Measurements of Wireless Devices in Reverberation Chambers

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Institute of Electrical and Electronics Engineers (IEEE)

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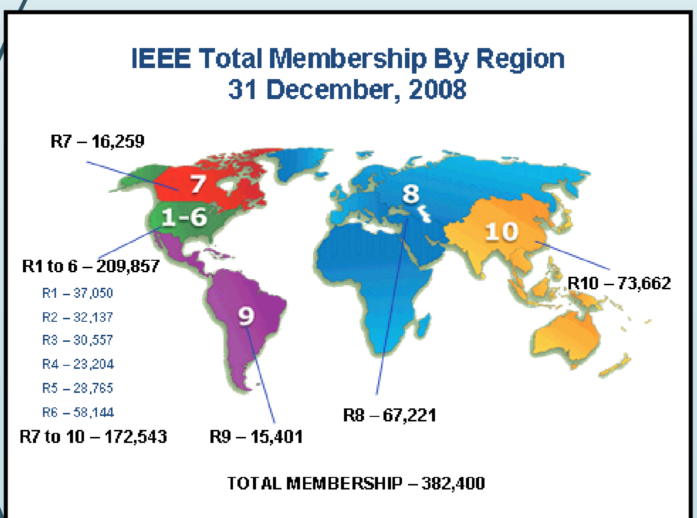
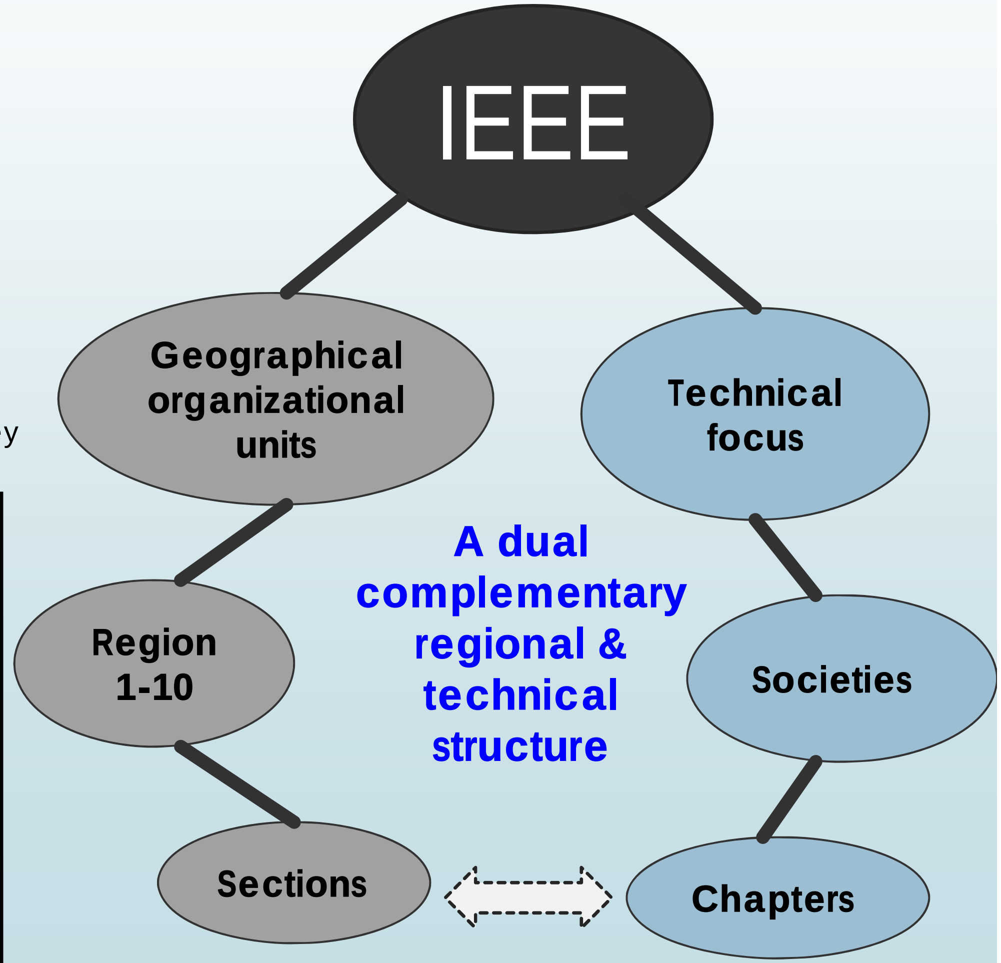




The Founding of IEEE

1884 — **1912** — **1963** — Present

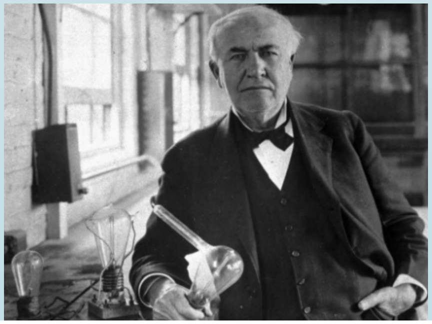
AIEE
American Institute
of Electrical Engineers

Thomas Edison,
Alexander Graham Bell,
and other notables
founded the
American Institute of Electrical Engineers.

IRE
Institute of Radio
Engineers

Pioneers of wireless
technologies
and electronics
founded the
Institute of Radio Engineers.

AIEE and IRE merged to become the Institute of Electrical and Electronics Engineers, or **IEEE**.



IEEE Today at a Glance

Our Global Reach

421,000+
Members

- Member
- Senior Member
- IEEE Fellow

39
Technical Societies

160
Countries

Our Technical Breadth

1,600
Annual Conferences

3,900,000+
Technical Documents

170+
Top-cited Periodicals

IEEE EMC Society

EMC SOCIETY®

IEEE Electromagnetic Compatibility Society:

the world's largest organization dedicated to the development and distribution of information, tools, and techniques for **reducing electromagnetic interference**.

The society's field of interest:

standards, measurement techniques and test procedures, instrumentation, equipment and systems characteristics, interference control techniques and components, education, computational analysis, and spectrum management, along with scientific, technical, industrial, professional and other activities that contribute to this field.

Founded in 1957

Professional Group on Radio Frequency Interference (PGRFI)

Institute of Radio Engineers (IRE)

IEEE EMC Society

EMC SOCIETY®

Global Reach

60th anniversary (2017)

~4,000
Members

- Member
- Senior Member
- IEEE Fellow

160
Countries

Technical Breadth

Flagship Annual Conference
IEEE International EMC Symposium

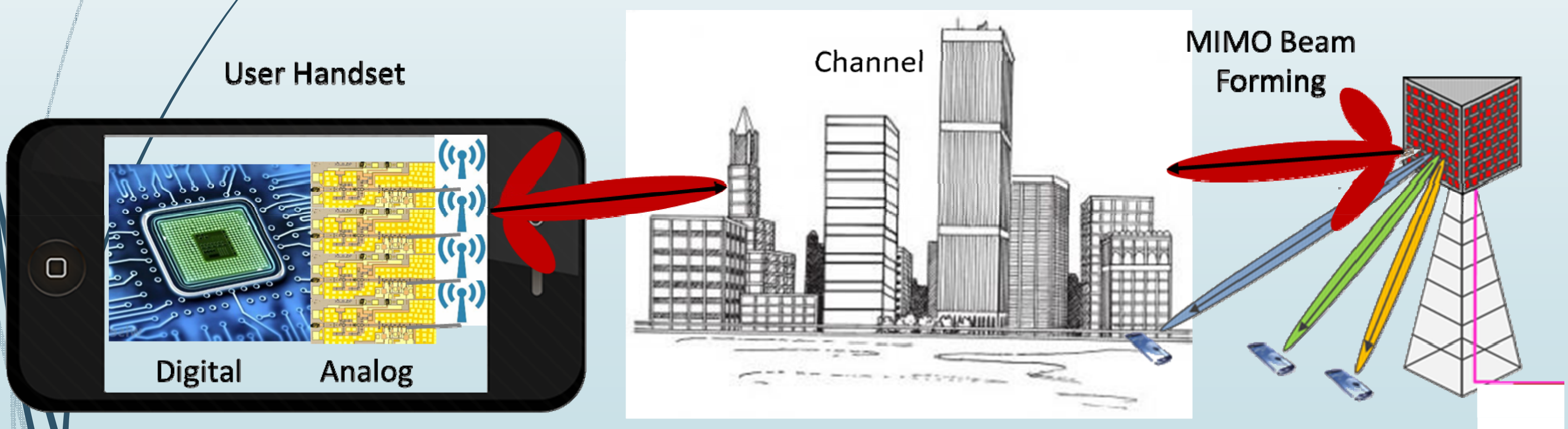
IEEE Trans. EMC
IEEE EMC Magazine
IEEE Trans SIPI

EMC Standards

NIST, Wireless, and 5G

Communications Technology Laboratory (March 2014)
Targeted research: test and measurement of new communication technologies

- Calibrations and traceability for wireless instrumentation
- Refinement and validation of test protocols, models, and simulation tools
- New test methods for spectrum sharing, 5G, and other national priorities



mmWave Transistors, Amplifiers

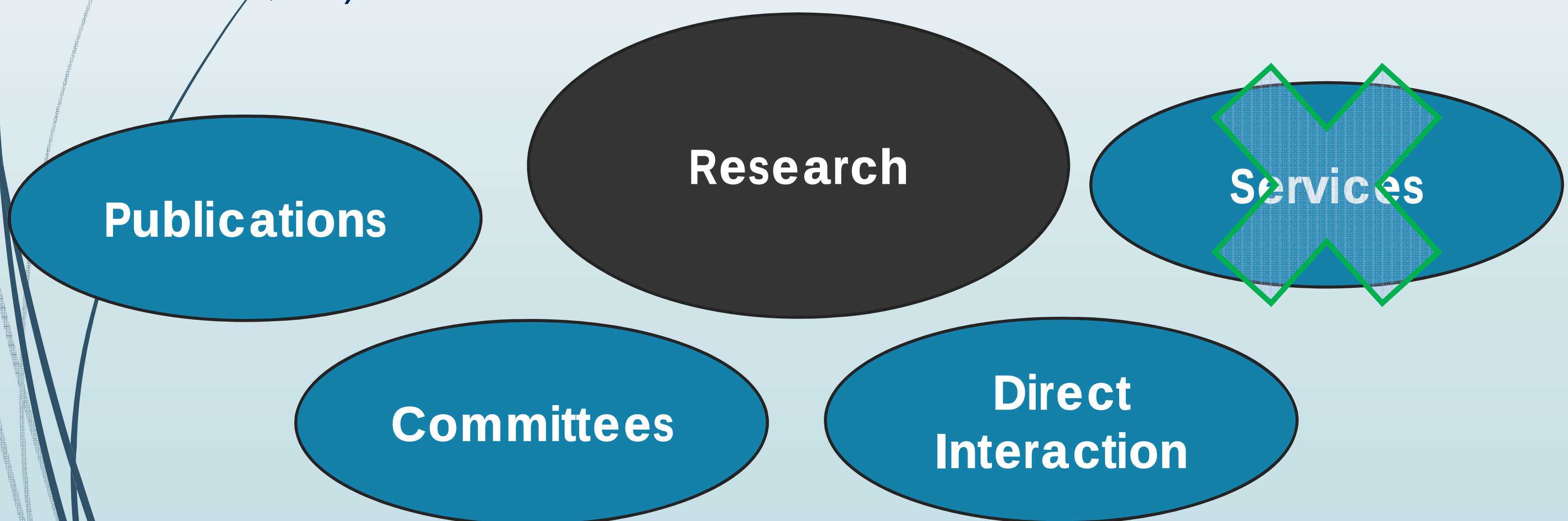
mmWave Modulated Signals

Channel Measurement and Modeling

Over-the-Air, Antennas and Massive MIMO

Metrology for Wireless Systems Group

- Test methods and uncertainties for modulated-signal measurements
- Support for standards development
  - Standards and certification groups (CTIA, IEEE, ANSI, …)
  - Data for standards development (smart manufacturing initiative, NFPA, …)



OTA Test in reverberation chambers involves all except calibration services

What is a Reverberation Chamber?

