Design of antennas for mobile communications devices: practical aspects.

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IMST GmbH

IEEE AP-S Distinguished Lecture
2012

Acknowledgements

→ Rens Baggen, Winfried Simon, Andreas Winkelmann (IMST)

→ Dirk Manteuffel (U. Kiel)

→ Jan Carlsson, Kristian Karlsson (SP)

→ Cyril Luxey (U. Nice Sophia-Antipolis)

→ Zhinong Ying (Sony)

→ Jussi Rahola (Optenni)

→ Jaume Anguera (Fractus S.A.)

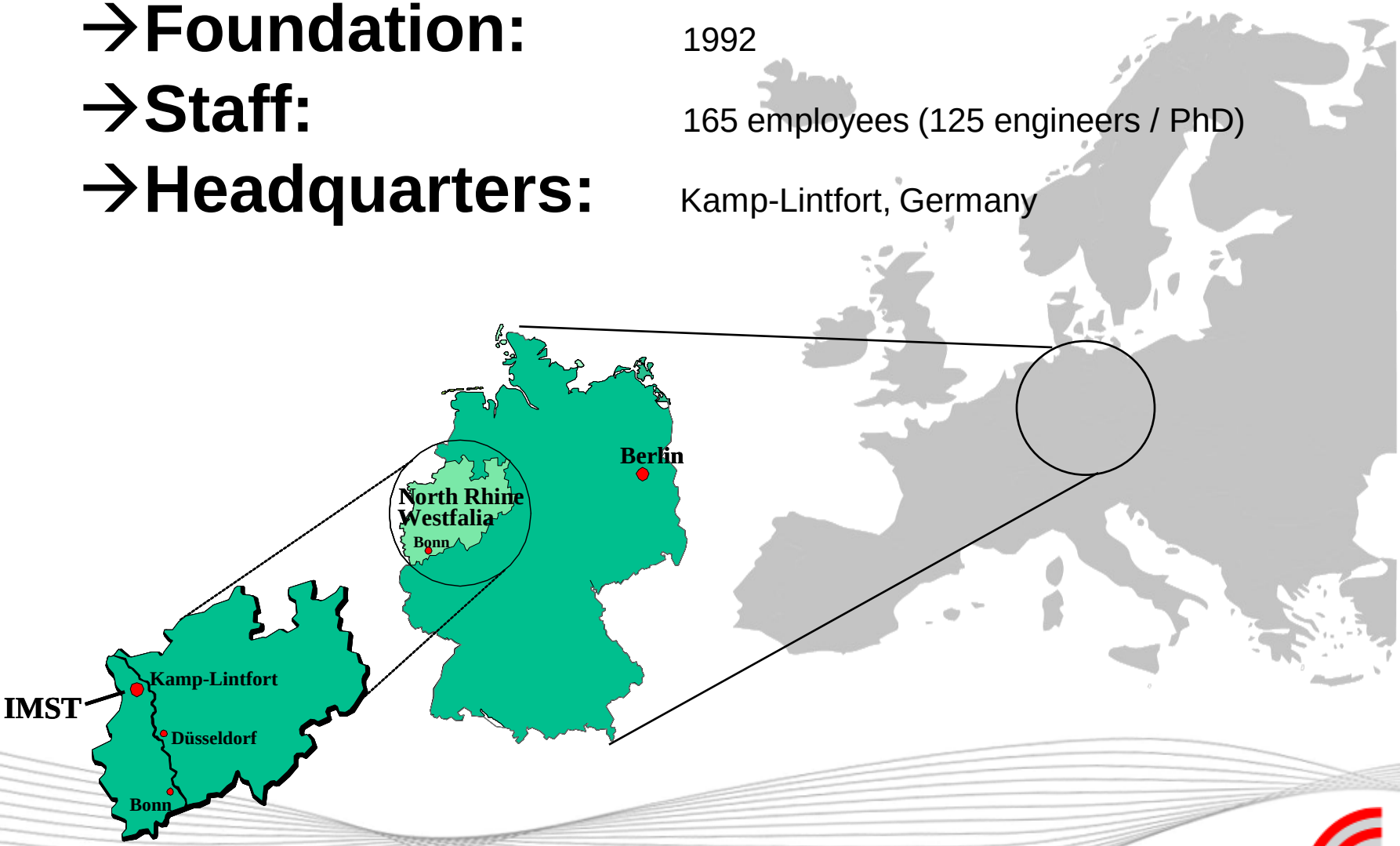
→ EURAAP WG “Small Antennas”

IMST GmbH in facts & figures

→**Foundation:** 1992

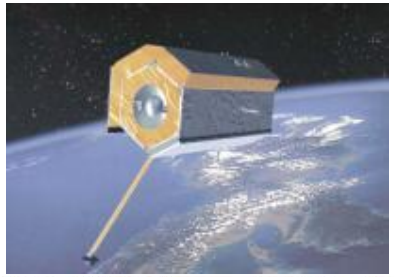
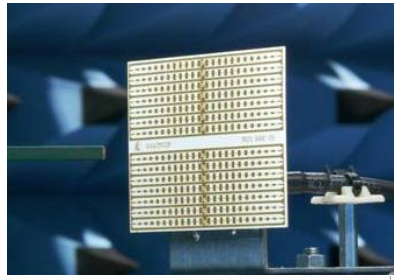
→**Staff:** 165 employees (125 engineers / PhD)

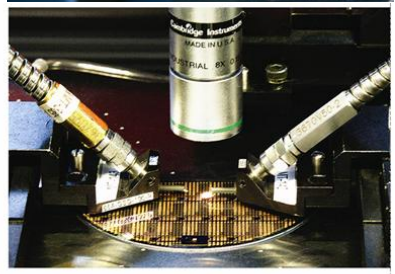
→**Headquarters:** Kamp-Lintfort, Germany

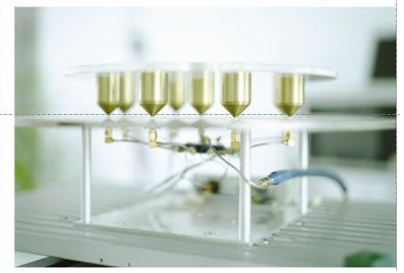
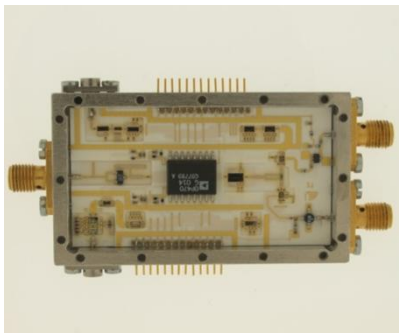
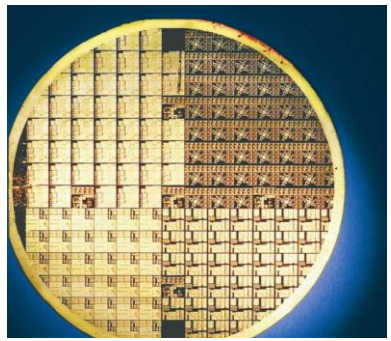
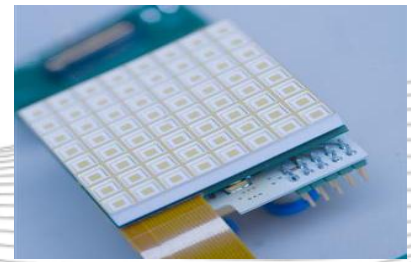
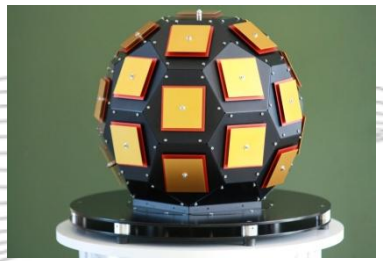


