Reverberation Chamber

“Statistically deterministic Chaos”

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REFTAS
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Overview

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- History
- Theory
- Electromagnetic Environment
- Statistical Distributions
- Calibration/Working Volume
- Correlation
- Applications
- Limitations

History

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- 1947 Patent
- 1968+ Early papers
- 1976+ Instituto Universitatio Navale (Paolo Carona)
- 1977+ Naval Surface Warfare Center, Dahlgren Division (Mike Hatfield, Mike Slocum,…)
- 1983+ National Institute of Standards and Technology (Crawford)
- 1991+ Ted Lehman Theory
- 1996+ Standards (GM, SAE, IEC, RTCA DO 160E, MIL STD)
- 1999+ NIST (Hill, Koepke, Ladbury,…)
- 2001+ Arnaut

Anechoic / Reverb Chamber

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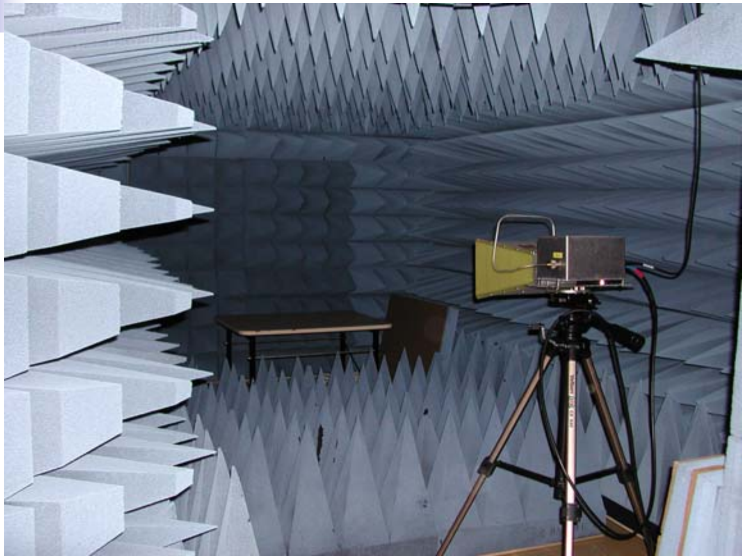

- **Pros**
  - Plane waves from one specific angle and polarization – great for antenna pattern measurements
  - Susceptibility – Large impact can be made if the characteristics of the device being tested are known
  - Emissions –Measures the radiated power in a specific direction
- **Cons**
  - Test time will be large if a complete test is done
  - Uncertainty levels are huge

- **Pros**
  - Plane waves from all angles and polarizations – great model for complex environments
  - Susceptibility - Uncertainty levels are much smaller and predictable (statistically)
  - Emissions – Directly measures max. radiated power
- **Cons**
  - Test time is large (especially for susceptibility)
  - No directivity information

Theory

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- Modal Structure
  - Sum of set of basis functions, useful for visualizing variations in fields as a function of location
  - Hard to include complex tuner boundary conditions (BC)
- Ray tracing
  - For simple geometries can evaluate amplitude and phase
  - Convergence is a problem for complex configurations
- Plane wave integral
  - Electromagnetic Environment (EME) inside a (Reverb Chamber) RC can be expressed as a sum of plane waves (Hill)
  - Applies only to source free region
- Chaos model
  - Can predict the large change in EME for small changes in BC
  - Limited work and relevance to RC not demonstrated; (Arnaut work might change things here!)

Modal structure

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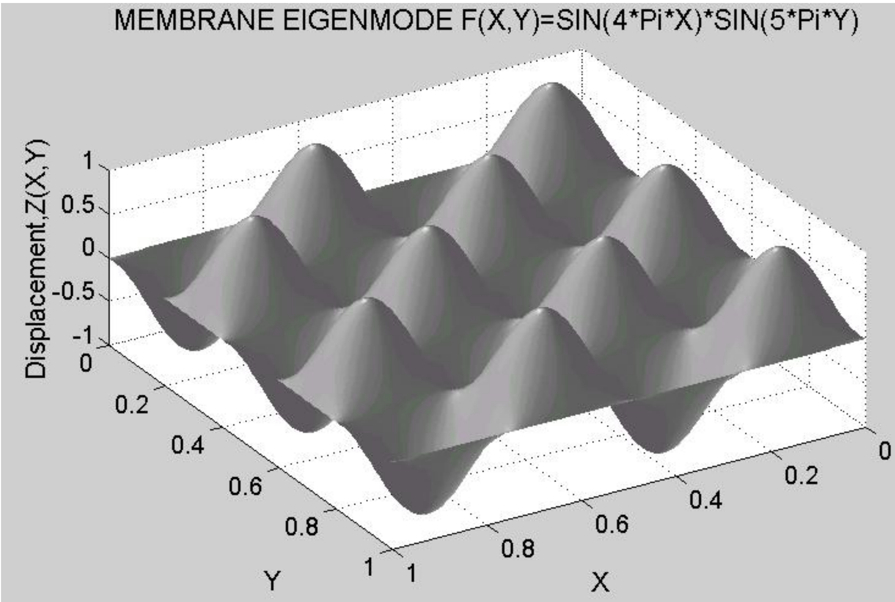

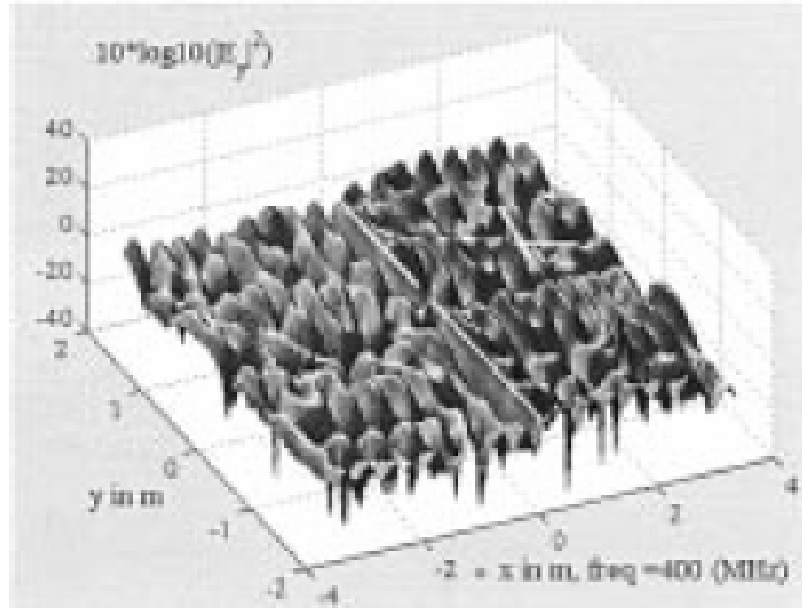

- Avoid cubical cavity or cavities that have dimensions as multiples of one side
- The more complex the structure, the better the reverberation but also think about structural rigidity and repeatability

1. http://aemes.mae.ufl.edu/~uhk/mem2.jpg
2. C. F. Bunting, *"Statistical Characterization and Simulation of a Reverb Chamber Using Finite-Element Techniques,"* IEEE Trans. on EMC, Vol 44, No.1, Feb 2002.

