

Measurement Aspects of Mobile Terminal Antennas

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Overview

- Introduction
- Small-antenna characteristics
- Standard measurement methods
- Other characterisation methods
- Specific error sources and solutions

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Mobile communications antennas

- Trend: Increasing number of communication systems
- small(est) mobile terminals
- ➔ complex antenna structures and multi-element antennas
- simulation-based design and evaluation, but prototyping and measurements usually needed



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Antenna Characteristics

The most important small-antenna characteristics are:

- input impedance / bandwidth
- 3-D radiation pattern
- gain / directivity / radiation efficiency
- User effect, Specific Absorption Rate (SAR)

Multi-element: Diversity and MIMO performance

complexity

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Radiation Efficiency

- The radiation efficient of an antenna is the ratio of the total radiated power and the (net) power accepted by the antenna:

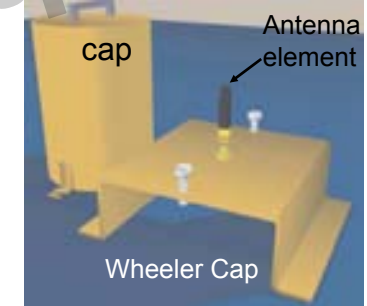
$$\eta_r = P_{\text{rad,tot}} / P_{\text{in}}$$

- Distinction between (physical) **radiation efficiency** η_r including only internal losses inside antenna structure, and **total antenna efficiency**, which is η_r reduced by mismatch losses (at the antenna connector)
- Efficiency is also given by $\eta_r = \text{Gain/Directivity}$

Wheeler Cap Method (WCM) (1/2)

- Measurement of S_{11} in free space is contrasted with measurement of S_{11} when antenna is placed inside a metal cap
- Difference in reflected power represents the radiated power in free space

- Cap eliminates radiation and thus also eliminates radiation resistance R_r
 - size and shape of the cap not significant, but cavity resonances must be avoided
- Loss resistance R_l remains ~unchanged



Wheeler Cap Method (cont'd)

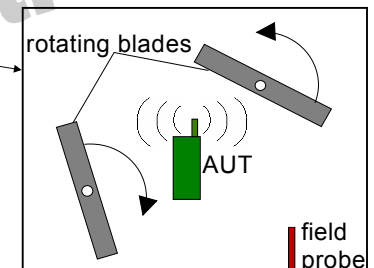
- Under these conditions the radiation efficiency can be determined with **two measurements** by first measuring the input resistance of the AUT without the cap ($R_{fs} = R_r + R_l$), and then with the cap ($R_c = R_l + R_s$)
- The **radiation efficiency** η_r can then be calculated as

$$\eta_r = \frac{P_r}{P_{in}} \times 100\% = \frac{R_r}{R_r + R_l} \times 100\% = \frac{R_{fs} - R_c}{R_{fs}} \times 100\%$$

- In practice, the current distribution and thus also the resonant frequency of the antenna under test inside cap change slightly
→ some uncertainty (several percents) in the measurement

Stirred mode chamber

- Stirred mode chamber [1]:
 - Shielded chamber with metal walls
 - Lots of resonant modes can exist
 - Moving metallic stirrers make all resonant modes equally strong
 - Time-average of field is homogeneous everywhere in the chamber
 - total radiated power is obtained by probing e.g. E-field in **one** point



[1] P. Corona, G. Ferrara, M. Migliaccio, "Reverberating chambers as sources of stochastic electromagnetic fields", *IEEE Transactions on Electromagnetic Compatibility*, Vol. 38 No. 3, Aug. 1996, pp. 348–356.