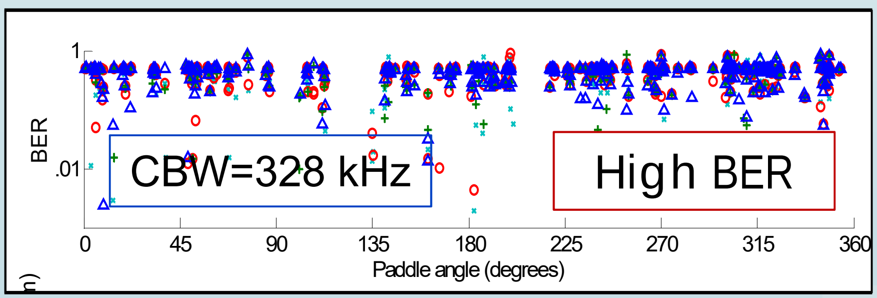
- A shielded, highly reflective radiated-signal test chamber

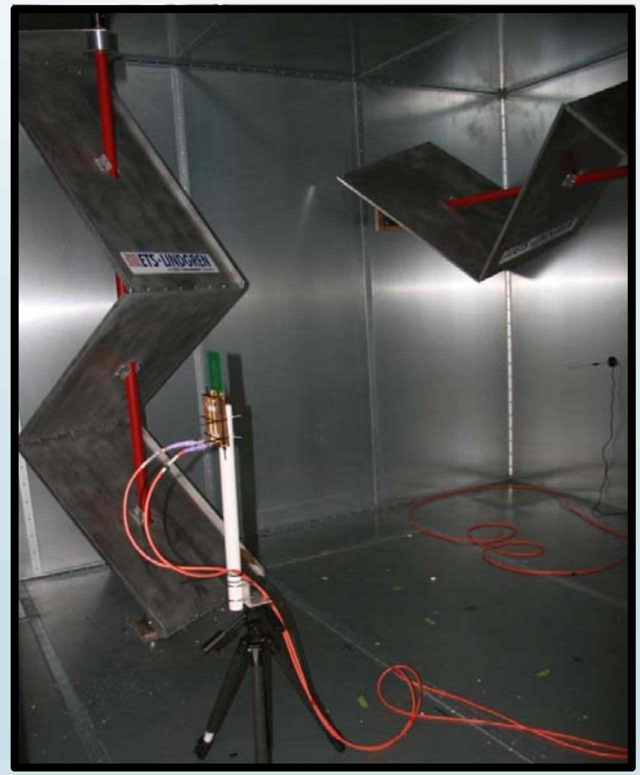
What you can do with one:

- Create known fields (EMC/susceptibility)
- Radiated emissions and power (CW and modulated-signal)
- Antenna parameters (Γ, efficiency, etc.)

You can also do communication system tests

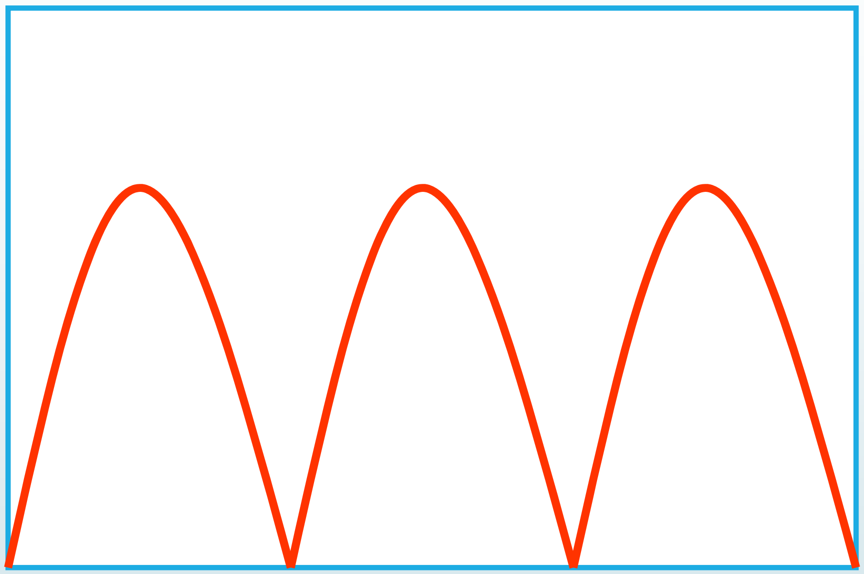
- Receiver sensitivity
- Throughput
- EVM, BER, etc.
- DUT needs realistic channel





NIST measurements of prototype 4G MIMO cellular telephone antennas

Fields in a Metal Box (Cavity)*

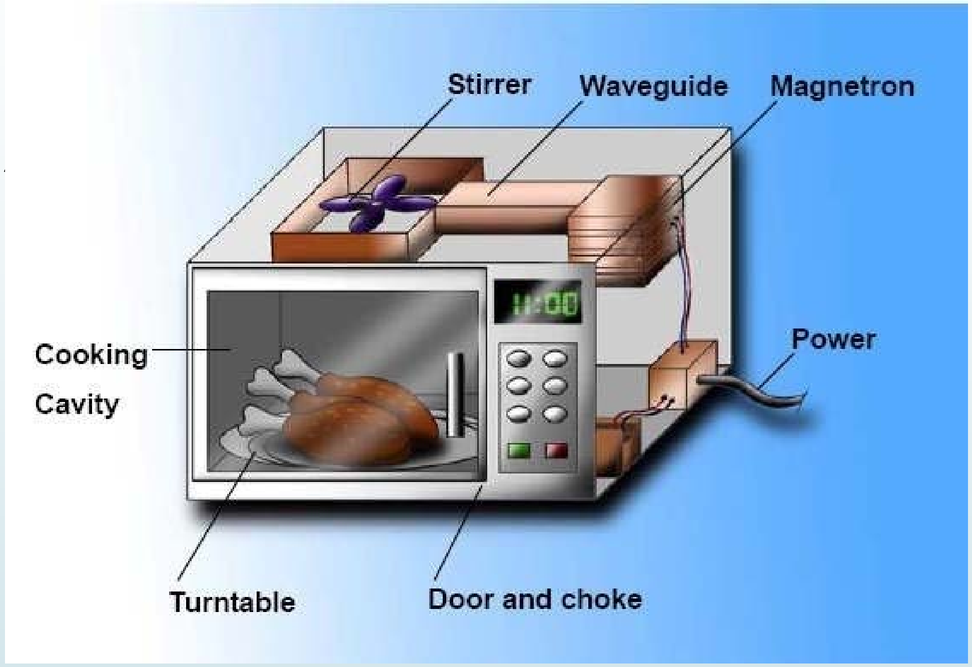


- In a metal box, the fields have well defined modal distributions.
  - Some locations have very high field values
  - Some locations have very low field values

* With thanks to Chris Holloway

Fields in a Metal Box with Large, Rotating Scatterer (Paddle)

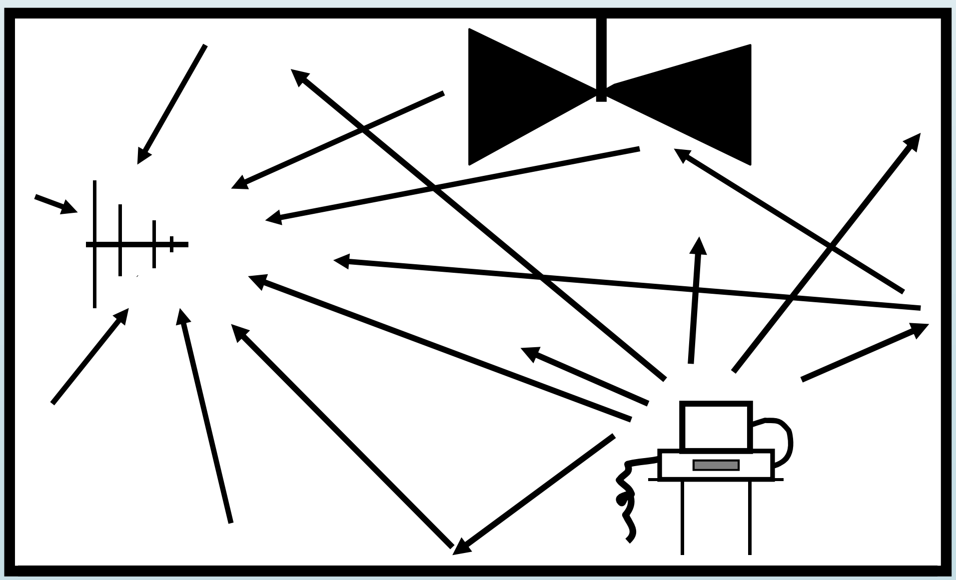
Frozen Food



- The paddle changes internal field distributions (modes) where the high and low field values occur
- Ideally, after one mode-stirring sequence, all locations in the chamber will have experienced nearly the same collection of field maxima and minima

A “Statistical” Test Chamber

- Quantities measured in the reverberation chamber are averaged over a *mode-stirring sequence*
- Randomize fields with
  - Mode-stirring paddles
  - Changing physical position or moving walls
  - Using multiple antennas with various locations, polarizations, etc.

