Antenna measurement

Outline

- What is an antenna
- What do we want to characterize
- Circuit measurements
- Field measurements
- Special cases : the electrically small antenna

What is an antenna ?

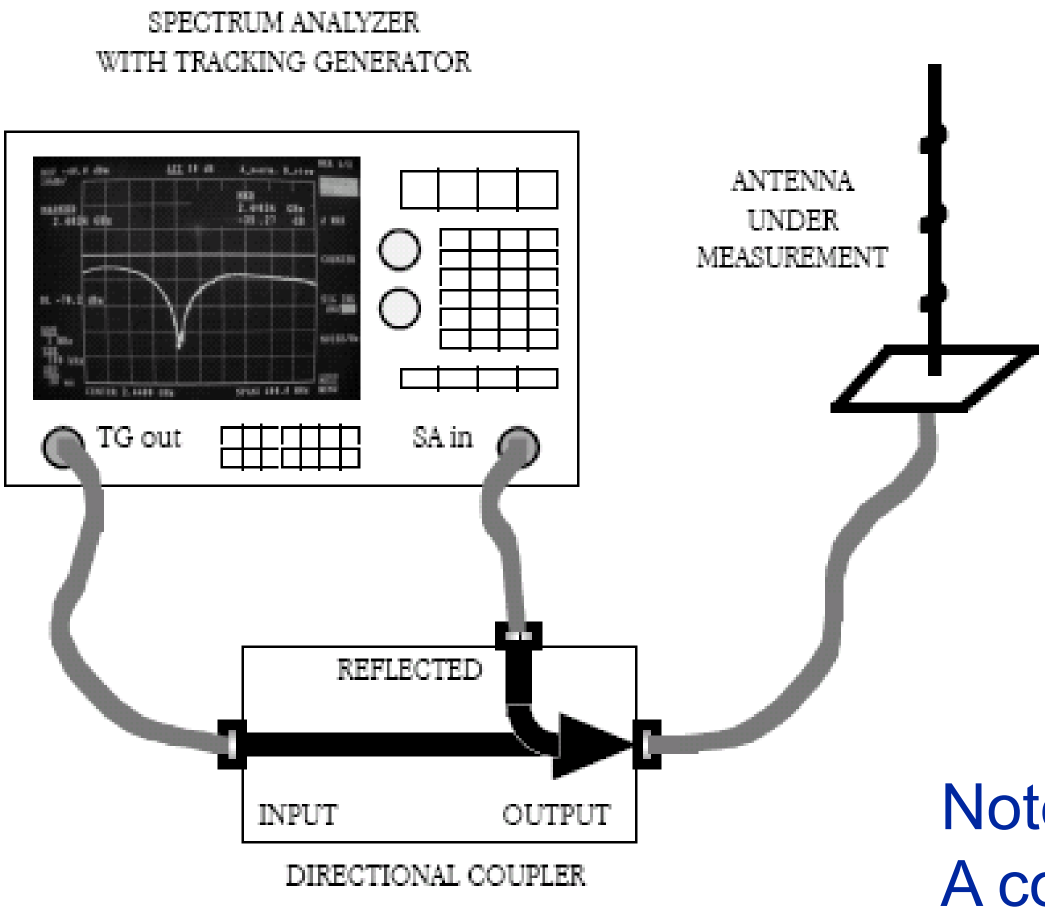
- An antenna transforms a guided wave to a radiated wave
- An antenna is a link between Krichhof’s world (circuit) and Maxwell’s world (fields)
- An antenna is a spatial filter and a spectral filter
- An antenna is a one port device
- An antenna is a two port device

Circuit characteristics

- Frequency response of the antenna (antenna bandwidth)
- Imput impedance of the antenna
- Reflection coeffcient of the antenna

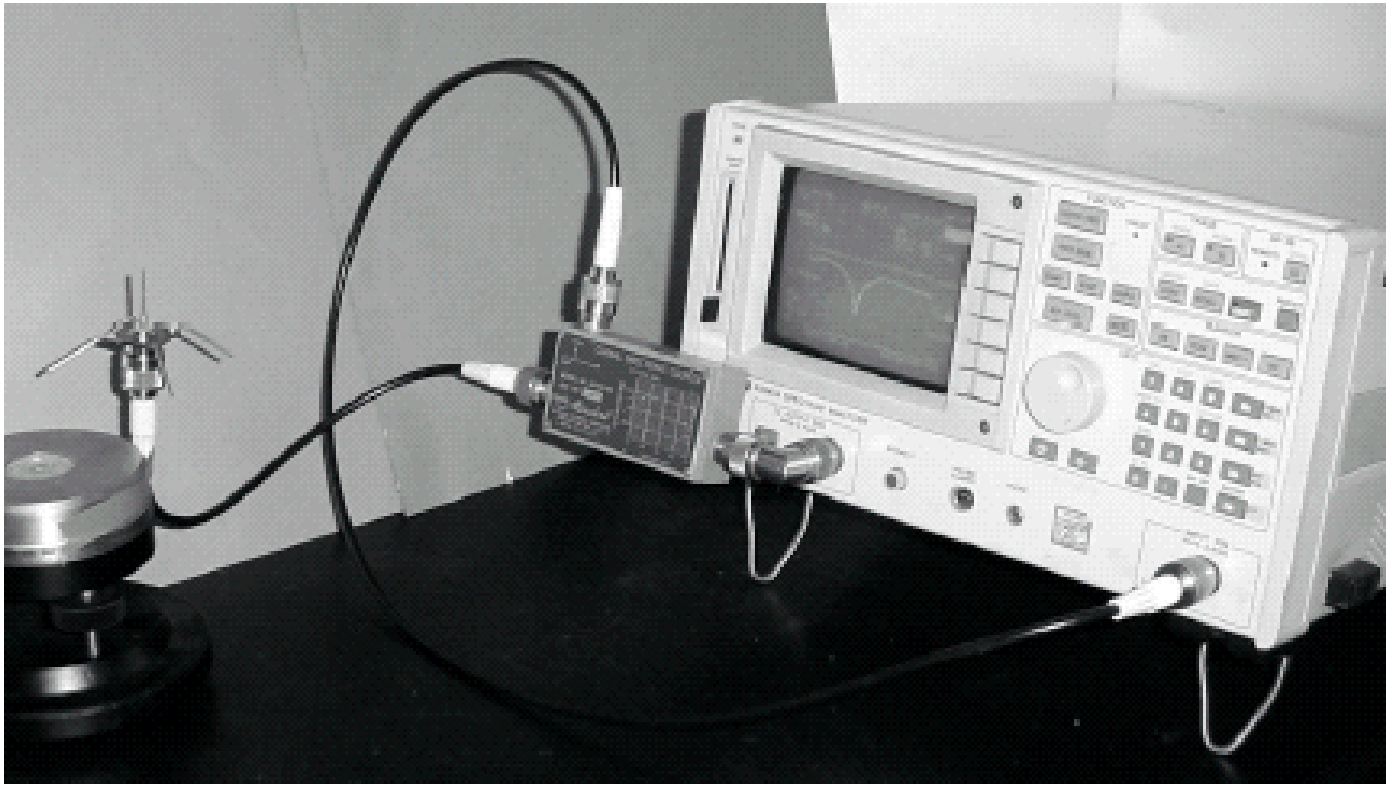
Can be measured using S parameter measurements or Power measurements

Antenna characterisation using power measurements



Note : we still need
A coupler !

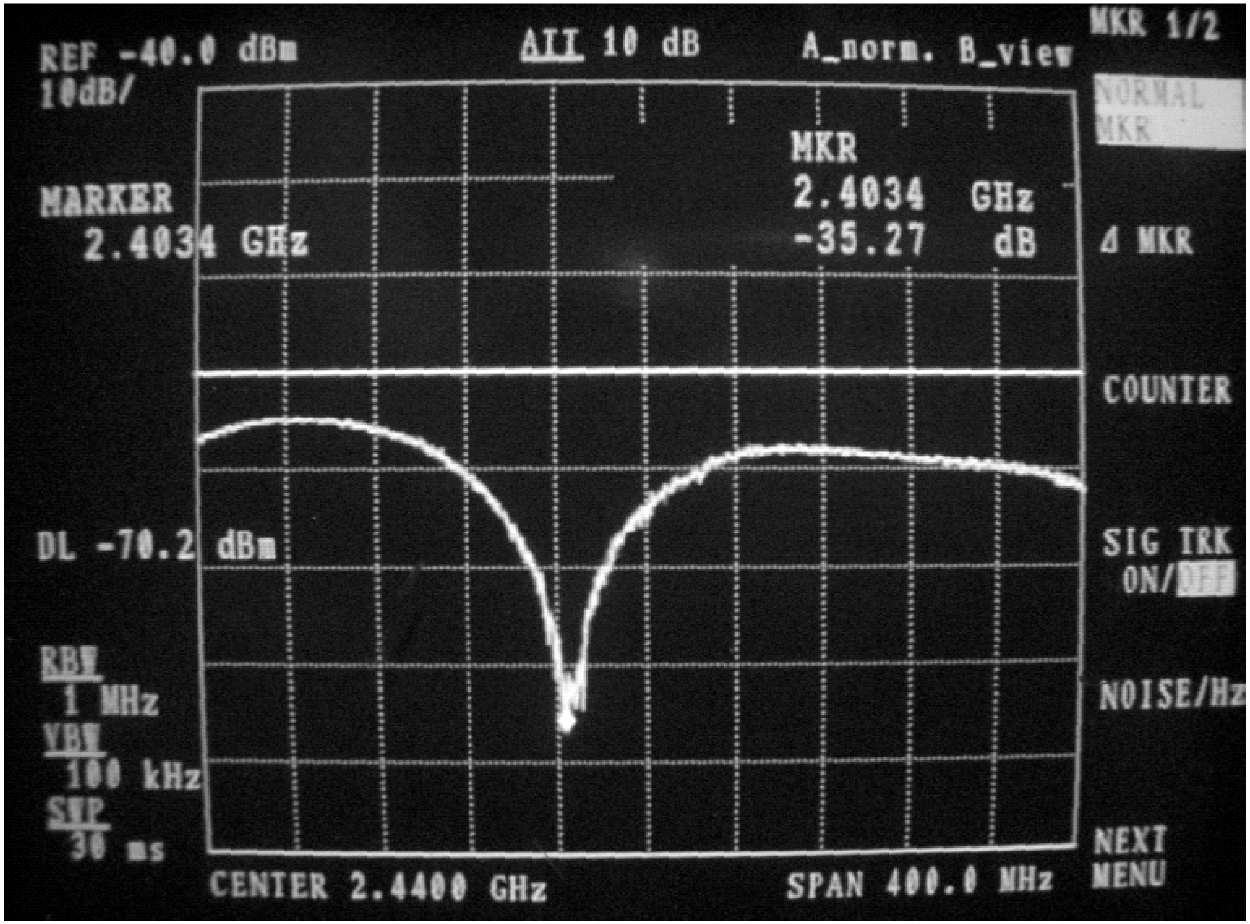
Matching measurement using a SA



Matching measurement using a SA : calibration procedure

- Measure first the reflected power in the absence of the antenna (opern circuit = max reflection), or better using a short circuit
- In the presence of the antenna, we measure the difference of reflected power, which corresponds to the transmitted (radiated) power

Example



Center frequency : 2.4 GHz

Refelcted power : 35 dB less than ref

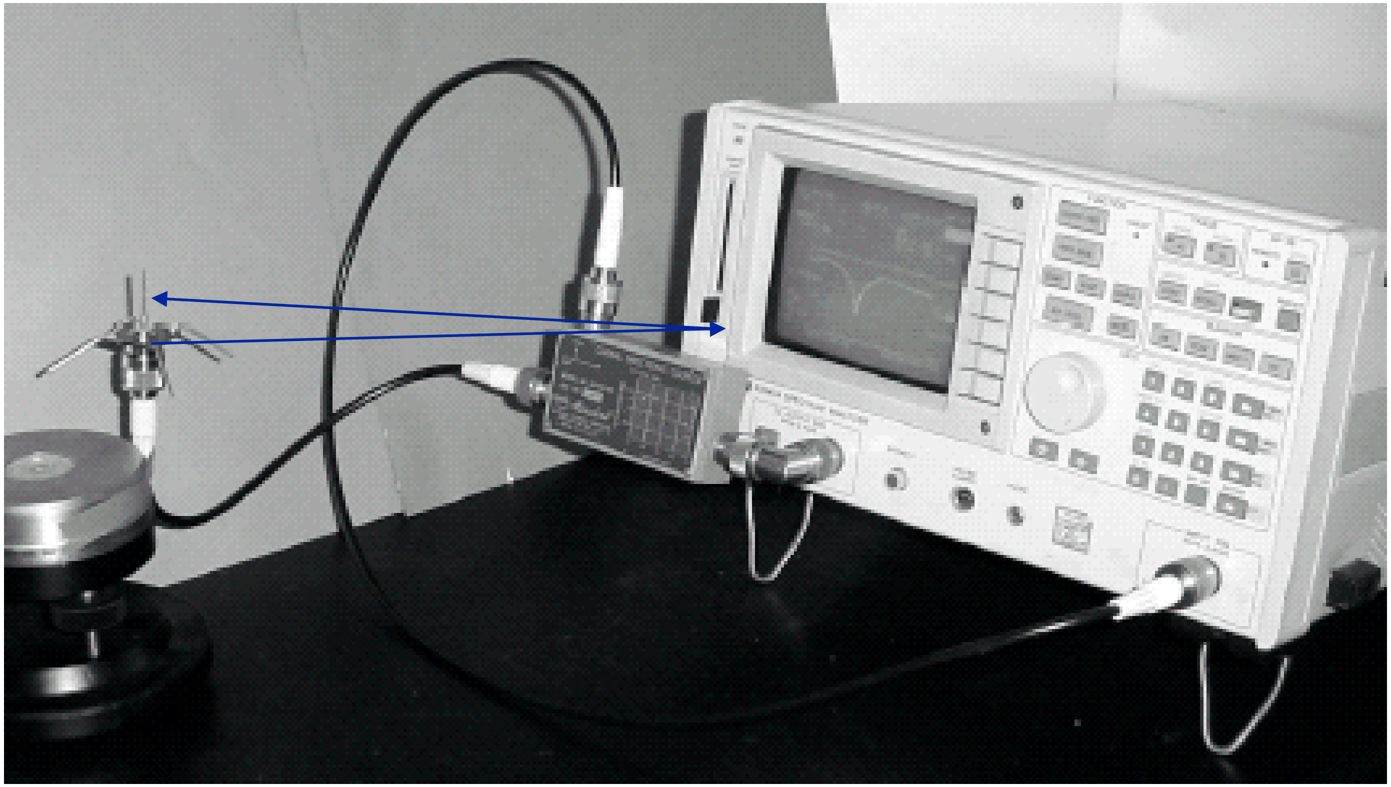
Circuit measurements using an NWA

- The antenna input reflection coeffcient is measured after a usual 1 port calibration procedure

Sources of errors

- Systematic errors (can be calibrated out)
- Random errors (noise, connexions, cables, etc.)
- Drift errors (can also be taken care off)
- Errors specific to antennas : spurious radiation

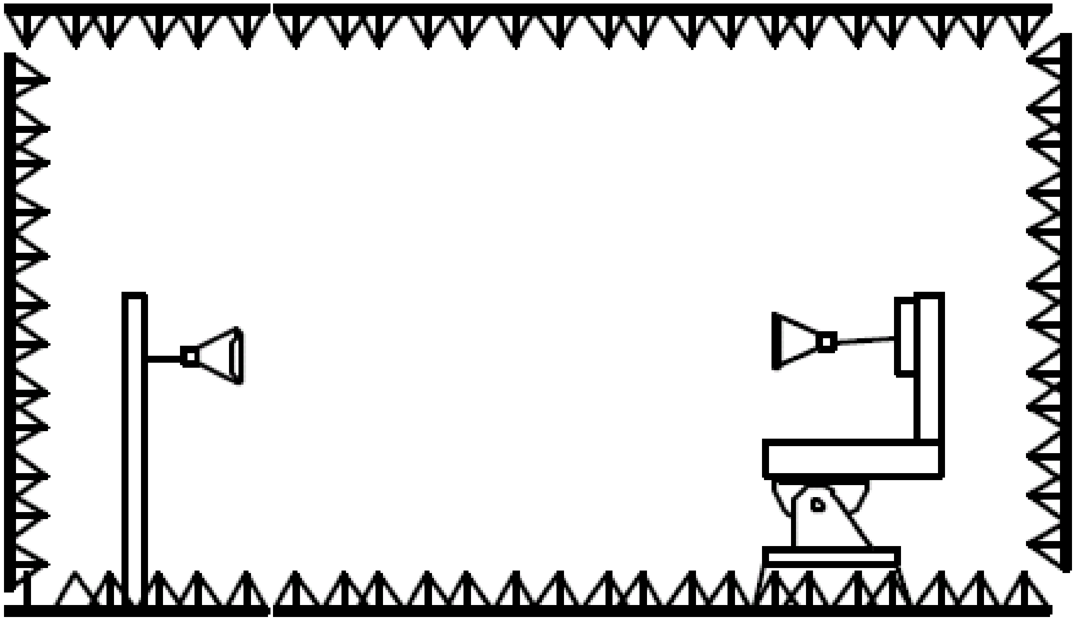
The importance of the environment



The solutions

- Anechoic chamber
- Outdoor ranges

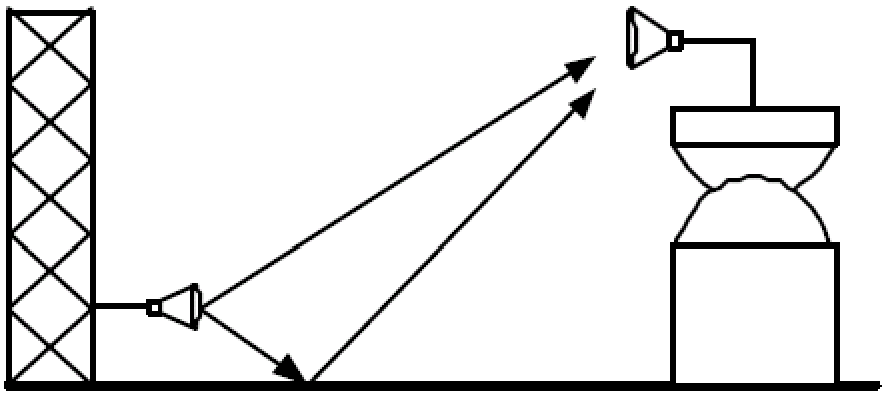
Anechoic chamber



Rectangular Anechoic Chamber

Outdoor ranges

Outdoor Elevated Range



Ground Reflection Range

Field characterisitcs

- Radiation pattern
- Directivity
- Gain
- Polarization
- Radiation efficiency

Most of these measurements imply the Measurement of an attenuation coefficient (transfer function)