Scattered field chamber measurement

- Goal: simulate a realistic propagation environment
- shielded chamber with (here: usually fixed) **reflectors**
- measurement antenna has **no line of sight** to AUT
- rotation of the AUT
→ Rayleigh distribution

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Pattern integration method

- by integrating the 3-D gain pattern*, the total radiated power is obtained
- Typically, in 3-D pattern measurements a reference antenna is needed
 - as gain reference, or
 - as efficiency reference
- The directivity D_0 can be obtained from any 3-D pattern with:

$$D_0 = 4\pi \frac{F_{\max}(\theta_0, \varphi_0)}{\int_0^{2\pi} \int_0^\pi F(\theta, \varphi) \sin \theta d\theta d\varphi}, \text{ where } F(\theta, \varphi) \text{ is the radiation pattern of the test antenna.}$$

- if a gain reference was used: $\eta_{AUT} = G_{\max}/D_0$
- if an efficiency reference was used: $\eta_{AUT} = \eta_{ref.ant.} \frac{P_{tot,rad,AUT}}{P_{tot,rad,ref.ant.}}$

(* for each direction, the received power in phi- and theta-polarisations needs to be summed up first)

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Anechoic Chambers

- Need: well-defined field strength at measurement position
- Means: placing the field source in a reflection-free environment

➤ all walls need to be completely covered by RF absorbing material:

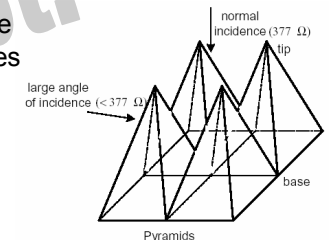


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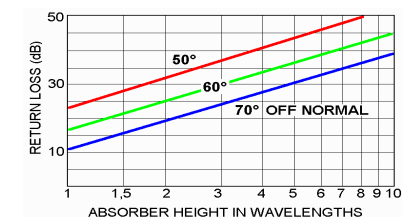
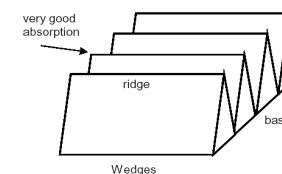
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Absorber lining

- Sharp tips → smooth change of impedance
- Area filled with absorbing material increases
- Absorber height $> \lambda/2$ of lowest frequency
e.g. $f_{min} = 900 \text{ MHz} \rightarrow h_{abs} \sim 30 \text{ cm}$
(better: $h > 45 \text{ cm}$)



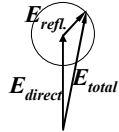
For 'flat' incidence waves,
wedges give better absorption



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Effect of non-ideal absorber lining



- Random reflections cause interference pattern
- In good chambers reflections level is -25 dB or better

Direct field / refl. field	Amplitude error/ripple	Phase error
0 dB	+6 ... -∞ dB	±180°
10 dB	+2.4...-3.3 dB	±18°
20 dB	+0.8...-0.9 dB	±5.7°
30 dB	± 0.3 dB	±1.8°
40 dB	±0.09 dB	±0.57°

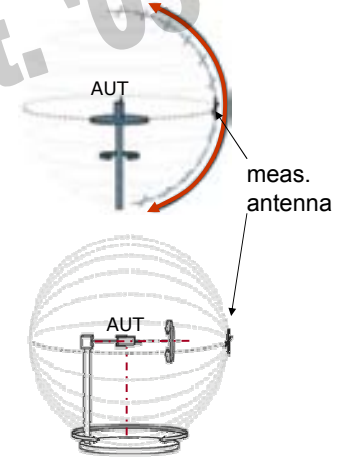
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Measurement setup

Option A: Measurement antenna moves on an **arch**, AUT is rotated around vertical axis → easy cabling (static), complex construction for measurement antenna (or array)