Target Markets

- → Telecom and IT
- → Automation
- → Automotive
- → Medical Device
- → Security
- → Space

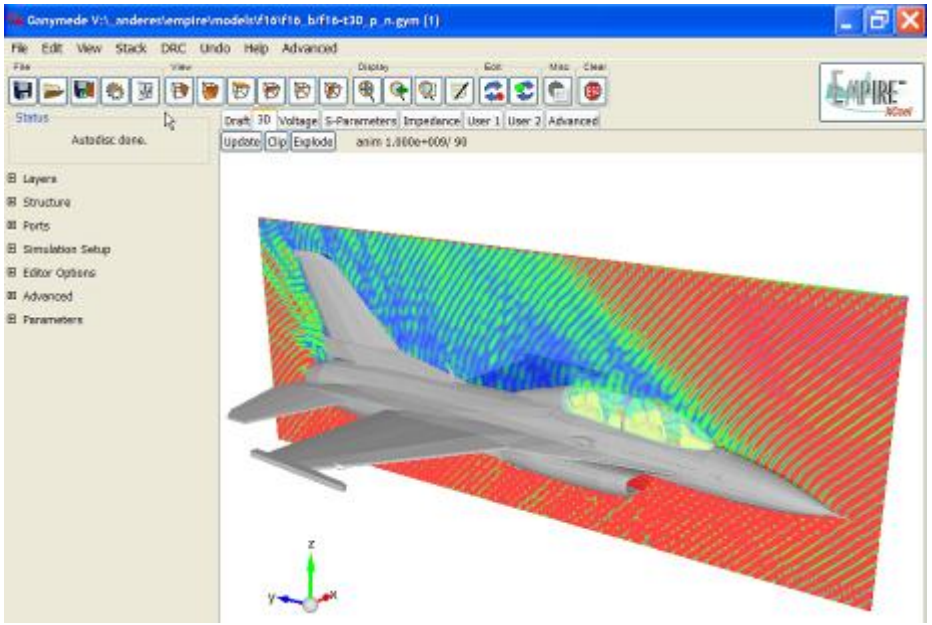


EM modelling tools

EMPIRE XCcel

Full wave 3D FDTD simulation

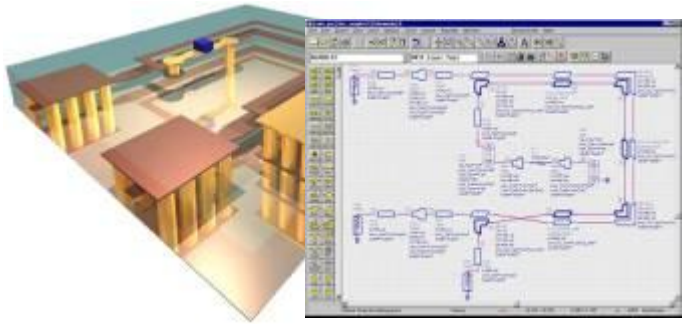


MULTILIB

For ADS™

Library for multilayered elements

Integrated in Agilent ADS™

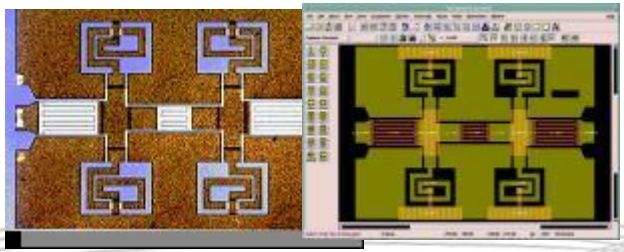


COPLAN

FOR ADS™

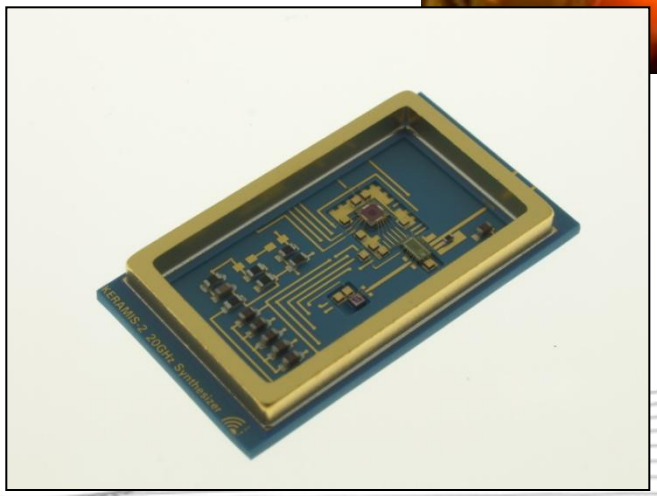
Coplanar element library

Integrated in Agilent ADS™



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