Reminders

- Radiated power per solid angle (Far field) :

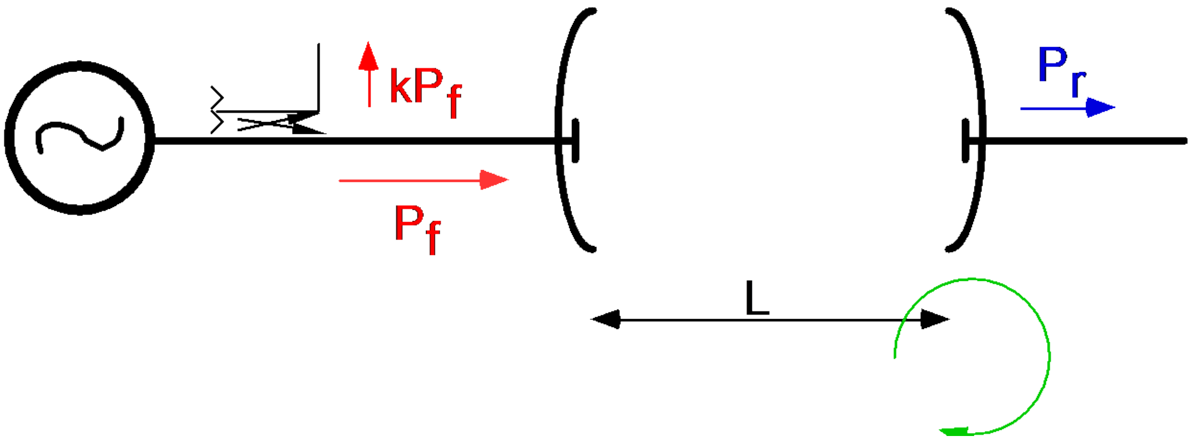
$$P_\Omega(\theta,\phi)d\Omega$$

- Gain (with respect to an isotropic radiator) :

$$G(\theta,\phi) = \frac{P_\Omega(\theta,\phi)}{P_f}$$

- Maximum gain : $G_{\max} = \max\left[G(\theta,\phi)\right]$

Principle



Mesured :
kP_f , P_r

Known :
k, L et λ

$$G_1 G_2 = \frac{P_r}{P_f}\left(\frac{4\pi L}{\lambda}\right)^2$$

Several solutions

- Known G_1
- Use two identical antennas (G_1=G_2)
- Do three measurements using three antennas (G_1G_2, G_1G_3, G_2G_3), :

$$G_1 = \sqrt{\frac{G_{12}G_{13}}{G_{23}}} \quad , \quad G_2 = \sqrt{\frac{G_{12}G_{23}}{G_{13}}}$$

$$G_3 = \sqrt{\frac{G_{13}G_{23}}{G_{12}}}$$

Radiation pattern

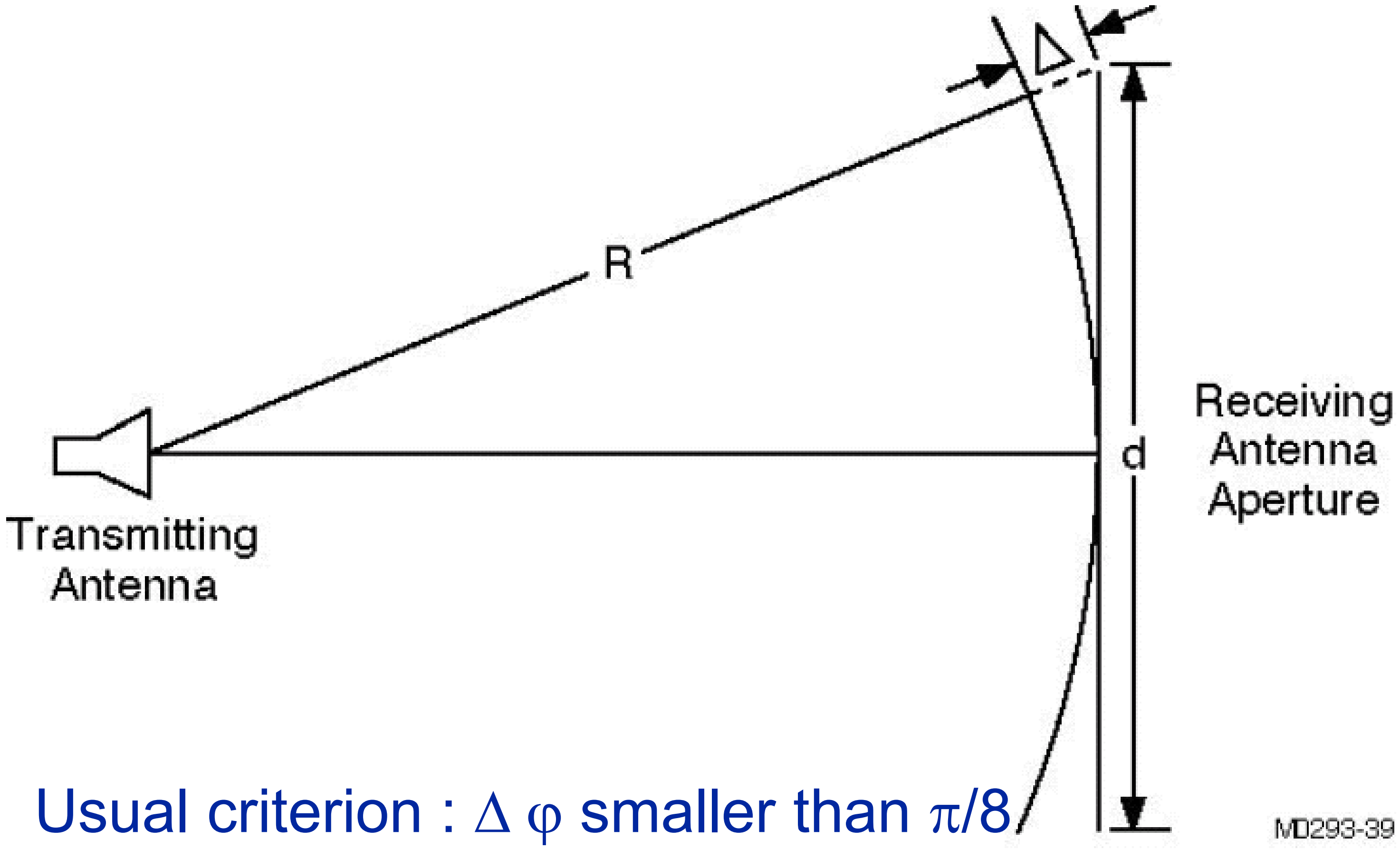
$$r(\theta,\phi)=\frac{G(\theta,\phi)}{G_{\max}} \qquad => \qquad 0\leq r\leq 1$$

Principle :

- You need two antennas or one antenna and a known reflector
- You need to be in the far field

$$L\geq\frac{2d^2}{\lambda}$$

Far field (variation of the phase over the range)



$$L \geq \frac{2d^2}{\lambda}$$

Usual criterion : $\Delta \varphi$ smaller than $\pi/8$

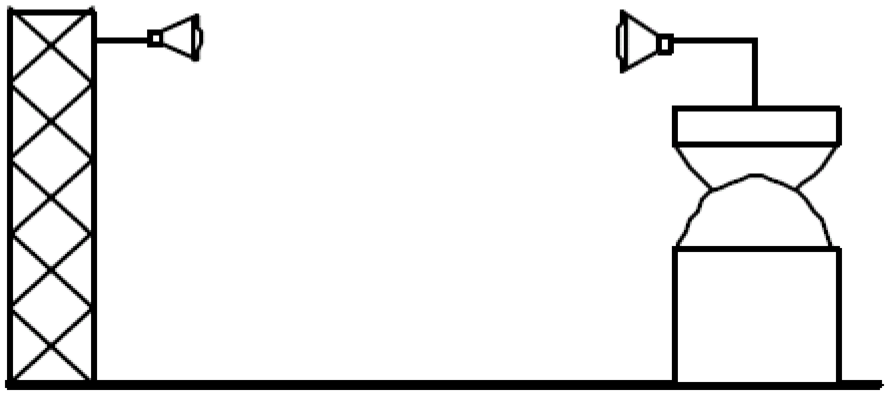
Amplitude variation over the range

- Usually up to 0.5 dB amplitude varaition is tolerated over the aperture of the antenna under test

Errors due to refelction

- A interfering field which is 30 dB below the direct path signal can cause a variation of ±0.25 dB in the measured maximum gain and can seriously affect the measured sidelobe structure of the pattern.
- Thus : us a directive transmitting antenna, an anechoic chamber or an outdoor range

Elevated outdoor range



Outdoor Elevated Range

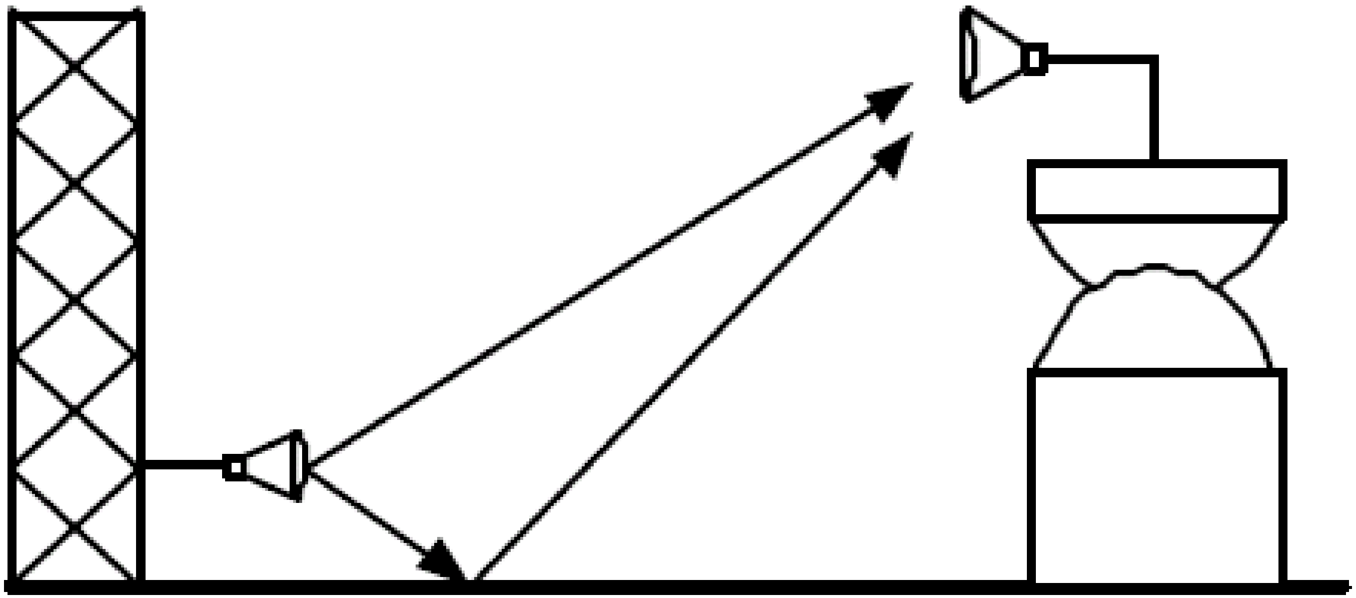
- Variations in the amplitude of the field incident over a test aperture must also be restricted for accurate far-zone measurements.
- For range geometries employing comparatively large transmitting and test tower heights (i.e., elevated range geometries), it is
- advisable to restrict amplitude taper to the order of 1/4 dB or less by using the following criterion:

$$d_t \leq \frac{\lambda R}{4D}$$

With

- d_t = transmitting antenna diameter
- λ = wavelength
- R = range length
- D = maximum test aperture dimension
- H > 6D

Ground reflection test ranges



Ground Reflection Range

Constructive interference with the ground reflected signal is Used. Good for low directive antenna test

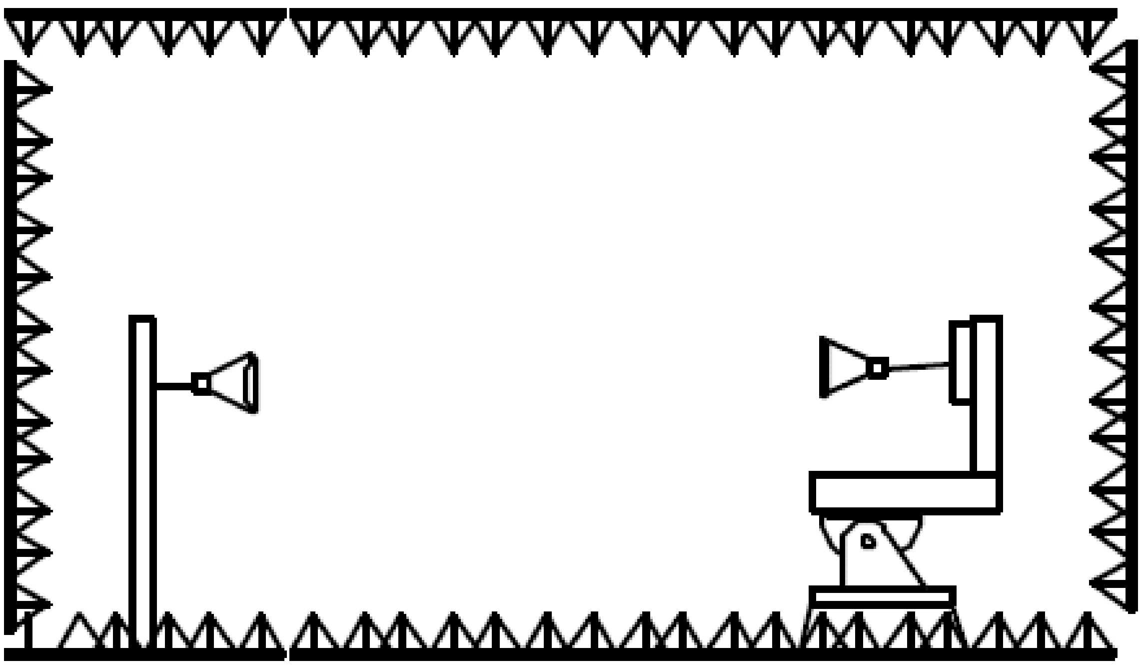
Ground reflection test ranges

$R \geq$	$\dfrac{2D^2}{\lambda}$	
$h_r \geq$	$3.3D$	Vertical-plane amplitude taper 1/4 dB
$h_t =$	$\dfrac{\lambda R}{4h_r}$	Peak of first interference lobe at h_r
$d_t \leq$	$\dfrac{\lambda R}{4D}$	Horizontal-plane amplitude taper $\leq$ 1/4 dB

In these expressions:

R	=	range length
D	=	test aperture diameter
λ	=	wavelength
h_r	=	height of the center of the test aperture
h_t	=	height of the center of the transmitting antenna
d_t	=	transmitting antenna diameter

Anechoic chambers



Rectangular Anechoic Chamber

$$L \geq \frac{2d^2}{\lambda}$$

Anechoic chambers

- Large chambers needed for large antennas (directive antennas)
- Large chambers needed for high frequencies

Expensive

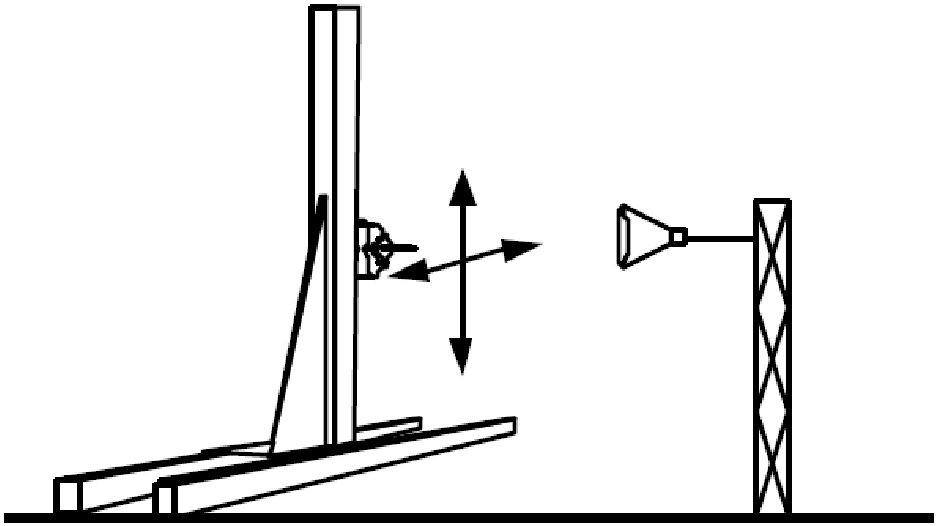
Solutions

- Near field measurements, then near to far field transform
- Compact ranges

Near field ranges

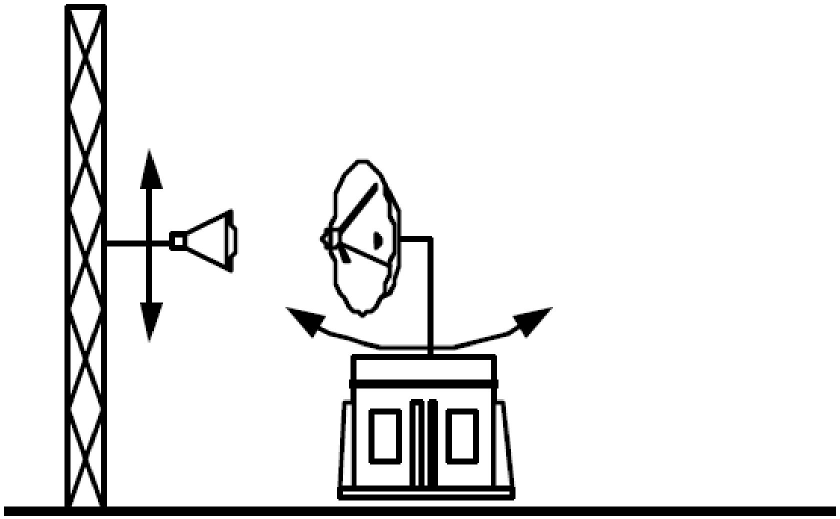
- Planar
- Cylindrical
- Spherical

Planar near field ranges



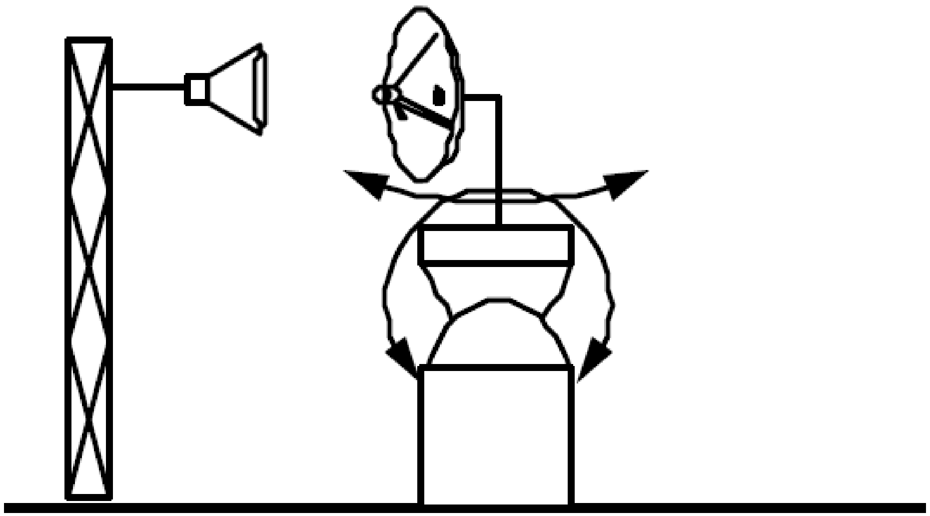
- **Planar Near-Field Method** – With planar near-field scanning, the probe usually is scanned in X and Y linear coordinates over the aperture of the test antenna. A large planar scanner is used to move the probe over a very accurate plane located in front of the test antenna's aperture. Once aligned to the scan plane, the test antenna is not moved during the collection of the nearfield data. Planar near-field provides limited angular coverage of the test antenna's field due to the truncation caused by the scanner's dimensions