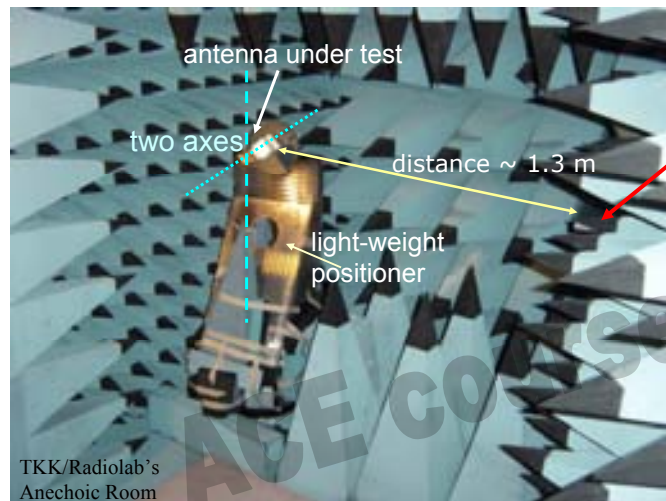
Option B: Measurement antenna fixed, AUT is rotated around **two** axes → complicated cabling (**rotary joints**), easy installation of measurement antenna(s)



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Small anechoic chamber



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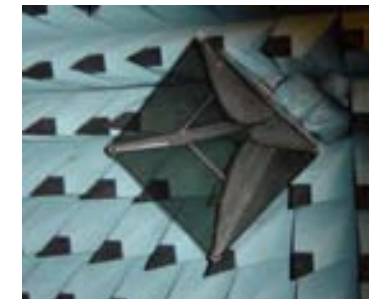
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Example: Dual-axis 3-D pattern measurement in the small anechoic chamber

AUT (embedded movie)



measurement antenna



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Novel measurement systems

Typical problems in far-field-pattern measurements with mobile terminals:

- **Long measurement time** for 3-D patterns due to mechanical movement of antennas (either probes or AUT)
- **Only amplitudes** of radiated fields of active mobile phones obtainable - the phase is needed e.g. for diversity or MIMO evaluation

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Satimo Stargate™ 64



- circular array of 64 dual-polarised field probes
- Perturbation technique gives amplitude **and phase** of the incident field at each probe
- far-field radiation pattern obtained through spherical wave expansion
- Usable frequency range: 0.8 – 3.2 GHz
- $\varnothing = 4\text{m}$ → user can also be in the setup
- Full 3-D far-field measurement within minutes

Source: <http://www.satimo.com>

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RAMS: Rapid antenna measurement system

- Simultaneous use of **32 dual-polarised antennas** located on a sphere around the AUT (possible to include a user)
- Measurement distance about 1 m
- **Phase-retrieval network** uses one of the measurement channels as phase reference
- **Spherical-Wave Expansion** yields full 3-D (complex) far fields
- **Measurement time** only 3 sec (per frequency point)



wideband Vivaldi-type antenna

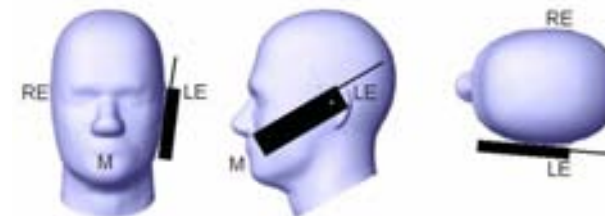
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Body phantoms

- Test-person effect important, variations up to 10 dB
- standardised head phantoms to model the handset user
- liquids for 900 MHz / 1800 MHz to model brain tissue
- Effect of user on radiation characteristics / efficiency

Standardised handset position 'cheek' on SAM:

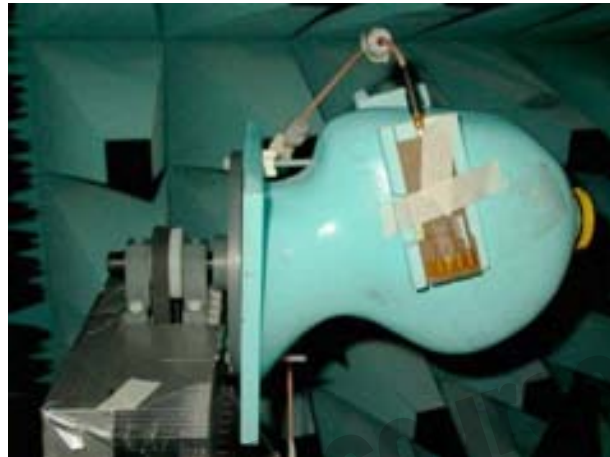


SAM = Specific Anthropomorphic Mannequin

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Antenna prototype with head phantom:



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Specific Absorption Rate

- Power dissipated in the user's head in W/kg
- Limits according to standards such as *EN50360*:
 - EU: 2 W/kg for 10-g volume-averaged SAR
 - US: 1.6 W/kg for 1-g volume-averaged SAR
- Representative head phantom: *SAM phantom*
- Frequency-specific fluid (see IEEE P1528 specifications)
 - Small isotropic E-field probe is moved inside liquid, while phone is placed in typical position(s) at ear

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SAR measurements

- Automated system required
- Standard *EN50361* applies
- Commercial **DASY4** system:



- Alternative: SAR prediction with EM-field simulations

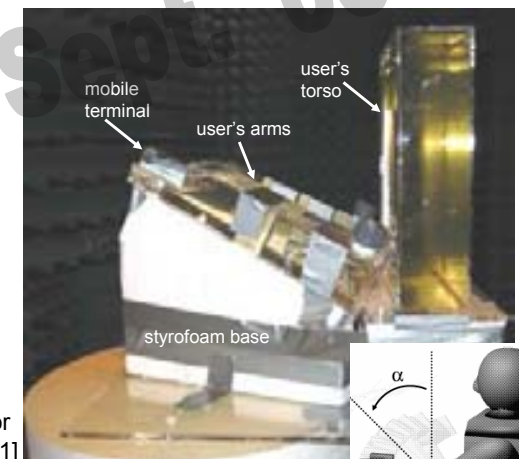


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User effect

- For terminals that feature Web & Video functionality, new user phantom(s) are needed to evaluate the effect a user has on the terminal performance (e.g. by shadowing)



Simple test set-up for
"browsing" position [1]

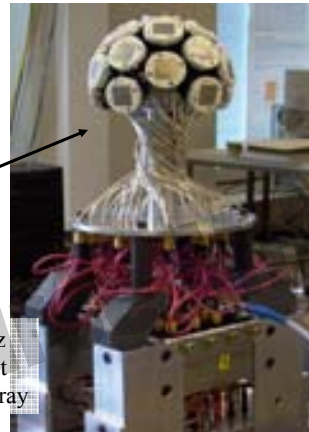
[1] J. Krogerus, "Phantoms for Terminal Antenna Performance Testing", COST273 TD(02)154, Lisbon, Portugal, September 2002, 6 p.

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Radio-channel sounder

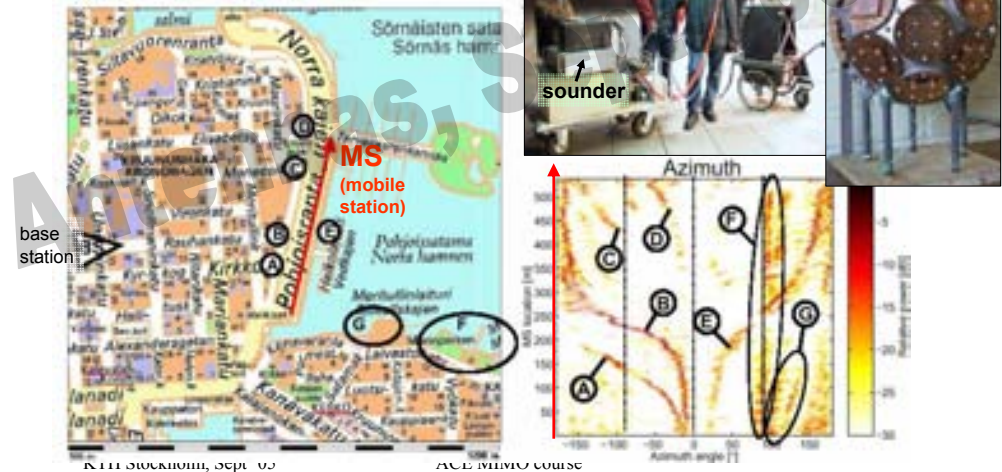
- Radio-channel sounder measurements
 - Fast-switched (\sim ms) multi-antenna arrays at both ends (BS and MS)
 - In multi-antenna systems, all antennas can be *simultaneously* measured
 \Rightarrow diversity/MIMO performance directly available
- Radio-channel characterisation
 - Multi-path environment
 - Spherical multi-element antenna array used as base- and mobile station
 - With beamforming methods the *directions of departure* (DOD) and *directions of arrival* (DOA) is obtained
 - \rightarrow **General** channel models for different environment categories