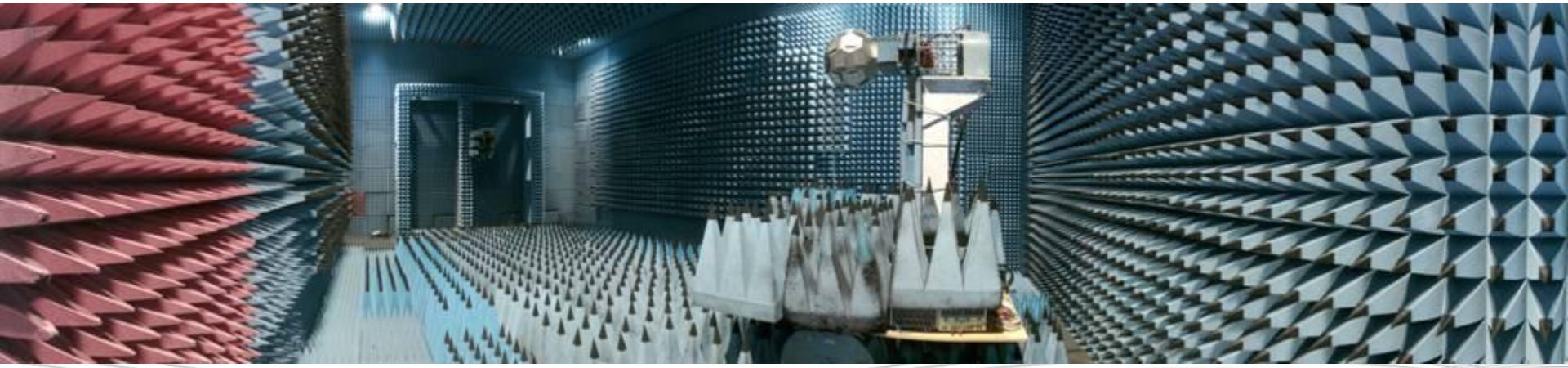


Measurements & Testing

- → 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



Scope of the talk

→Introduction & historical review

→Practical considerations & design flow

→State of the art

Scope of the talk

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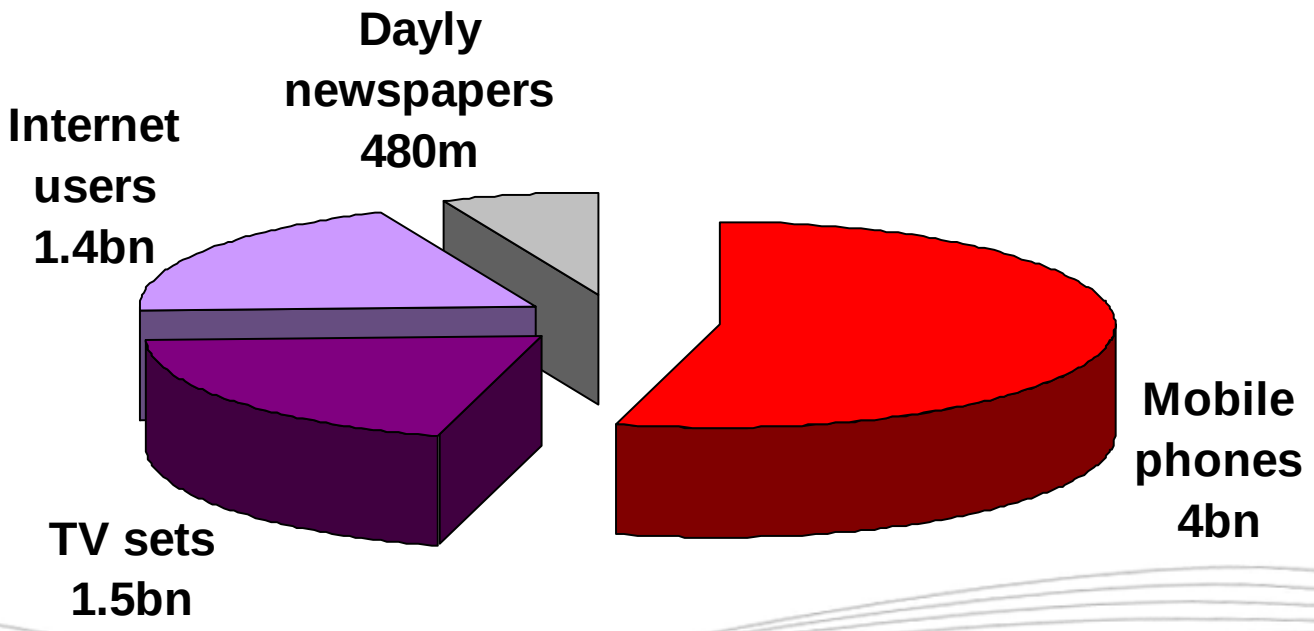
Mobile market

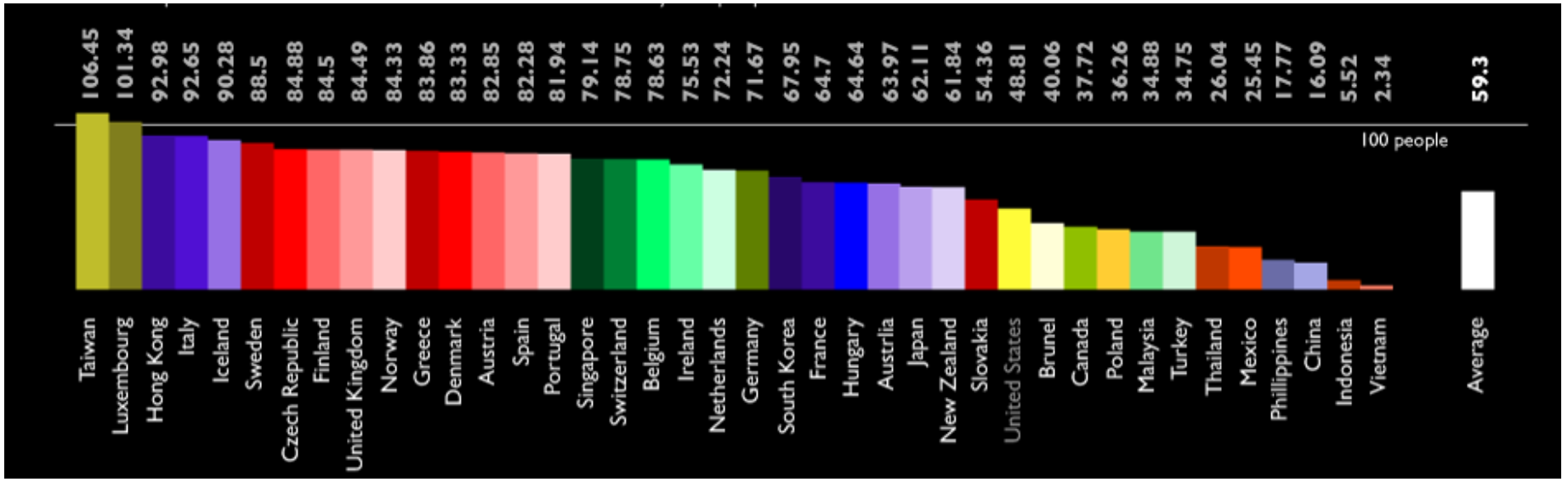
Mobile subscriptions worldwide:

- 2010: 4bn
- 2011: 6bn = 87% of the world population!!!!