Cylindrical near field ranges



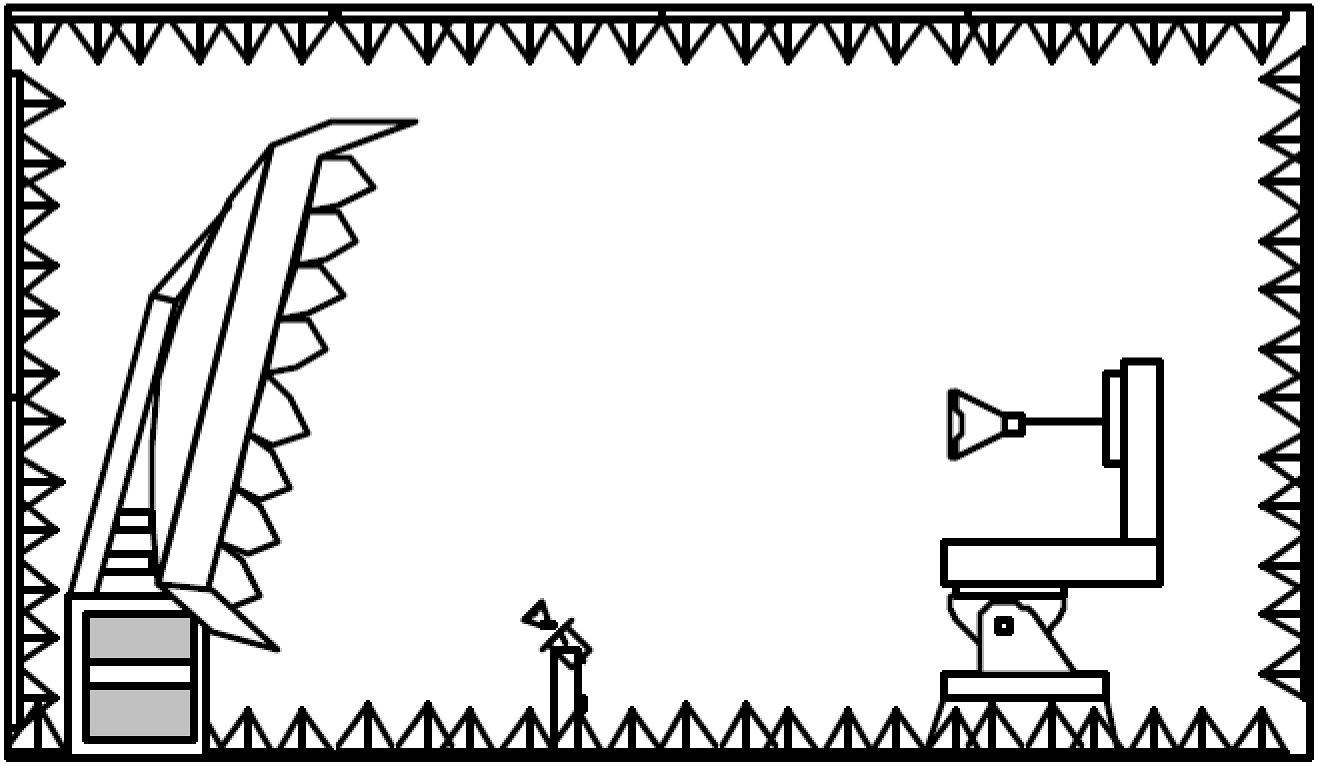
- **Cylindrical Near-Field Method** – For this method the probe typically is scanned in one linear dimension using a single axis linear positioner. The test antenna is stepped in angle on a rotary axis oriented parallel to the linear axis. The resulting scan describes a cylindrical surface around the test antenna. Cylindrical near-field scanning can provide complete angular coverage of the test antenna's field in one plane. The orthogonal plane has limited angular coverage due to truncation caused by the finite length of the linear scanner.

Spherical near field ranges



- **Spherical Near-Field Method** – Spherical near-field scanning normally involves installing the test antenna on a spherical scanning positioner. The probe antenna is normally fixed in space. The test antenna is normally scanned in one angular axis and stepped in an orthogonal angular axis. The resulting data is collected over a spherical envelope surrounding the test antenna. Full or nearly-full coverage of the test antenna's radiating field can be evaluated with this type of near-field system.

Compact ranges



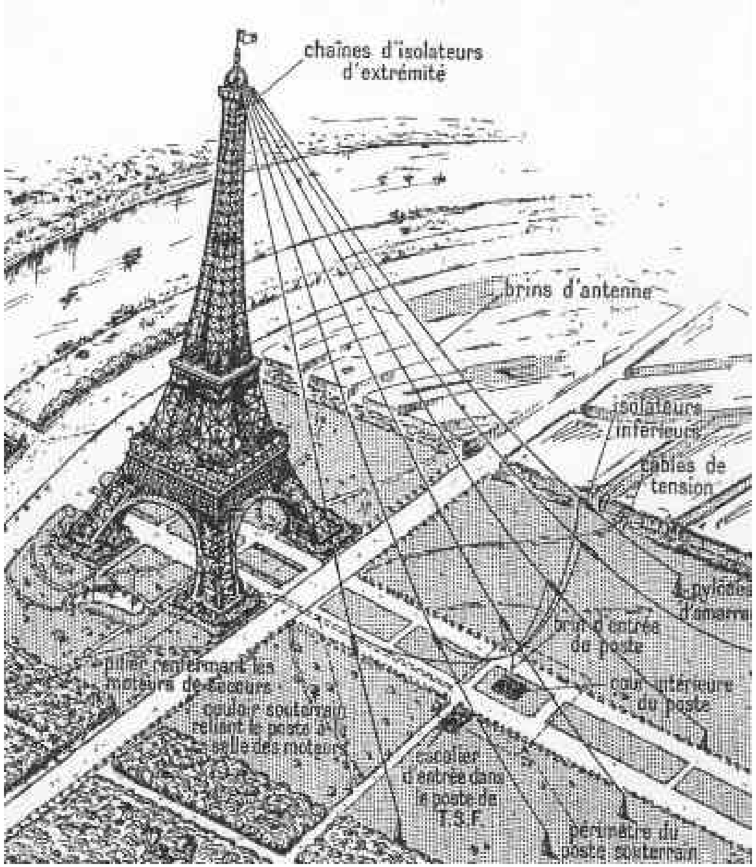
Compact Antenna Test Range

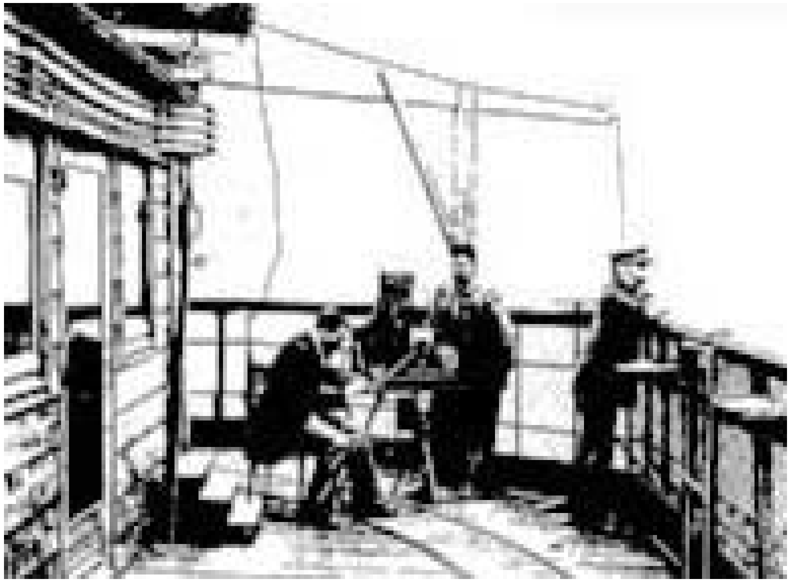
Advantages of compact ranges

- Anechoic
- Reasonable size for directive antennas
- Reasonable cost

Measurements of electrically small antennas

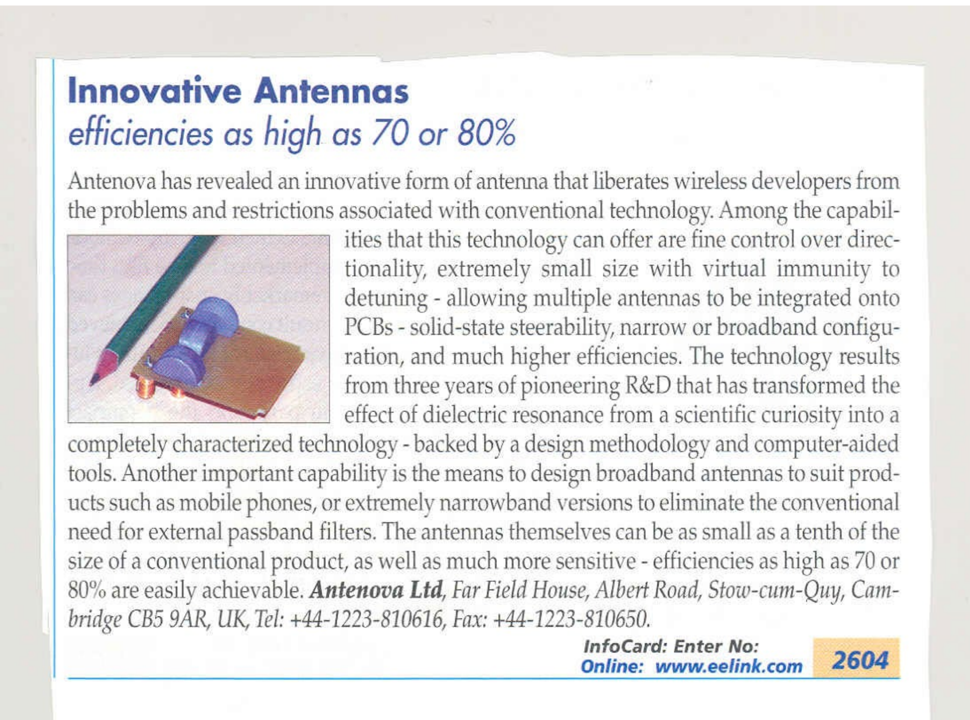
1898, in Paris





Size of the antenna : a few fractions of wavelengths

100 years later ...



Innovative Antennas

efficiencies as high as 70 or 80%

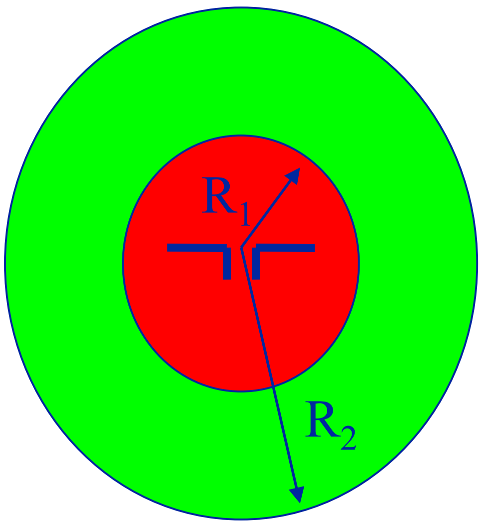
Antenova has revealed an innovative form of antenna that liberates wireless developers from the problems and restrictions associated with conventional technology. Among the capabilities that this technology can offer are fine control over directionality, extremely small size with virtual immunity to detuning - allowing multiple antennas to be integrated onto PCBs - solid-state steerability, narrow or broadband configuration, and much higher efficiencies. The technology results from three years of pioneering R&D that has transformed the effect of dielectric resonance from a scientific curiosity into a completely characterized technology - backed by a design methodology and computer-aided tools. Another important capability is the means to design broadband antennas to suit products such as mobile phones, or extremely narrowband versions to eliminate the conventional need for external passband filters. The antennas themselves can be as small as a tenth of the size of a conventional product, as well as much more sensitive - efficiencies as high as 70 or 80% are easily achievable. ***Antenova Ltd****, Far Field House, Albert Road, Stow-cum-Quy, Cambridge CB5 9AR, UK, Tel: +44-1223-810616, Fax: +44-1223-810650.*

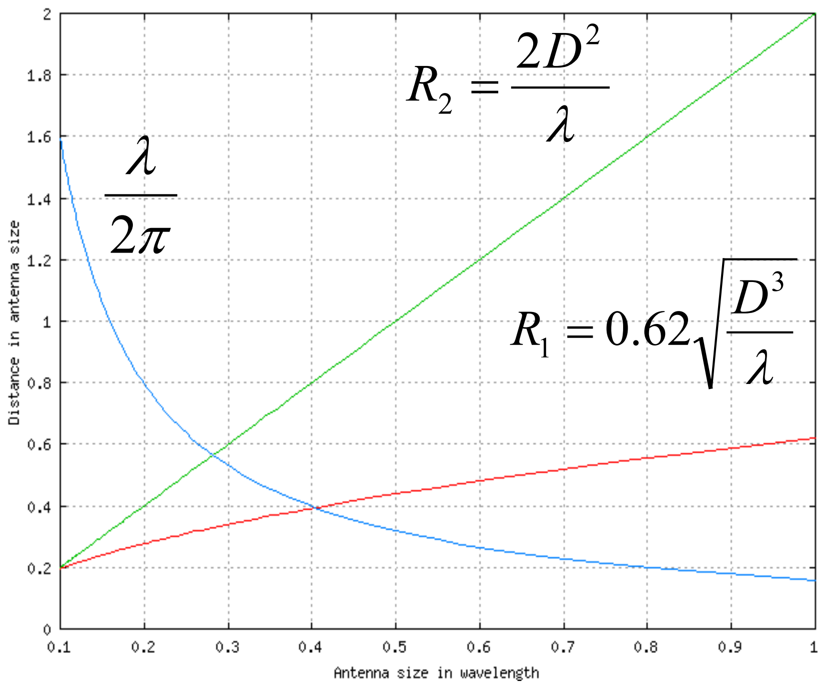
InfoCard: Enter No: 2604
Online: www.eelink.com

- Size of the antenna : a tenth of wavelength
- Max. 3 dB bandwidth : 1.5 %

The problem is the same !!!

What is a small antenna ?





Wheeler:
- λ/2π (radiansphere)

Usually:
- λ/2

Why small antennas ?

System	Frequency [MHz]
GSM (2G)	900 / 1800 / 1900
UMTS (3G)	1955 / 2155
DECT	1890
PHS	1900
CT 2	866
GPS	1575
Satellite link	1620 (up) / 2490 (down)
Pager	< 900

The wavelength is between 14 cm and 35 cm.

On a portable device, the antenna is between a fifth and a tenth of a wavelength.

Application example

Evolution on cell phones' size

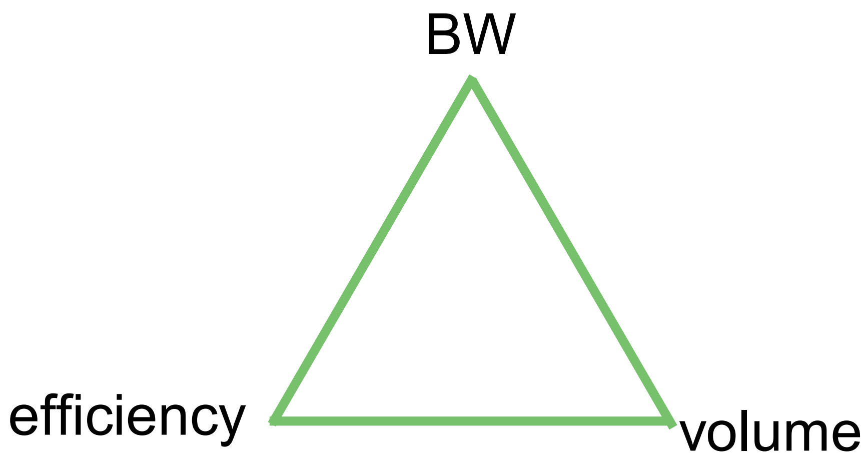
Late 1980s | 1992 | 1995 | 1997 | 2002 | 2003

Where are the limitations ?

