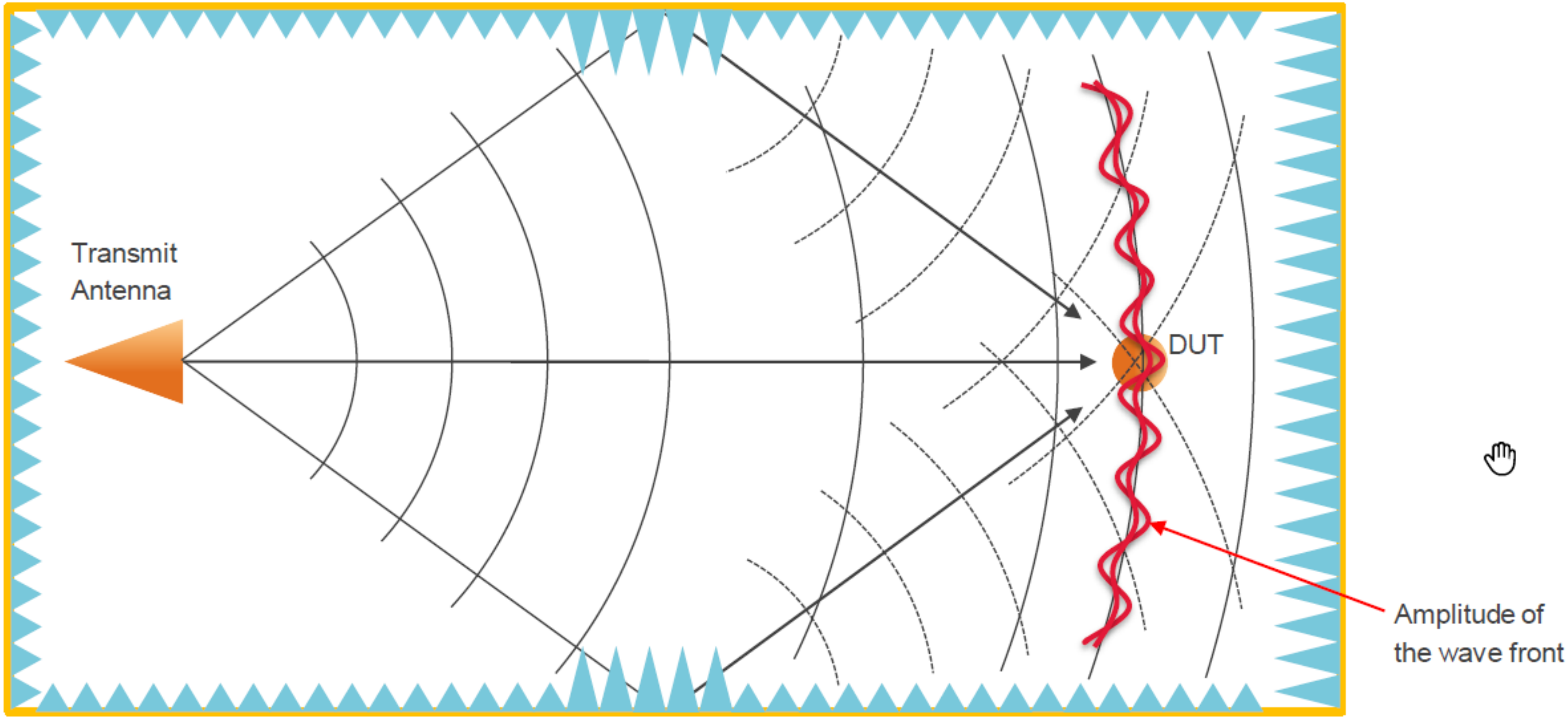
- The calibration measurement is done by using a reference antenna (SGH) with known efficiency or gain values. In the calibration measurement the reference antenna is measured in the same place as the DUT, and the attenuation of the complete transmission path (C↔A,) from the DUT to the measurement receiver (EIRP), and from the RF source to DUT (EIS) is calibrated out.



