IEEE Phoenix EMC Chapter

ETS-LINDGREN®
An ESCO Technologies Company
BEYOND MEASURE™

Reverberation Chamber Test Advantages for Military and Commercial Applications

Edwin Mendivil
ETS-Lindgren
Edwin.Mendivil@ETS-Lindgren.com

October - 2018

Agenda

- Introduction
- Basic RC theory
- RC characterization for LFF devices
- RC characterization for MIMO testing
- RC calibration for military applications
- Conclusions

Introduction

- Reverberation Chambers have been used for several decades
- One of the advantages is that high field strengths can be generated with less power than by other test environments
- The growth in demand for mobile devices has also increased the demand for systems to test these devices
- Reverberation chambers are being used for SISO/MIMO OTA testing of wireless devices
- Several Automotive, military and industrial standards have published procedures for chamber calibration and testing

Introduction

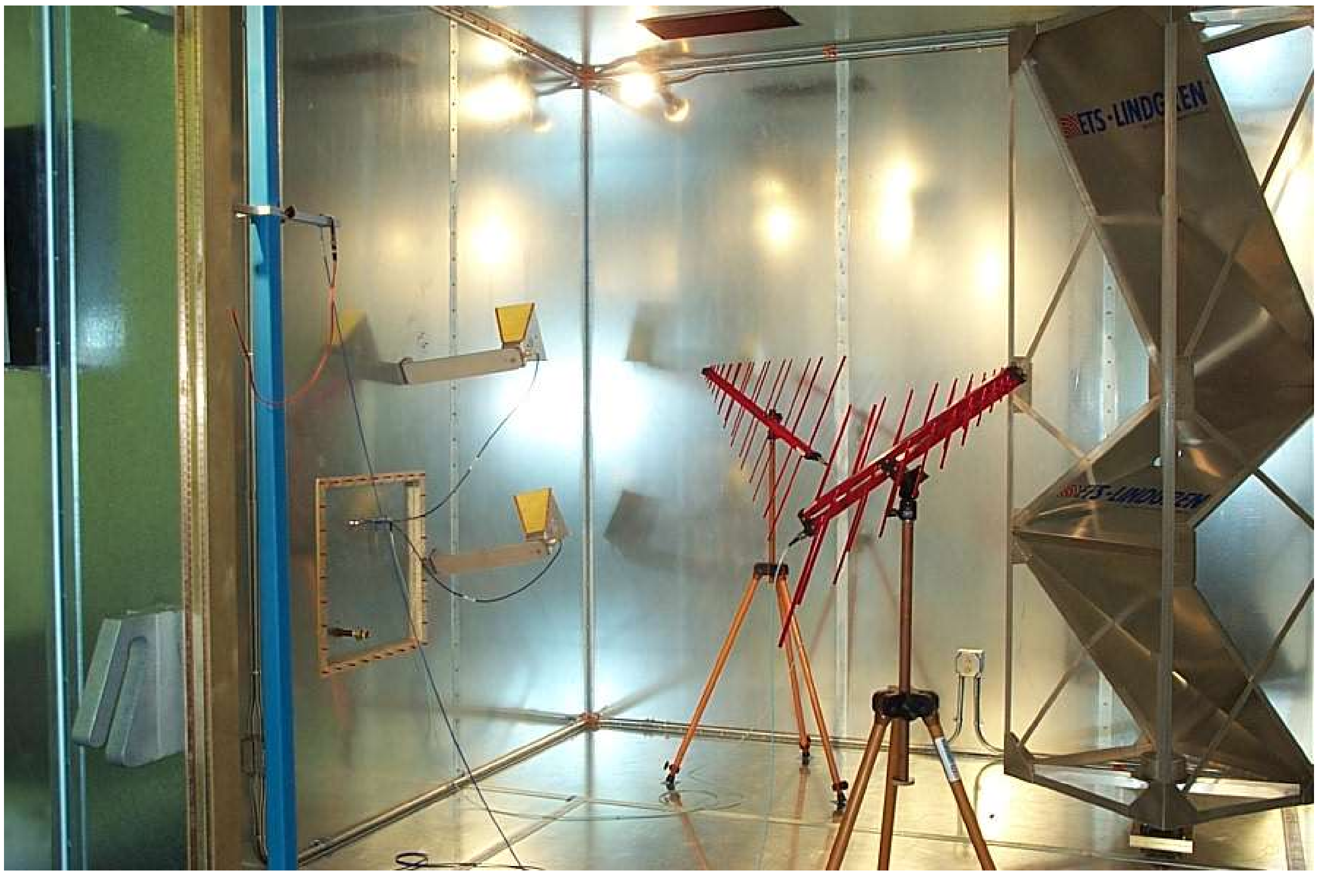
- **The reverb chamber method is accepted as an alternative to the anechoic chamber method for RE and RI testing to RTCA DO160G.**
  - Revision F could only be used for tuned measurements
  - Revision G can be used for tuned and stirred measurements
- **A calibration and test method is also described in the IEC 61000-4-21 standard.**
  - This describes both tuned and stirred methods.
  - But only the tuned calibration method can be used for DO160G

Introduction

- Typical 80MHz Chamber

Introduction

- Typical 200MHz Chamber



Introduction

- Typical 700MHz Chamber

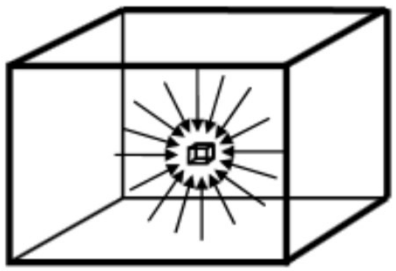
Agenda

- Introduction
- **Basic RC Theory**
- RC calibration for LFF devices
- RC calibration for MIMO testing
- RC calibration for military applications
- Conclusions

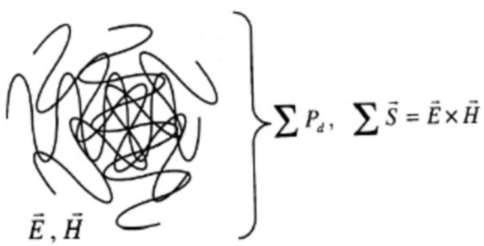
Basic RC Theory

- **A reverberation chamber is a cavity resonator with highly conductive metallic walls that provides an acceptable isotropic, randomly polarized, and uniform environment**
  - Isotropic implies RC EME is the same in any direction (inside the usable volume)
  - Random polarization implies that the phase relationship between polarized components is random
  - Uniform implies all spatial locations within the usable volume of the RC are equivalent