- Limitations on the bandwidth
  - Theoretical minimum Q as a function of the size (Chu, Harrington, McLean, Collin).

- Limitations on the efficiency
  - Theoretical maximum gain as a function of the size (Harrington).

The small antenna challenge

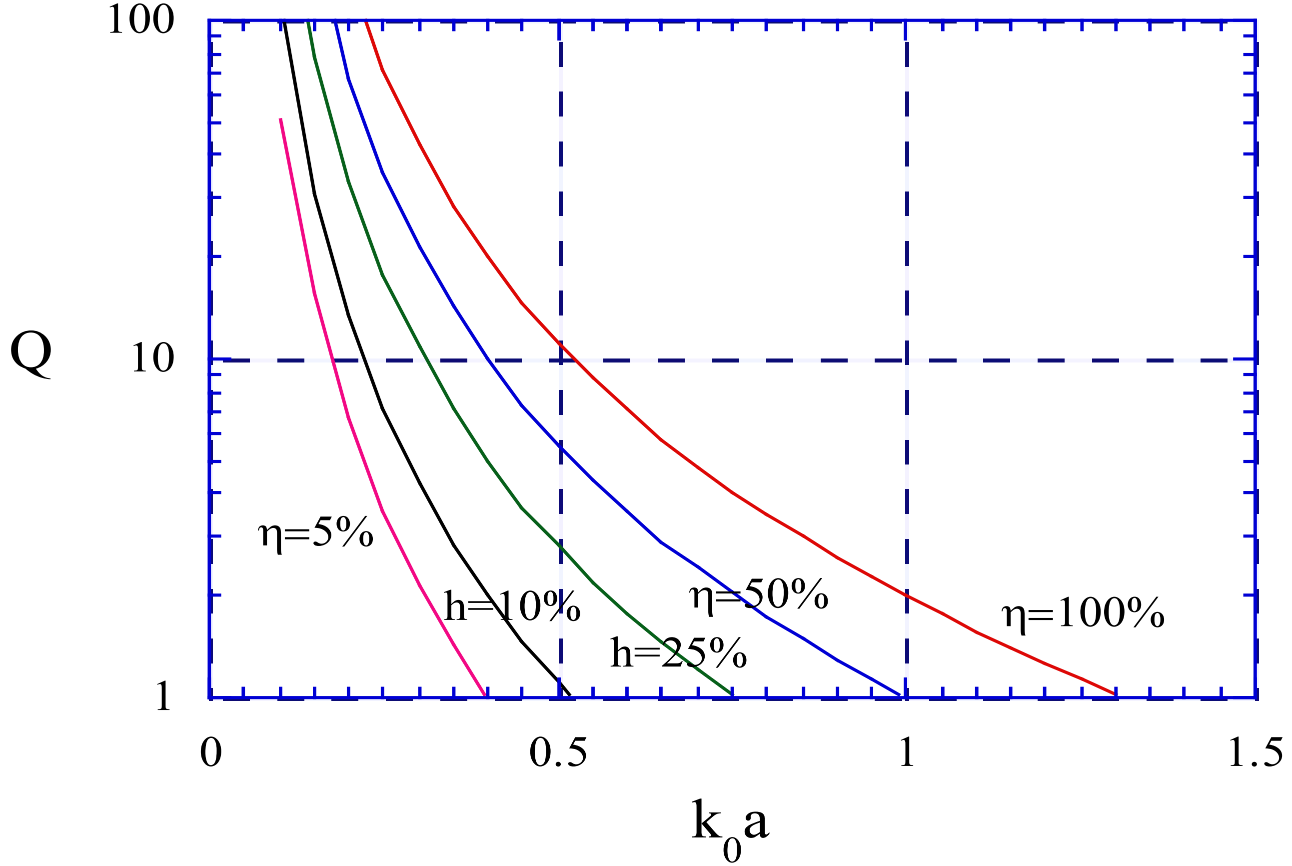


How can we obtain the best compromise between those characteristics ?

Rule of thumb

$$\frac{\text{gain (or efficiency) x bandwidth}}{\text{volume}} = \text{constant}$$

Q in presence of losses



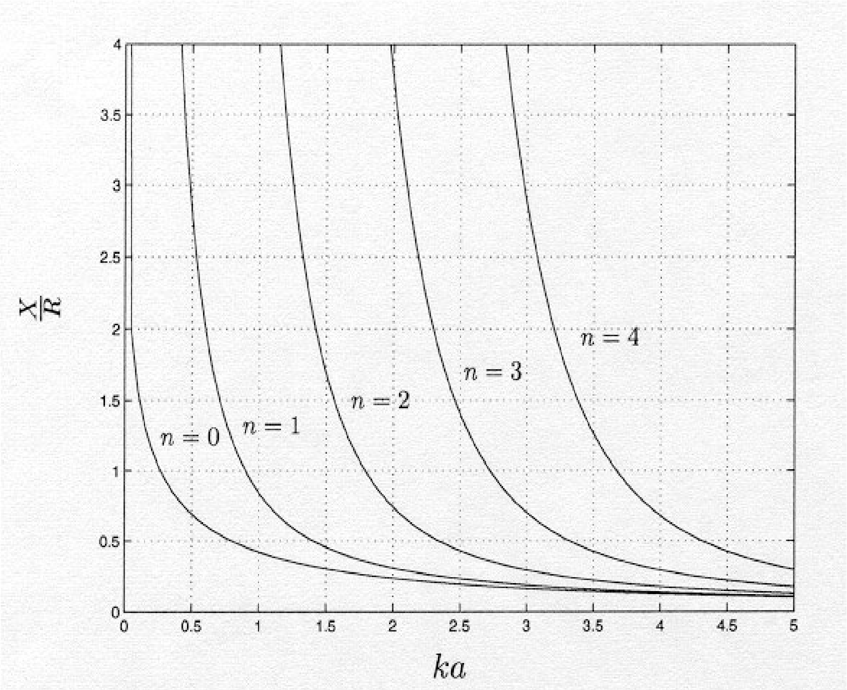
Practical gain limitation

$$G(\theta) = \frac{4\pi\, r^2 S_r(\theta)}{\overline{P_f}}$$

$$G = N^2 + 2N$$

Wave impedance of a TM wave

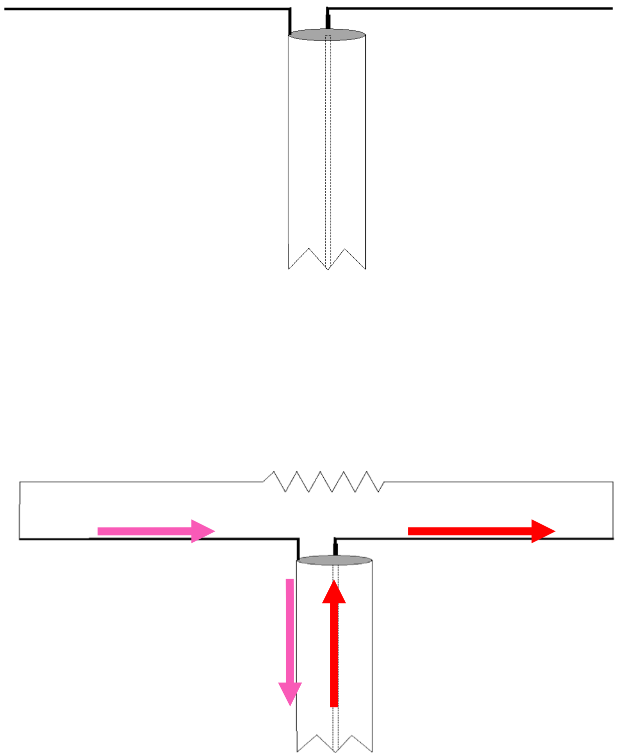
$$Z_{+r}^{TM} = \frac{j\eta}{kr} + \frac{\eta}{\left|h_n^{(2)}\right|^2}\left[\frac{2}{\pi kr} + j\left(j_n j_n^{'} + n_n n_n^{'}\right)\right]$$

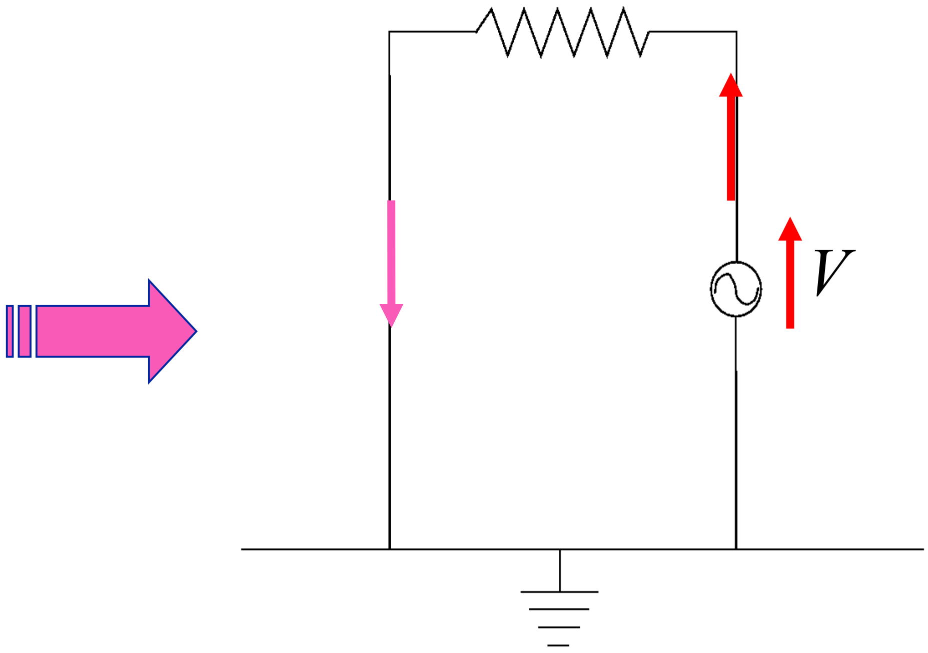


Measurement: What is the problem ?

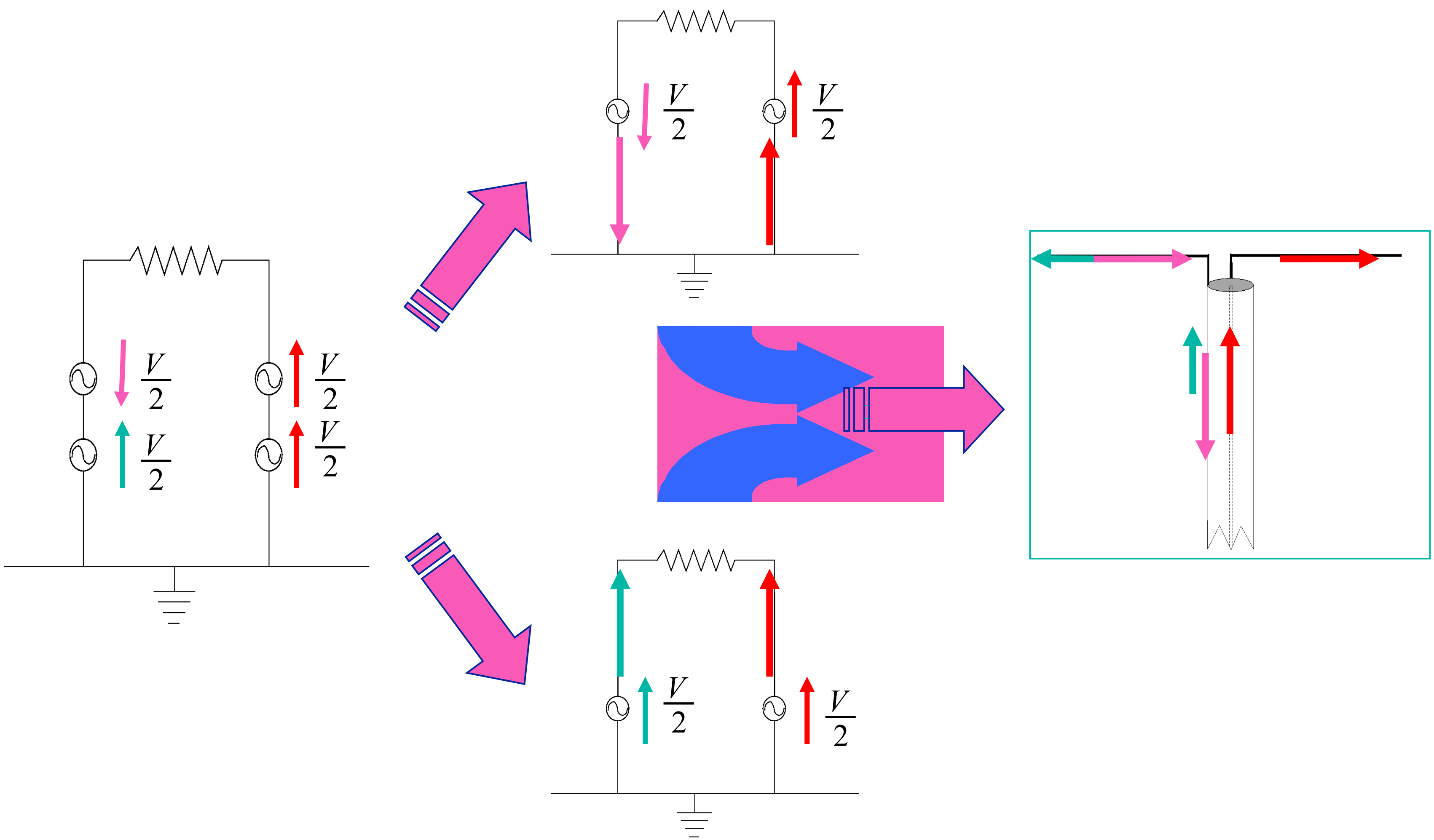
- Commercial DECT antenna :
  - Ceramic chip, 6 x 9 x 1.8 mm
  - Gain of 2.2dBi at 1.89 GHz
  - Max Gain after Harrington : -3.3 dBi !!
  - Gain measured at LEMA : -8 ± 2 dBi
- The discrepancy is due to measurement errors

