# TESTING OF WIRELESS DEVICES – THE PAST, THE PRESENT AND THE FUTURE

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20 YEARS ANNIVERSARY

# INTRODUCTION

# ABOUT BLUETEST AB


- A privately held company founded in the year 2000 by Chalmers University Professor Per-Simon Kildal
  - Head Office in Gothenburg, Sweden (Lindholmen)
- Market leader in Over-The-Air MIMO test solutions
  - More than 350 delivered OTA test systems
- Worldwide sales network
  - Regional sales and support offices in North America and China (Beijing, Shenzhen, Shanghai)
  - Distributors in Japan, Korea & other countries
- Our corporate values: Customer Focus, Team Work, Innovation & Trust

# OUR CUSTOMERS

Mobile phone manufacturers
(Most of the top 10)

Mobile operators
(Asia, Europe, USA)

Test institutes

Network equipment manufacturers

Antenna and component manufacturers

Laptop & Wi-Fi device manufacturers

Automotive

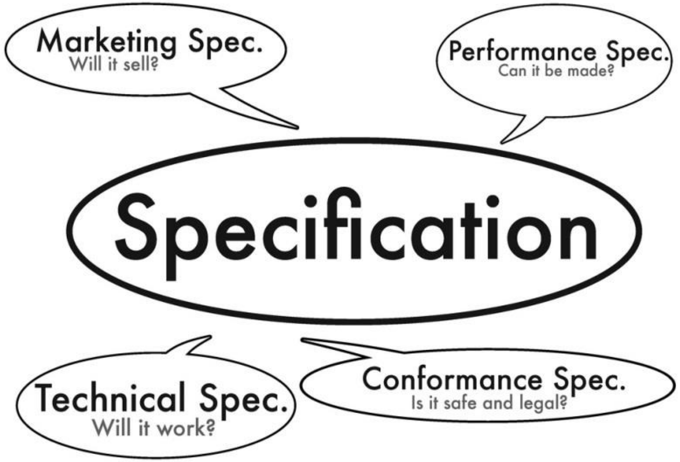
Universities

# WHY DO WE TEST (1)?

- To fulfill **internal product requirements**
  - R&D testing
  - Verification test
  - Production test

- Requirements comes from
  - Internal design specifications
    - System design
    - Intended operational environment
    - Product positioning
  - External requirements (customers & authorities)

- Test methods
  - Often selected relatively freely
  - Low cost, fast and small is an advantage



# WHY DO WE TEST (2)?

- To fulfill **conformance requirements**
  - E.g. from authorities & regulatory bodies
  - Regulatory requirements
  - Ensure co-existence between radio systems, safety etc.
  - Spectrum purity, power, immunity to interference etc.

- Strictly specified requirements
  - Based on simulations and past experience

- Strictly specified measurement methods
  - One or multiple
  - Proprietary method is not good

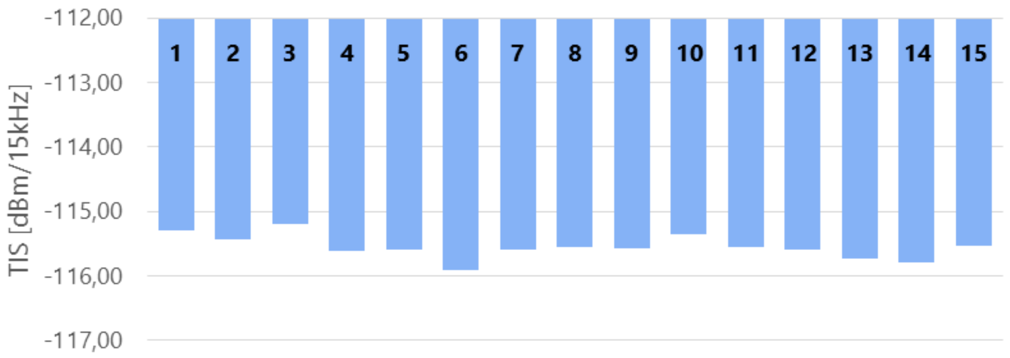
# WHY DO WE TEST (3)?

- To fulfill **customer requirements**
  - Eg. operators like KT, Orange, NTT docomo, AT&T…
  - …or you and me (perception of performance)

- Requirements
  - Can be customer specific
  - Or based on standardized requirements
    - 3GPP, CTIA

# EXPECTATIONS ON TEST RESULTS (1)

- It shall be possible to repeat the measurement and get the same result
  - In different locations with different units of equipment
  - At different times of the day
- Lab environment preferred over unpredictable real life environment



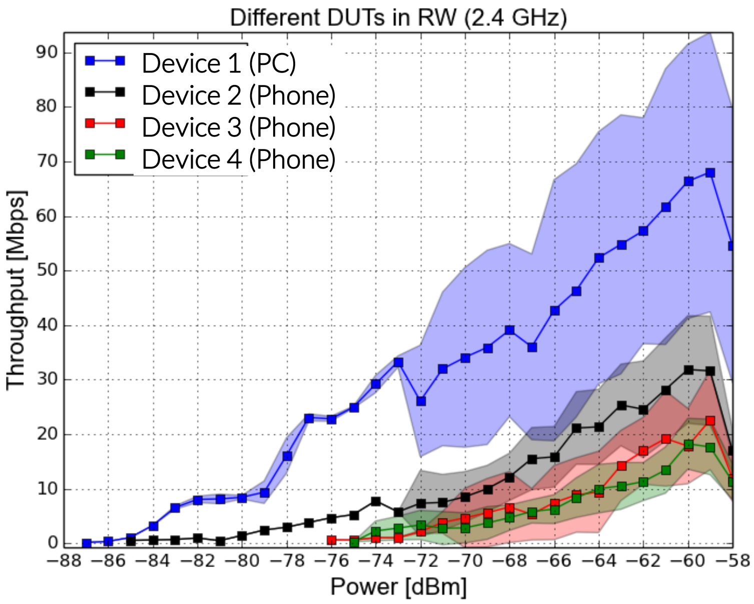

Repeatability testing on receiver sensitivity
Results within +/-0.5dB = OK

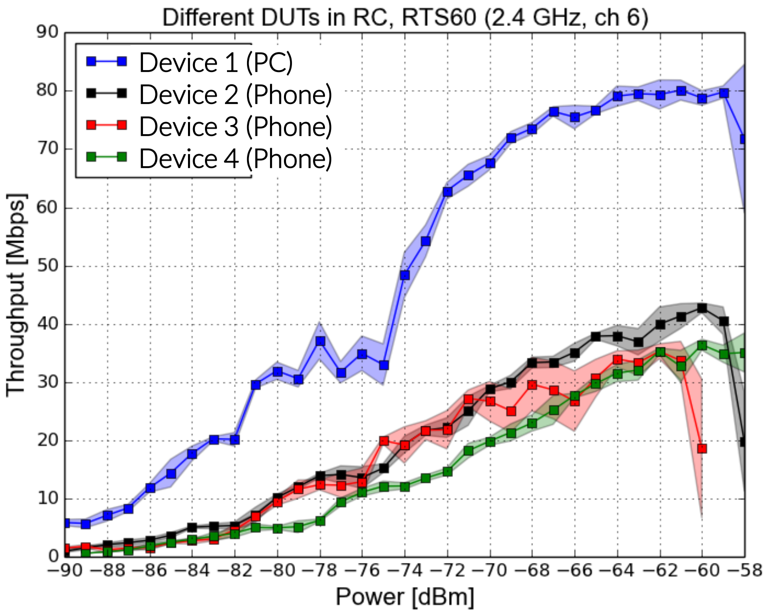
# WLAN EXAMPLE: REAL WORLD VS LAB

- Downlink IP data throughput measurements
  - Domestic house in countryside
    - Far away from other interfering WLAN sources
  - Measured with Bluetest TTS11 WLAN throughput tester
  - Several positions and devices evaluated

# WLAN EXAMPLE - RESULTS

- Reality (residential house) vs lab



# EXPECTATIONS ON TEST RESULTS (2)

- The measurement shall give a relevant result
  - Translating to performance under actual user conditions
    - A good device in the lab shall be good in real life
    - A bad device in the lab shall be bad in real life
  - But we can never replicate real life to 100%
    - Need to select a few representative test cases


  - Compare with automotive emissions testing..
    - Values are completely disconnected from real life
    - and different % off for different cars => ranking between cars is off!
      - => Measurement is of low value

# THE PAST

# 1906-2008

# THE BIRTH OF RADIO REQUIREMENTS

- In 1906 the first International Radiotelegraph Conference gathered 29 states in Berlin to sign the ´International Radiotelegraph Convention´

- Its annex contained the world's first set of rules that later came to be known as the *Radio Regulations*

- These regulations have since been expanded and revised by numerous radio conferences

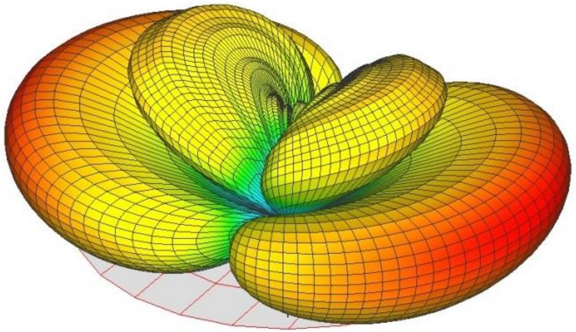
- Focus on co-existence between radios

International Telecommunication Union

# ANTENNA PATTERN TESTING

- Traditionally antenna testing has mainly involved
  - Antenna pattern testing
  - Return loss
  - Isolation between ports in multiport antennas

- Main measurement methods
  - Farfield approaches
  - Near field measurements



Source: Wikipedia

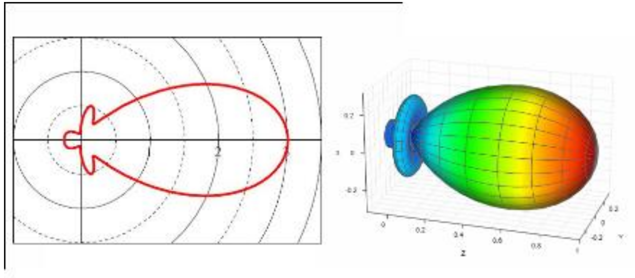
# ANTENNA MEASUREMENT STANDARD

- 149-1979 - IEEE Standard Test Procedures for Antennas
  - Reaffirmed 1990, 2003, 2008
  - Status: active – Approved

- Abstract:
  - This standard comprises test procedures for the measurement of antenna properties.
  - It is a comprehensive revision of the previous test procedure ANSI/IEEE Std 149-1965.
  - It is assumed that the antenna to be measured is a **passive, linear, and reciprocal** device.
  - The measurement of radiation patterns on an antenna range, the design of antenna ranges or antenna test facilities, the instrumentation required for the antenna range, directions for the evaluation of an (existing) range, and the operation of ranges are discussed.
  - A variety of special measurement techniques are also included.