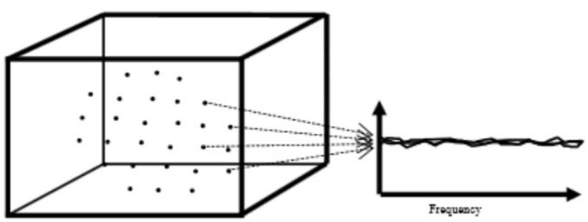
Basic Theory



Isotropic

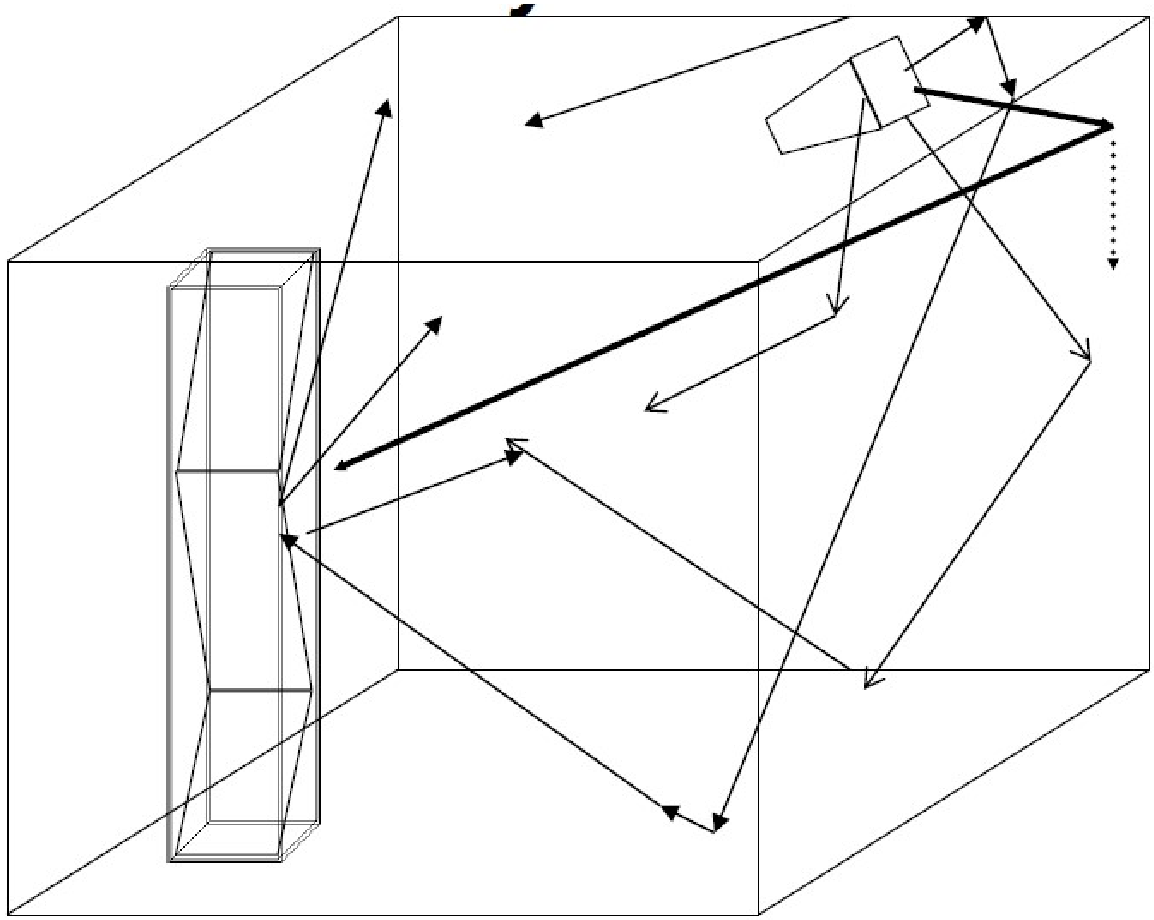


Randomly Polarized



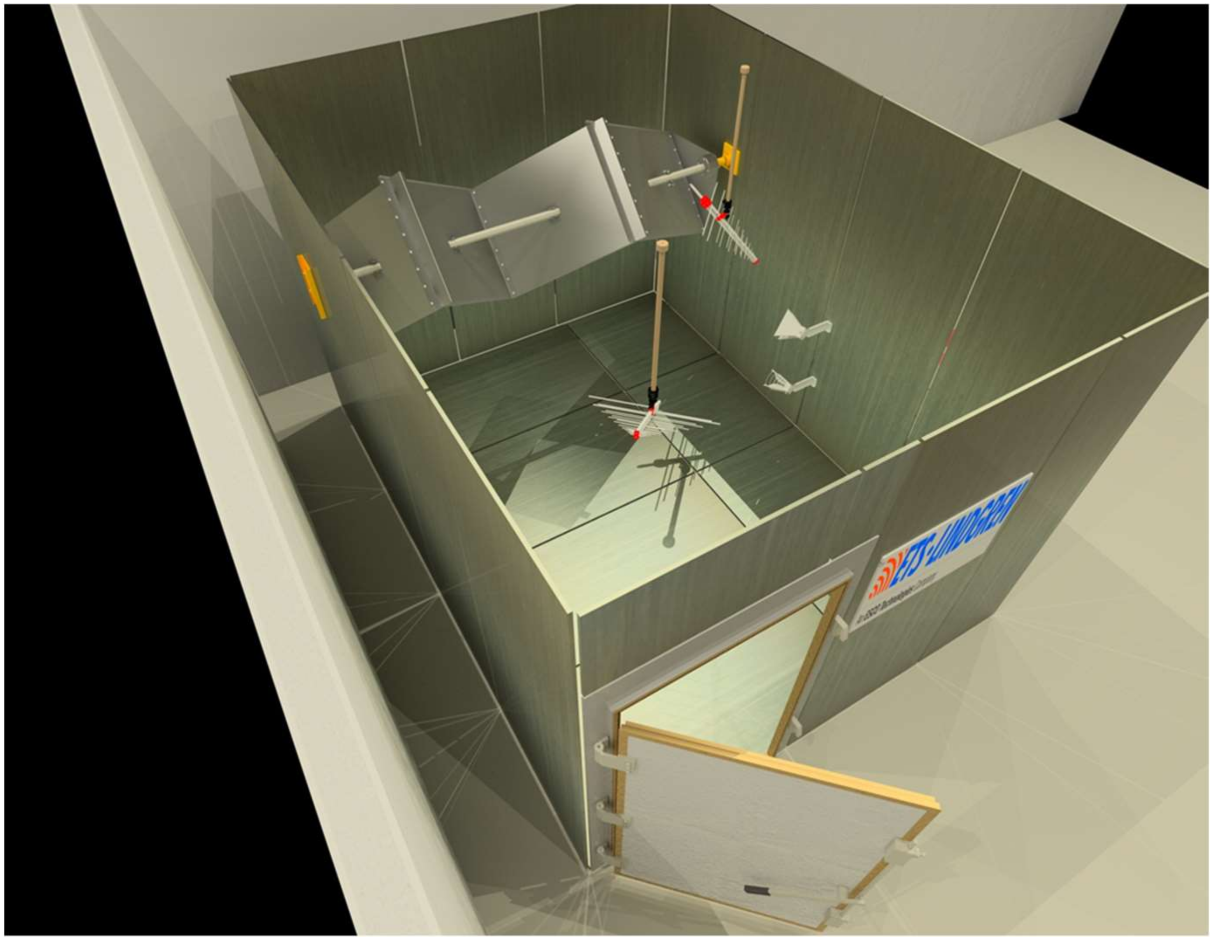
Uniform

Basic Theory



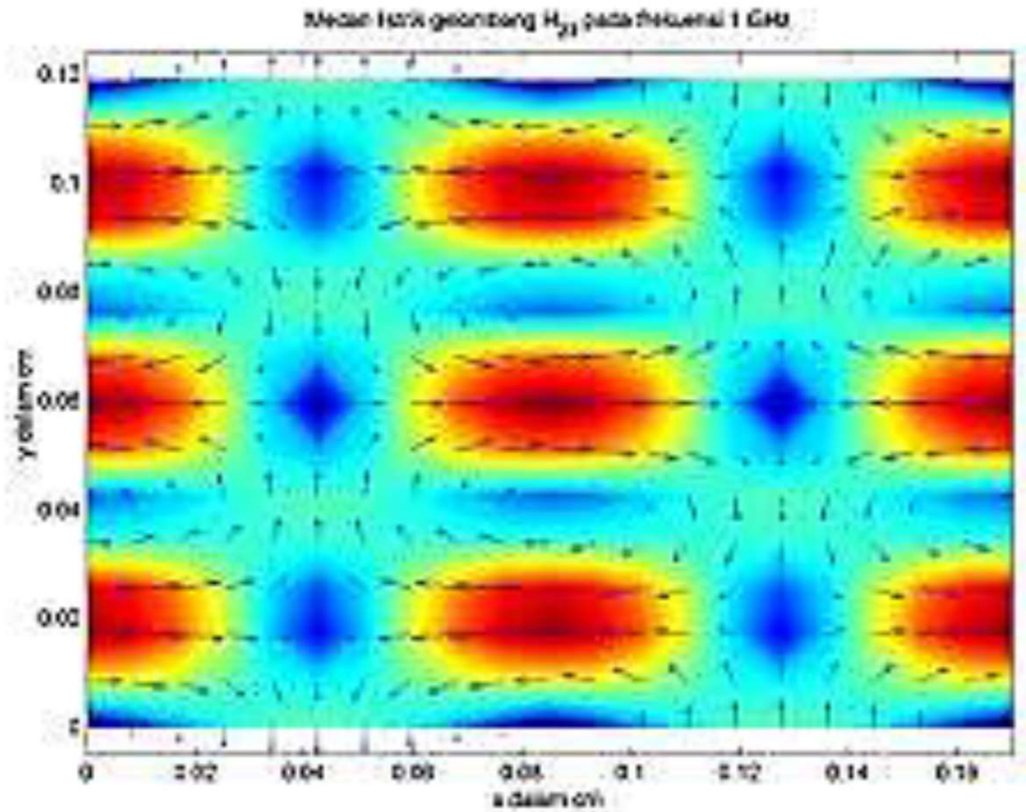
Reflections

Basic Theory



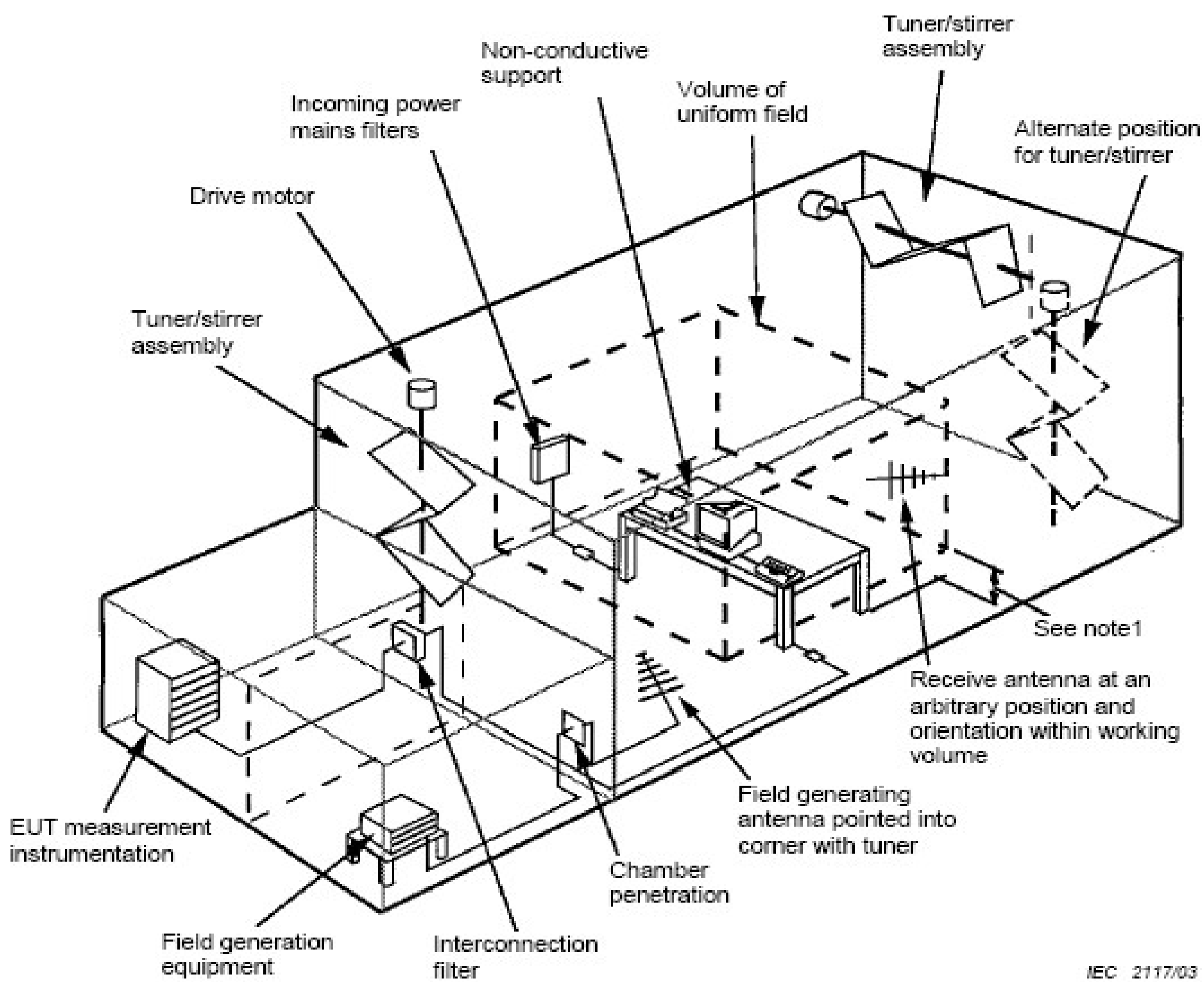
Reverb chamber layout

Basic Theory



Modes

Basic Theory



Basic Theory

- What drives the design of a Reverb Chamber :
  - Operating Frequency, especially the lowest frequency
  - Volume to be occupied by the DUT.
  - Peak $\bar{E}$ field to be generated.
  - Test type, Immunity (CW, Pulse), Emission.

- Size has to be large to support several modes
- Size large enough to accommodate DUT without being overloaded
- Low loss or lossy cavity depending on use.

Basic Theory

- **The reduction of the inhomogeneity of the standing waves can be achieved:**
  - Mechanical changes in the geometry of the chamber
  - Electrical changes in the source signal
- **Boundary conditions changes**
  - Mode-stirred - rotates continuously
  - Mode-tuned – step-and-hold tuner
- **When large number of modes are present, and a good stirring sequence is used, a statistically uniform, and isotropic environment can be created**
- **The lowest usable frequency of operation (LUF) is inversely proportional to the size of the chamber**

Basic Theory

- The available modes can be calculated based on the dimensions using the mode equation as shown below:

$$f_{l,m,n}(MHz)=150\sqrt{[(l/L)^2+(m/W)^2+(n/H)^2]}$$

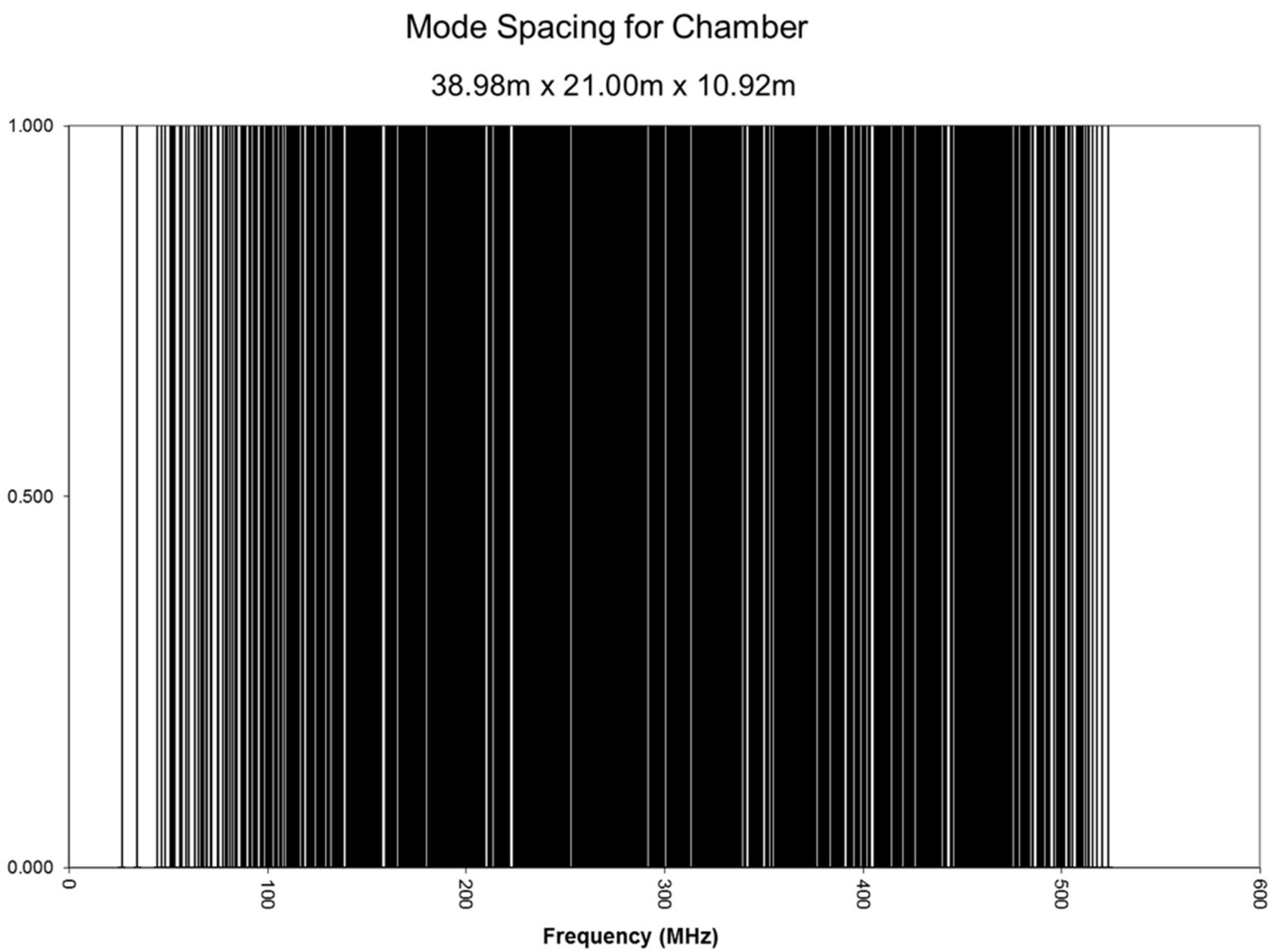
- For a Chamber with dimensions **9.5m x 7m x 5m**
- The first mode can be calculated as -

$$f_{1,1,0}(MHz)= 26.62MHz.$$

- For operation from 100MHz with the 100th mode -

$$f_{7,0,1}(MHz)= 114.53MHz$$

Basic Theory



Basic Theory

- When the dimensions are **unrelated**
  - The mode lines are much more tightly packed with fewer gaps.
- When dimensions are **closely related**
  - There can be large gaps close to frequencies where common modes exist.
  - Large gaps = no modes to be stirred = no $\bar{E}$ field

Basic Theory

- **Mechanical Tuners:**
- ***The tuners have to be effective at stirring the available modes in the chamber.***
  - The dimensions of the tuner is related to the lowest operating frequency of the chamber.
  - The tuner should ideally be at least half of the wavelength at the lowest frequency of operation.
    - $\lambda/2$ at 200 MHz = 0.75m = 29.5" … 3030 Tuner x 1
    - $\lambda/2$ at 80 MHz = 1.87m = 73.8" …. 6060 Tuner x 2
  - Stirred Volume = V_t/V_c = Tuner volume / Chamber volume
  - SMART 200 = 2.08/53.18 = 0.039
  - Tuner smallest dimension > $\lambda/3$ - MIL STD 461G.
  - with >3% stirred volume … a good rule of thumb…

Basic Theory

- A reverb chamber relies on the behaviour of a resonant cavity under varying boundary conditions.
- In simple terms :-
  - The Ē field peaks associated with the resonant modes are moved throughout the volume of the chamber
  - The movement of these peaks can be achieved by several methods:
    - Mechanical changes in the geometry of the chamber
    - Electrical changes in the source signal.
  - These variations can create a statistically *uniform*, *homogeneous* and *isotropic* test environment.
  - Can be used to perform EMC RI, RE, SE tests as well as measurements of wireless devices…

Agenda

- Introduction
- Basic RC Theory
- **RC characterization for LFF devices**
- RC characterization for MIMO testing
- RC calibration for military applications
- Conclusions

RC Characterization for LFF devices

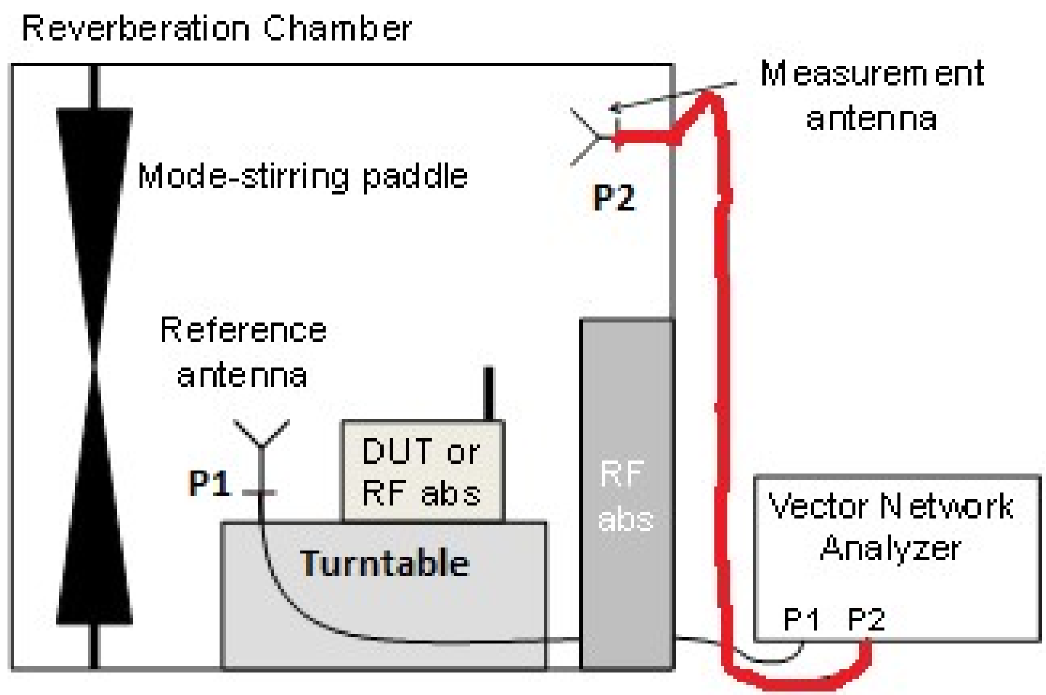
- **The latest version of the CTIA LFF test plan (v1.2), includes testing of the following technologies:**
  - GSM
  - CDMA
  - WCDMA
  - LTE
- **Future releases may include:**
  - Bluetooth
  - WiFi
  - NB-IoT
  - Zigbee

RC Characterization for LFF devices

- Cable Loss
- NA Two Port Calibration
- Coherence Bandwidth
- Frequency Flatness
- Power Transfer Function
- Proximity Effect
- Lack of Spatial Uniformity