CATR calibration system setup for EIRP

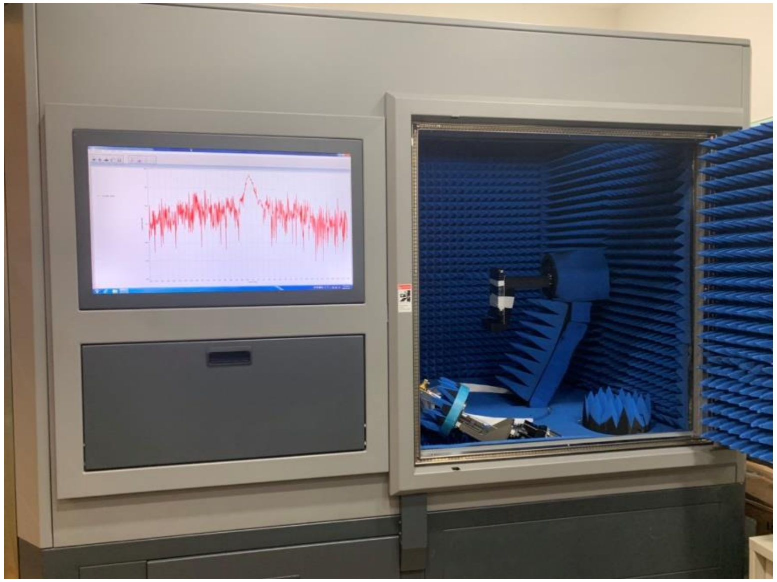
Chamber Quiet Zone

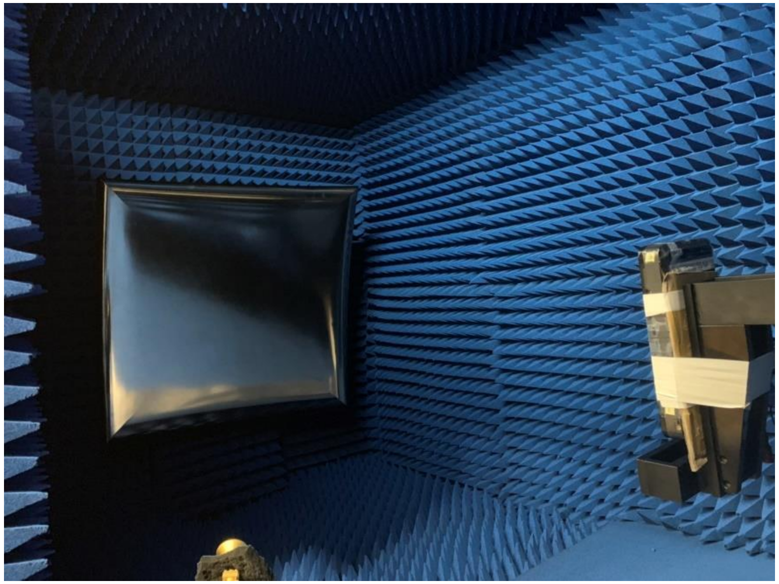
- Volume within the anechoic chamber where electromagnetic waves reflected from the walls are stated to below a certain specified minimum.

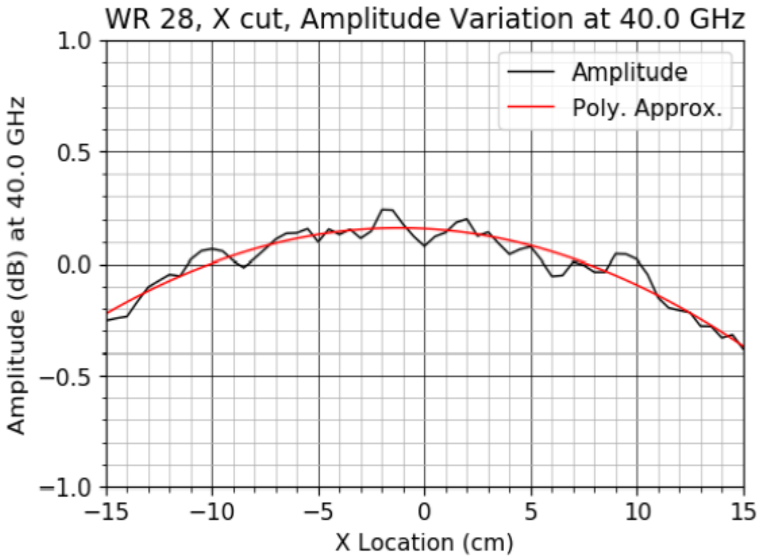


Adding RF absorbers on the walls reduces the amplitude of the reflected wave fronts and improves the quiet zone