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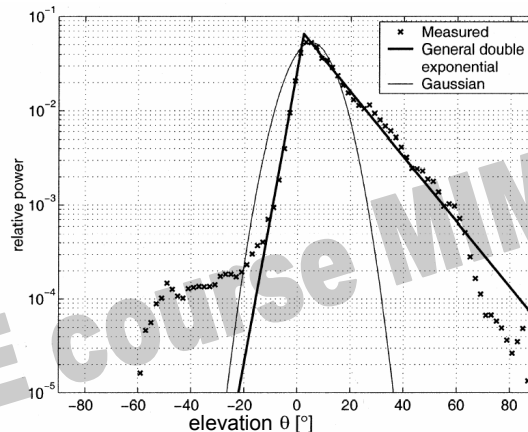
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Example: Urban measurement (@2.1GHz)



Models of urban environment

Measured **elevation** power distribution at 2.1 GHz in an urban macrocell environment, and two simplified models:

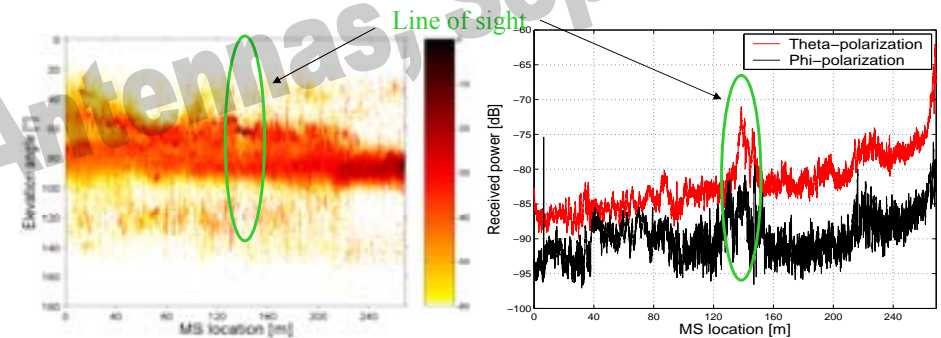


Source: Kalliola, K. et al: "Angular power distribution and mean effective gain of mobile antenna in different propagation environments", IEEE Transactions on Vehicular Technology, Vol. 51, Issue 5, 9/02, pp: 823-838

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Example 2: Elevation power distribution and θ - and ϕ -polarized powers in another macrocell route (transmitter at rooftop level):



- Incident signal power arrives mainly from the directions just above the azimuth plane - especially true in macrocell environments

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Multi-element terminal antennas

