An alternative set-up to characterize MIMO arrays

STSM Ref. Code: **COST-STSM-ECOST-STSM-IC1407-151115-067828**

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- Ricean k-factor
- Goodness of Fit Tests

Contents

- University of Twente (NL):

Faculty of Electrical Engineering, Mathematics & Computer Science

- Telecommunication Engineering Group [**Prof. Fr. Leferink**]
- Time Span of the STSM: **15/11/2015** to **25/11/2015**

- **A two-step mission**:
  - 1st step, **VIRC validation** (field uniformity, number of samples, quality factor, lowest usable frequency, isotropy, etc.) through comparison with a traditional reverberating chamber of equal size.
  - 2nd step, **MIMO array characterization** (evaluation of the correlation and capacity of MIMO channels and mutual coupling, radiation efficiency and diversity gain of these antennas with the VIRC).

Introduction

MIMO features

Scope: MIMO arrays characterization

- **Modern antennas operate in rich scattering environments and the establishment of radio links mainly relies on diversity techniques rather than on LOS between the coupled antennas.**
- **MIMOs are very good candidates for:**
  - **IEEE 802.16 (WIMAX)**
  - **IEEE 802.11 (WIFI)**
  - **3GPP LTE (4G-??)**

because of :

- **the spatial multiplexing / diversity gain**

Or in other words:

- **the QoS is enhanced ㅌ , while RF chains are increased ㅎ**

However thanks to the Antenna Selection scheme:

- **Transceiver complexity decreases ㅌ at the cost of QoS ㅎ**
- **Battery life is enhanced ㅌ**

Statement of the issue: MIMO facilities

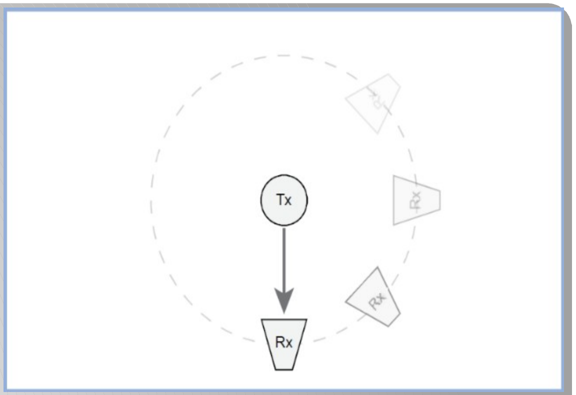
- Before entering the market they have to be characterized in facilities which can recreate the same EM conditions (multipath fading, frequency selective fading).

- The Anechoic Chamber (free space) is the most commonly used facility where, when equipped with a multi-probe system and fading simulators, the same conditions can appear at the cost however of increased costs ㅎ and limited working volume ㅎ .

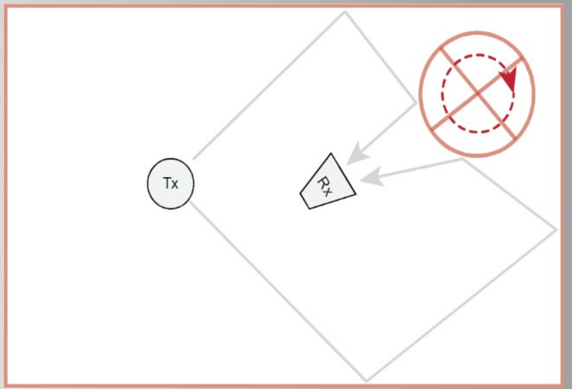
- Motivated by:
  - the long duration of the tests
  - the high costs
  - the lack of tests repeatability
  - the tests accuracy

we focus our interest on the use of the RCs and the VIRC by Frank Leferink *et al.*.