# FARFIELD PATTERNS

- At long distances the radiated pattern of an antenna has a shape that doesn't change with increasing distance
- The farfield distance depends both on the size of the antenna and the wavelength
- Short farfield distance for small antennas:
  - Dipoles
  - Patch antennas
  - Cell phone antennas
- Long farfield distance for large antennas:
  - Reflector antennas
  - Base station antennas



$$d = \frac{2D^2}{\lambda}$$

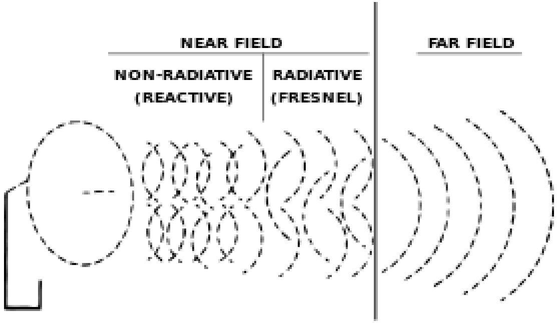
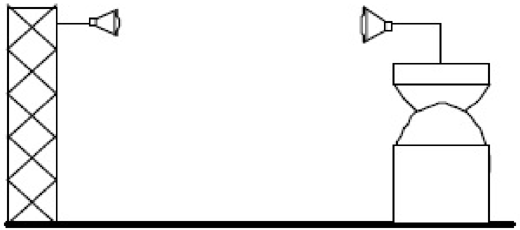


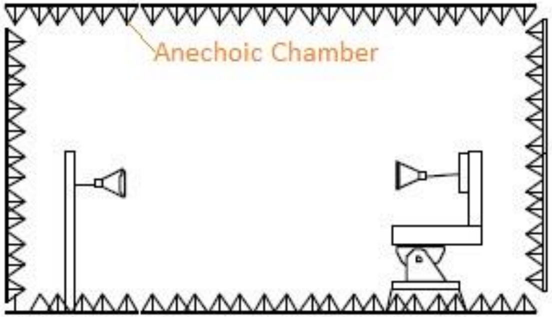

Illustration from www.wikipedia.org

# FARFIELD MEASUREMENT RANGES

- A planar wave is created by simply placing DUT far from measurement antenna
- DUT antenna is rotated to sample pattern in different directions of sphere
- For wireless devices mainly performed in an anechoic chamber
- Vector Network Analyzer often used as test instrument



Outdoor Elevated Antenna Range

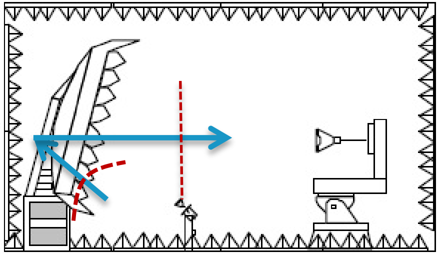



Indoor Far Field Antenna Range

Illustration from www.test-and-measurement-world.com

# COMPACT RANGE (CATR)

- A parabolic surface converts a spherical wave to a plane wave
- The DUT is placed in region with planar wavefront
  - Then rotated to sample various directions



Compact Antenna Range

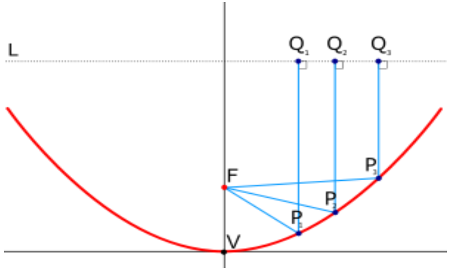
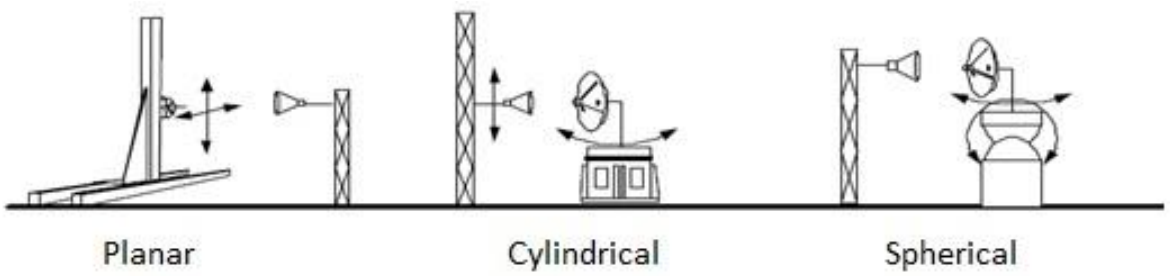



Illustration from www.test-and-measurement-world.com and www.wikipedia.org

# NEARFIELD RANGE

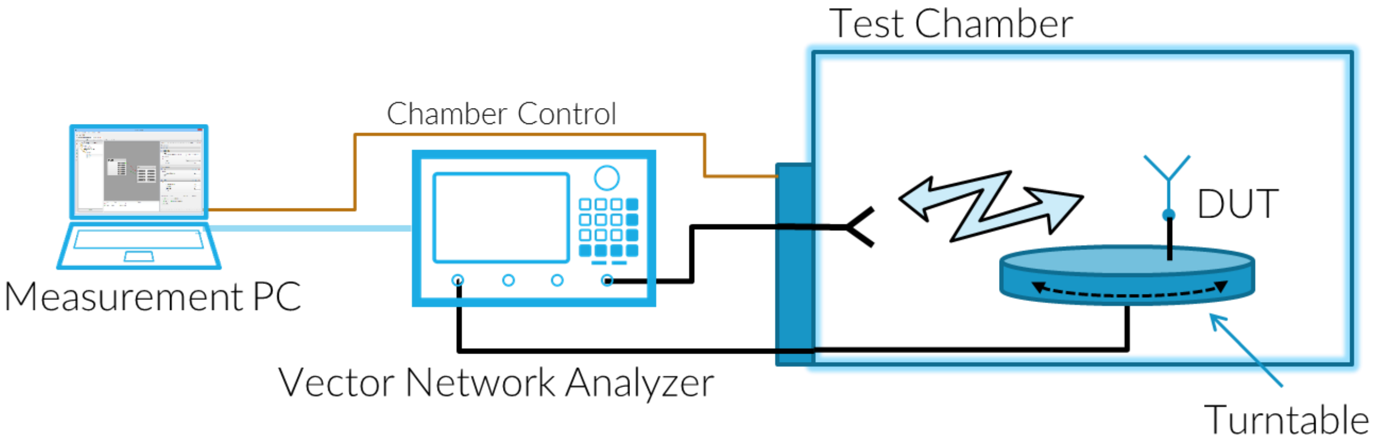
- Field is sampled in close vicinity of antenna using a probe antenna
  - Farfield is computed from acquired nearfield data
- Planar nearfield to farfield transform is closely related to discrete Fourier transform




Near Field Antenna Ranges

# PASSIVE ANTENNA MEASUREMENTS

- Typical test setup
- VNA sends out test signal
  - Measures transmitted power and reflected power over frequency

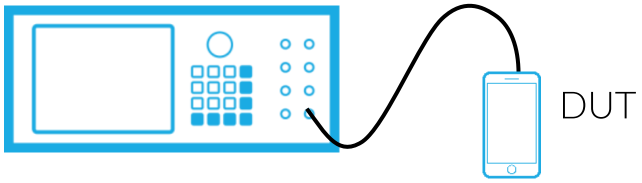


# ADDING THE RADIO TO THE ANTENNA

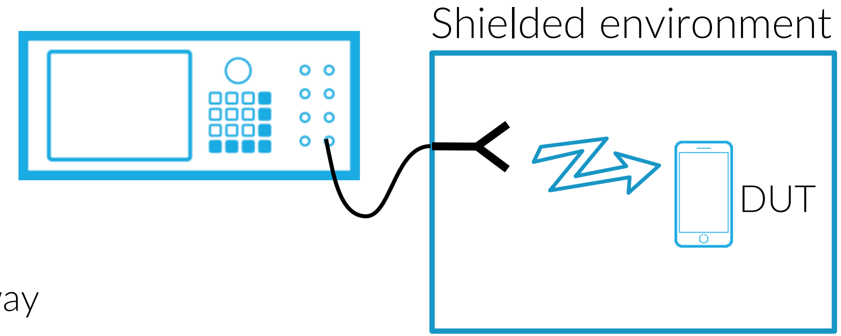
- Ericsson NMT
  - "Harry Hotline"
  - Early 80's

# CONDUCTED vs OTA

- Conducted testing
  - The device under test (DUT) is connected via cables to the measurement instrument
  - Easy test set-up but limitations in what can be measured
    - Quickly gets more complicated if channel emulators are added
  - Antenna performance including matching between front end and antenna **not included** in measurement




- Over the air (OTA) testing
  - The DUT is connected via radio waves, “over the air”, to the test instrument
  - DUT placed in a controlled radio environment shielded from interfering signals
  - Measures the actual performance of the device the way it is intended to be used



# SISO – SINGLE IN SINGLE OUT

- The basic radio
  - One transmitter antenna
  - One receiver antenna
    - Receiver diversity on base stations

- Radio examples
  - NMT
  - GSM
  - WLAN – 802.11 a/b/g
  - Bluetooth

# CELLULAR STANDARDS
## ACTIVE SISO TESTS

- OTA Radio performance testing
  - GSM
  - WCDMA

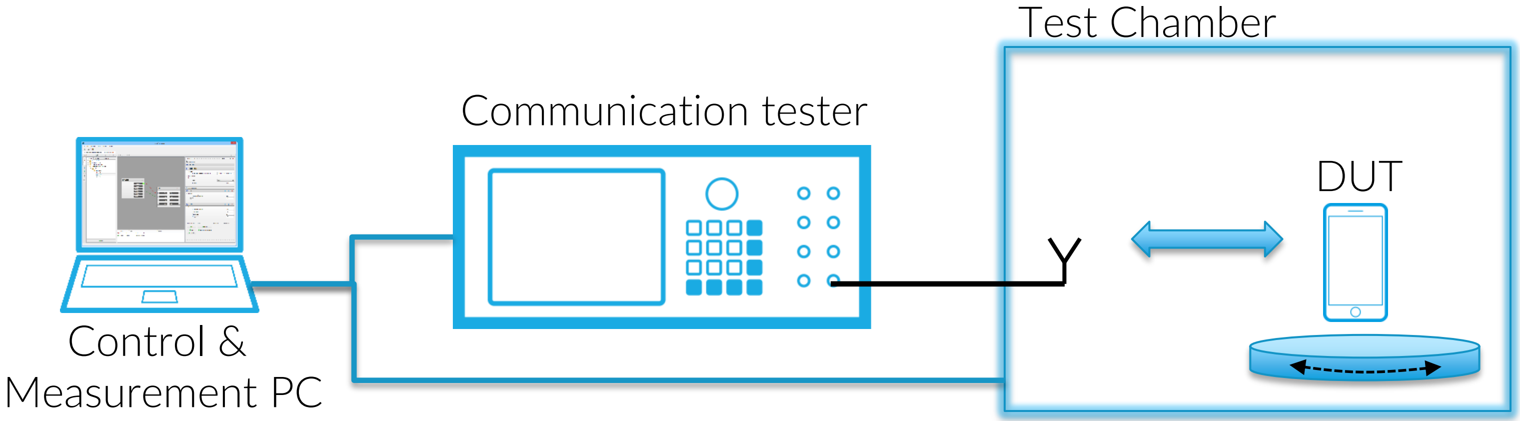
- TRP – Total Radiated Power
  - Actual transmitted power from the antenna (dBm)
- TIS – Total Isotropic Sensitivity/TRS – Total Receiver Sensitivity
  - Receiver sensitivity when averaged in all directions (-dBm)

- Typically measured in every supported band and low, mid, high frequency within each band

- For example 3GPP TS34.114

# TRP & TIS TEST SETUP

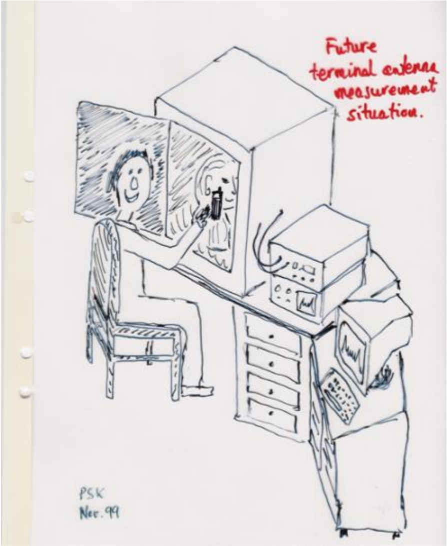
- Traditionally used the anechoic chamber measurement method
  - Replace Vector Network analyzer with a base station communication tester
  - Signaling test:
    - Base station sends command to device OTA (Set standard, frequency, BW etc)
    - Base station receives information OTA from the device (like BER or received power)



# THE ADAPTATION OF THE REVERBERATION CHAMBER TO WIRELESS PERFORMANCE TESTING

- Also called mode stirred chamber
- Reverberation chambers (RC) invented in the 1960's
  - Then mainly used for EMC measurements
  - Can generate high field strengths with low power

- In 1999 Prof. Per-Simon Kildal had an idea
  - Adapt the RC to wireless performance testing
  - Much higher degree of accuracy and repeatability needed than for EMC
  - Focus on TRP & TIS + passive antenna measurements
    - But not antenna pattern!