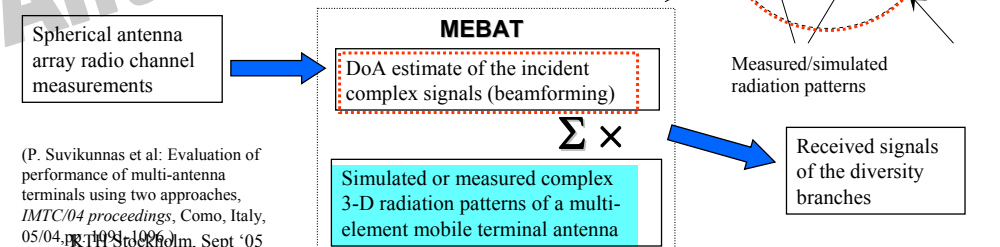
- Simplest case: *Diversity* (e.g. dual-polarised terminal antenna)
- Most complex case: *MIMO* (multi-element arrays at both ends)
- Static or separate single-channel measurements not sufficient
- Average performance affected by time- and place-dependent characteristics of the (dynamic) radio propagation environment
- Dynamic MS measurements in real propagation environments are time consuming and expensive**

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MEasurement Based Antenna Testbed

- MEBAT is HUT/Radiolab's novel multi-antenna system evaluation tool
- Computational performance evaluation of a multi-antenna configuration already in the early phase of the design process:

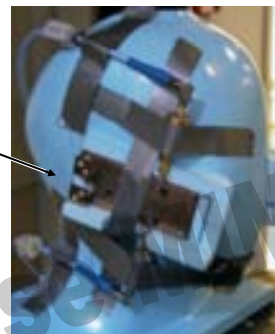


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Mutual coupling

- when measuring a combination of two closely spaced antennas such as a mobile-handset diversity antenna, mutual coupling may have an effect
- in typical measurement arrangement both antennas connected to matched loads: due to mutual coupling dissipation in both antennas (+ mismatch) => possibly less power received than with single antenna



dual-element antenna on head phantom ("SAM")

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Mutual coupling (cont'd)

- mobile antennas show mostly resistive mutual impedance
- normalised mutual resistance is approximately equal to the correlation coefficient:

Envelope correlation	Normalised mutual res.	Attenuation of received power [dB]	Coupling betw. loads S_{21} [dB]
0	0	0	- inf.
0.3	0.55	-0.4	-10.6
0.7	0.84	-1.6	-5.9
1	1	-3.5	0

← ideal case

← real cases

← worst case

Source: R. Vaughan and J. Bach Andersen, "Antenna diversity in mobile communications", *IEEE Transactions on Vehicular Technology*, Vol. 36, No.4, November 1987, pp. 149-172.

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Measurement errors

- General accuracies of RF signal source, the VNA, cables losses, connectors, wall reflections
- Positioning of antenna(s)
 - Choice of range (minimum distance)
 - Phase center alignment
- Effect of RF cable shield
 - Reflection and re-radiation
 - Parasitic radiation

Phase centre alignment

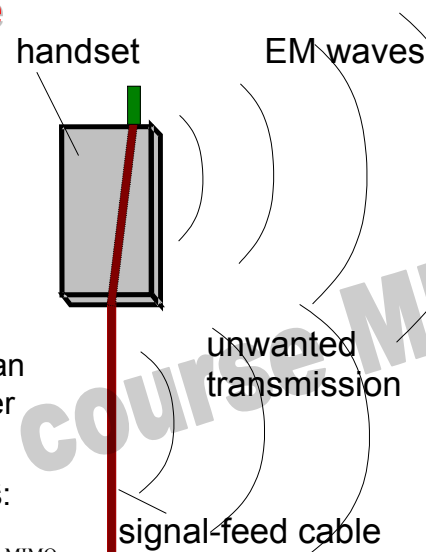
- Typical assumption is that the phase centre is at the feed point of the antenna – true only for simple structures
- But for complex structures such as handsets the location of the phase centre varies as a function of frequency!
- In the presence of a head phantom, the location of the (effective) phase center may move outside the handset perimeter

Measured field-strength uncertainty when rotating Δ off the phase centre:

misalignment	$d = 5$ m	$d = 1$ m	$d = 0.5$ m
$\Delta = 10$ mm	<0.1 dB	± 0.1 dB	± 0.2 dB
$\Delta = 30$ mm	<0.1 dB	± 0.3 dB	± 0.5 dB