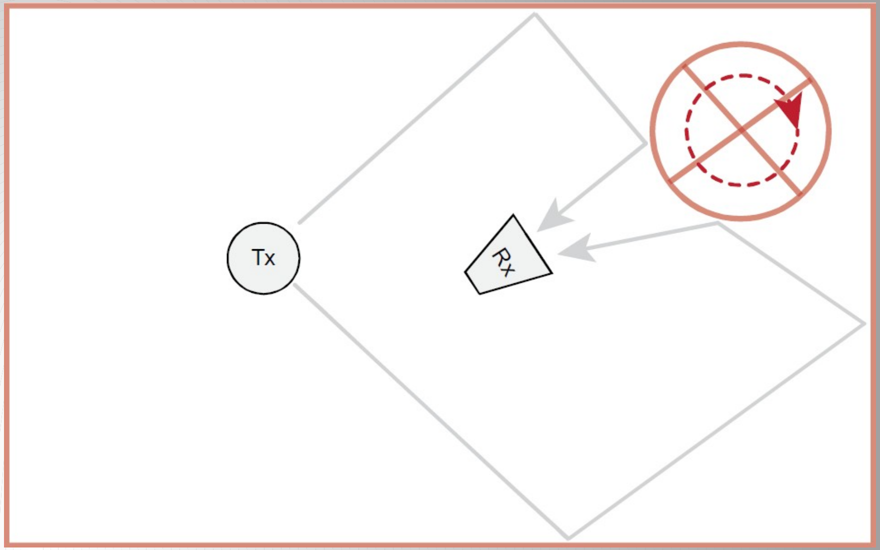
Line of sight
- **Free Space**
- **Anechoic chamber**



Multipath
- **Real EM ambient**
  - Street
  - Building
  - Plane
- **Reverberating chamber**



Multipath environments

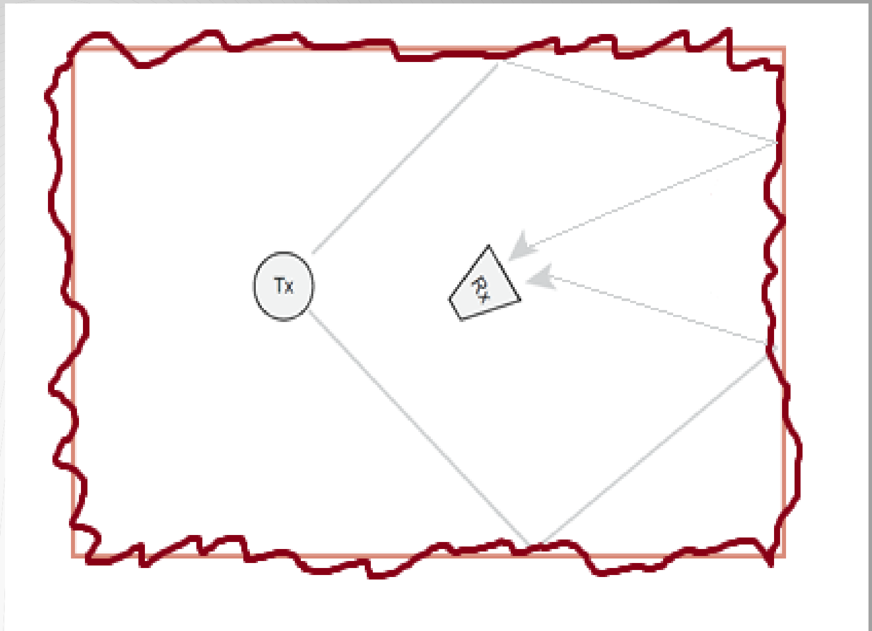


- RC
  - Faraday cage
  - Closed, shielded
  - Reflective walls
  - Low losses
- Field mixing
  - Mechanical stirrer
  - Samples collected over different stirrer positions