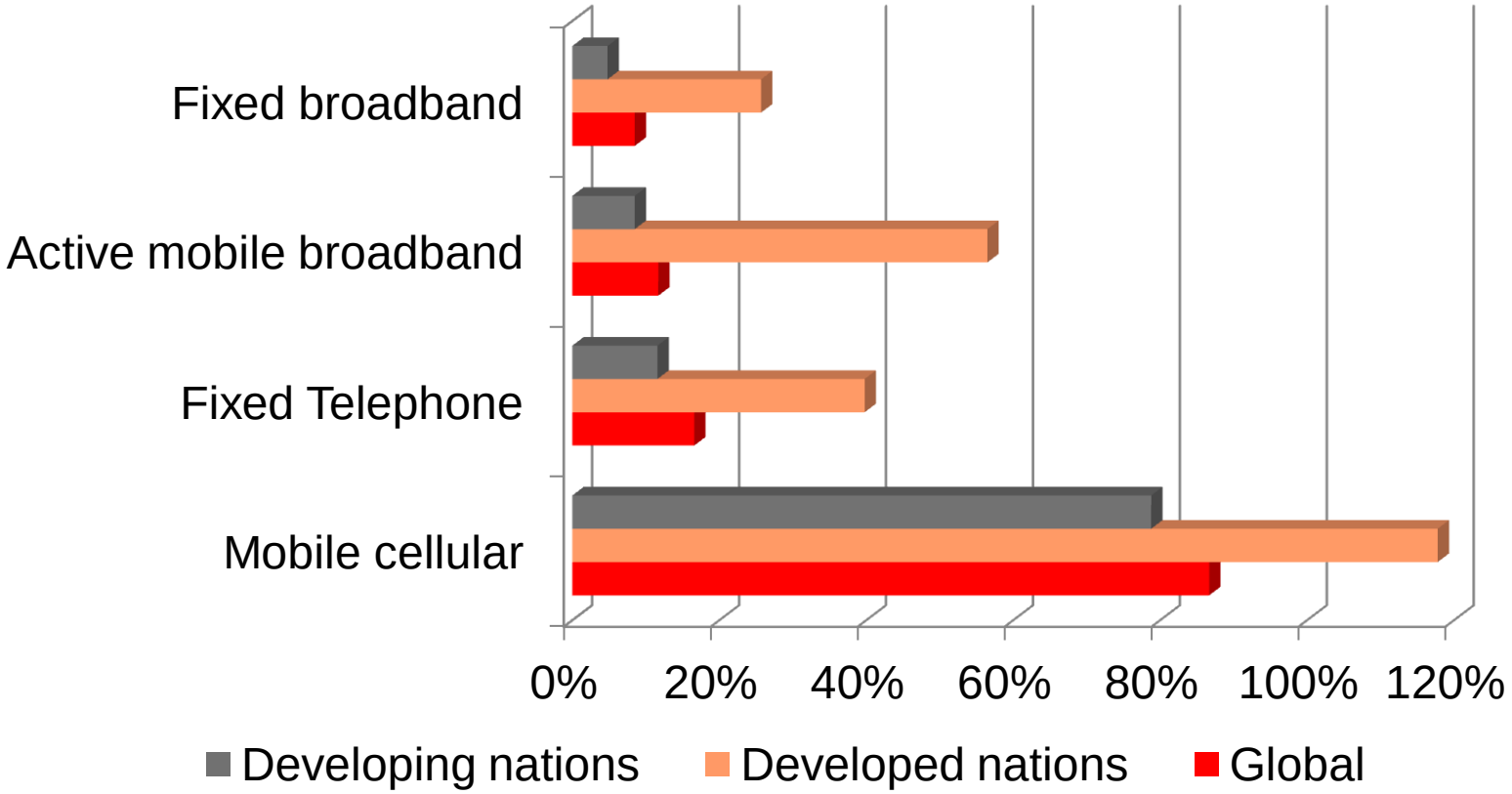
Mobile market

Number of mobiles for every 100 people

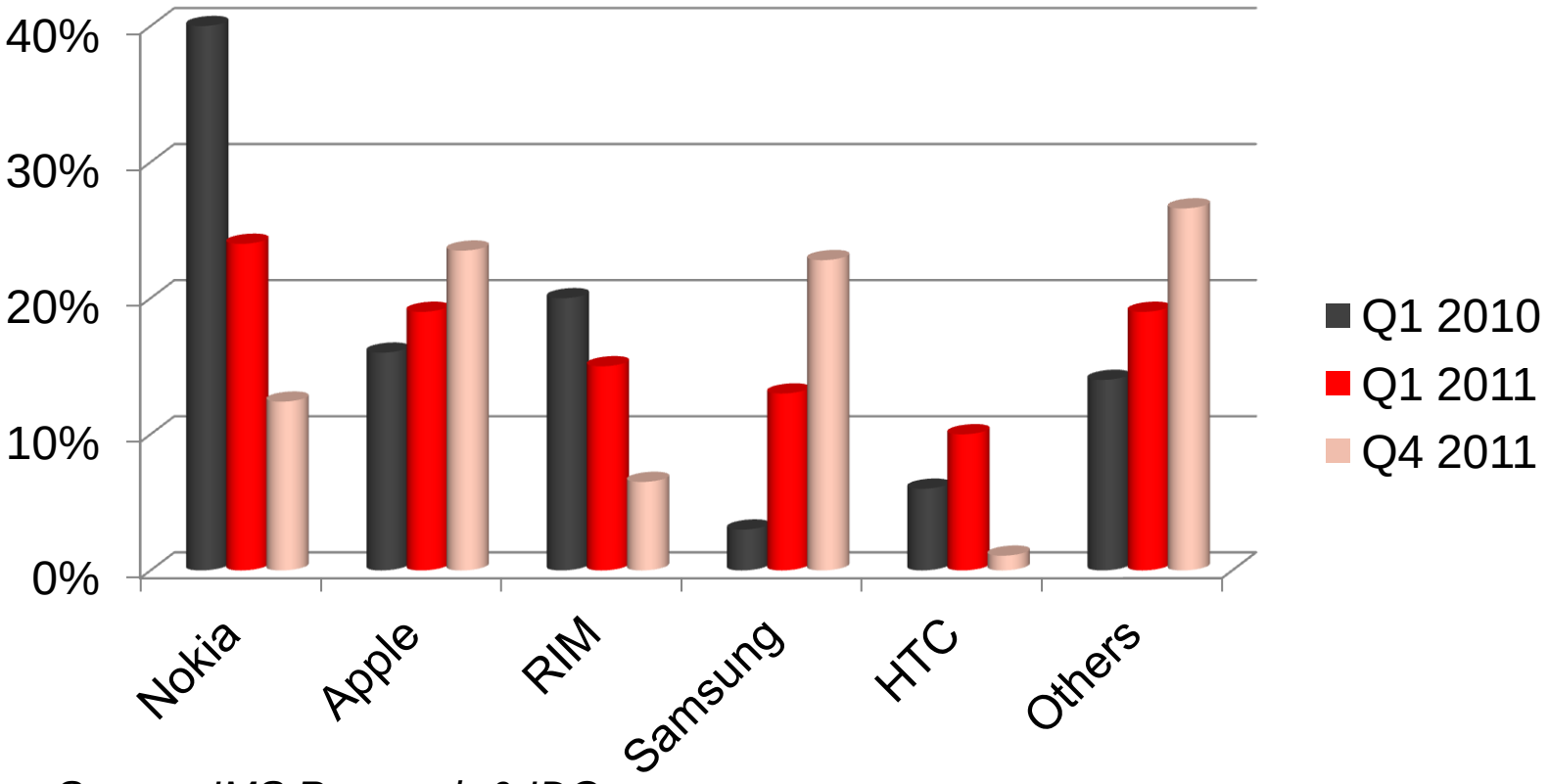


Source: i-strategy

Global telecom indicators (ITU, 2011)