LitePoint CATR Chamber







Let’s talk about test equipment and measurements

iQgig-5G

For mmWave Fixed Wireless Terminals, Small Cells and UE

Faster, Simpler and Smarter

Single box solutions that are **simple and easy to use** enabling our customers to run **fast and efficiently**.

IQgig-5G™
Fully Integrated 5G mmWave Test System

Supported in Qualcomm QDART

IQgig-5G for 5G mmWave

First fully-integrated 5G mmWave test system

- Simplest 5G testing with single unit covering the key 28 GHz and 39 GHz bands
- All signal generation, analysis, and RF front-end routing H/W are self-contained
- Single intuitive S/W interface

5G measurements in minutes

- Simple connections – just power up and go
- Three bi-directional 2.92 mm connectors enable testing both H and V polarizations in one setup
- Source and Measure capabilities fully calibrated to the instrument front panel

No Compromise 5G performance

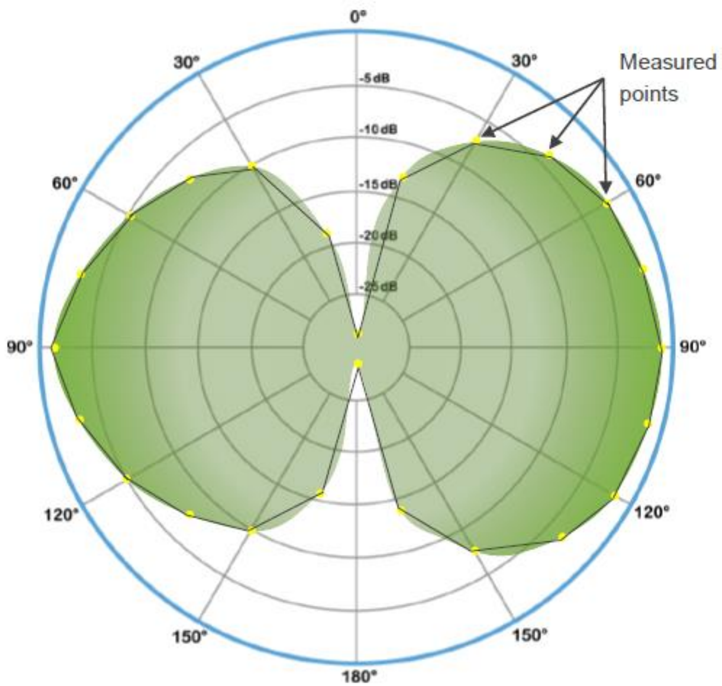
- License-upgradeable to support the pre-5G and 3GPP NR standards evolution
- 1 GHz of single-shot bandwidth.
- EVM performance up to -40 dB (1%)