Reverberating Chamber

VIRC

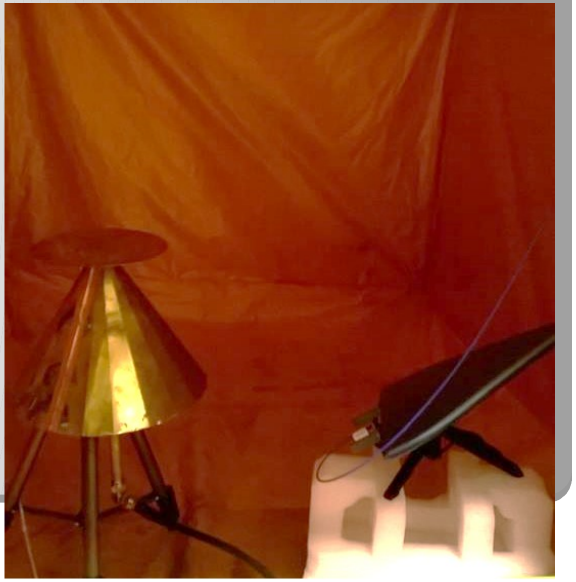
- VIRC
  - Faraday cage
  - Closed, shielded
  - Reflective walls
  - Low losses
- Field mixing
  - Flexible walls
  - Samples collected over different wall shapes



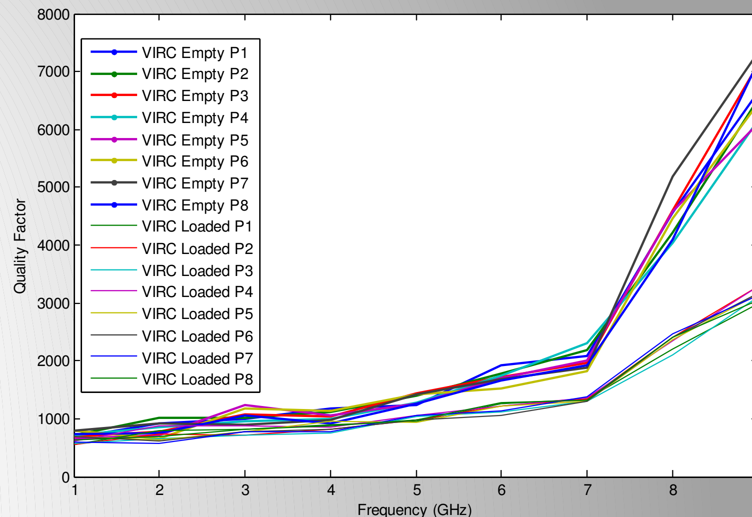
Test set-up (1/2)

RC
- 1.5m x 1.3m x 1.0m
- 1 vertical stirrer
  - Standard Z-fold shape
  - 40cm diameter

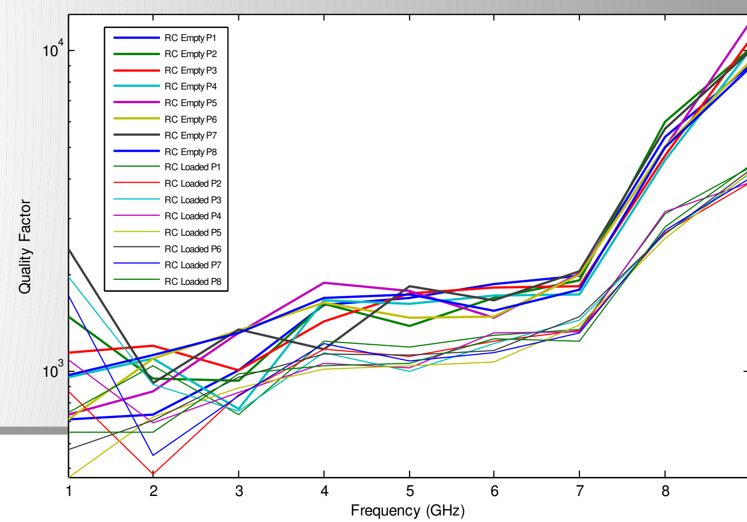
VIRC
- 1.5m x 1.2m x 1.0m
- Flexible walls shaken with 2 DC motors
  - 1 continuous
  - 1 random (changing direction)



- Measured for RC and VIRC in every position
- Validation that the chambers are indeed similar
  - Q-factor incorporates:
    - Volume information
    - Losses information



Wrong X axis, different Y scales, but it is something



Quality Factor

Test set-up (2/2)

