Design of antennas for mobile communications devices: practical aspects.

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IMST GmbH

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Acknowledgements

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→ EURAAP SWG “Small Antennas”

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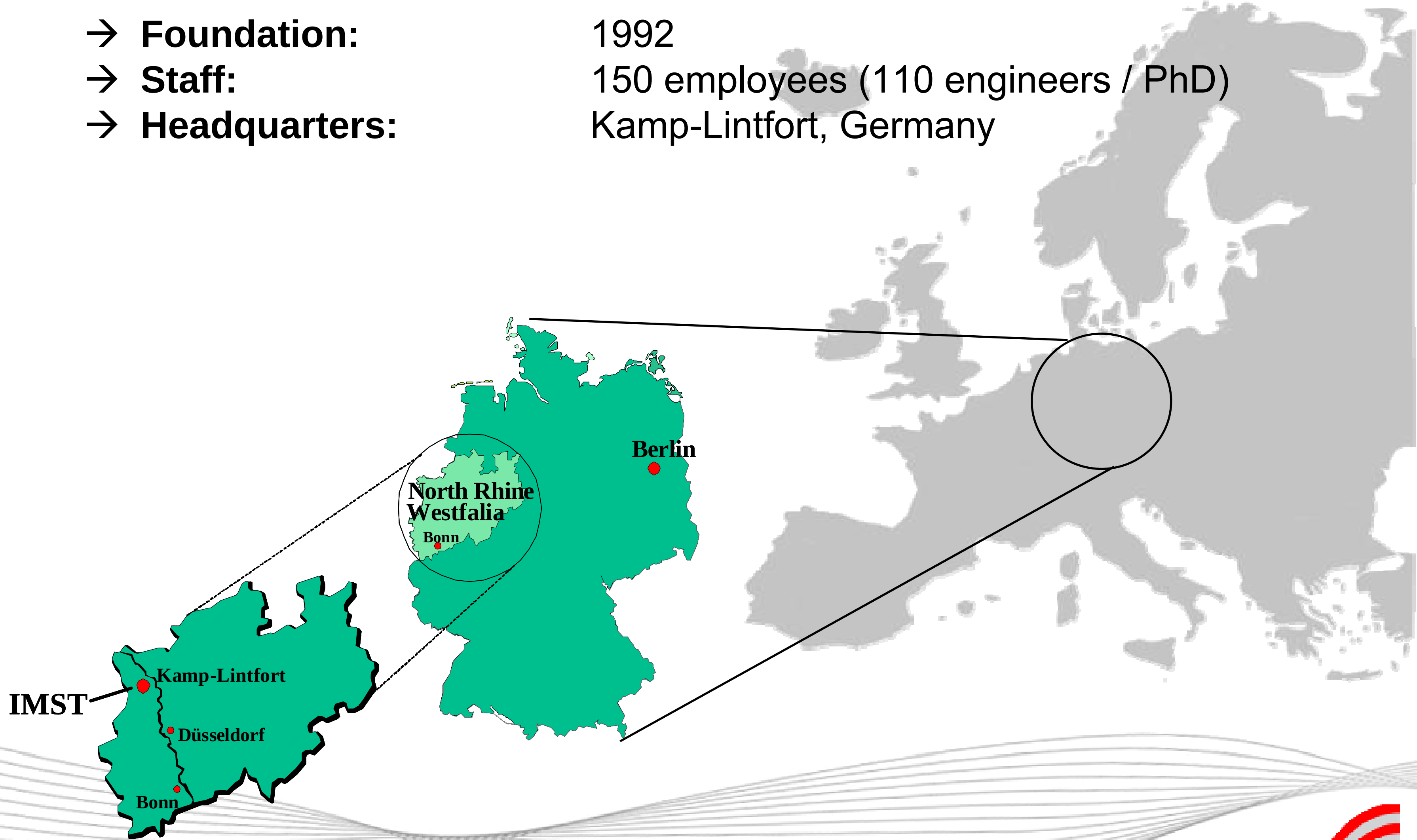
IMST GmbH: facts & figures

→ **Foundation:**	1992
→ **Staff:**	150 employees (110 engineers / PhD)
→ **Headquarters:**	Kamp-Lintfort, Germany



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Target markets

→ Telecom and IT

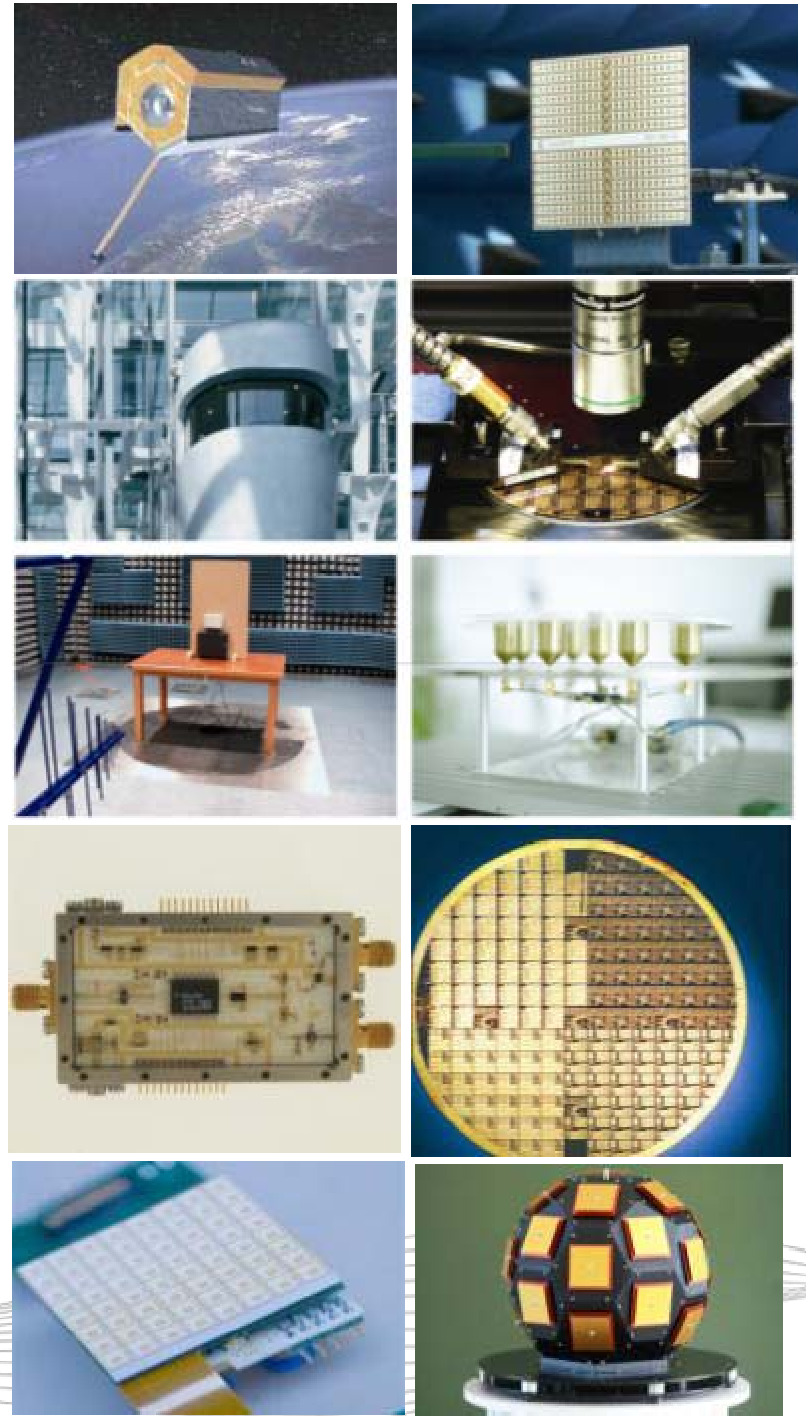
→ Automation

→ Automotive

→ Medical Device

→ Security

→ Space



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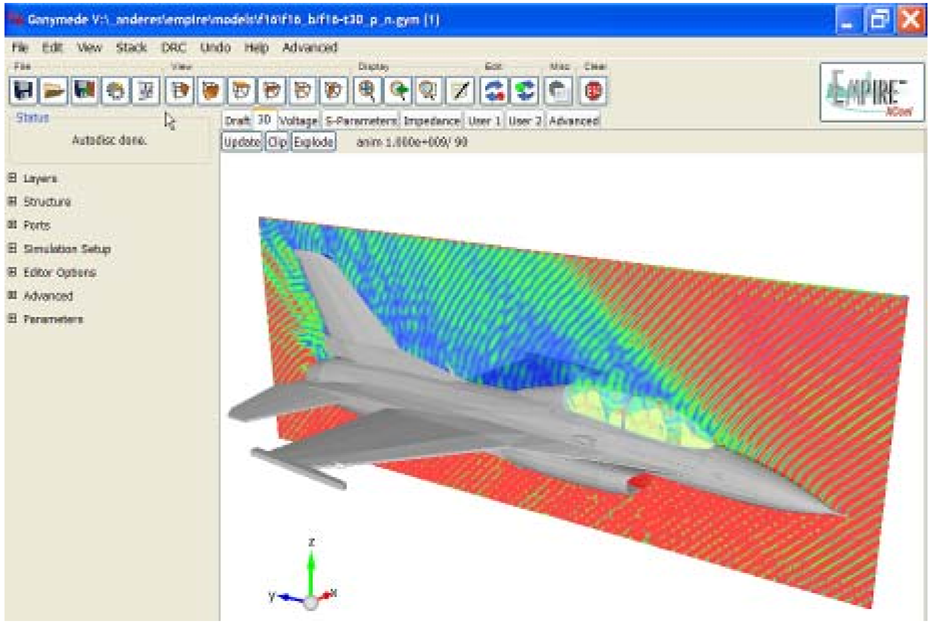
EM modelling tools

EMPIRE™ XCcel

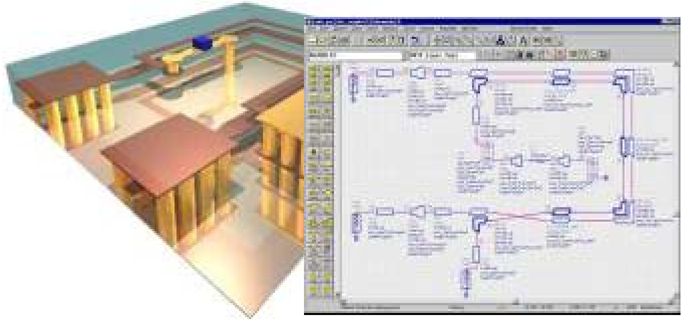
Full wave 3D FDTD simulation



MULTILIB

For ADS^{TM}

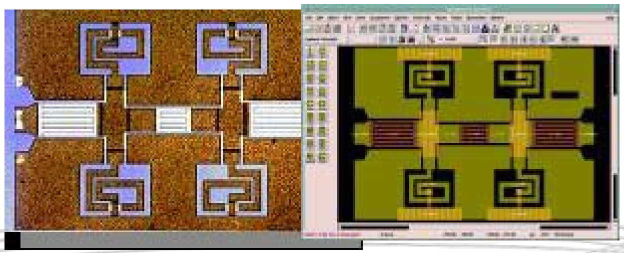
Library for multilayered elements
Integrated in Agilent ADS^{TM}



COPLAN

FOR ADS^{TM}

Coplanar element library
Integrated in Agilent ADS^{TM}



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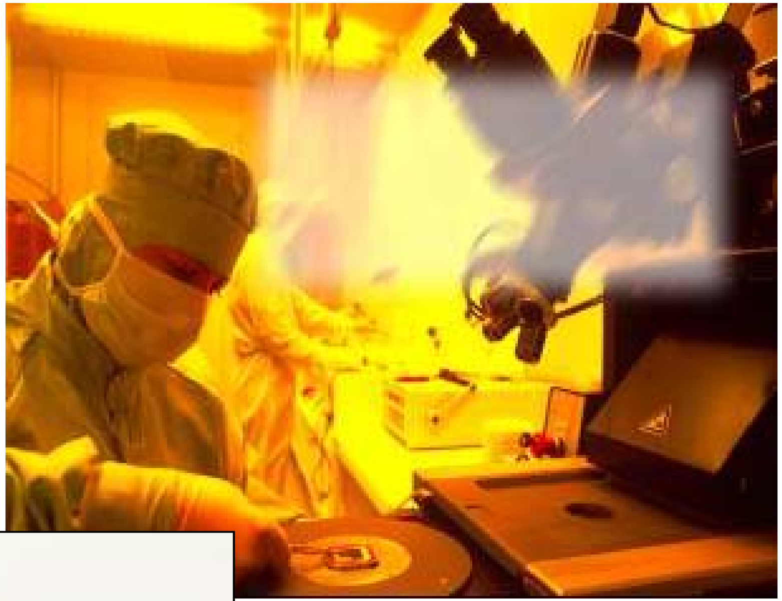
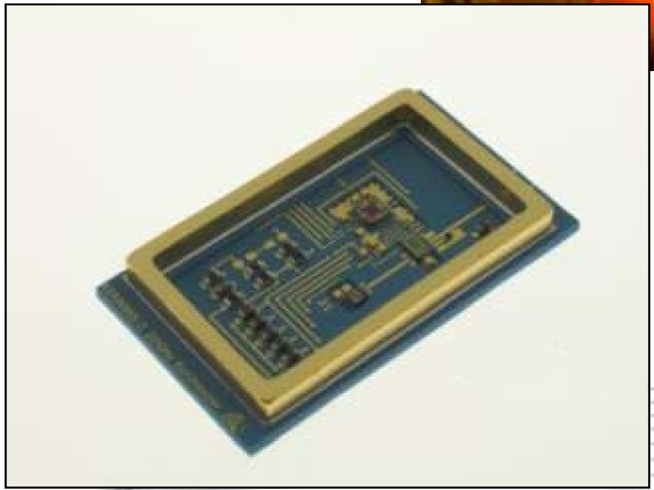
In-house technology & prototyping

- → Clean rooms: class 100 to 10,000
- → Thin film and thick film technology
- → Hybrid circuits, bonding
- → Etching techniques
- → Fast prototyping
- → LTCC capabilities





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Measurements & testing

- → Indoor nearfield / farfield
- → 3D air-interface characterisation of mobile devices
- → Specific Absorption Rate (SAR)
- → RF measurements up to 110 GHz
- → CE certification