Measurements

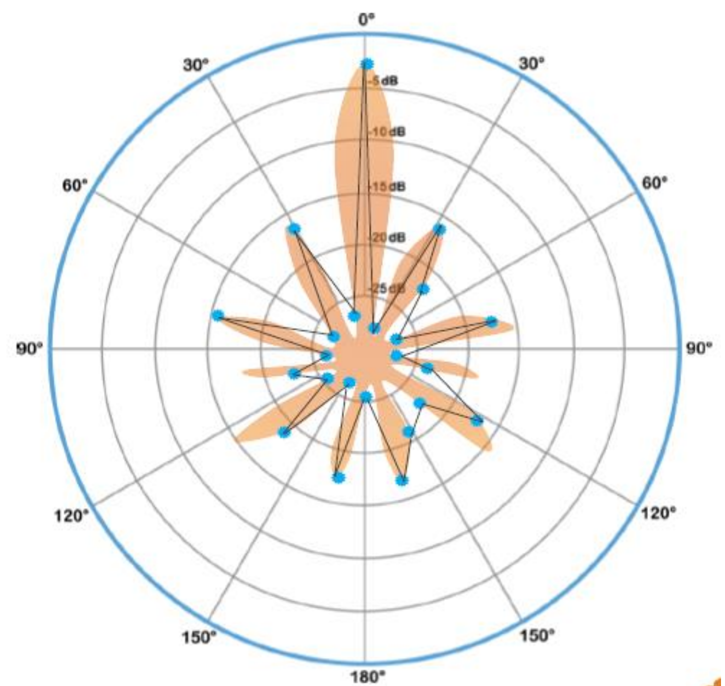
- The TX beam peak direction is found with a 3D EIRP scan (separately for each orthogonal polarization).
- The RX beam peak direction is found with a 3D EIS scan (separately for each orthogonal polarization).
- Beamforming Characterization
- Beam could be characterized first and then test pre-defined beam (separately for each orthogonal polarization).
- Measurement Tool
  - Chipset tool
  - LitePoint IQCaveMeas software sweeps angles for Theta/Phi, measures EIRP for V&H polarization and analyzes raw data to 2D/3D radiation pattern
  - LitePoint IQfact+ software as ATE tool for manufacturing test

Measurement Precision

- At low frequencies, the consumer antenna are pretty much omni-directional. The measurement step can be 15 degrees can give us accurate results.
- In the mm-wave range, the antenna patterns can be extremely directional (large array) and a 15 degrees measurement step can miss completely a peak in the radiation pattern.



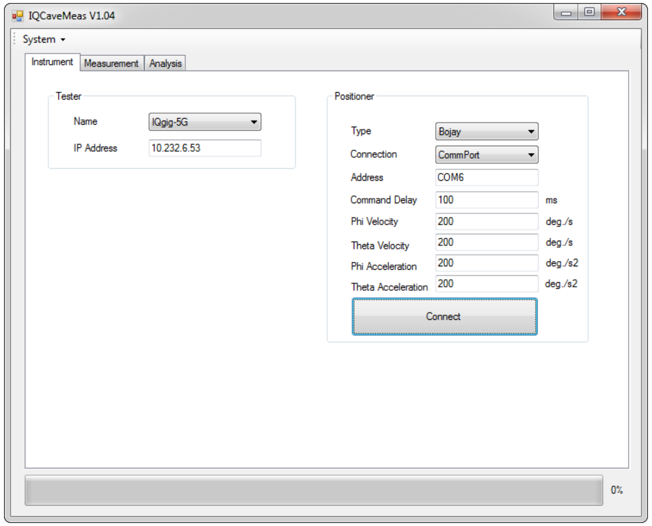
The measured pattern looks similar to the antenna radiation pattern.



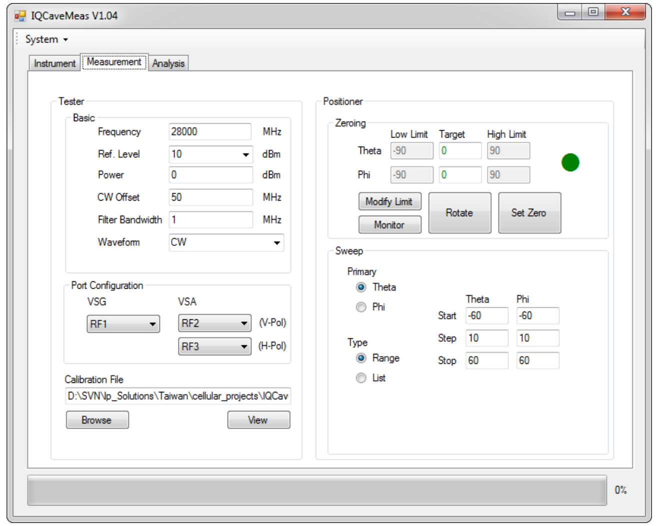
Narrow beam pattern.