Simulation

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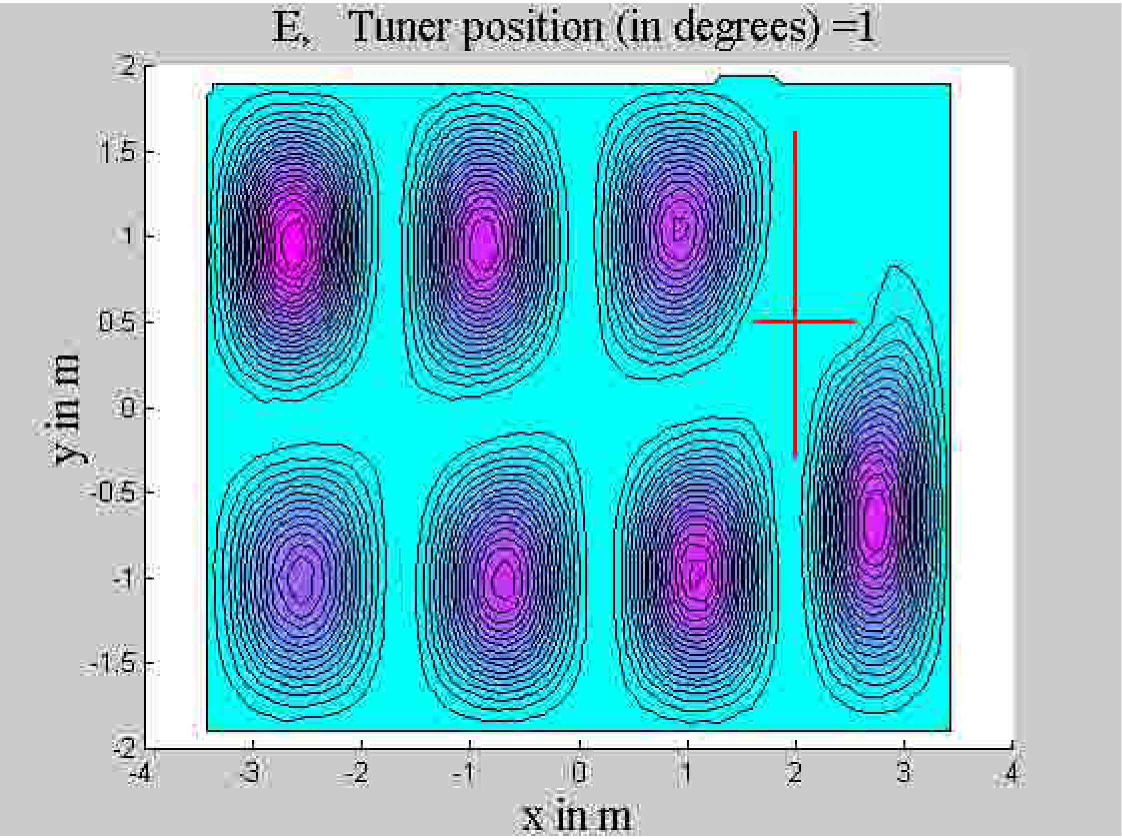

Simulation of the EME inside RC

Ack: Charles F. Bunting

Reverb chamber operational frequency

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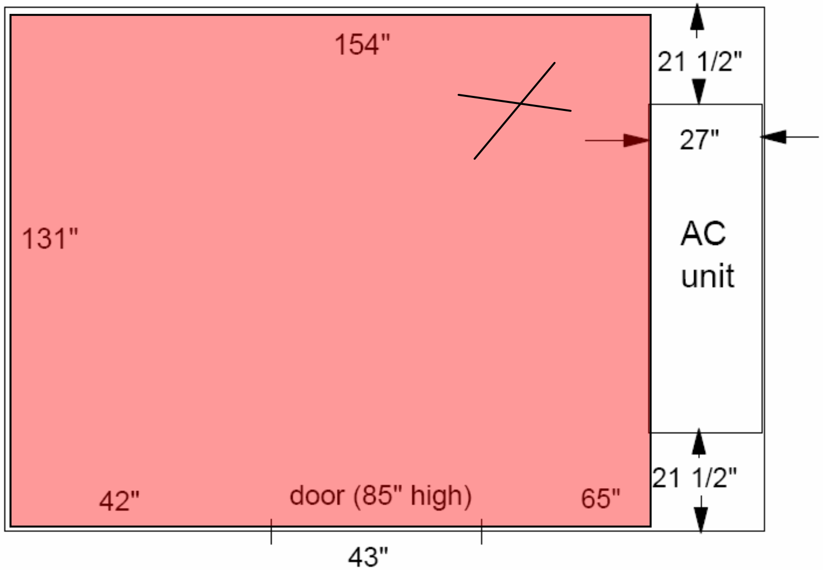
10.92’ x 10.58’ x 8.88’

- Avoid cubical chamber!
- Theoretical modes are calculated for the chamber size (eliminating the small regions at 2 corners)
- Higher the conductivity of the material used to construct the chamber, higher the Q

top view (height=106.5")



IBM Chamber

- Rule of thumb
  - The chamber can operate from 3x or 6x frequency with ‘x’ being the cutoff frequency of the cavity
  - At least 160 modes to start reverberation
- IBM chamber can go from 350MHz and above

($f_0 = 64.76\ MHz$)

Chamber modes & Bandwidth per mode

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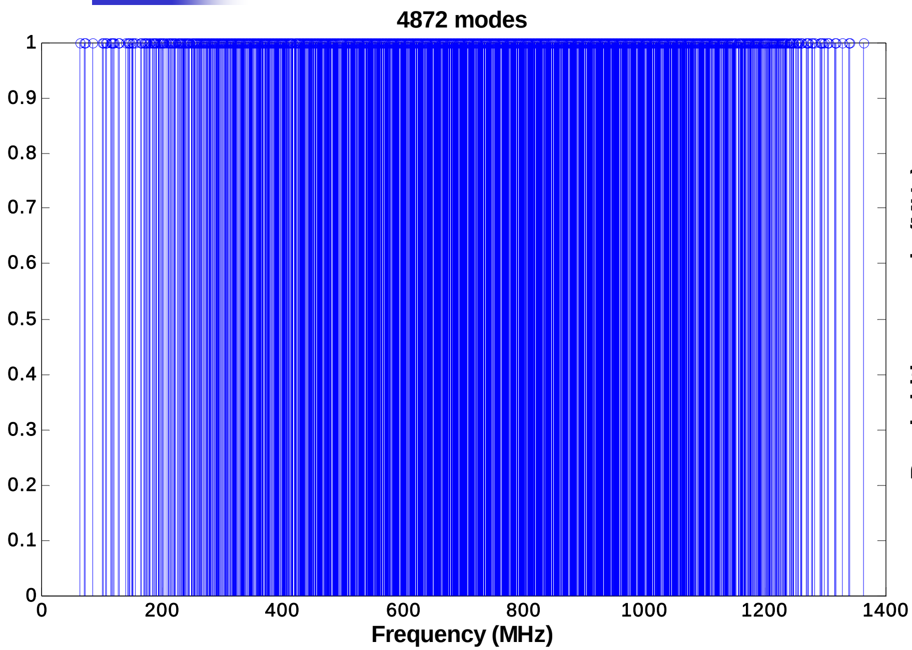

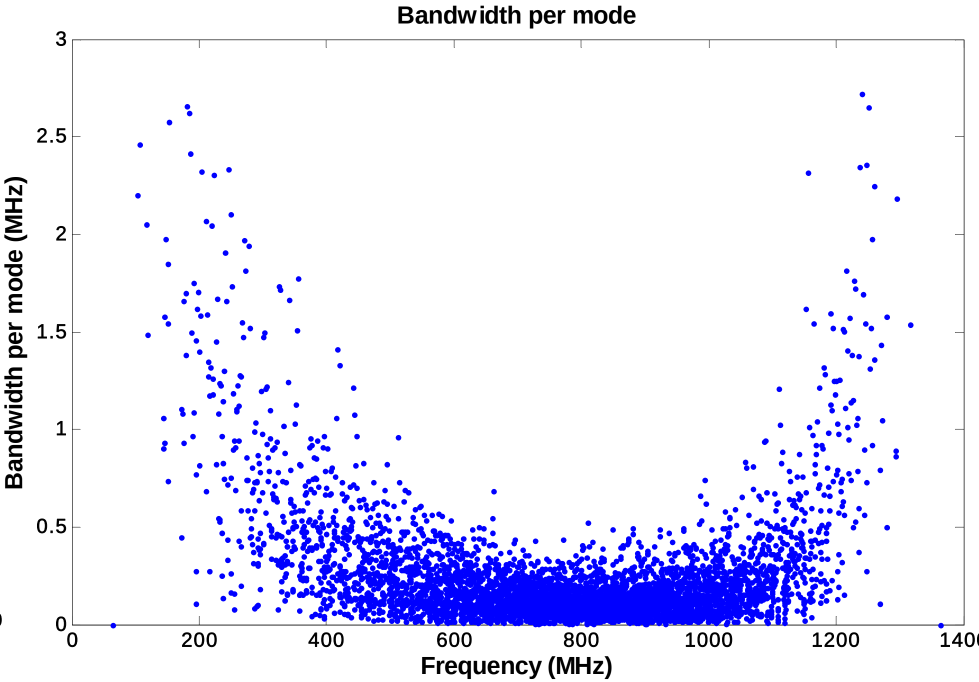

- The energy has to be distributed among several modes
- A statistical uniform field is experienced by the use of a complex tuner