Deutscher Akkreditierungs Rat DAR

DAT-P-152/98-01

TÜV CERT
DIN EN ISO 9001 : 2000
QA-Nr.: 0410020031543

CTIA Authorized Test Lab
LAB CODE 20070212-00

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Scope of the talk

→Introduction & historical review

→Practical considerations & design flow

→State of the art

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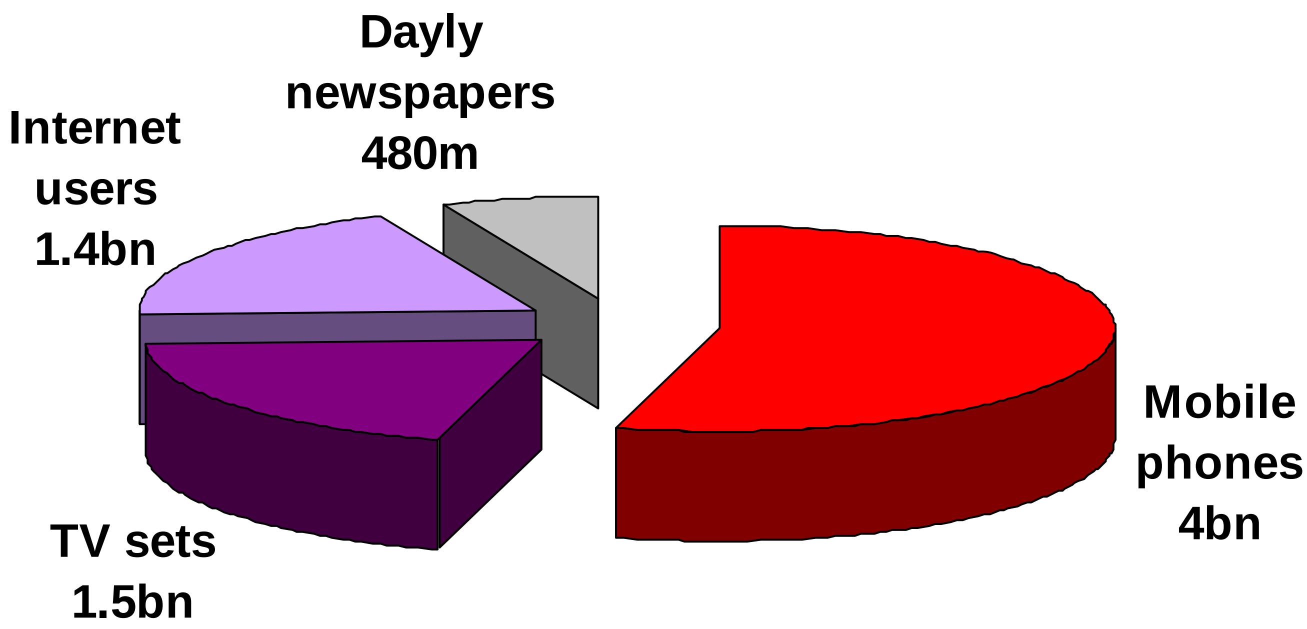
Mobile market



4bn mobiles worldwide = half of the population of the planet!!!

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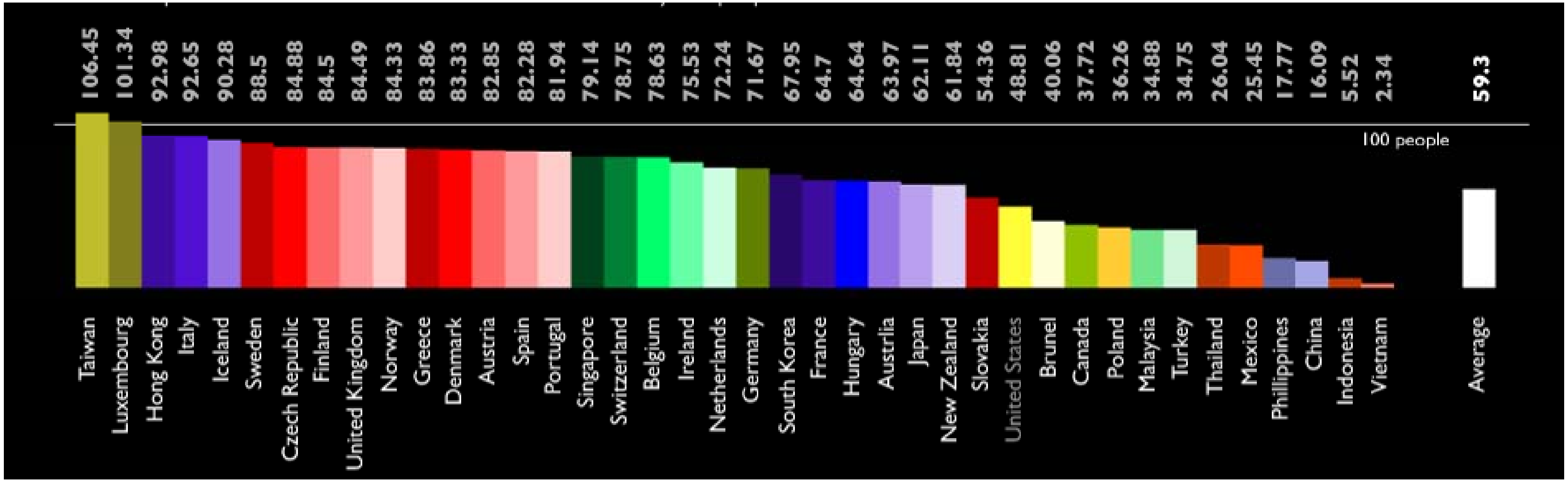
Mobile market

Number of mobiles for every 100 people



Source: i-strategy

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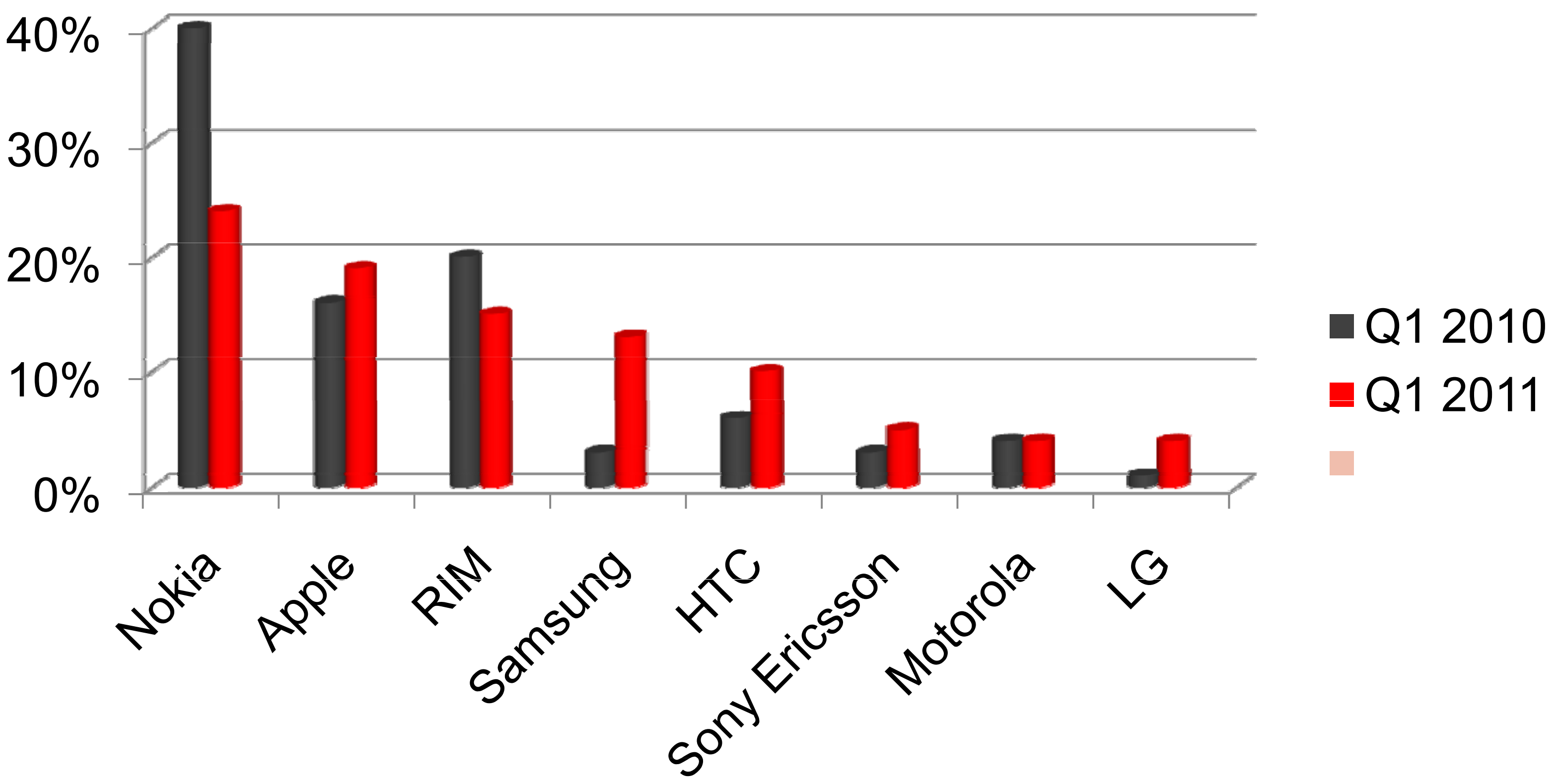
Market Evolution



Source: IMS Research 2011

Expected smartphone sales (2011): 420 Million
28% of total market

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First mobile ever?

Get Smart! (1965)

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These are indeed!

Motorola DynaTAC
First mobile phone prototype (1973)
Size: 229 x 127 x 45 mm
Weight: 1,130 g
Display: None
Talk time: 35 minutes
Recharge Time: 10 hours
Features: Talk, listen, dial

Motorola's DynaTAC 8000X
First commercial mobile phone (1983)
Prize: $3,995
Size: 330 x 89 x 45 mm.
Weight: 780 g
Display: LED
Talk time: 30-minutes
3 different colour combinations: tan/gray, tan and dark gray.

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Nowadays…

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Requirements

User / market

→ Small dimensions

→ Low weight

→ Low SAR levels

→ Low cost

→ High efficiency

Service providers / networks:

→ Multiband capability

→ Broadband operation

→ Robust to changes in the environment

→ Optimised use of the available channel capacity

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Challenges

Go wireless!!!

… but please provide:

→Small antennas

→Internal antennas

→Light weight

→Cheap

→Multi-band

→Multi-antenna systems

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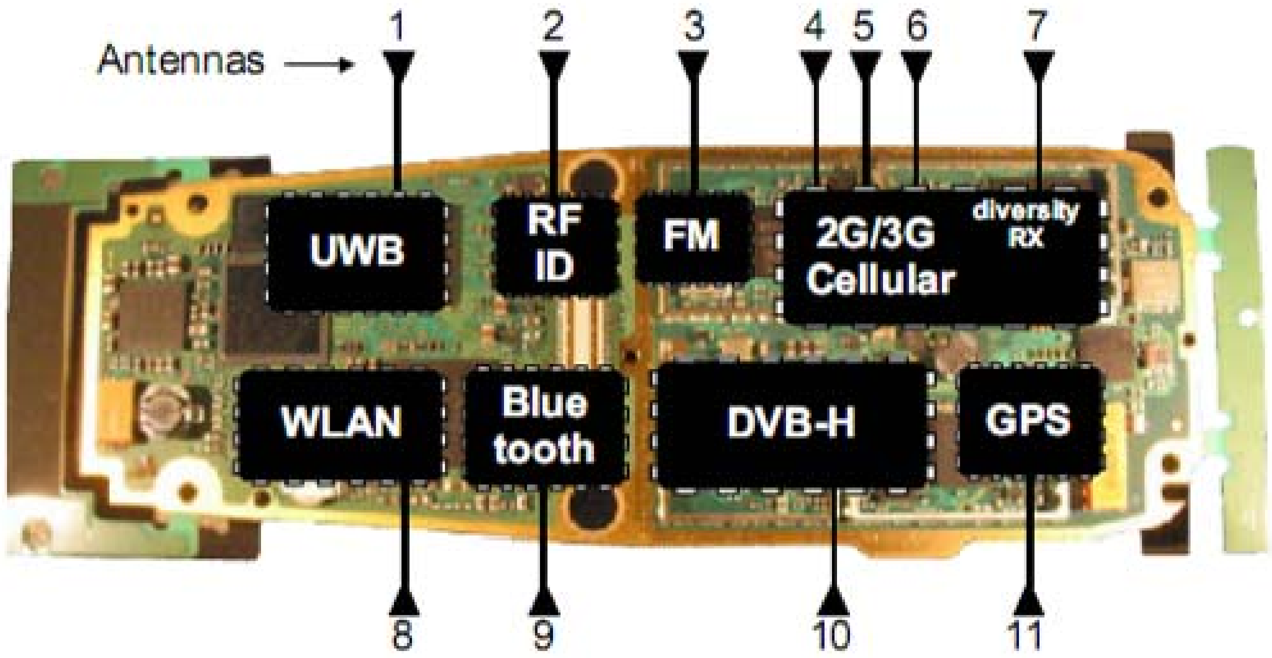
Which means…