- **RX: discone, TX: Log-per, cross-pol**
- Generator & receiver: NI USRP
  - I&Q components
- **8 positions**
  - > λ/4 distance
- 9 main frequency points
  - 400 MHz – 2.0 GHz
- **5 frequency stirring points per main**
  - 0, ±5 MHz, ±10 MHz
- Empty chamber and loaded with absorber
- **RC: 2500 samples**
  - one full stirrer rotation
- VIRC: 120k samples
  - 120 seconds with 1kHz sampling rate

Field Repeatability (1/2)

Sample

- Repetition of a sequence of values
- Independent, no memory
- Every full stirrer rotation in the RC
  - Periodic
  - Autocorrelation □ 1
- Impossible in the VIRC
  - Autocorrelation □ 0

Example

RC: X value for Y stirrer position

Statistical

- Repeatability of data statistics
  - Distribution
  - Average
  - Peak
- Related to number of independent samples
  - Limited in RC
  - What about VIRC?

Example

RC: X peak value after 360°

VIRC: X peak value after 2 sec

Field Repeatability (2/2): Frequent Research Questions

- Is it so important to repeat exactly the same field structure?
  - For a given stirrer angle
  - Only in RC
- Is it so important to have a more statistically repeatable field?
  - Dependency on the number of independent samples
- RC generates a limited number of independent samples
  - Limited statistical repeatability
  - Improved by spatial/source/frequency tricks or more stirrers
    - Not always easily implementable or applicable
- VIRC generates samples continuously?
  - How many? When does it stop/saturate?
  - Is the statistical repeatability better than RC?

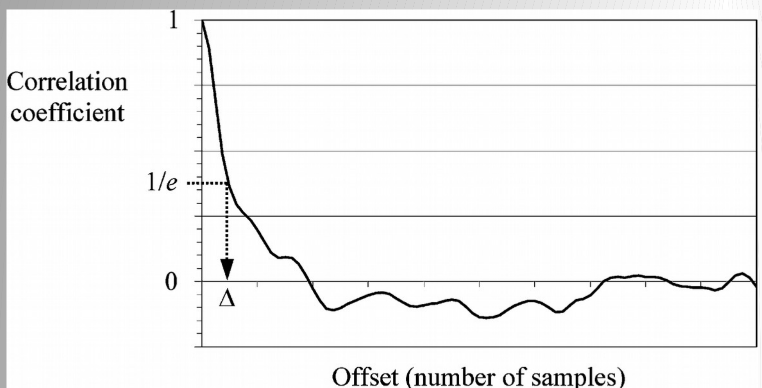
Number of Samples (1/7): Methods’ Outline

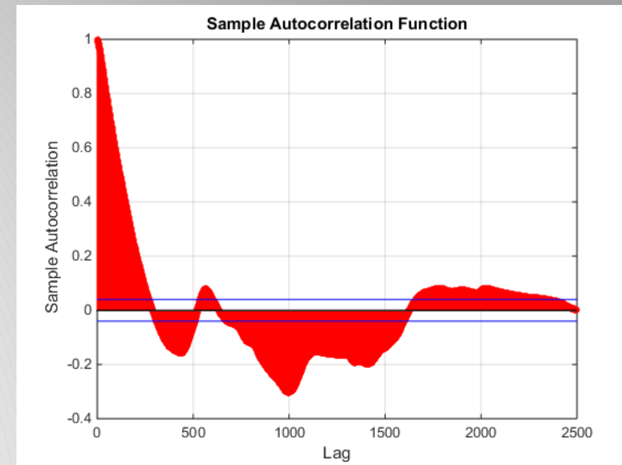
- ACF (autocorrelation function)
- From stirrer volume
- Sample difference
- From maximal E
- From multipoint field statistics
- From the behavior of scatter plots
- … and more

