Electrically Small Antennas

Measurement Concepts

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Fraunhofer Institut
Integrierte Schaltungen

Introduction

Fraunhofer-Society in Germany

Leading Organisation doing applied research in Europe

56 Instituts on 40 locations

12 700 employees, 1.2 billion € turnaround

Combination of Institute Competencies in Technology Clusters and Alliances

- Microelectronics
- Information and Communication Technology
- Defense and Security Research
- Materials, Components; Production; Life Sciences; Surface Technology and Photonics

Fraunhofer-Institute for Integrated Circuits IIS

Founded: 1985

Locations: Erlangen, Fürth, Nürnberg, Dresden

Employess: about 520

Turnaround: € 60 Mio.

Financing
- > 80% Projects
- < 20% basic founding

www.iis.fraunhofer.de

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Overview

Parameters

- Pattern
- Polarisation
- Efficiency
- Matching
- Noise Parameters
- Sensitivity / Radiated Power (CTIA)

Methods

- Far-Field
- Near-Field
- Reverberation Chamber
- GTEM Cell
- Wheeler Cap

Some Definitions

Gain and Directivity

Directivity and Gain are angular dependent functions

Relation between gain and directivity gives the efficiency

By measuring the pattern of the antenna and peak gain of the antenna one can determine the efficiency

$$D(\theta,\varphi)=\frac{S(\theta,\varphi)}{\oint\!\!\oint S(\theta,\varphi)\sin\theta\, d\theta d\varphi}$$

$$G(\theta,\varphi)=\eta\cdot D(\theta,\varphi)$$

$$G_{max}=\eta\cdot D_{max}$$

Radiation Regions

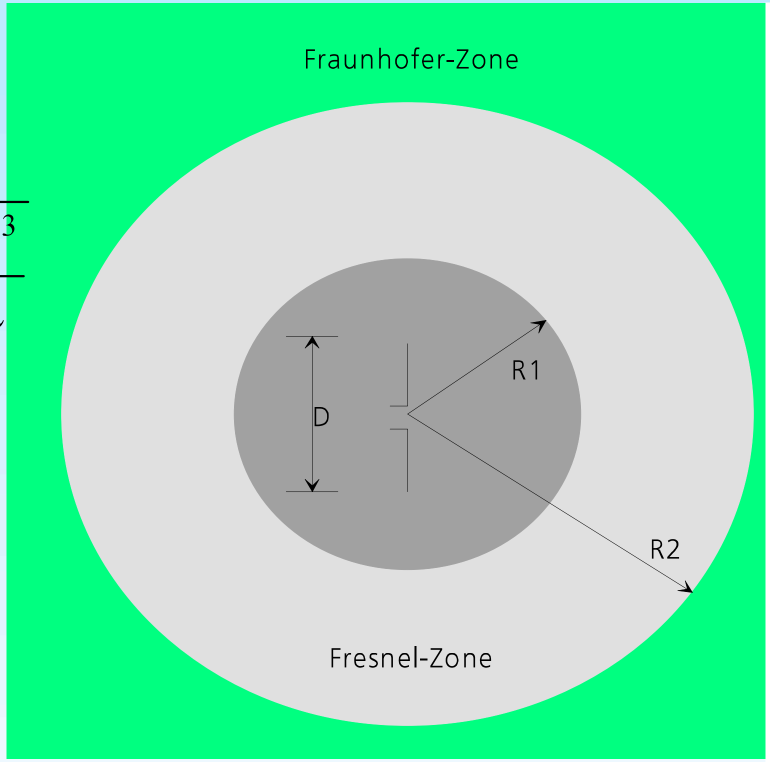
Reactive Near-Field $R = \frac{\lambda}{2\pi}$

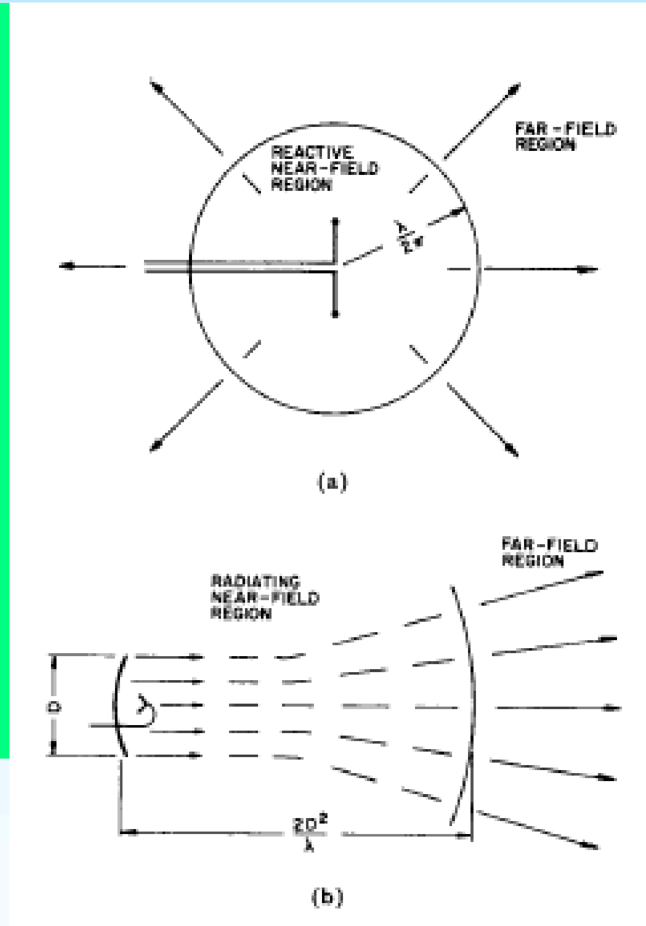
Radiating Near-Field (Fresnel Region) $R_1 = 0.62\sqrt{\frac{D^3}{\lambda}}$

$R_1 = \frac{\lambda}{2\pi}$

Far-Field, Fraunhofer-Region $R_2 = \frac{2D^2}{\lambda}$

Region of plane waves





How is the Far-Field Region for Antenna Measurements defined?

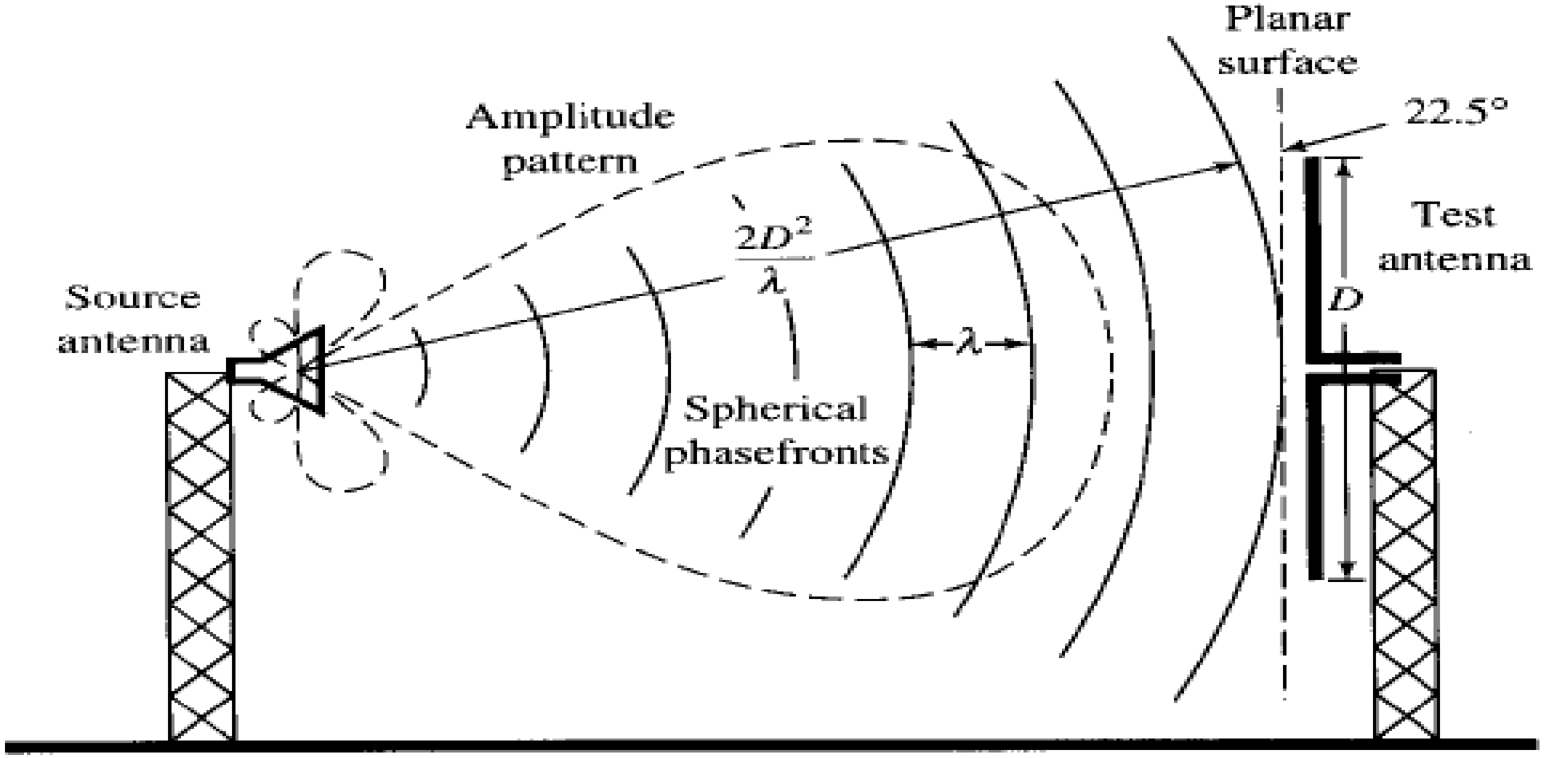
$$R_1 = R + \frac{1}{16}\lambda \qquad (\Delta\varphi = 22{,}5°)$$

$$R_1^2 = R^2 + \left(\frac{D}{2}\right)^2$$

$$\rightarrow R = \frac{2D^2}{\lambda}$$

AUT (Antenna under Test) has to be in Far-Field Region!

This distance is only defined by the AUT and not by the probe antenna!



How is the Far-Field Region defined?

Let's assume an electrically small antenna being smaller than the halfwavelength dipole.

This means, we are always in the far-field with respect to the measurement definition.

So, near- and far-field approaches lead to the same results and no transformation would be necessary – except for a better angular resolution.

$$R_1 = R + \tfrac{1}{16}\lambda \qquad (\Delta\varphi = 22{,}5°)$$

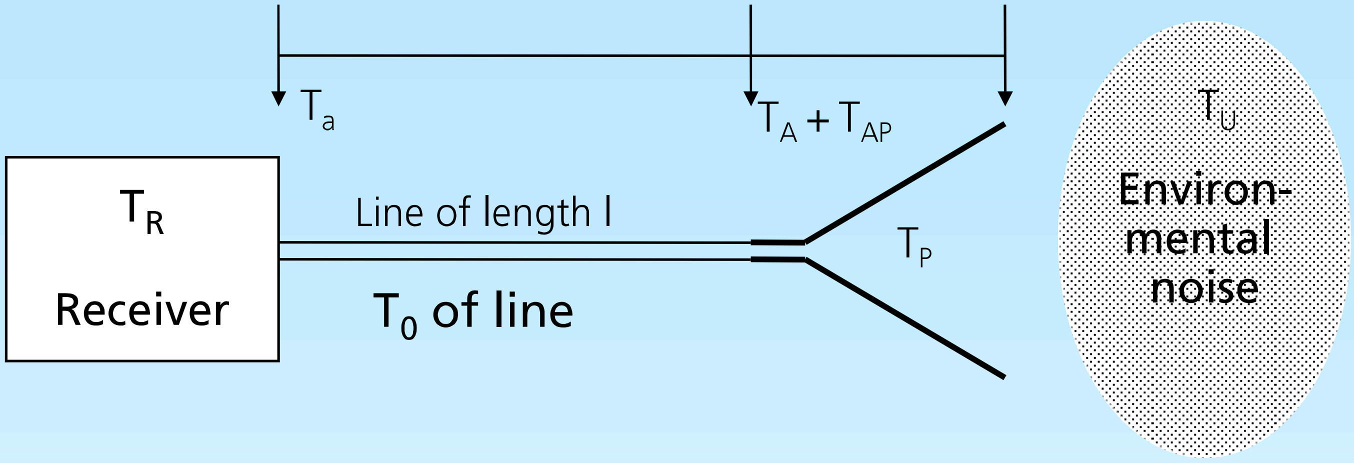
$$R_1^2 = R^2 + \left(\tfrac{D}{2}\right)^2$$

$$\rightarrow R = \frac{2D^2}{\lambda}$$

$$D = \lambda/2$$

$$\rightarrow R = \frac{2D^2}{\lambda} = \frac{\lambda}{2}$$

Antenna Noise Temperature



Antenna noise temperature T_A:
Integration of environmental noise weighted with antenna gain

$$T_A = \frac{\int_0^{2\pi}\int_0^{\pi} T_U(\theta,\varphi)\cdot G(\theta,\varphi)\cdot \sin\theta \; d\theta \; d\varphi}{\int_0^{2\pi}\int_0^{\pi} G(\theta,\varphi)\cdot \sin\theta \; d\theta \; d\varphi}$$

Antenna noise temperature due to physical temperature T_P of antenna:

$$T_{AP} = \left(\frac{1}{e_A} - 1\right) T_P \qquad e_A \approx 0{,}9\text{-}1$$

Cumulative noise temperature at receiver input:

$$T_a = T_A e^{-2\alpha l} + T_{AP} e^{-2\alpha l} + T_0\left(1 - e^{-2\alpha l}\right)$$

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CTIA Measurements

CTIA acceptance tests include Over-the-Air measurement in a reflection and interference-free environment.