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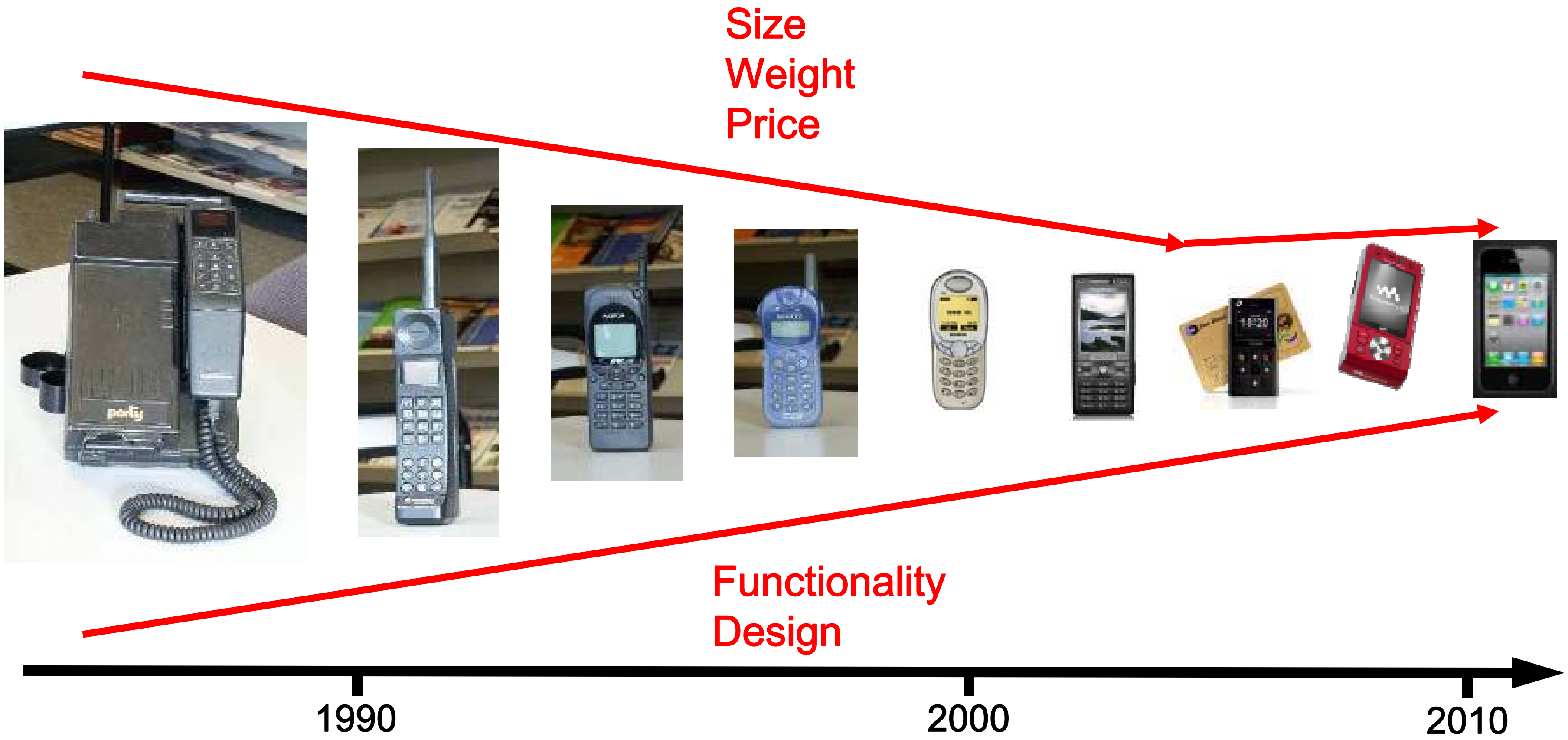
Handset evolution



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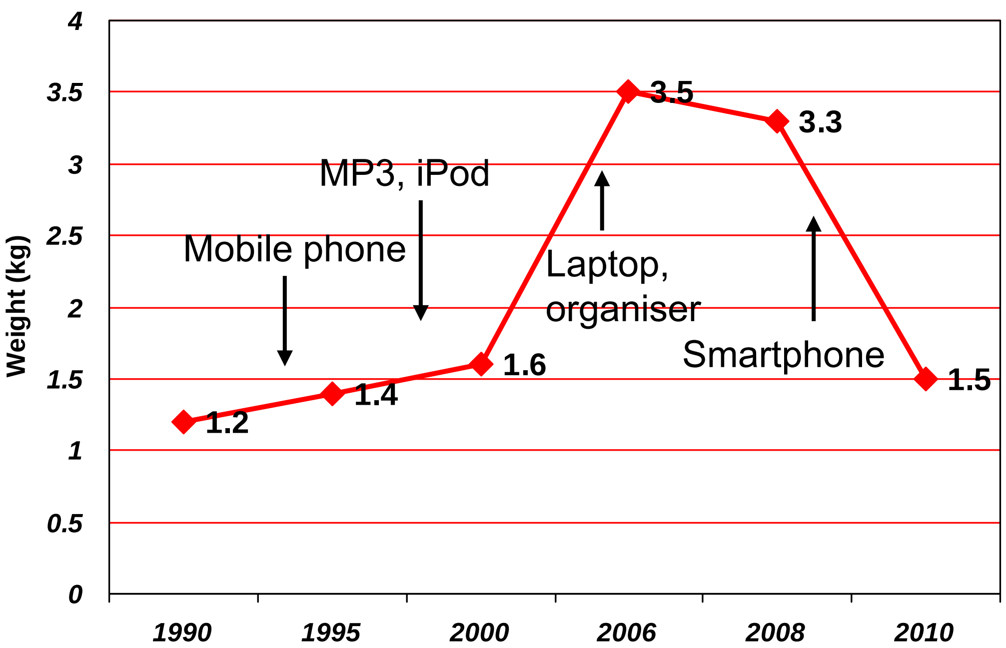
From a different point of view…

→ Last 15 years: impact of laptops and mobile phones

→ Weight dropped by 57 percent in the last two years!

→ Reason: **smartphones**!



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From external to integrated

1. ***Use of patch antennas** instead of whips*
2. ***Ergonomics:** tapering and weighting to encourage users to hold it below the antenna*
3. ***Plastic casing:** part of the cover made of plastic*

Nokia 8810 (1998)
Source: www.wired.com

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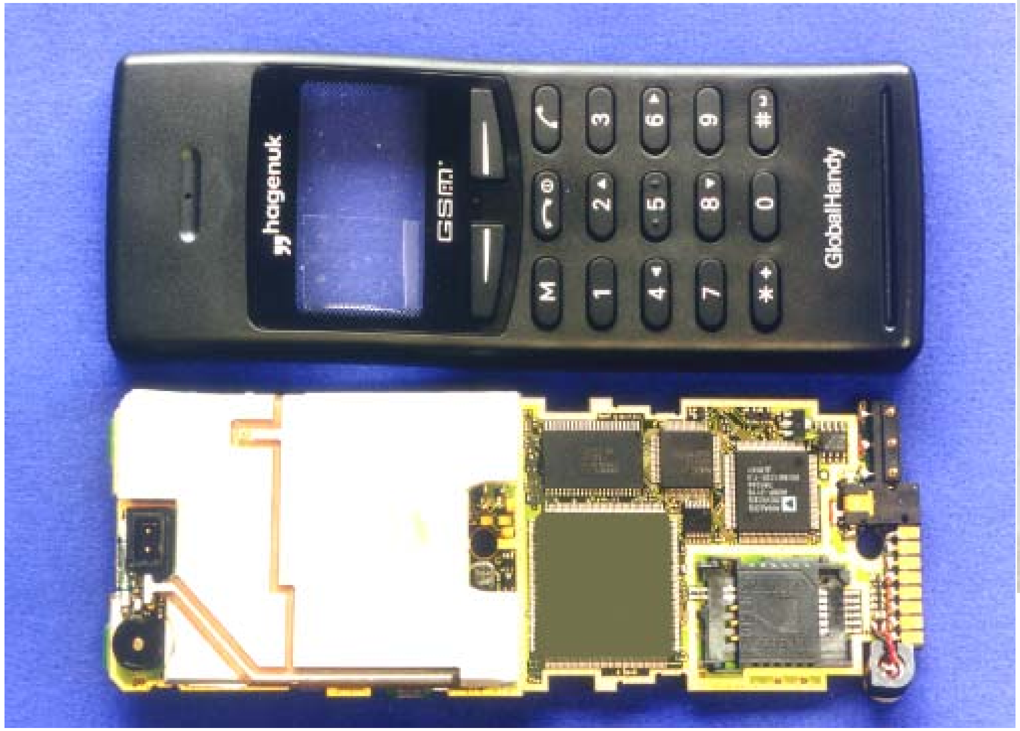
Meet the pioneer!



Hagenuk Global Handy (1996):

The first GSM-phone with an integrated antenna!

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Problems with the law

→Moore‘s law:

„The number of transistors that can be placed inexpensively on an integrated circuit has doubled approximately every two years„

→Antennas don't follow Moore's law

→**Maxwell‘s laws!!!**

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From mobile to smartphone

Motorola 8900 (1997)
First dual band GSM phone
130 x 59 x 25 mm
248 g

iPhone 4 (2010)
5-band GSM/UMTS
+ Bluetooth/Wi-Fi + GPS
115 x 59 x 9 mm
137 grams

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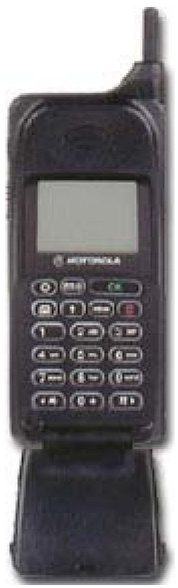
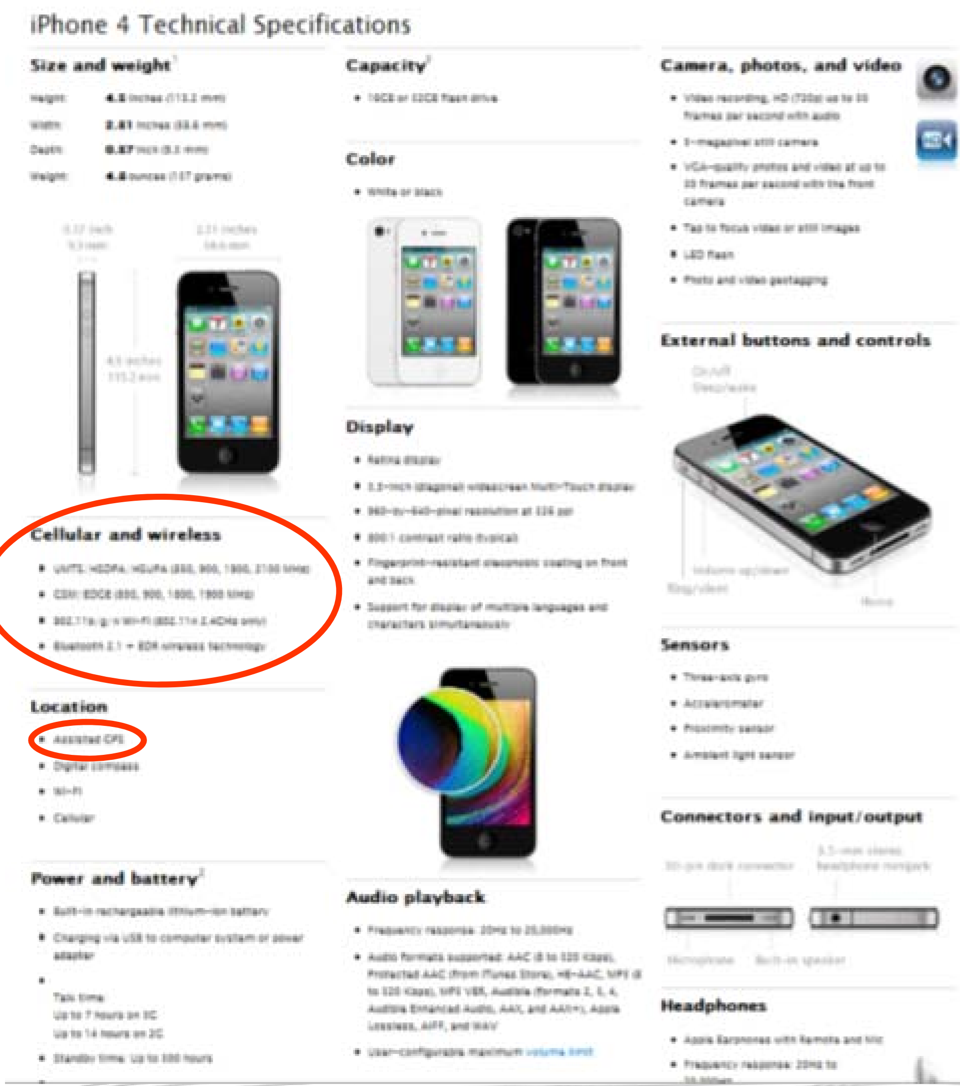
Handset evolution



→ GSM 900/1800
→ Battery type: NiMH 950 mAh
→ Battery life:
→ Standby time: 100-130 hours
→ Talk time: 330-420 minutes
→ Time of full re-charging: 90 minutes
→ LCD display with the resolution of 96x32 pixels, which can show up to 4 text lines, one line with icons
→ Phonebook: 100 phone numbers + SIM-card memory.
→ The list of the last 10 received/dialed calls
→ 16 menu languages
→ User's menu configuration
→ Vibrating alert
→ Speed dialing
→ Autodial
→ Fax
→ SMS
→ Dimensions: 130x59x34 mm^3
→ Weight: 248 g.



Source: www.apple.com

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Scope of the talk

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→Practical considerations & design flow

→State of the art

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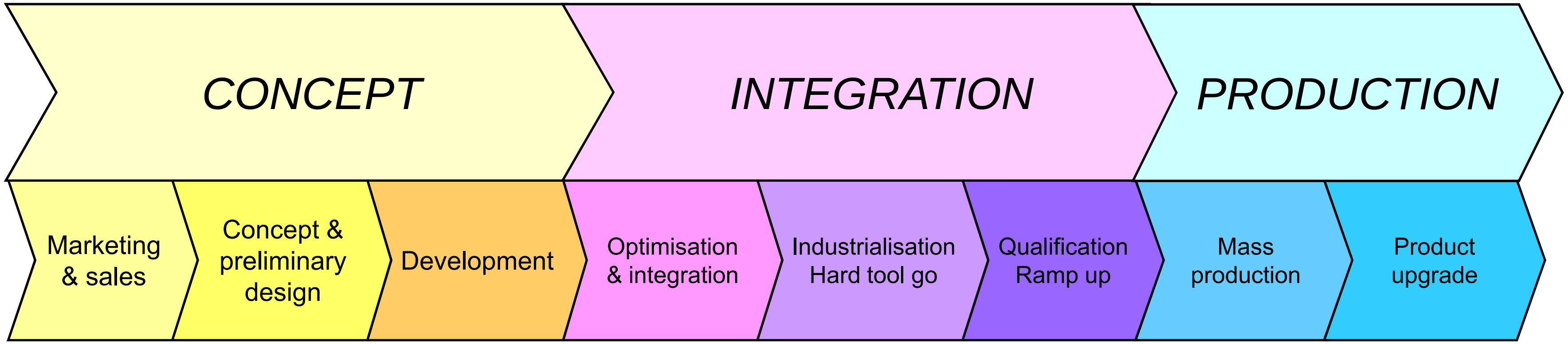
Mobile handset development



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Design flow

Antenna design process

Antenna concept / Simulation

Test hardware

First Measurements

Demonstrator (electrical properties)

Antenna development process

Mechanical design of the antenna

Technology & contacting

Prototyping

Production and delivery

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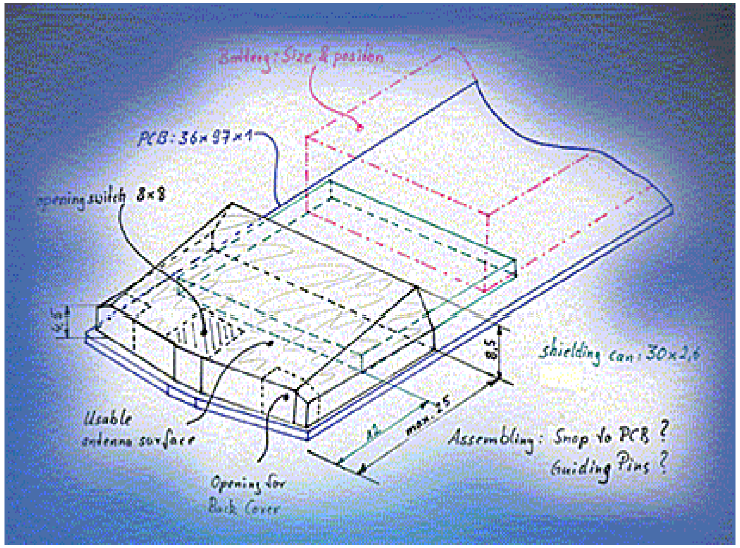
Customer requirements