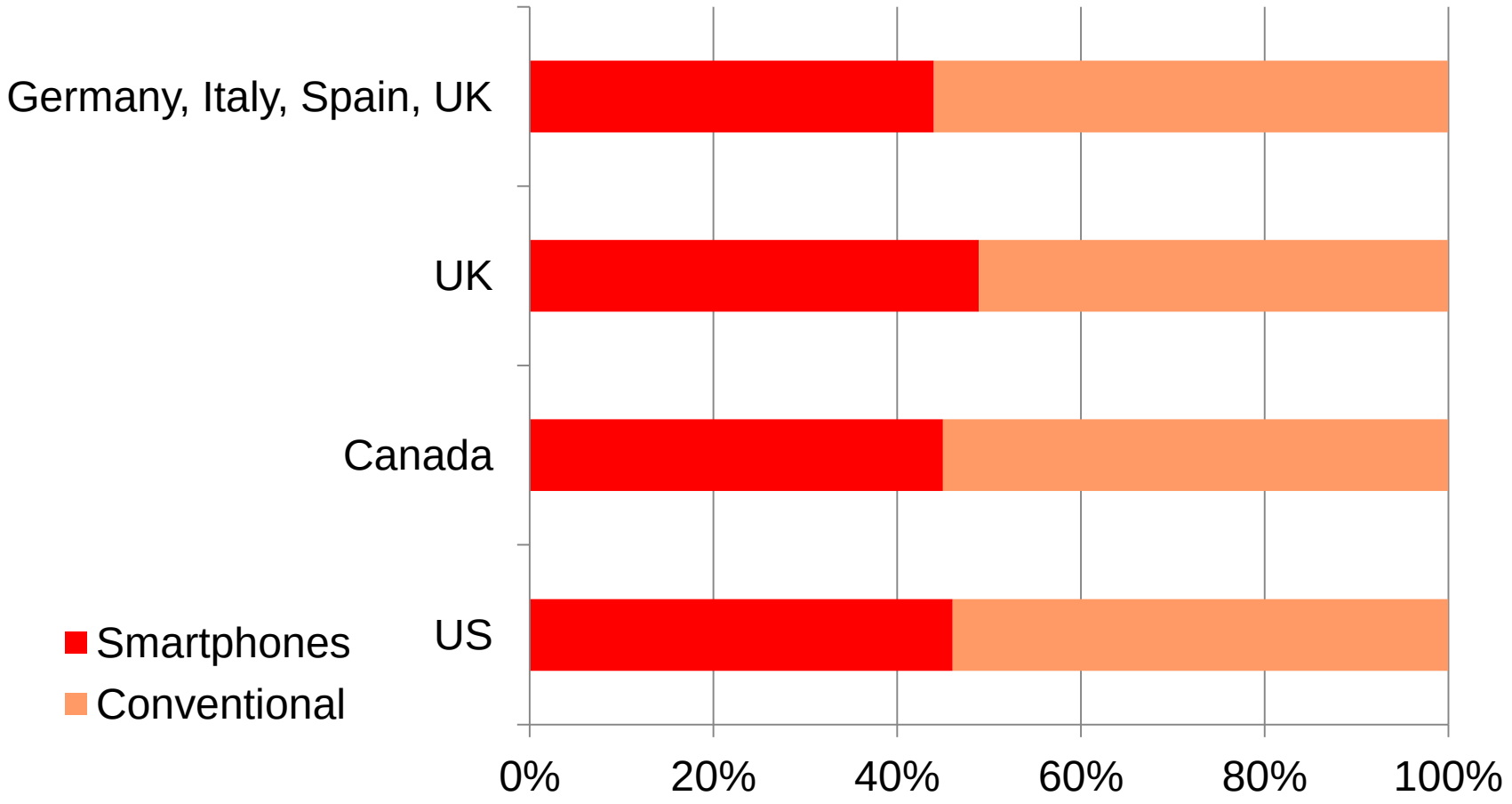
Market Evolution



Source: IMS Research & IDC

Smartphone sales (Dec 2011): 472 Million (+58%)
31% of total market

Smartphone penetration (2011)



First mobile ever?

Get Smart! (1965)

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.

Nowadays…

GSM, 3G, LTE

Bluetooth

WLAN

GPS

DVB-H

FM

etc…

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

Challenges

Go wireless!!!

… but please provide:

→Small antennas

→Internal antennas

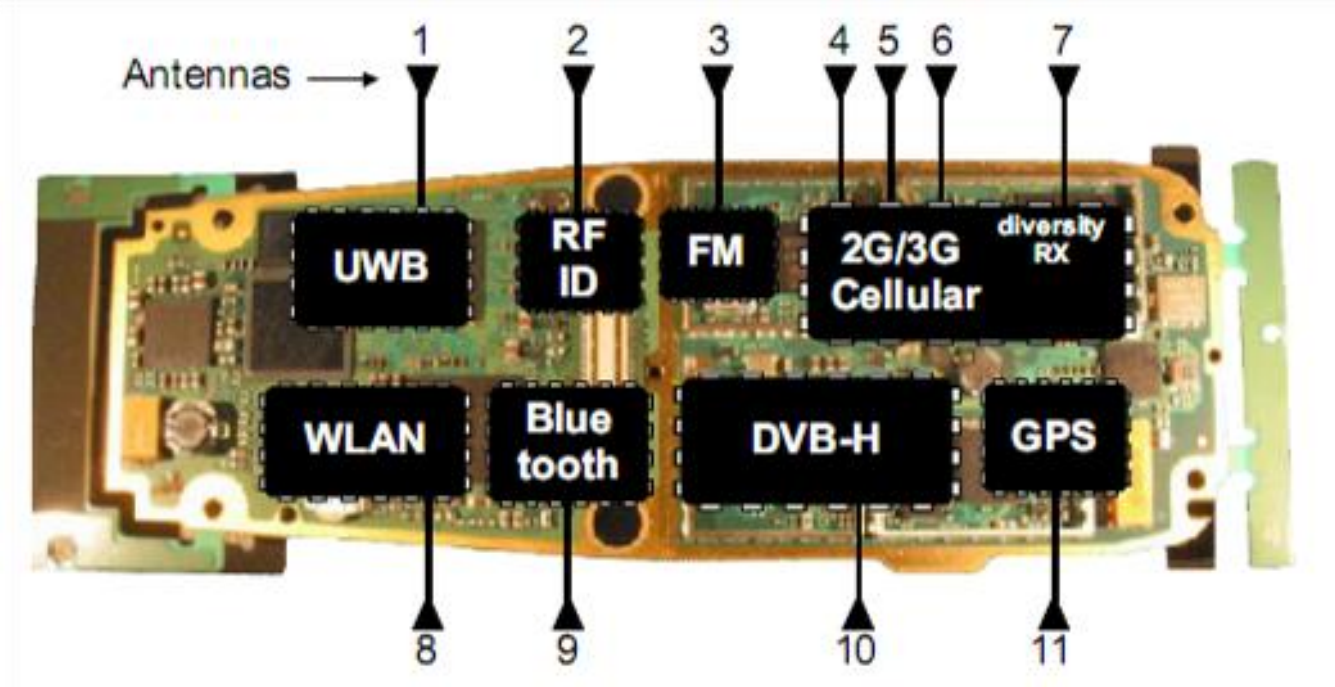
→Light weight

→Cheap

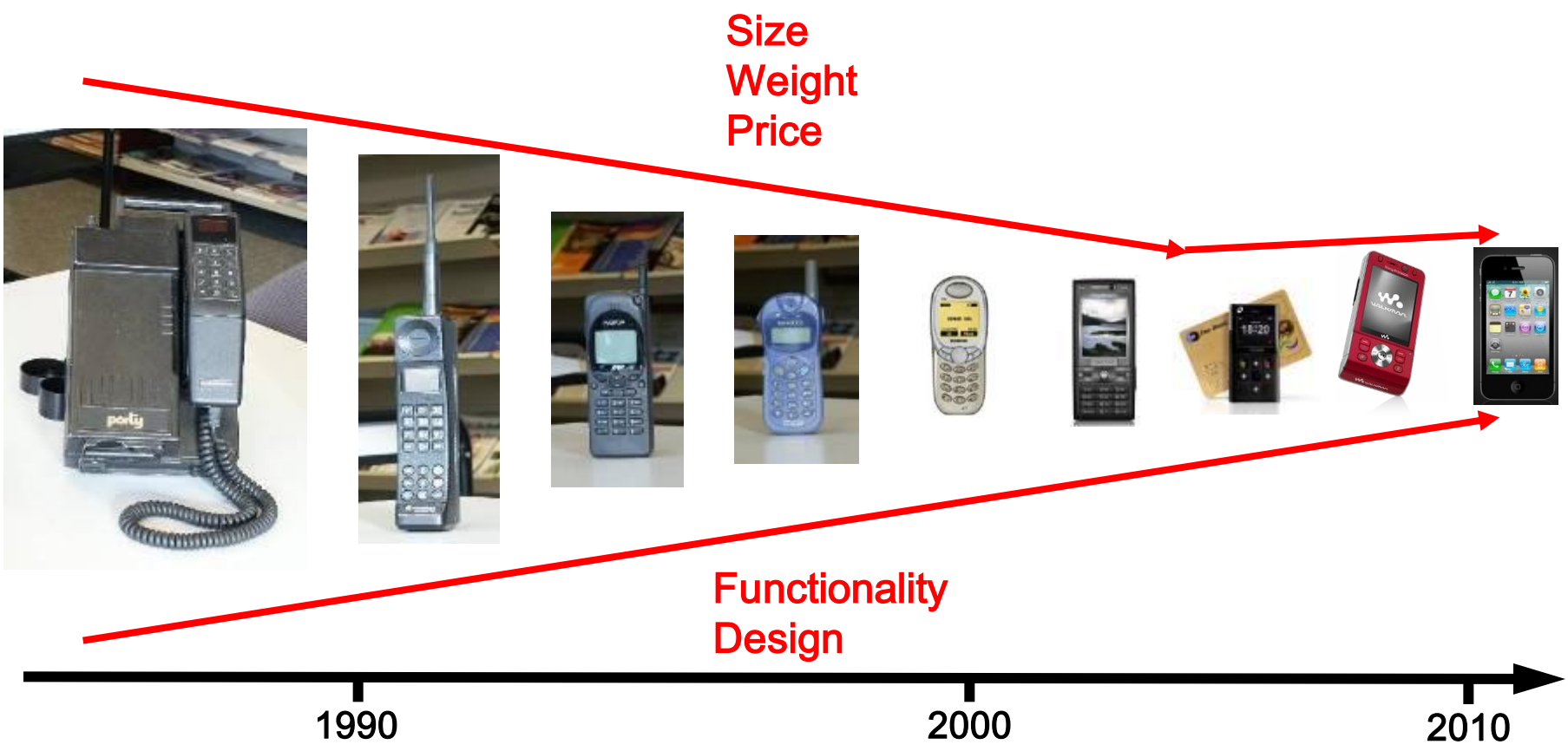
→Multi-band

→Multi-antenna systems

Which means…



Handset evolution

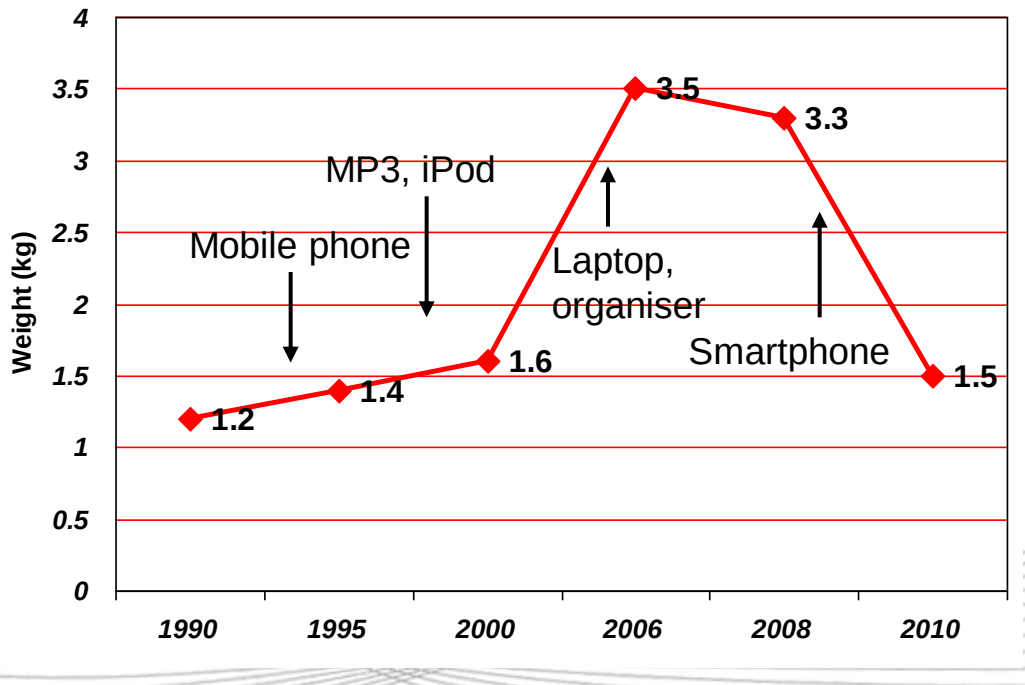


From a different point of view…

→ Last 15 years: impact of laptops and mobile phones

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

→ Reason: smartphones!



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

Meet the pioneer!

Hagenuk Global Handy (1996):

The first GSM-phone with an integrated antenna!