Key aspects included:

- Shielded Anechoic chamber – Controlled environment
- Over-the-Air tests include
  - Base Station Simulator interface
  - Radiated power pattern
  - Sensitivity pattern (Bit-error-rate, for GSM BER=2.44%)
  - Intermediate channel test
- Fixed spherical grids: Theta-Phi:
  - Radiated power: Every 15 degrees in theta and phi, excluding 0 and 180, 2-pols
  - Sensitivity: Every 30 degrees in theta and phi, excluding 0 and 180, 2-pols

CTIA - Cellular Telecommunications & Internet Association

CTIA Measurements: Radiated Power

Total Radiated Power (TRP)

Integration over the complete sphere

$$\mathrm{TRP} = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\left(\mathrm{EIRP}_\theta(\theta,\varphi) + EIRP_\varphi(\theta,\varphi)\right)\cdot\sin\theta \;\mathrm{d}\theta\;\mathrm{d}\varphi$$

Near-Horizon Partially Radiated Power

Integration ±30° or ±45° from horizon

$$\mathrm{NHPRP45} = \frac{1}{4\pi}\int_0^{2\pi}\int_{\pi/4}^{3\pi/4}\left(\mathrm{EIRP}_\theta(\theta,\varphi) + EIRP_\varphi(\theta,\varphi)\right)\cdot\sin\theta \;\mathrm{d}\theta\;\mathrm{d}\varphi$$

$$\mathrm{NHPRP30} = \frac{1}{4\pi}\int_0^{2\pi}\int_{\pi/3}^{2\pi/3}\left(\mathrm{EIRP}_\theta(\theta,\varphi) + EIRP_\varphi(\theta,\varphi)\right)\cdot\sin\theta \;\mathrm{d}\theta\;\mathrm{d}\varphi$$

CTIA Measurements: Sensitivity

Total Isotropic Sensitivity (TIS)

Integration over the complete sphere

$$\mathrm{TIS} = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi}\left(\frac{1}{EIS_{\theta}(\theta,\varphi)} + \frac{1}{EIS_{\varphi}(\theta,\varphi)}\right)\cdot \sin\theta \;d\theta \;d\varphi}$$

Near-Horizon Partial Isotropic Sensitivity

Integration ±30° from horizon

$$\mathrm{NHPIS30} = \frac{4\pi}{\int_0^{2\pi}\int_{\pi/3}^{2\pi/3}\left(\frac{1}{EIS_{\theta}(\theta,\varphi)} + \frac{1}{EIS_{\varphi}(\theta,\varphi)}\right)\cdot \sin\theta \;d\theta \;d\varphi}$$

Methods not Needing an Anechoic Chamber

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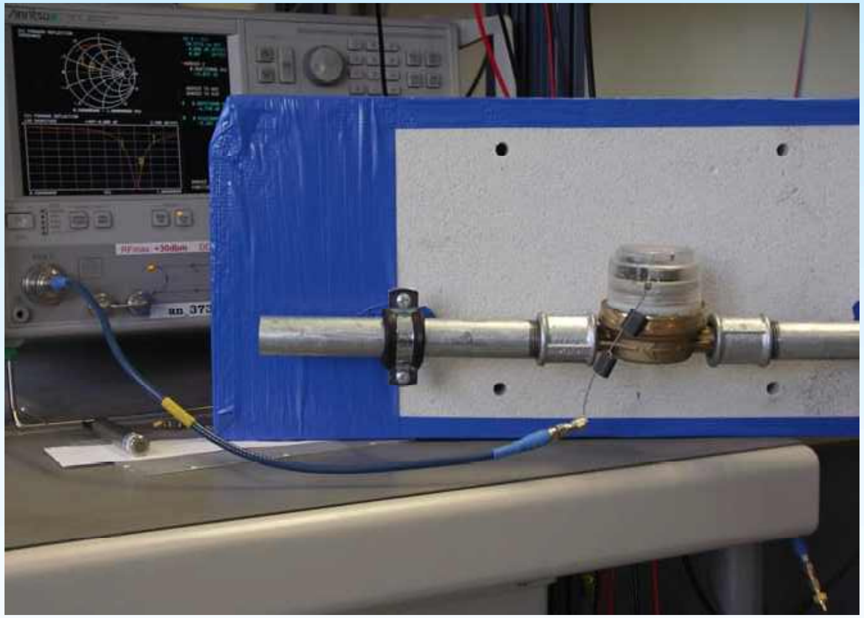
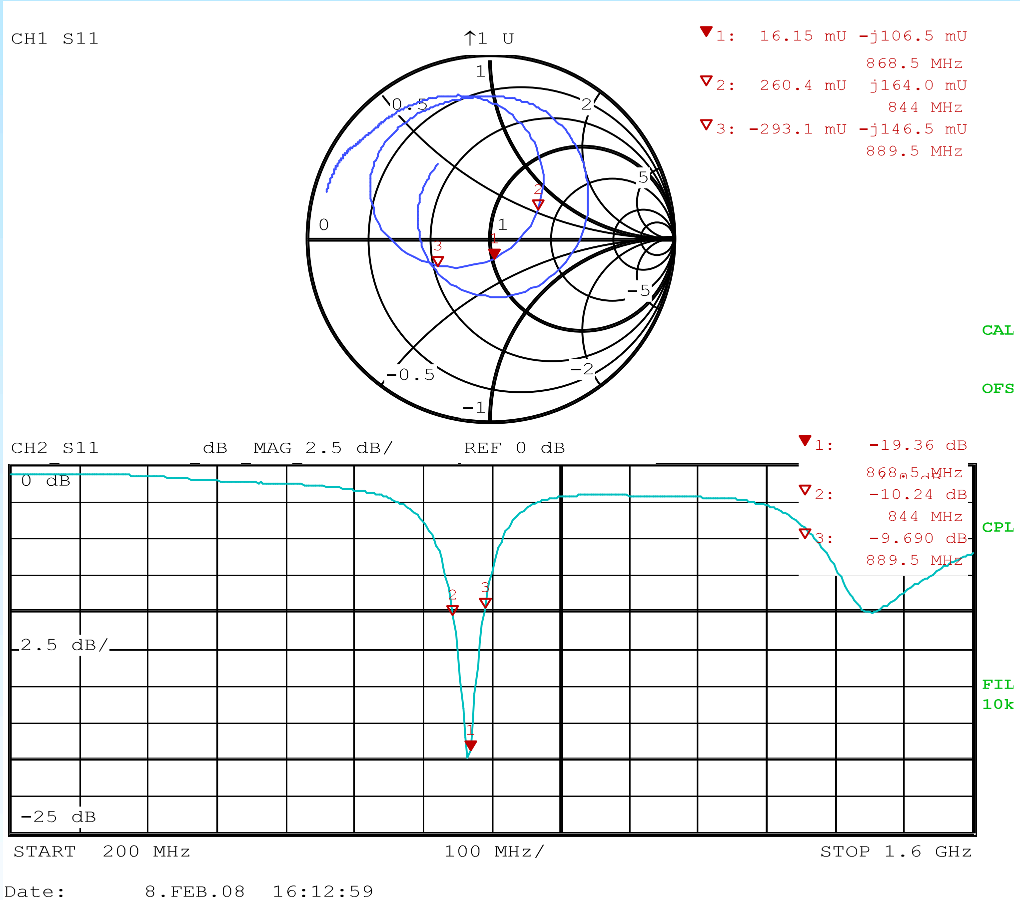
Input Impedance: Wireless Transmitter in Water Metering System

Measurement of Matching Properties at Vector Network Analyzer

Simulated environment with water pipe segment and porous concrete brick





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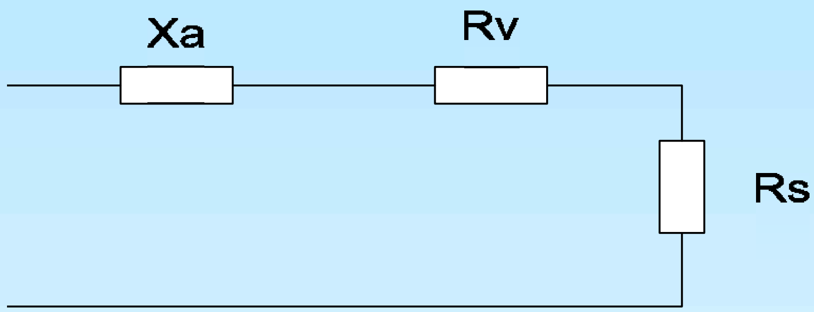
Wheeler Cap

Only applicable for determining the efficiency of an antenna

Comparison between free space operation and operation in a small resonator

Equivalent circuit of an antenna



$$Z_A = R_v + R_s + jX_A$$

Efficiency definition based on network elements

$$\eta = \frac{R_S}{R_S + R_V}$$

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Wheeler Cap

Measurement of Z using VNA in free space

Real part related to radiation and loss resistance

Measurement of Z with Wheeler Cap

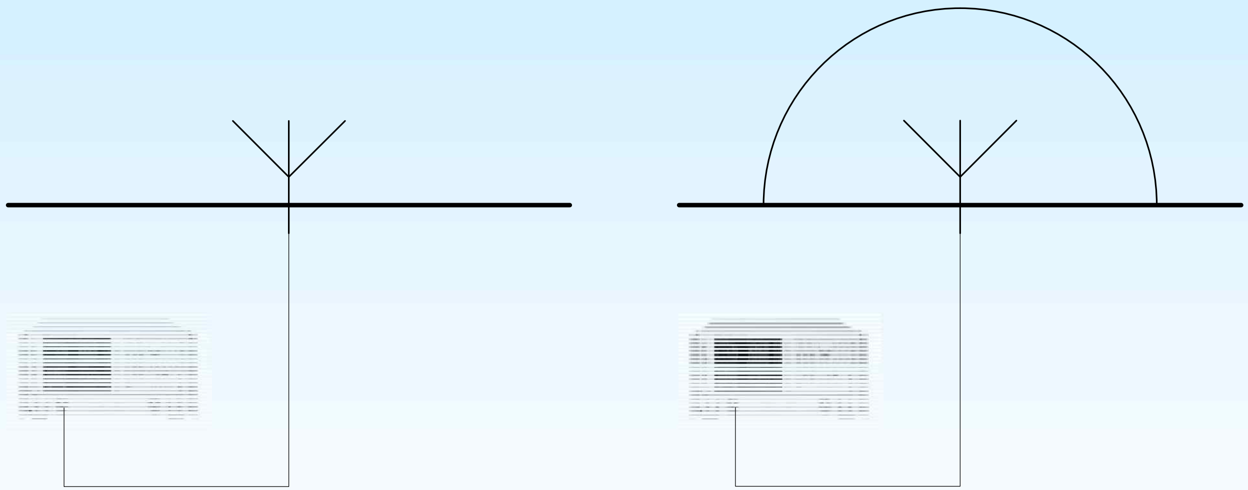
Real part related to loss resistance only

Radius of Wheeler Cap should be smaller than $\lambda/2\pi$

$$Z_{FreeSpace} = R_S + R_L + jX$$

$$Z_{Wheeler} = R_L + jX$$

$$\eta = \frac{\mathrm{Re}(Z_{FreeSpace}) - \mathrm{Re}(Z_{Wheeler})}{\mathrm{Re}(Z_{FreeSpace})}$$

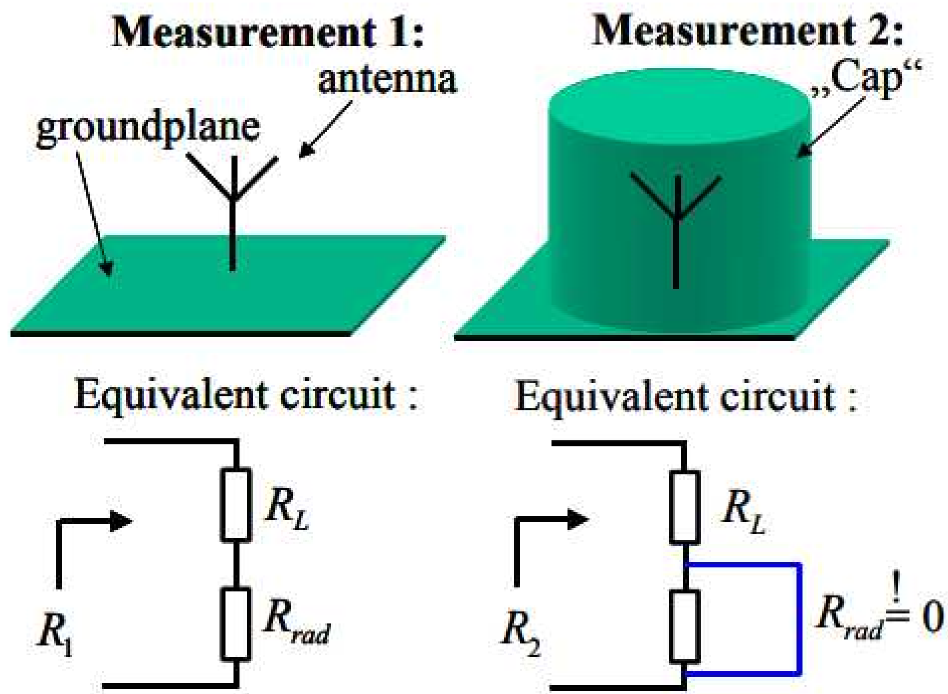


Wheeler Cap Method of Antenna Radiation Efficiency Measurement

O. Litschke, "Adoption of the Wheeler-cap method for measuring the efficiency of mobile handset antennas"

$$\eta_{rad} = \frac{R_{rad}}{R_L + R_{rad}} = \frac{R_1 - R_2}{R_1}$$

$$\eta_{rad} = \frac{\mathrm{Re}\{\underline{Z}_{rad}\}}{\mathrm{Re}\{\underline{Z}_V\} + \mathrm{Re}\{\underline{Z}_{rad}\}} = \frac{\mathrm{Re}\{\underline{Z}_1\} - \mathrm{Re}\{\underline{Z}_2\}}{\mathrm{Re}\{\underline{Z}_1\}}$$



GTEM Cell Measurement

Coaxial Line

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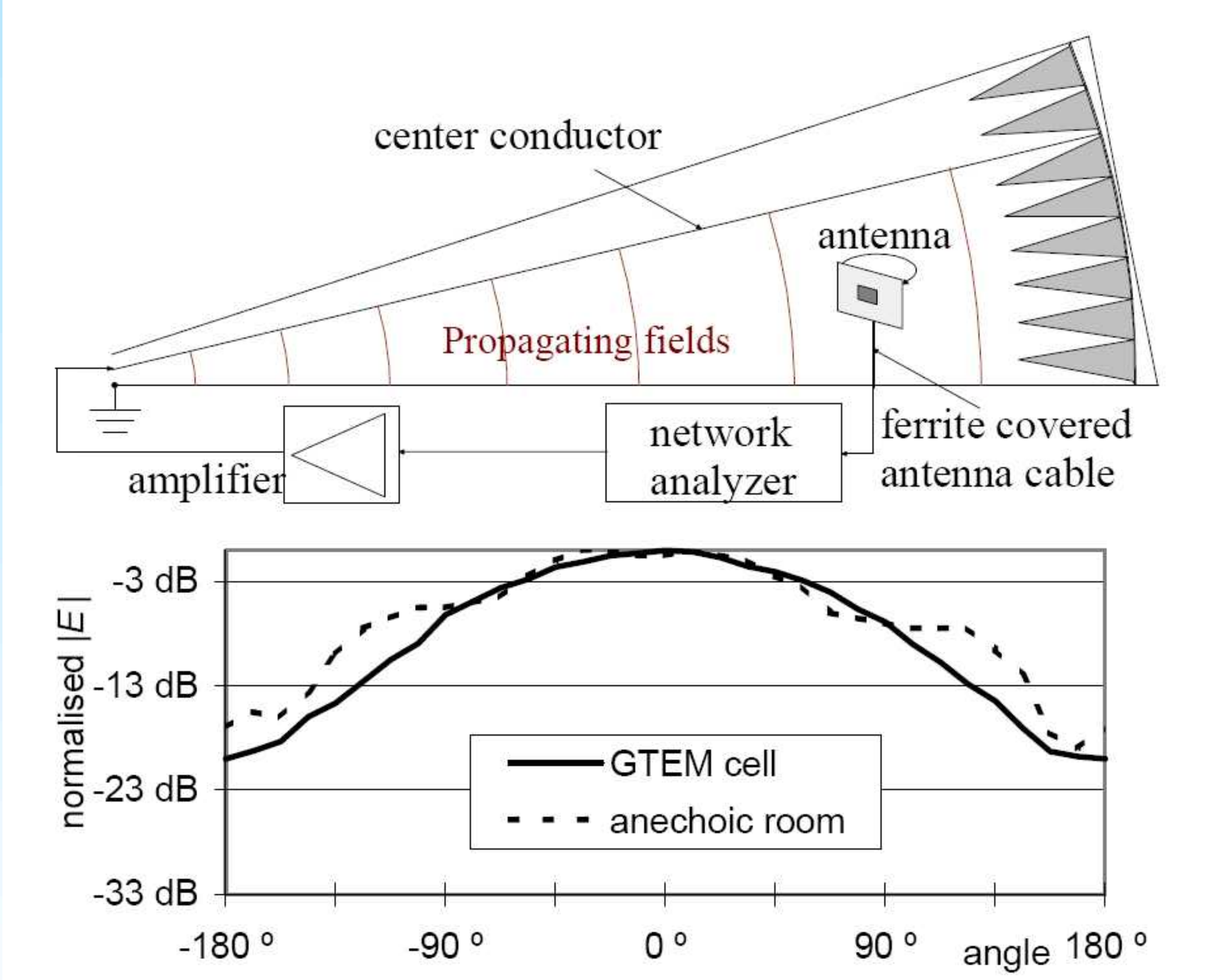
GTEM Cell Measurement