# THE PRESENT 2009-2020

# THE WIRELESS EVOLUTION

- More and more equipment becomes wireless
  - Increased need for capacity, speed & reliability
- MIMO (and diversity) are introduced on a large scale
  - Multipath radio environment supports multiple data streams in the same frequency space
  - Enhances capacity and/or coverage (reliability)
  - MIMO implementation currently driven by LTE and WLAN
- Devices use multiple communication standards...
  - LTE, Wi-Fi, Bluetooth etc.
  - Often at the same time
- ...or multiple carriers/radios on the same standard
  - LTE-Advanced - carrier aggregation

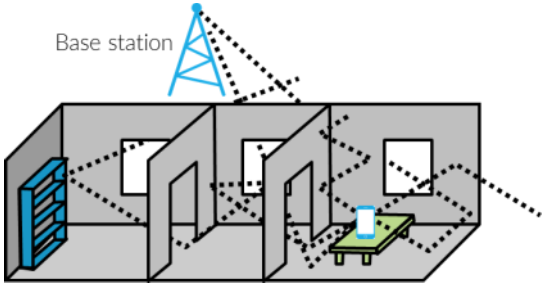
# MULTIPATH PROPAGATION

- In the beginning of radio communication multipath was an undesirable feature of radio propagation that cause signal distortion

- Later technologies appeared that mitigate multipath distortion
  - I.e. receiver diversity

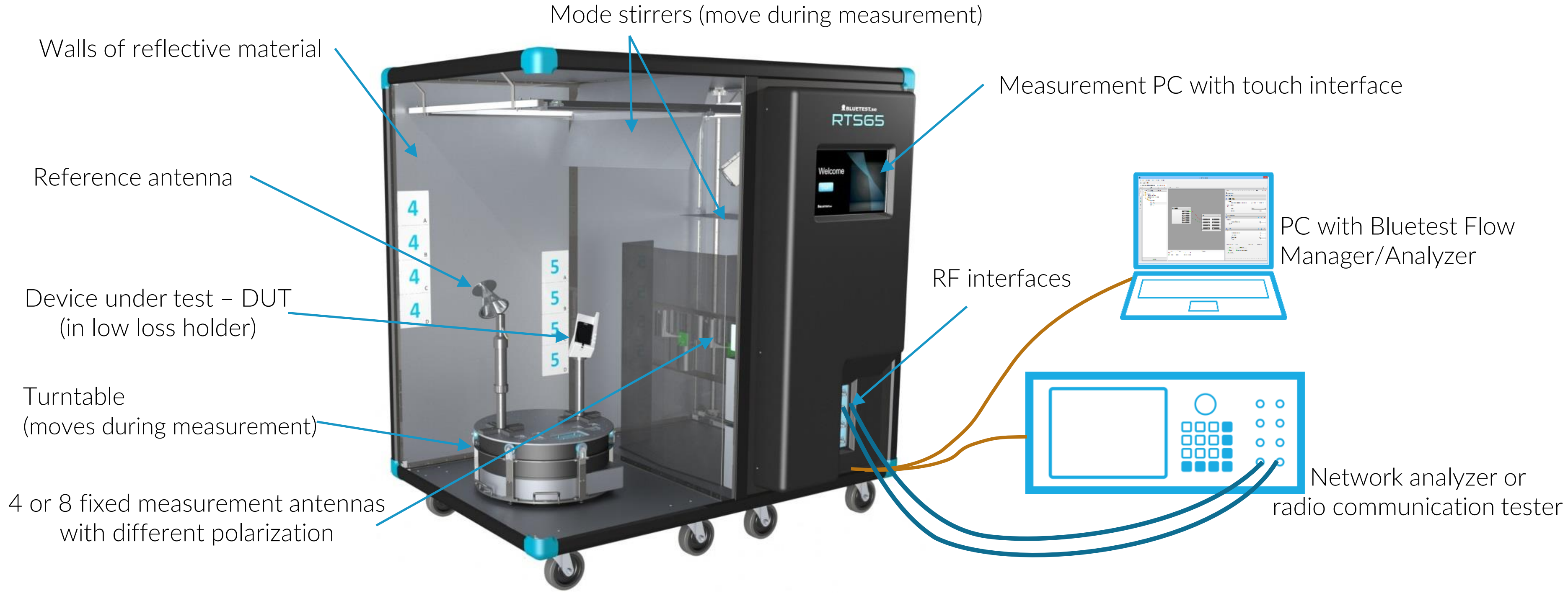
- Now MIMO radio technologies such as LTE and WLAN 802.11n/ac **depend** on multipath to deliver high data throughput

- Wireless devices mainly used in-doors and in city environments
  - Excellent environments for multipath




# Opportunities for new test methods!

# THE REVERBERATION TEST SYSTEM

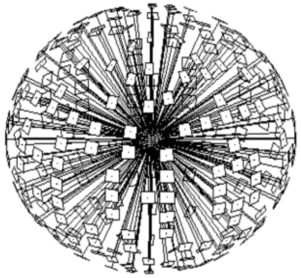



One test session consists of collecting many samples to create a stable average value

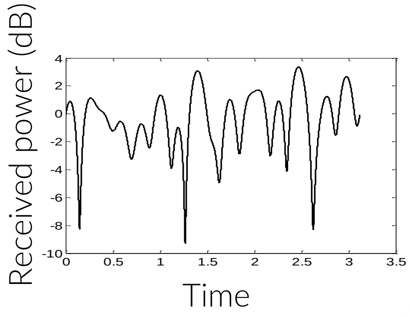
# USEFUL PROPERTIES OF THE REVERBERATION CHAMBER

- Creates scattering environment
- Average transmission level in chamber proportional to
  - Total radiated power
  - Radiation efficiency of antenna


- Isotropic field environment when averaged over large number of independent field samples



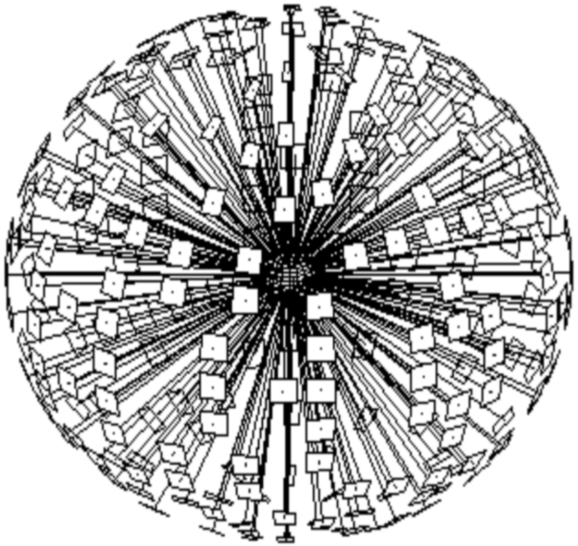
- Rayleigh faded signal transmission



# A BIT OF RC THEORY

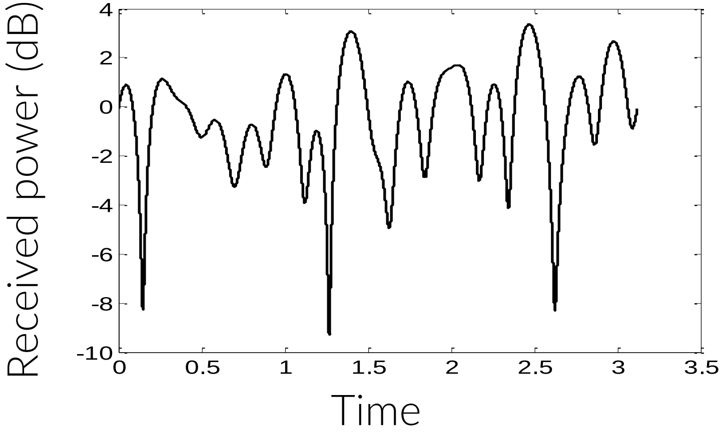
# ISOTROPIC FIELD ENVIRONMENT

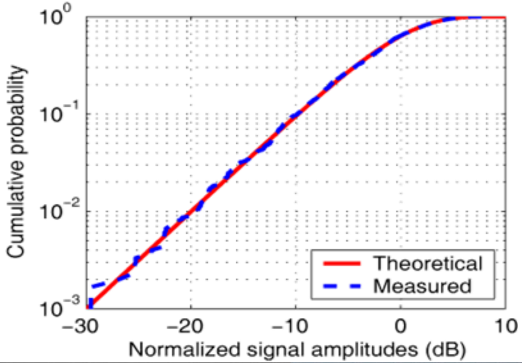
- Any angle of arrival equally probable
- Any polarization equally probable
- Average power equal in each direction and polarization
- Statistical property
  - Valid for a complete sequence
  - Instantaneous field NOT isotropic
- RIMP – Rich Isotropic Multipath
- We can extract
  - Radiation efficiency
  - Reflection coefficient
  - Total Radiated Power
  - Total Isotropic Sensitivity



# RAYLEIGH FADING

- Transmission samples in chamber are Rayleigh distributed
- Reverberation chamber = multipath fading simulator
- Able to extract important parameters for small antennas/wireless units:
  - Diversity gain
  - MIMO capacity