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!!!**

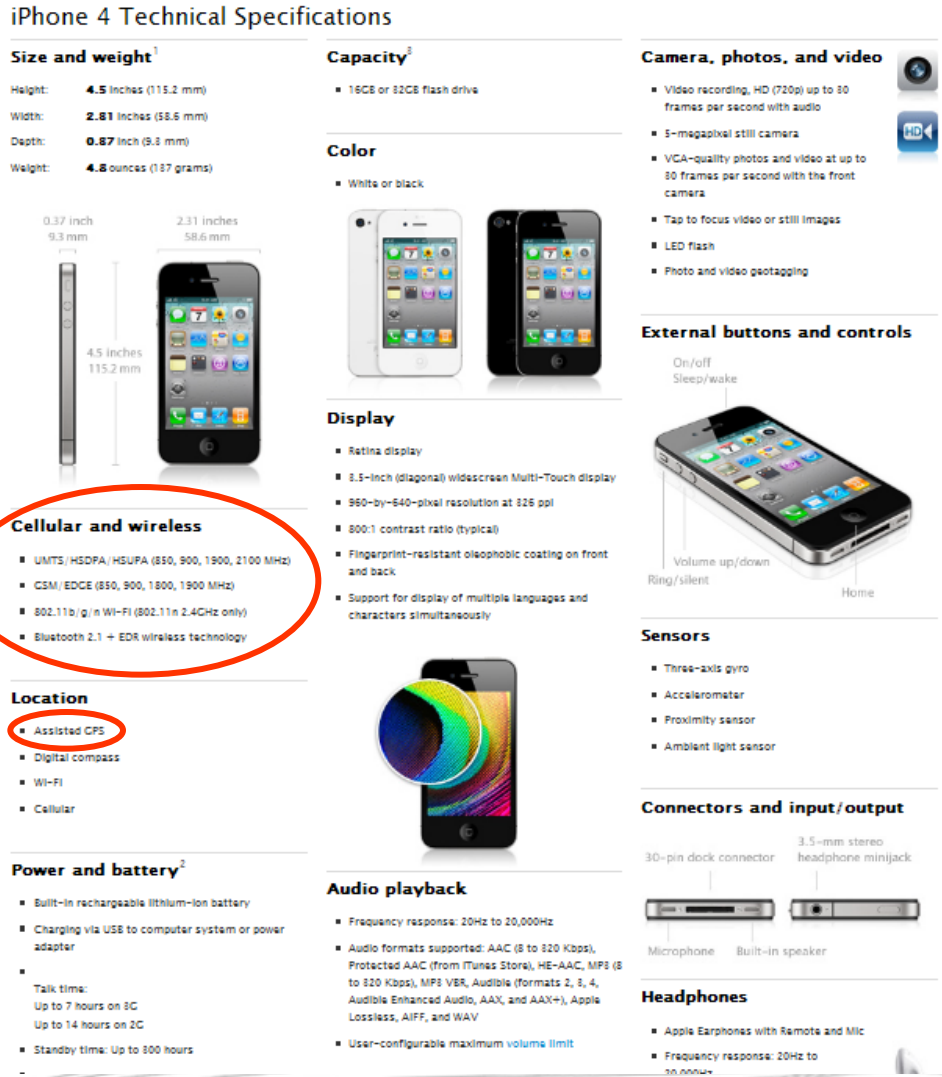
From mobile to smartphone

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

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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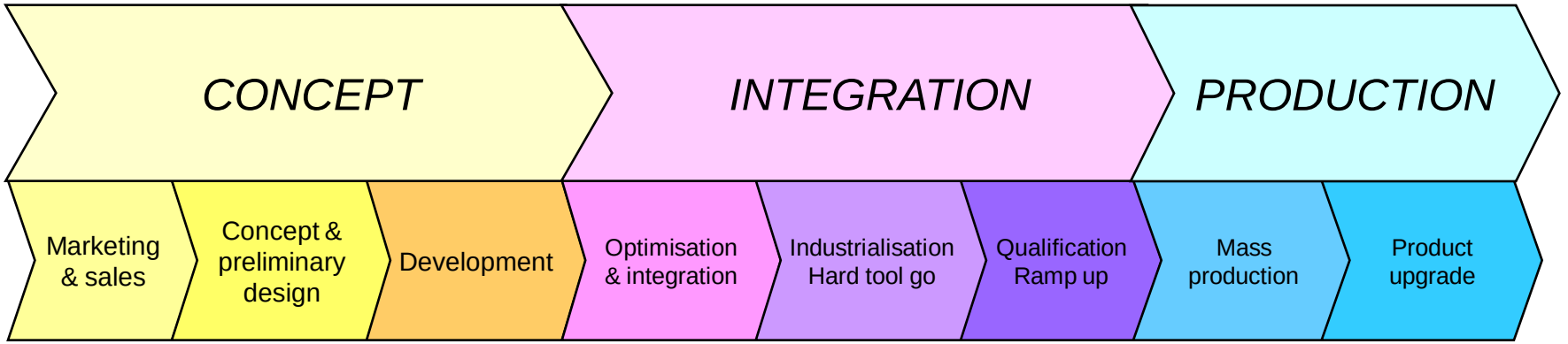
Mobile handset development



Design flow

Antenna design process

Antenna concept / Simulation

Test hardware

First Measurements

Demonstrator (electrical properties)

Antenna development process

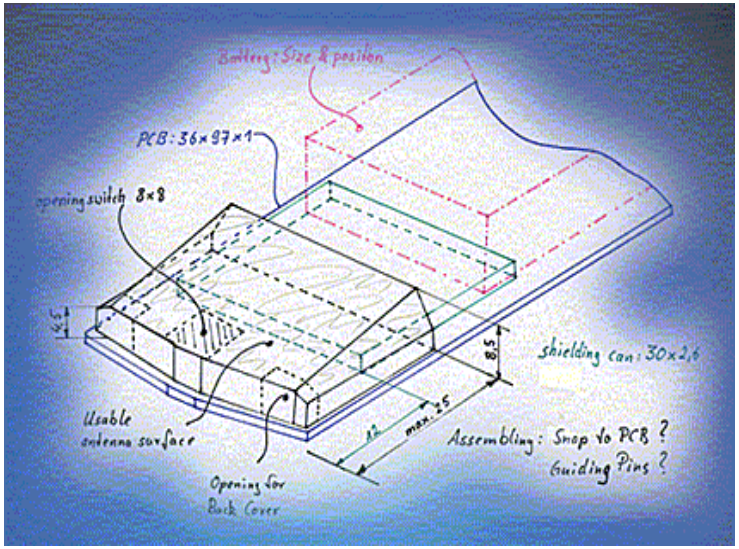
Mechanical design of the antenna

Technology & contacting

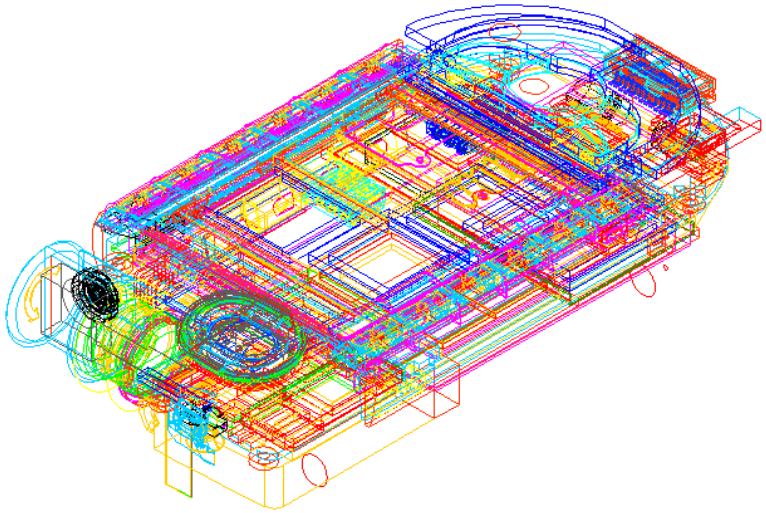
Prototyping

Production and delivery

Customer requirements



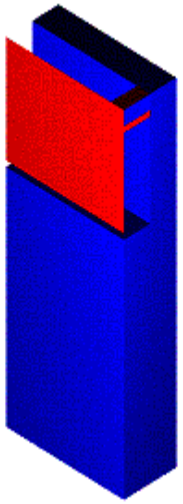
- → Pre-defined mobile phone
- → Antenna functionality
- → Available space / Shape
- → Pre-defined position of feed contacts



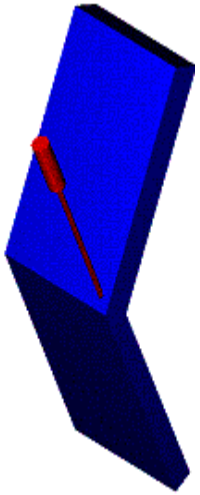
- → Interaction necessary with other design departments (circuits, mechanics…)
- → Antenna design should start at the same time as handset development!!!

Types of mobile phones

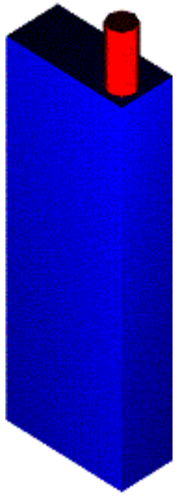
Typical Platforms and Antenna Concepts of Mobile Phones