- Antenna placed in the homogenous field region of the GTEM cell
- Rotation around y-axis of cell
- Power measured using VNA
- Comparison with anechoic chamber measurement shows a good agreement for a $\lambda/4$ patch @ 1.92 GHz
- Efficiency also possible



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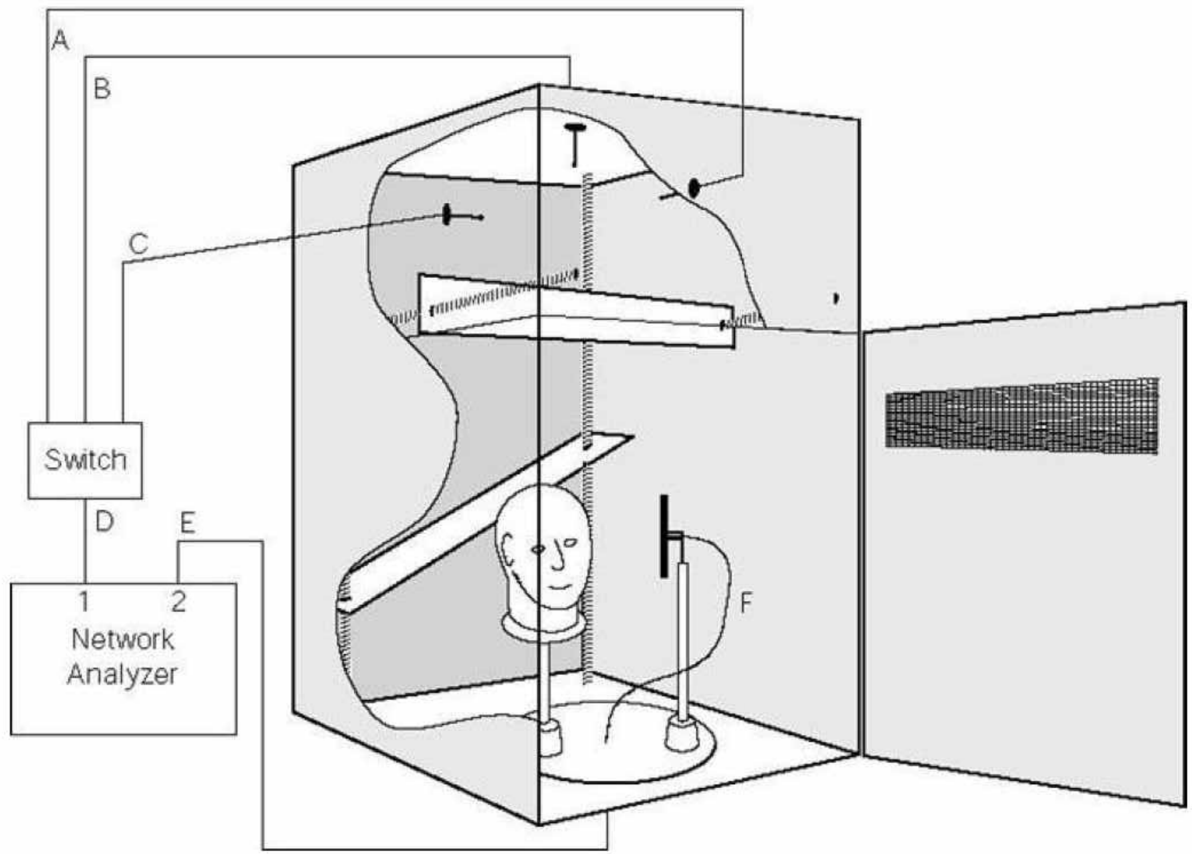
Reverberation Chamber

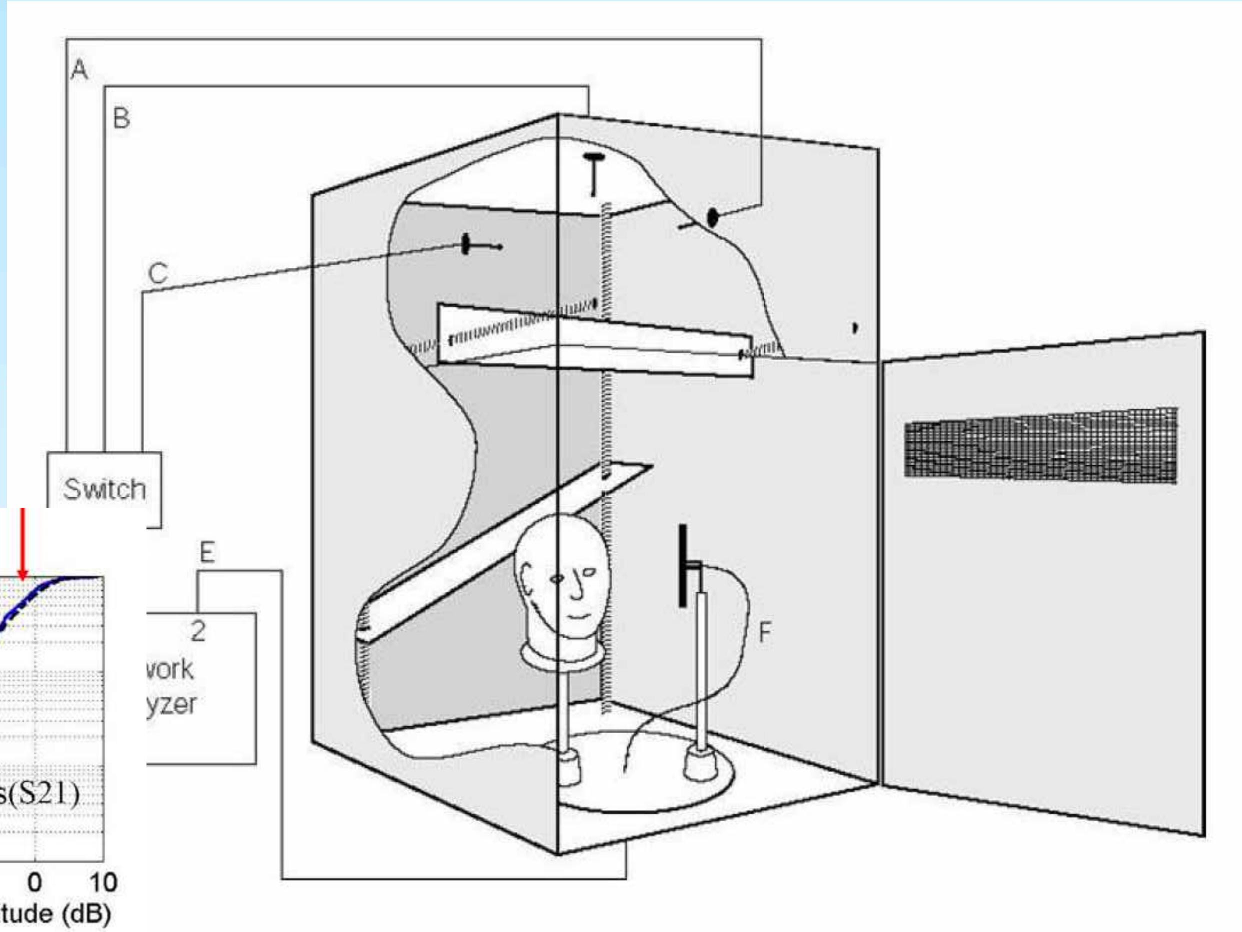


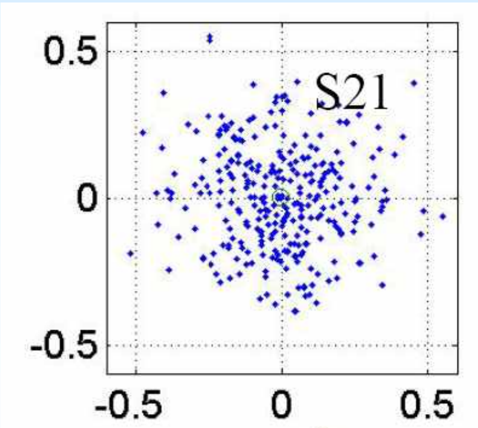
Picture Source: http://www.bluetest.se

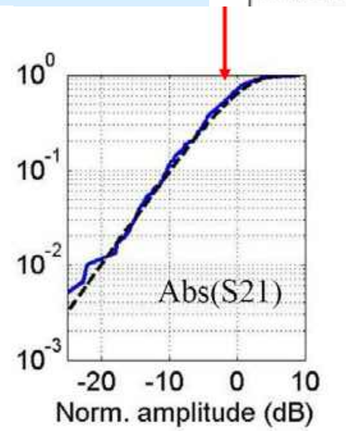
Reverberation Chamber

Mode stirring chamber

Rayleigh-Fading channel can be simulated as S21 has complex Gaussian distribution and a Rayleigh envelope







Reverberation Chamber: Determination of Antenna Parameters

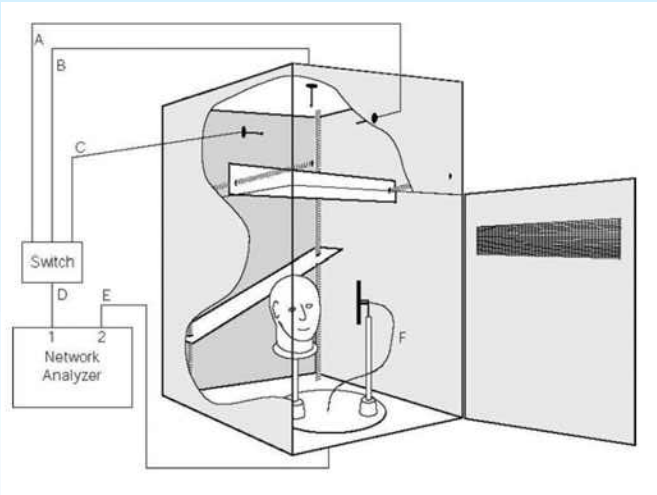
Avaraging over N stirring positions

Free Space Reflection Coefficient of AUT

$$\bar{S}_{22} = \frac{1}{N}\sum_{n=1}^{N} S_{22}^{(n)}$$

Relative received power of AUT

$$P_{AUT} = \frac{1}{N}\sum_{n=1}^{N} \frac{\left|S_{21}^{(n)}\right|^2}{\left(1-\left|\bar{S}_{11}\right|^2\right)\left(1-\left|\bar{S}_{22}\right|^2\right)}$$



Radiation efficiency is related to a well known reference antenna

$$\eta = \frac{P_{AUT}}{P_{ref}}\left(1-\left|\bar{S}_{22}\right|^2\right)$$

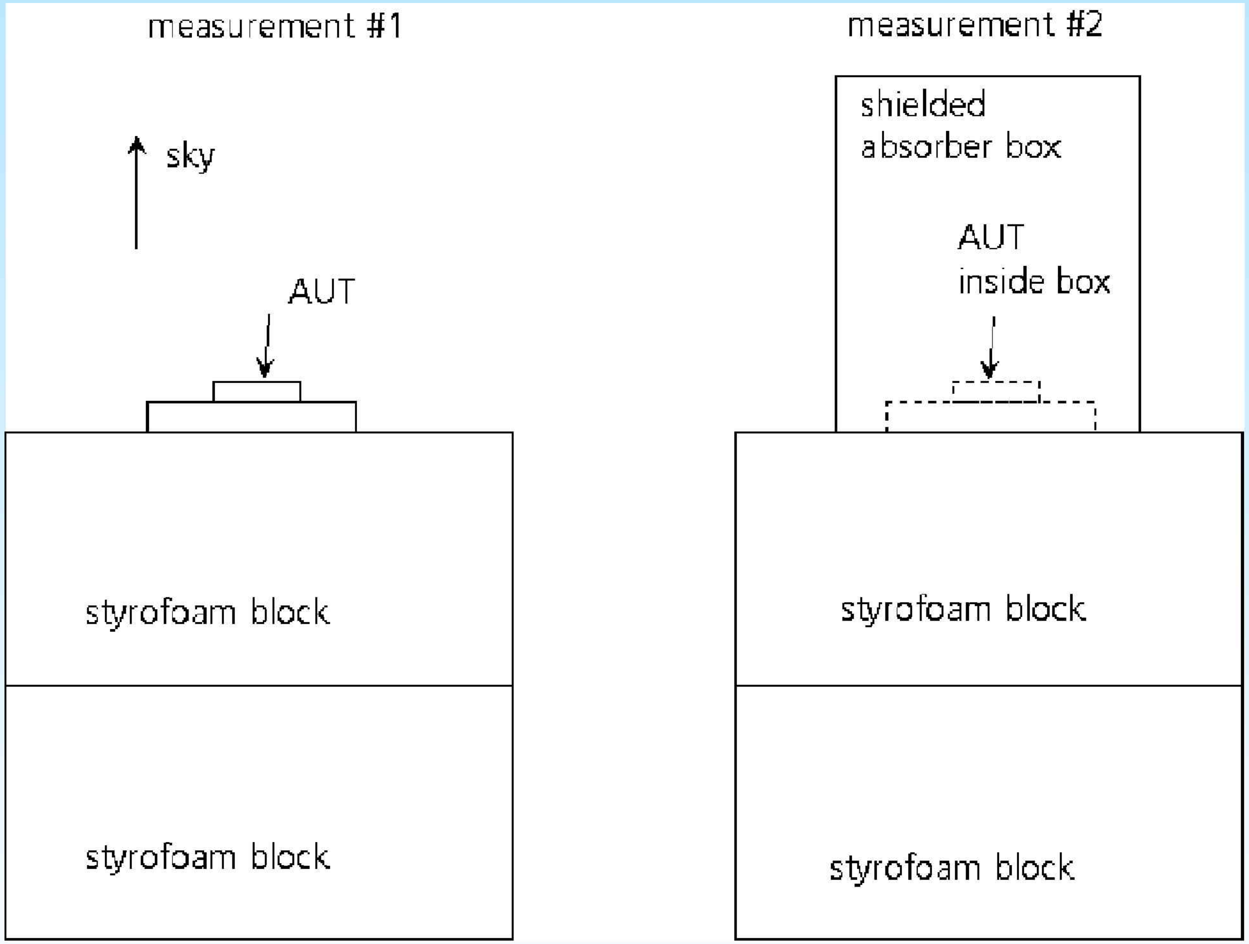
Antenna Noise Temperature

- Outdoor Method
- Measurement in an electromagnetically quiet environment
- Possible for low gain antennas with D > 4-5 dBi
- Adaptation of method for measurements in house in process
- For directivities below 3 dBi a direct method is required which can evaluate the received power level

Antenna Noise Temperature

Y-Factor Method:

– Compare the received power when antenna is pointing to cold sky with a black radiator at environment temperature



Anechoic Chamber Methods

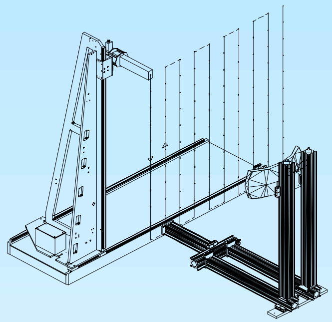
Near-field Scan Types

Planar Near-field
- Directional antennas
- Gain > 15 dBi
- Max angle < ± 70 °

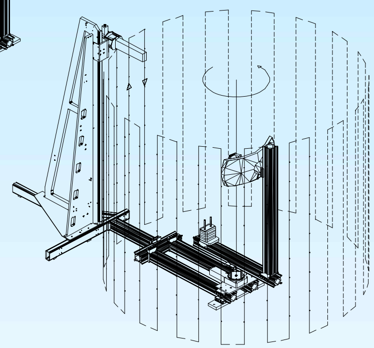
Cylindrical Near-field
- Fan beam antennas
- Wide side/ backlobes