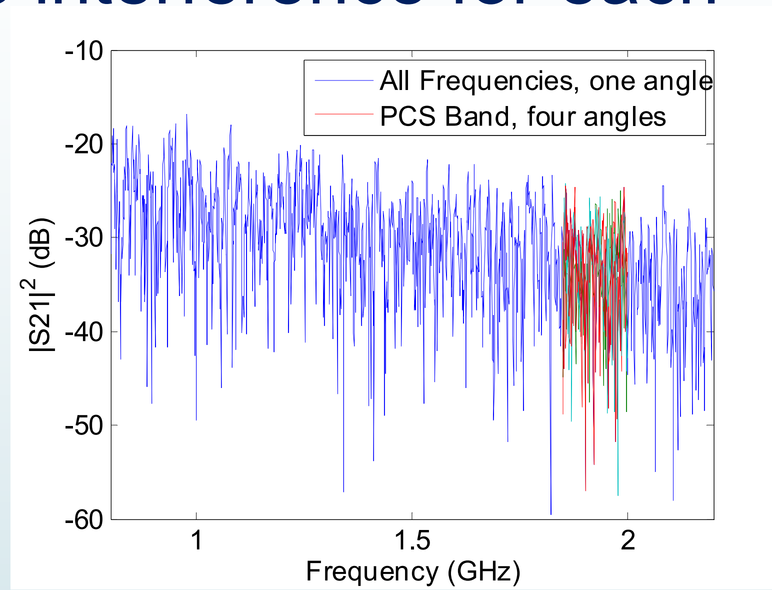


Reverberation Chambers Come in All Shapes and Sizes

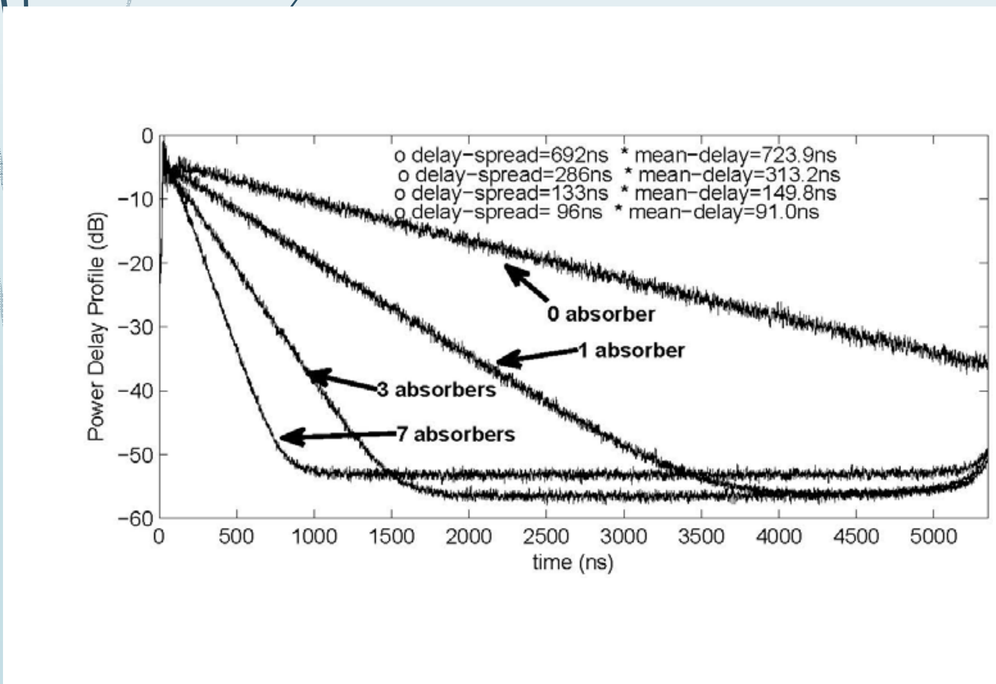
Lowest frequency of operation, uncertainties determined by chamber size, wall loss

Reverberation Chamber Characteristics

Constructive and destructive interference for each mode-stirring sample



- Frequency domain ($|S_{21}|^2$): Reflections create multipath



- Time domain (power delay profile): Decay time of reflections depends on chamber reflectivity

Original Applications

- ***Radiated immunity: high field strength***
  - components
  - large systems
- ***Radiated emissions***
- ***Shielding***
  - cables
  - connectors
  - enclosures
- ***Antenna efficiency***
- ***Calibrate RF probes***
- ***RF/MW Spectrograph***
  - absorption properties
- ***Material heating***
- ***Biological effects***
- ***Conductivity and material properties***

Wireless Applications

- ***Multipath environments***
  - Rayleigh, Rician multipath channels: with/without channel emulators
  - Time response: power delay profile, delay spread
- ***Biological effects of modulated-signal exposure***
- ***Gain from multiple antenna systems***
  - TX or RX diversity
  - MIMO
- ***Standardized over-the-air test methods***
  - Radiated power of mobile wireless devices
  - Receiver sensitivity
  - Large-form-factor and body-worn devices (with phantoms)
  - Public-safety emergency equipment

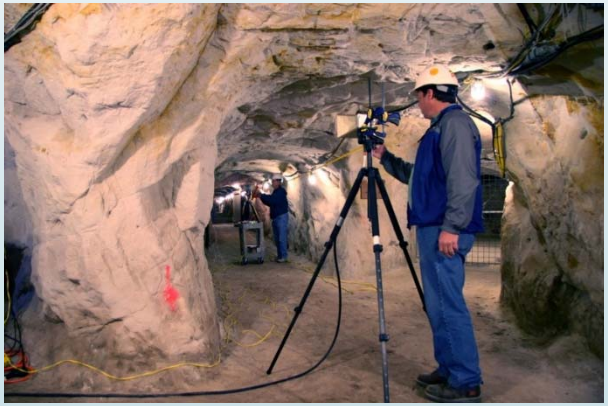
Emulating Multipath Environments

Apartment Building

Oil Refinery

Office Corridor

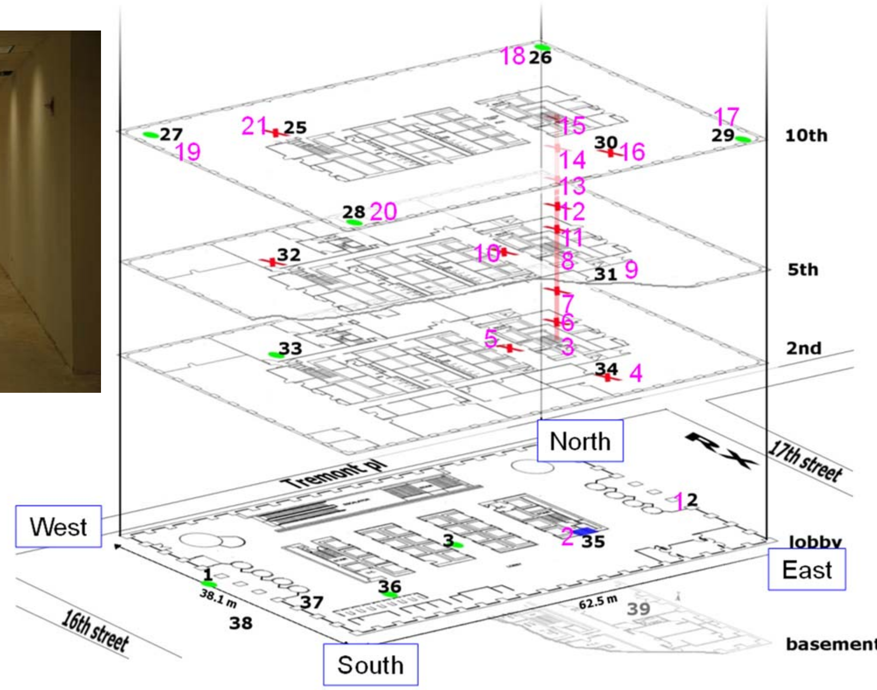
Automobile Plants



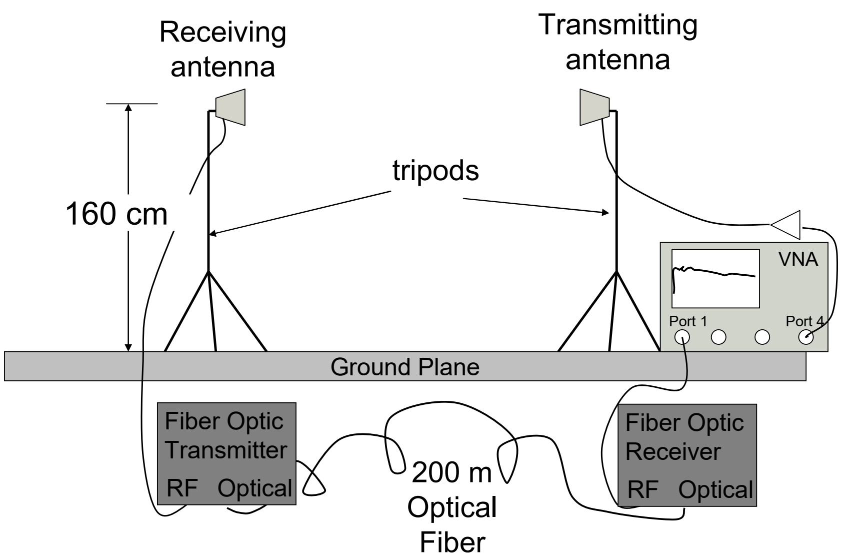
Subterranean Tunnels

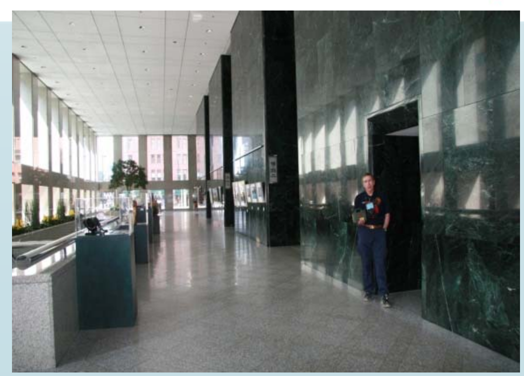
NIST channel measurements: Standards development for electronic safety equipment such as firefighter beacons