Computational model

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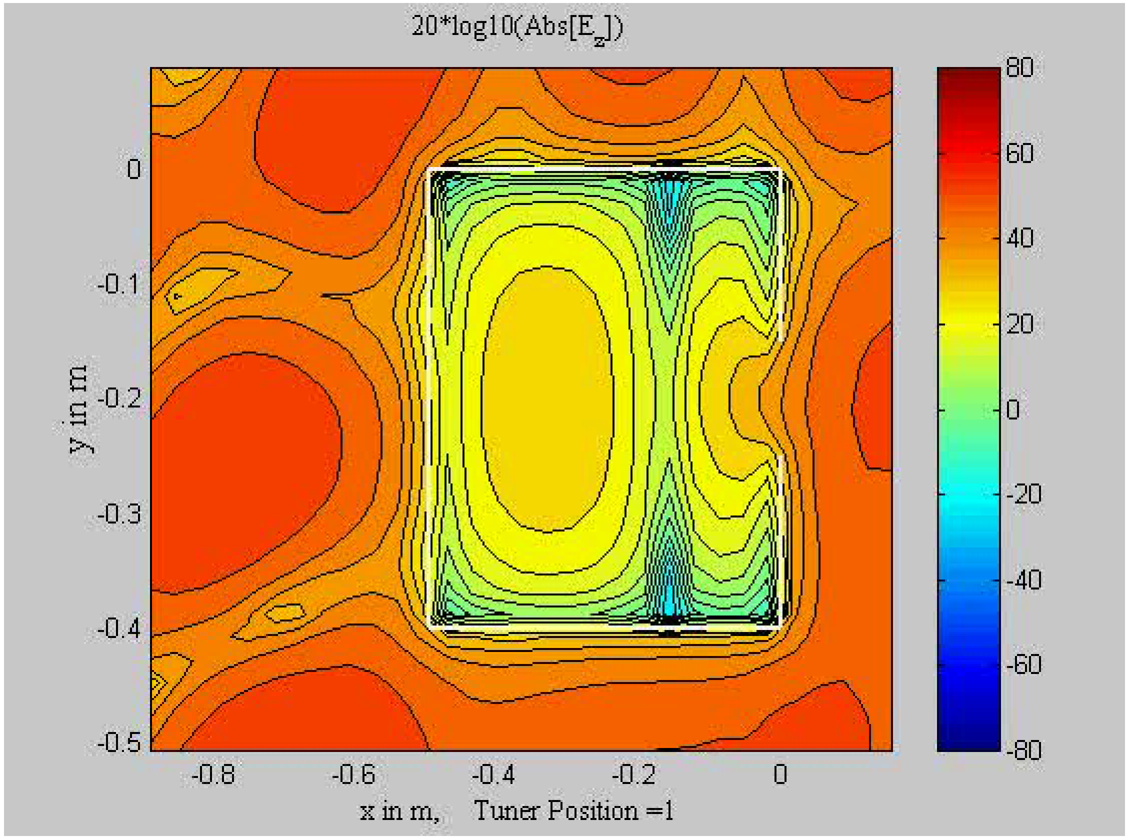

Simulation of the Electromagnetic Environment (EME) inside Reverb Chamber (RC)

Ack: Charles F. Bunting

Chambers

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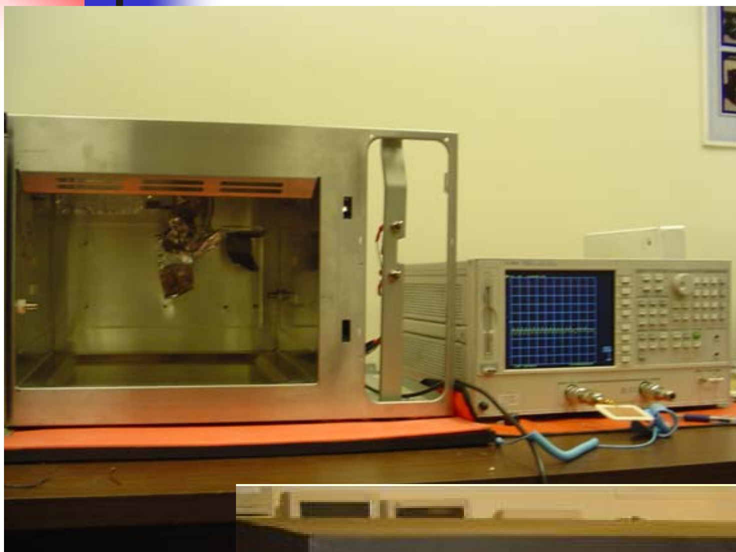


Chambers – cont’d

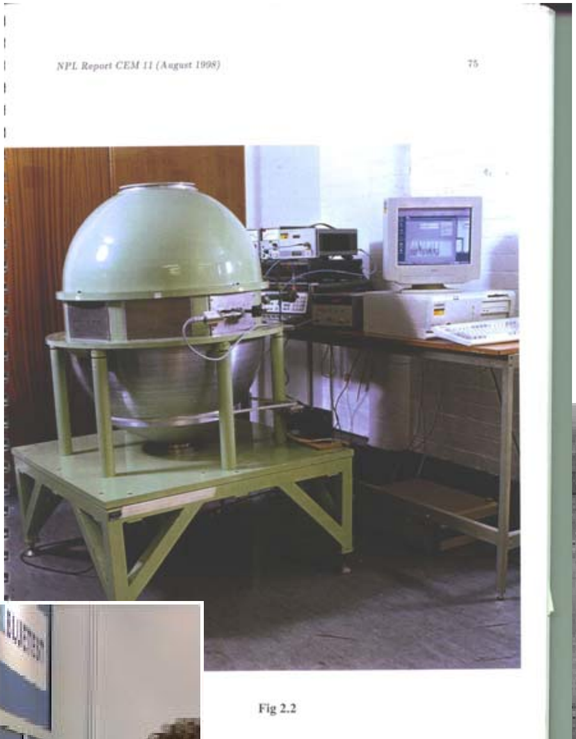
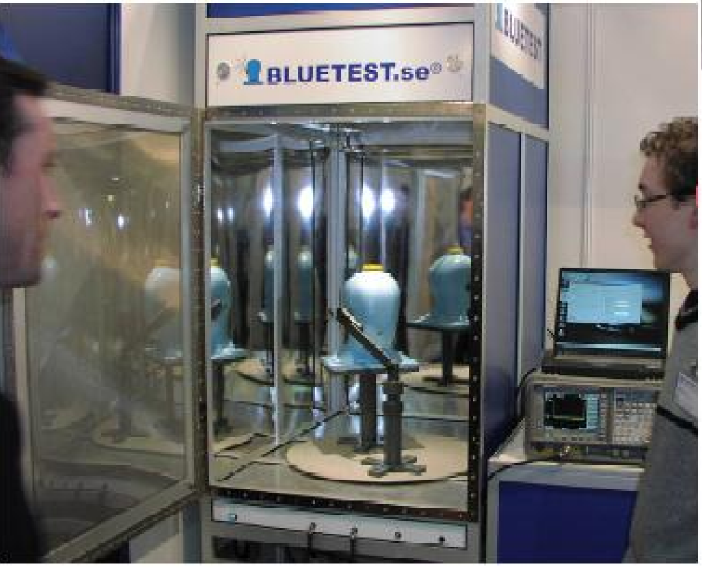
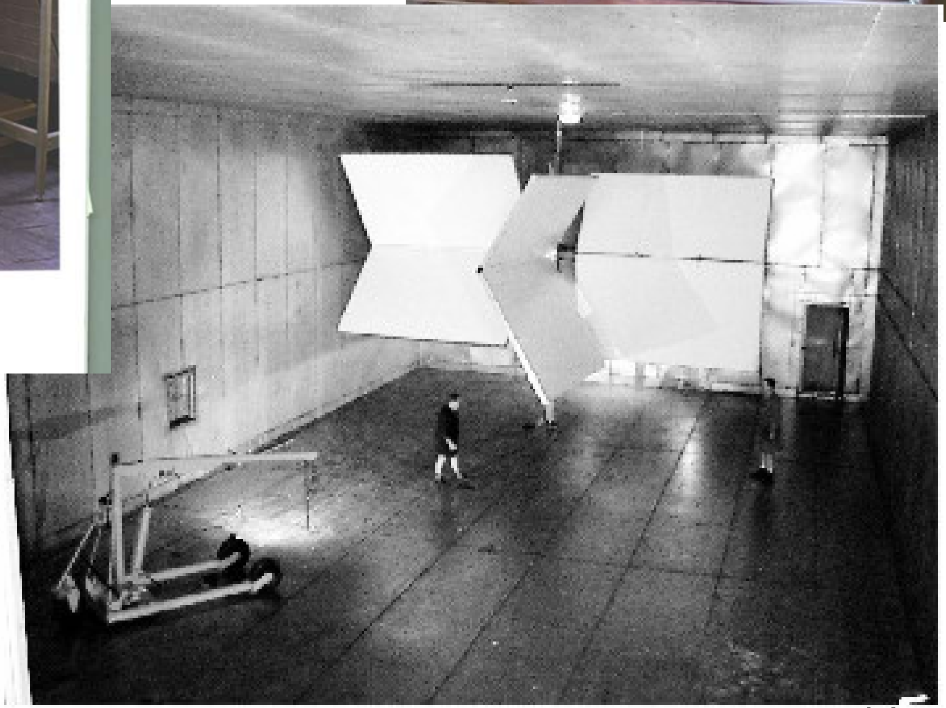