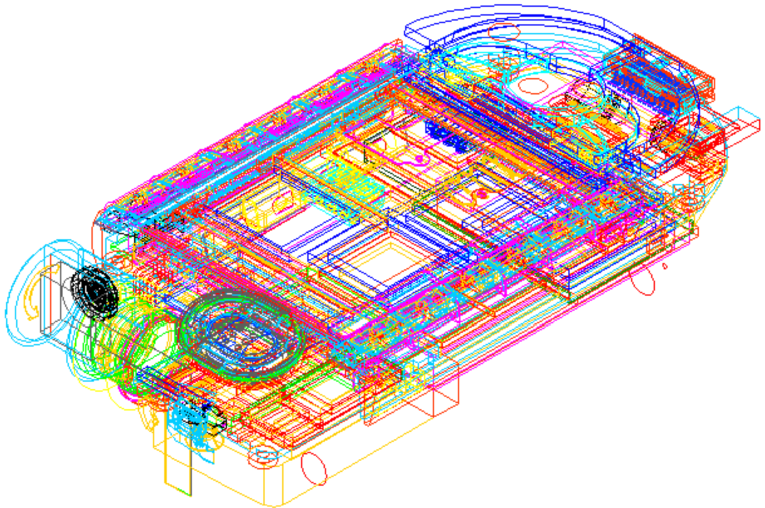


→ Pre-defined mobile phone

→ Antenna functionality

→ Available space / Shape

→ Pre-defined position of feed contacts



→ Interaction necessary with other design departments (circuits, mechanics…)

→ Antenna design should start at the same time as handset development!!!

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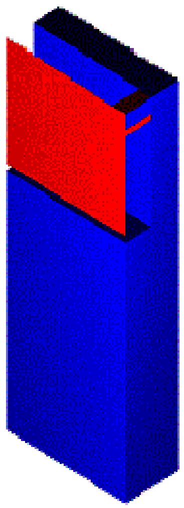
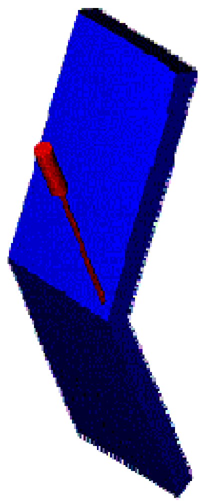
Types of mobile phones

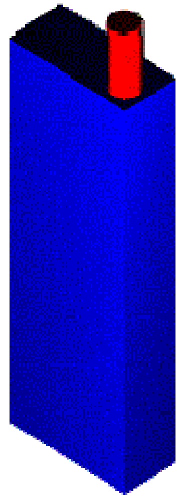
Typical Platforms and Antenna Concepts of Mobile Phones



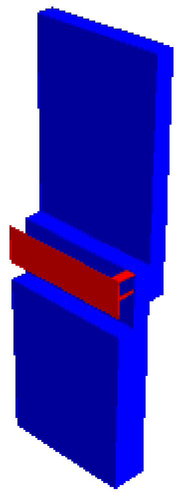
Bar phone with integrated antenna



Flip-phone with external antenna



Bar phone with helix antenna



Slide phone with integrated antenna

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Handheld terminals

→ Multiband antenna

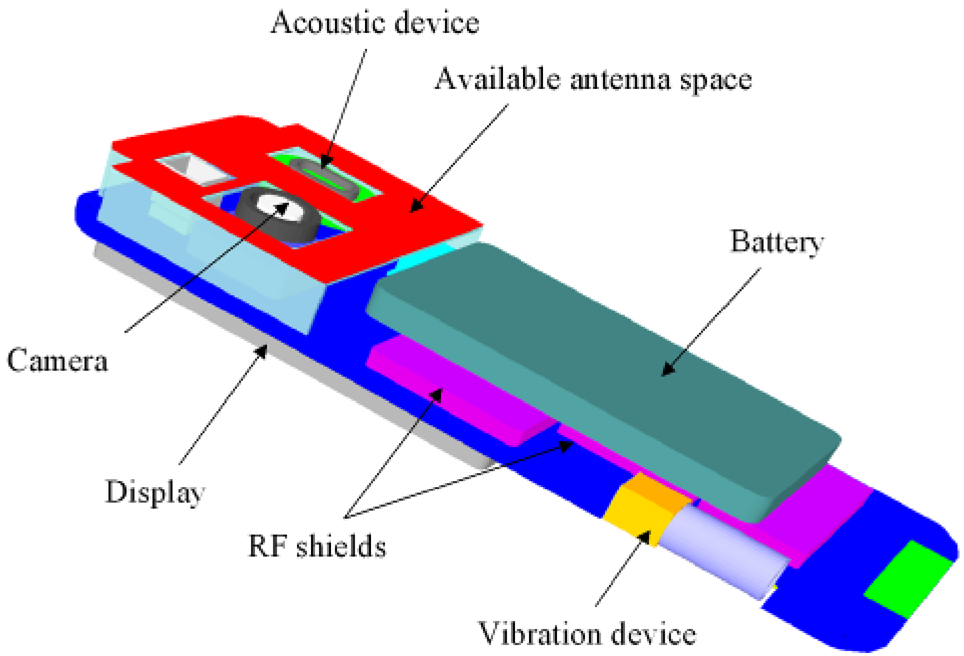
→ Integrated in casing

→ Effect of battery, RF elements and plastic cover

→ Mechanically robust

→ Low cost

→ High efficiency



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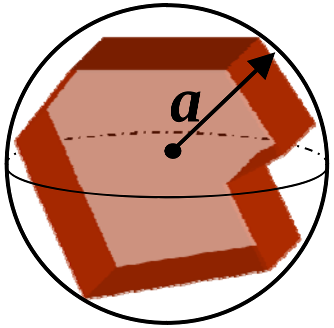
Bandwidth limitations

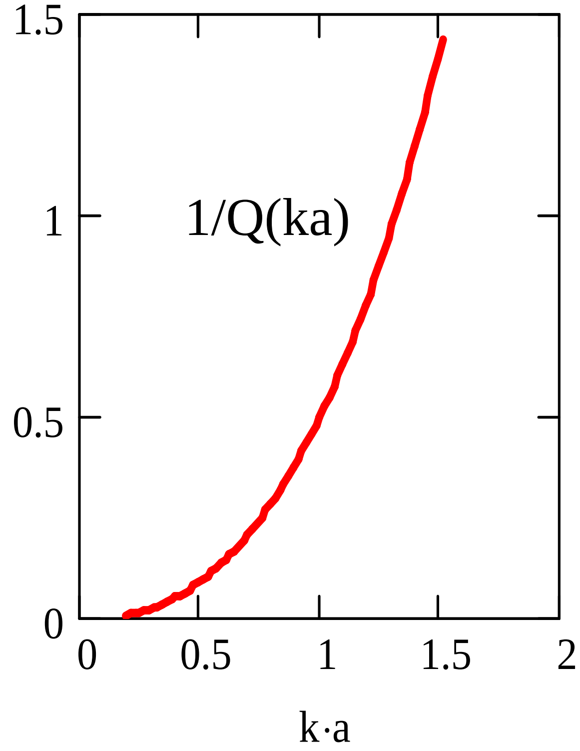
Chu-Harrington theoretical limits:

Antenna in free space enclosed in a sphere of radius ***a***:



$$Q_{min} = \frac{1+3k^2a^2}{k^3a^3(1+k^2a^2)}$$

$$BW_{max} = \frac{1}{Q}$$



→ **Relation bandwidth - antenna volume**
→ **Goal: optimising this relation**

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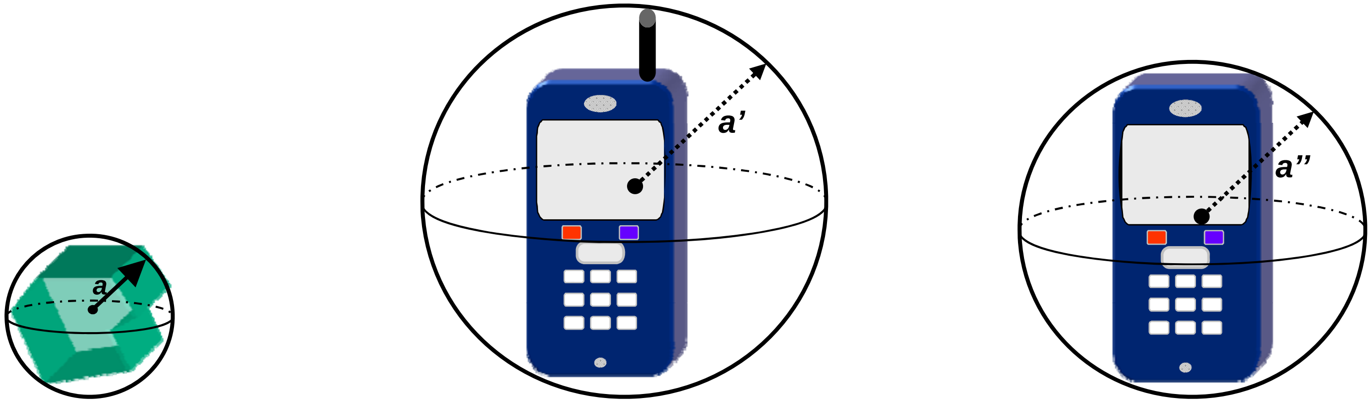
Handset antennas



Antenna only *External antenna* *Internal antenna*

Antenna not in free space:

→ Finite ground plane

→ Effect of handset components (battery…)

→ User's presence

Influence on antenna performance!!!

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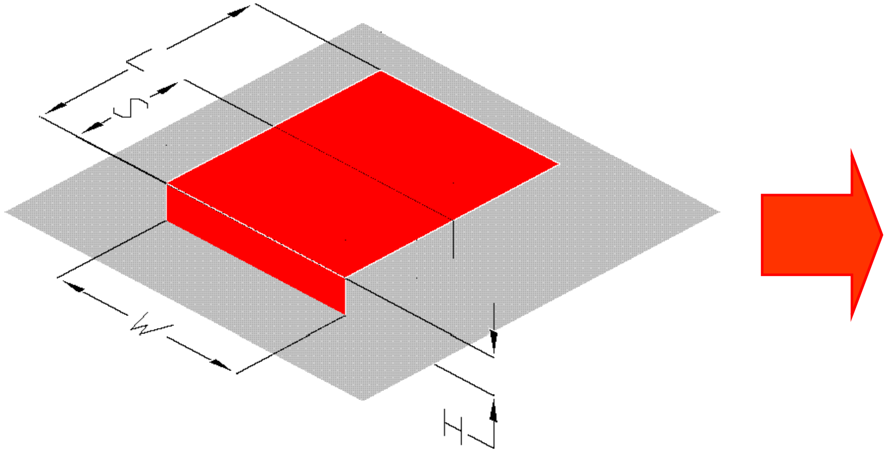
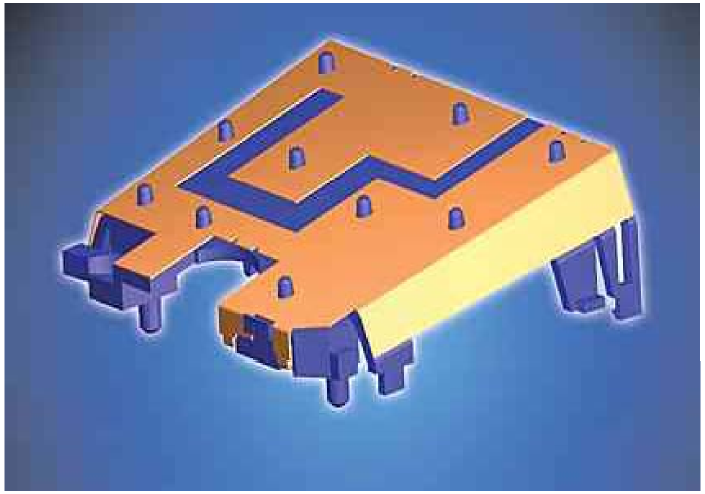
Concepts for internal antennas

Basis: Planar Inverted-F-Antenna (PIFA)



$L + H \approx \lambda_0 / 4$	Resonance frequency
$Z_{in} = f(S)$	Input Impedance
$BW = f^{*}(H, W)$	Bandwidth

Result: handset antenna



→ Folded radiator (miniaturisation)

→ Shape adapted to cover

→ Slots and cuts to induce multimode

$\Rightarrow$ **individual design for each mobile device!!**

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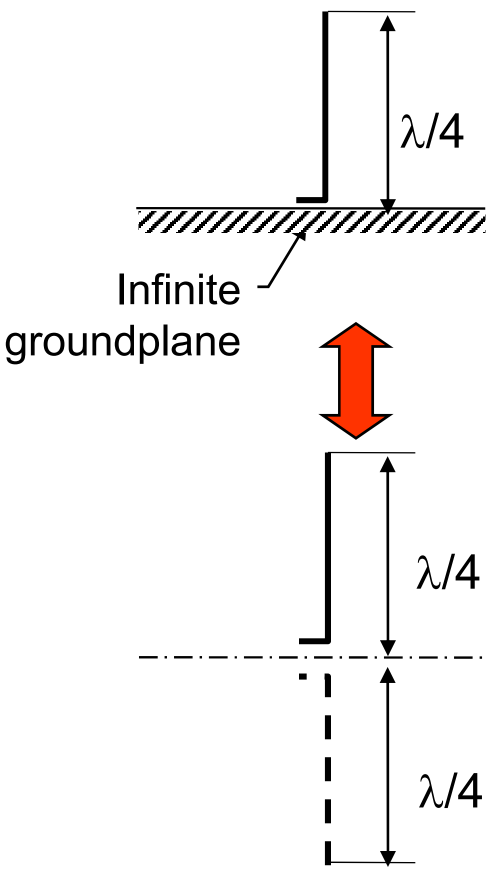
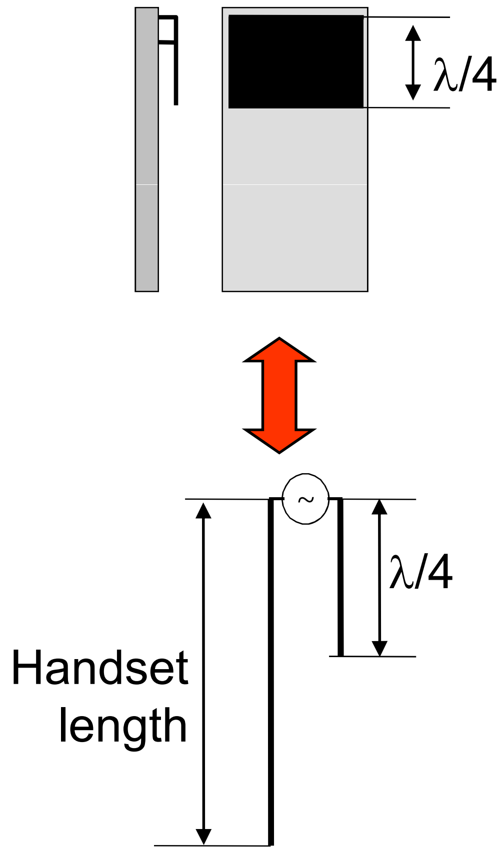
Effect of the finite ground

Monopole over infinite ground



Handset with integrated PIFA



ASSYMETRICAL PROBLEM!