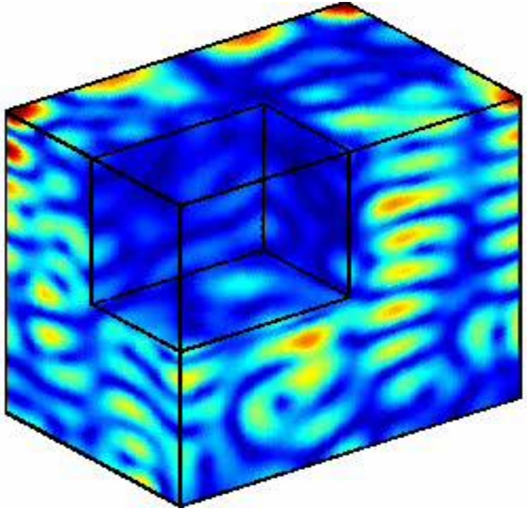


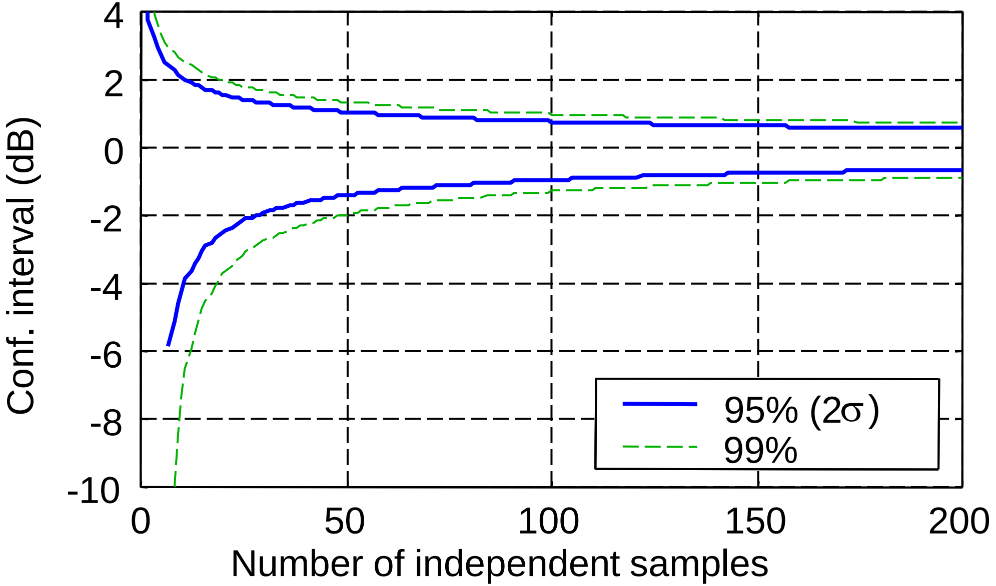
# SIMULATED RAYLEIGH FADING

- Instantaneous signal level will differ over
  - Time (mode stirrers moving)
  - Position in the chamber

- Average over time is the same regardless of position in the chamber (within certain limits)



# CONF. INTERVAL FOR MEAN RECEIVED POWER




Standard deviation for the mean received power goes as:

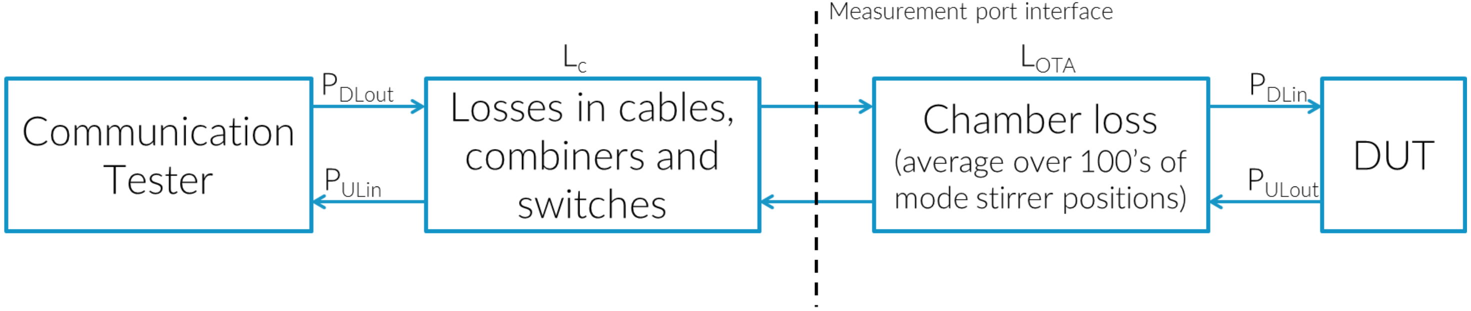
$$1/\sqrt{N_{indep}}$$

$N_{indep}$ is the number of independent field distributions created and sampled

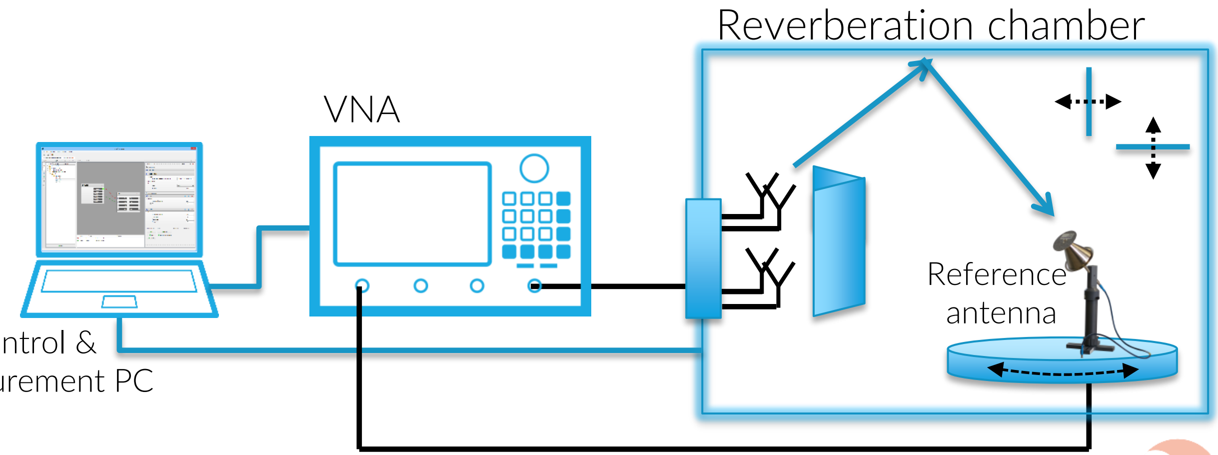
The independence of samples is determined by how well we mode stir the chamber

*For more info, see Kostas, Boverie, "Statistical model for a mode-stirred chamber", IEEE Trans. on EMC, Vol 33(4), Nov 1991.*

# SYSTEM CALIBRATION

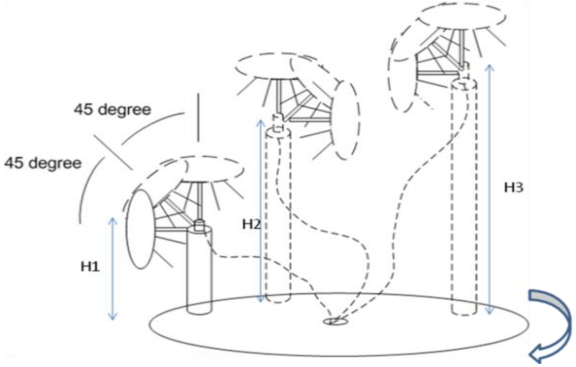


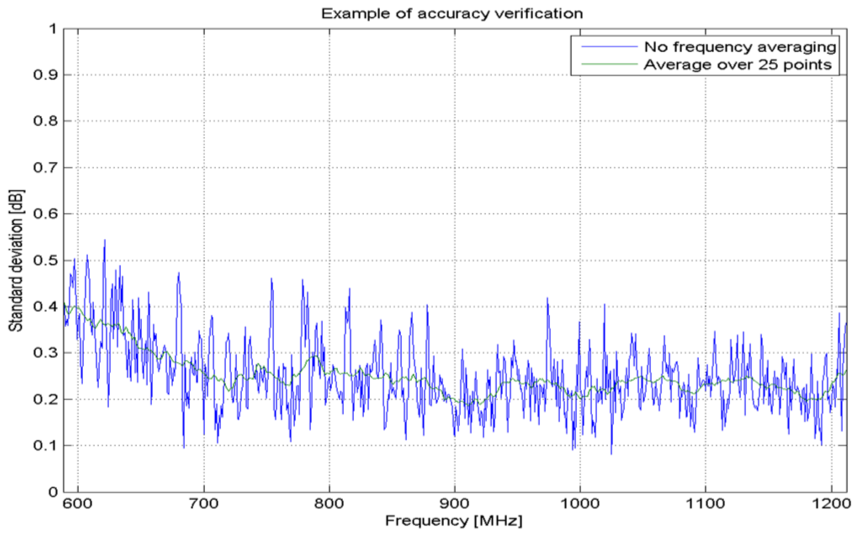

- Use a VNA to measure cable loss and chamber loss
- A reference antenna with known loss is used as the DUT
- Average chamber loss during continuous mode stirring



# CHARACTERIZING MEASUREMENT UNCERTAINTY IN A REVERBERATION CHAMBER

- Measure average transfer function in chamber
- Repeat many times (e.g. 9)
- Calculate standard deviation between repetitions



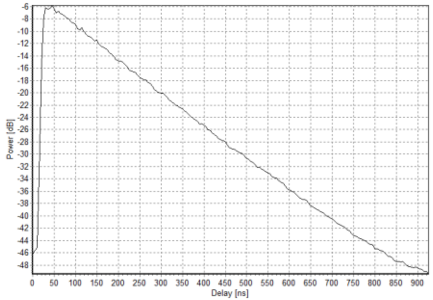
# BREAK

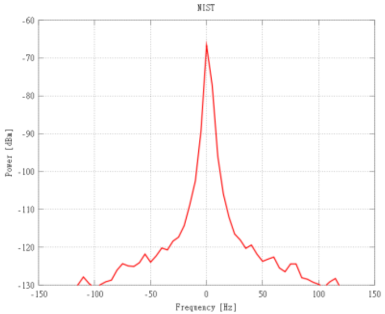
# ADAPTING TEST TO REAL LIFE
## (WHAT DOES REAL LIFE LOOK LIKE?)

# CHANNEL MODELS

- The channel model describes the RF environment from base station to device
  - A model of the real life environment
  - The channel model has an impact on throughput measurements