Spurious radiation from cables

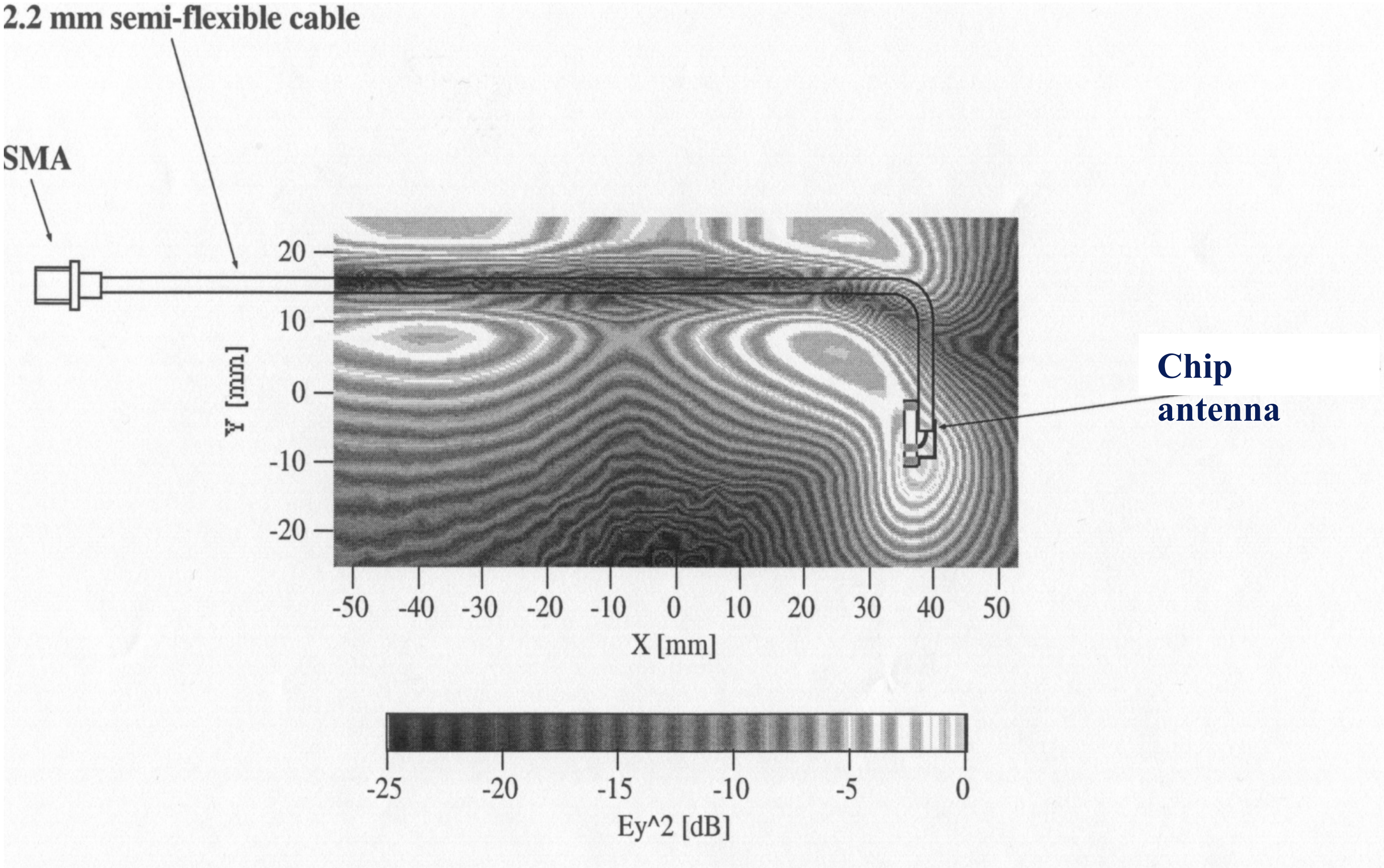




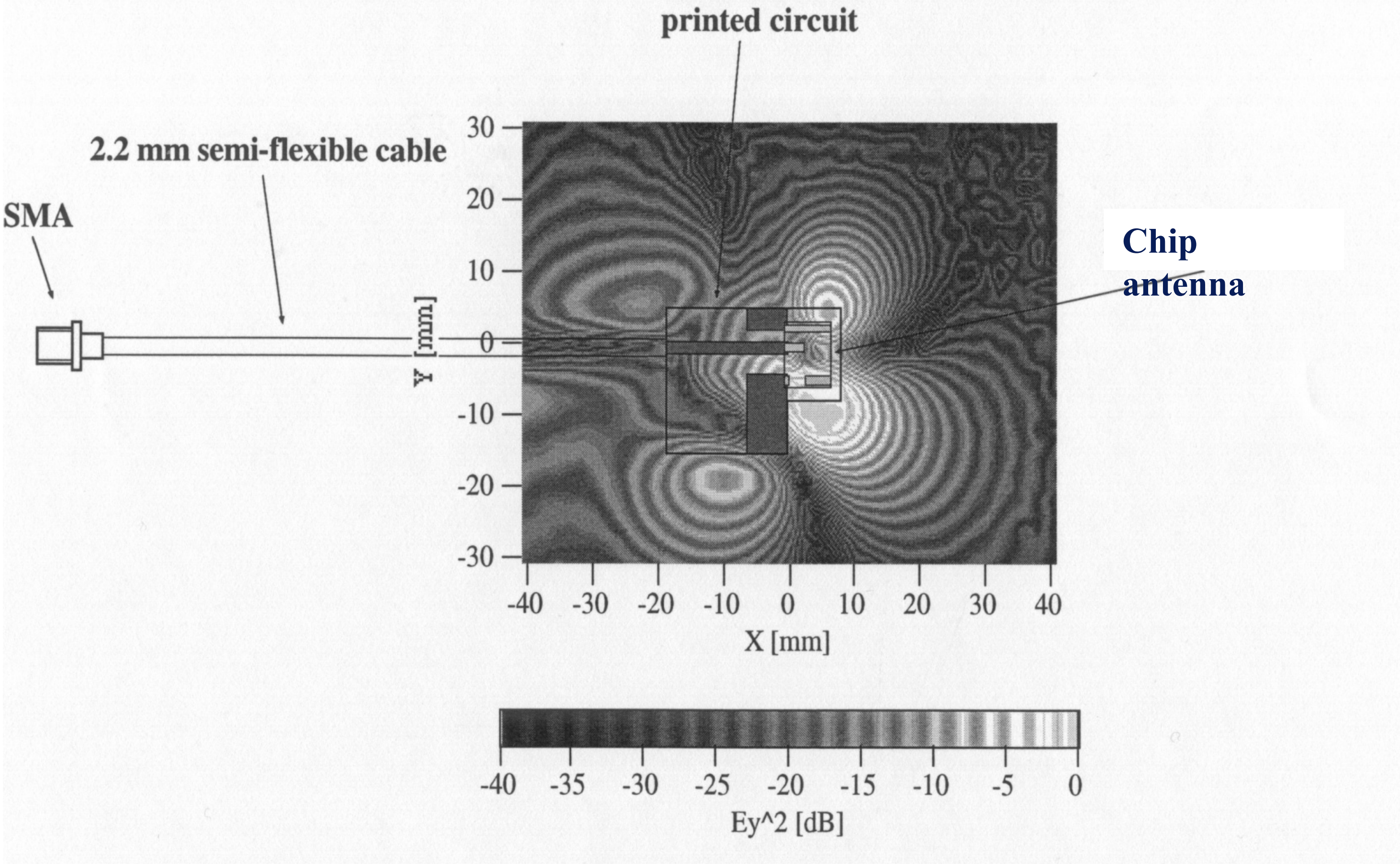
Spurious radiation from cables



Effect of Spurious radiation in the case of the chip antenna



Effect of Spurious radiation in the case of the chip antenna



Effects on radiation characteristics

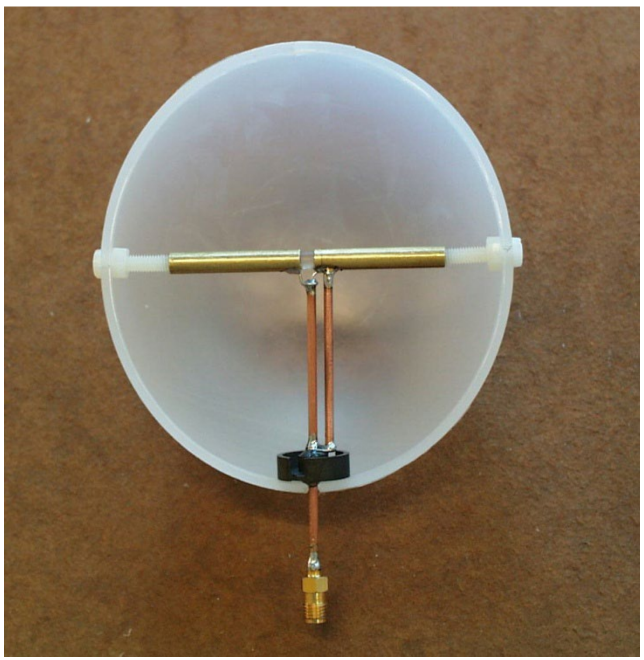
- Unwanted radiation in unwanted directions
- Increase of measured gain up to 10 dB
- Destruction of both polarization and radiation pattern

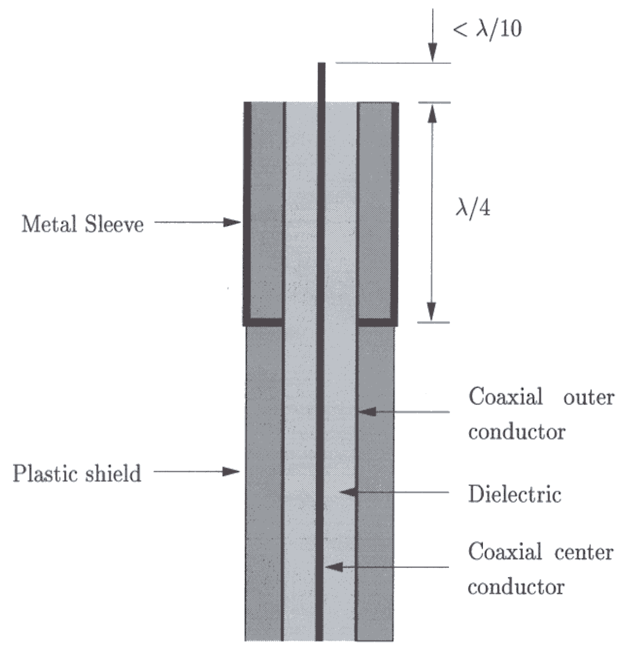
Measurement solutions

- Baluns
- Wheeler cap method
- System measurement methods
  - reverberation chamber
  - anechoic chamber

Baluns

The spurious radiation can be attenuated using for instance ferrite cores, chockes or baluns.





Baluns

- Advantage :
  - good for both circuit and radiation measurements

- Disadvantages :
  - mostly narrow-band
  - cumbersome for the characterization of multi-band antennas

Wheeler cap

- Introduced by Wheeler in 1959 [Wheeler, H.A., "The Radiansphere Around a Small Antenna", Proc. IRE, pp. **1325-1331,** August **1959.**
- Based on the measurement of the radiation resistance

Wheeler cap

Efficiency : $$\eta = \frac{P_{rad}}{P_{in}}$$

Thus : $$\eta = \frac{P_{rad}}{P_{rad} + P_{loss}} = \frac{R_{rad}}{R_{rad} + R_{loss}}$$

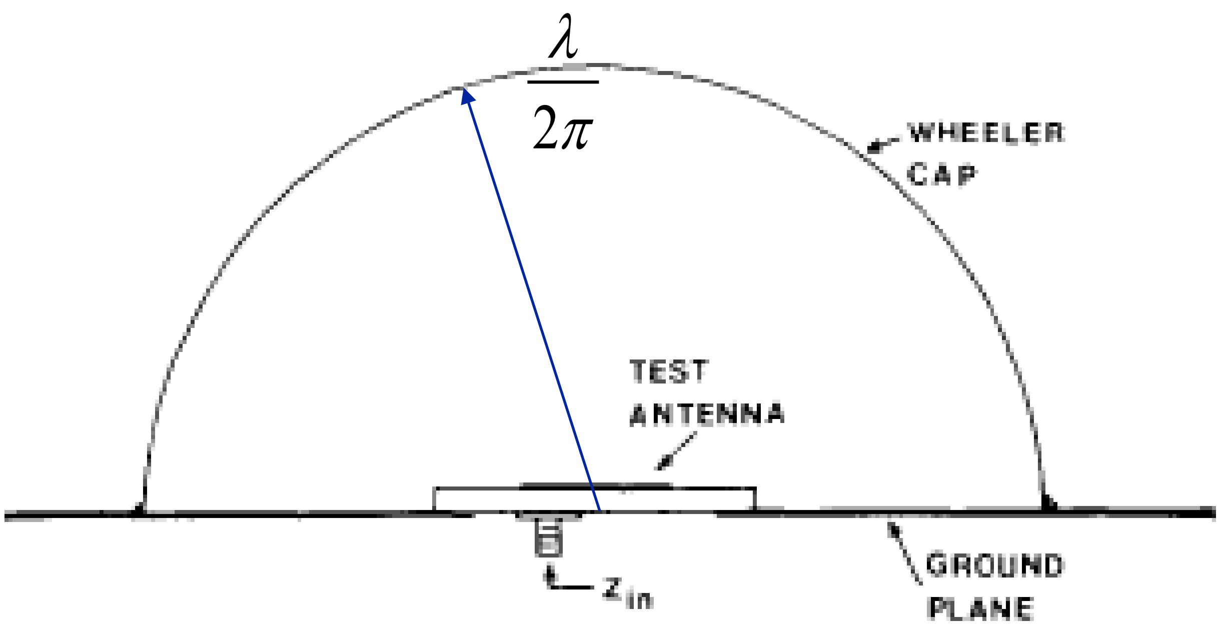
when the equivalent circuit of the antenna can be represented as an series RLC circuit

Wheeler cap

- We need to measure the input resistance and the loss resistance.
- The loss resistance obtained when the radiation resistance is removed in the measurement setup

$$\eta = 1 - \frac{R_{loss}}{R_{tot}}$$

Wheeler cap



The radiation resitance is removed by surrounding the antenna by a grounded sphere (the cap)

Wheeler cap

- the radius of the sphere is of one radianlength, which marks the near-field - far field transition
- the far field is thus removed, without disturbing the near field or the loss
- In practice, the shape, the size and the material of the cap is not so important

Wheeler cap

- if the antenna can be modeled as a series RLC circuit, its reflection coefficient vs. frequency is a constant R circle on the Smith chart, we get :

$$\eta = 1 - \frac{1 - \left| s_{11cap} \right|^2}{1 - \left| s_{11freespace} \right|^2}$$

Wheeler cap

- if the equivalent circuit is more complicated, adjustments and approximations need to be done

- The method implies that the antenna has a ground plane of reasonable size

Wheeler cap : references

- H. A. Wheeler, "The radiansphere around a small antenna," *Proc. IRE.* pp. 1325-1331, Aug. 1959.
- Pozar, D.M., Kaufman, B.: "Comparison of three methods for the measurement of printed antenna efficiency", *IEEE Transactions on Antennas and Propagation*, vol. 36, no. 1, pp. 136 –139, Jan. 1988.
- Johnston, R.H., McRory, J.G.: "An improved small antenna radiation-efficiency measurement method", *IEEE Antennas and Propagation Magazine*, vol. 40, no. 5, pp. 40 –48, Oct. 1998.

Integrated gain and efficiency measurements

System measurement

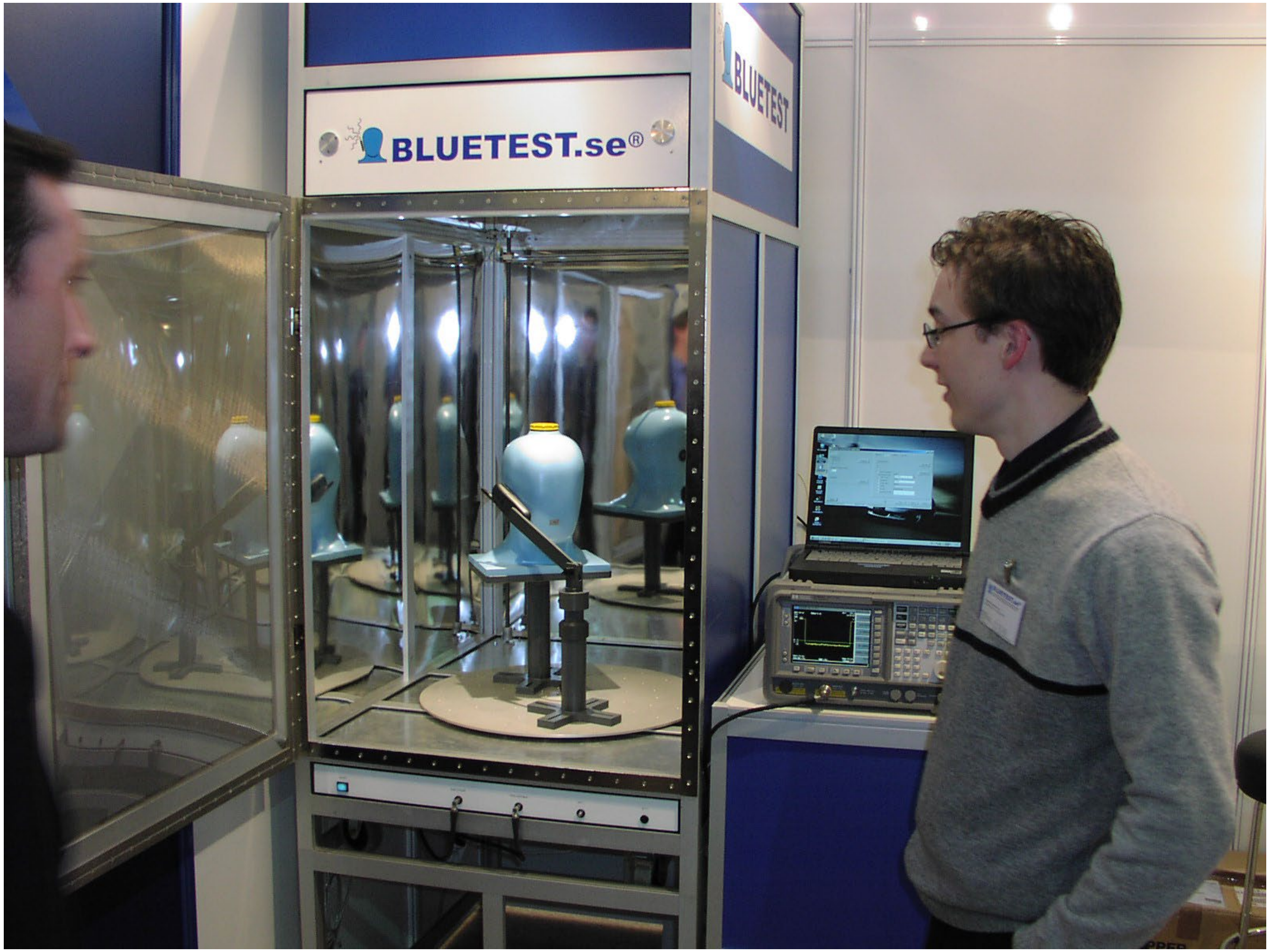
- Get rid off the cables
- Take the casing into account
- Minimize disturbations
- Compare to known system

Two solutions : in reverberation chamber and in anechoic chamber

Reverberation Chamber

- Thanks to Prof. P.S. Kildal, from University of Chalmers in Gothenburg for providing the information and slides
- More information can be found on the website :http://www.elmagn.chalmers.se/elmagn/antenna/

Reverberation chamber



Reverberation chamber

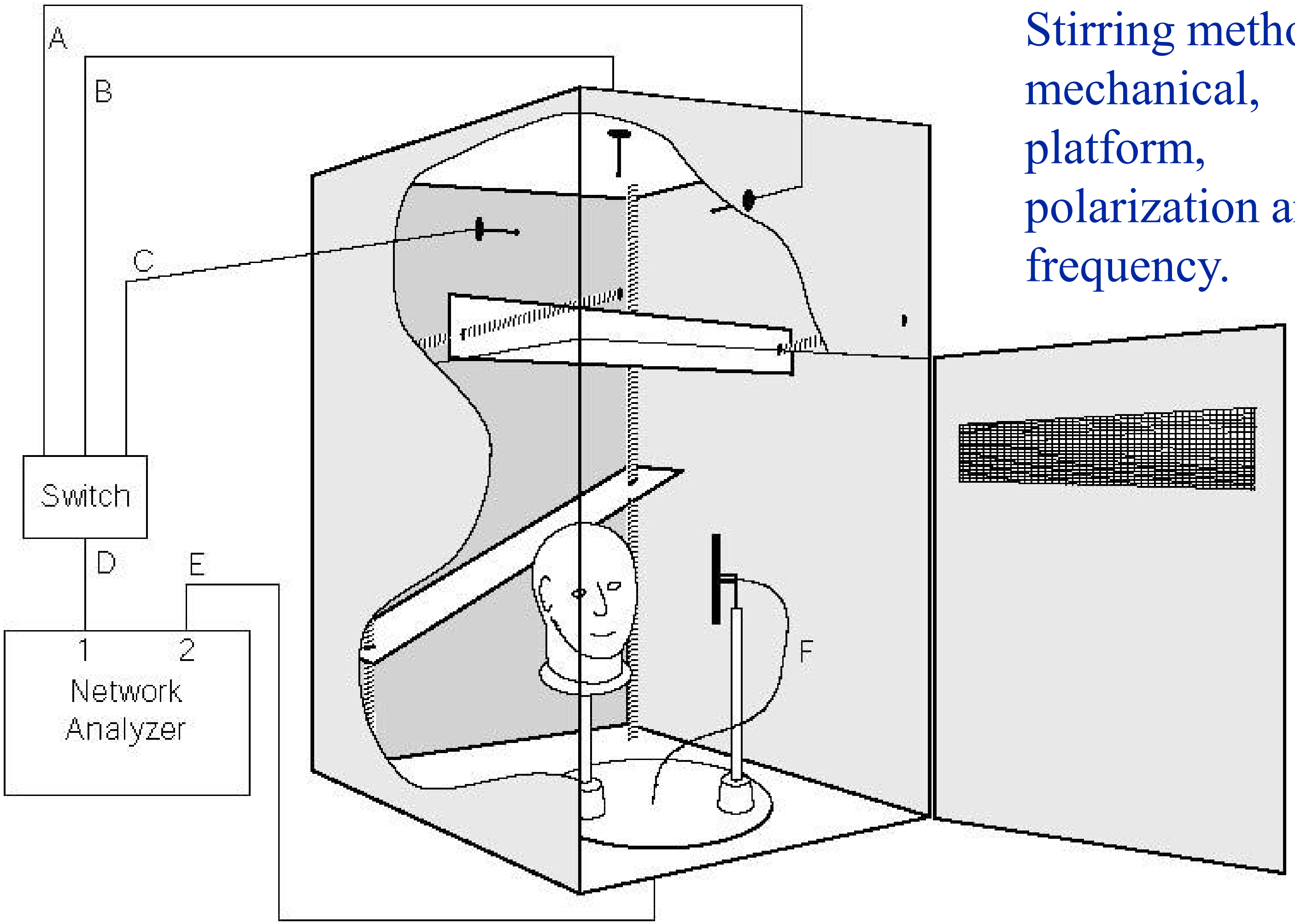
- Principle
- Theoretical work by David Hill
- What can be measured:
  - Antenna efficiency
  - Antenna impedance
  - Total radiated power
  - Diversity gain of antennas
  - Diversity gain of active terminals (DECT)
  - Receiver sensitivity, Bit Error Rate (BER)
  - BER in fading environment
  - Channel capacities of MIMO systems