LitePoint IQCaveMeas Software

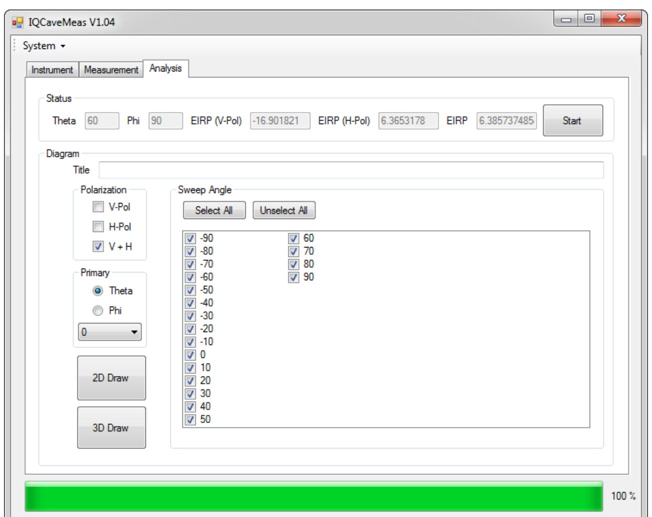
Instrument Settings



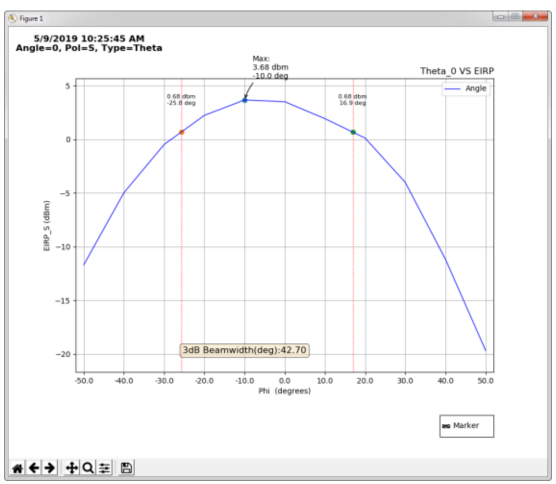
Measurement Settings



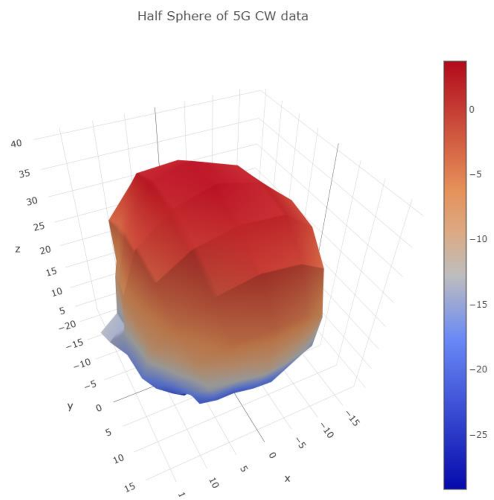
Analysis Settings



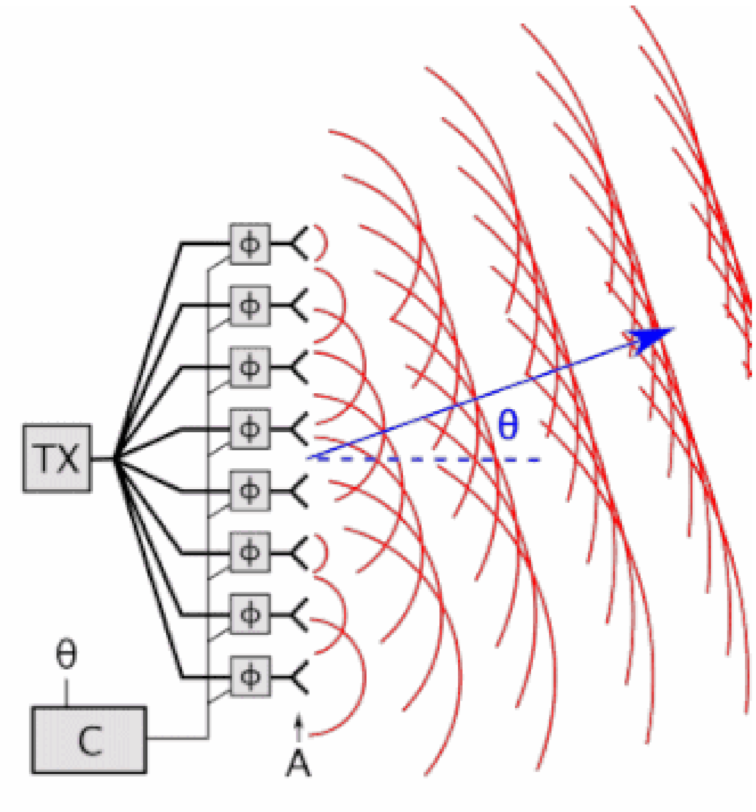
2D Radiation Pattern

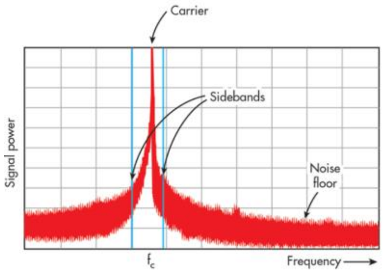


3D Radiation Pattern



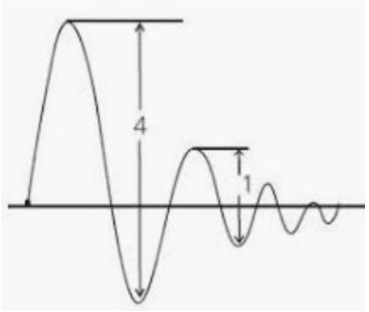
Beamforming Characterization