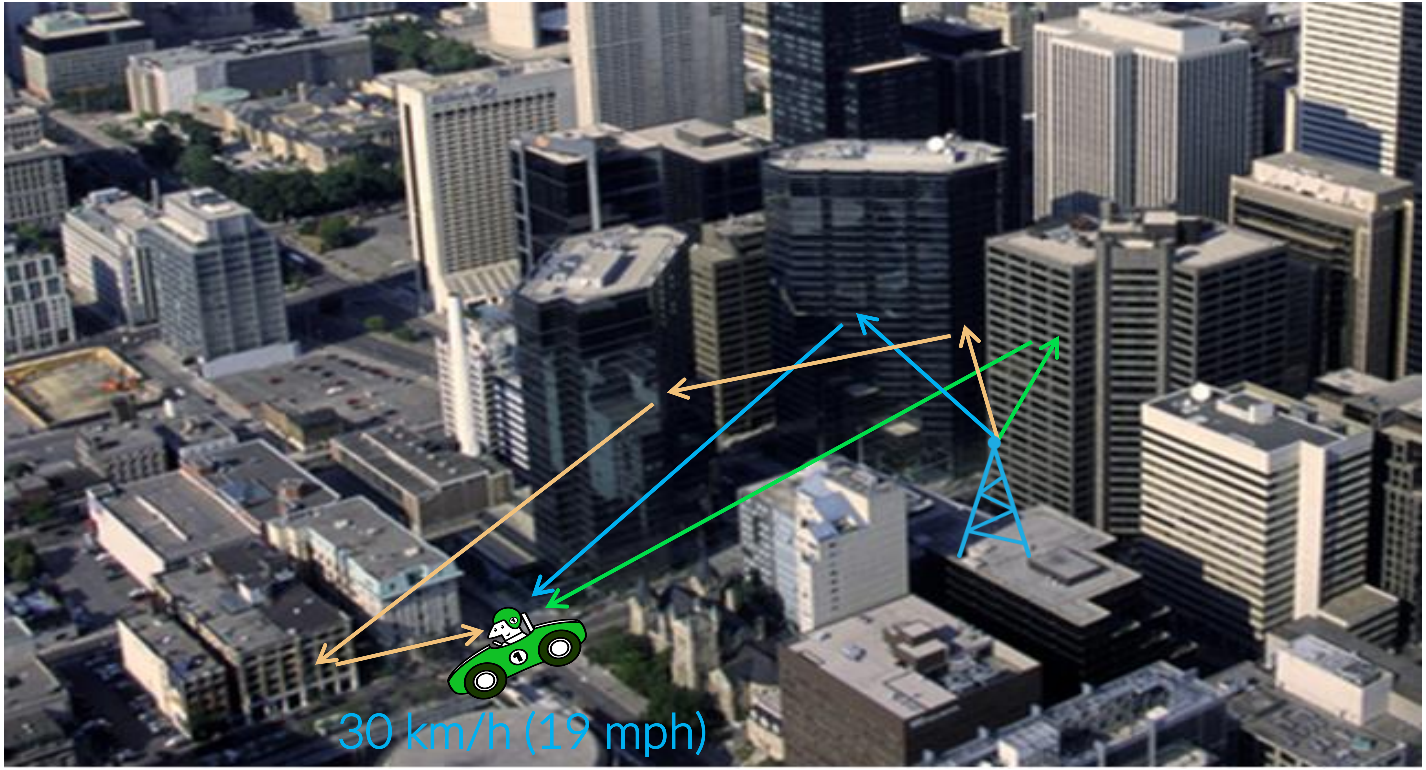
- Inherent, "built-in" RC channel model
  - NIST channel model (3GPP TR 37.977)
    - One delay spread cluster (tuned to 80ns RMS delay spread)
    - Low Doppler speed
  - With or without interference
  - Example of real life situation
    - Outdoor to indoor scenario with DUT having walking speed
      For example: Person using phone at work




NIST = National Institute of Standards and Technology

# URBAN AREA WITH MACRO BASE STATION



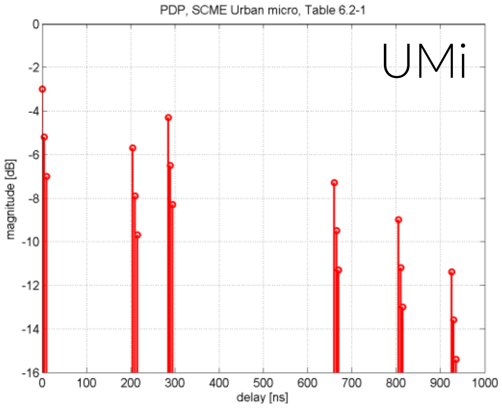
# CHANNEL MODEL PROPERTIES

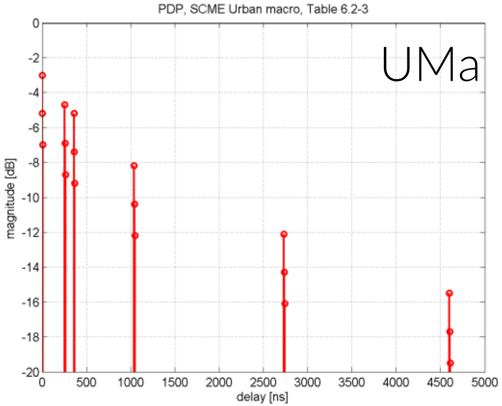
- Doppler - Speed of device
- Delay spread - Distance to travel
  - Base station to device
  - For each RF path
- Angle of departure – Between RF path and base station antennas
  - For each RF path
- Angle of arrival – Between RF path and device antenna
  - For each RF path
  - Note that device antenna can be arbitrary angled towards RF paths in real life
    - I.e a full isotropic 3D evaluation is beneficial

# UMi & UMa CHANNEL MODELS

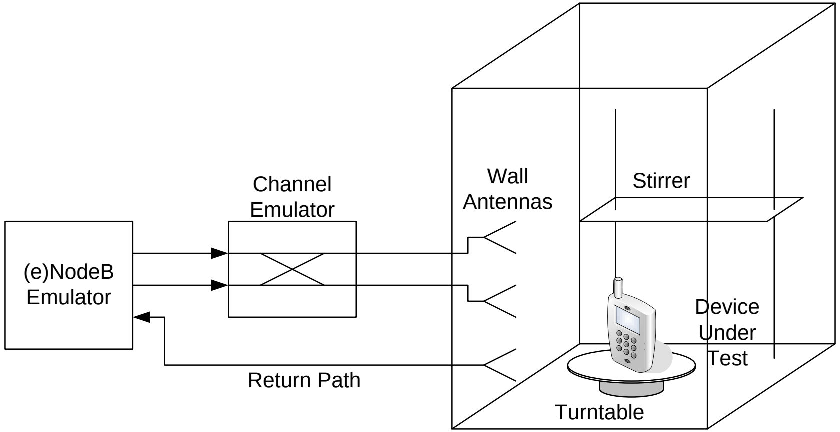
- Commonly used channel models for 3G/4G
  - UMi = Urban Micro (cell)
  - UMa = Urban Macro (cell)
  - Description can be found in 3GPP TR37.977

- Short summary of properties:
  - UMi
    - 30km speed (Doppler)
    - **Low** base station antenna **correlation**
    - **Short delay** spread profile
  - UMa
    - 30km speed (Doppler)
    - **High** base station antenna **correlation**
    - **Long delay** spread profile
  - Both are normally used without interference



# RC + CE MEASUREMENT SETUP



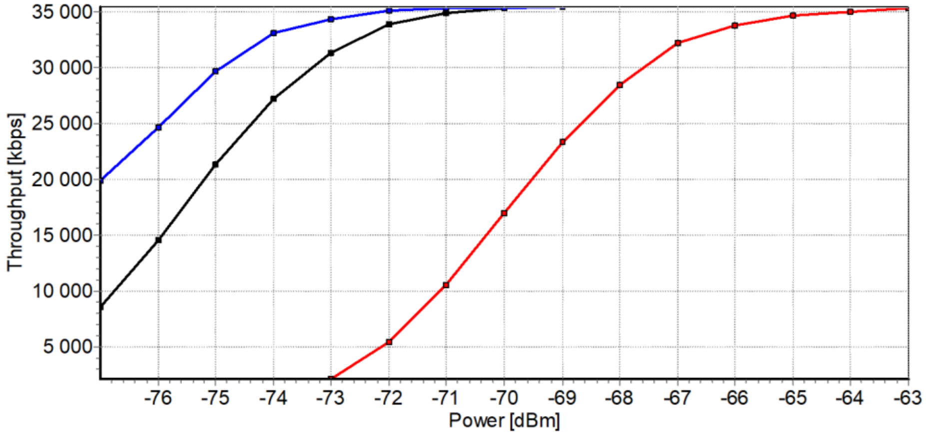

- Channel Emulator adds
  - Doppler shift (speed)
  - Delay spread
    - Multiple reflections spread out in time
  - Correlation between transmitter antennas
  - UMi-IS and UMa-IS are isotropic (RC adapted) versions of the UMi and UMa models

- The reverberation chamber environment still ensures:
  - An isotropic environment when averaged over a large number of independent field samples
  - Polarization balance
  - A full 3D evaluation representative to MIMO channel conditions

# MEASUREMENT EXAMPLE

- MAC layer data throughput
  - Single carrier
  - 2x2 MIMO

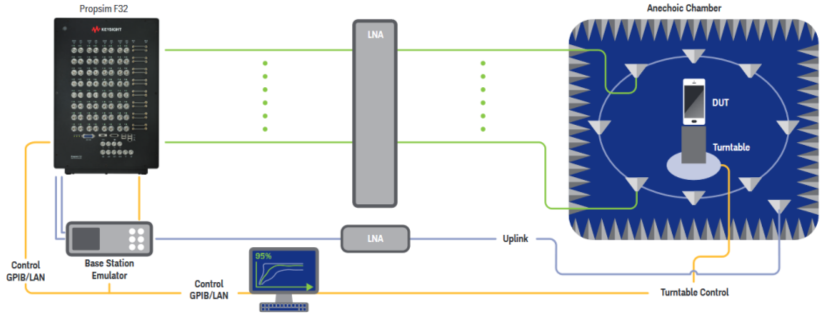
- Blue = NIST
- Black = UMi
- Red = UMa



# MPAC
## MULTIPROBE ANECHOICH CHAMBER

- Many source antennas surround DUT in an anechoic chamber
- Excitation on each probe is controlled by channel emulators
  - Can emulate specific and standardized channel models
- This allows generation of arbitrary field in close vicinity to the DUT in the azimuth plane
- Typical size of testzone is 0.8 λ radius with 8 probes
  - I.e. 10cm @ 2.5GHz
- ”3D-testing” by rotating device

- Still only support for 1 carrier with 2x2 MIMO



# BUT WHAT ABOUT STANDARDS?

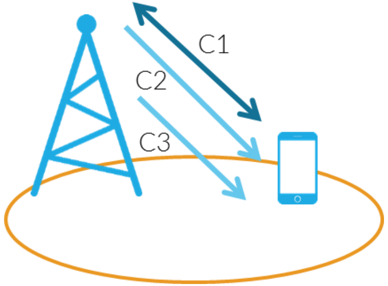
- Performance requirements was a long running soap opera ended after its 8th season
  - The big players didn't like the new kid on the block..
  - Lots of politics!
  - But we agree to focus on data throughput

- MPAC standard for 1CC 2x2 MIMO
  - For small devices
- But RC standard for large form factor devices
  - And de-facto standard for Carrier Aggregation and 4x4 MIMO

Late standards results in operator specific measurements
(and room for proprietary innovations…)

# THE NEED FOR SPEED

- LTE-Advanced
  - Carrier Aggregation
    - In-band or between bands
    - 2-band DL carriers launched in Korea June 2013

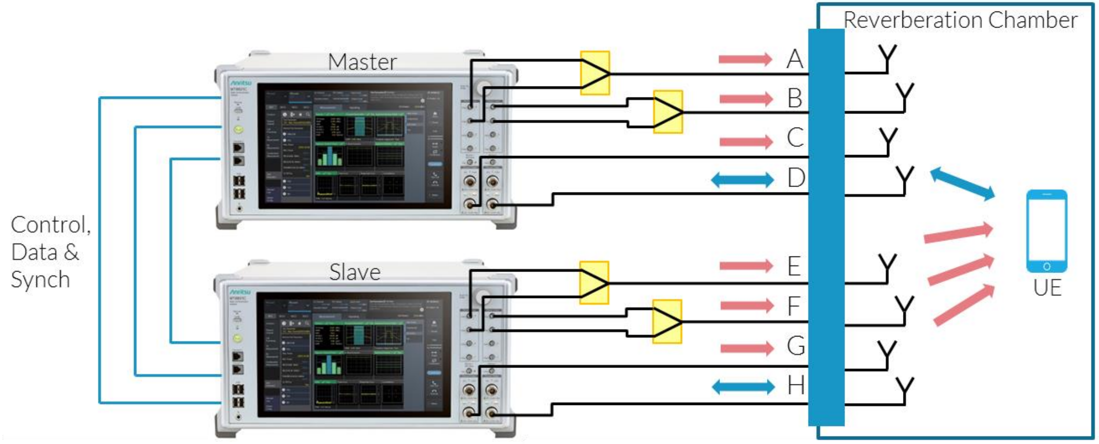




- LTE today:
  - 5 or even 6 carriers
  - 4x4 MIMO
  - 256QAM
  - 10 streams breaks the 1Gbps barrier