Principle

- A cavity mode can be expanded in a series of 8 plane wave
- The cavity modes are stirred mechanically in order to obtain all possible plane wave excitation. This creates a Rayleigh distributed transfer function between two antennas inside the chamber

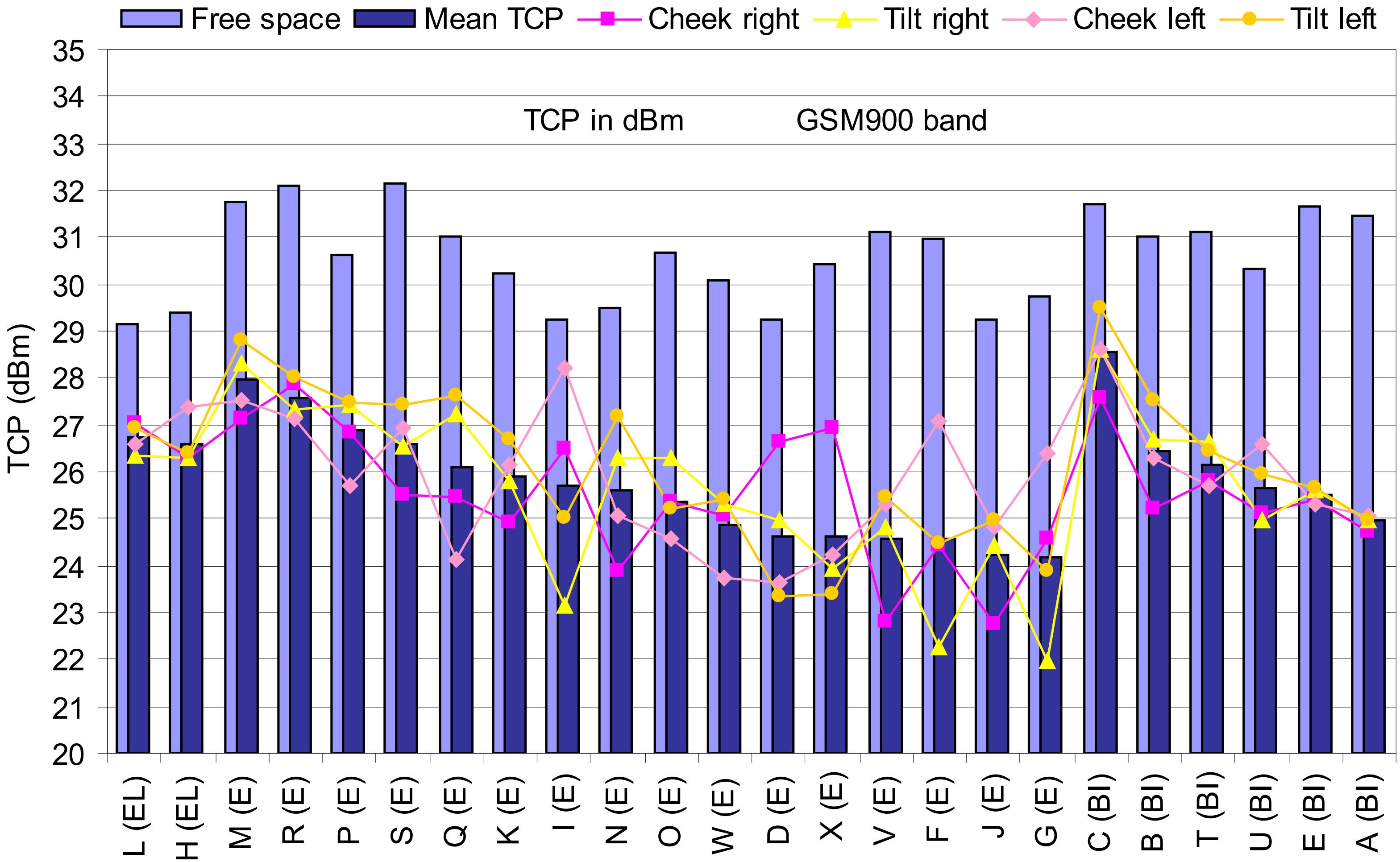
- The mean response of the system is obtained analyzing the results of these plain wave excitations

Reverberation chamber and set-up for antenna measurements

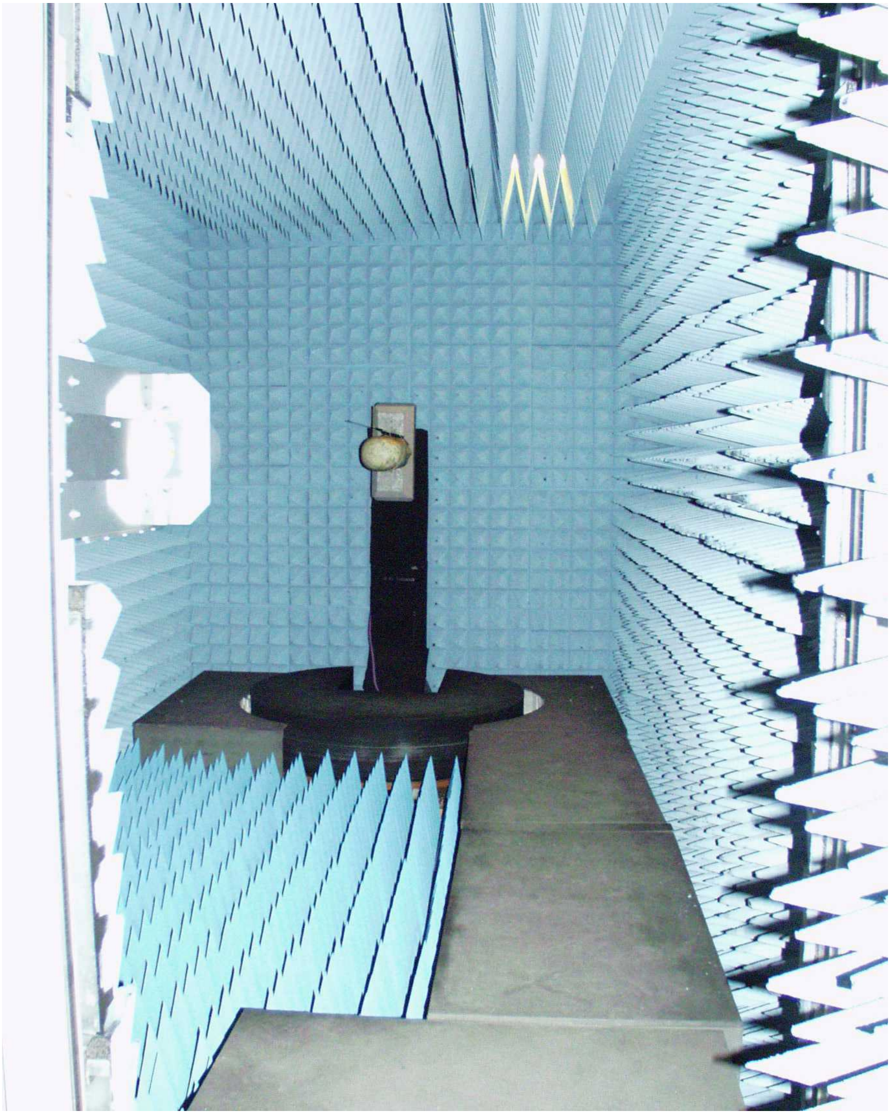


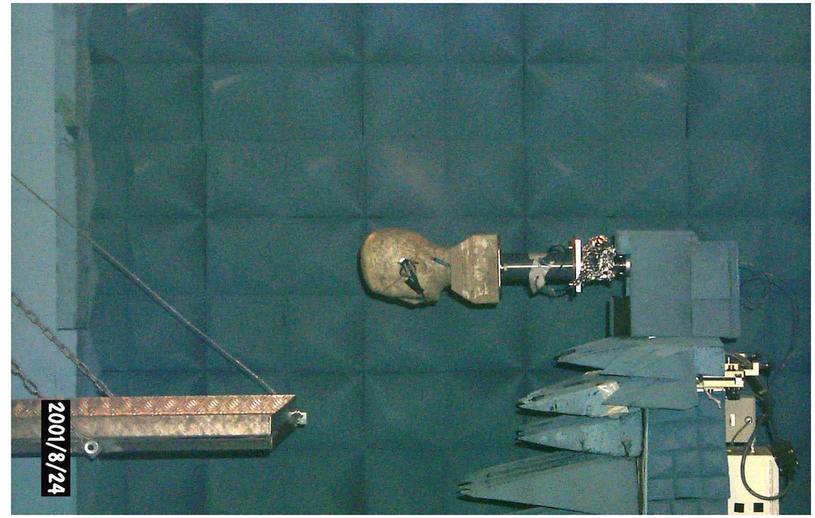
Stirring methods: mechanical, platform, polarization and frequency.

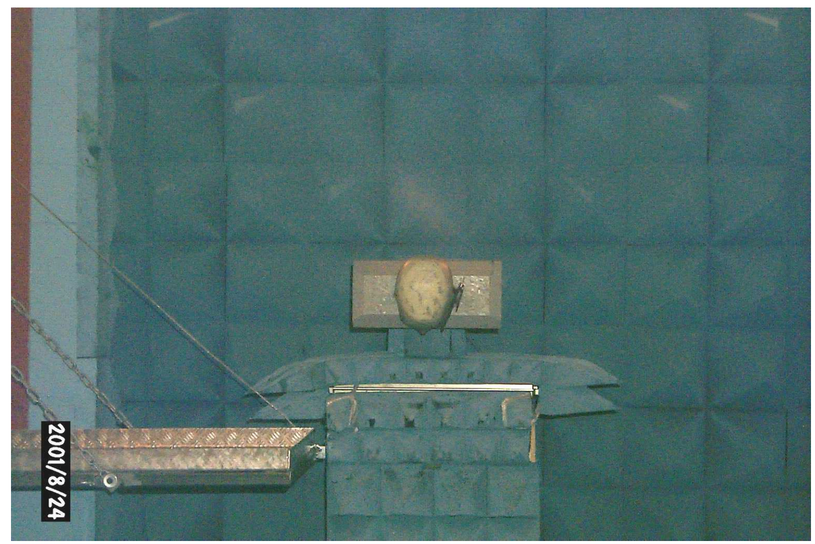
Example of results for radiated power
20 phones, 5 positions, 900 MHz



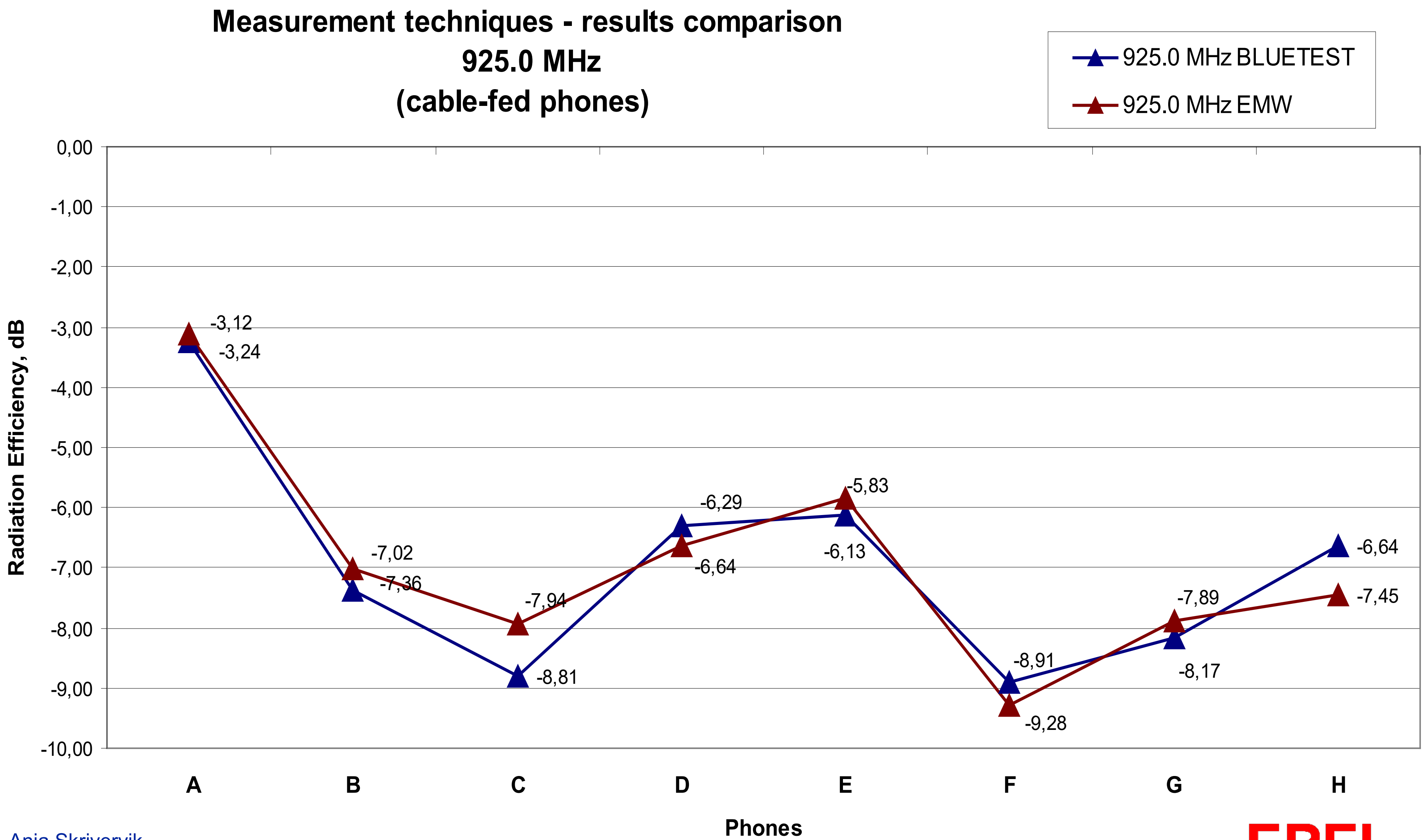
Validation against Anechoic Chambers



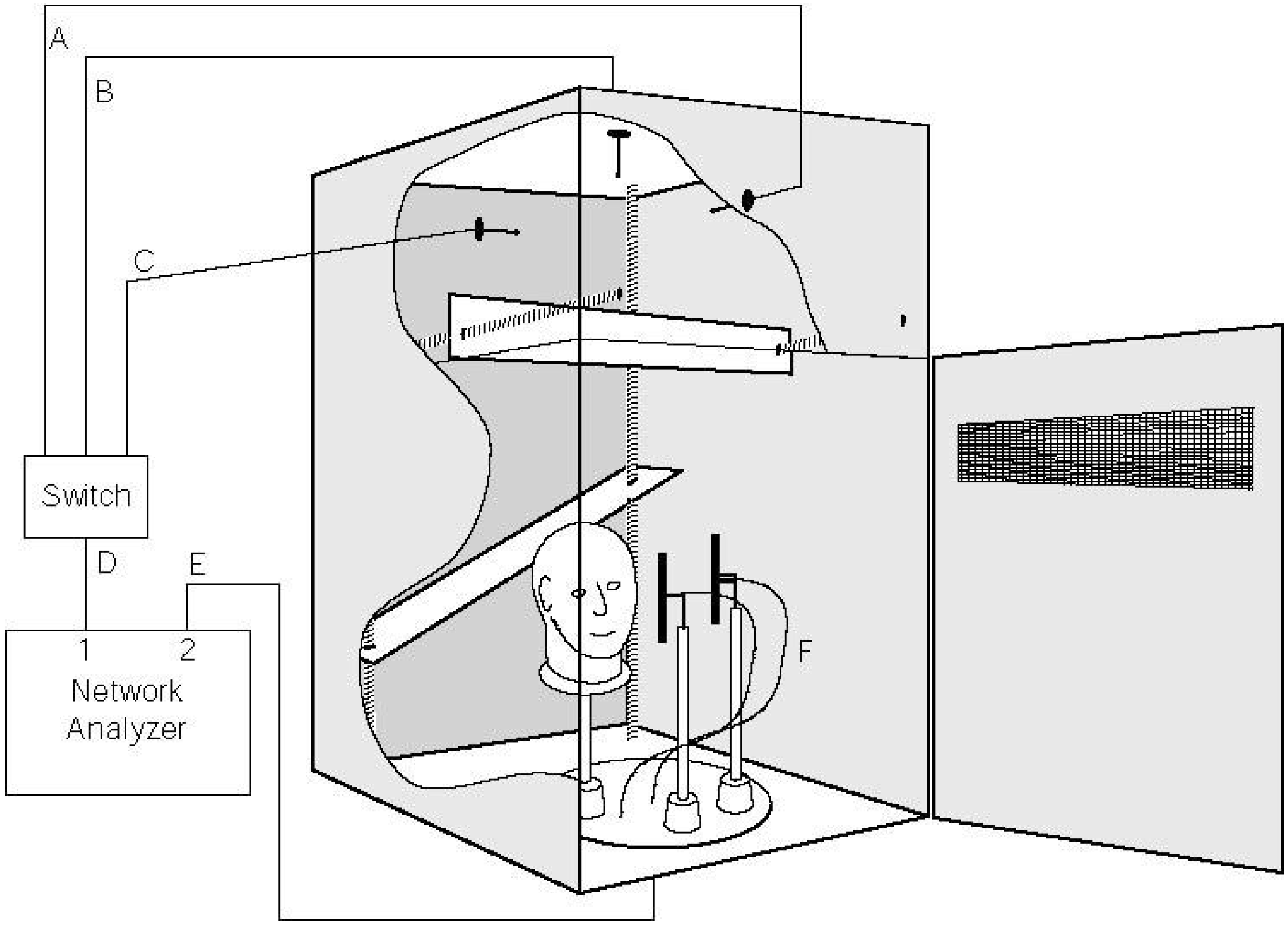




Example of validation results: 2 chambers: 925 MHz, 8 phones, 1 pos.