Spherical Near-field
- Low gain antennas
- Wide or omni-directional patterns on any antennas

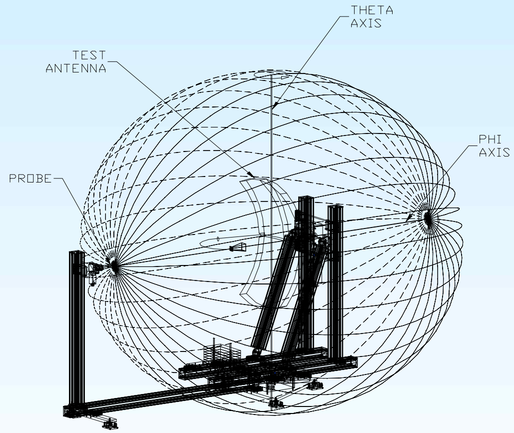
Planar



Cylindrical

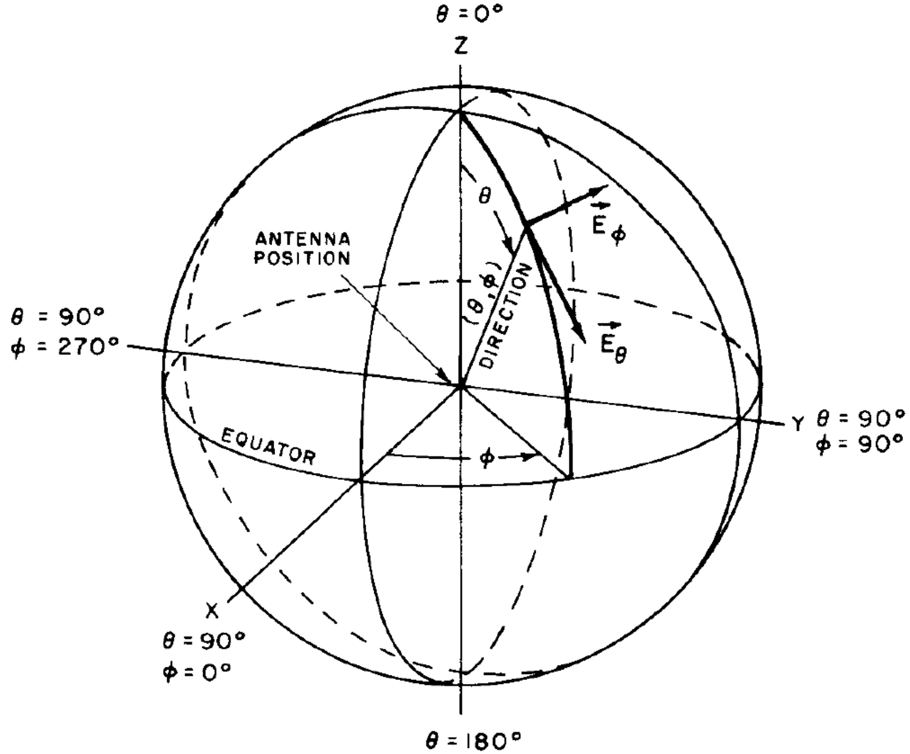


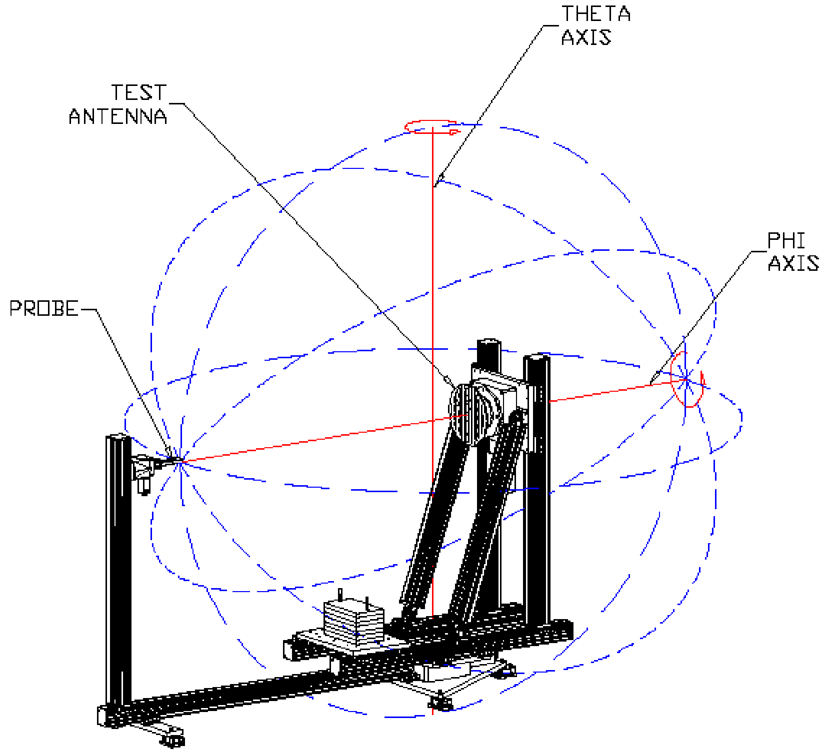
Spherical



Spherical Coordinate System and Spherical Scanner for Spherical Far- or Near-Field Methods

Small antennas need to be measured on spherical scanners as they can collect the complete radiation





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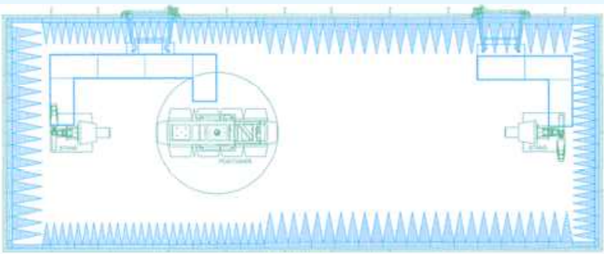
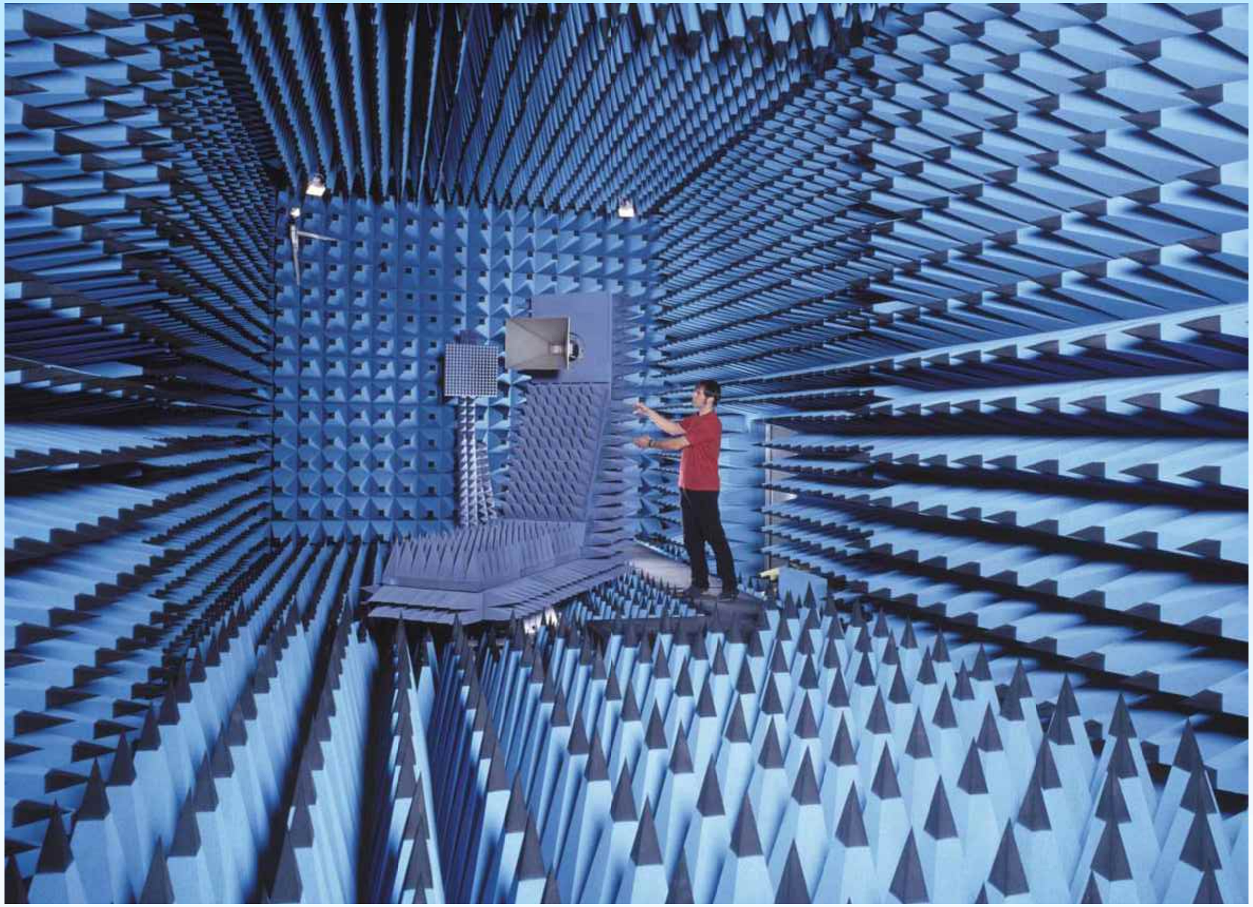
Combined Far-/Near-Field Antenna Test Range at Fraunhofer IIS

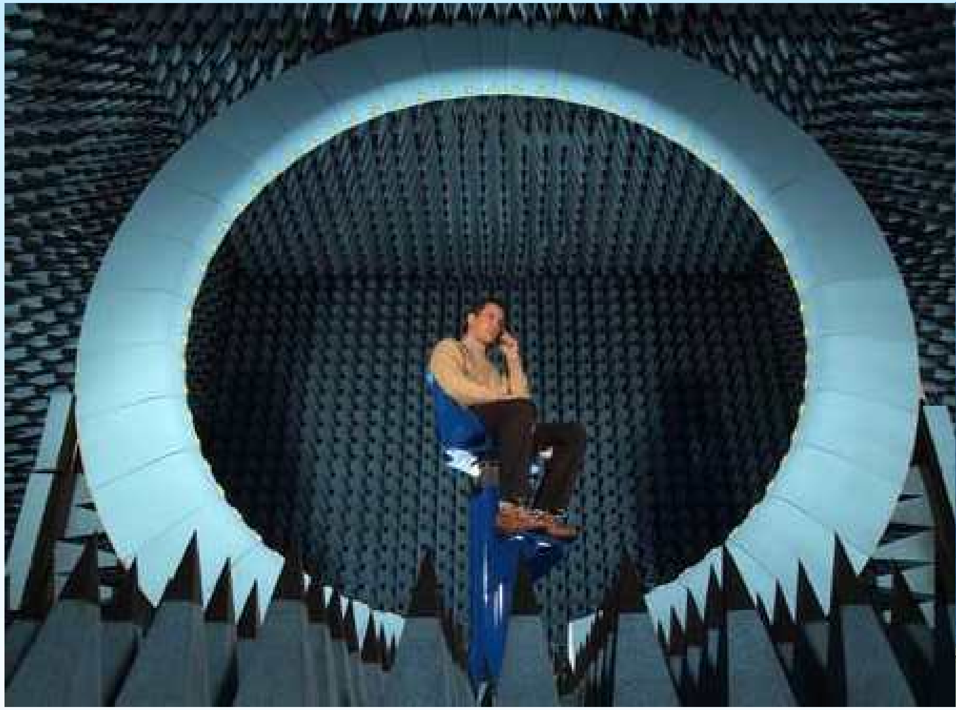
- Size: 6mx6mx15m
- Frequency range: 0.5 GHz - 40 GHz
- Max. probe – AUT distance: 7.5m
- Spherical Scanner (NSI 700S-60)

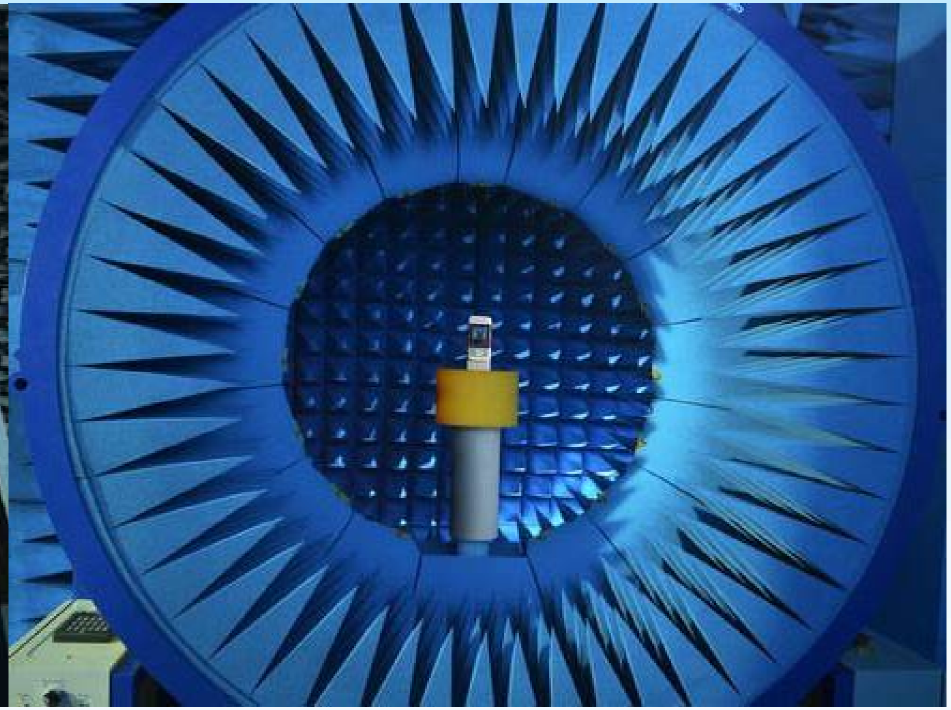




Near-Field: Stargate / Starlab by Satimo

Switched multiple probe approach lead to fast measurement times and reduced shadowing by absorbers



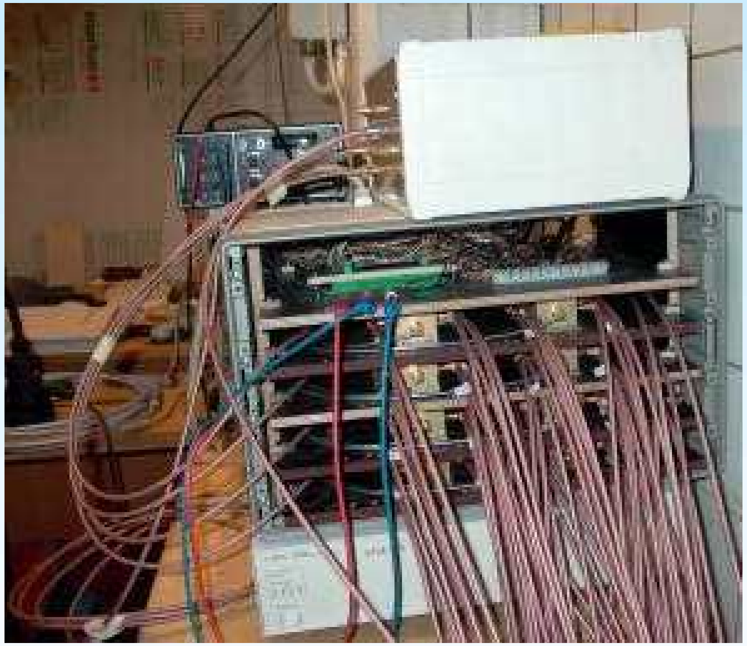


Picture Source: http://www.satimo.fr/engl/index.php?categoryid=171&p2008_sectionid=5