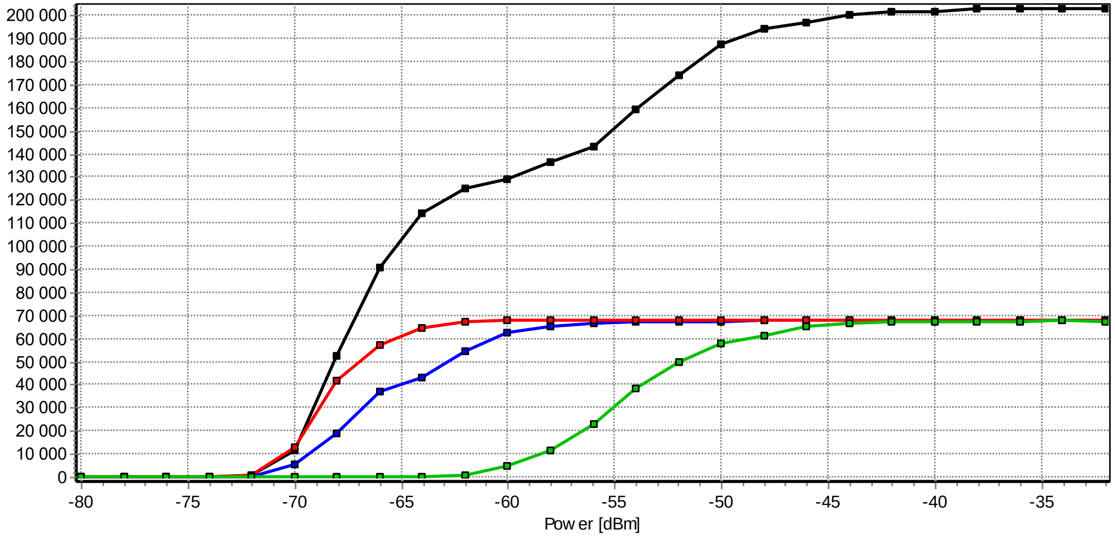
# LTE CARRIER AGGREGATION

- Measure TPUT, TIS & TRP with LTE carrier aggregation
  - Very straight forward to add additional MIMO streams to the test set-up because of the reverberation chamber properties
    - Multiple carriers at multiple frequency bands supported at the same time
  - ”Just add a cable and a measurement antenna”




>1Gbps LTE configuration, Anritsu MT8821C shown

# 3-BAND CA TPUT EXAMPLE RESULT



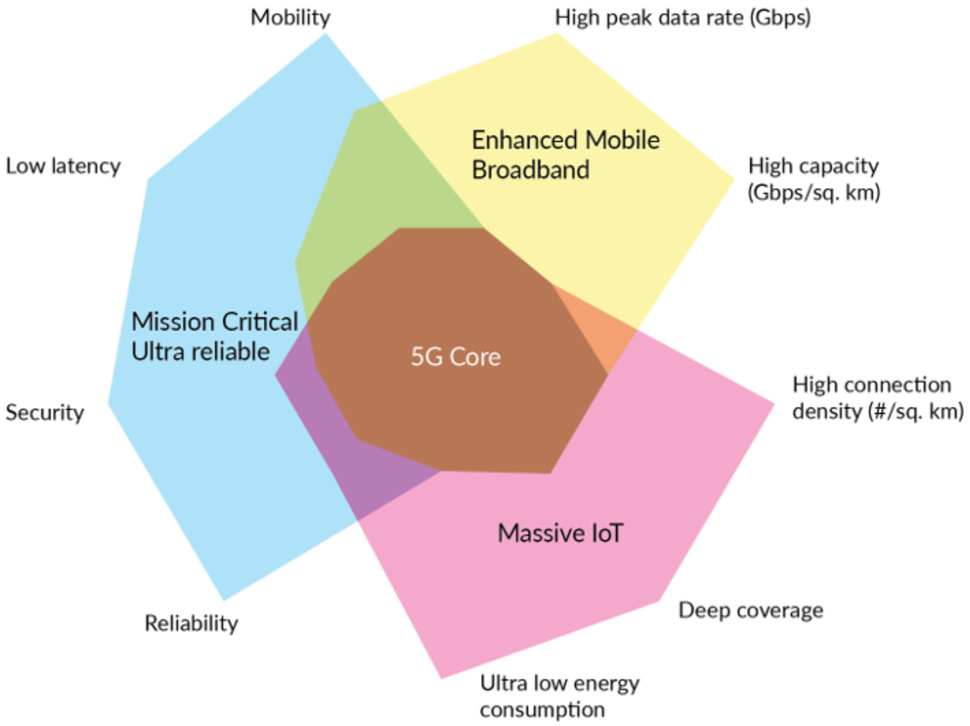

- PCC band 3 (blue)
- SCC1 band 1 (red)
- SCC2 band 5 (green)
- Aggregated capacity (black)

- Bands correspond to 850MHz, 1800MHz and 2100MHz
  - Which band is green curve and why?

# AND THEN COMES…

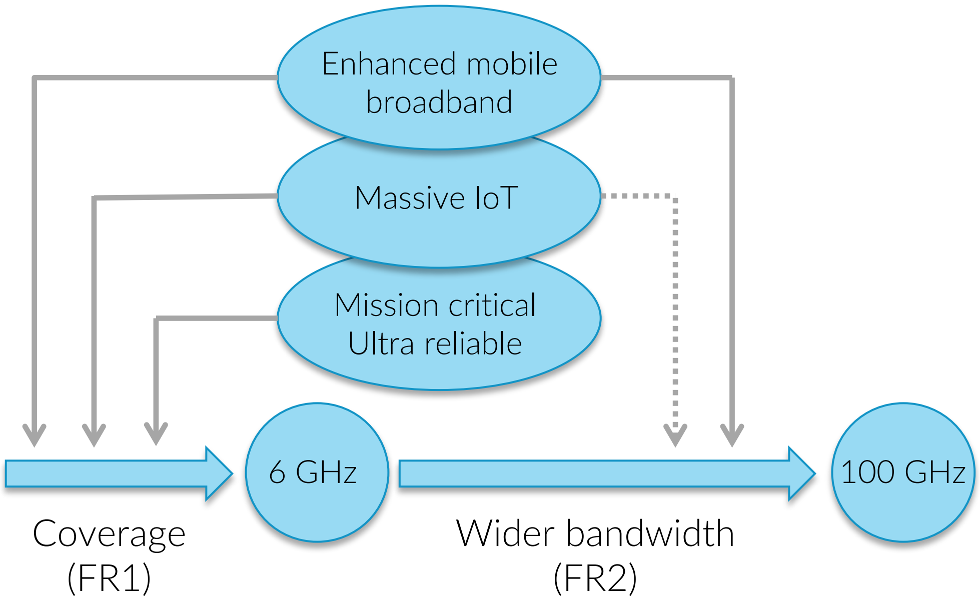
# THREE MAIN 5G USE CASES

- 5G wants to do everything
- What is the impact on testing?
  - Different test solutions?
  - Testing of maximum data rate different from testing of ultra-reliability etc.



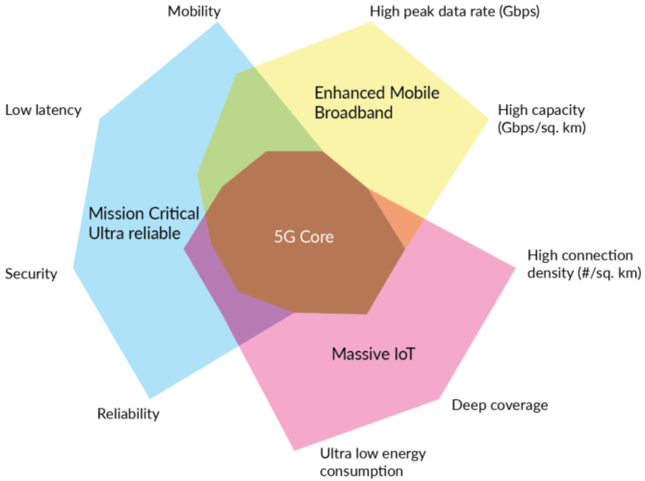
# 5G ADDS mmWAVE BANDS

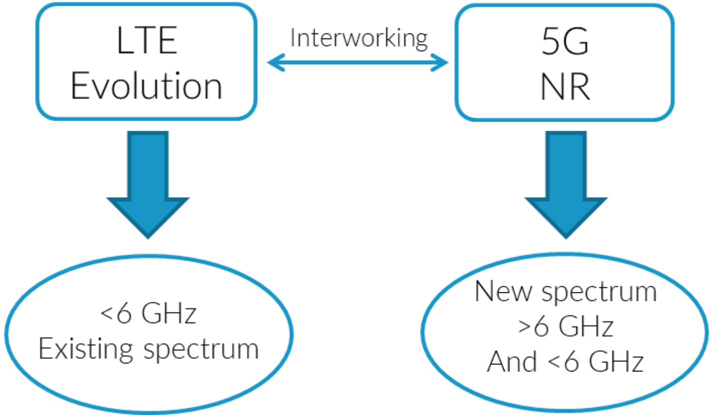
- More spectrum needed to support increased data rates
- Frequency bands below 6 GHz provide
  - Good coverage
  - Small to medium bandwidth
- Frequency bands above 6 GHz provide
  - Wide bandwidths - Good capacity
  - Poor coverage due to increasing path loss
- Dual connectivity needed to provide
  - Coverage
  - Connection stability
  - Capacity



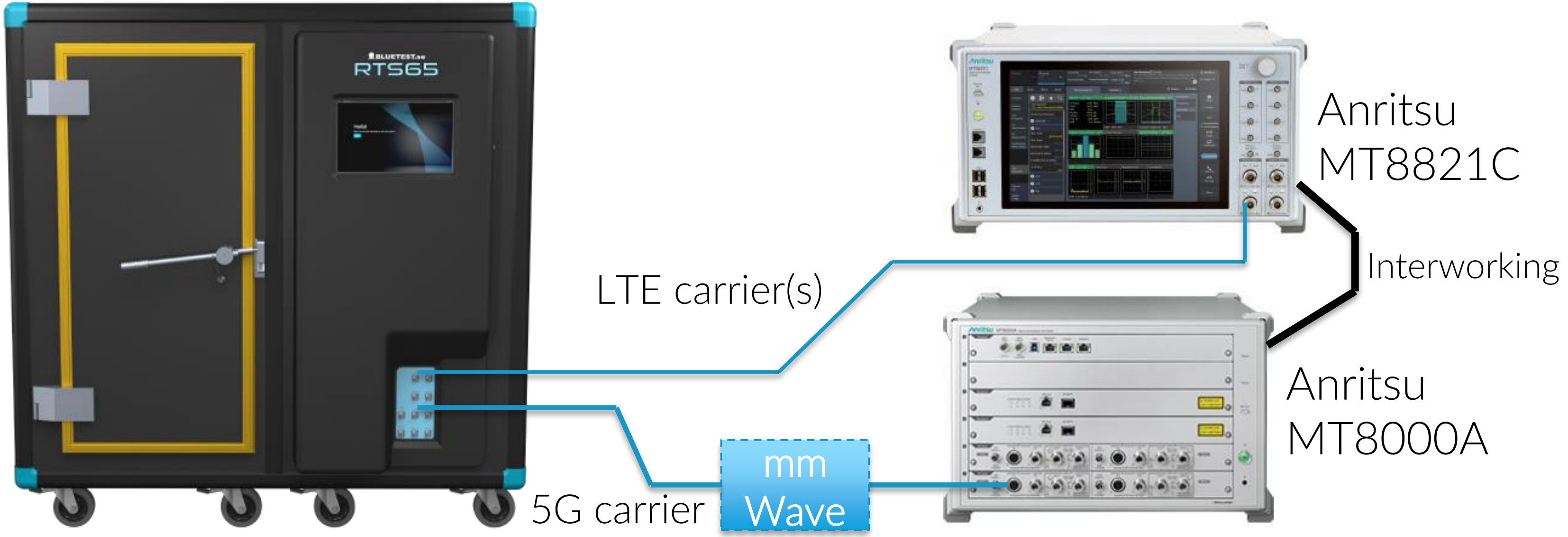
# 5G – INITIAL FOCUS

- Strong focus on Enhanced broadband for initial deployment of 5G
- 5G Non-Stand-Alone, Dual connectivity with LTE carrier (EN-DC)
  - 5G carrier on sub 6GHz
  - or mmWave (28/39GHz)
- Advantage if test solution covers both sub 6GHz and mmWave