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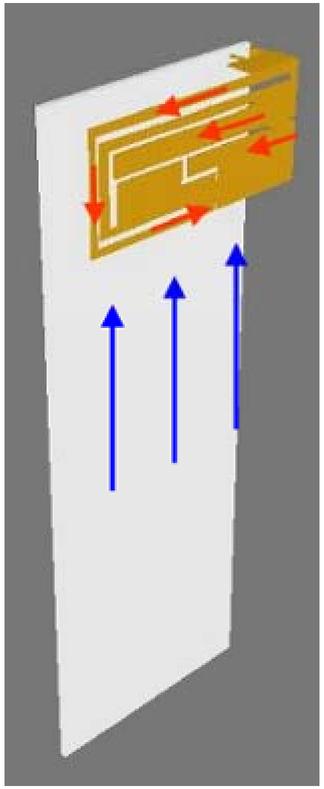
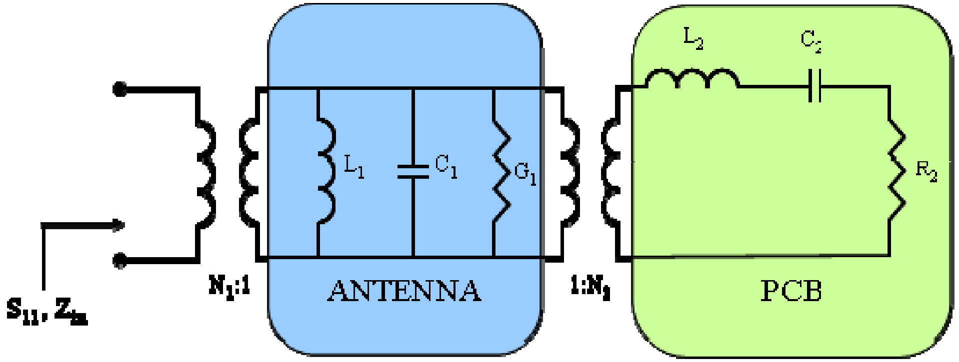
Effect of the PCB

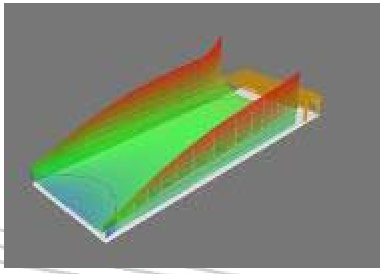


→ Current distribution on the patch induces currents on PCB (frequency related!)

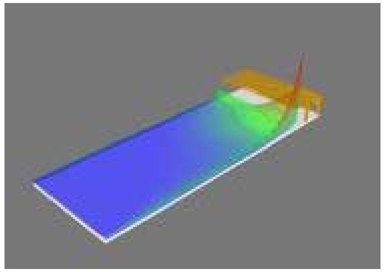
→ PCB contributes to radiation

→ Equivalent circuit model

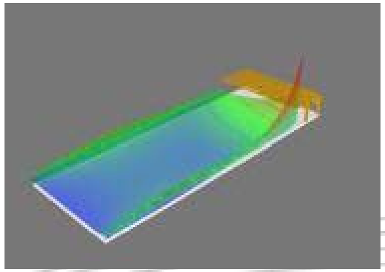




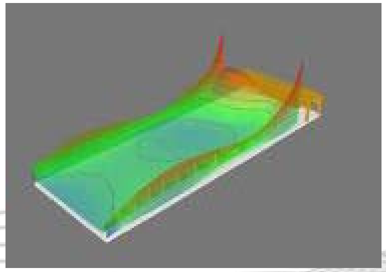
GSM



DCS



PCS



UMTS

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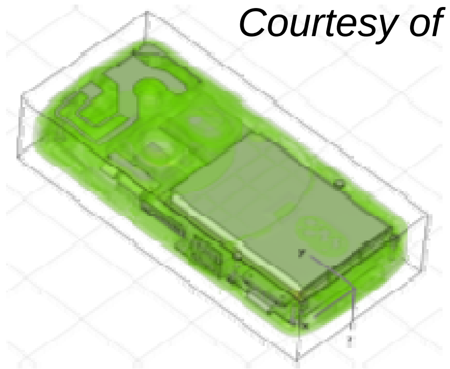
Antenna analysis

Courtesy of ST



Mobile antennas

→ 3D structures, irregular shape

→ Influence of different elements

EM field solvers

→ Analysis

→ Design

→ Commercial packages vs. dedicated software

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Limitations of *em* tools

Reasons:

→ Geometry of the problem
- Size of the structure
- Complexity
- Simplified structures

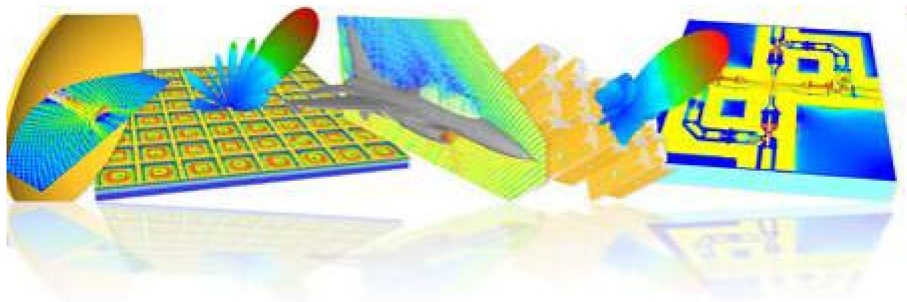
→ Mathematics
- Model limits
- System complexity
- Numerical stability

→ Physics
- Irregular grid (ghost reflections)
- Spatial truncation
- Source modelling (mismatching, cable effect)
- Properties of the materials (lossless, isotropic)

Influence of:

→ Hardware
- Memory requirements
- Processing capabilities
- Simulation time

→ User
- Understanding of the models
- Experience: select appropriate tools, discard elements, detect limits



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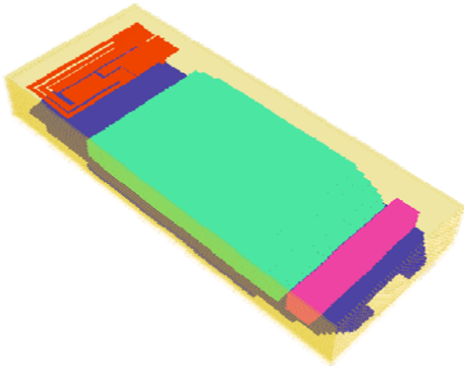
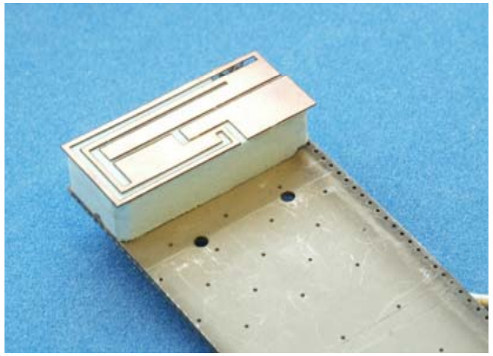
From concept to prototype





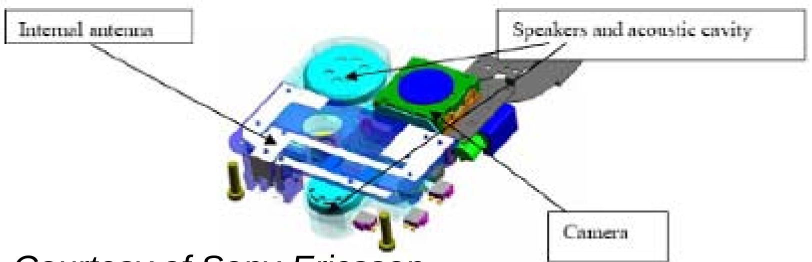
Simulation model

→ Simplified structure

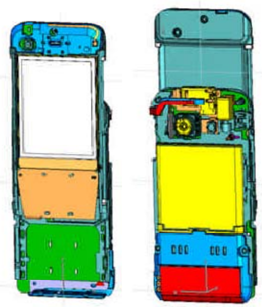
→ Metallic patch

Implementation (demonstrator)

→ Antenna with foam carrier: mechanical stability

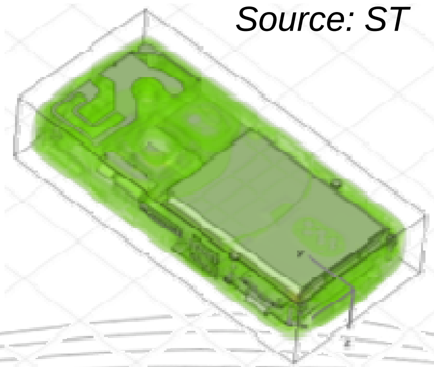


Courtesy of Sony-Ericsson



Courtesy of Nokia

Source: ST



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Human-mobile interaction

2 points of view:

Effect on the user: SAR

Specific absorption rate

$$SAR = c\frac{dT}{dt}$$

$$SAR = \frac{\sigma}{2\rho}|E|^2 = \frac{\sigma}{\rho}E_{eff}^2$$

Effect of the user: losses

Radiated power

$$P_{rad} = P_{in} - P_a - P_L - P_{abs}$$

- Radiated: P_{rad}
- Delivered: P_{in}
- Antenna: P_a
- Mismatch (including user): P_L
- Absorption: P_{abs}

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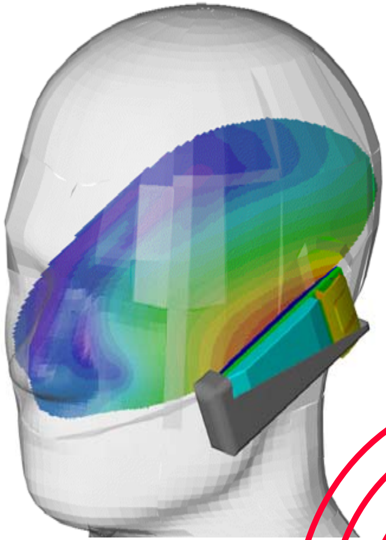
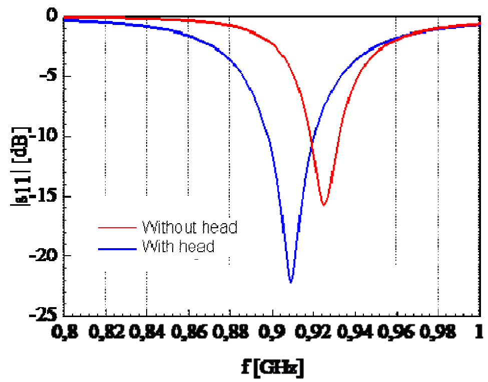
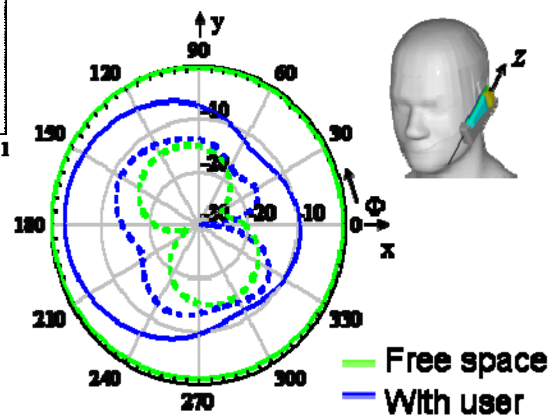
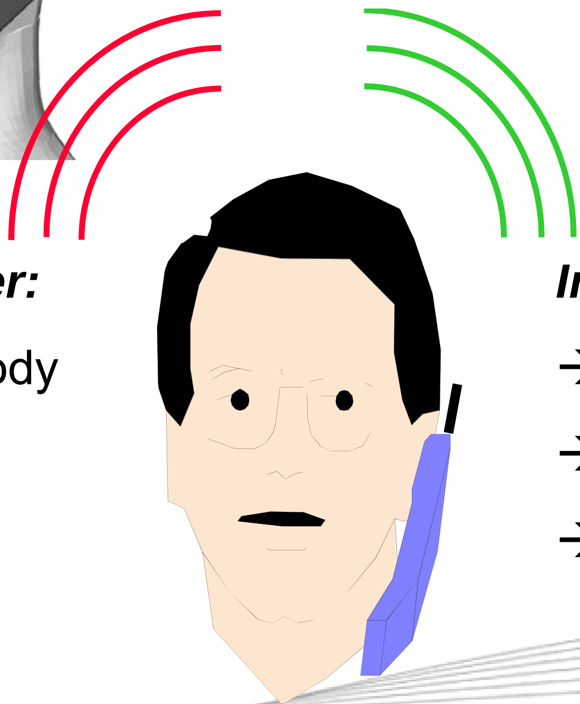
Human-mobile interaction









Influence on the user:

→ EM fields in the body

→ Biological effects?