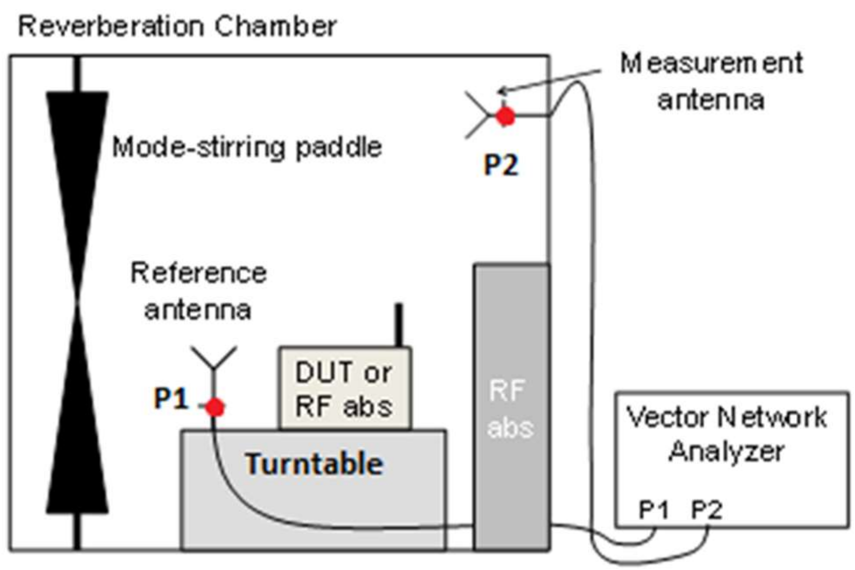
Cable Loss

- **Measure the MA cable loss across all frequencies of interest.**



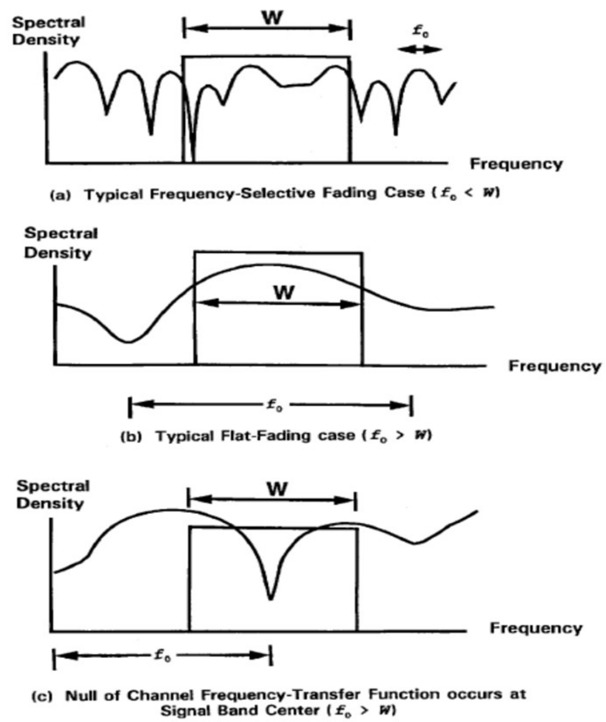
NA Two Port Calibration

- The NA should be calibrated at the Reference and Measurement antenna connectors inside the RC.
- Ideally the calibration should be done every 0.5MHz or less.



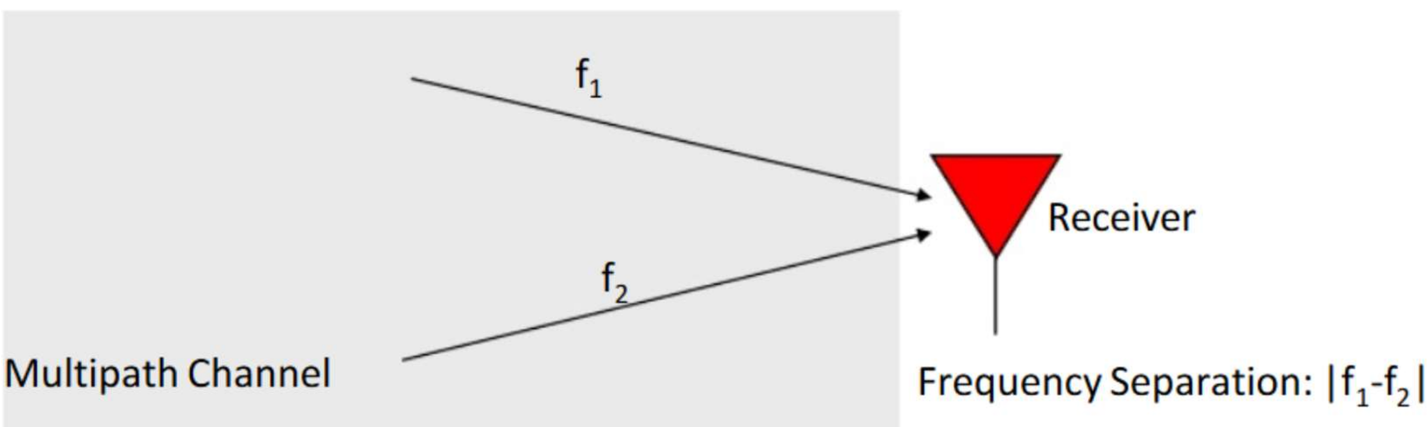
Coherence BW

- It is a statistical measurement of the range of frequencies over which the channel can be considered ‘flat’.



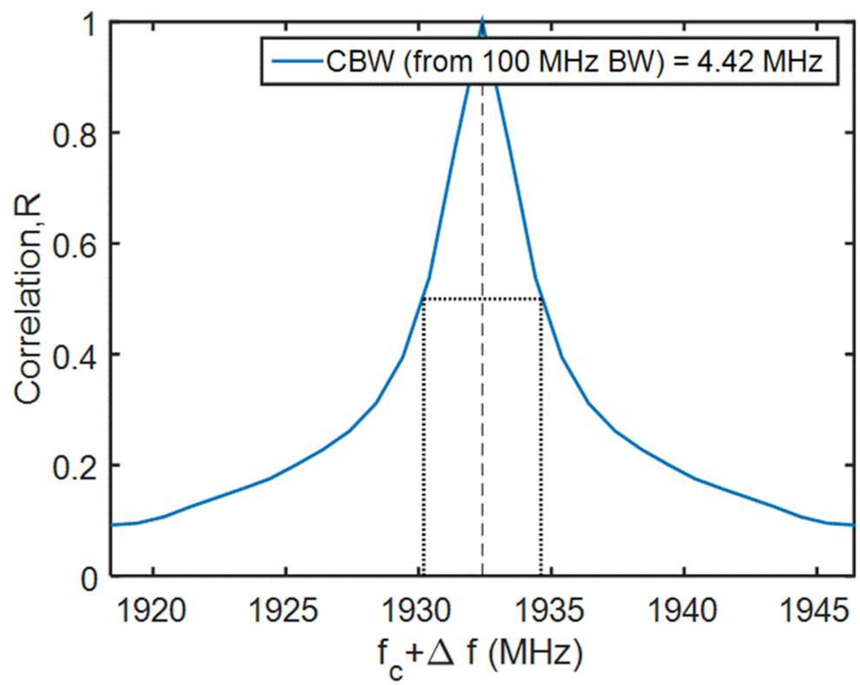
Coherence BW

- The RMS delay spread is measured in order to calculate the Coherence Bandwidth
- This is important in order to minimize any Inter Symbol Interference



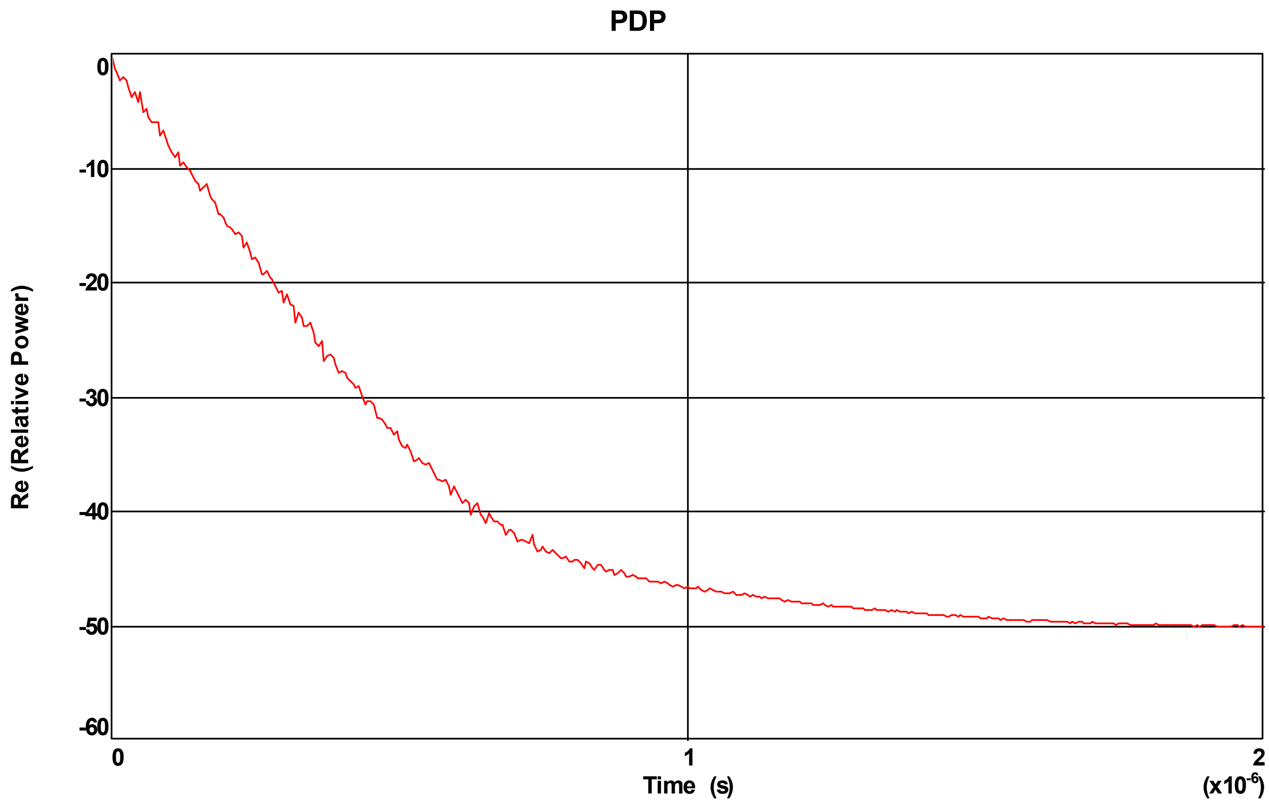
Coherence BW

- **It is evaluated at the center frequency of each band to be tested using 100 MHz bandwidth and a threshold value of 0.5.**



Coherence BW

- This graph shows the typical RMS delay spread measurement for a chamber loaded for a 4.35MHz Coherence BW



Coherence BW

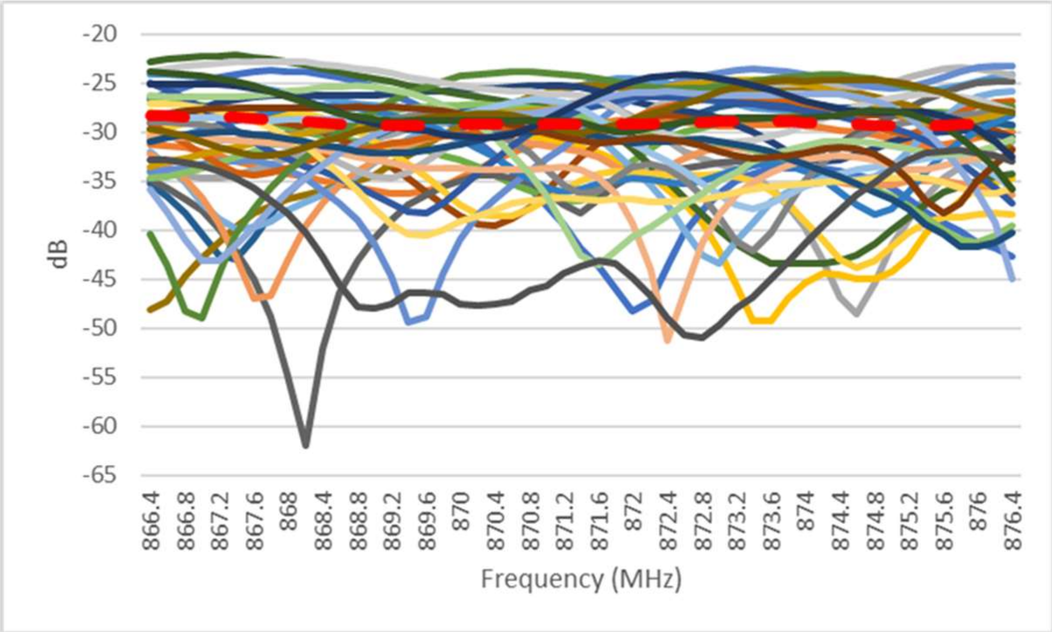
- The RC should be loaded until the coherence bandwidth is greater than the minimum requirements in the table below. More loading normally helps with connection stability, but it also increases measurement uncertainty. Care should be taken not to exceed the MU uncertainty limits.

Transmission standard	Channel Bandwidth (MHz)	Coherence Bandwidth (MHz)
GSM\GRPS\EGPRS	0.2	0.2
CDMA\1xEVDO\1xRTT	1.23	1.3
UMTS (WCDMA)	3.84	4.0
LTE	No. resource blocks x 180 kHz	4.0[1]

Note 1: The CBW for LTE is based on the upper limit for loading (WCDMA) as opposed to actual channel bandwidth.

Coherence BW

- These are typical measurements using loading for a 4.4MHz CBW and a 10 MHz channel.
- In WCDMA nulls at the center of the channel can cause drop calls, lost of transport blocks, and therefore wrong measurements.