Near-Field: RAMS by TKK

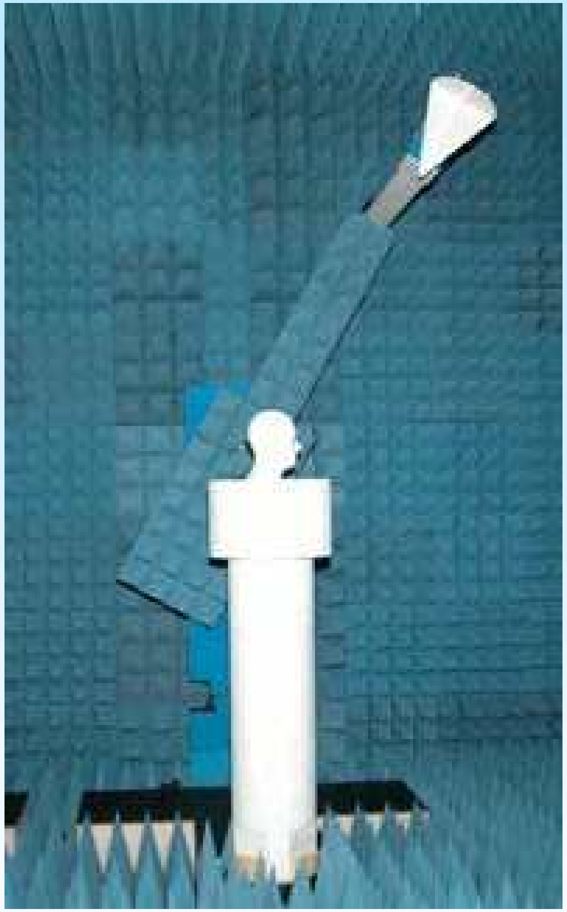
Multi-arch architecture

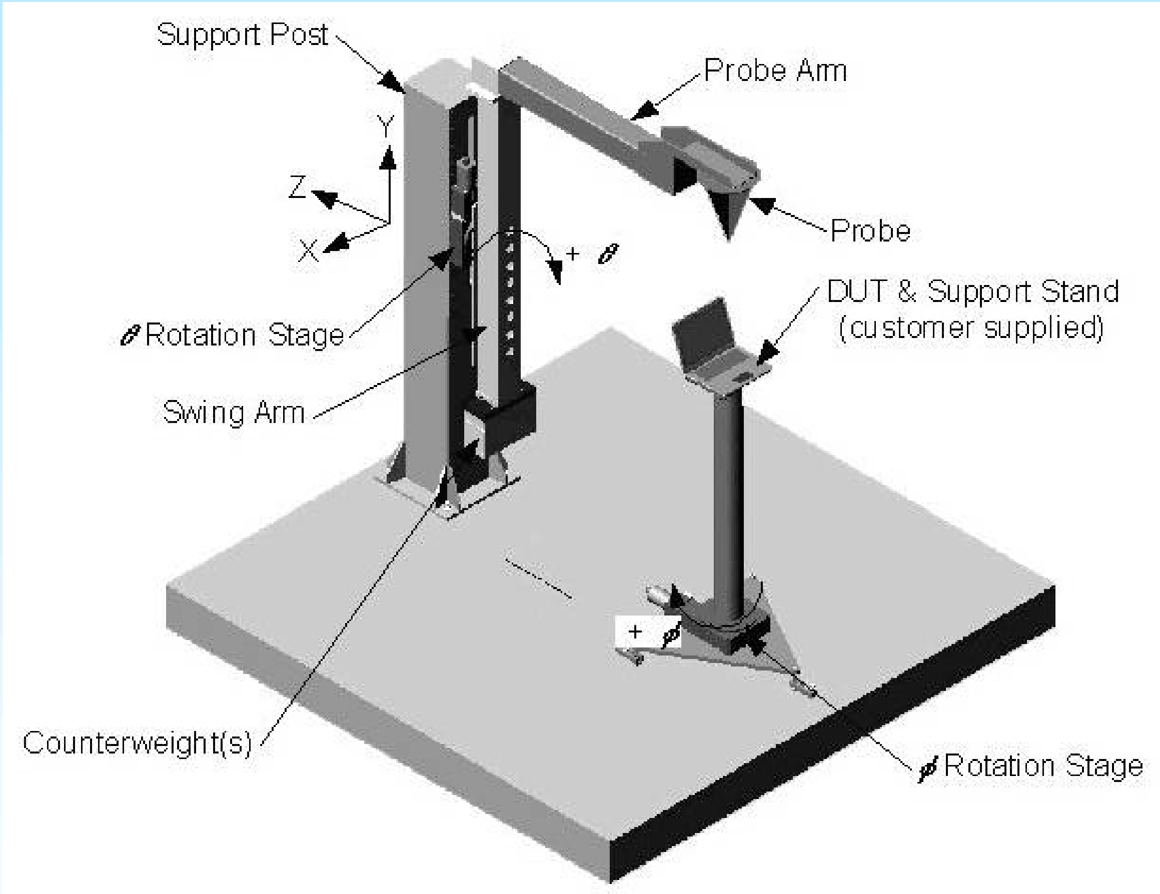
Measurement times should reduce to some ten ms, so it can be used to characterise the radiation properties of mobile handsets for all relevant communications systems, with the possibility to perform tens of full 3-D measurements within a second



Picture Source: http://www.hut.fi/Units/Radio/research/RAMS.html

CTIA Measurements





Picture Source: *http://www.nearfield.com/Sales/datasheets/NSI-700S-90-CTIA.htm*

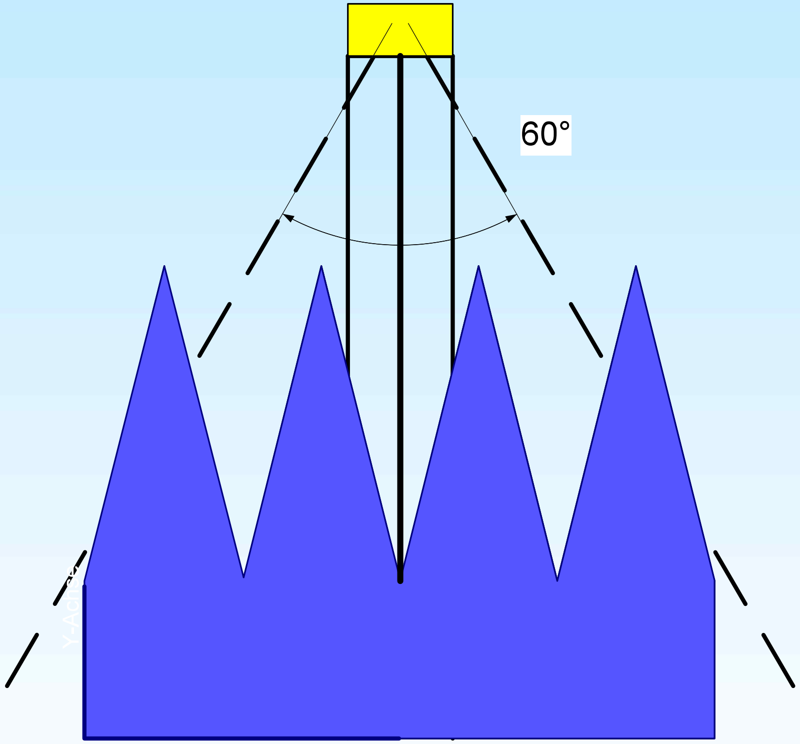
Measurement Impairments

Sources of Errors

Cabling	jacket currents on cables
	Exact positioning and fixture of cables
Mismatch	BALUNs and impedance transformation at antenna footpoint
Fixture	Reflective Fixtures
	Size of fixture
	Repeatability of mounting antenna to fixture
Scanner	Shadowing effects
	Reflection on metallic interface
	Misalignment

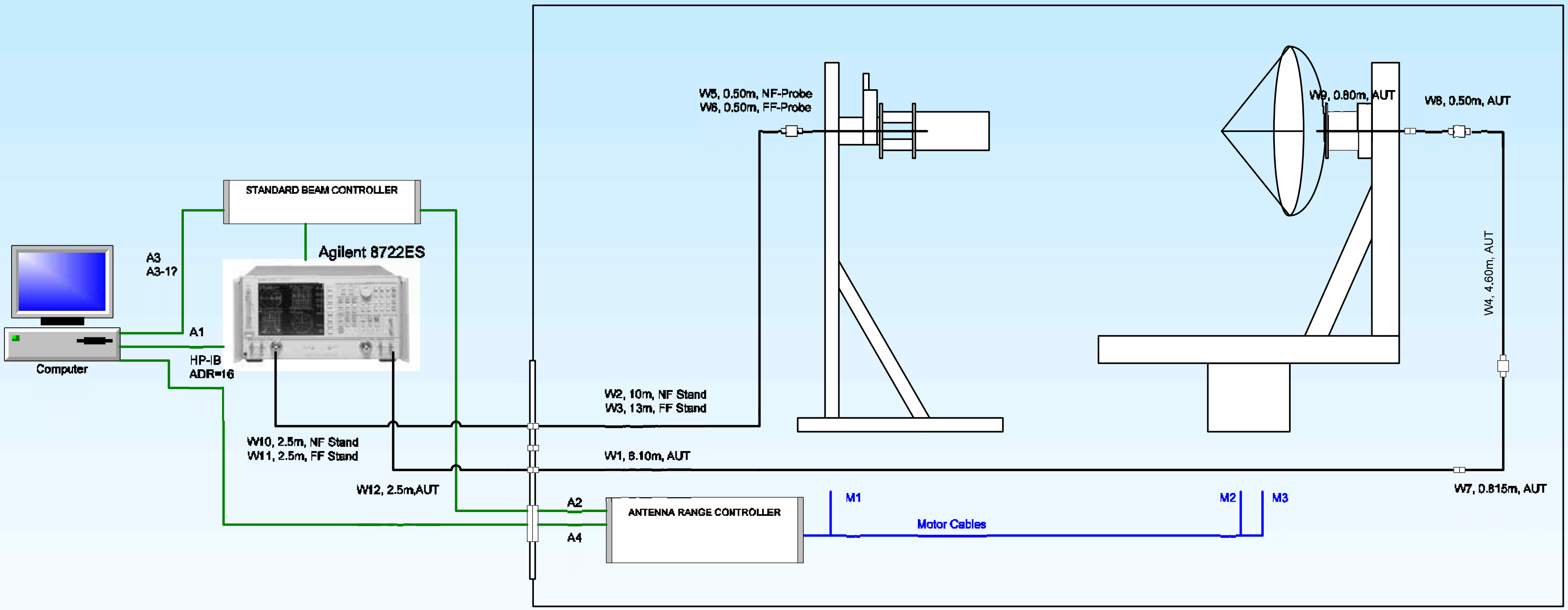
Shadowing Caused by Positioner and Absorber

Theta Scan range is limited to positioner and Absorber nearby AUT – reduction of about 30° for a half sphere



Detailed Measurement Setups

Setup for Pattern and Gain Measurement in Near-Field Mode (same for Far-Field Mode)



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Setup of Measurement Example