NPL Report CEM 11 (August 1998) 75

Fig 2.2





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Tuner

- The tuner is used to stir the field inside the chamber thereby creating a statistically uniform field over a specified volume of the chamber
- Tuner usually occupies considerable (25-30%) volume of the chamber
- Though reverb chamber testing asks for randomness, for repeatability the effects must be deterministic
- Measurement time is also proportional to the tuner settling time

Tuners

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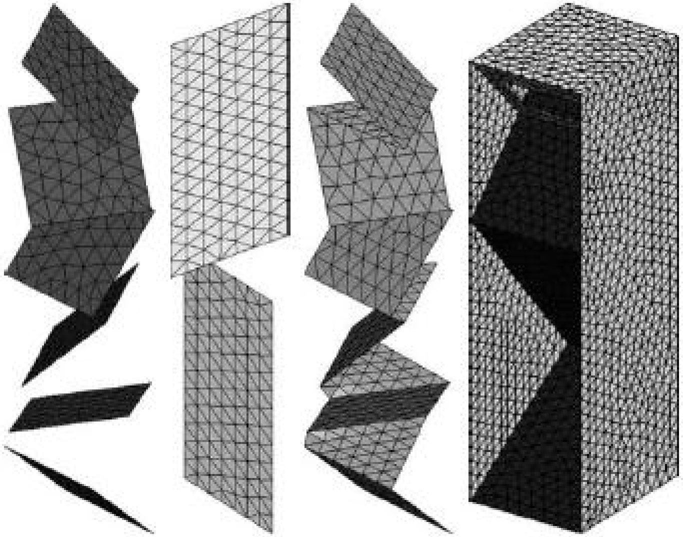

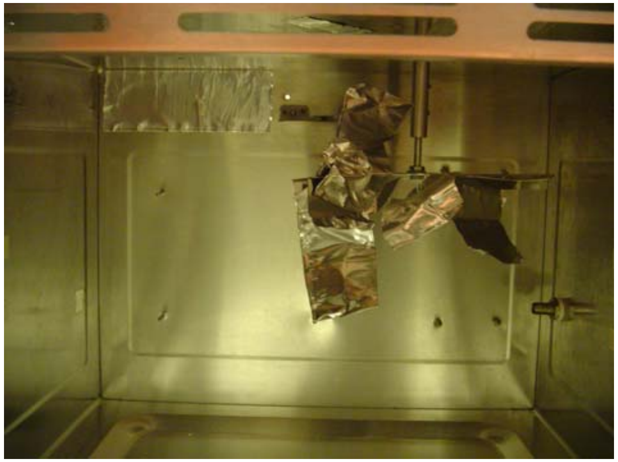

Ack: Cessna, Christian Bruns

EME - Electromagnetic Environment

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- A well stirred RC provides a test EME that is statistically isotropic, randomly polarized and uniform within an acceptable uncertainty and confidence limit
- ***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

Reminder

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- A tuner is used to change/alter the mechanical boundary conditions associated with the chamber
- A statistically uniform field over a specified volume of the chamber is created by rotating the complex tuner
- Rotating the tuner once is sufficient

Mode tuning

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- Repeated fixed tuner positions, consistent with the standards requirements
- Dwell time (amount of time an EUT is exposed to a certain field level, as given by the standard) is controllable
- Provides enough setting/response time for the devices that operate with the chamber (ex: Field probes, antennas, etc…)
- Mathematically less difficult to derive boundary conditions and predict field levels
- Problem: test time is large

Mode Stirring

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- The tuner is rotated continuously
- Can utilize all available independent samples
- Highest EME and lowest uncertainty available for the chamber
- Multiple tuners reduce uncertainty even further
- Problems: Mathematically very intense,

  Response/Settling time of devices have to be considered

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Frequency Sampling (Stepped/Scan)

- Excites modal structure as a function of frequency bandwidth for fixed boundary conditions (tuner is not moved!)
- Can provide enough number of independent samples with the excitation bandwidth is large
- Problem: The sensitivity depends on the excitation bandwidth, i.e.… statistics gets better with bigger bandwidths

Combined Stirring

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- Combined stirring utilizes both the mechanical movement of the tuner along with the scan in the operating frequency
- A well stirred field (or uniform EME) can be established
- The number of independent samples is the product both methods operated individually
- Problem: Very complex procedure

Why statistics for RC ?

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- ***In principle***, an EMC test is deterministic
  - EME determined by EM source and boundary conditions
  - Specific operating state of specific EUT in a specific configuration (e.g. cable and component arrangement)
  - Specific instrumentation configuration and procedures
- ***In practice***, an EMC test has many statistical variables
  - Facility dependent
    - EME
    - Instrumentation
    - Calibration and test procedures
    - Operator and software
  - EUT dependent
    - Unit to unit variations
    - Test configuration
    - Software system (version, cycle time, etc)
    - Operational state

Importance of statistics

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- It is possible to construct and operate a reverberation chamber (RC) without understanding statistical basis to implement a few relatively simple tasks based on performance rules and a robust software support system
- However, without statistics not possible to understand,
  - theoretical basis for operation
  - techniques for evaluating RC performance
  - RC test procedures
  - directivity / polarization effects
  - predict expected values for EME and associated uncertainty and confidence limits
- Without statistics you cannot OPTIMIZE test time versus desired results

Distributions of interest to RC

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- Uniform
- Normal
- chi with 2 dof (component of electric field)
- chi with 6 dof (total electric field)
- chi square with 2 dof (received power)
- maximum to mean ratios (chi with 2 dof, chi square with 2 dof) including linear and logarithmic formulations of above

Characterization

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- Statistical characteristics
  - Stirring ratio
  - Independent samples
  - Q factor
  - Insertion loss
  - Chamber time constant, etc…
- Introducing a known signal into the RC and mostly looking at the received power as a function of tuner position, the above mentioned parameters can be measured/calculated