Influence on the performance

→ Losses in the tissues

→ Changes in radiation pattern

→ Antenna mismatch

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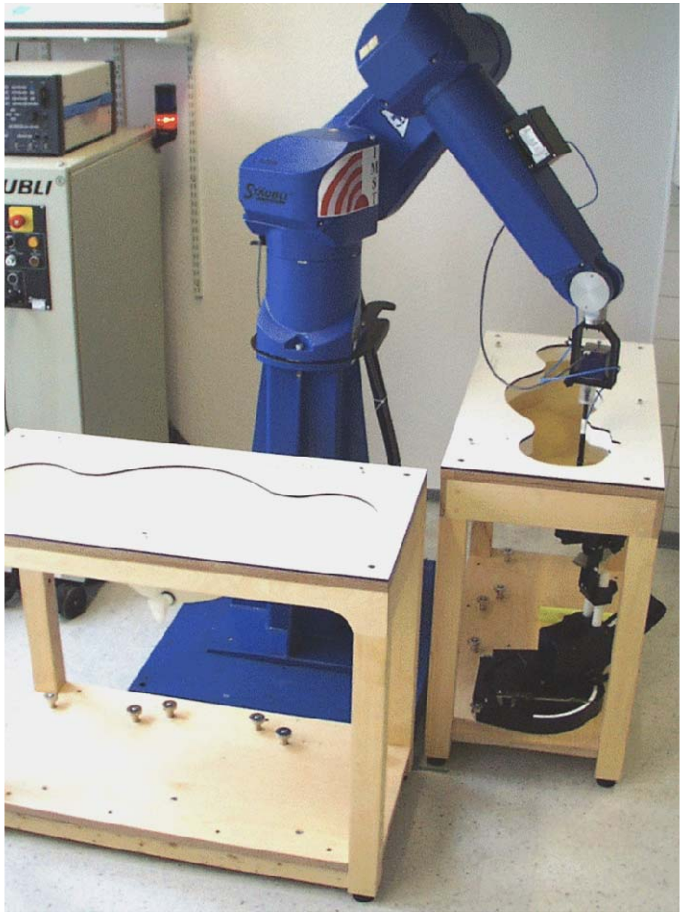
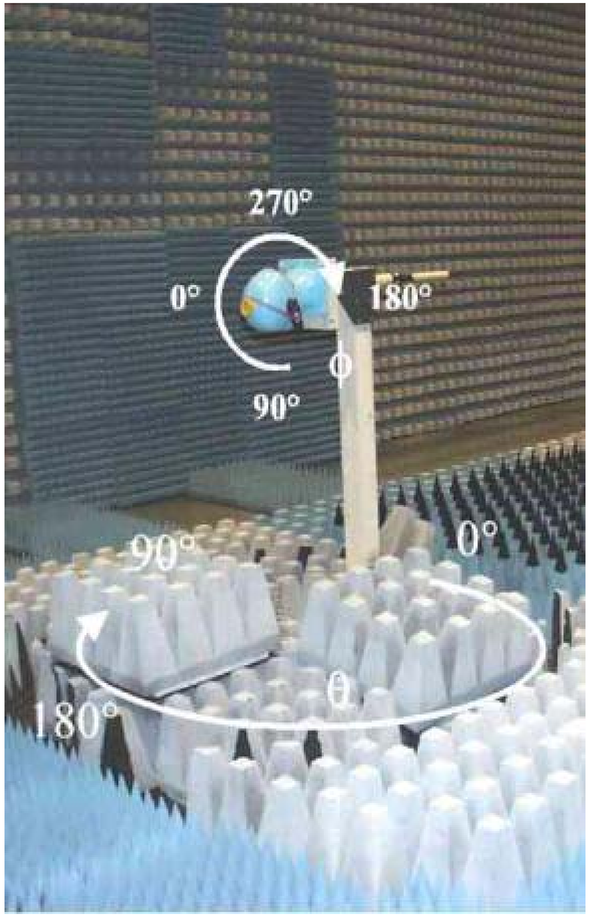
Characterisation of the interaction



SAR-measurements
DASY III setup



Radiated power in presence of user
3D measurement setup

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Specific Absorption Rate (SAR)

Different limits according to:

→ CENELEC (Europe)

→ FCC (USA)

→ ACA (Australia)

Human tissue parameters

Frequency	ε_r	σ (S/m)	ρ (kg/m^3)
900 MHz	42.5	0.86	1040
1800 MHz	41	1.69	

SAR recommended limits

	Max. local SAR (W/kg)	Averaged over (g)
Europe	2	10
USA	1.6	1

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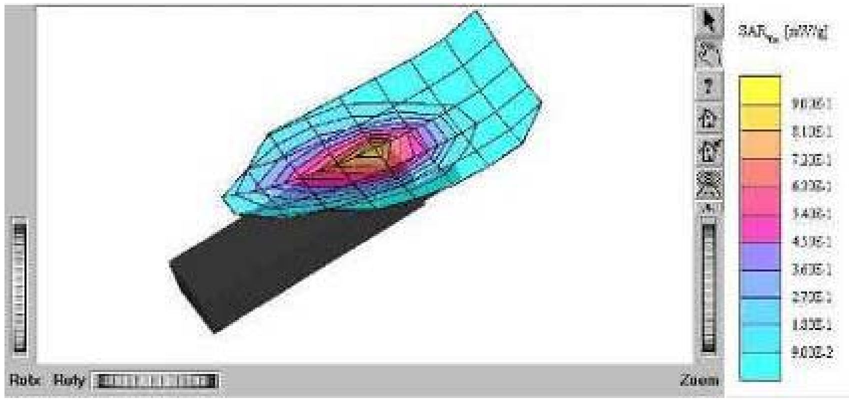
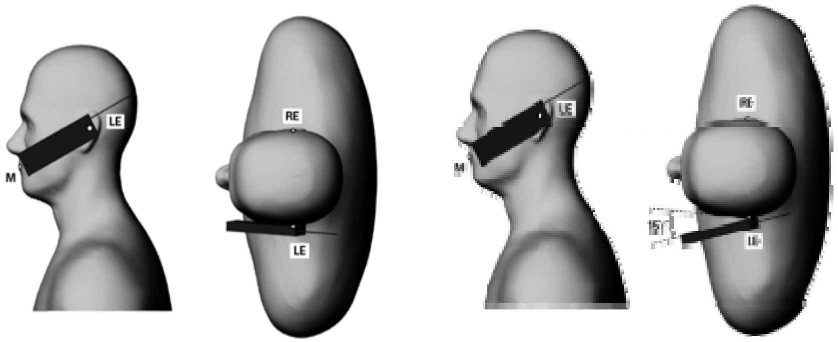
Measurements according to EN 50361

- → 4 standard positions: Cheek and Tilted, left and right side
- → Phone in transmit mode, maximum power
- → SAR at 3 different frequencies: band centre, upper and lower limits
- → Different liquids needed in different bands



Cheek-Position *Tilted*-Position



3-band mobile phone:

3 bands x 3 frequencies/band x 4 positions

= 36 measurements!!! (~ 18 hours!)

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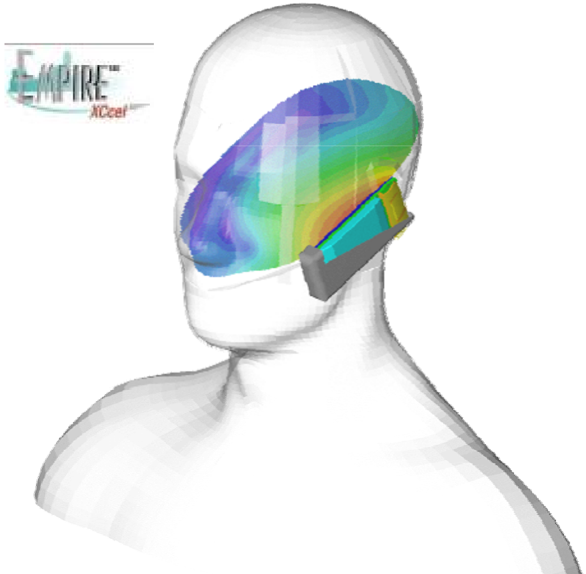
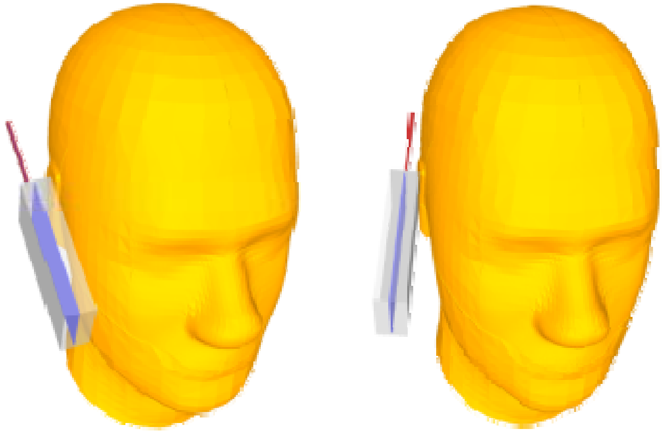
SAR simulation during the design phase



Source: IMST



Cheek position **Tilted position**

Source: IMST

Standard IEEE P1528: will specify FDTD computational techniques for dosimetric investigations with wireless handsets (IEEE SCC-34 WG-2)

Simulation model:

→ grid= 0.5 mm – 3 mm

→ cells= 170 x 170 x 315

Simulation time: ~ 5 min

→ (2 x Xeon 5350, 2.66 GHz)

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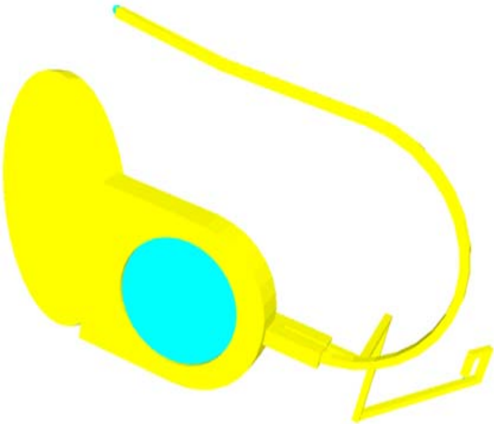
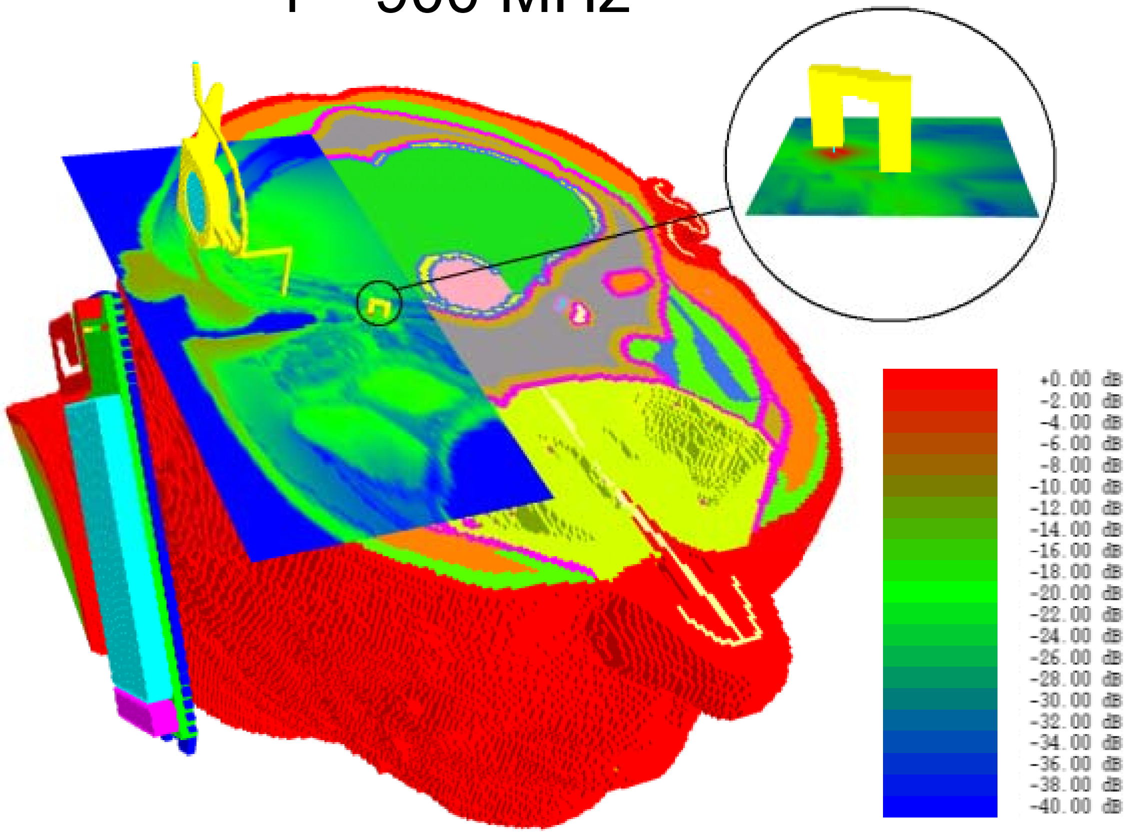
Dosimetric assessment



Cochlea implant

f = 900 MHz



Normalised local SAR-distribution (1W input power)

Vorlage Aug-11 © IMST GmbH - All rights reserved

Scope of the talk

→Introduction & historical review

→Practical considerations & design flow

→State of the art

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Integrated vs. external antennas

✓PROS

→Aesthetical design

→Lower cost

→Mechanical robustness

✘CONS

→Small available volume

→Interaction with other components

→Shadowing

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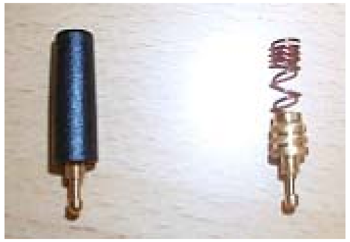
External antennas

Monopole
→ Large size
→ Mechanically fragile
→ Relatively high SAR values



Helix
→ More robust than monopole
→ Multiband operation (combined elements, variable pitch)

Meander line
→ Multiband operation
→ External/internal

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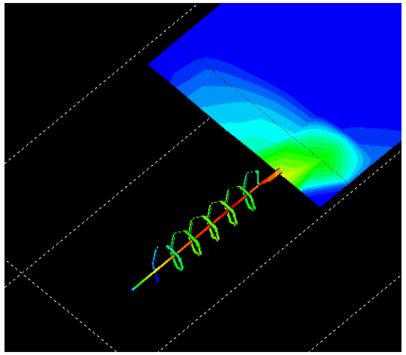
Some examples:

Dual-band, non-uniform helical antena

→Most popular dual band external antenna for mobile phones (over 100-200 M)

→Z.Ying (Ericsson, 1996)

→High efficiency, cheap, easy to manufacture.



Dual-band mono-helix

→Patent by Nokia, extensively used by Motorola

→Relatively expensive solution

Source: Sony-Ericsson

Branch meander multi-band antenna

→Z. Ying (Ericsson, 1997)

→Flexible and easy to manufacture

→Volume over 15 millions.

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Where are the antennas?