Channel Measurements: Denver High Rise



VNA measurement test locations are in pink



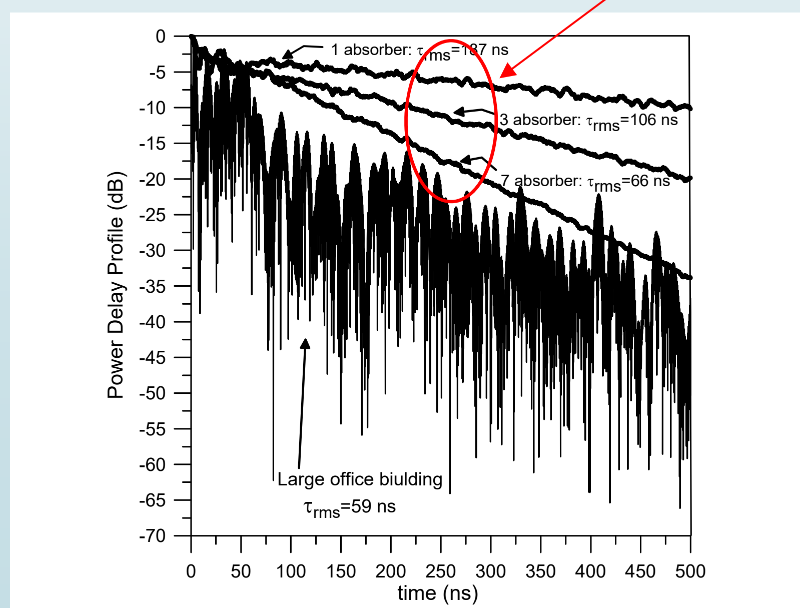


Replicate Environment in Reverberation Chamber

- Add RF absorbing material to “tune” the decay time of the chamber
- Distributed multipath (reflections) matched by chamber’s decay profile

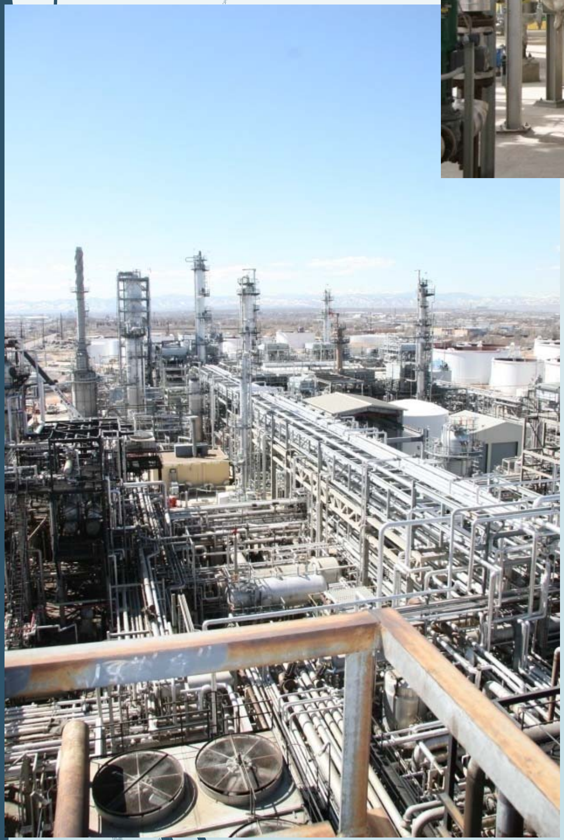
Reverberation chamber with absorbing material

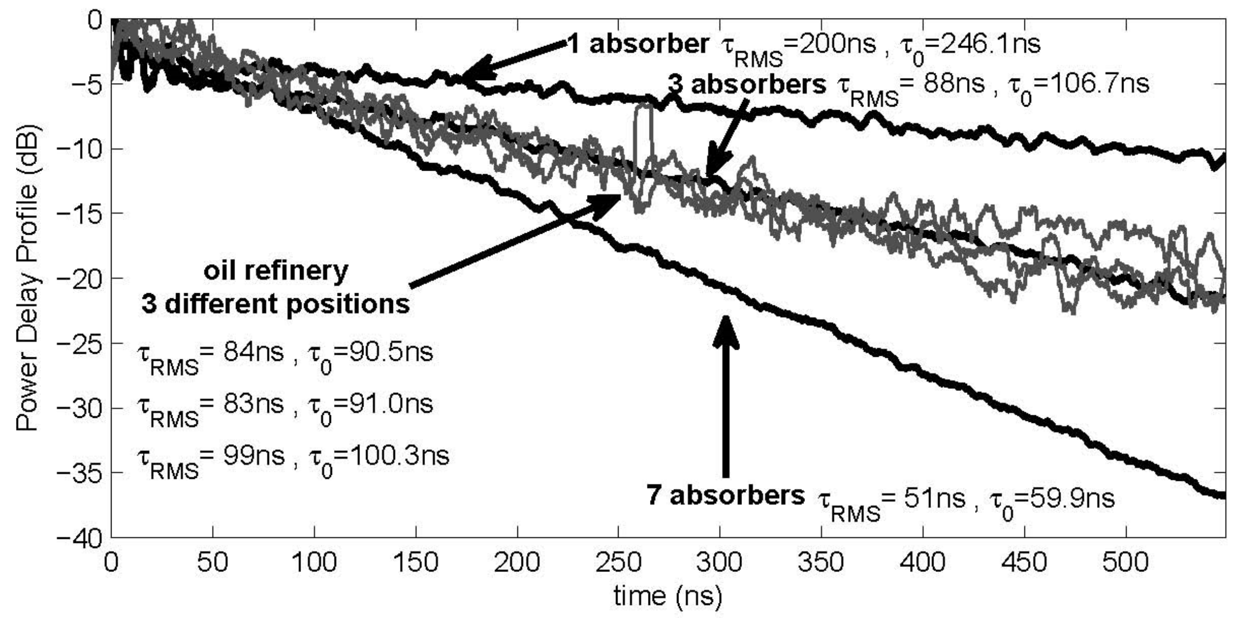
Time response of channel replicated in chamber