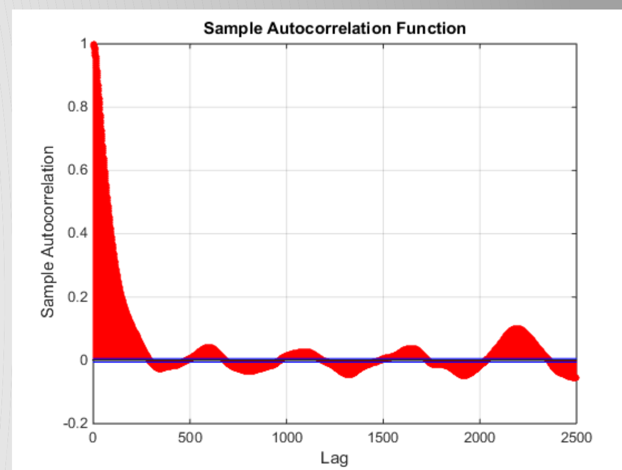
Number of Samples (2/7): Autocorrelation Coefficient

- ACF
  - IEC 61000-4-21 reference
  - Usable only in RC
    - N=360°/X°

      X – angle after which ACF drops below 1/e







  - Not usable in VIRC
    - Not periodic
    - Random motor “cheats” the ACF

- From stirrer volume

"Models for the Number of Independent Samples in Reverberation Chamber Measurements With Mechanical, Frequency, and Combined Stirring", Kent Madsén, Paul Hallbjörner, and Charlie Orlenius

- Usable only in RC
  - Known stirrer volume
  - Support reference
- Not usable in VIRC
  - No defined stirrer
  - Walls are stirrers
    - Volume?

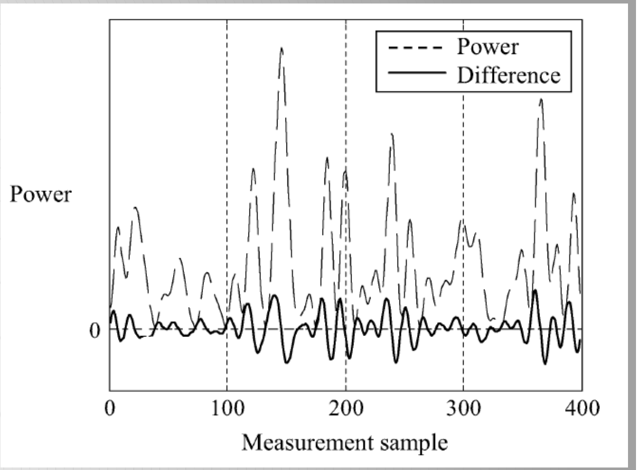
$$N_{ind} = C_{mech} \frac{QV_s}{V}$$

Number of Samples (3/7): Stirrer Volume

- Sample difference

"Estimating the Number of Independent Samples in Reverberation Chamber Measurements From Sample Differences", Paul Hallbjoerner

- Results comparable to ACF
- Usable in both RC and VIRC
  - Direct comparison



$$\hat{N}_{ind,5} = \frac{C_5 N_{meas} \hat{\mu} |dW|}{\sqrt{\hat{\mu}_P}}$$

$$\hat{N}_{ind,6} = \frac{C_6 N_{meas} \hat{\sigma} |dW|}{\sqrt{\hat{\mu}_P}}$$

Freq(GHz)	2.5	5	7.5	10
Sample Diff.	55±8	92±6	120±11	148±14
ACF	42±4	78±5	106±7	130±7

Number of Samples (4/7): Sample Difference

- From maximal E

"Evaluation of the NASA Langley Research Center Mode-Stirred Chamber Facility", J. M. Ladbury, G. H. Koepke, and D. G. Camell

- E_{max}^2 is a function of number of samples:

$$\frac{\left\langle E_{R\max}^{2} \right\rangle}{\mu} \cong 0.577 + \ln\left(N_1 \right) + \frac{1}{2N_1}$$