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Internal antennas

→Small, compact terminals

→External design independent of antenna

→More robust handsets

→Easy to produce, cost effective

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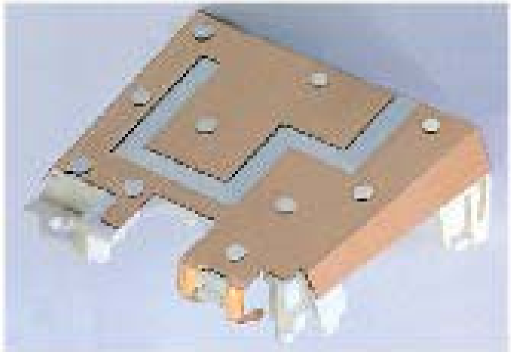
Patch antennas



→Very popular

→Good electrical properties

→High efficiency

→Mechanically robust, easy to manufacture

→Low cost

→Easily tuneable

→Multiband antennas operation possible

→Mechanical fixation necessary

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Multiband patch antennas

→Coupled resonators (fed / coupled)

→Small in size, low production cost

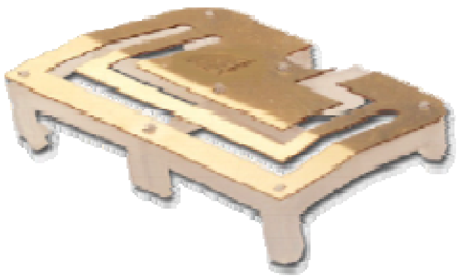
→Centre frequency and bandwidth can be controlled to some extent

→Bandwidth for lower bands limited

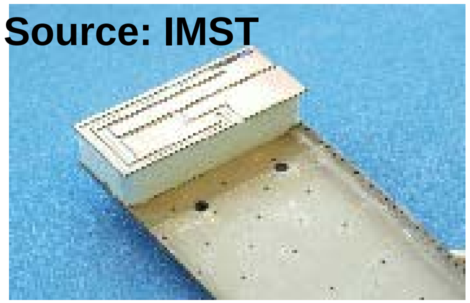
→Require experienced engineers and reliable CAD tools

Combination patches / slots

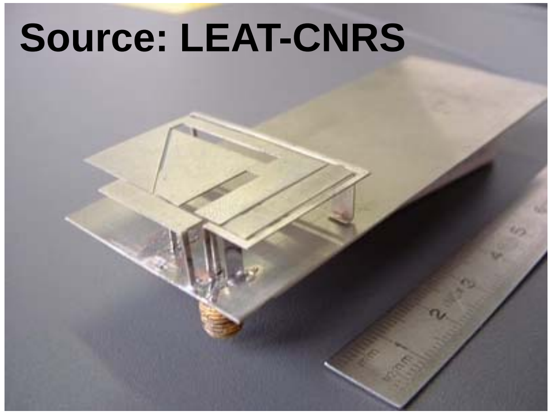
Source: IMST



3 bands:
GSM 900/1800/1900



4 bands:
GSM 900/1800/1900/UMTS



5 bands:
GSM 900/1800/1900/UMTS/WLAN

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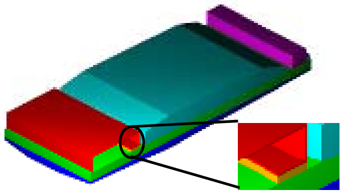
Integrated patch antennas



Sony CMD-C1

→Patch Antenna

→Air-filled

→Capacitive end to reduce size

Nokia 8810

→C-patch antenna

→Air-filled

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Integrated patch antennas

Nokia 3210: planar Antenna

→3D-MID-Technology

→3-D flexibility

→High tooling costs: production volume must be high

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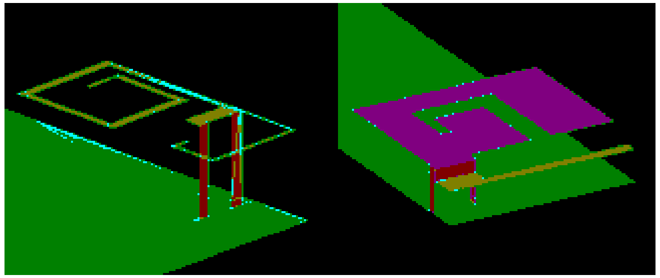
Other examples

Source: Sony-Ericsson



Twin spiral and dual band PIFA

→First dual band internal twin spiral antenna

→Z. Ying (Ericsson, 1998), extended to dual band branch PIFA for cellular phone

→Similar patents filed from different companies

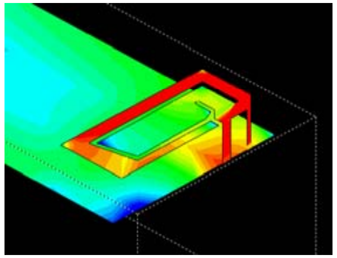
→Very popular in Nokia, Siemens, Ericsson products.

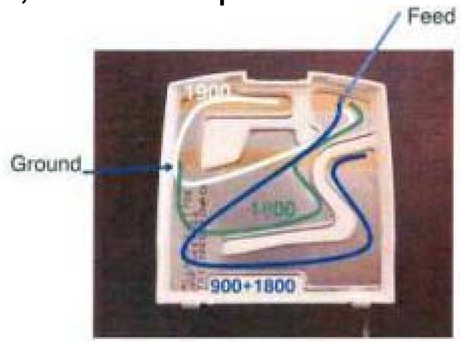
Branch PIFA

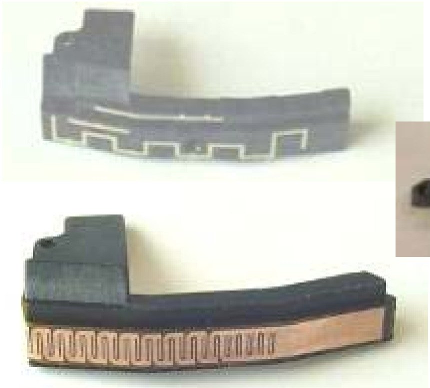
→First used in Nokia 8210 (1999)

→Different variants in the following years

→2-/3-band solutions







Multiband folded monopole antenna

→Branch or non-uniform meander line for multi-band operation

Source: Sony-Ericsson

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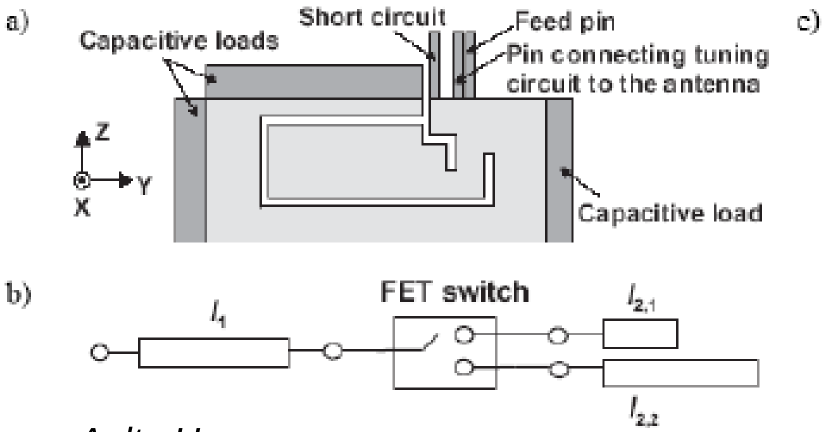
Frequency-Tuneable Antennas

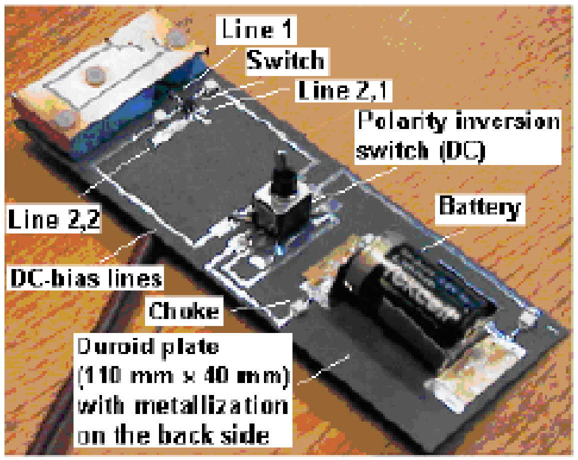
→Frequency agility to cover different bands

→Use of switches and matching networks

→Use of FET transistors, PIN diodes

→In the future: MEMs





Source: Aalto U.

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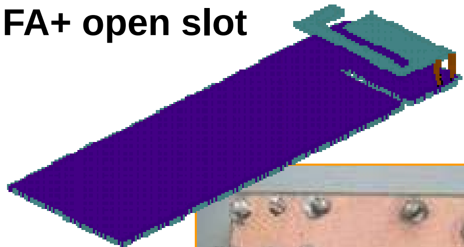
Antennas with slotted PCB

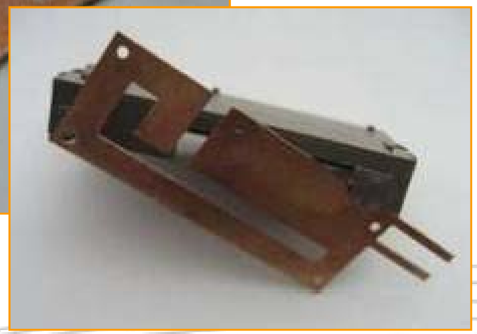
Universitat Ramon Llull

fractus
Optimised Antennas
for Wireless Devices

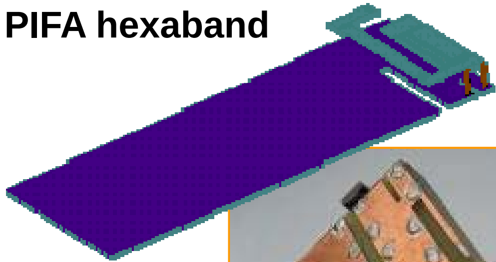
PIFA+ open slot



Patent app. WO 01/22528



PIFA hexaband



Patent app. WO 03/023900

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•Jaume Anguera, Iván Sanz, Alfonso Sanz, Antonio Condes, David Gala, Carles Puente, and Jordi Soler, "Enhancing the performance of handset antennas by means of groundplane design". IEEE International Workshop on Antenna Technology: Small Antennas and Novel Metamaterials (iWAT 2006). New York, USA, March 2006.

•Jaume Anguera, Iván Sanz, Alfonso Sanz, Antonio Condes, Carles Puente, and Jordi Soler, "Multiband Pifa Handset Antenna by Means of Groundplane Design", IEEE Antennas and Propagation Society International Symposium, Albuquerque, New Mexico, USA, July 2006.

•Cristina Picher, Jaume Anguera, Arnau Cabedo, Carles Puente, Sungtek Kahng, "Multiband handset antenna using slots on the ground plane: considerations to facilitate the integration of the feeding transmission line", Progress In Electromagnetics Research C, Vol. 7, 95-109, 2009. (pdf)

•Arnau Cabedo, Jaume Anguera, Cristina Picher, Miquel Ribó, Carles Puente, "Multi-Band Handset Antenna Combining a PIFA, Slots, and Ground Plane Modes", IEEE Transactions on Antennas and Propagation, vol.57, nº9, Sep. 2009 , pp.2526-2533

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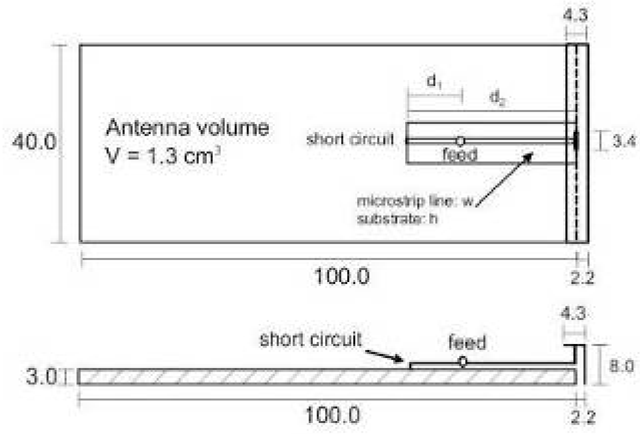
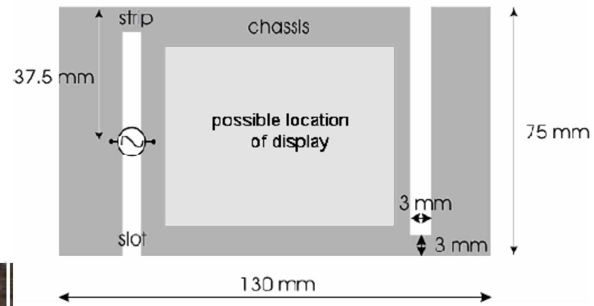
Coupling structures

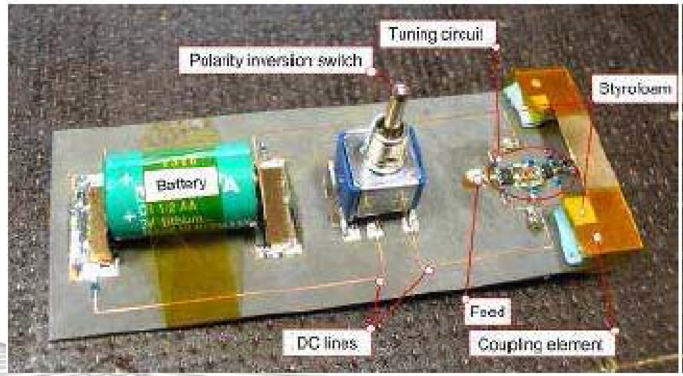
- → Small-size + bandwidth difficult to meet simultaneously with self-resonant antennas
- → 900 MHz: power radiated by surface currents on ground plane
- → Small non-resonant, non-radiating structures: couple power into the characteristic wavemodes of the chassis
- → Necessary resonances created by matching circuits.