Emulating Other Reflective Environments

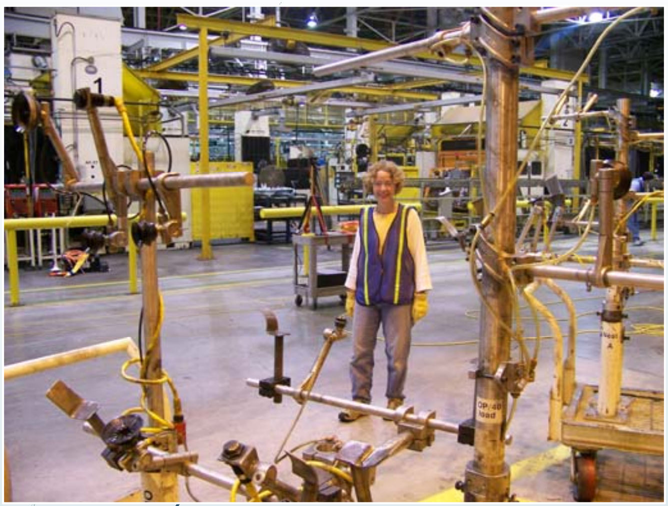
- Oil Refinery

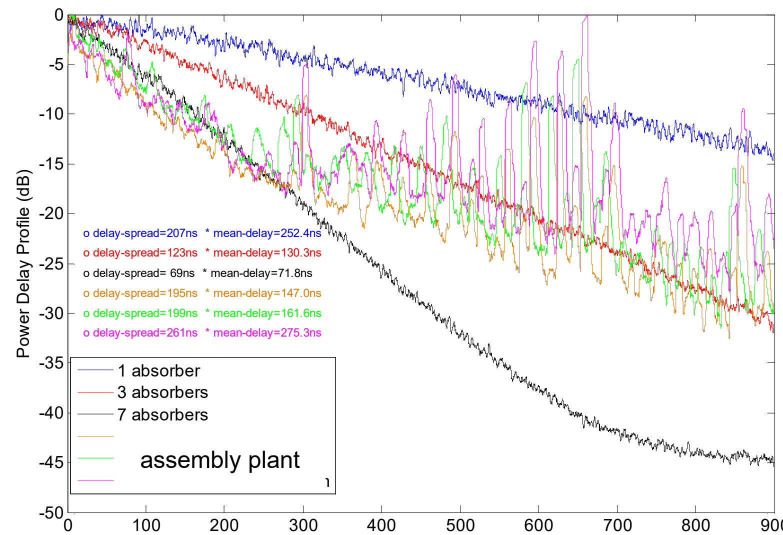


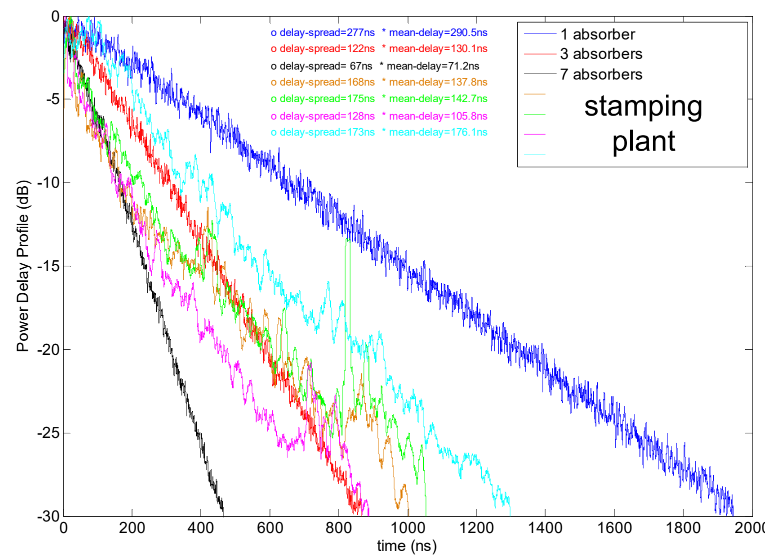


Emulating Other Reflective Environments

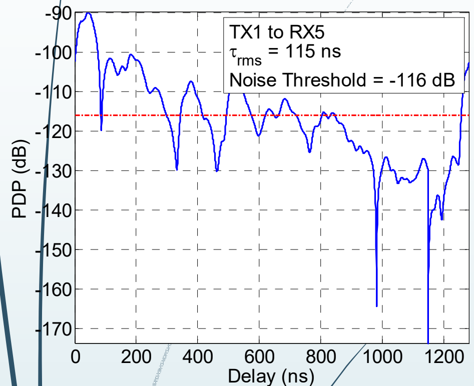
- Automobile Factories



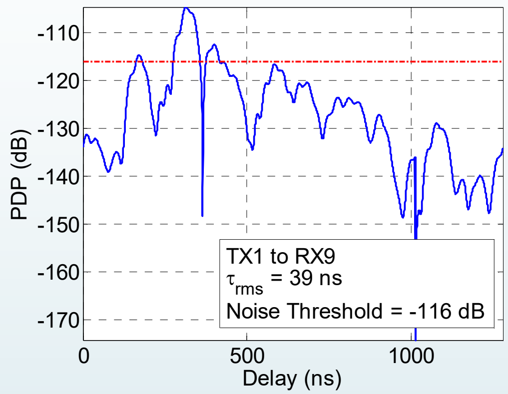




Urban Canyon Multipath Effects

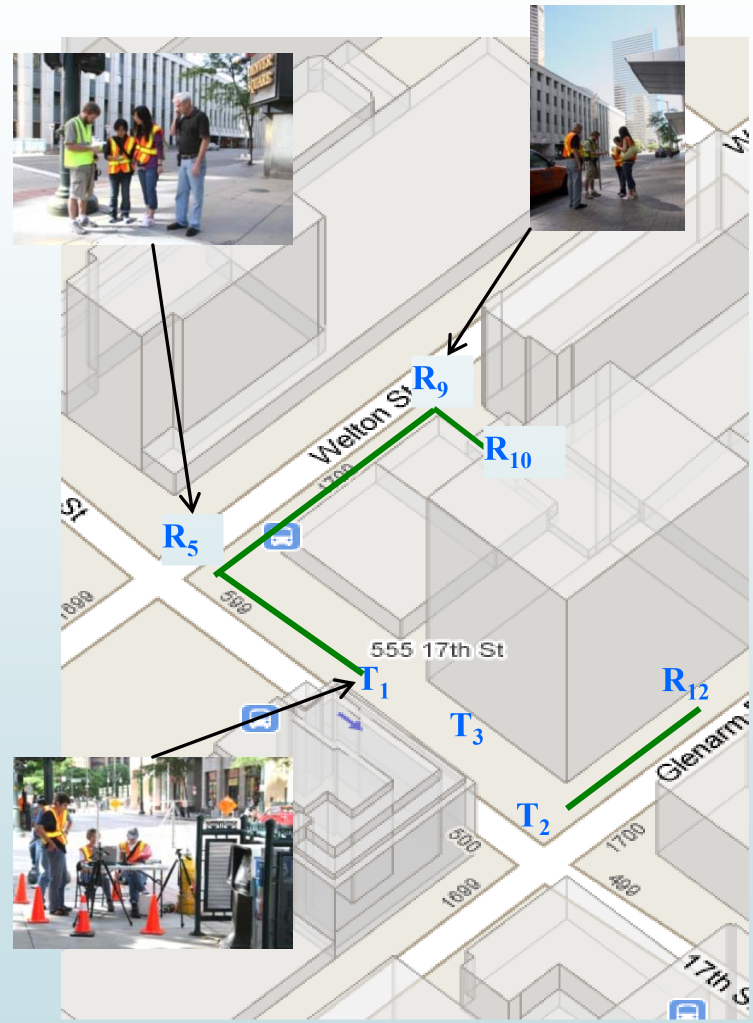


Line of Sight (LOS)

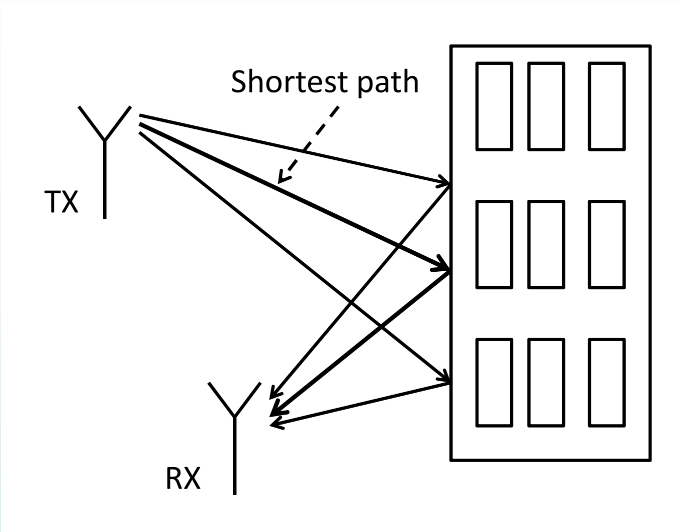


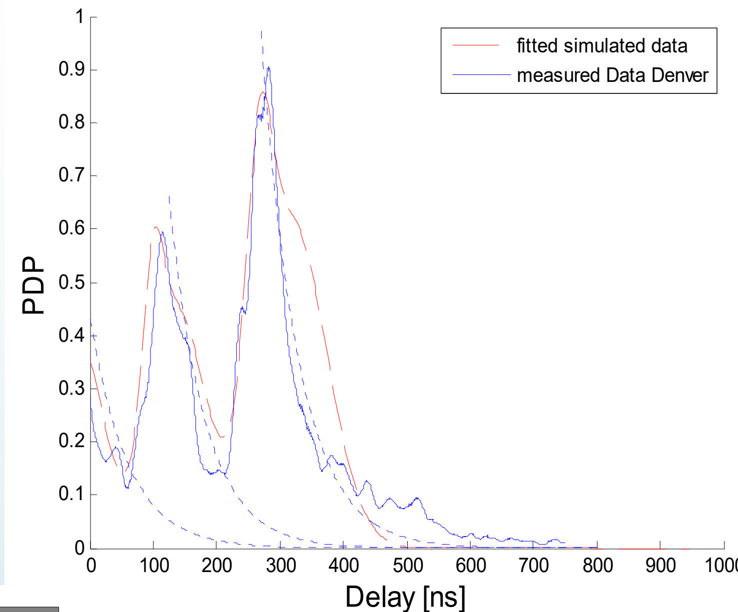
Non Line of Sight (NLOS)

- Measurements made in Denver urban canyon 2009
- Channel characterization: LOS and NLOS

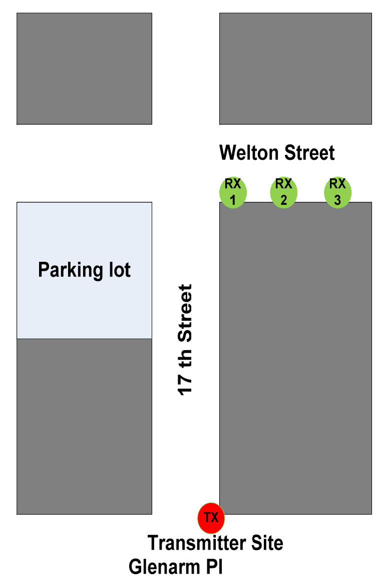


Replicating Clustered Multipath in Reverberation Chamber





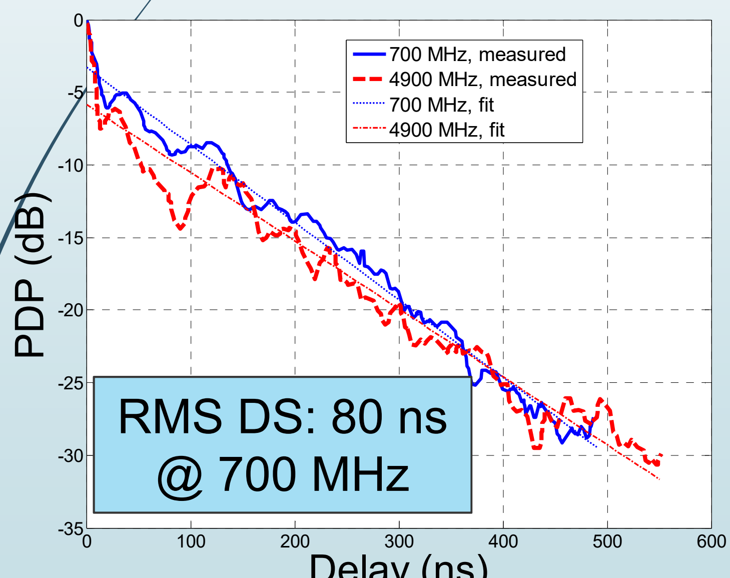
Clusters of exponentially distributed signals received off of buildings



- Blue: Mean of 27 NLOS measurements
- Red: RC + channel emulator
- Dashed: Exponential model

“Channel Models” used for standardized over-the-air (OTA) tests

- Outdoor-to-indoor channel model for 700 MHz
  - 8 environments, hundreds of measurements
- Included in proposed 3GPP reverberation-chamber-based test methods



Reverberation chamber can easily replicate diffuse multipath

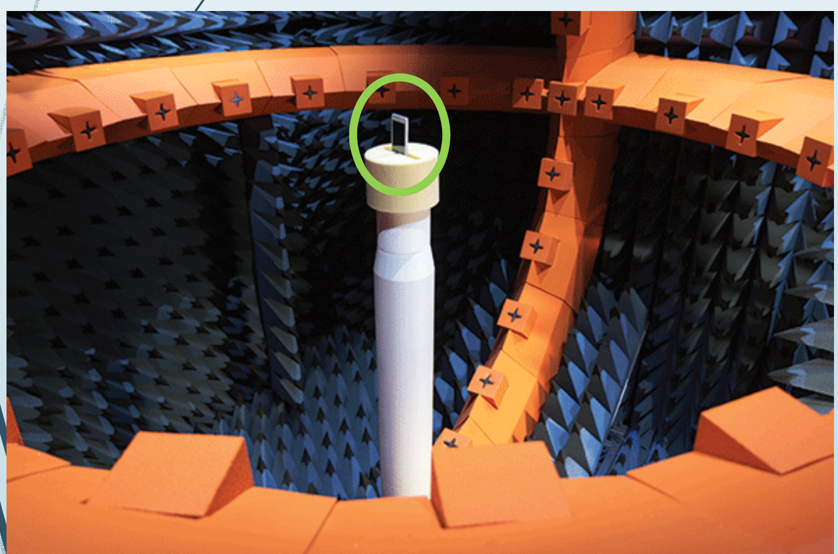
Excess tap delay [ns]	Relative power [dB]
0	0.0
40	-1.7
120	-5.2
180	-7.8
210	-9.1
260	-11.3
350	-15.2

Discrete version of the “NIST Model” for anechoic-chamber measurements

D.W. Matolak, K.A. Remley, C.L. Holloway, and C. Gentile, “Outdoor-to-Indoor Channel Dispersion and Power-Delay Profile Models for the 700 MHz and 4.9 GHz Bands,” *IEEE Antennas and Wireless Propagat. Lett.*, vol. 15, 2016, pp. 441-443.