# BLUETEST 5G TEST SET-UP

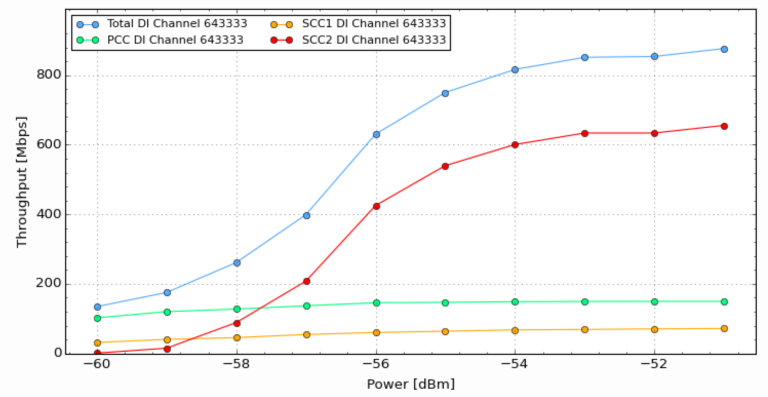



- For sub 6GHz the MT8000A is connected directly to the chamber
  - No mmWave remote head is needed
- Supports simultaneous measurement on LTE & 5G including aggregated throughput

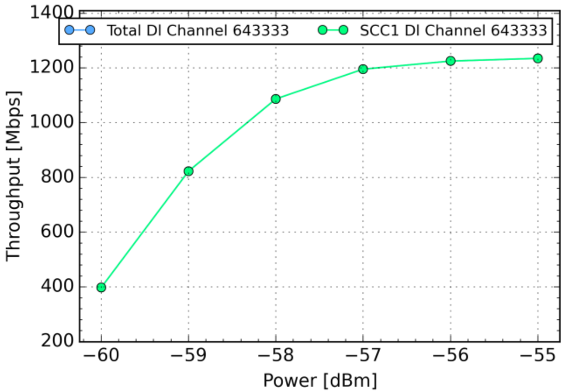
MT8000A & MT8821C pictures from Anritsu

# 5G MEASUREMENT EXAMPLE

- 2CC LTE
  - 20MHz + 10MHz
  - Band 3 + 5
  - 4x4 MIMO
  - MCS28
- 1CC 5G NSA
  - Band n78 (3.5GHz)
  - 100MHz BW
  - 2x2 MIMO
  - 64QAM
- Up to 5CC LTE can be supported





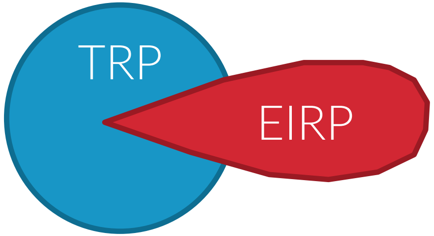



- 5G NSA
  - Band n78 (3.5GHz)
  - 100MHz BW
  - 4x4 MIMO
  - 256QAM
- (LTE anchor in band 3)

# EIRP & EIS ON mmWAVE (FR2)

- Interesting to also evaluate antenna pattern, gain and pointing direction
  - Directivity needed for link budget

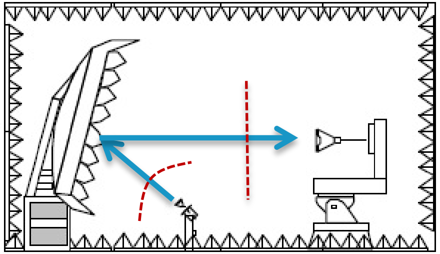
- 3GPP focus on EIRP, EIS for mmWave devices
  - Include antenna gain in performance figure
  - $EIRP = TRP + D_{dBi}$
  - $D_{dBi}$ = antenna directivity in main beam (vs isotropic antenna)




- Note: EIRP/EIS only of interest for 5G on mmWave
  - 5G on sub 6GHz expect to continue with TRP/TIS due to low antenna gain/no beamforming

# CATR – COMPACT ANTENNA TEST RANGE

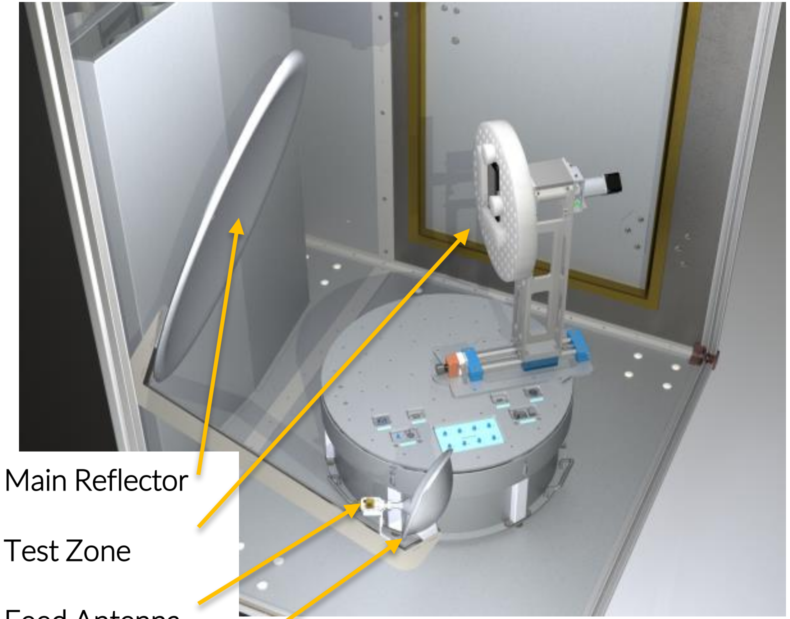
- Main (only) 3GPP method for measuring beamforming mmWave devices



Compact Antenna Range

- Can EIRP/EIS be measured in a Reverberation Chamber?
  - Several possible ways forward have been evaluated
  - Some solutions require “white box” testing due to small quiet zone