Note: Frequency dependent

Good data!
Received power as a function of tuner position

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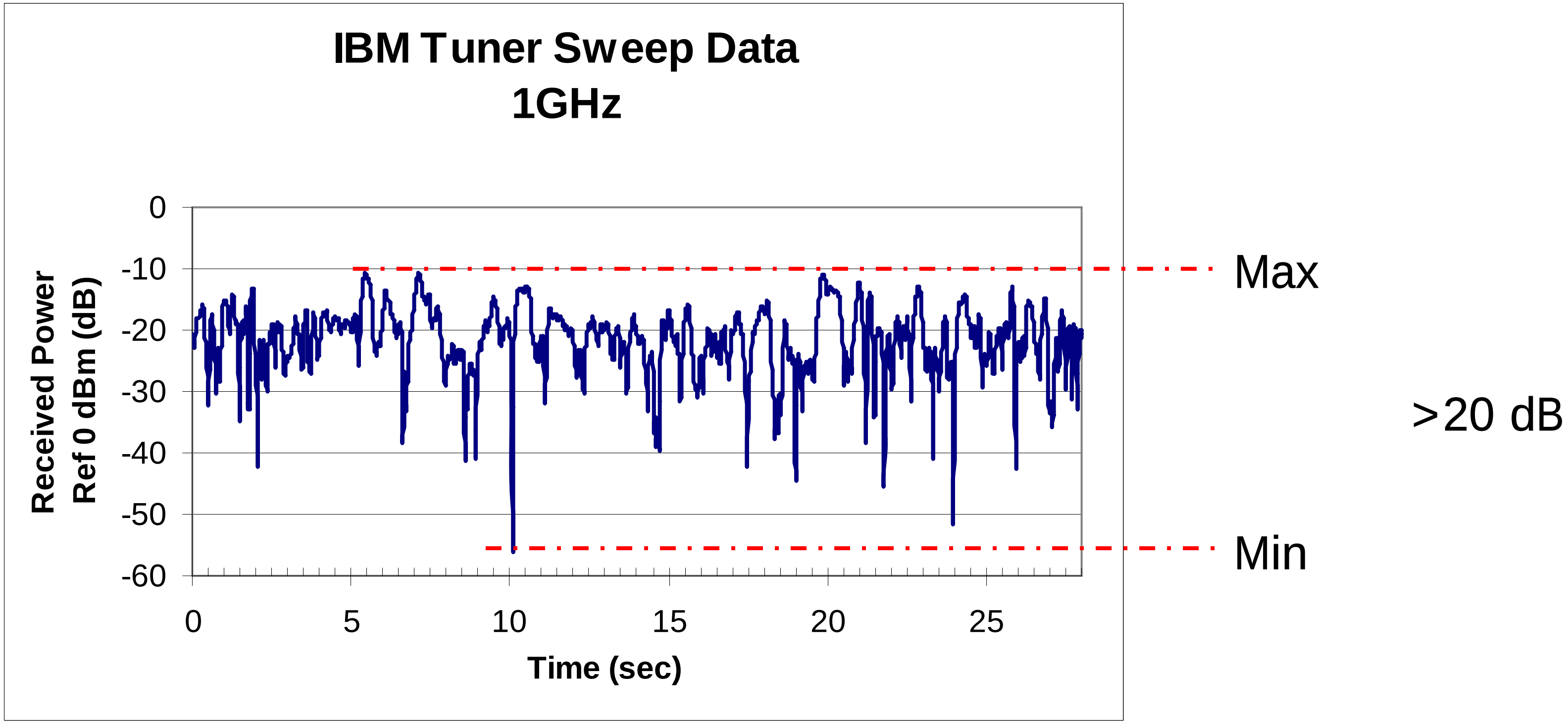

- $\langle P_{rec} \rangle$ gives a sense of the Q of the chamber
- Everything is valid for one complete rotation of the tuner
  - No measurement or calculation is valid at only one tuner position

Note: < > means ensemble or average taken over all tuner positions

E field

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- Can be measured using a set of three electrically short orthogonal dipoles
- Ideally the centers of these dipoles should be located at a single point in space (differences will be negligible if separated by a electrically short distance)
- In a well stirred chamber, the average electric field is assumed to be independent of orientation

$$<|E_{R1}|>=<|E_{R2}|>=<|E_{R3}|>$$

- The magnitude of the total electric field is

$$|E_T| = \sqrt{|E_{R1}|^2 + |E_{R2}|^2 + |E_{R3}|^2}$$

E field and power transitions

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$$<|E_i(f)|>= 0.166 f(MHz)\sqrt{\frac{<P_{rec}(f)>}{\eta_{Rx}}}$$

$$|E_{i\max}(f)| = 0.187 f(MHz)\sqrt{\frac{P_{rec\max}(f)}{\eta_{Rx}}}$$

- An estimate of the mean V/m of a single field component and by using the maximum to mean ratio for N independent samples based on a *2 dof chi distribution* to estimate the max
- From mean P_{rec}, P_{max} can be found using the maximum to mean ratio for N independent samples based on a *2 dof chi square distribution* to estimate the max power

Independent Samples

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- The number of independent samples can be defined as the number of statistically independent field configurations that can exist inside the chamber (frequency dependent)
- The number of independent samples can be found by autocorrelation which measures the relative correlation between a sequence of N samples and an offset of the same sequence
- Tuner complexity can contribute to the no. of independent samples
- Correlation analysis is usually used to indicate the sample independence

Correlation analysis

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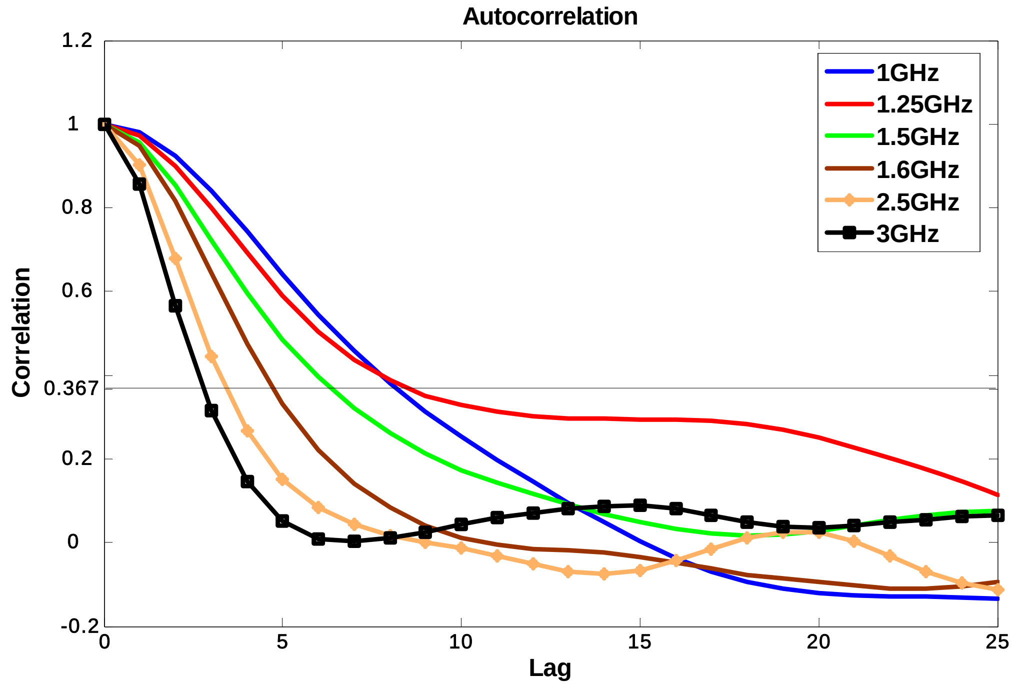

$$N_{ind} = \frac{Nmeas}{\Delta}$$

- Nmeas is the total number of measured samples and Δ is the lag (in samples) in which the correlation coefficient reduces to 1/e (0.367)