Diversity measurements in Bluetest chamber



Comparison diversity measurements

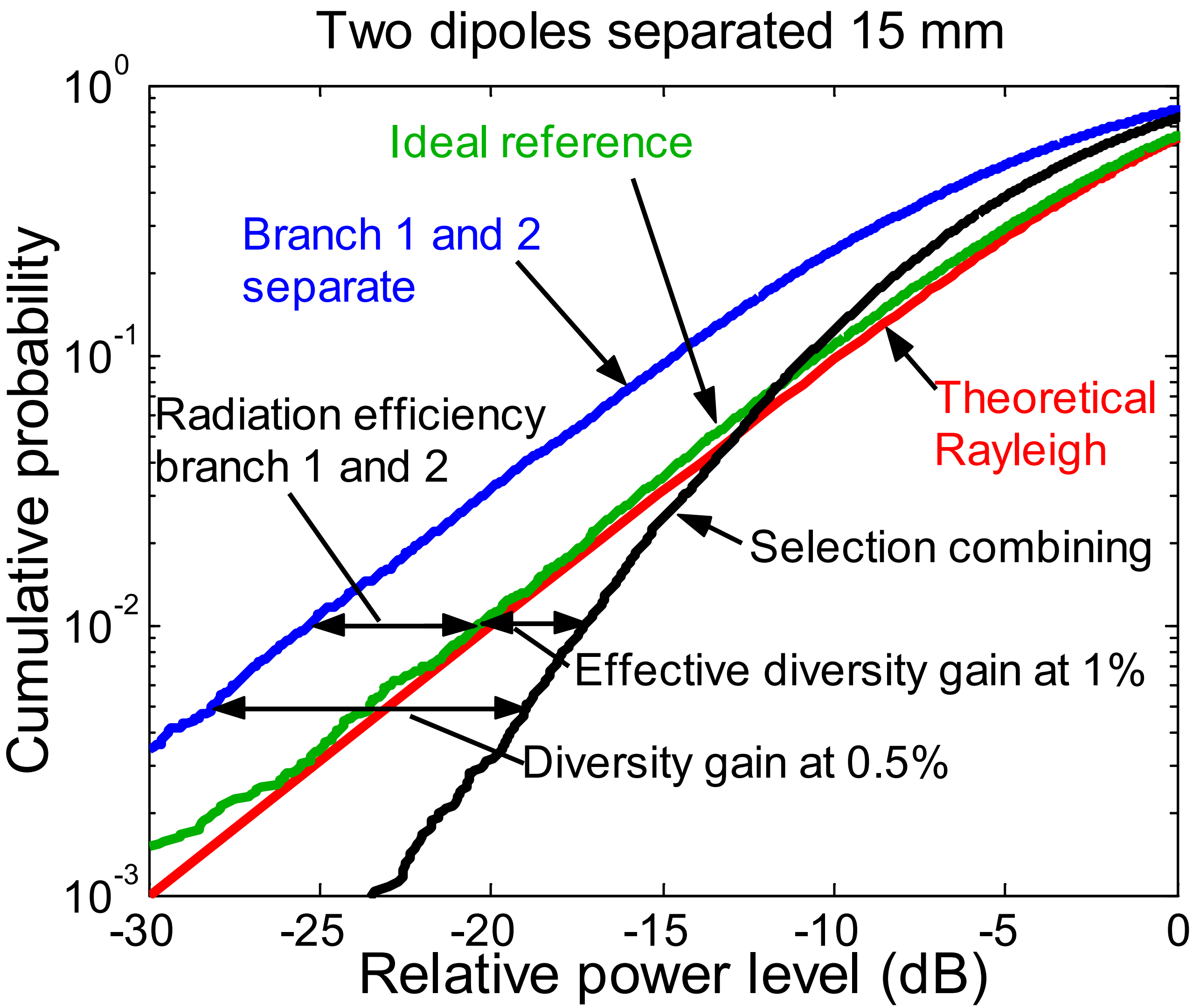
In real environments

- Rayleigh distribution
- Statistics has elevation dependence
- Different environments have different statistics
- Measurements not reproducible
- Field measurements
- Need 2 or 3 measurement receivers
- Time-consuming

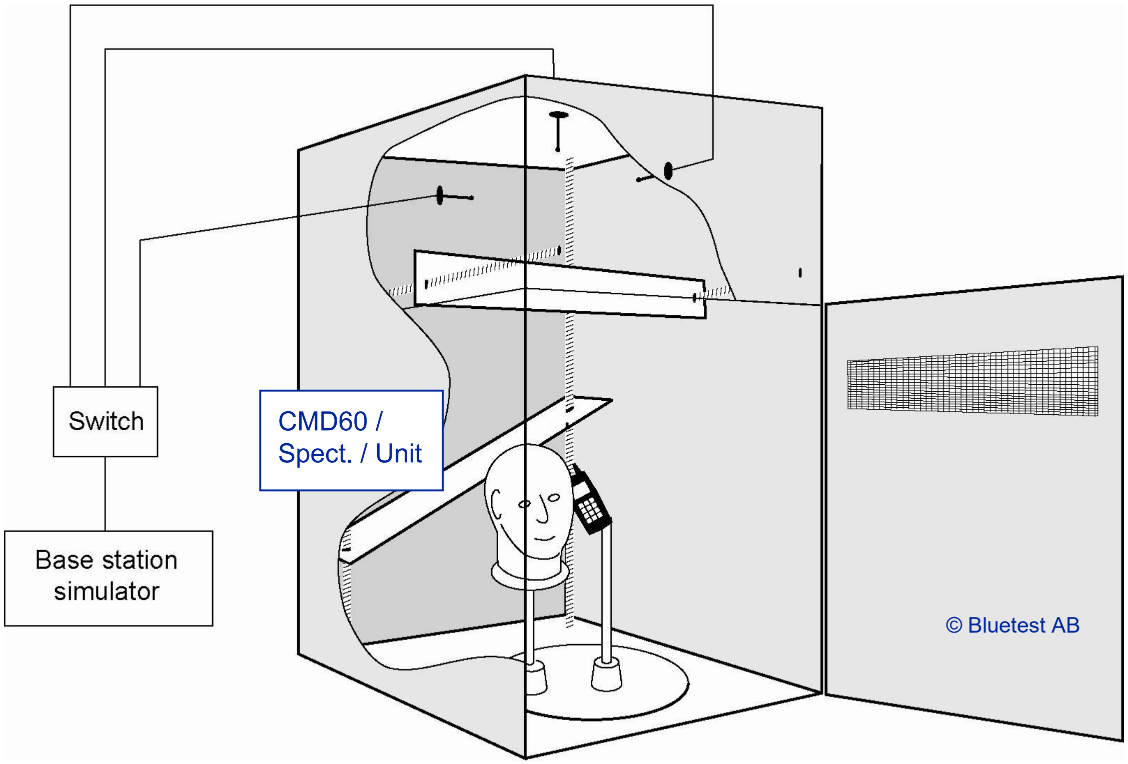
In reverberation chamber

- Rayleigh distribution
- Uniform/isotropic multipath environment
- Field statistics are reproducible
- Measurements are both statistically and deterministically reproducible
- Laboratory measurements
- Need 1 measurement receiver or network analyzer
- Fast

Cumulative probability distributions and effective and apparent diversity gain

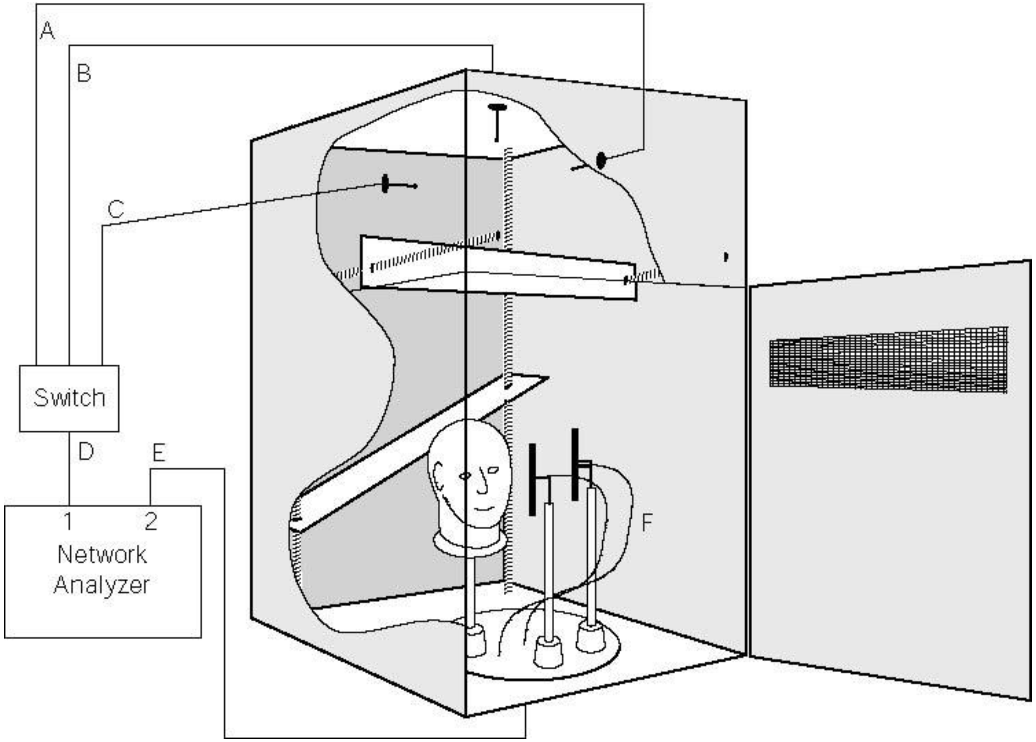


“Total radiated power” of DECT phone with diversity



Measurement system

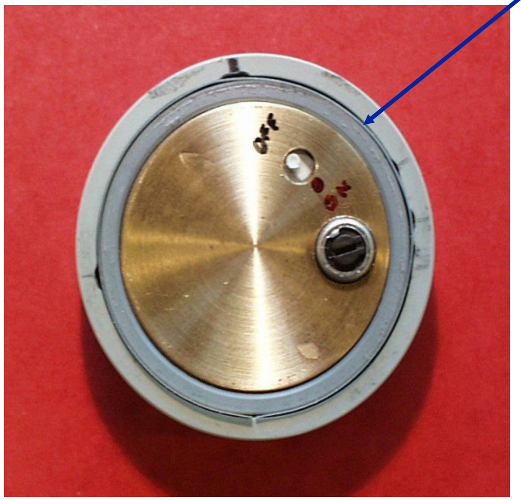
Conclusion



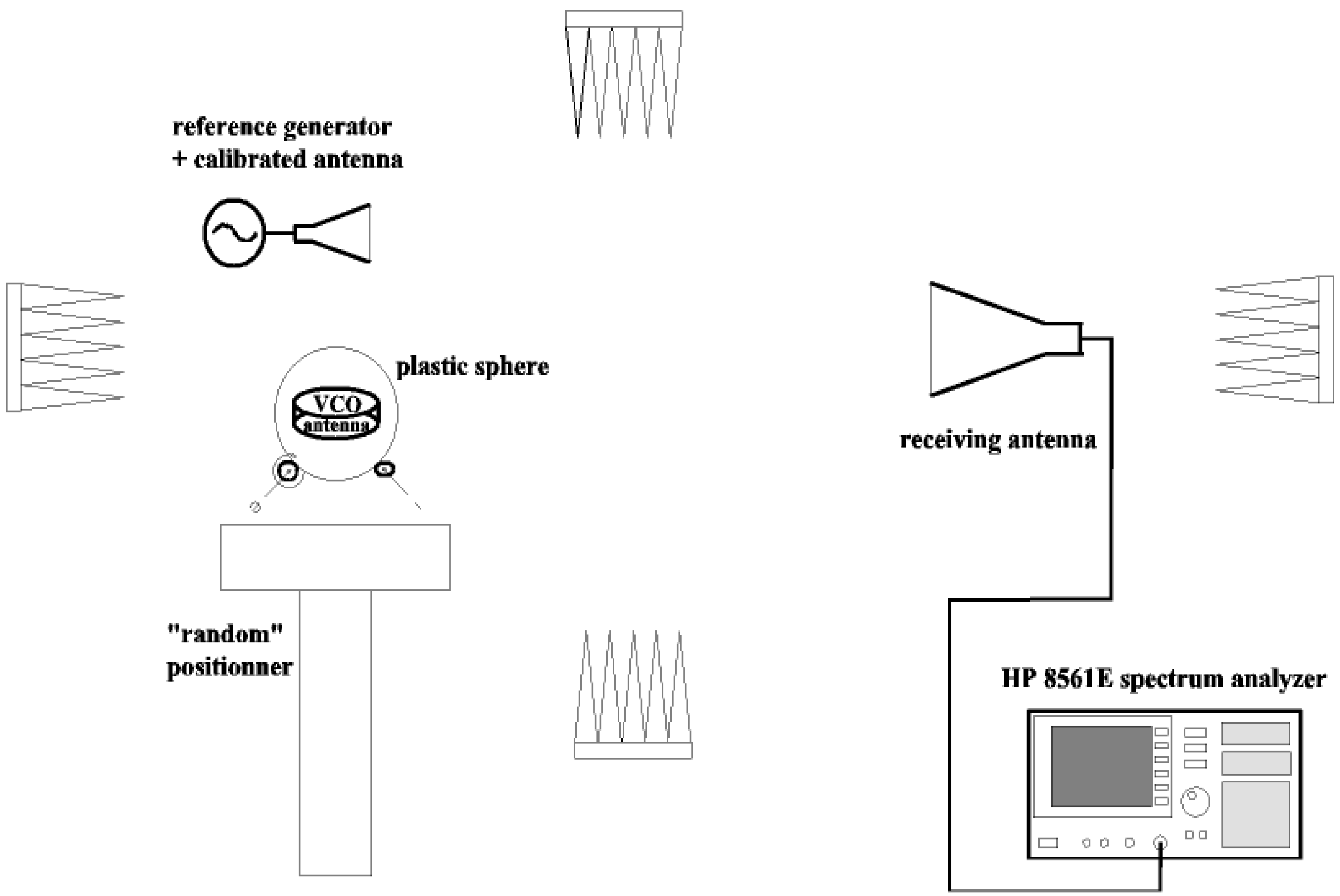
Reverberation chamber can be used to measure multipath performance of antennas and wireless terminals:
radiation efficiency, total radiated power, BER, diversity gain, active diversity gain, capacity of MIMO systems.

Anechoic chamber method

The antenna is mounted on the actual device case and powered by a VCO and a miniature battery.



Principle of measurement (Max. gain)

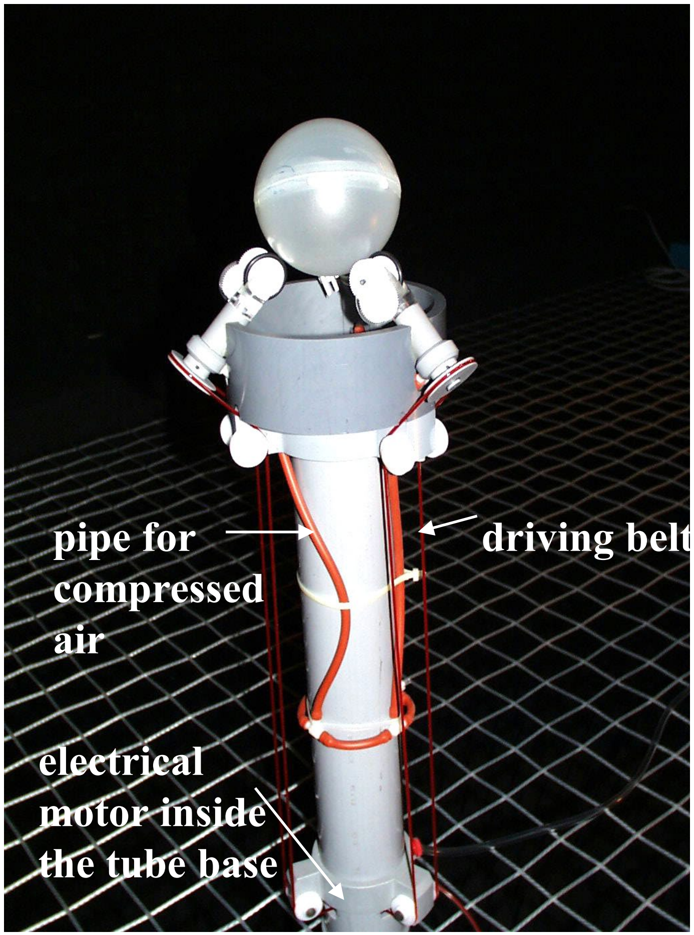


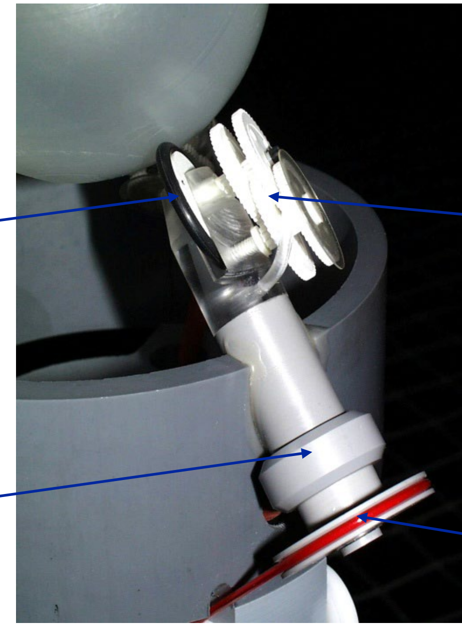
Principle of measurement (Max. gain)