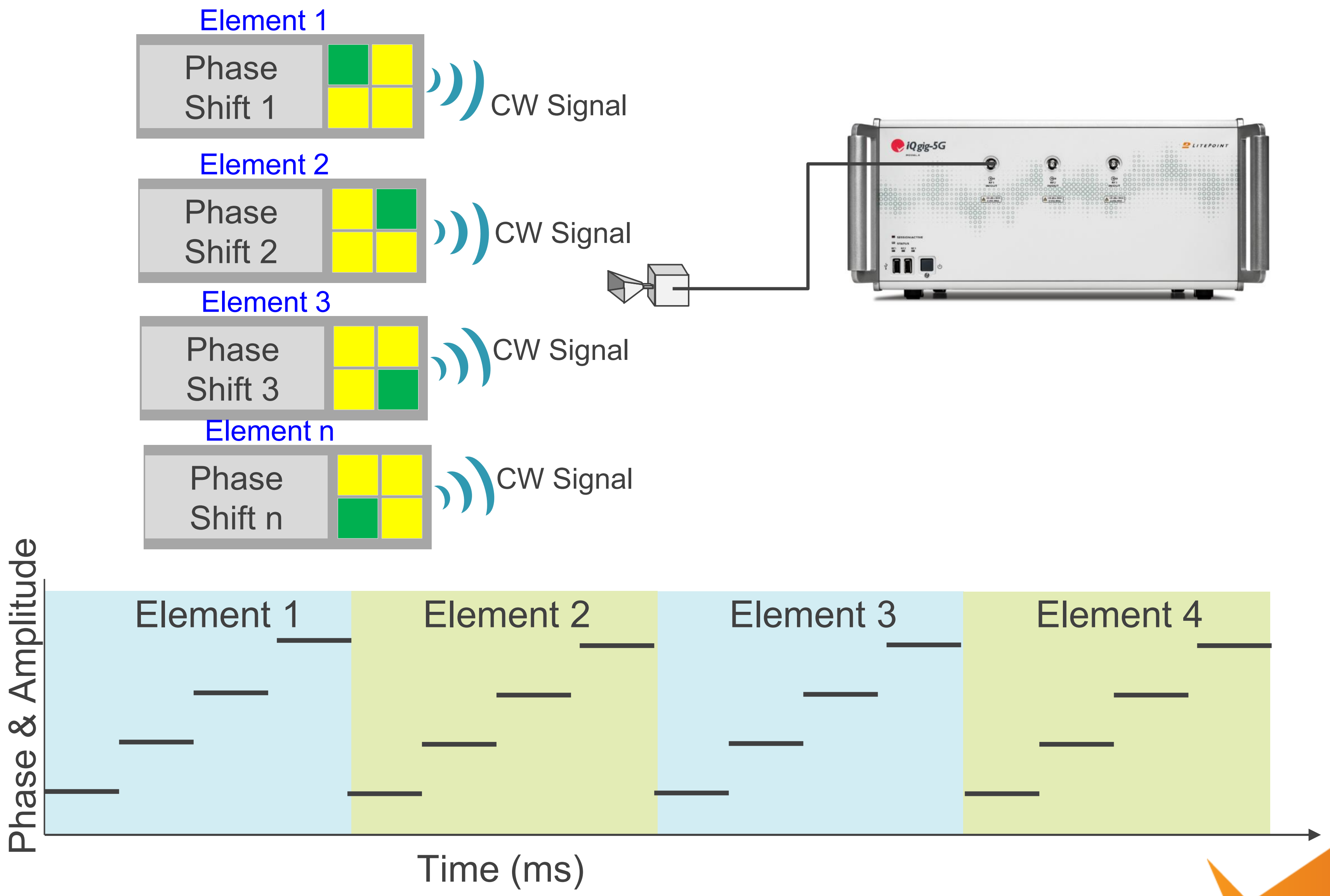
PLL Noise Measurement

Time / Phase Tuning



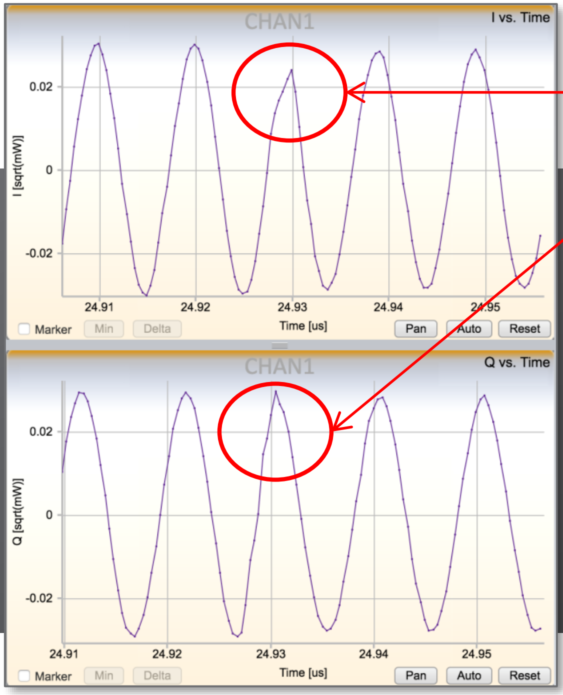
Amplitude Tuning

Per Element Phase Measurement

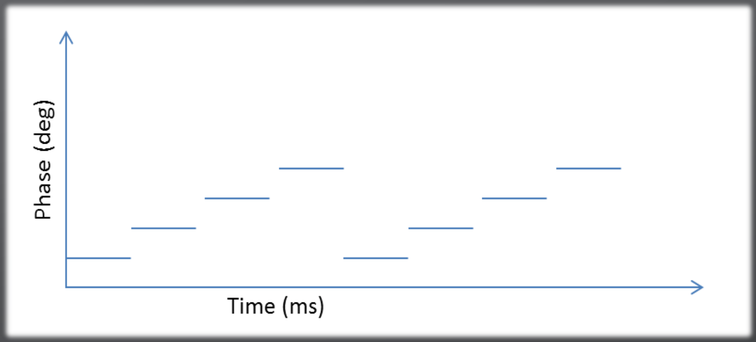


LitePoint Fast Array – Operation Example

- Process
  - Test Element by element
  - IQgig-5G can be triggered by phase change in addition to legacy RF trigger or external trigger
  - Measure each relative phase and amplitude change



Phase Change calculated from I/Q of the CW signal



Sequence Mode Sequence Diagram

Summary

- DFF and CATR test method for UE RF testing
- Far field Criteria for DFF vs CATR, when D < 5 cm, DFF and CATR is similar in terms of path loss performance
- Calibration measurement procedure by use of SGH
- LitePoint DFF chamber and CATR chamber
- LitePoint IQgig-5G single box 5G mmWave solution