E-GSM & DCS



DVB-H



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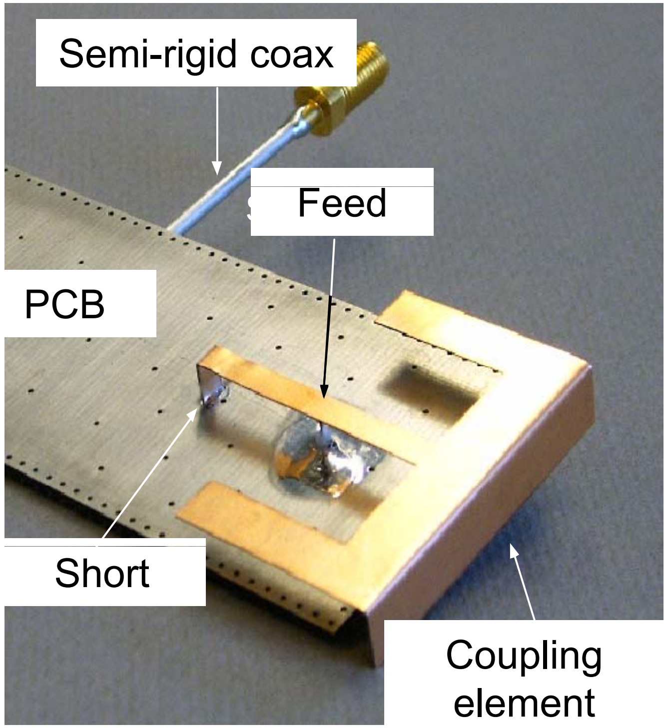
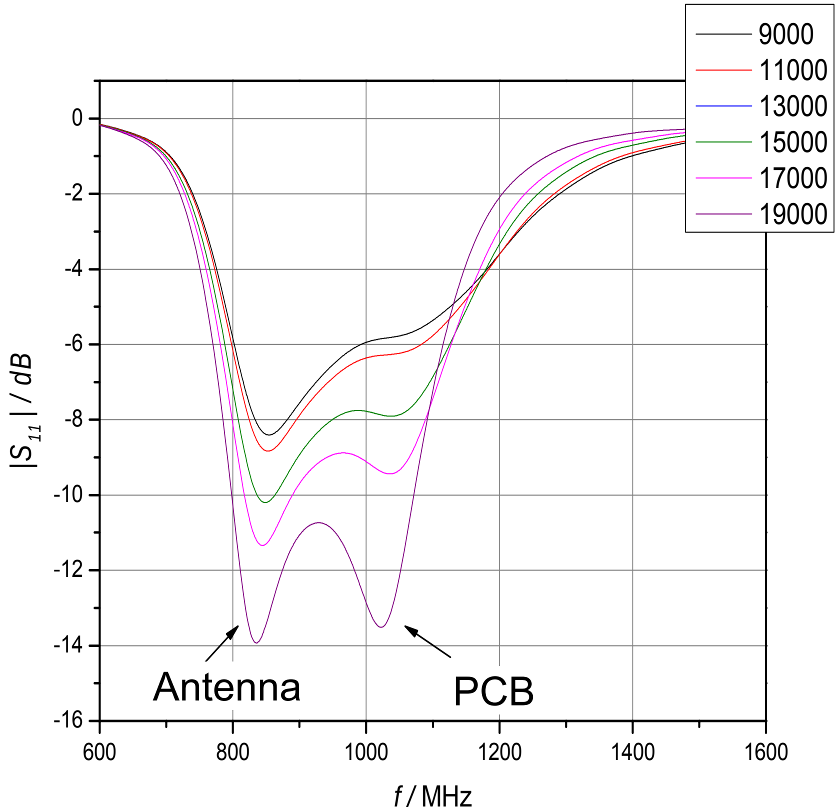
Coupling elements





→ Optimised coupling to the PCB

→ Optimised bandwidth

→ High efficiency (whole device acts as antenna)

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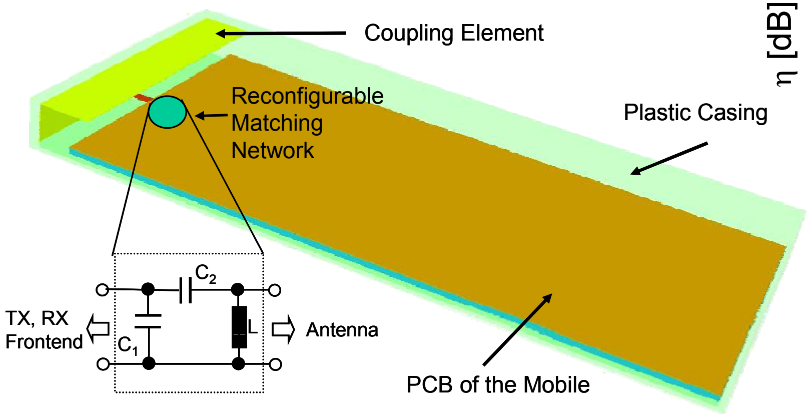
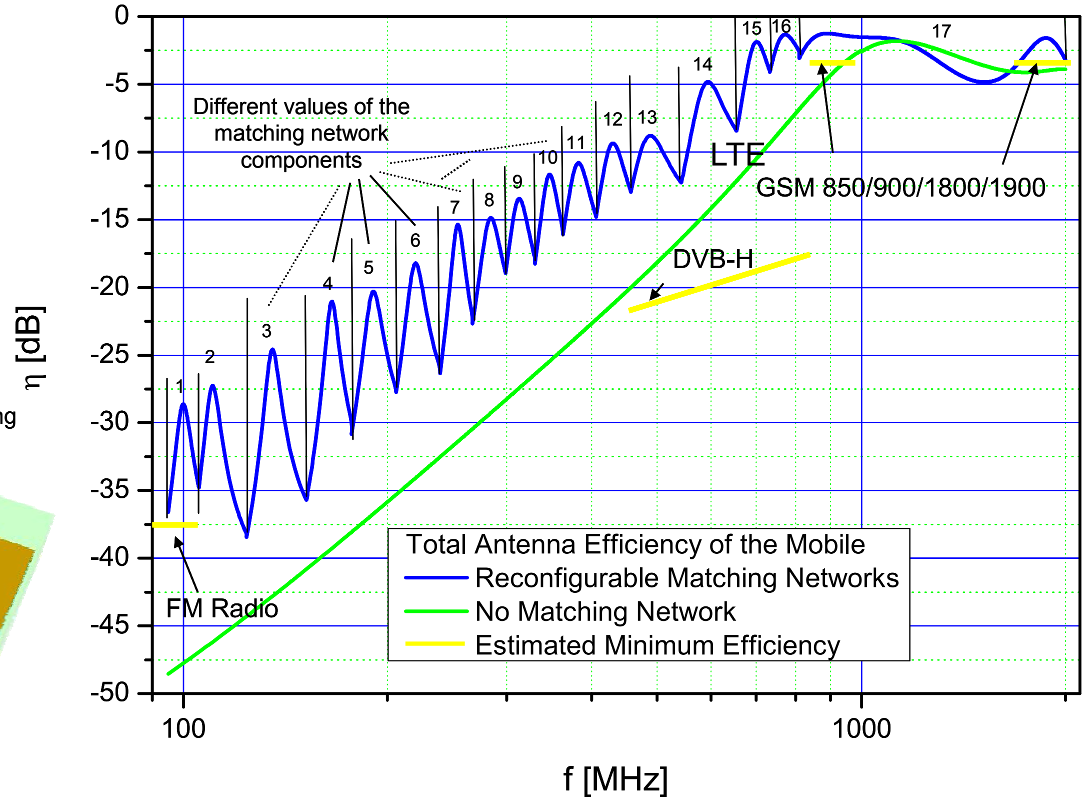
Reconfigurable coupling elements





→ Reconfigurable matching network

→ Multiband operation

D. MANTEUFFEL, M. ARNOLD: Considerations for Reconfigurable Multi-Standard Antennas for Mobile Terminals. In: IWAT2008 - IEEE International Workshop on Antenna Technology: Small Antennas and Novel Metamaterials, Chiba, Japan, March 2008.

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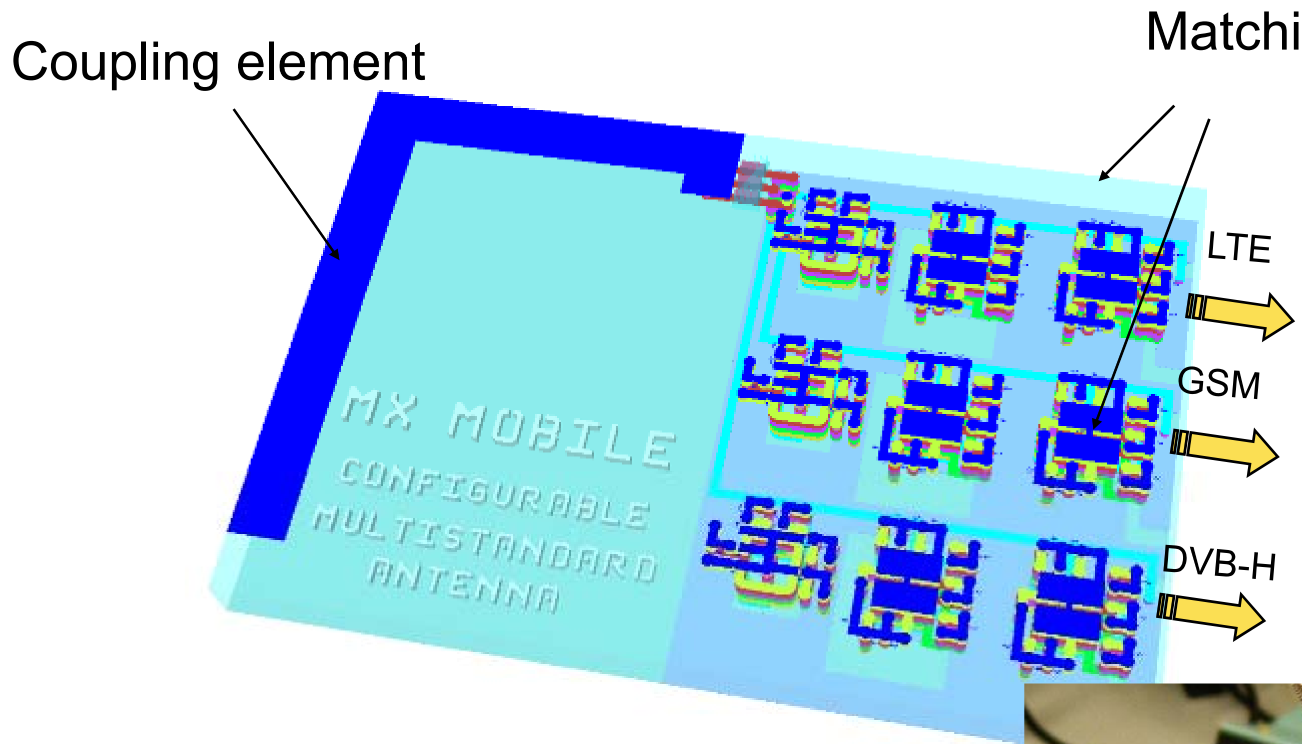
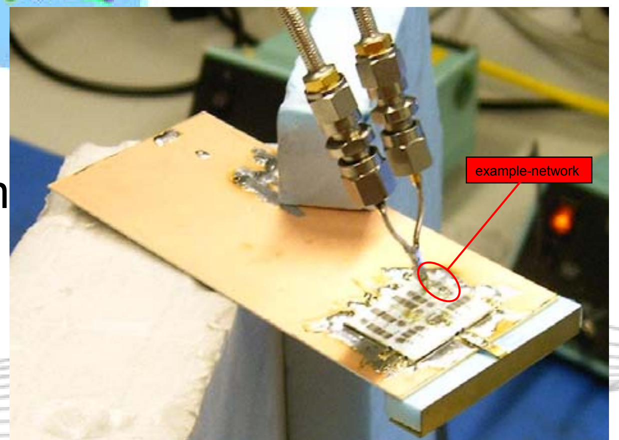
Reconfigurable multistandard antenna





→ Multistandard operation, single m

→ LTCC technology

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Looking again at the iPhone…

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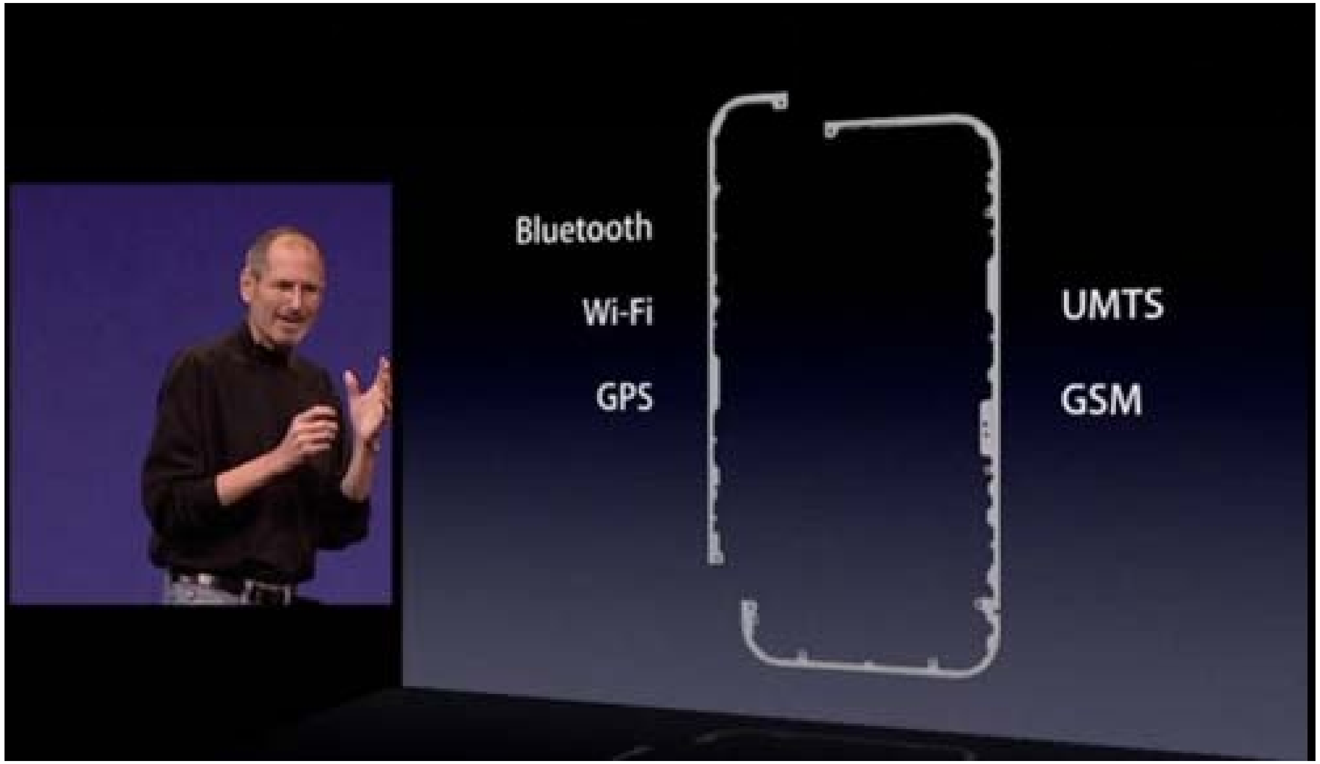
iPhone 4 antennas



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The future?

→ Nokia Morph concept device - Nokia Research Center (NRC), Cambridge Nanoscience Centre

→ Nanoscale technologies, flexible and transparent materials, …

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