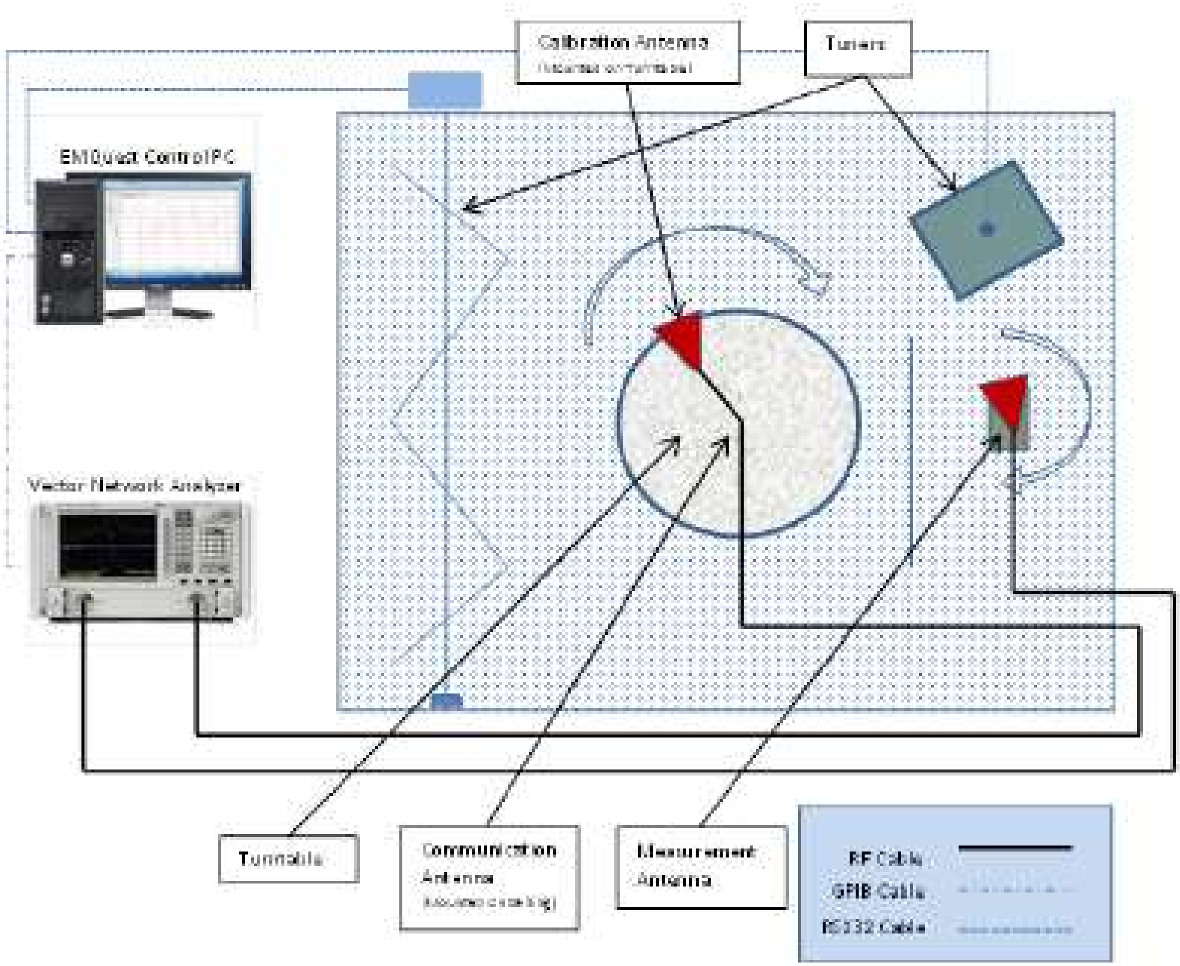
Frequency Flatness

- This test ensures that the frequency step is small enough to measure the power transfer function
- This is done using the highest band to be tested and the minimum loading to be used
- Starting with 41 measurement points within the channel to be measured, repeat the measurements using a subset of points (21,11,5,3)
- The frequency interval to be used for the power transfer function can be determined from the number of points that have a difference of their averages < 0.05dB.

Power Transfer Function

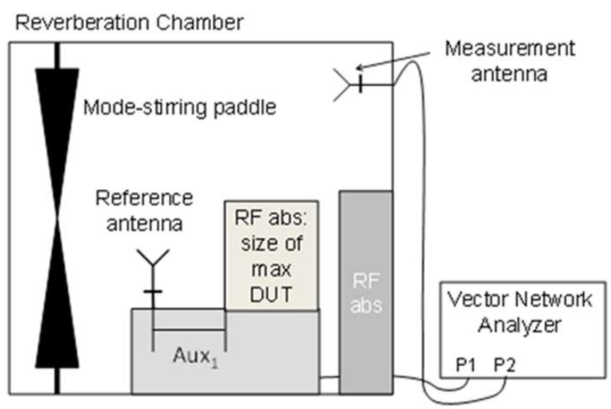
- The reference antenna is placed in such a way that undergoes the same stirring sequence that the DUT during the TRP or TIS measurement.
- The power transfer function (G_{ref}) is estimated from T sets of the proposed stirring sequence using T uncorrelated reference antenna positions.
- Increasing the number of antenna positions (Tcal >1) may be needed in order to lower the MU budget
- The power transfer function is used to calibrate the RC and to calculate the uncertainty due to the lack of spatial uniformity

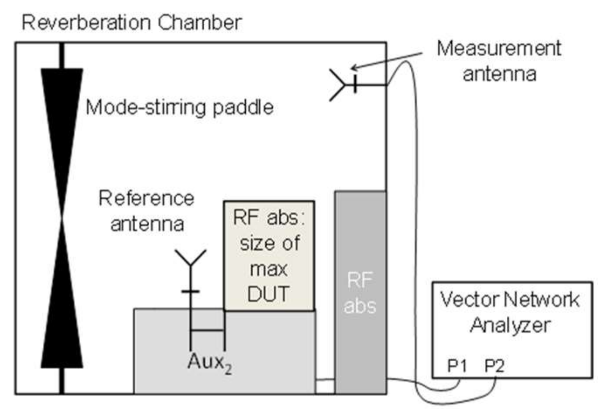
Power Transfer Function



Proximity Effect

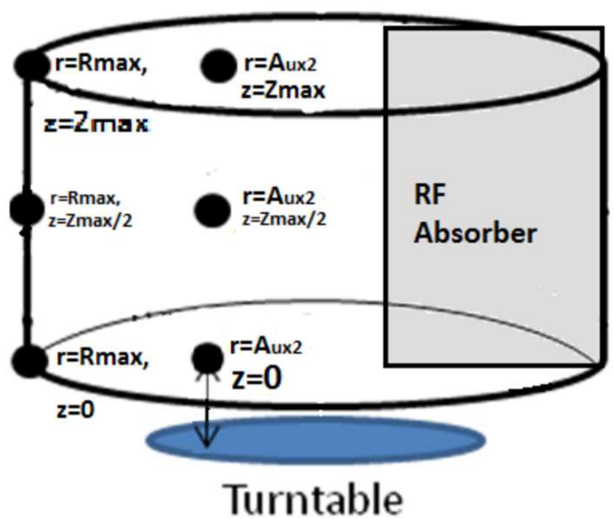
- **This is the effect of the loss of power from the DUT or Reference antenna that is absorbed by lossy material without undergoing any reflection in the chamber.**





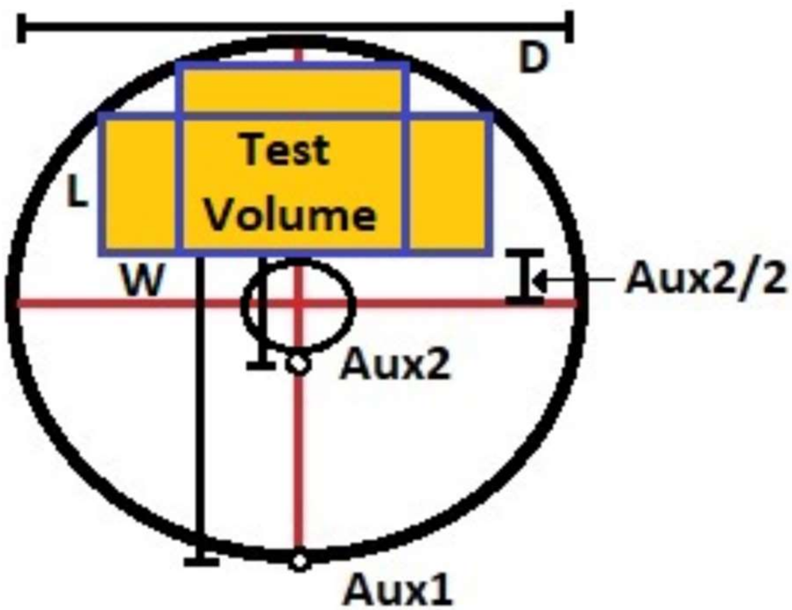
Proximity Effect

- For this test the Gref is measured using the reference antenna, three orthogonal polarization, and three heights in 2 uncorrelated locations (Aux1 and Aux2).
- This will give two sets of nine power transfer function (T=9). The standard uncertainty is calculated for both sets. If the interval of the two sets overlap +/-2.31σ, the proposed ref antenna location is considered acceptable, otherwise the ref antenna should be moved farther from the lossy objects.



Proximity Effect

- Test volume is determined from the Proximity effect test results, where the positions of Aux1 and Aux2 are defined

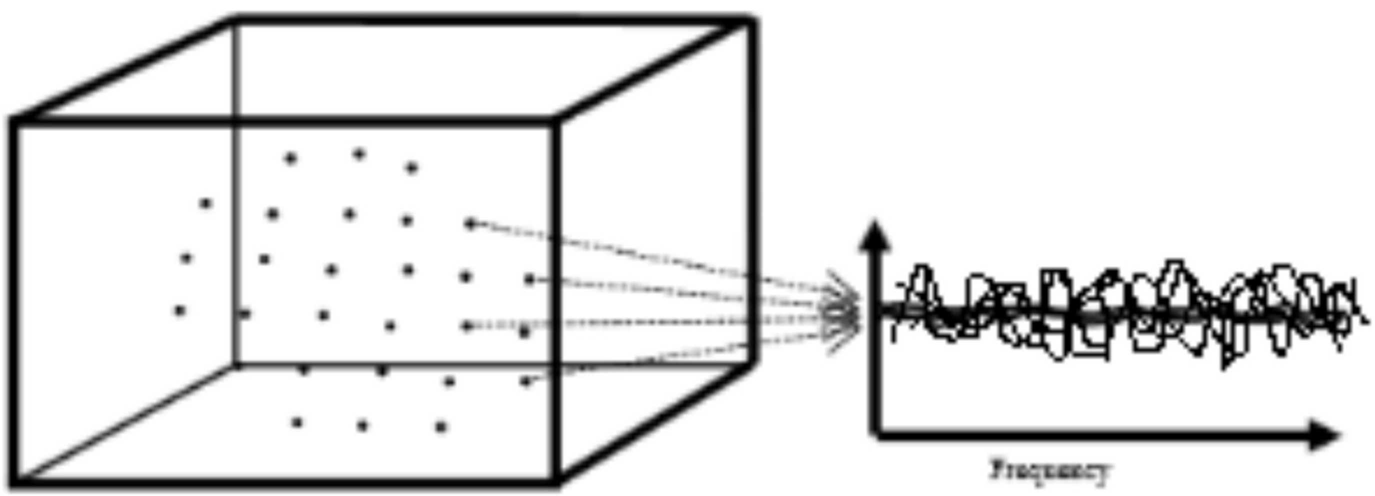


Lack of Spatial Anisotropy

- Ideally the average transmission between two antenna ports, should be the same within the RC test volume, regardless of the position or orientation. This test measures how much the RC deviates from this ideal.
- This is done during the pre-characterization step, using absorbers and antennas in positions where they will be located during the TRP/TIS measurements, and absorbers with absorption in excess of the expected DUT shall be placed in the DUT location.
- Absorbers location should be documented for later use.
- The corresponding chamber loss, coherence bandwidth, and uncertainty due to lack of spatial uniformity are determined for each loading condition, and antenna position. All this data is entered into a table for future use.

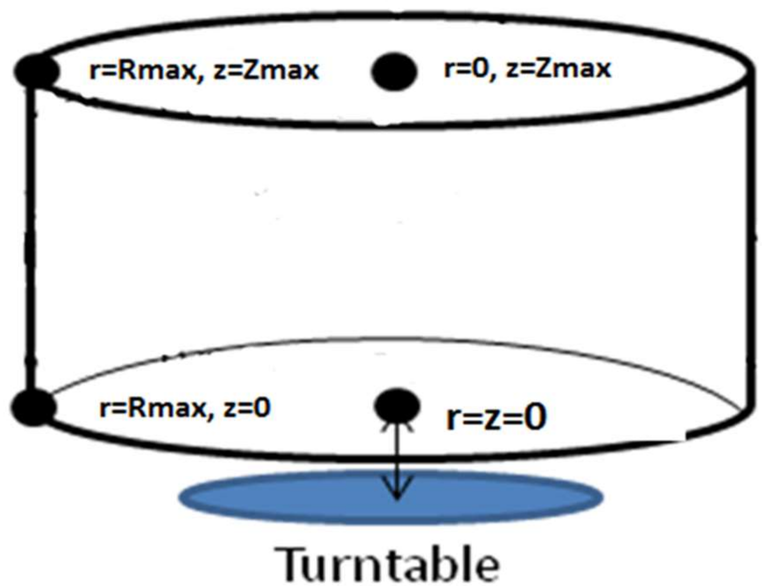
Lack of Spatial Anisotropy

- The amount of variation in the results that we can obtain by making the measurements in different locations. This is known as error due to the lack of spatial anisotropy.



Lack of Spatial Anisotropy

- The Ref Antenna will be placed at r=0, r=Rmax, z=0, and z=Zmax, and three orthogonal polarizations at each location for a total of 12 measurements for each loading condition. The uncertainty due to lack of spatial uniformity is calculated for each technology to be tested and entered into the Pre-Characterization table.



Agenda

- Introduction
- Basic RC Theory
- RC Characterization for LFF devices
- **RC Characterization for MIMO testing**
- RC calibration for military applications
- Conclusions

RC MIMO Calibration

- **Channel Model Validation**
  - Power Delay Profile (PDP)
  - Base Station Correlation (BSC)
  - Doppler
  - Rayleigh
  - Isotropy

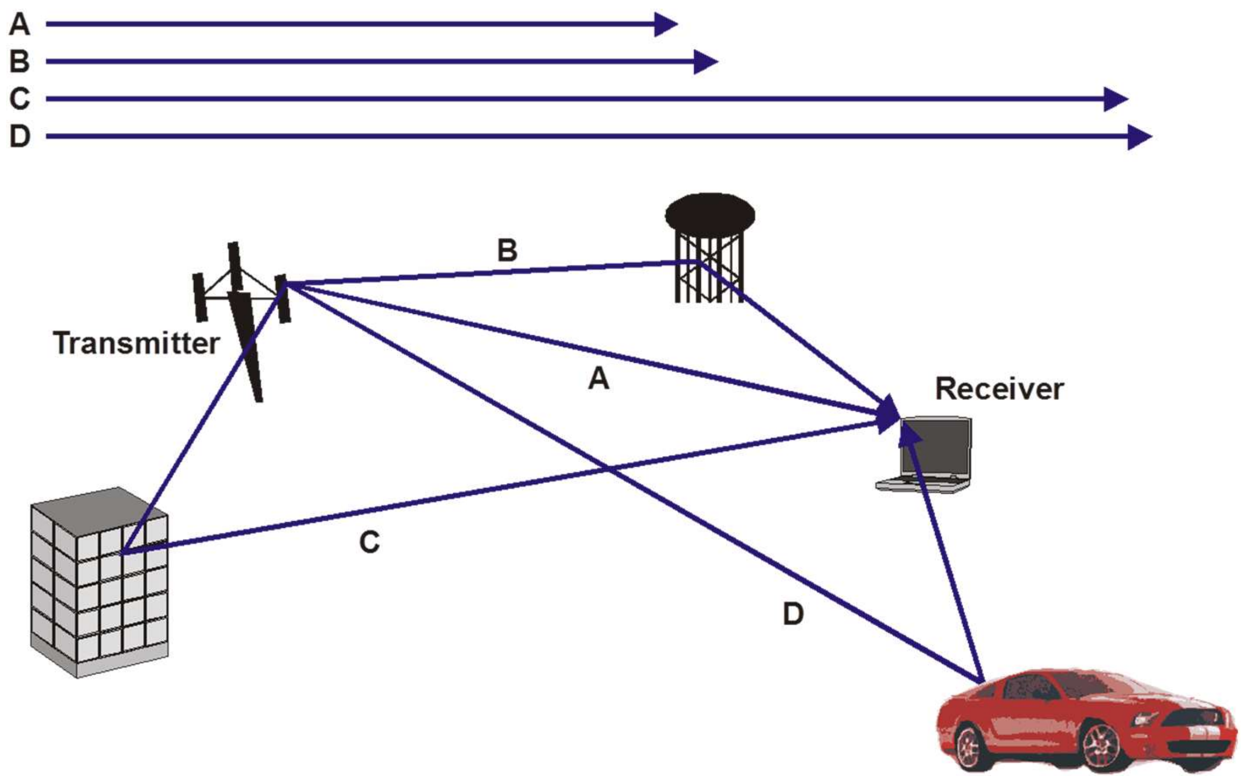
RC characterization for MIMO testing

MIMO: Channel Model Validation (UMa-IS)

- The channel emulator simulates the wireless channel between transmit and receive radios using a channel model.
- Channel models simulate not only a given environment, but also properties of the base station and mobile device including antenna patterns, antenna separation, and angles of departure/arrival (AOD/AOA).
- These validation tests show that the Long Delay Spread high correlation channel model (UMa-IS) in the RC is as expected for the reference channel model.