Cellular Wireless: Over-the-Air Tests Required

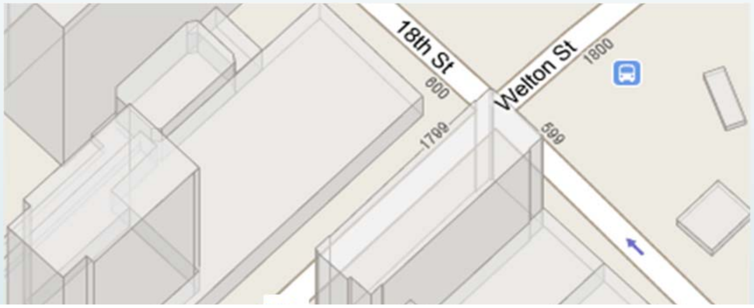
- Network providers assess performance of every wireless device model on their network:
  - Total Radiated Power (TRP)
  - Total Isotropic Sensitivity (TIS)
- OTA testing traditionally done in anechoic chambers



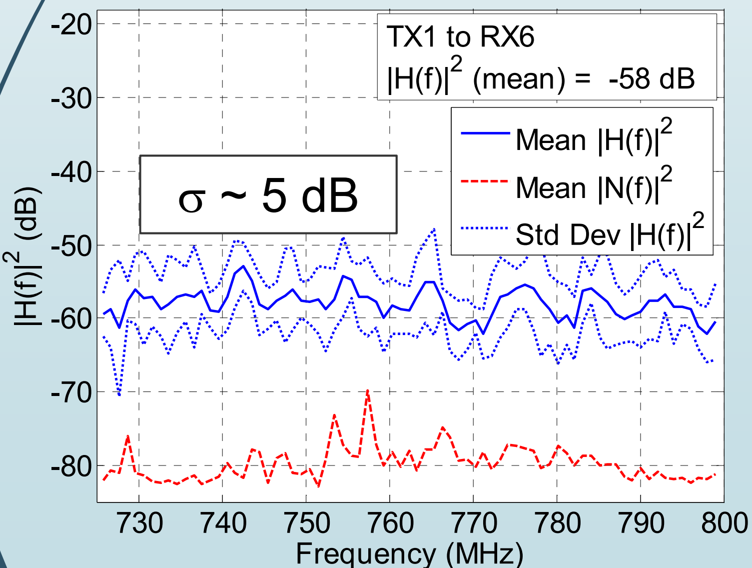
Reverberation chambers can be used as well!

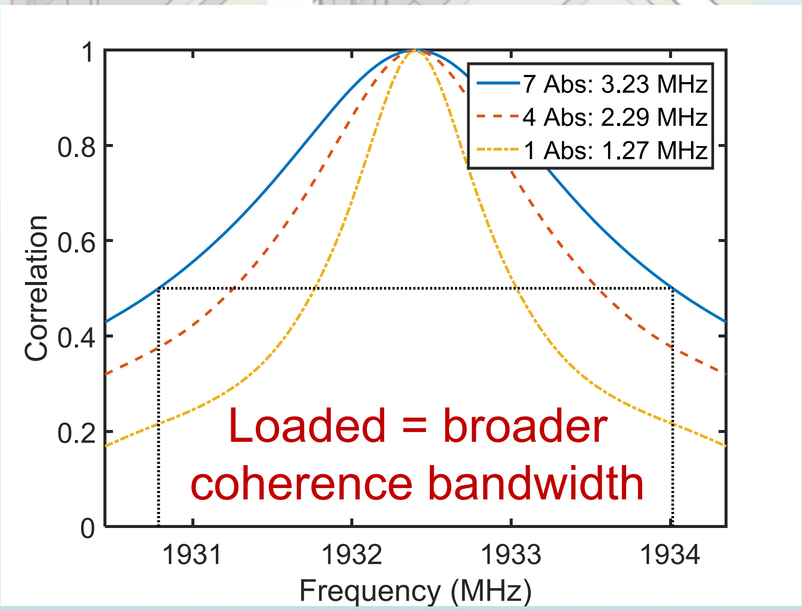
Modulated Signals in RCs:
What is different from EMC Testing?

- Receiver needs a realistic “frequency flat” channel
- Loading required: Add RF absorber to chamber
- Coherence bandwidth should match DUT design
- Spatial uniformity decreases
- Position stirring required



Real Channel:
Slow Variations with Frequency

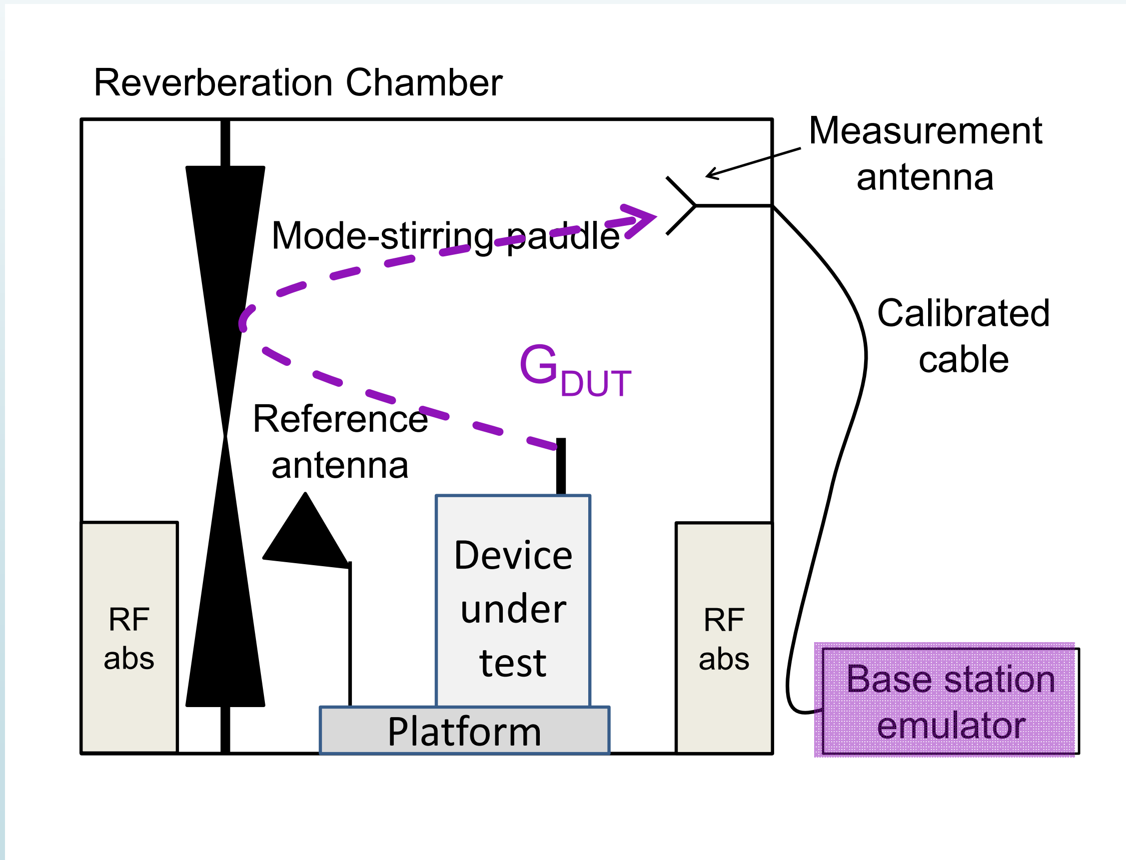




Cellular Device Testing: How is it done?

- Reference measurement provides:
  - Chamber loss: Transfer function of chamber
  - Spatial uniformity of averaged fields in chamber
  - Rotating platform:

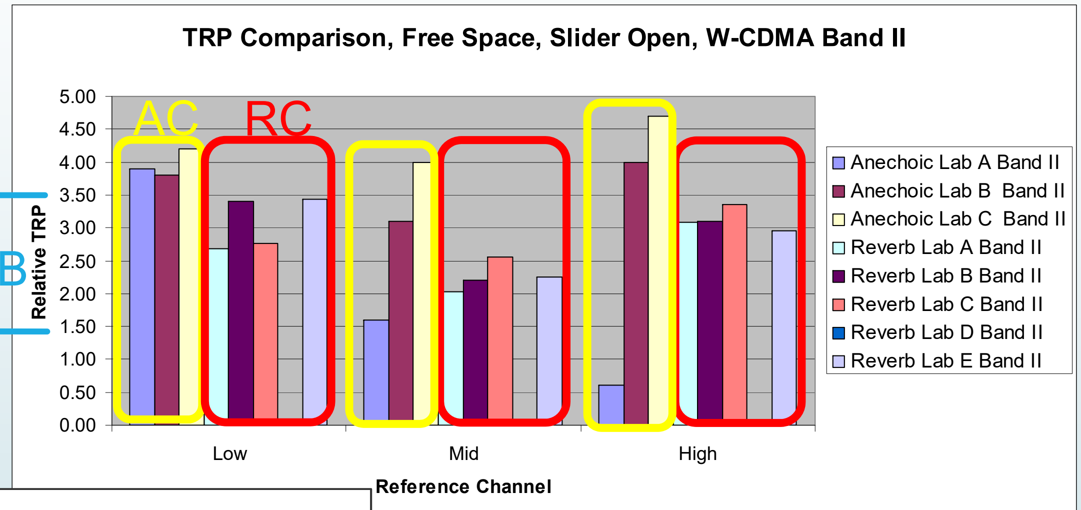
    Gref = <Gref,p>
- DUT measurement:
  - Same set-up as Ref
  - Assume $G_{DUT} = G_{ref}$



Total Radiated Power from Cell Phones

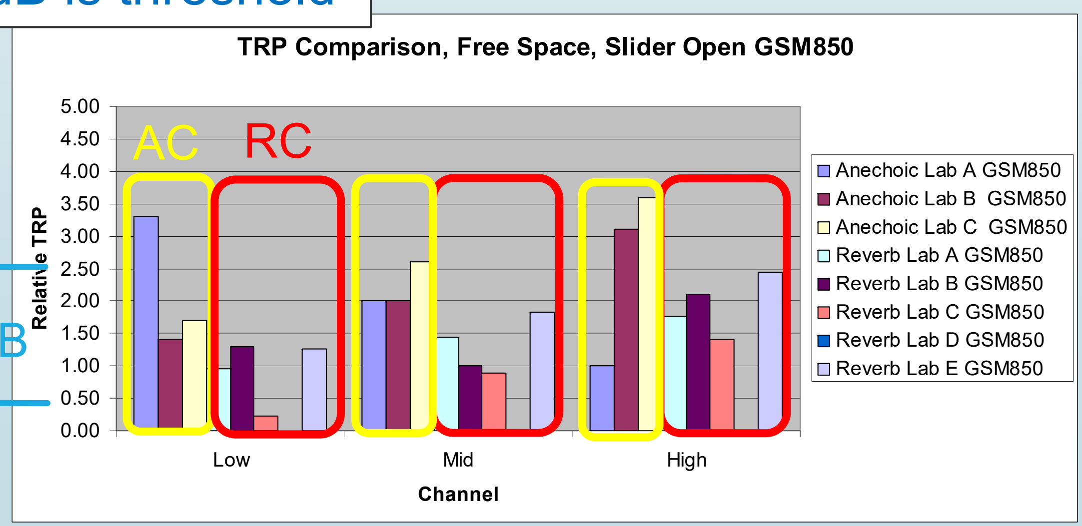
Data from CTIA working group shows good agreement between anechoic and reverberation chambers

Cell phone



2 dB

+/-2 dB is threshold



2 dB

- **Cell phone testing: ca. 2010**
- **But in 2017…**

The Machine-to-Machine (M2M) Revolution

- By 2019: 11.5 billion mobile devices (world population 7.6 B)*
- M2M/IoT growing faster than smart phones
  - 2014: 495 million
  - 2019: 3 billion