Effect of RF cable

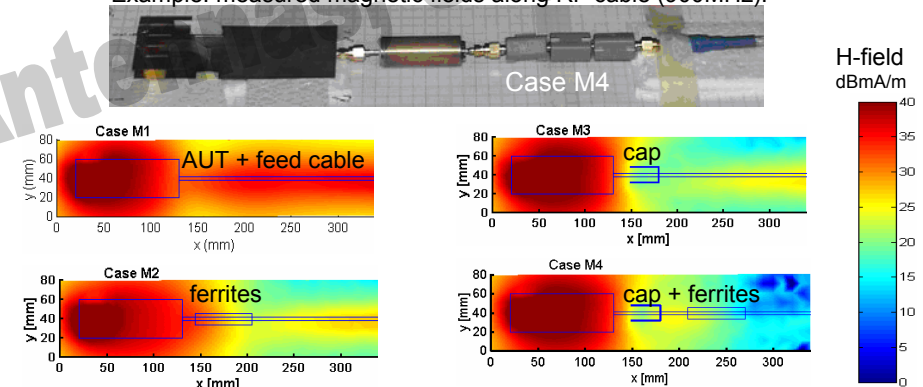
- With an external signal source (e.g. VNA), we need an additional RF cable
 - **no free-floating AUT**
- Antenna prototypes are mostly measured without an independent RF transmitter
- there are several solutions:



Current chokes

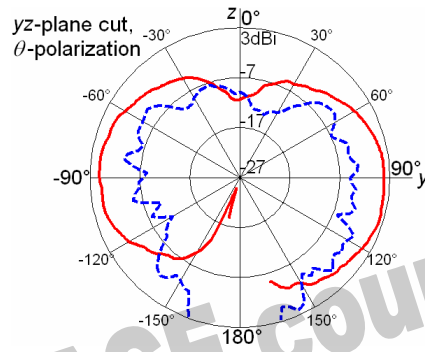
ferrite bead (lossy, wideband), cap/balun (resonant, narrowband)

Example: measured magnetic fields along RF cable (900MHz):



Current chokes (cont'd)

Comparison of θ -pol. yz-plane gain patterns at 920 MHz
for an AUT set-up with bare RF feed cable only - - -
and a set-up including a balun and ferrites —.

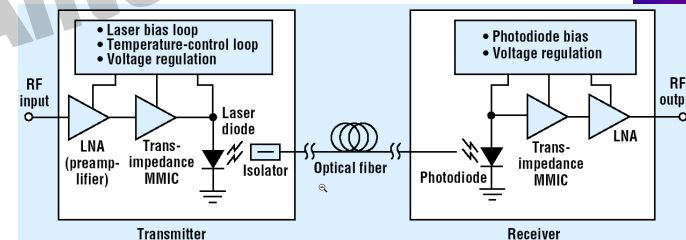


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Optical RF links

- ideal: no RF cables from/to AUT
- still not many commercial products
- power consumption, size
- typically phase information is lost
- no information obtained about S_{11}



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Select reading

- IEEE Standard Test Procedures for Antennas, ANSI/IEEE Std. 149-1979, IEEE Press, New York, NY, 1980, 143 pages
- John D. Kraus (ed.), *Antennas* (3rd ed.), McGraw-Hill, Chapter 24
- Hiroyuki Arai, *Measurement of mobile antenna systems*, Artech House, 214p.
- Clemens Icheln, *Methods for measuring RF radiation properties of small antennas*, Doctoral dissertation, <http://lib.hut.fi/Diss/2001/isbn9512256886>
- A. Lehto, A. Räsänen, *Mikroaaltomittaustekniikka*, 3. painos, Espoo, Otatieto Oy, 1995, 215 sivut
- K. Hirasawa, M. Haneishi, *Analysis, Design, and Measurement of Small and Low-Profile Antennas*, Artech House, 1992
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