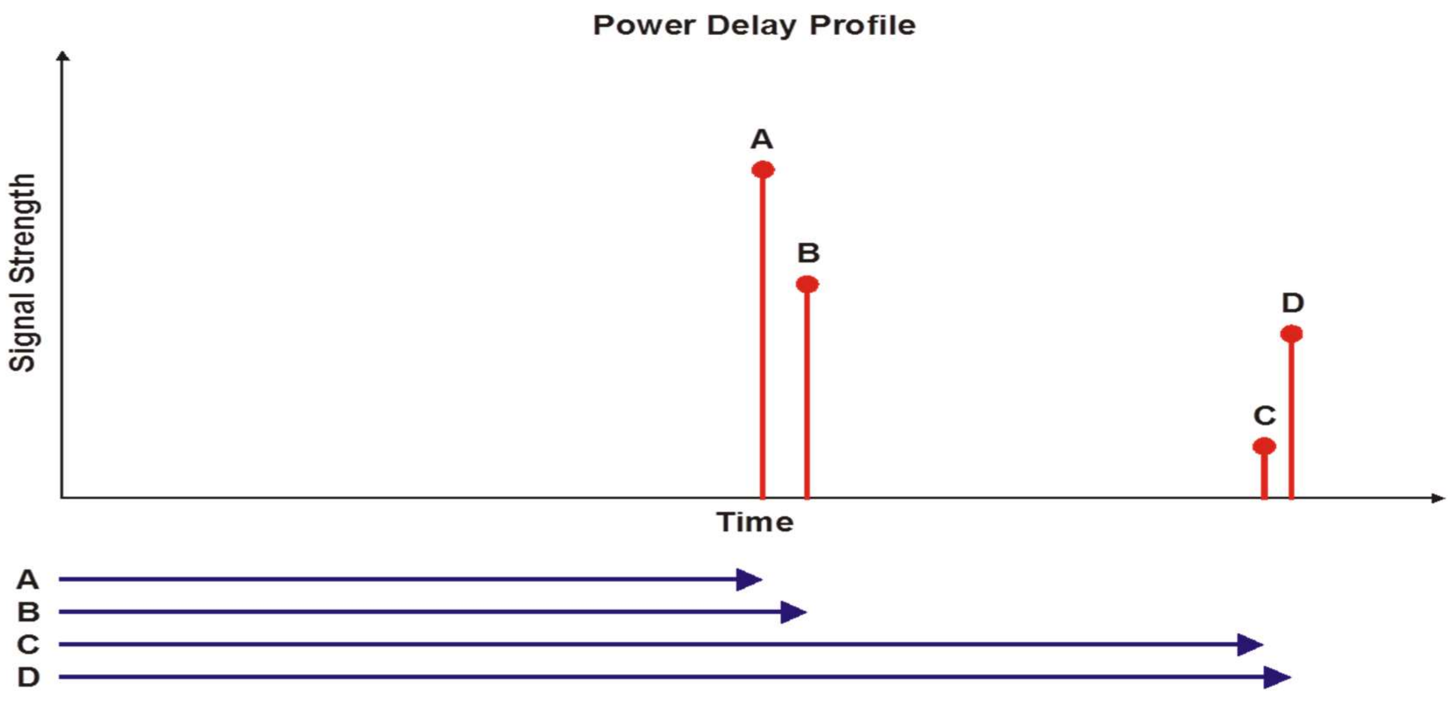
RC Characterization for MIMO testing

- In the real world, various objects in the environment cause reflections of the transmitted signal that are seen at the receiver.

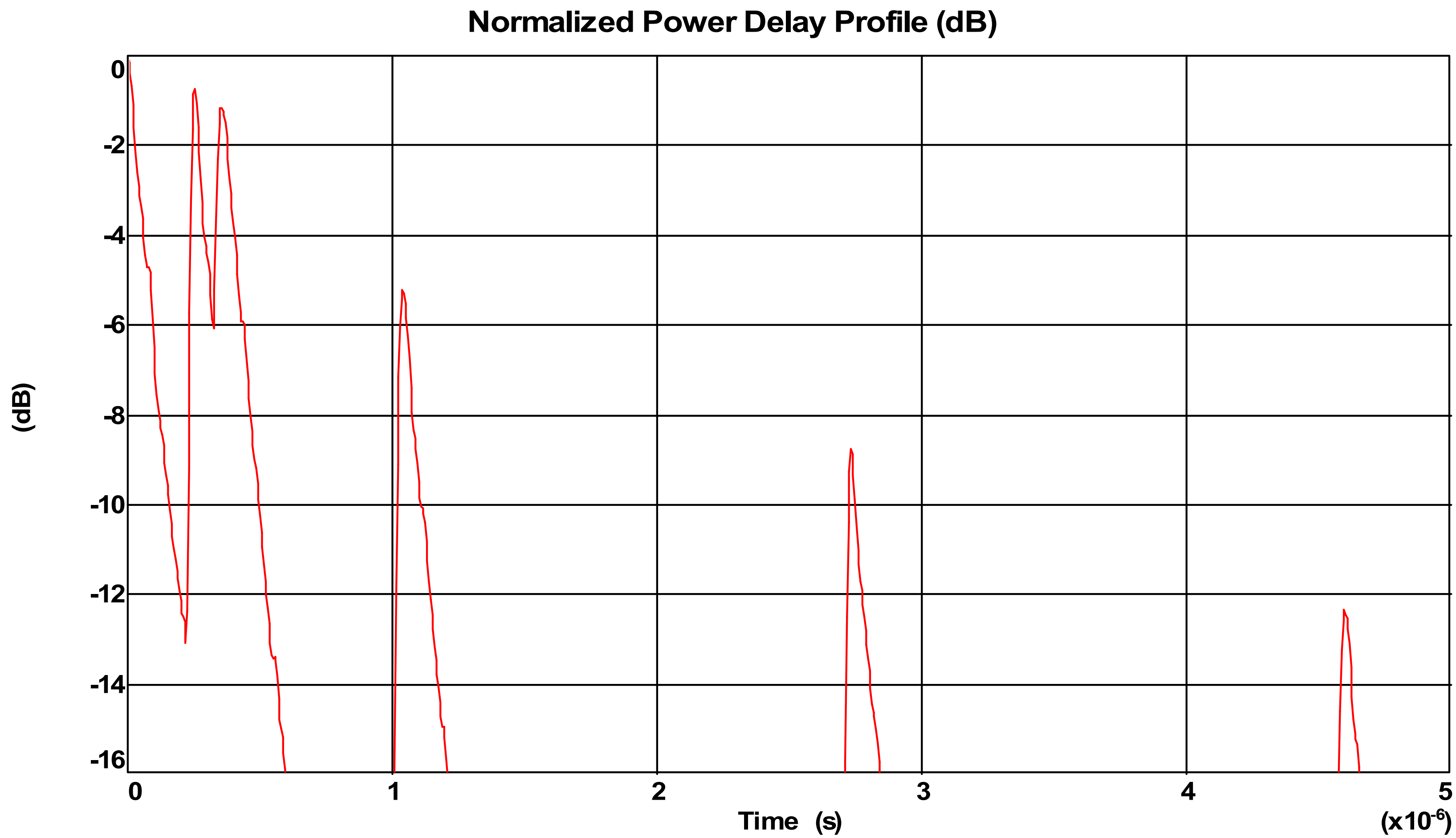


Power Delay Profile

- Different paths are of different lengths, this creates multiple copies being received at different times
- Plotting the signal strength vs. time gives a power delay profile (PDP) for the model.



Power Delay Profile (UMa)



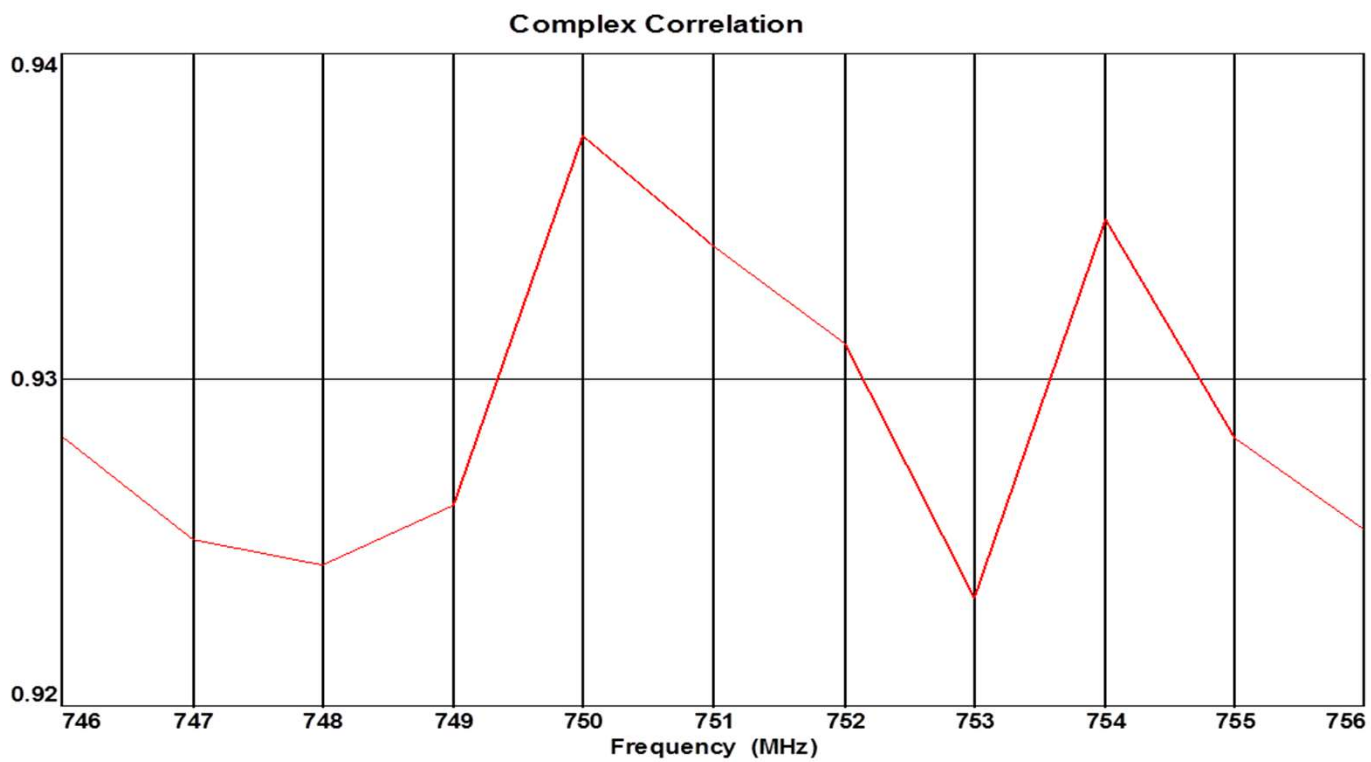
Power Delay Profile

- We can see form these RC measurement results that the location of the delay taps and their power level obtained in the RC agree with the channel model (UMa) used

Tap	UMa Model		Measured		Delta	
	Delay (ns)	Power (dB)	Delay (ns)	Power (dB)	Delay (ns)	Power (dB)
1	0	0	0	0.0	0	0.0
2	360	-2.2	360	-1.7	0	0.5
3	255	-1.7	255	-1.4	0	0.3
4	1040	-5.2	1038	-5.3	-2	-0.1
5	2730	-9.1	2733	-8.8	3	0.3
6	4600	-12.5	4600	-12.5	0	0.0

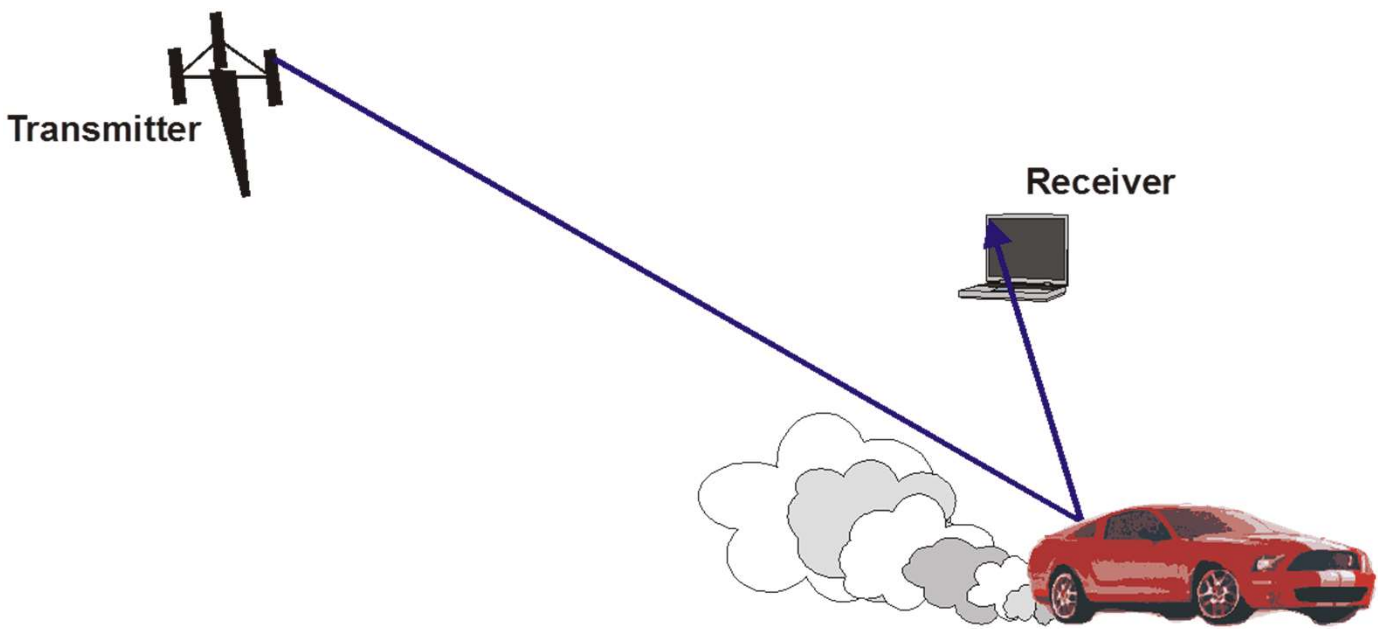
Base Station Correlation

- For this test the Complex Frequency Coefficient is calculated. The expected value is ~94%.