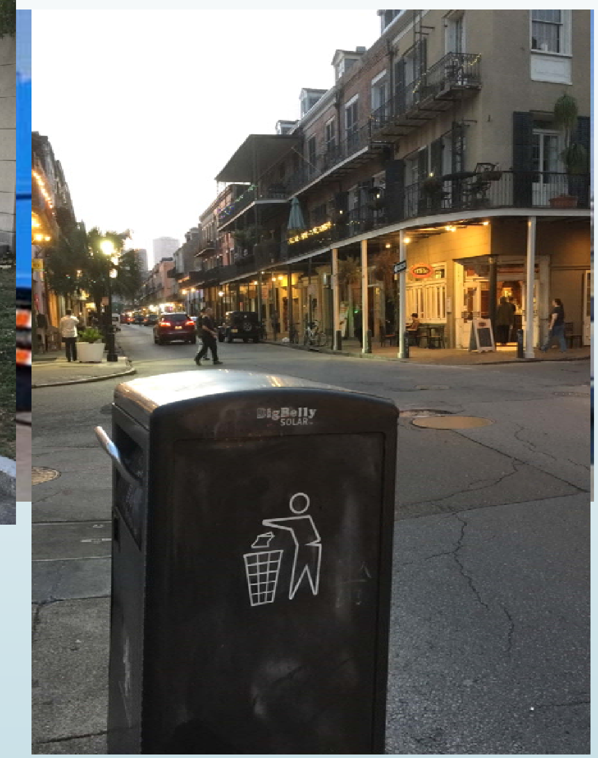
* Source Cisco

M2M and the Internet of Things (IoT)

- Large, cellular enabled devices:
- Low-cost, rough duty, solar-powered, becoming ubiquitous

San Diego

Boston



New Orleans

Illustration of name brands does not imply endorsement by NIST: other products may work as well or better

Testing Large Form-Factor Devices

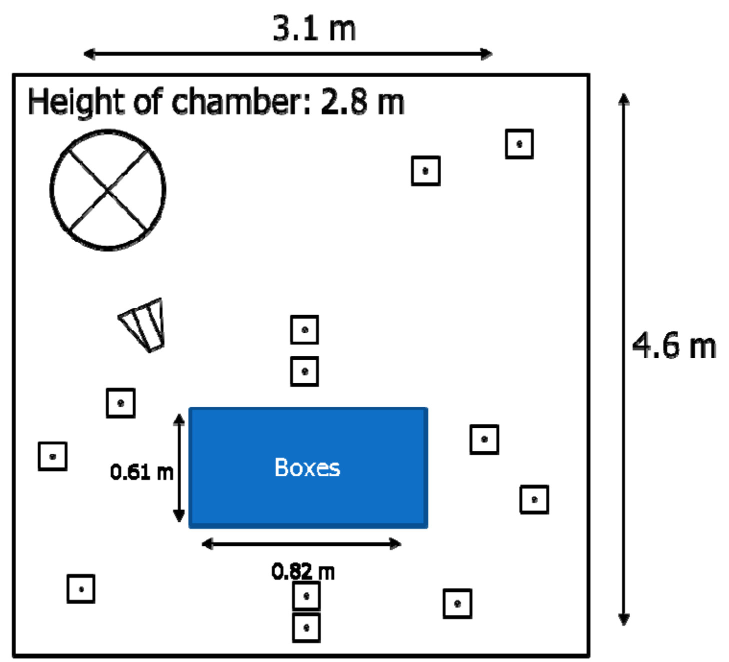
- Integrated antennas: test of entire device required
- Reverberation chamber: currently only option for single-antenna devices
- Device placement not critical within chamber
- Relatively low cost
- OTA test issues: Large devices, loaded chamber

Loading Provides Improved Channel

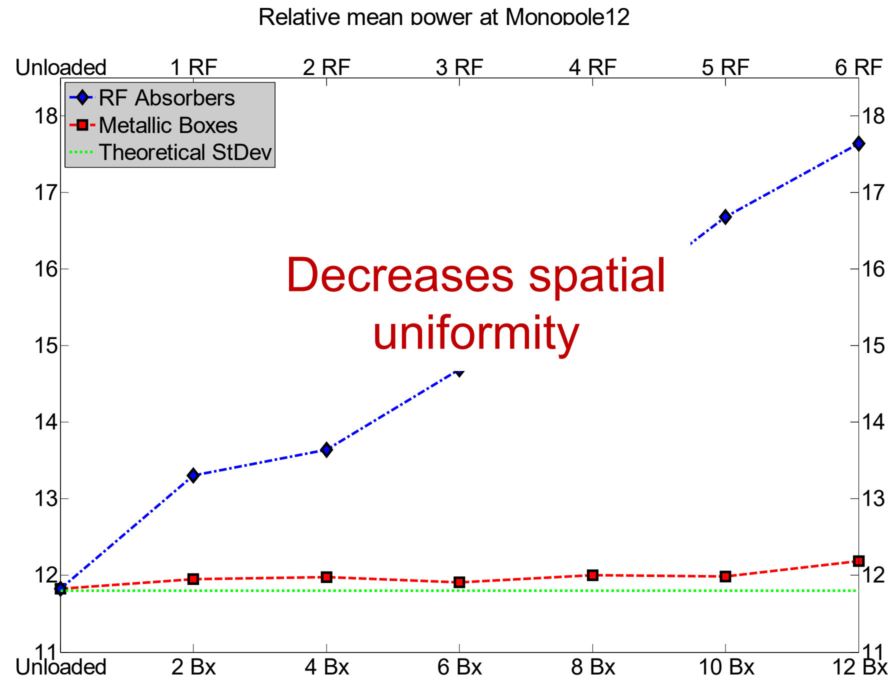
Loading helps with demodulation:

Test DUT response to stimulus, NOT to chamber

But it introduces other “nonideal” effects



- “Boxes” = Metallic
- “Absorbers” = RF Absorber

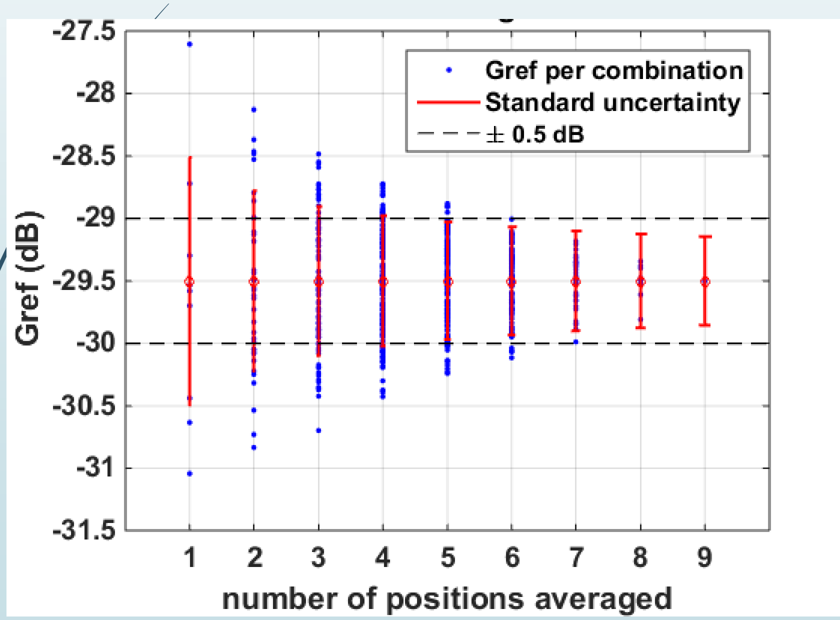


σ increases with loading (in percent)

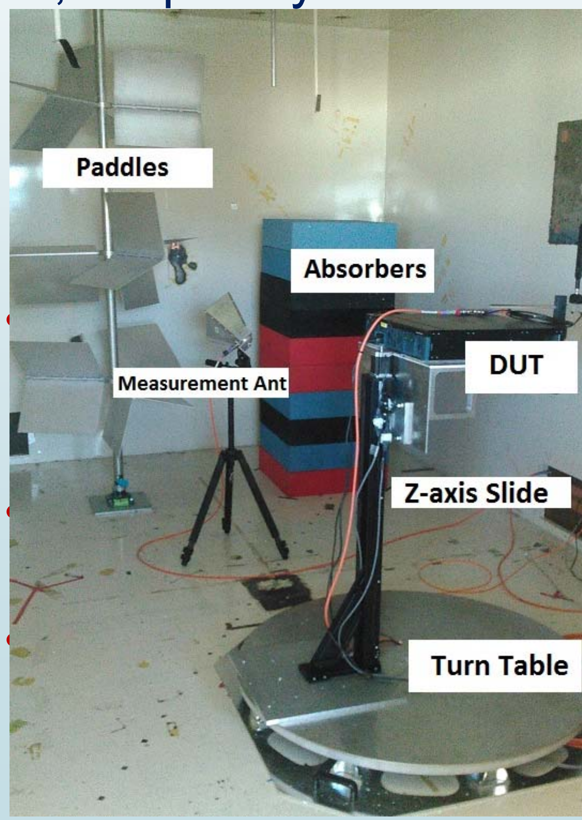
S. van de Beek *et al.*, *Characterizing large-form-factor devices in a reverberation chamber,* EMC Europe 2013.