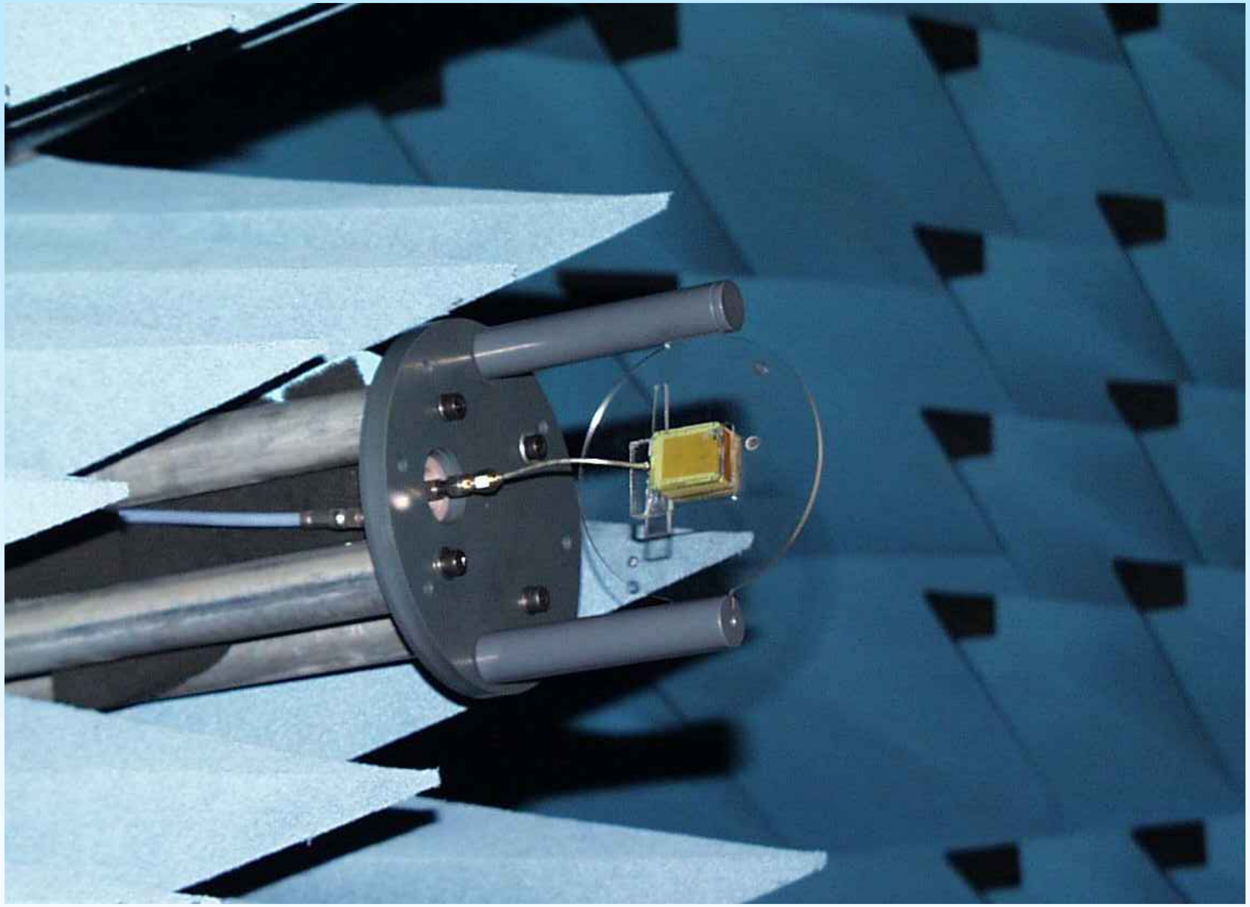
AUT size:
20mm x 30mm x 10mm

Fixture size:
200mm x 200mm

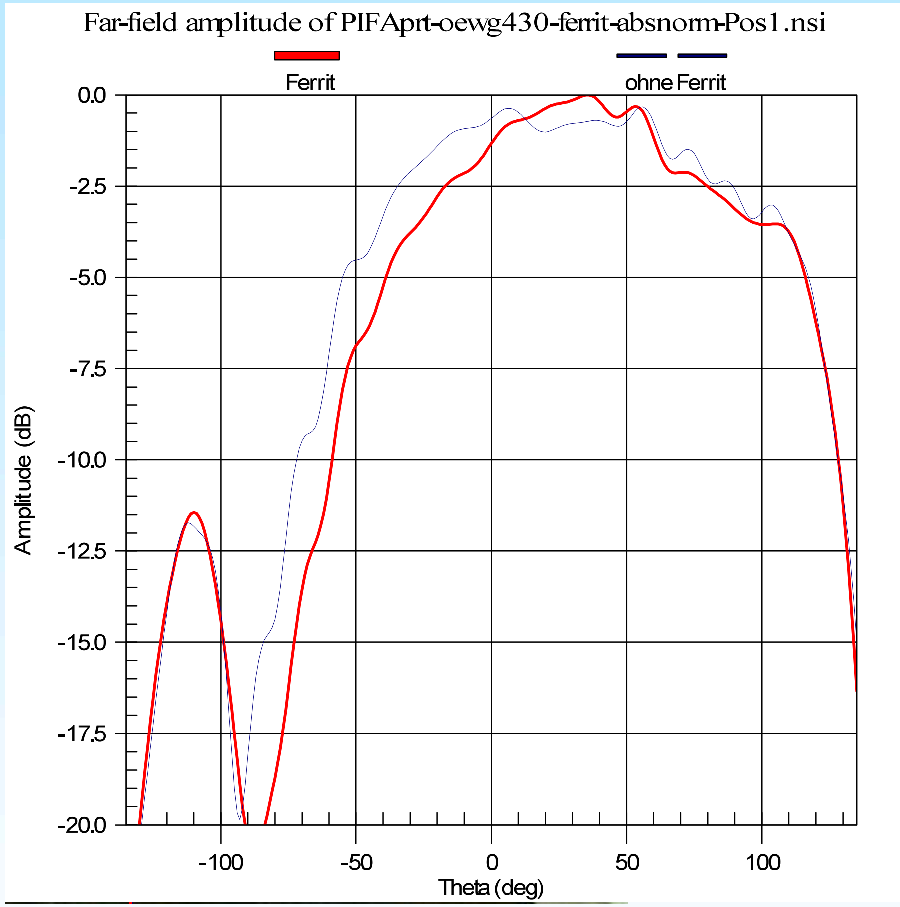
Absorber:
40 cm pyramidal absorber

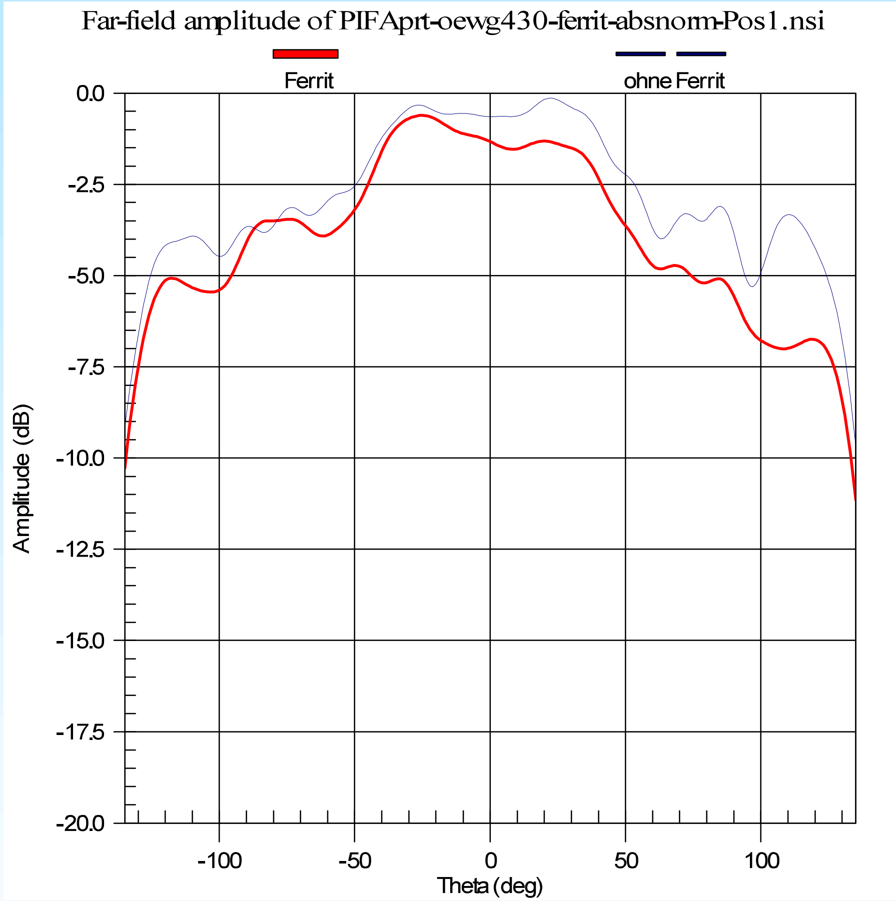
– Different cabling

– Different absorber position



Measurement Results: Cables With and Without Ferrites to Suppress Jacket Currents





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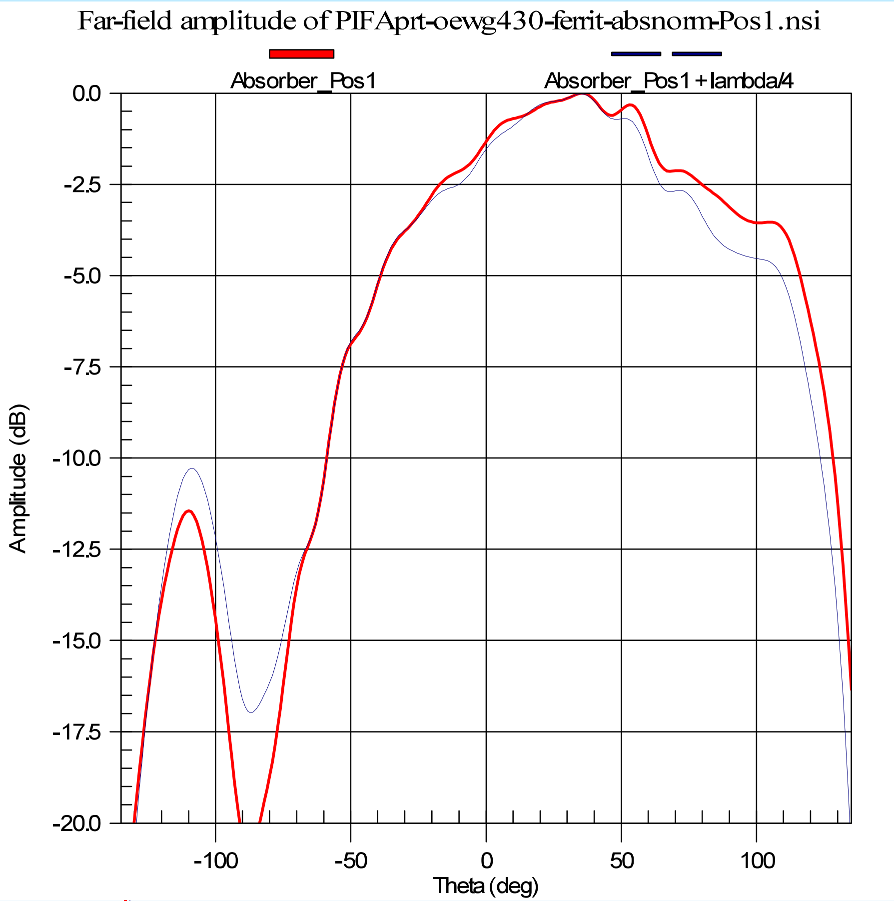
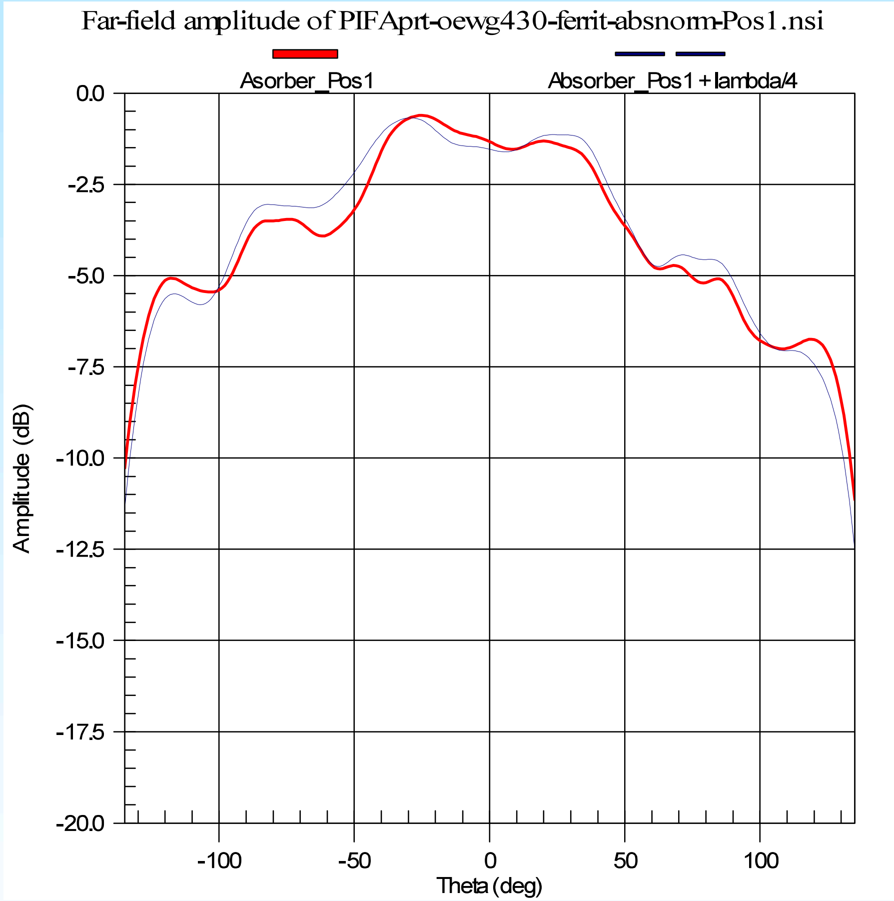
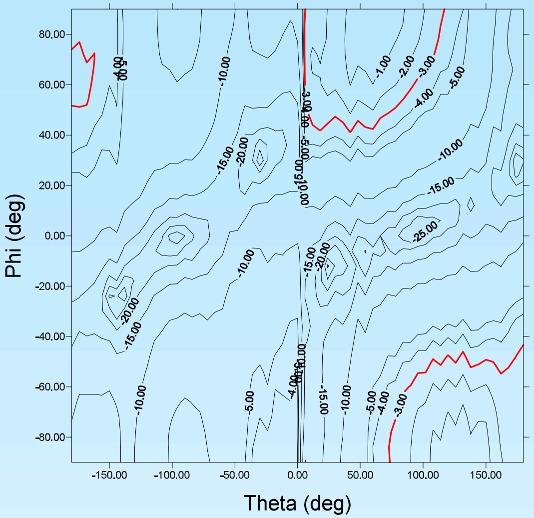
Measurement Results: Different Absorber Positions Behind Antenna, Absorber moved $\lambda/4$ towards antenna



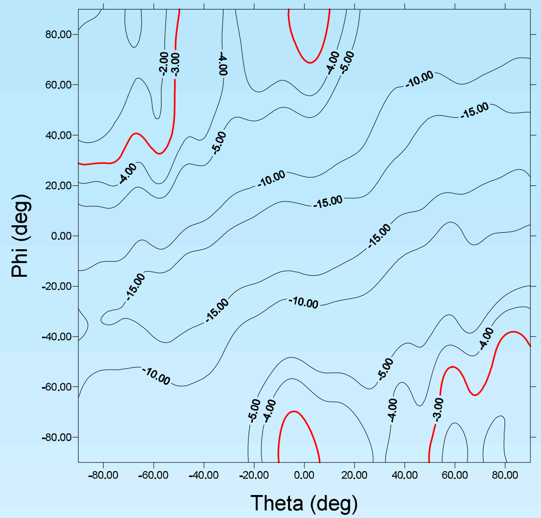


Measurement Results: Combination of two FF Data Sets

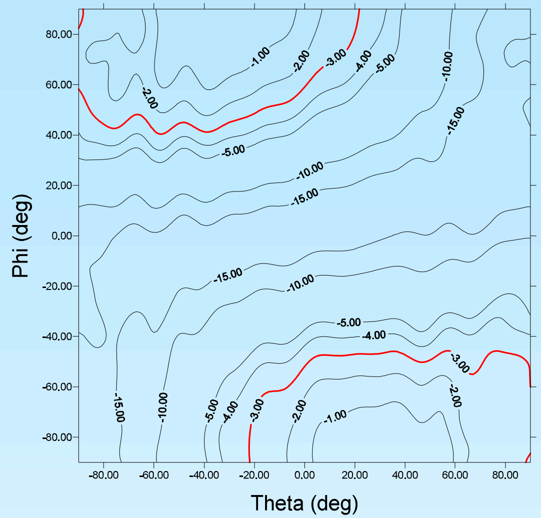
Near-field amplitude of PIFAprt-oewg430-ferrit-absnorm-Pos2.nsi



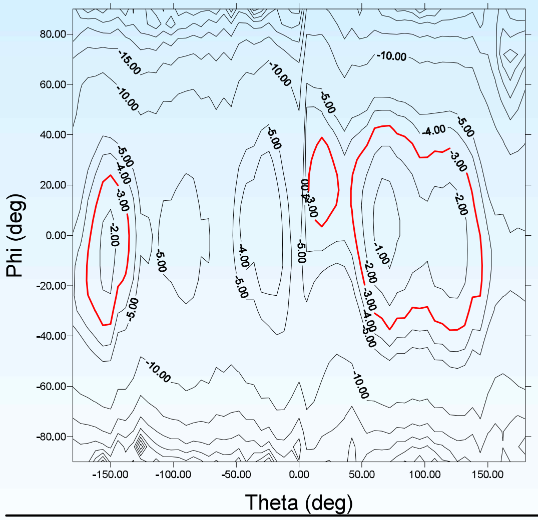
Far-field amplitude of PIFAprt-oewg430-ferrit-absnorm-Pos2.nsi



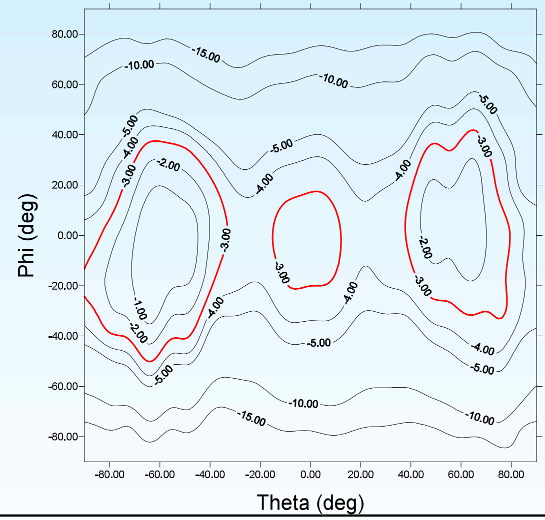
Far-field amplitude of PIFAprt-oewg430-ferrit-absnorm-Pos1.nsi