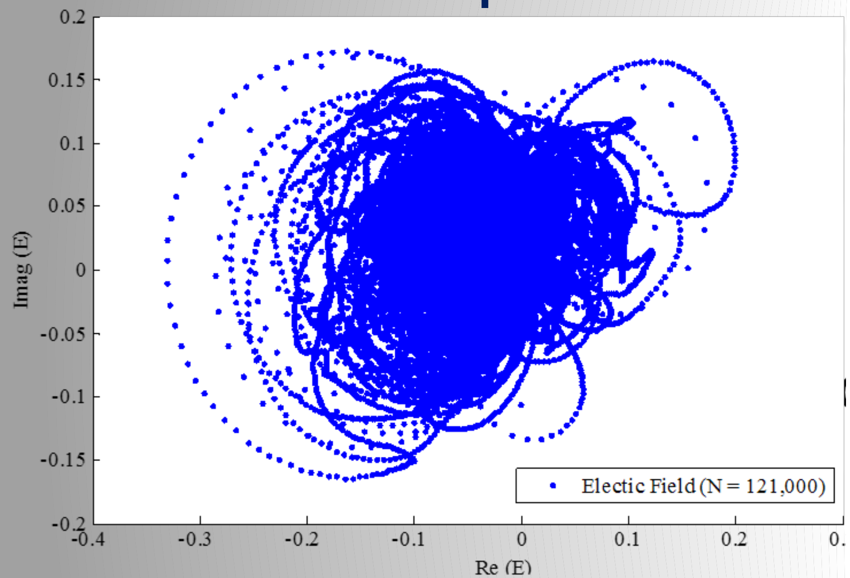
Number of Samples (5/7): Maximal E

- From multipoint field statistics
  - Compare with numerically generated, known data
  - 8 positions x 5 frequencies = 40 sets of data
    - Measured
    - Simulated
  - Introduce X% simulated sample dependencies by interpolation
  - Increase the number of dependent samples
  - Compare standard deviations of the 40 means until $\sigma_{meas} = \sigma_{sim}$
  - Brave assumptions regarding distributions
  - Qualitative, general comparison
  - Supported by other methods

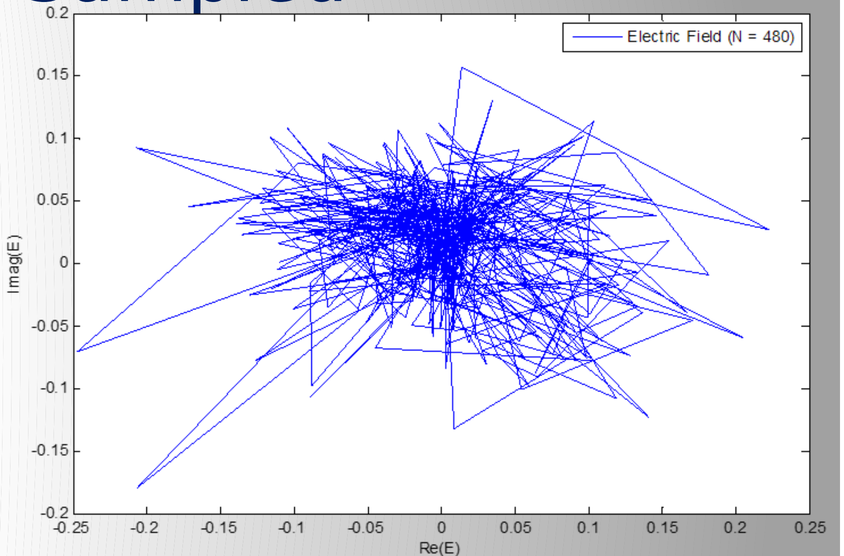
Number of Samples (6/7): Multipoint Field Statistics

- From scatter plots
  - E.g. 1st, 2nd derivative
  - Work in progress

Oversampled



Sampled



Number of Samples (7/7): Scatter Plots

- Stirred energy
  - Energy scattered by the stirrer/walls
  - Changes when the stirrer/walls are moved
- Unstirred energy
  - Energy unaffected by the moving stirrer/walls
  - Also direct coupling between TX and RX antennas

- Rician k-factor
  - Ratio between unstirred and stirred components

- VIRC is expected to produce less unstirred components because the energy is more likely to be reflected from the surrounding moving walls

Ricean k-Factor

Goodness of Fit Tests

- **How well does the recorded data fit the theoretical distribution**
  - no LOS field strength is Rayleigh distributed
- **Quick, simple, and solid test for proper overmoded operation**
  - Multipath model usability
- **E.g. Kolmogorov–Smirnov**
  - Maximal difference between empirical and theoretical CDFs

Thank you for your attention!

Questions?