Scatter plot

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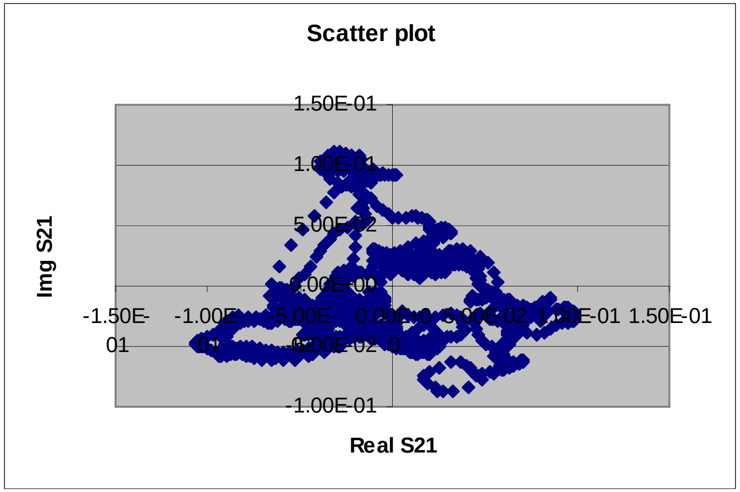
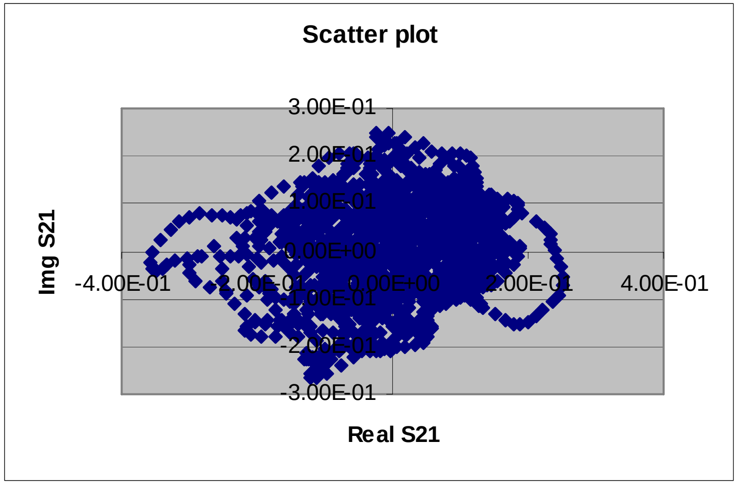
Bad



Good



- Scatter plot represents the association between the two variables
- For a reverb chamber, the real and img. components of S_{21} must be independent of each other
- Scatter plot does not specify dependent or independent variables
- Correlation can be seen because of a poor (non complex) tuner
- Strong correlation can also be seen if there is path of direct coupling between the Tx and the Rx (not desirable for a reverb chamber)

Quality factor (Q) of the chamber

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- Q can be defined as the ratio of energy stored in cavity to power dissipated per cycle

<u>Theoretical</u>

$$Q_{wall} = \frac{3}{2}\frac{V}{S\delta_W} \qquad \delta_W = \frac{1}{\sqrt{\pi f \sigma \mu}}$$

$$Q_{One-Ant} = \left(\frac{5.85 * 10^{-6} * freq(MHz)^3 * Vol(m^3)}{m_i} \right)$$

$$Q_{two-Ant} = \left(\frac{Q_{one-Ant}}{2} \right)$$

$$Q_{Total} = \left(\frac{Q_{Wall} * Q_{Ant}}{Q_{Wall} + Q_{Ant}} \right)$$

<u>Measured</u>

$$Q = 16\pi^2 \frac{V}{\lambda^3} \frac{<P_r>}{P_t}$$

V- Volume

S- Surface area

δ_W - Skin depth

λ - Lambda (c/f)

P_r – Power received

P_t – Power transmitted

Received power as a function of tuner position

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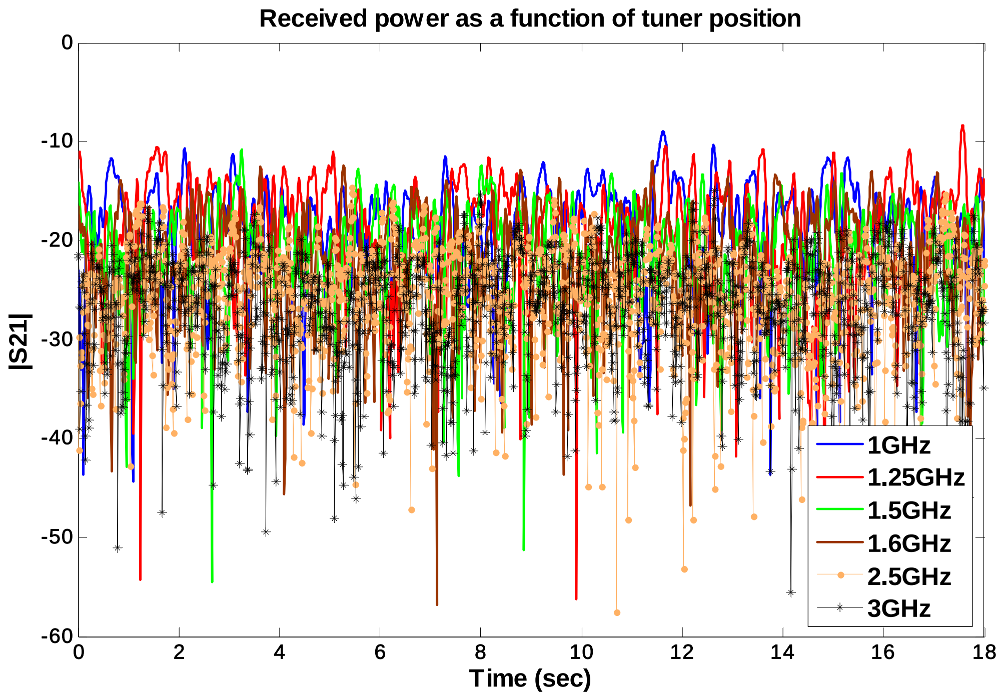

- For good stirring the max to min variation must be at least 20dB
- Complexity increases with frequency
- $\langle P_{rec} \rangle$ gives a sense of the Q of the chamber

Note: < > means ensemble or average taken over all tuner positions

Theoretical Q

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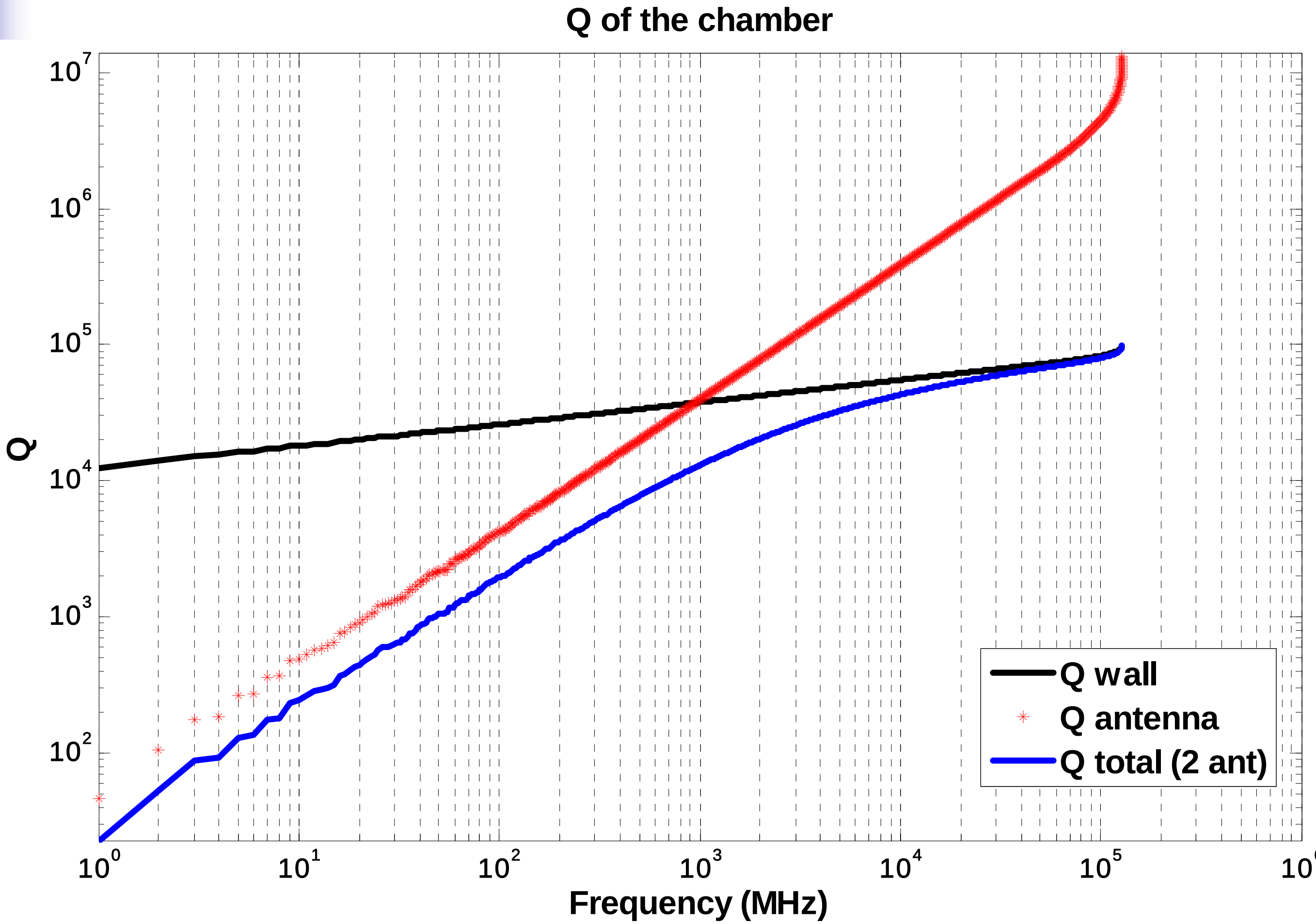