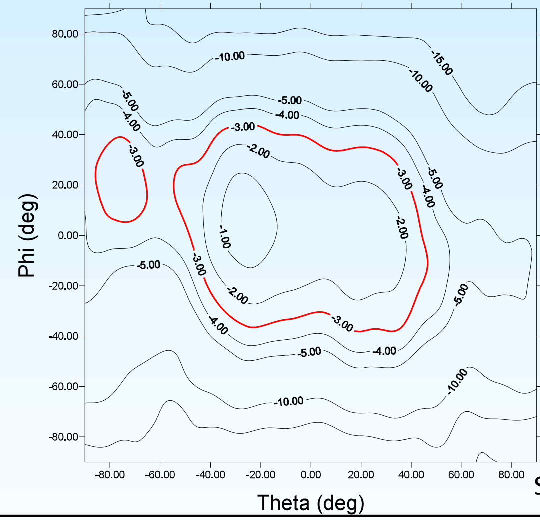
Near-field amplitude of PIFAprt-oewg430-ferrit-absnorm-Pos2.nsi



Far-field amplitude of PIFAprt-oewg430-ferrit-absnorm-Pos2.nsi



Far-field amplitude of PIFAprt-oewg430-ferrit-absnorm-Pos1.nsi



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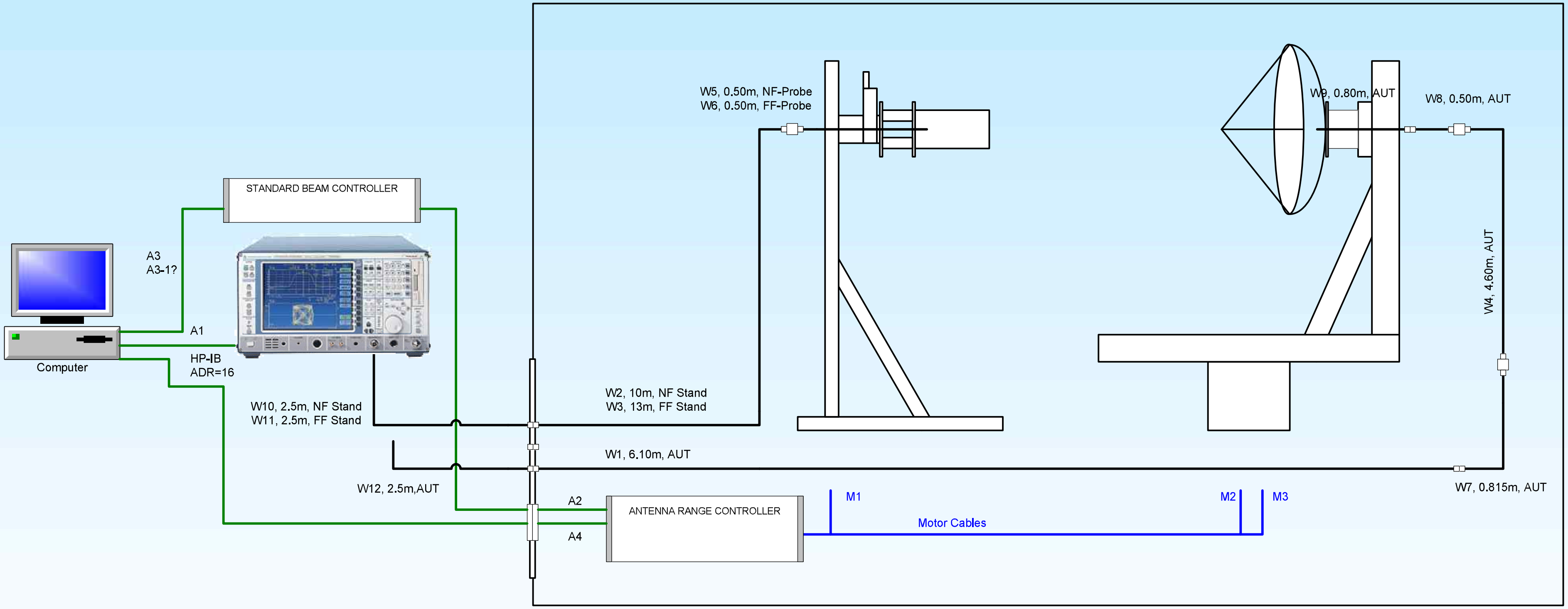
Setup for Pattern Measurement in Far-Field Mode Using Spectrum Analyzer



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Setup for Pattern Measurement in Far-Field Mode Using Spectrum Analyzer

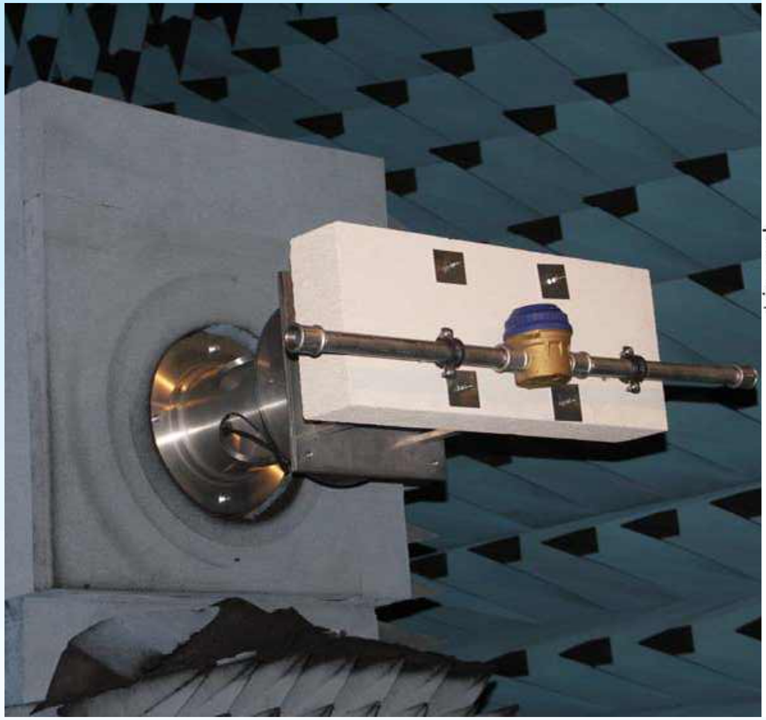
Measurement is performed using a battery powered transmitter sending a CW signal

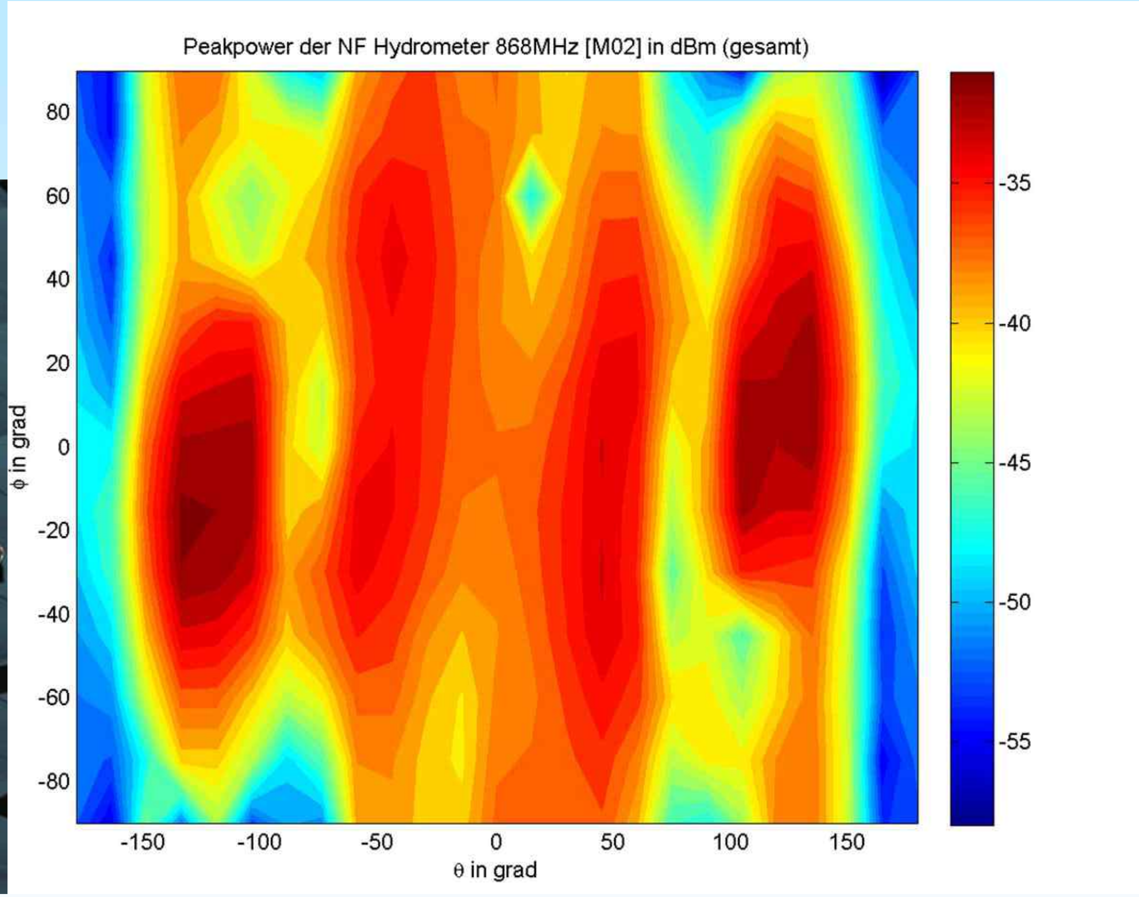
Measurements are done in STOP mode (positioner moves to position, stops, power spectrum is measured, positioner moves to next position)

Everything is done using a script to control the positioner and the spectrum analyzer

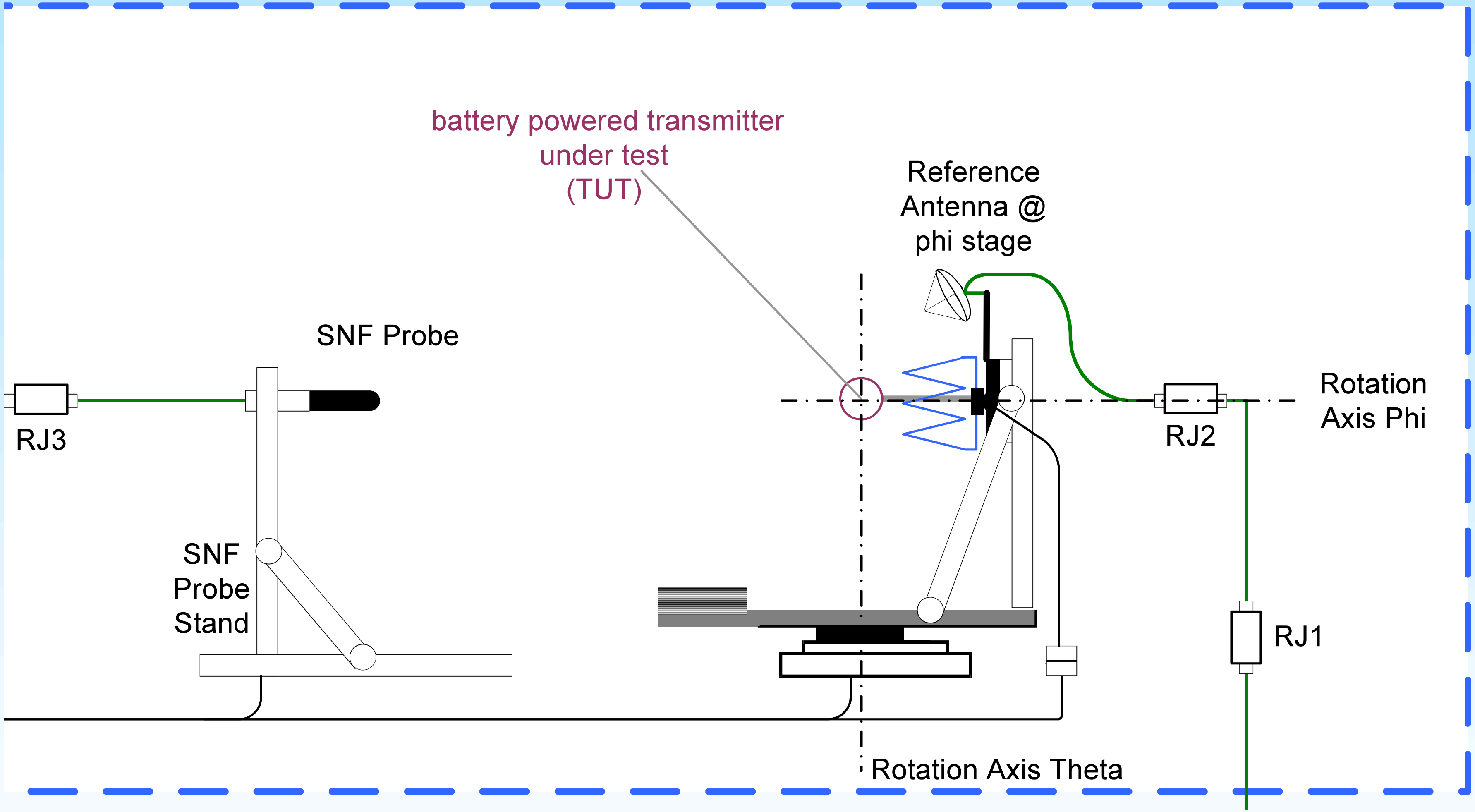
Measurement Example: Wireless Transmitter in Water Metering System