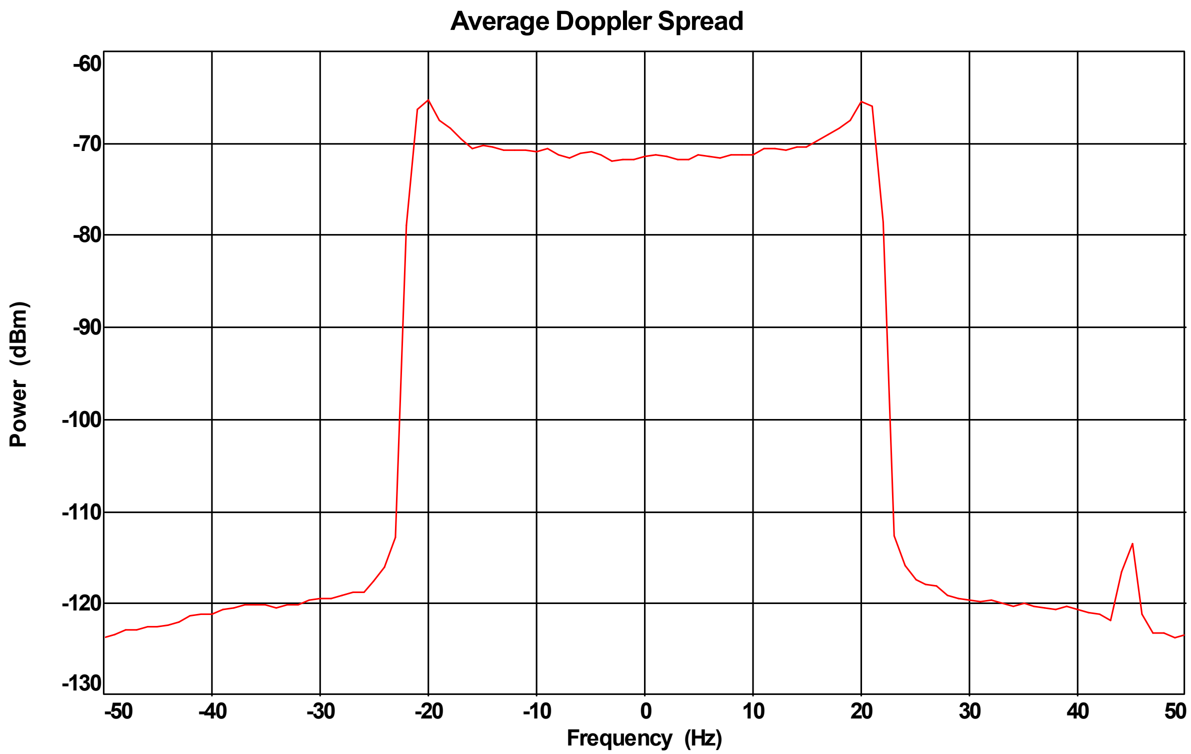
Doppler

- **Motion of the transmitter, receiver, or other objects within the environment causes Doppler shift of the frequency.**



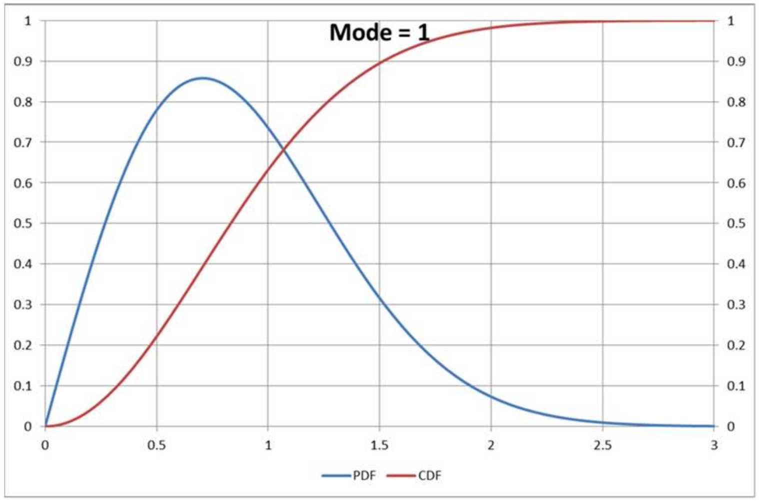
Doppler

- The theoretical Doppler for 30Km/hr at 751 MHz is +/- 21Hz. The results obtained in the RC agree with that.



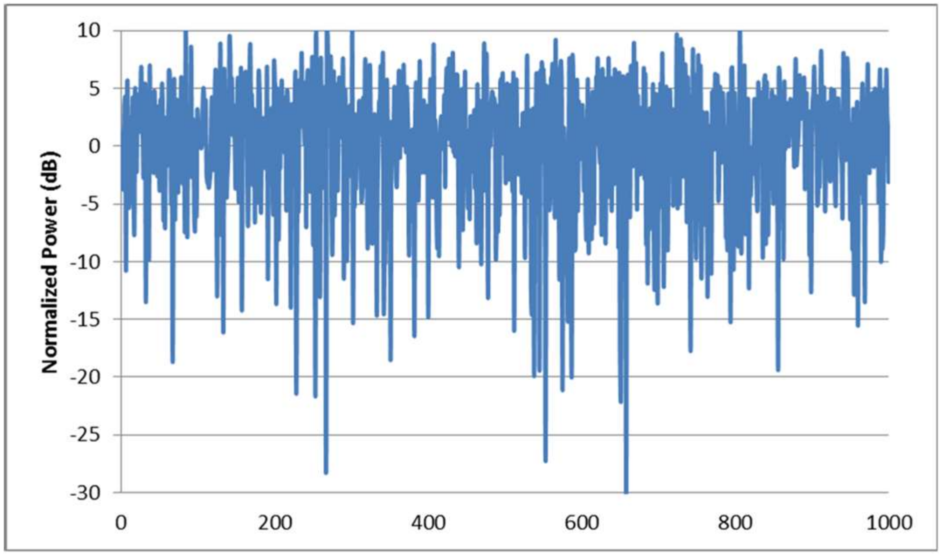
AMS-7200 (Rayleigh)

- The Rayleigh distribution is observed when the overall magnitude of a vector is related to its directional components. Assuming that each component is uncorrelated, normally distributed with equal variance, and zero mean. An example of the distribution arises in the case of random complex numbers whose real and imaginary components are Gaussian, with equal variance and zero mean. In that case, the absolute value of the complex number is Rayleigh-distributed . The product of 2 independent Rayleigh distributed signals follows a Double Rayleigh distribution.



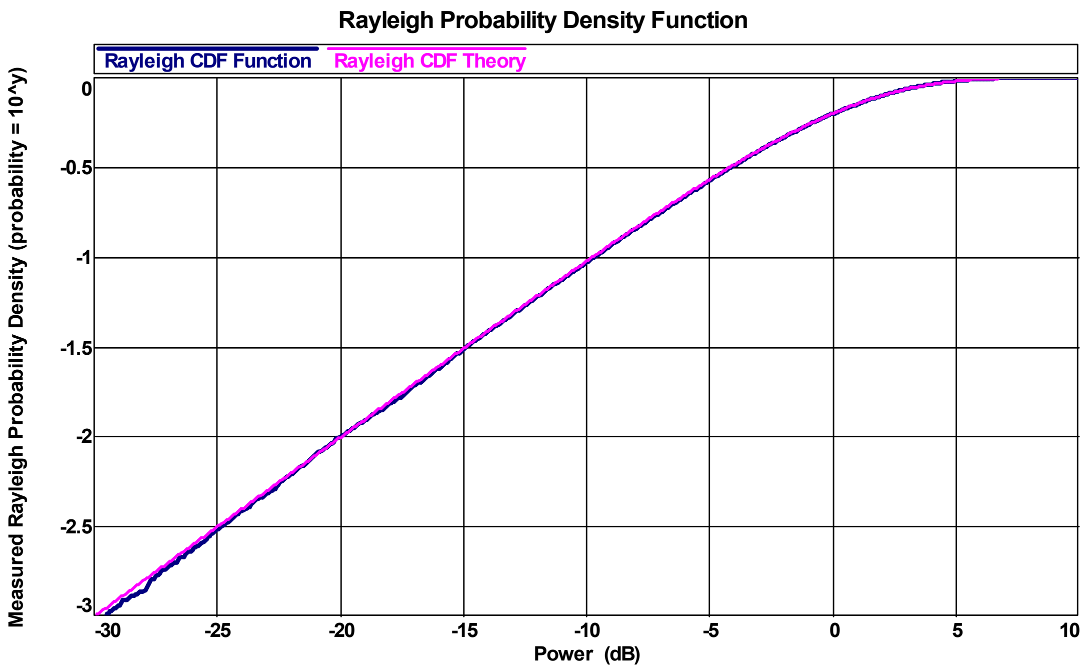
AMS-7200 (Rayleigh)

- In a Reverberation Chamber Rayleigh Distributed fading is artificially created when the received power at the DUT changes due to the variation in the stirring mechanisms (tuners or turntable)



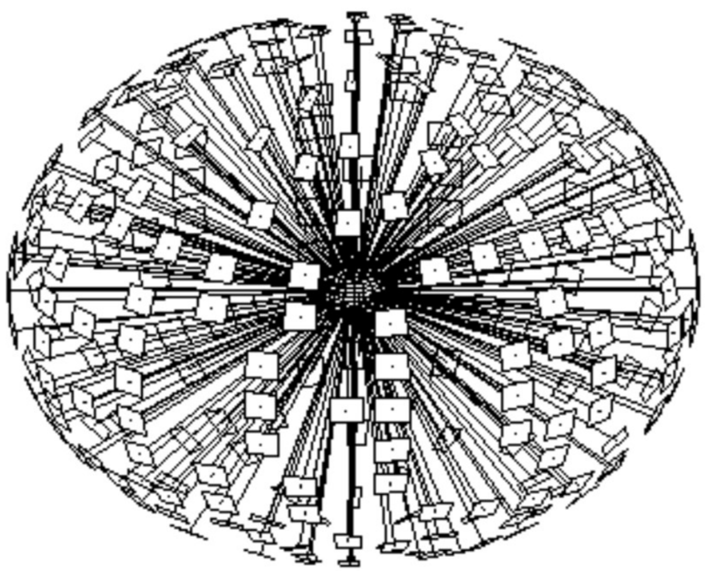
Rayleigh

- The diff. to the theoretical Rayleigh-fading values measured in the RC were:
  - Max difference to theoretical +10 to -20 dB: <0.31 dB
  - Max difference to theoretical - 20 to -30 dB: <1.44 dB



Isotropy

- RC's operate by using their interior surfaces to reflect internally radiated RF fields. The paddles, or tuners, are used to change the cavity boundary conditions. This creates fields having statistical isotropy and field homogeneity over a large working volume



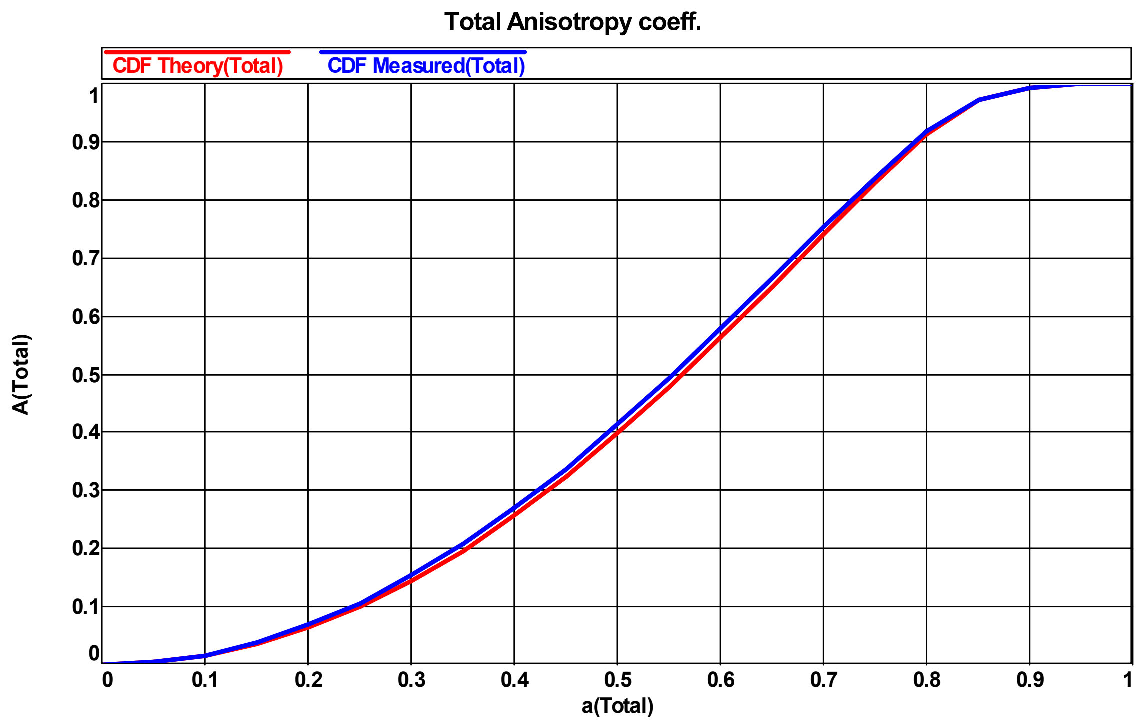
Isotropy

- Isotropy means the field is uniform in all orientations
- At any instant in time a reverberation chamber may not necessarily be isotropic
- Anisotropy coefficients measure the bias of the average direction of polarization of the electric field in the chamber.
- The bias is computed by comparing three components of the electric field obtained from dipole-antenna measurements.
- The observed and ideal anisotropy coefficients are then compared