- The antenna losses dominate at the low frequencies

Q measured & K factor

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Frequency (GHz)	Q measured	No. of independent samples
1	3507	178
1.25	7278	178
1.5	6604	229
1.6	8026	320
2.5	12072	400
3	17059	534

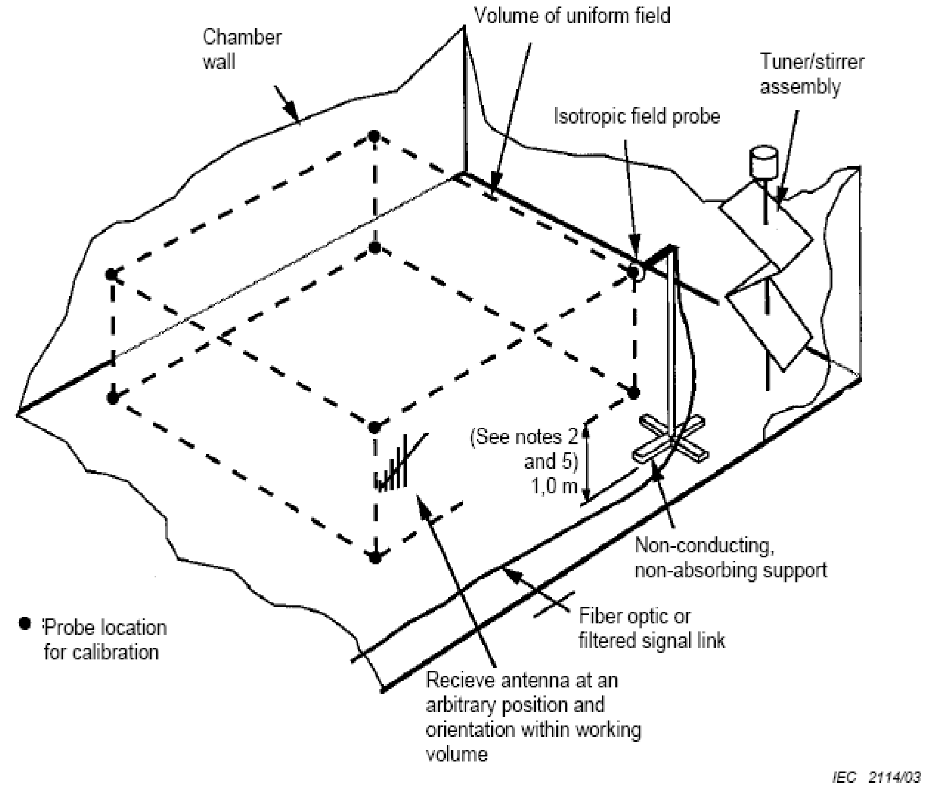
Note: No. of measured samples = 1601 (all cases)

- *K factor (must be less than 5)*

$$K = \left(\frac{Q_{theory}}{Q_{measured}}\right) = \frac{12893}{3506} = 3.67$$

- K < 5

Calibration



- The receiver antenna is placed in the working volume
- The E field probe is placed at the corners of the cube forming the usable volume
- The tuner is stepped in discrete steps over one complete rotation of the tuner
- Record maximum and average power, maximum field strength for each axis
- The antenna position or orientation or polarization is changed inside the working volume for every probe position
- This is started at the LUF of the chamber and repeated at all frequencies
- 18 steps for 3fs to 6fs and 12 steps above that
- Standard deviation will show you the uncertainty and standard calls for $\pm 3dB$

Working Volume

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- Volume defined at the lowest usable frequency, ~$\lambda/4$ to $\lambda/2$ away from any metals
- If the EUT has to be tested on a ground plane, chamber floor can be used
- For a well stirred chamber there must be no shadowing
- When EUT is placed inside the working volume, before the test, it must be ensured that the EUT did not load the chamber badly
- In some cases if the Q is too high, the chamber can be intentionally loaded to increase the time constant associated with the chamber
- Some do multiple unit testing at one run - as far as all the units are placed inside the usable volume, this is possible

Directivity / Polarization effects

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- The directivity of the device is not changed when placed inside the reverberation chamber
- Direct illumination (both Tx and Rx) to the EUT is avoided
- The directivity and polarization effects are washed out as the EUT is illuminated equally from all directions
- Better test environment than a plane wave environment

Correlation

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- Every test technique produces or measures a different EME
- Open Area Test Site (OATS) requires a 2D scan (1 to 4m vertically and 360° horizontally) for horizontal and vertical polarizations and every test frequency
- Fully anechoic chamber requires a four aspect angle illumination at EUT face normals
- RC has an all aspect angle, randomly polarized, isotropic EME
- True directivity of the device is not known (most cases)
- Any correlatibility between test techniques will be fortuitous
- Based on an extensive test uncertainty associated with AC has been found to be 12dB

Applications – Emissions and Susceptibility

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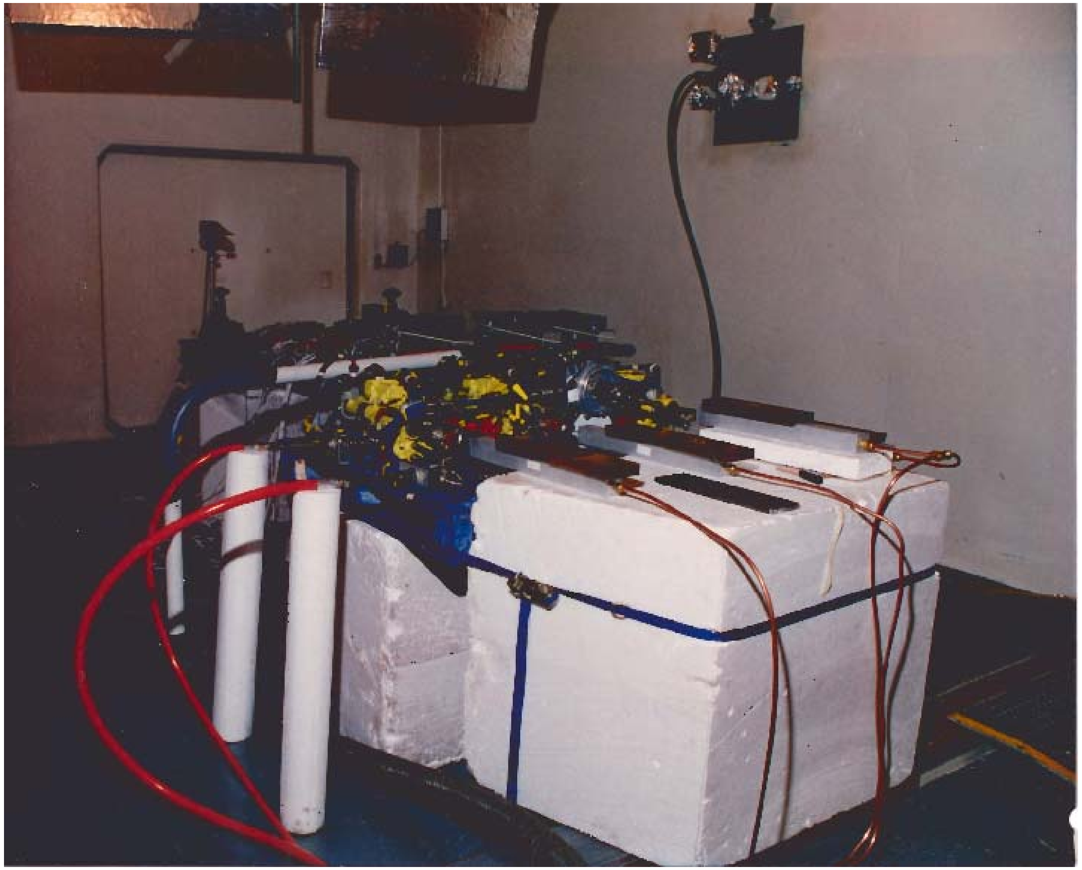