- The AUT is placed in front of the receiving antenna
- The VCO is tuned to get the max. power.
- The AUT is placed in the sphere on the positionner
- The maximum power is recorded
- The AUT is replaced by a ref. antenna
- Power is adjusted to get the same signal
- Verification with a Power meter

$$P_{to\_dipole} + Gain_{Dipole} - Power_{VCO} = Gain_{AUT}$$

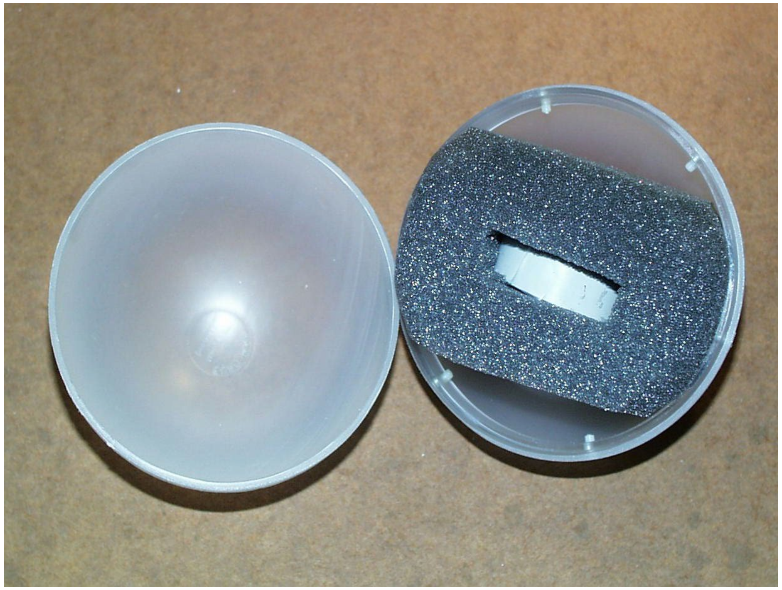
The random positioner

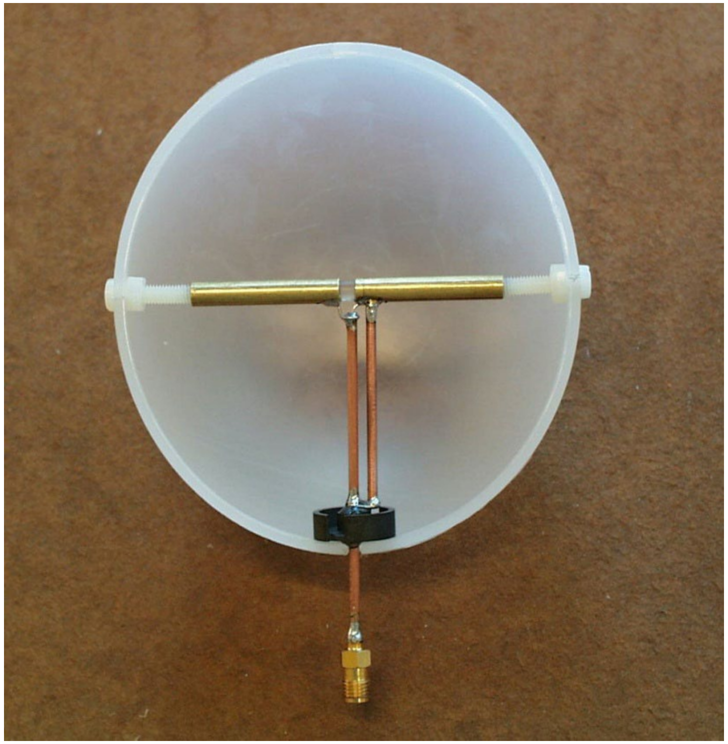




- 3 air motors (different speeds)
- 1 electric motor

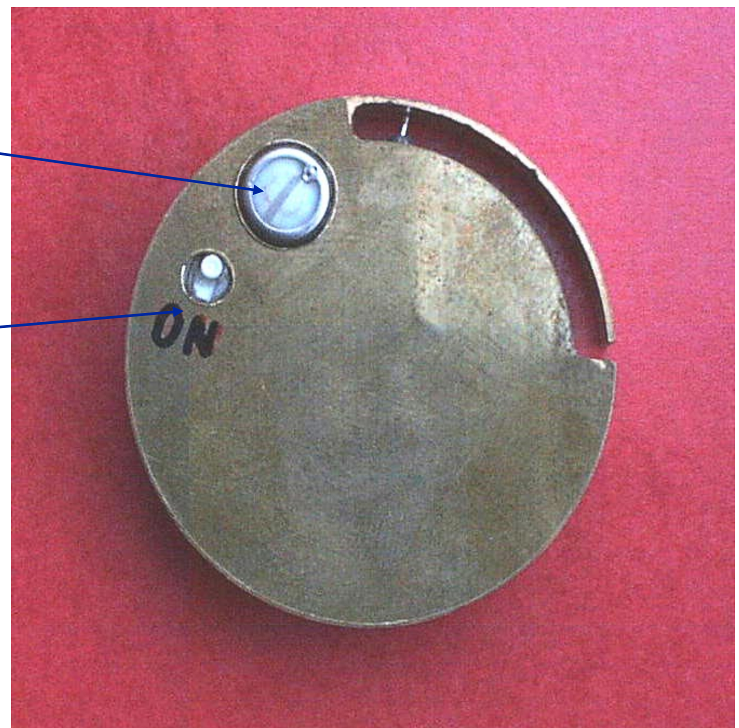
The dipole and the DUT





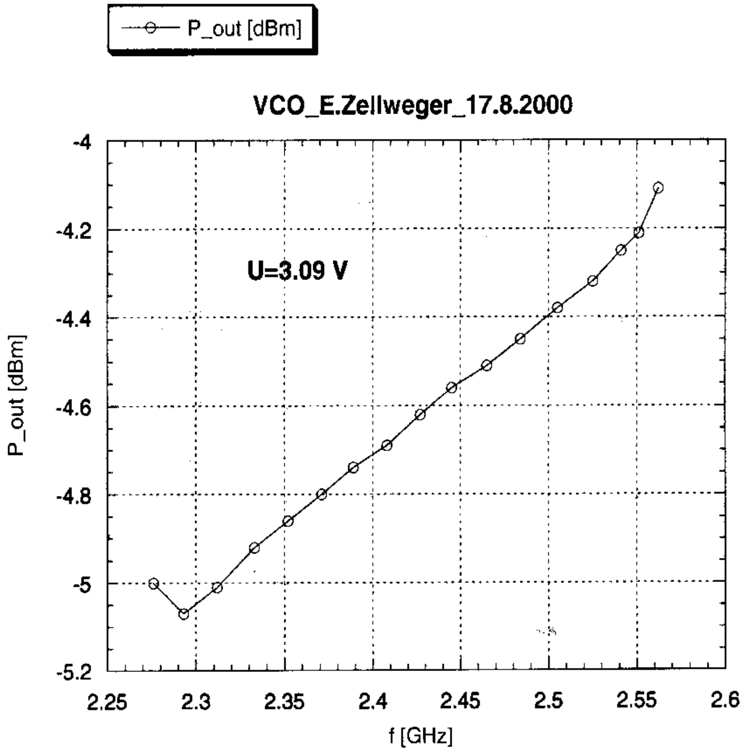
Example of maximum gain measurement

- Watch integrated communication device
- Antenna size : 0.2 λ



VCO

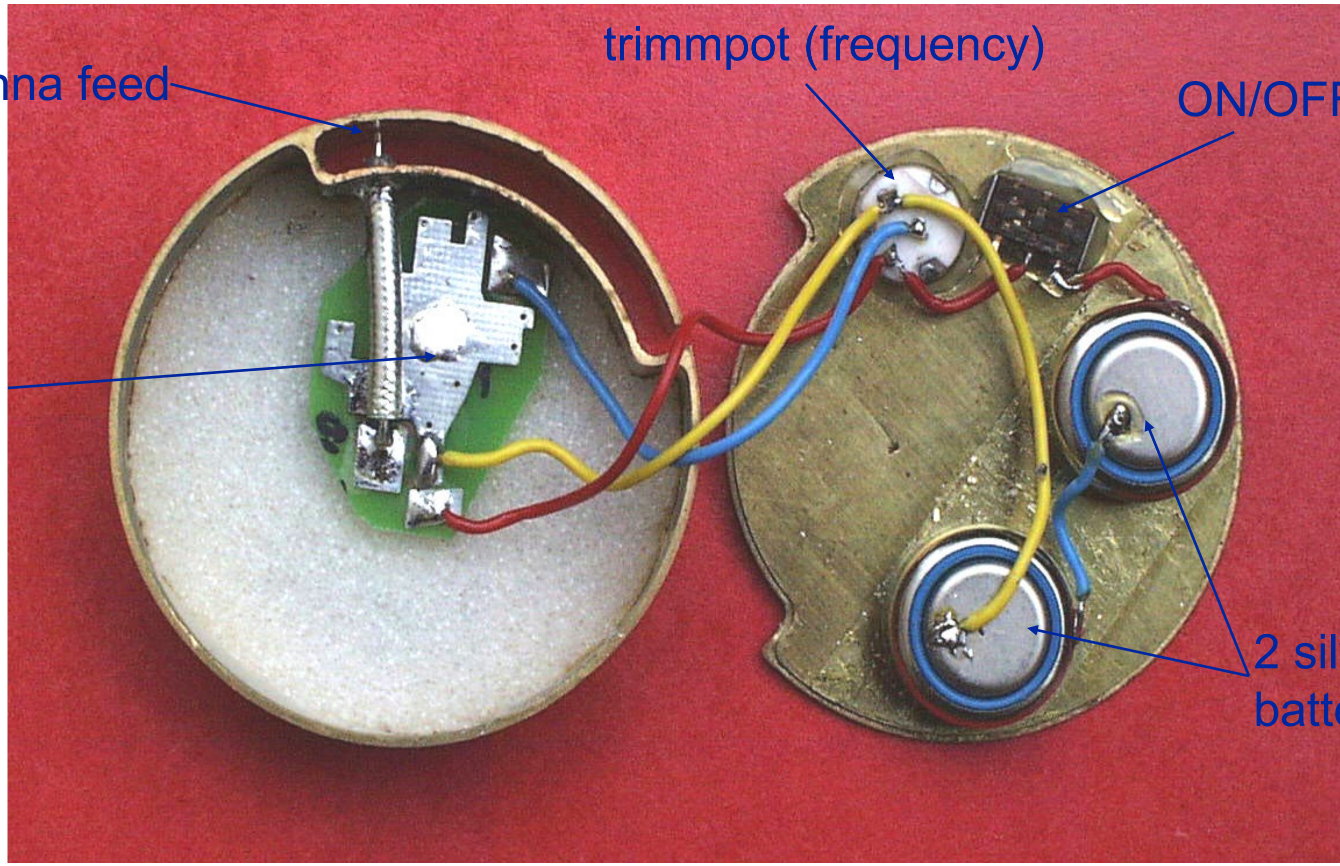
A VCO was realized and integrated at LEMA:



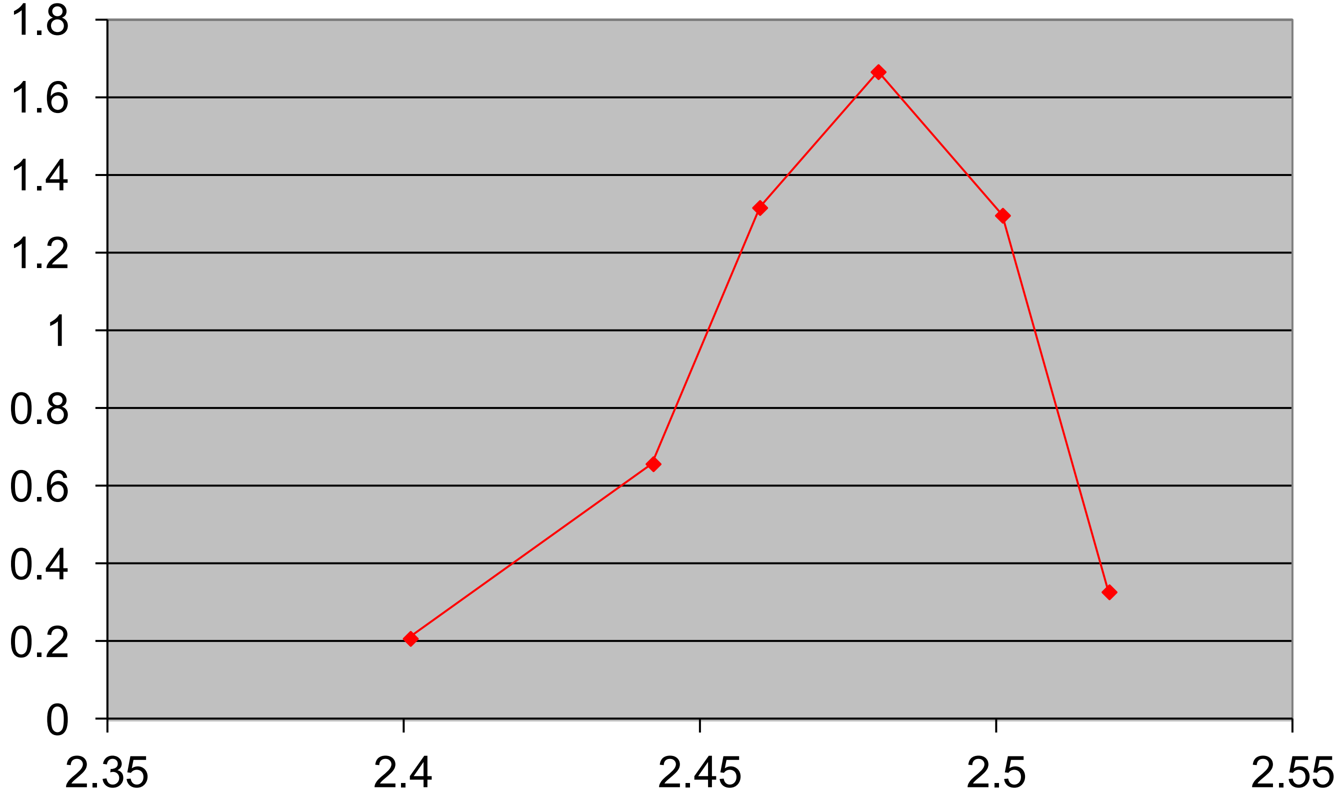
tuning range: 2.28 - 2.56 GHz

output power: -5.1 - -4.1 dBm

Internal view of the device

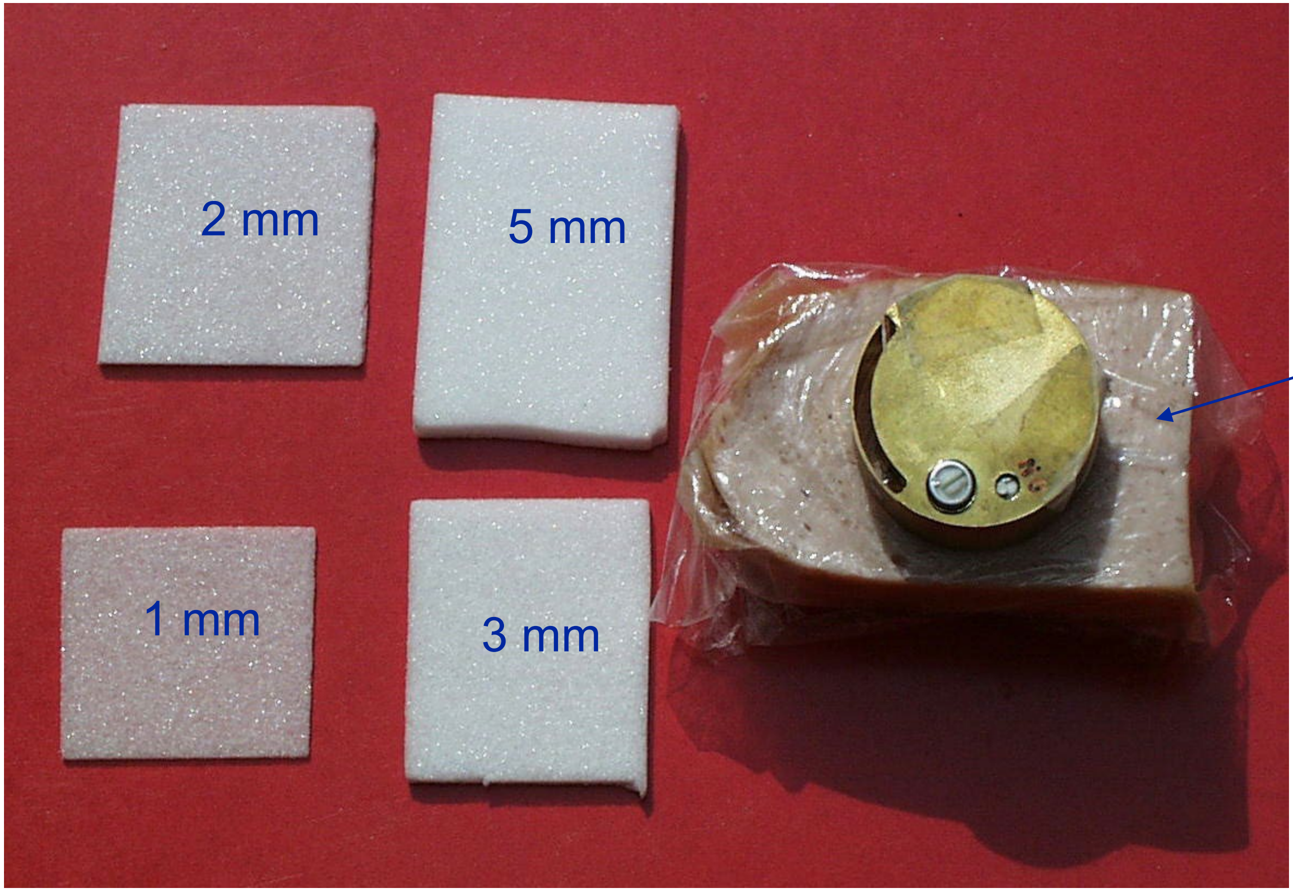


Gain of antenna alone



DUT mounted within the plastic sphere

Measurement conditions



Plastic film

Gain vs. the proximity of the antenna to the virtual arm