Pattern Measurement in Anechoic Chamber





Measurement System for Time Delay Measurements



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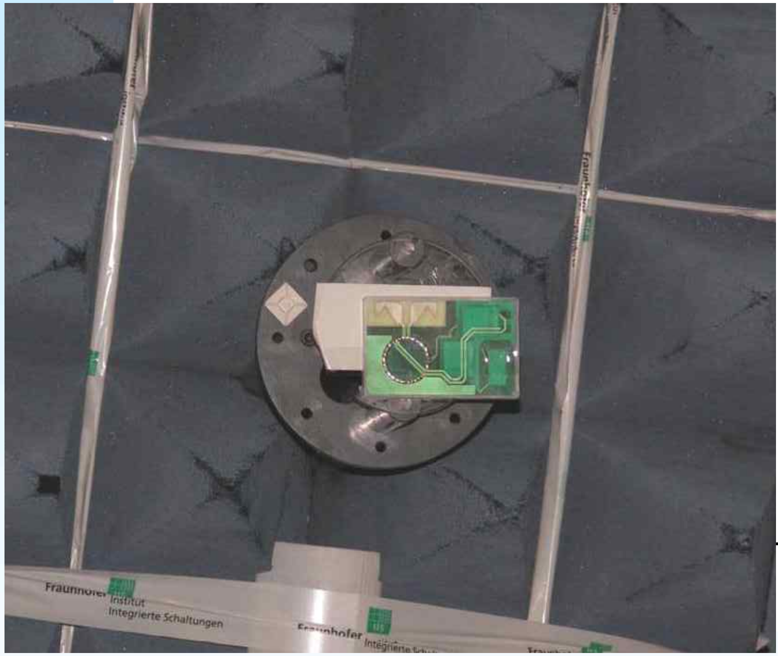
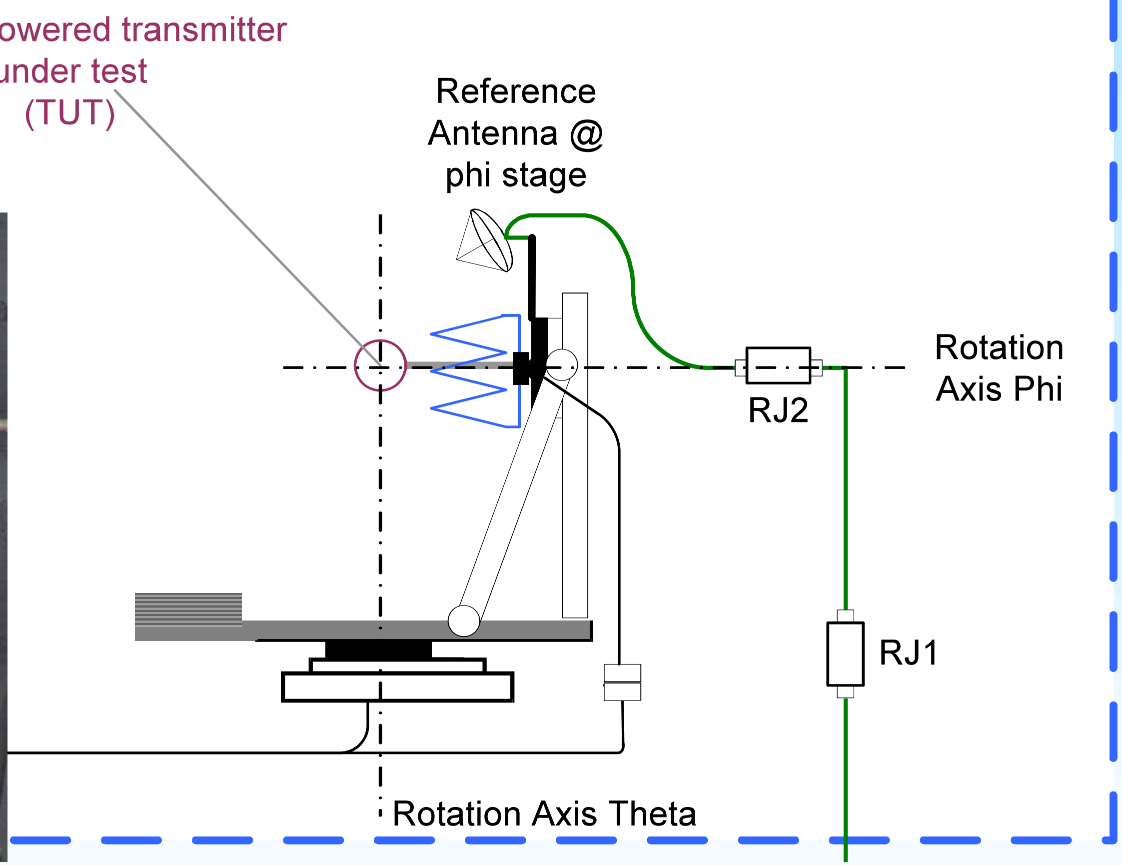
Measurement System II





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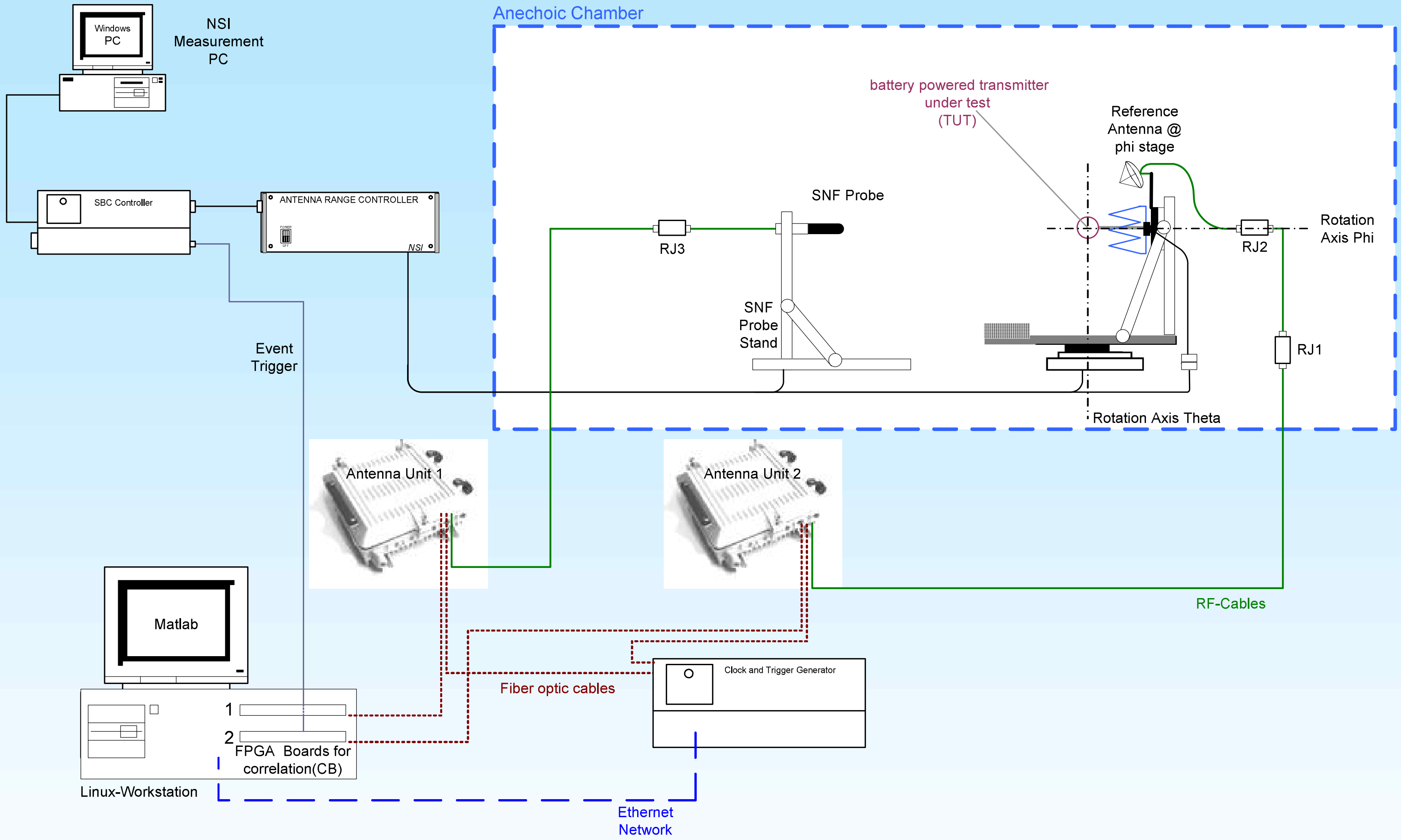
Measurement System III



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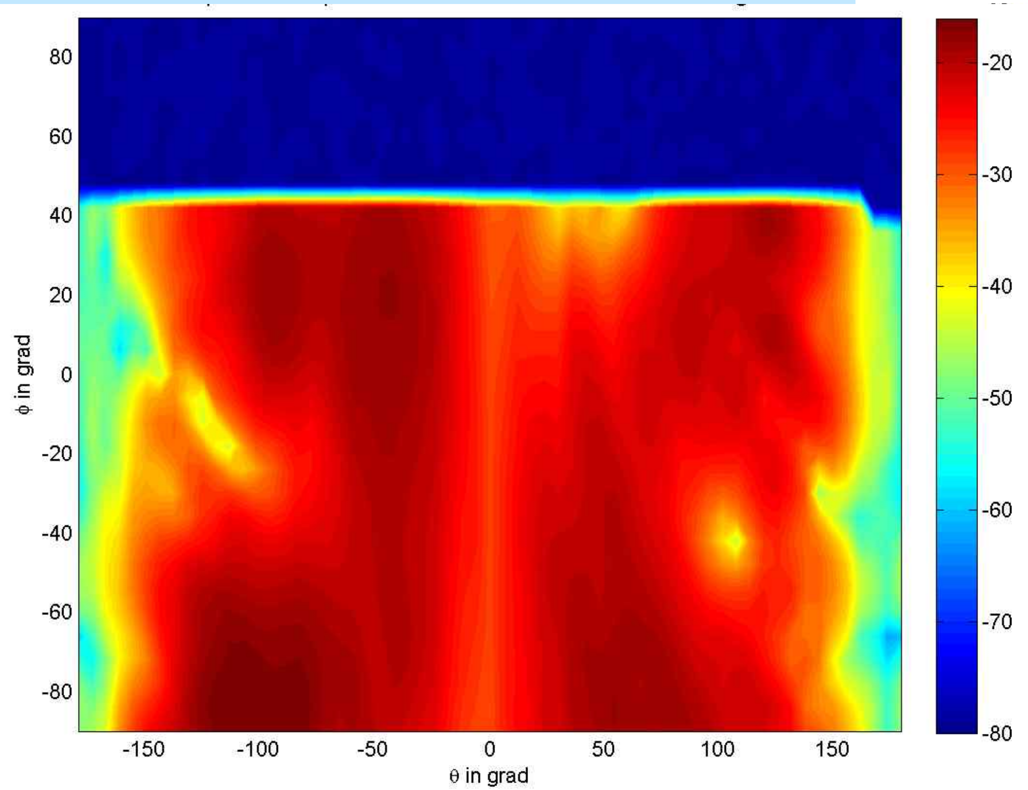
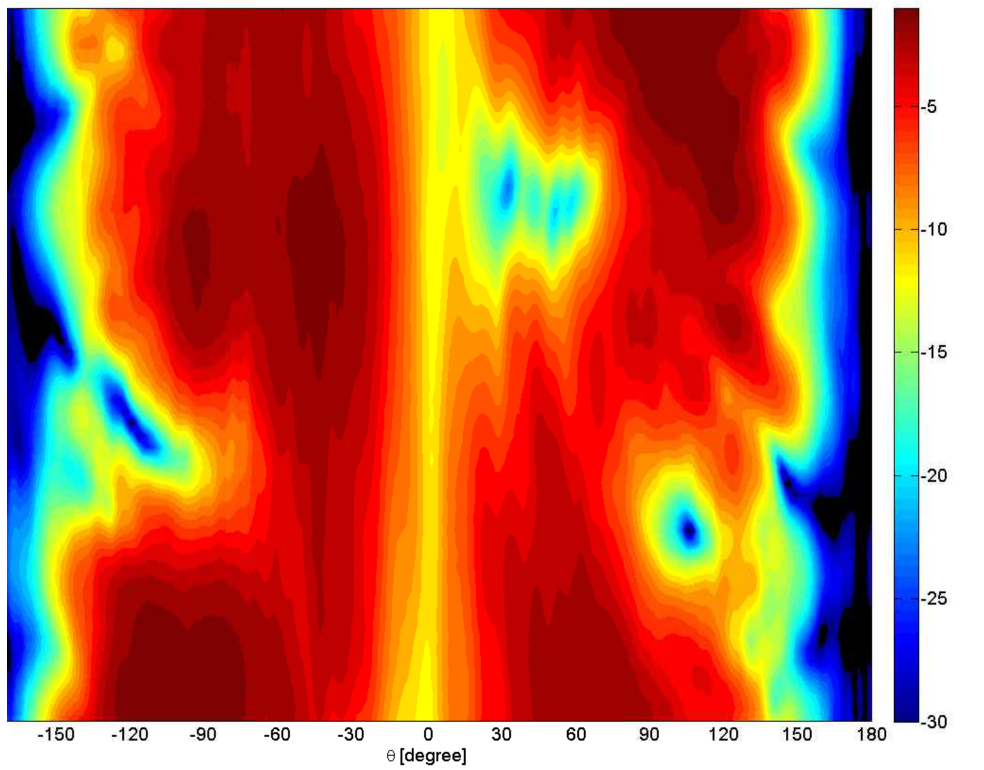
Results Transmitter with Integrated Dipole Antenna

3D directivity

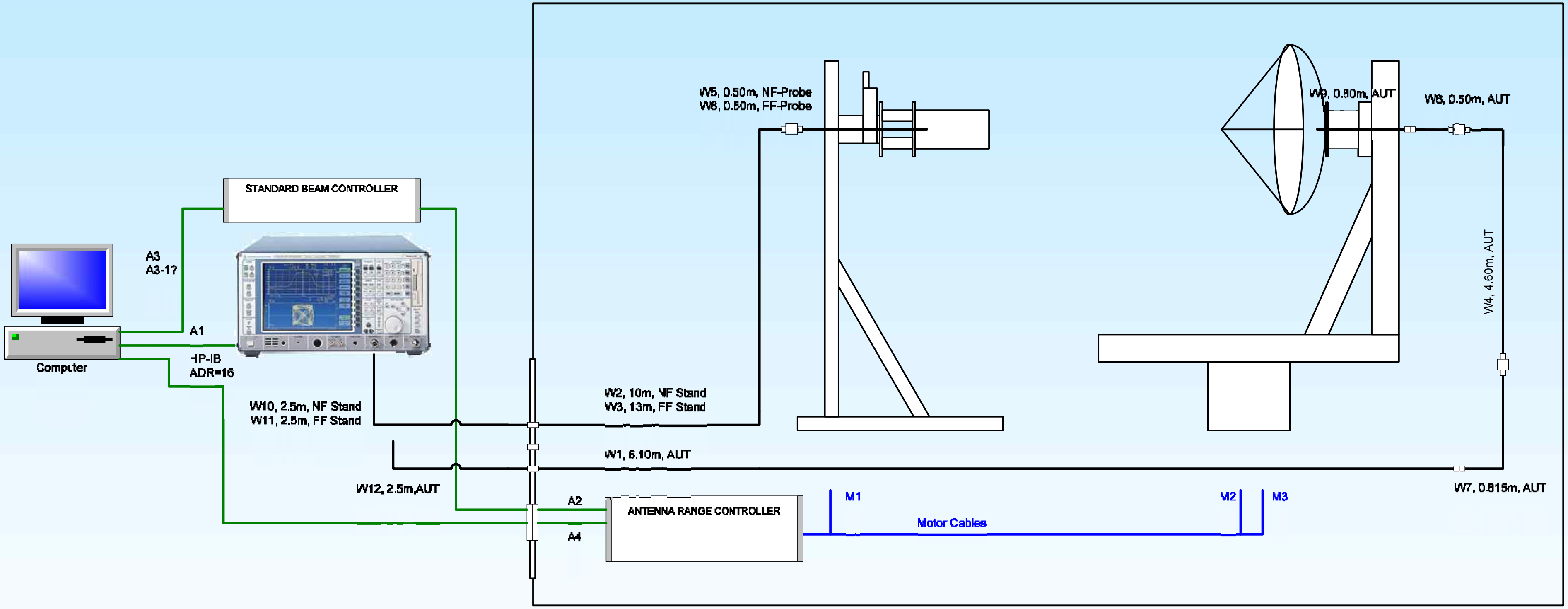




CTIA Measurement Setup Using Communication Tester

Radiated Power: Communication Tester establishs call with mobile and records the received power level @ maximum output power mode of mobile

Sensitivity: SW changes power level of base station simulator and determines the BER of the received signal (mobile acts as repeater), measurements can last several hours



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Recommendation for Measurements in Anechoic Chambers

- Construct a fixture that is small and reliable
- Define the co-ordinate system properly
- Be aware of Your cabling and its influences on the measurement
- Always use the same absorber behind the antenna and put it as far away as possible
- Measure full NF data, with two positions of the antenna
- Look at the whole picture: Compare NF and FF data

Then You should get repeatable measurements

Summary: Comparison of the Different Methods

Parameter/ Method	Pattern	Polarisation	Efficiency	Matching	CTIA
Far-Field	green	green	yellow	yellow	yellow
Near-Field	green	green	yellow	yellow	red
Reverberation Chamber	red	red	green	green	yellow
GTEM Cell	yellow	yellow	green	green	red
Wheeler Cap	red	red	green	red	red

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