Isotropy

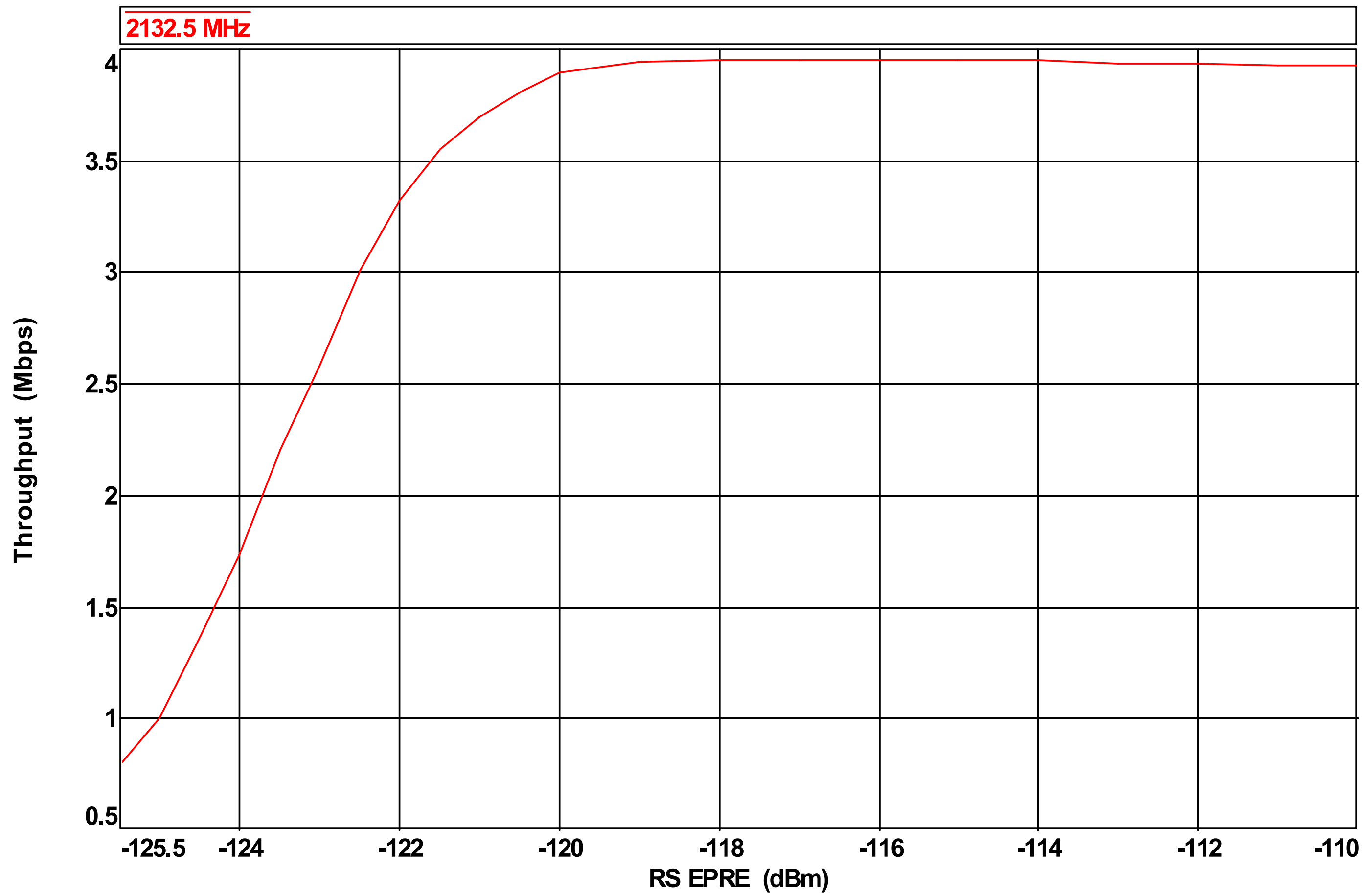
- Using the Chi-square test to determine if the RC is isotropic:

  T(K-1)= 10.1 at the 1% significance level (< 29.14)



Test Results

- Typical result for a LTE MIMO TP test



Agenda

- Introduction
- Basic RC Theory
- RC Characterization for LFF devices
- RC Characterization for MIMO devices
- **RC calibration for military applications**
- Conclusions

ETS·LINDGREN
An ESCO Technologies Company
BEYOND MEASURE™

RC calibration for military applications

DO-160 Reverb Progression

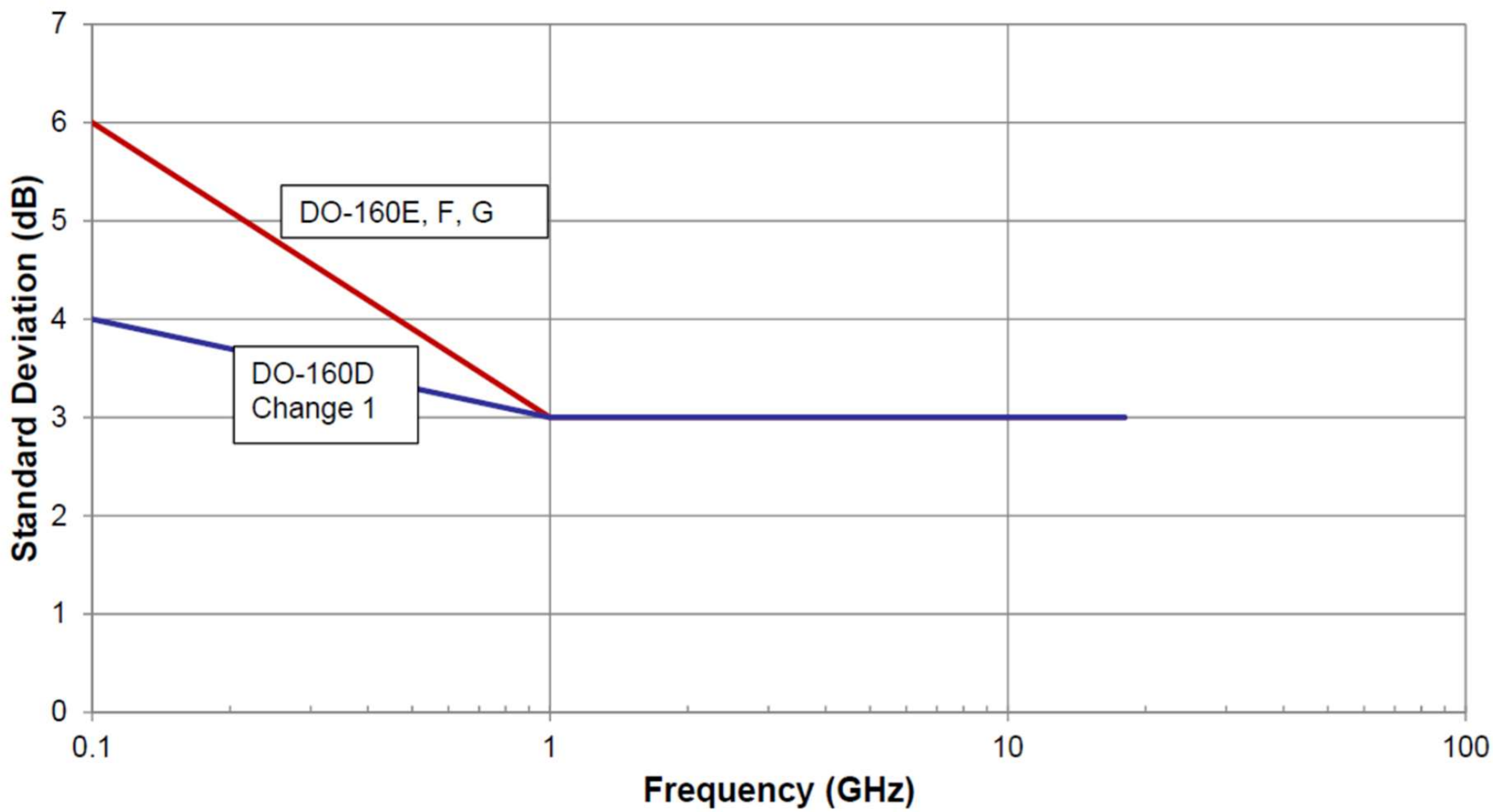
DO-160 Revision	Date Published	Section 20 Radiated RF Susceptibility Procedures
DO-160C Change 3	May 1993	Semi-Anechoic Only
DO-160D Original	July 1997	Semi-anechoic, mode-stirred, and mode-tuned
DO-160D Change 1	December 2000	Semi-anechoic and mode-tuned
DO-160E	December 2004	Semi-anechoic and mode-tuned
DO-160F	December 2007	Semi-anechoic and mode-tuned
DO-160G	December 2010	Semi-anechoic and mode-stirred

RC calibration for military applications

- **RTCA DO160G**
  - Tuned mode method of chamber characterization.
    - Measures the standard deviation of the $\bar{E}$ field in the test volume.
    - Measures the peak normalized E field.
    - Measures the chamber loss
    - Measures the Chamber Q and Time constant
  - Stirred mode method for DUT testing.
    - Measures the DUT loading of the chamber
    - Measures the normalized $\bar{E}$ field
    - Uses this to calculate the needed input Power for test

RC calibration for military applications

Field Uniformity Limit changes



RC calibration for military applications

- Using the MIL-STD461G relationship
- A Chamber with dimensions **9.5m x 7m x 5m**
- The first mode can be calculated at **26.62MHz**.
- For operation from 100MHz with 100 modes -

$$N = \frac{8\pi}{3} a b d \frac{f^3}{c^3}$$

= 103

RC calibration for military applications

- Ultimately the chamber has to satisfy the validation requirements of the standard – DO160G.

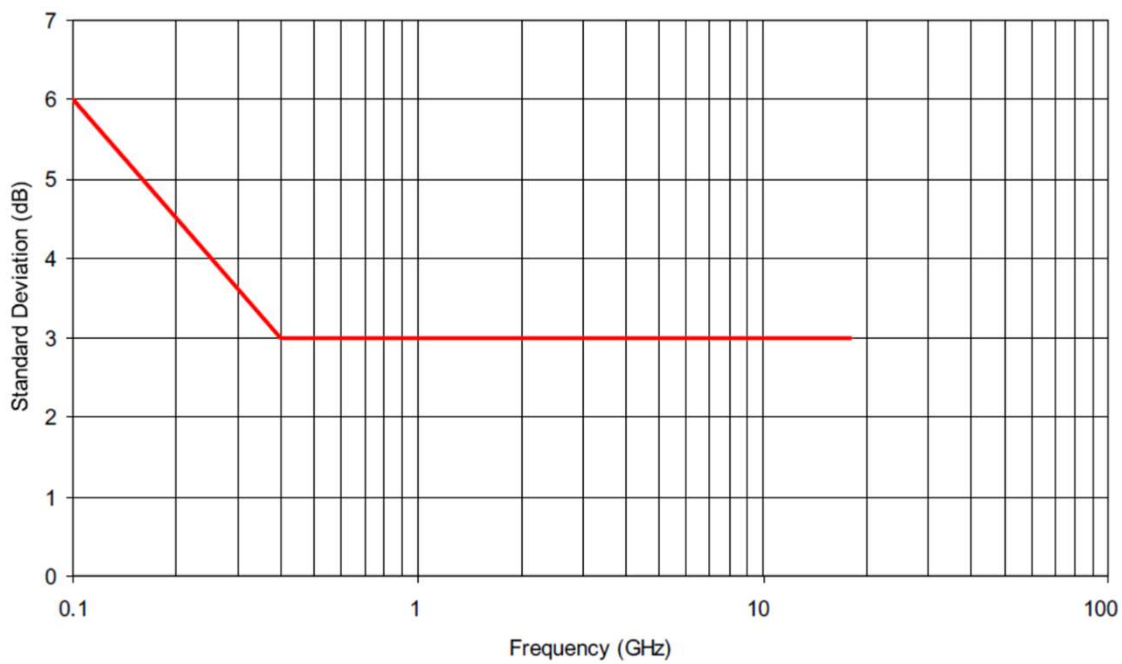


FIGURE 20-11 ALLOWABLE STANDARD DEVIATION FOR FIELD UNIFORMITY TEST

RC calibration for military applications

- Ultimately the chamber has to satisfy the validation requirements of the standard – DO160G.

iv. Step the tuner through 360° in discrete steps (mode-tuned operation) and at each step care must be taken to ensure that the dwell time is sufficiently long enough that the amplitude measurement instrumentation and E-field probes have time to respond properly. Each step must be an equal angular movement. The limitation on the minimum number of tuner positions is that the field uniformity requirements must still be met. The limit on the maximum number of positions is that each step should vary the field pattern in the chamber enough to be statistically significant eg an independent sample.

Extract from DO160G

RC calibration for military applications

- Ultimately the chamber has to satisfy the validation requirements of the standard – IEC 61000-4-21 (MIL STD 461G)

Table B.2 – Field uniformity tolerance requirements

Frequency range MHz	Tolerance requirements for standard deviation
80 to 100	4 dB [a]
100 to 400	4 dB at 100 MHz decreasing linearly to 3 dB at 400 MHz [a]
Above 400	3 dB [a]
[a] A maximum of three frequencies per octave may exceed the allowed standard deviation by an amount not to exceed 1 dB of the required tolerance.	

Extract from IEC 61000-4-21

RC calibration for military applications

- Ultimately the chamber has to satisfy the validation requirements of the standard – IEC 61000-4-21 (MIL STD 461G)

Table B.1 – Sampling requirements

Frequency range	Minimum number of samples[a] required for validation and test[d]	Number of frequencies[b] required for validation
f_s to 3 f_s [c]	12	20
3 f_s to 6 f_s	12	15
6 f_s to 10 f_s	12	10
Above 10 f_s	12	20/decade

[a] The minimum number of tuner steps is 12 for all frequencies. For many chambers the number of tuner steps will need to be increased at the lower frequencies. The maximum number of tuner steps is the number of independent samples that a given tuner can produce. This number varies with frequency and needs to be verified when commissioning the chamber. In the event that the chamber fails to meet the uniformity requirement, the number of tuner steps may be increased up to the number of independent tuner samples. An example of increased numbers of tuner steps in this case is shown in Figure A.12.

[b] Log spaced.

[c] f_s = Start frequency (see A.1.3 for LUF)

[d] The tuner sequencing used for validation of the chamber shall be the same as for subsequent testing.

Extract from IEC 61000-4-21

RC calibration for military applications

- Ultimately the chamber has to satisfy the validation requirements of the standard – MIL STD 461G

d. The lower frequency limit is dependent on chamber size. To determine the lower frequency limit for a given chamber, use one of the following methods:

(1) Using the following formula, determine the number of possible modes (N) which can exist at a given frequency. If, for a given frequency, N is less than 100 then the chamber should not be used at or below that frequency.

$$N = \frac{8\pi}{3} abd \frac{f^3}{c^3}$$

where: a, b, and d are the chamber internal dimensions in meters

f is the operation frequency in Hz

c is the speed of propagation (3×10^8 m/s)

Extract from MIL STD 461G

RC calibration for military applications

- Ultimately the chamber has to satisfy the validation requirements of the standard – MIL STD 461G

TABLE XII. Required number of tuner positions for a reverberation chamber.