# CATR IN RTS65



Main Reflector

Test Zone

Feed Antenna

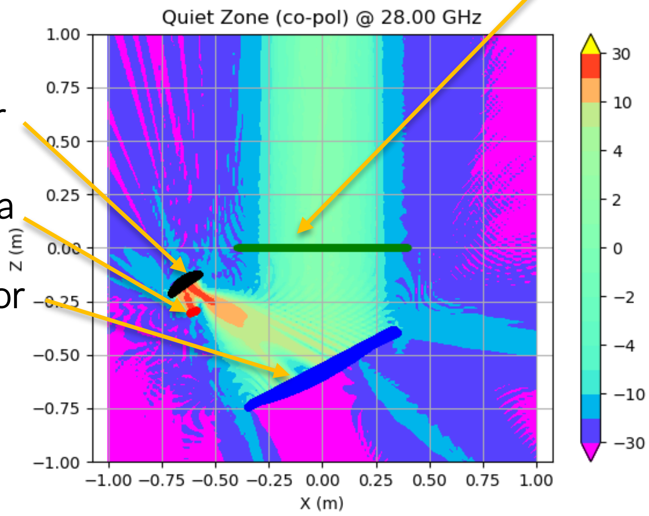
Sub Reflector

Test Zone

Sub Reflector

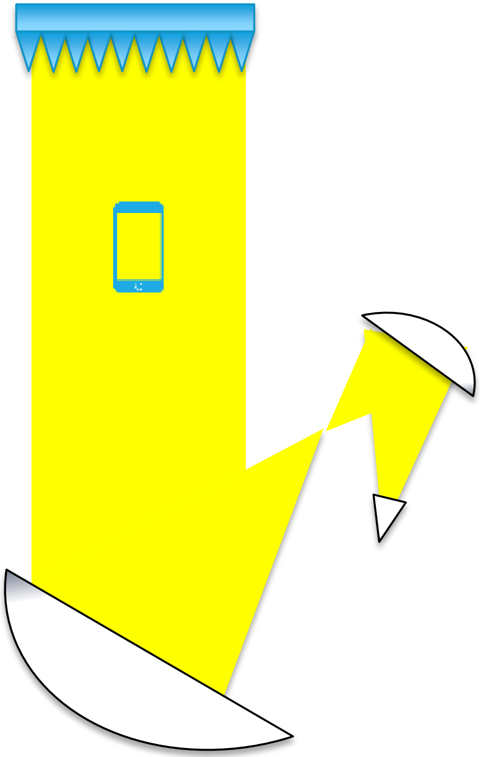
Feed Antenna

Main Reflector

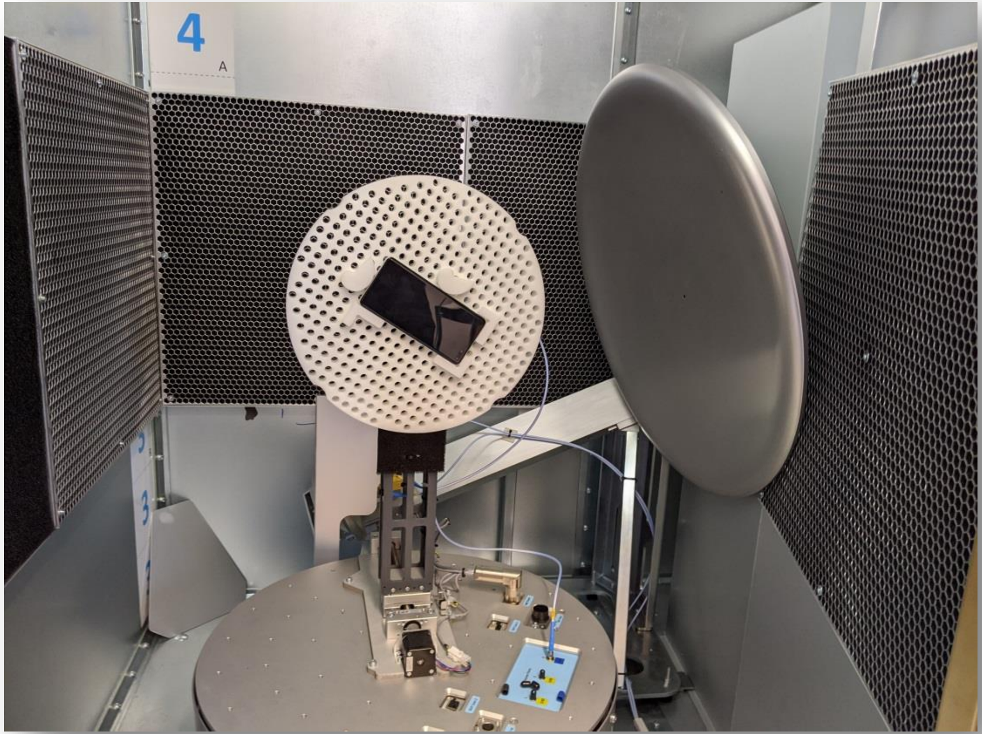


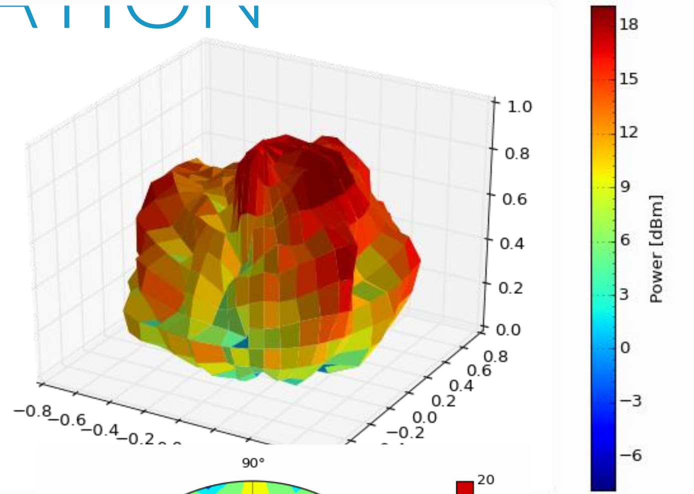
# WHAT ABOUT ABSORBERS ?

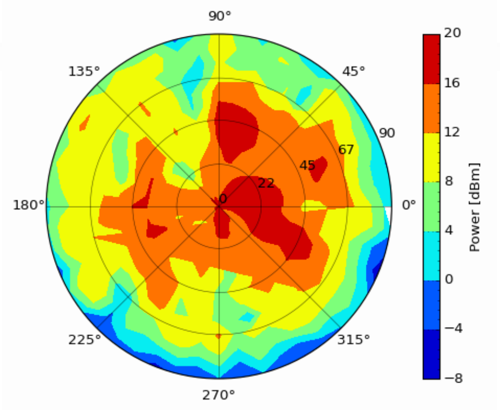
- Important to minimize interfering reflections
  - In RC we have lots of reflections
  - And we still want reflections in FR1!
- Control radiation flow and place absorbers in strategic places to get good directive measurements
  - Oversized reflectors
  - Patentented frequency selective absorbers



# FINAL CATR CONFIGURATION

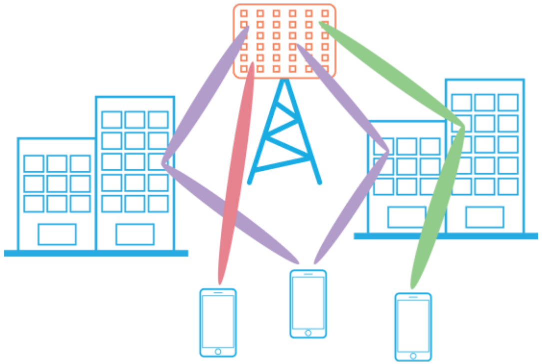


# TESTING OF 5G BASE STATION

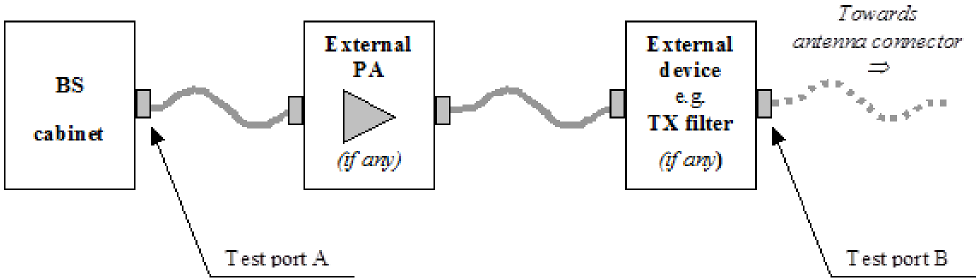
- Antenna arrays & **Massive MIMO**
  - Base stations with 32-128 antenna elements
- "Beamforming"
  - On sub 6GHz as well as mmWave
  - Improves capacity and range



- Measurement standards focus on conformance testing
  - I.e. fulfill a minimum spec to co-exist with other radios

# CONFORMANCE TESTING

- Previous (GSM, WCDMA, LTE) conformance testing specified as conducted
  - The requirements apply to **all** antenna connectors



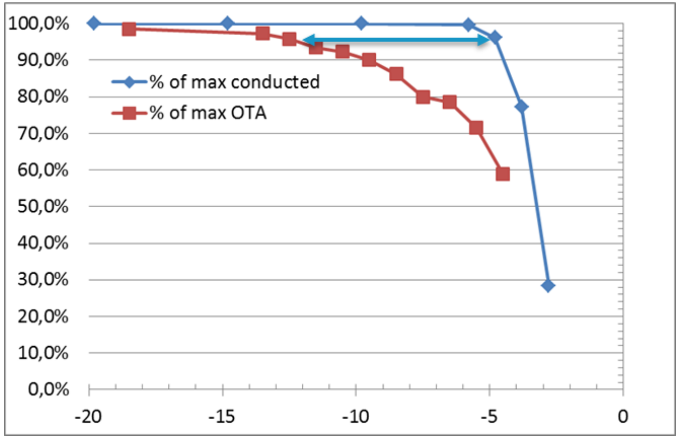

- But how to do with Massive MIMO
  - 32 or more antenna connectors…
  - Integrated electornics and antenna elements
  - mmWave frequencies

- Base station conformance testing need to move to OTA
  - 3GPP TS38.141-2

# RX CONFORMANCE

- Large challenges when going OTA
- Focus on anechoic chamber so far
  - Sensitivity
  - Selectivity
  - Blocking*
    - In-band
    - Out of band

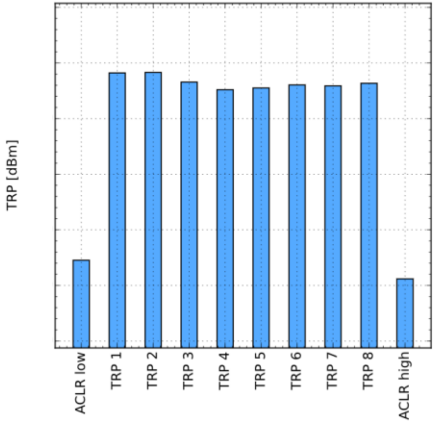
Δ ≈8dB @ 95%

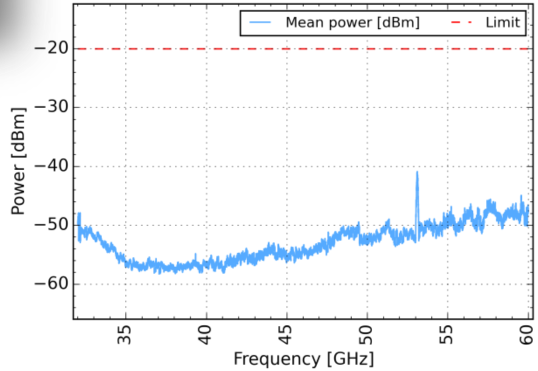



- No channel model/no fading when measured conducted
  - RC adds fading => results not comparable
    - Adapt test specification
    - Or find new relevant test method
- *Blocking may be suitable candidate for new method
  - Blocker may appear in any direction
  - Takes very long time in AC

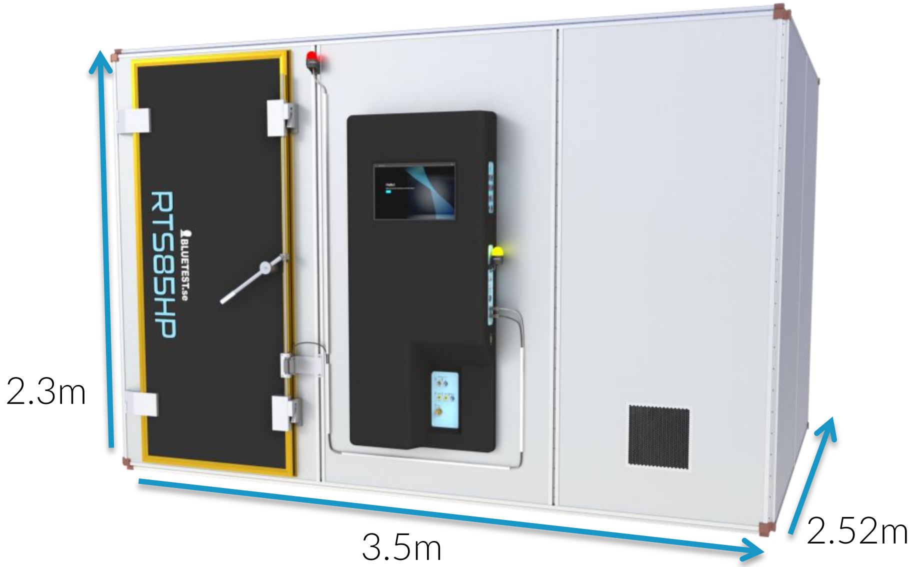
# TX CONFORMANCE

- Suitable for anechoic chamber:
  - Beam pattern
  - Beam pointing
  - Total gain and EIRP
- Suitable for RC:
  - Total power (TRP)
  - Adjacent Channel Leakage Ratio (ACLR)
  - Spurious emission
    - Up to 60GHz



# RTS85HP – FOR BASE STATIONS




- 0.5-67GHz
- Base station/RRU power >100W
  - Antenna gain >20dBi
- RRU size 1.2 x 0.5 x 0.5m

# THE FUTURE 2020-

# FULL FOCUS ON 5G

- Initial phase of defining 5G test cases ready
  - Time pressure - Focus on getting something ready
    - Use whatever that seems to work
  - 3GPP specifications still a moving target with changes and additions
    - FR2 main challenge with discussions on upper frequency limit (60 or 200 GHz..)
- New test needs will emerge from practical experience
  - Existing test cases may need re-evaluation or adaptation to become relevant
- Will mmWave 5G become a success?
- Operators already starting to discuss own end-to-end testing setups
  - Find out how device will actually perform in their network
  - Bad devices associated with substantial cost and end-user dissatisfaction

# OTHER WIRELESS STANDARDS

- Standard owner or Interest Group specifies a minimum test scope
  - Focus on interoperability within standard
- Performance testing re-using tests from cellular side
  - TRP, TIS, Data throughput (end user experience)
- Signaling testers not available for all IoT standards
  - Use real base station/gateway for the testing

# CONCLUSION

# CONCLUSION – WIRELESS TESTING

Testing needs to adapt to the wireless evolution

Large focus on representative environments

Standards often come too late

=>

Large potential for proprietary (good) solutions

Wide variety of test solutions needed to cater for different test needs

Exciting future ahead!

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