- An EM engineers nightmare, is to test a something like this for susceptibility and emissions!
- Consistent results possible with reverberation chamber

Applications – Shielding effectiveness

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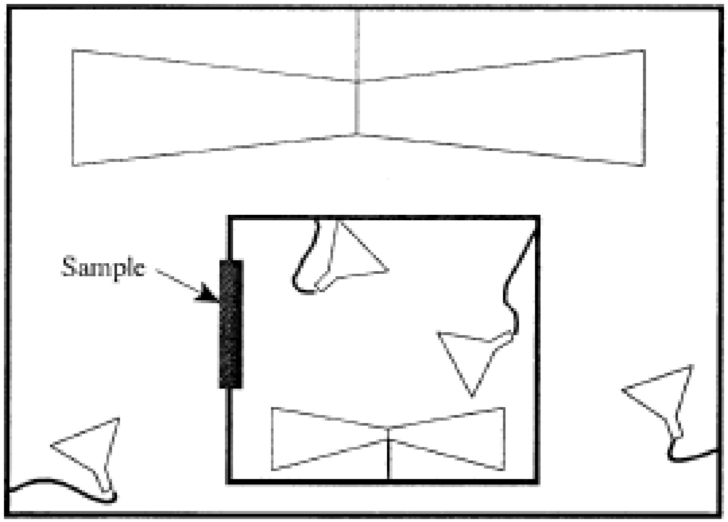

- The use of reverberation chambers for determining the shielding effectiveness has the advantage over other techniques in that the reverberation chamber exposes the material to a more realistic environment
- in a reverberation chamber, the fields are incident on the material with various polarizations and angles of incidence

Ref: Shielding Effectiveness Measurements of Materials Using Nested Reverberation Chambers; Christopher L. Holloway, David A. Hill, John Ladbury

Applications – Simulation of a Radio Environment

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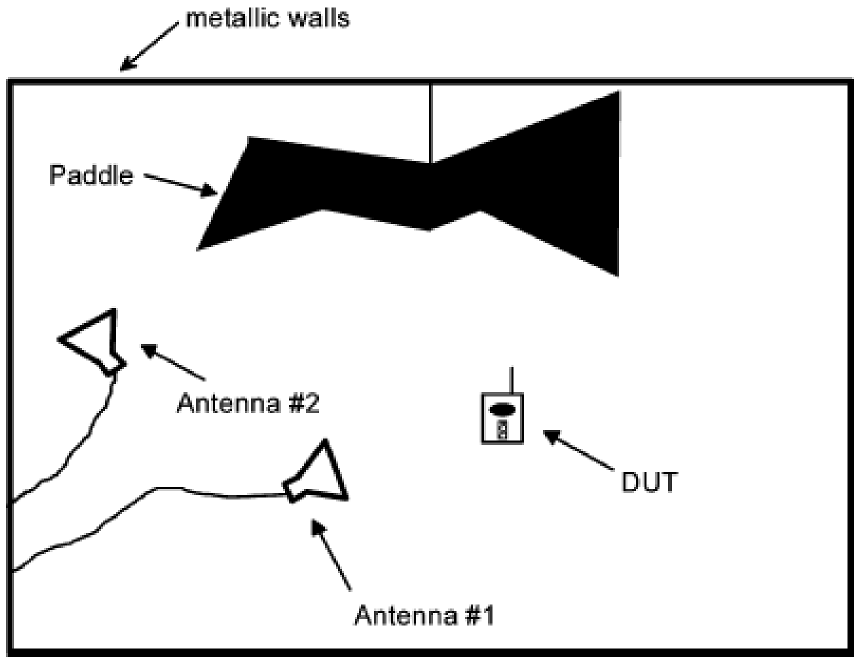

- Reverberation chamber can be used to simulate a controllable Rician radio environment for the testing of a wireless device
- by varying the characteristics of the reverberation chamber and/or the antenna configurations in the chamber, any desired Rician -factor can be obtained

Ref: On the Use of Reverberation Chambers to Simulate a Rician Radio Environment for the Testing of Wireless Devices; Christopher L. Holloway, David A. Hill, John M. Ladbury, Perry F. Wilson, Galen Koepke and Jason Coder

Applications – Measuring antenna efficiency

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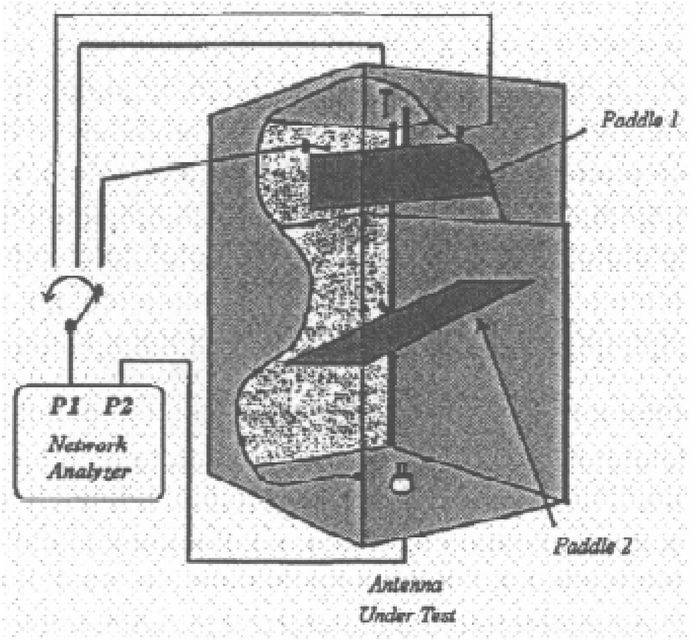

- For antenna efficiency measurement, the scattering parameters for transmission and reflection coefficient at the excitation antenna with respect to antenna under test is needed
- The scattering parameters are measured at two antenna ports between one port of the fixed transmitting antenna (Port 1) and the port of AUT (Port 2) from the network analyzer
- Ex: 3^{rd} generation cell phones

Ref: A Comparative Study of Small Antenna Efficiency Measurements; A.A.H. Azremi, H. Ghafouri Shiraz and Peter S. Hall

Advantages

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- Repeatability and reproducibility
- Robust test
- Replicates the EME close to real world
- More field strength for less input power
- Facility cost is significantly less
- Lower uncertainties
- Results are correlatable under certain conditions

Limitations

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- Directivity of the device cannot be measured in RC
- For emissions, RC measures the maximum radiated power and AC measures the field strength at a distance
- With the current method specified by the standard, the test time associated with susceptibility is large
- RC is gaining wide popularity in the EMC community but some gray areas have to be addressed
- Statistical procedure

On the whole RC is not an
EMC test *panacea*
but a better test method

Acknowledgements

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- Dr. Gus Freyer
- Ted Lehman
- John Ladbury, Galen Koepke (NIST)
- Mike Hatfield, Mike Slocum (NSWCDD)

References

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- IEC 61000-4-21
- MIL-STD 461E
- RTCA DO 160E
- SAE J551/J113
- Tech note 1508
- Lehman, Interaction notes 494
- Papers from NIST, Corona, Freyer, Hill, Arnaut, Lehman, Bunting, Bruns, Moglie…