Frequency Range (MHz)	Tuner Positions
200 - 300	50
300 - 400	20
400 - 600	16
Above 600	12

Extract from IEC 61000-4-21

RC calibration for military applications

- **> 60** modes should be available at lowest useable frequency (LUF).
- Chamber dimensions must be non-integer multiples of each other to maximize mode effectiveness
- EUT effective volume up to 8% of chamber volume
- Efficient tuners, (Z-fold) - length ~85% of chamber dimension, width is ~1/2λ at LUF.
- Software for data collection, interpretation and presentation is critical for efficient testing

RC calibration for military applications

- ***The tuners have to be effective at stirring the available modes in the chamber*.**
  - The dimensions of the tuner is related to the lowest operating frequency of the chamber.
  - The tuner should ideally be at least half of the wavelength at the lowest frequency of operation.
    - λ/2 at 200 MHz = 0.75m = 29.5” … 3030 Tuner x 1
    - λ/2 at 80 MHz = 1.87m = 73.8” …. 6060 Tuner x 2
  - Stirred Volume = V_t/V_c = Tuner volume / Chamber volume
  - SMART 200 = 2.08/53.18 = 0.039
  - Tuner smallest dimension > λ/3 - MIL STD 461G.
  - with >3% stirred volume … a good rule of thumb…

RC calibration for military applications

- Chamber design for Immunity
  - To optimize a chamber for immunity:
    - Keep the chamber size as small as possible given DUT size and LUF.
    - Use high conductivity material for the chamber = High Q.
    - Use efficient antennas
    - Use low loss cables and waveguides as much as possible
    - Minimize cable and waveguide lengths
    - Minimize DUT losses
      - Cover non essential components with metal
      - Keep support equipment out of the chamber where possible
      - Test ONLY what must be in the chamber as part of the setup
    - Use maximum number of tuner steps for best results.

  - Perform Chamber Calibration based on IEC 61000-4-21
  - Assess normalized E field performance based on DO 160G.

RC calibration for military applications

- DO-160G method of calculating Field Level
- Estimate of E field in the test volume given by –

$$E_{max} = \sqrt{\frac{377 * 8 * P_{rcv\ max}}{\lambda^2}}$$

- Method of calculating required Power given by -

$$P_{Target} = 20 * log\left(\frac{E_{desired}}{E_{max}}\right) + P_{Fwd}$$

RC calibration for military applications

- **Chamber Q …**
  - A measure of how well the chamber stores energy i.e. its efficiency.
    - Q = 2π x (Total energy stored)/(Energy lost per cycle)

- $Q = \frac{16\pi^2}{\eta_{Tx}\eta_{Rx}\lambda^3} V\{\frac{PAveRec}{P_{input}}\}$…. *From IEC 61000-4-21*

- Where
  - V = Chamber volume (m^3)
  - λ = Wavelength (m)
  - η = Antenna efficiency
  - P = power (Watts)

RC calibration for military applications

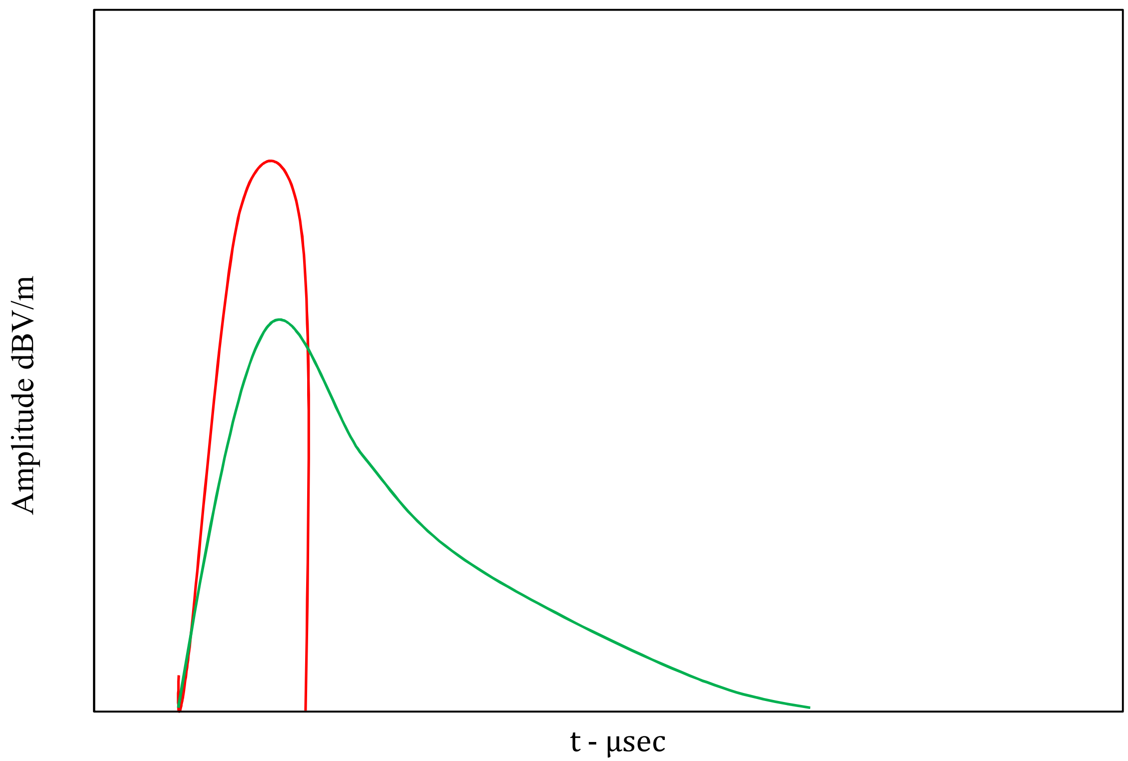
- **Chamber Q …**
  - Q Bandwidth
    - BW_Q= f/Q … from IEC *61000-4-21*
  - BW_Q is a measure of the frequency bandwidth over which the modes in a reverberation chamber are correlated.
  - Use of Copper can result in a >20% improvement in E norm compared to galvanized steel, or up to 30% over painted steel…
  - This could be important when you are testing to Cat G (3kV/m) and Cat L (7.2kV/m)…
  - 80V/m per watt = 8.1kW or 104V/m per watt = 4.8kW

RC calibration for military applications

- **Why is Q important?**
  - It is related to decay time for the incident energy
    - High Q => long decay time => slows pulse decay ✗
  - Power density (mw/cm^{2})
    - Ratio of : Field strength (V/m per watt) to Input power ✓
    - High Q => High Ratio
  - Mode Density
    - Wide Mode bandwidth => Mode overlap => complex field
    - High Q => Lower bandwidth >= fewer available modes ✗
      - BW_Q=f/Q
      - re modes can be excited as a result of the overlap

RC calibration for military applications

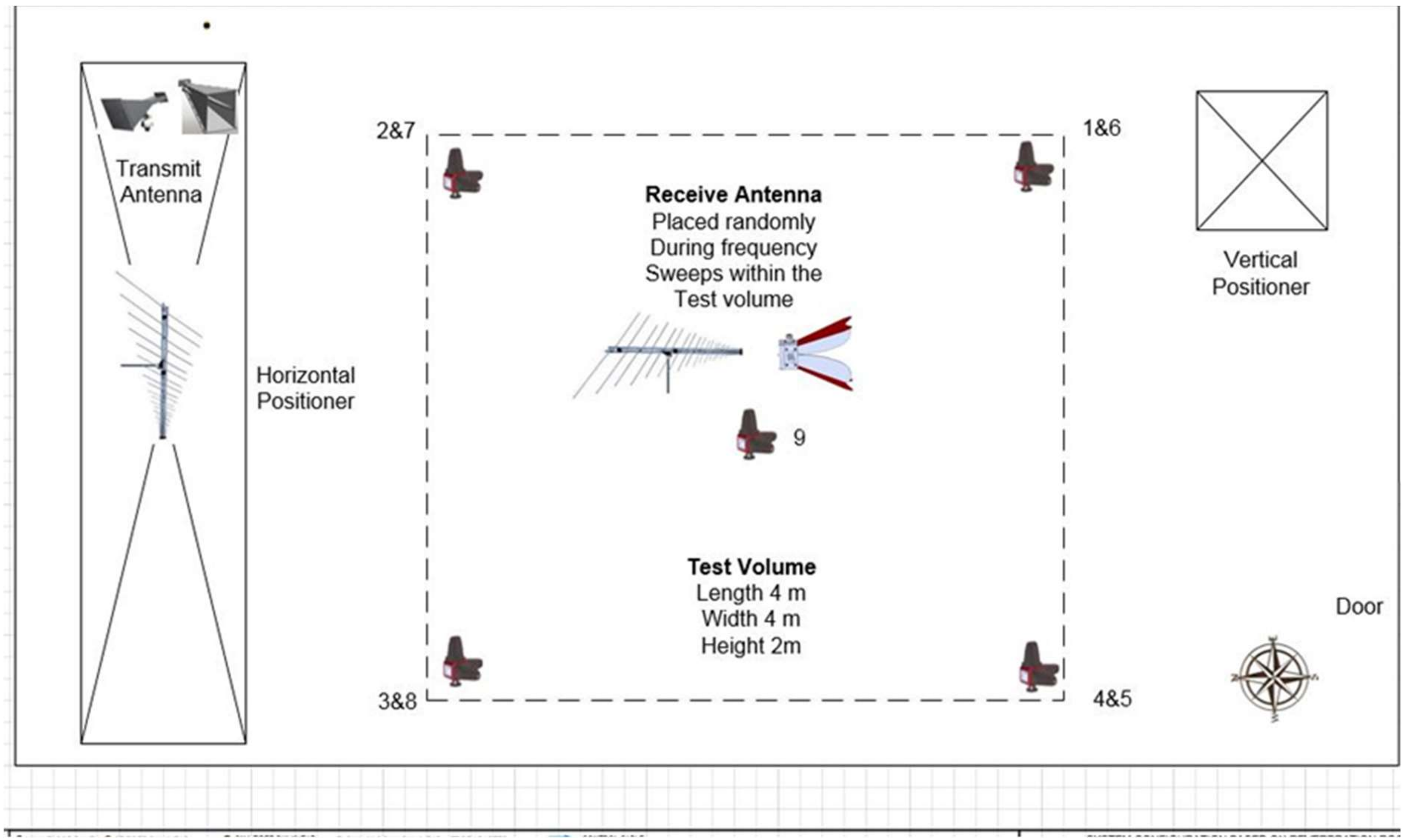
- **Effect of High Q**
  - Related to decay time of the incident energy
    - High Q => long decay time => slows pulse decay.



RC calibration for military applications

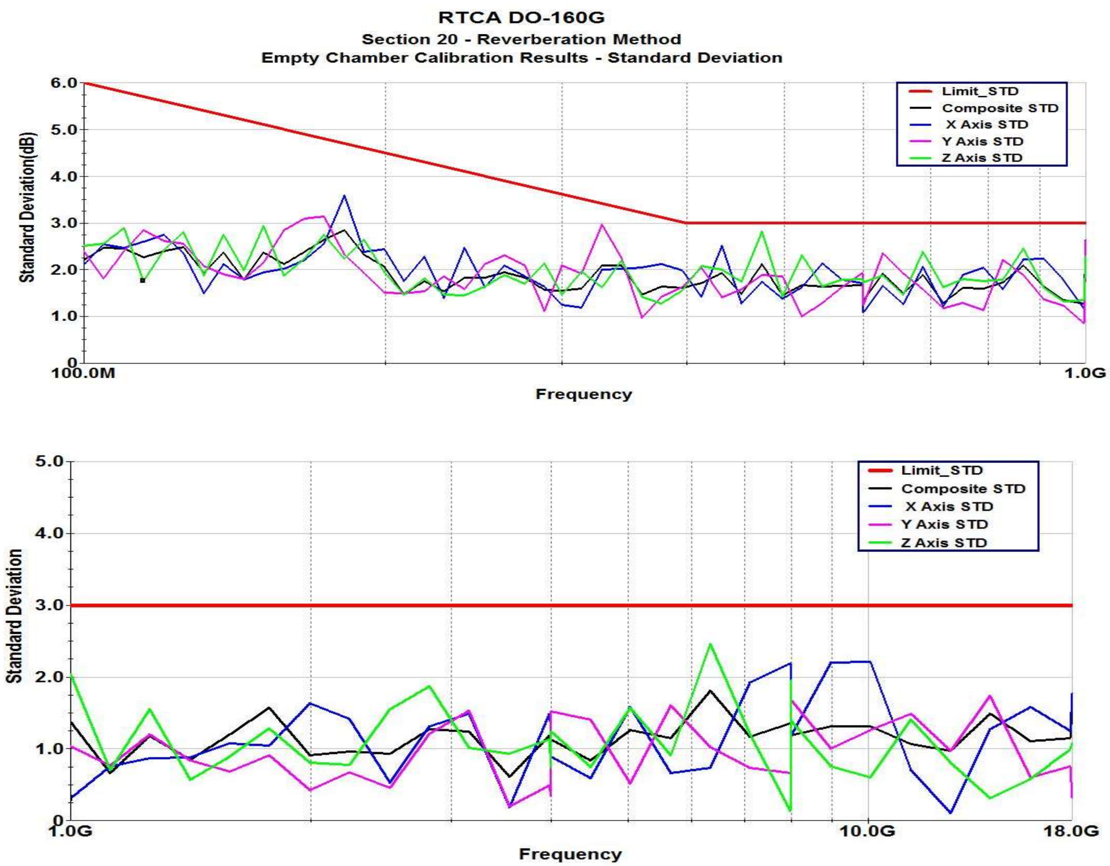
- **Basic Calibration method:**
  - Using a 3 axis field probe = $\bar{E}_{xyz}$ (f)
  - Measure the E field at 8 (9) probe locations = M
  - Step tuner to multiple locations
  - Calculate linear average over M locations
    - $< \bar{E}_{i}(f))> M$ $< \bar{E}_{3i}(f))> M$
  - Calculate the linear Standard deviation of the above
    - σ_i (f) | M σ_{3i} (f) | M
  - Compare the result to the required standard deviation

RC calibration for military applications



RC calibration for military applications

Characterization Data



RC calibration for military applications

- The **DO160G** Procedure :
  - The TUNED calibration is used to verify that the chamber is suitable for measurements ONLY.
  - A second set of measurements with the DUT present is needed to measure the Normalized $\bar{E}$ field using STIRRED or TUNED control for testing.
  - Calibration data cannot be used for an indication of $\bar{E}$ field performance.
  - STIRRED testing with significantly increased samples has a significant effect on measured normalized $\bar{E}$…
  - STIRRED can be used if the DUT exposure requirements are met.

Agenda

- Introduction
- Basic RC Theory
- RC Characterization for LFF devices
- RC Characterization for MIMO devices
- RC calibration for military applications
- **Conclusions**

Conclusions

- Low cost RC’s can be used for EMC testing of small and large devices
- By adding a turntable and tuners the same chamber can be used for wireless mobile, and large devices
- Extensive efforts are underway to standardize the use of RC’s for compliance testing of wireless devices (SISO/MIMO)
- For MIMO, the ability to perform realistic RF environment simulation and evaluate end user metrics in real-world scenarios is an invaluable resource to wireless technology developers.

Conclusions

- **When designing a Reverb chamber :**
  - The selection of wall material is important for field strength, pulse width and rise-time considerations.
    - **NOTE:** High conductivity is good but may be irrelevant.
  - Chamber dimensions depend on EUT size and LUF.
    - **NOTE**: Keep the chamber as small as possible
  - Tuner dimensions and configuration depend on LUF.
    - **NOTE**: Keep tuner volume as small as possible
  - Performance can largely be predicted based on waveguide equations.
  - Severe, fast, cost effective….

ETS-LINDGREN
An ESCO Technologies Company
BEYOND MEASURE™

Questions?