Loading and Position Stirring go Hand in Hand

- Industry uses position, polarization and source stirring to reduce K factor, improve estimate of DUT performance
- Non-negligible K factor a necessity:
  - unstirred energy
  - correlated samples: paddle angle, spatial, frequency



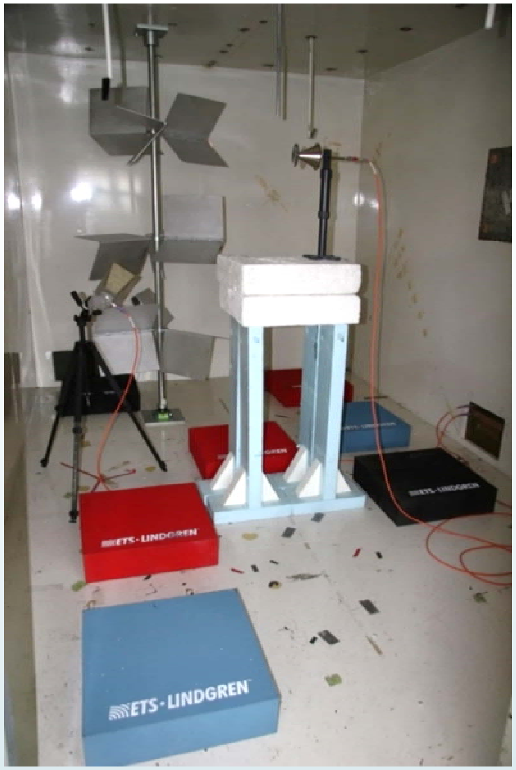
Measured estimate of chamber’s power transfer function (Gref) improves with position stirring



ts

Set-up: Absorber Placement

- Standing on floor
- Lying on floor
- Stacked



Considerations:
- Exposed absorber surface area
- Exposed metal surfaces
- Absorber location

Comparable Loading, Different Uncertainty

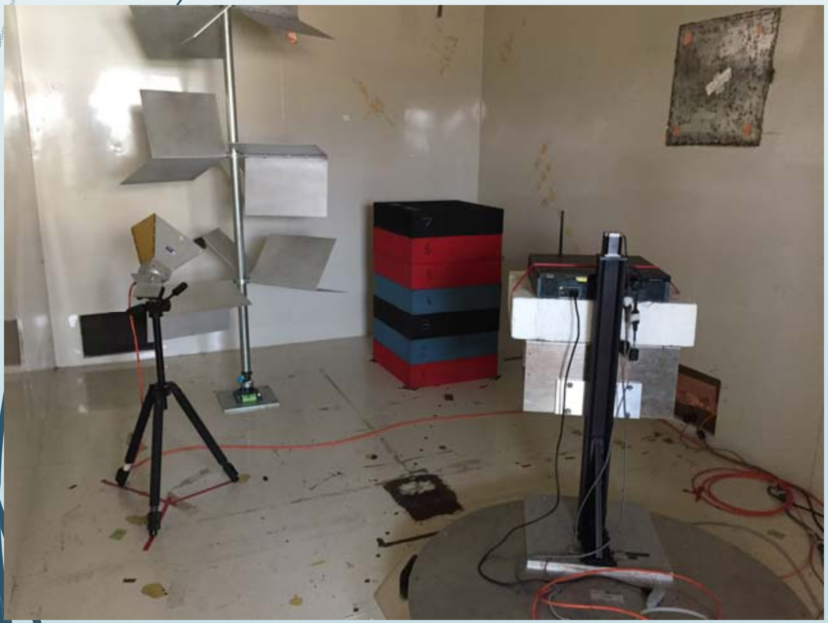
PCS band measurement (~1950 MHz)

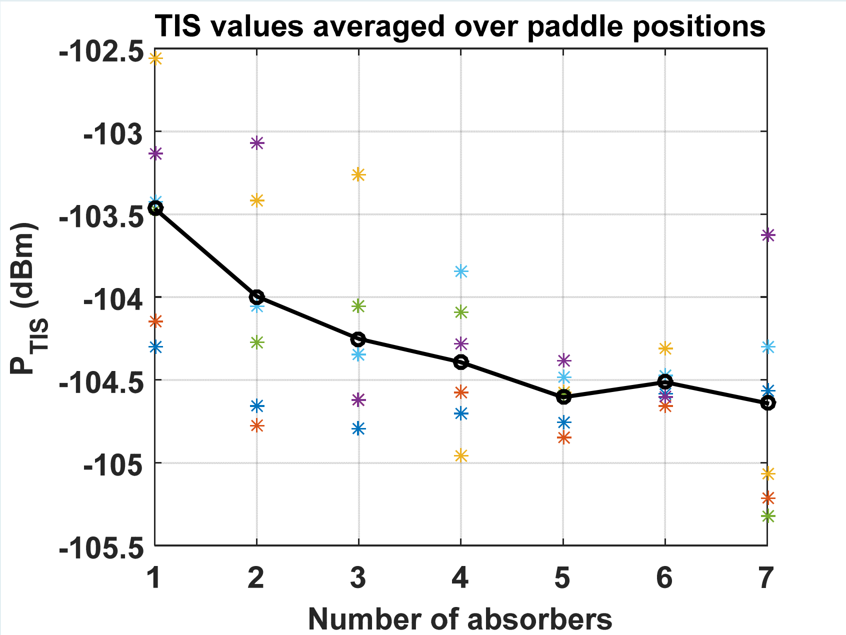
- Load chamber for approximately the same CBW
- Chamber loss approximately the same as well
- $\sigma_{G_{\mathrm{ref}}}$ is higher when absorbers lie on floor
  - Less exposed metal surface
  - Higher proximity effect

	Distributed on Floor: Standing	Stacked	Distributed on Floor: Lying
CBW (MHz)	3.13	3.32	3.48
No. abs	3	7	4
G_{ref} (dB)	-29.46	-29.69	-29.78
$\sigma_{G_{\mathrm{ref}}}$ (dB)	0.15	0.30	0.35

Total Isotropy Sensitivity (TIS): Wireless Router

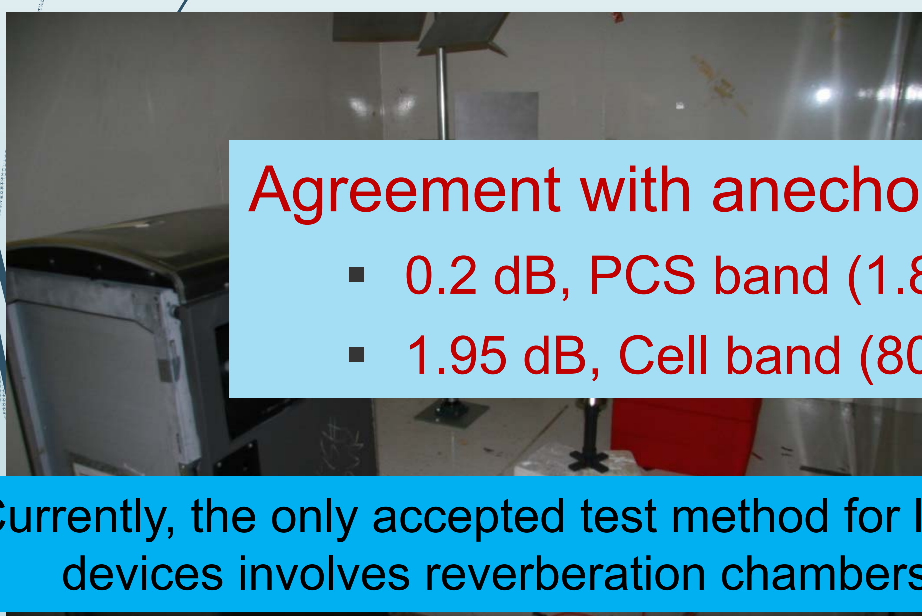
- Absorbers stacked
- Reference and DUT measurements:
  - 9 different locations, heights
- TIS underestimated with insufficient loading

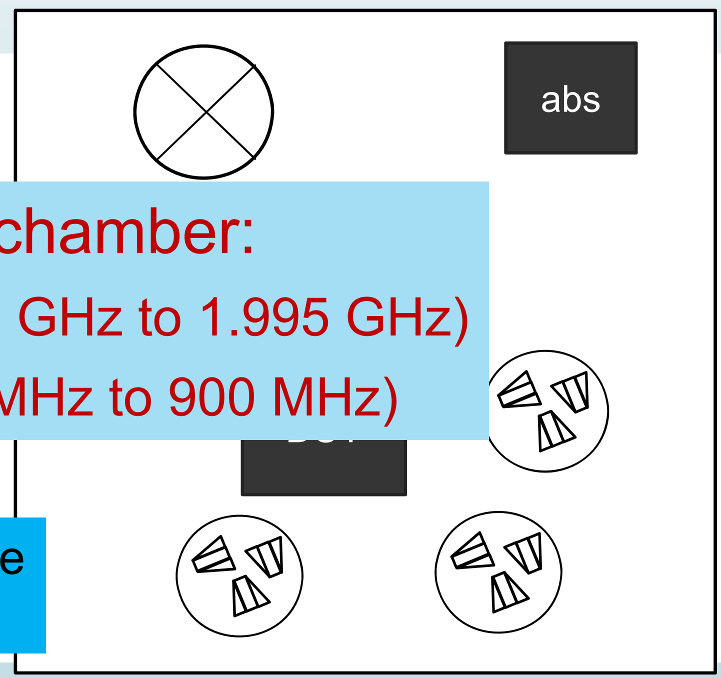




TRP for Large M2M Device

- Wireless, solar-powered trash compactor
- TRP measured for W-CDMA signal (BW = 3.84 MHz)
- Loading: stacked absorbers
- Coherence bandwidth: Verified >3.84 MHz (4.42 MHz)
- Antenna proximity effect: No effect at 1 λ (at f_c)
- Reference: Nine locations, DUT one location



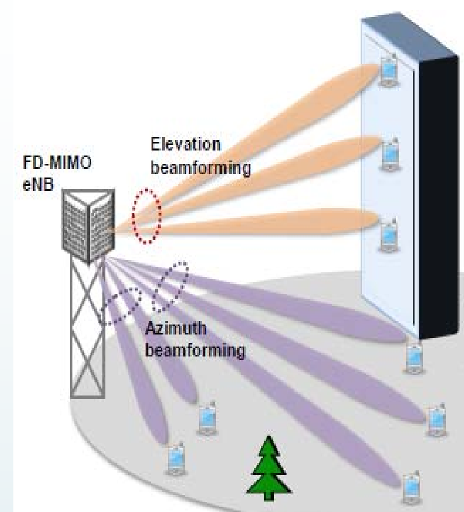


Agreement with anechoic chamber:

- 0.2 dB, PCS band (1.850 GHz to 1.995 GHz)
- 1.95 dB, Cell band (800 MHz to 900 MHz)

Currently, the only accepted test method for large devices involves reverberation chambers

Summary: Cellular Device Testing in Reverberation Chambers

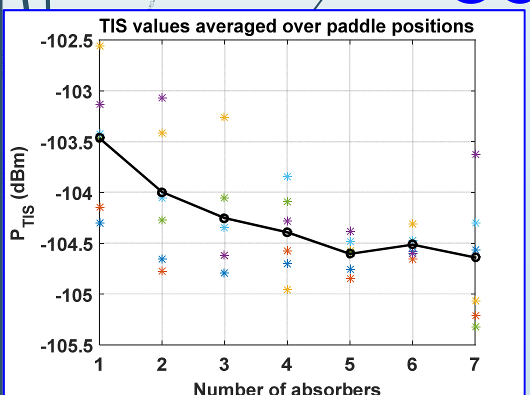


Samsung May 2014

OTA Tests Require Loading:

- Provide realistic channel for receiver
- Increase unstirred energy
- Reduce spatial uniformity

Configure Chamber with Care:



- Placement of absorbers, antennas affects accuracy
- Validation of set-up required
- RC OTA tests compare well to other methods

The Future Will Bring:

- OTA for multiple antenna systems
- mmWave testing for 5G

Watch this space for more information on over-the-air testing with reverberation chambers