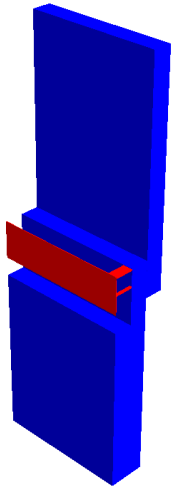
Bar phone with integrated antenna



Flip-phone with external antenna



Bar phone with helix antenna



Slide phone with integrated antenna

Handheld terminals

→ Multiband antenna

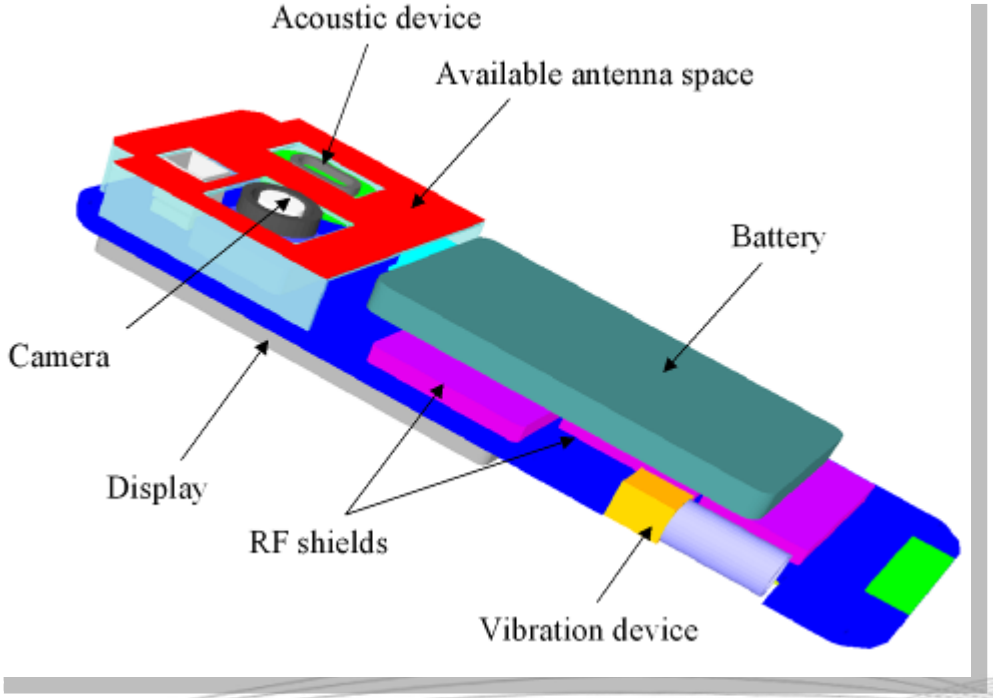
→ Integrated in casing

→ Effect of battery, RF elements and plastic cover

→ Mechanically robust

→ Low cost

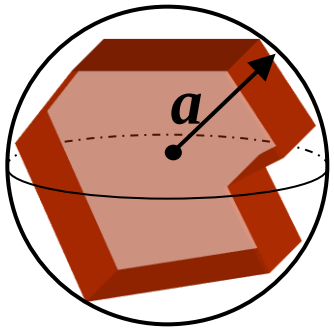
→ High efficiency



Bandwidth limitations

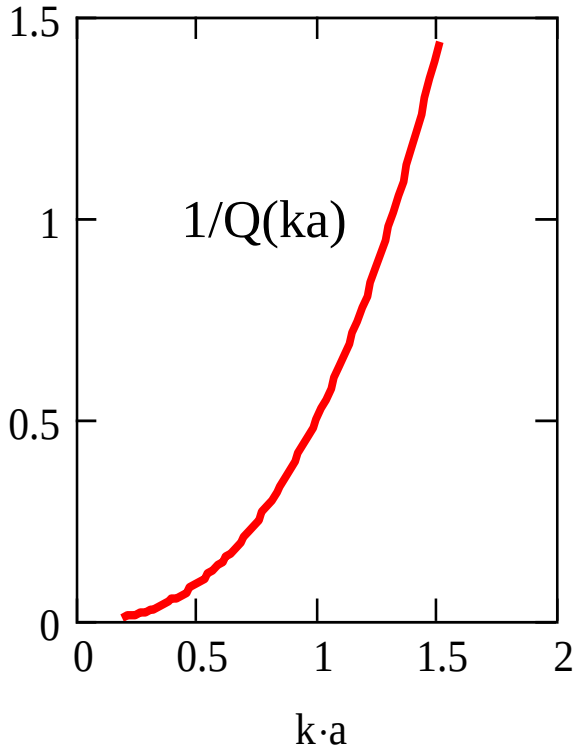
Chu-Harrington theoretical limits:

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



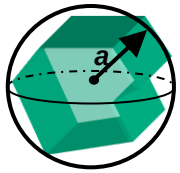
$$Q_{\min} = \frac{1+3k^2a^2}{k^3a^3(1+k^2a^2)}$$

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

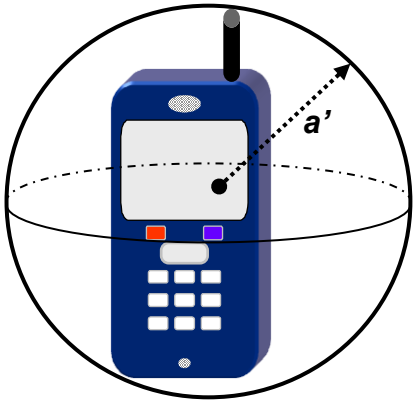


→ **Relation bandwidth - antenna volume**
→ **Goal: optimising this relation**

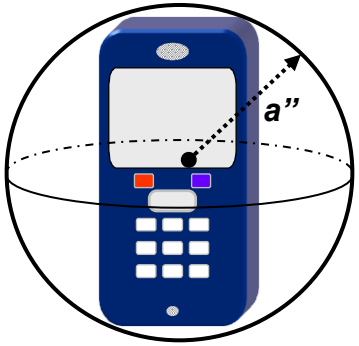
Handset antennas



Antenna only



External antenna



Internal antenna

Antenna not in free space:

→ Finite ground plane

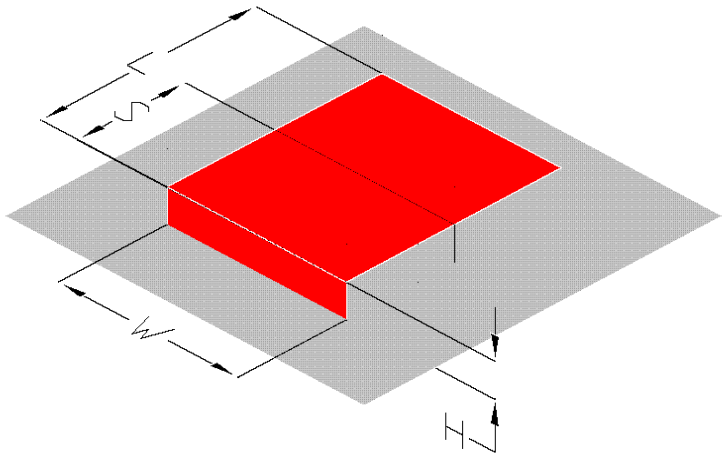
→ Effect of handset components (battery…)

→ User's presence

Influence on antenna performance!!!

Concepts for internal antennas

Basis: Planar Inverted-F-Antenna (PIFA)

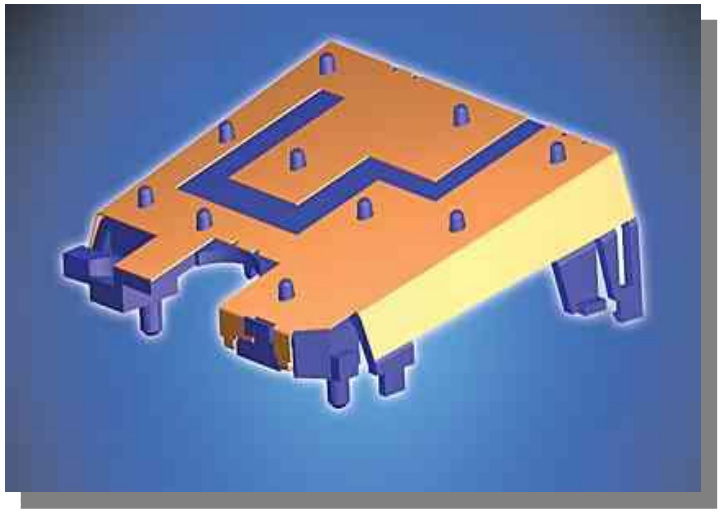


$L + H \approx \lambda_0 / 4$ Resonance frequency

$Z_{in} = f(S)$ Input Impedance

$BW = f^*(H, W)$ Bandwidth

Result: handset antenna



→ Folded radiator (miniaturisation)

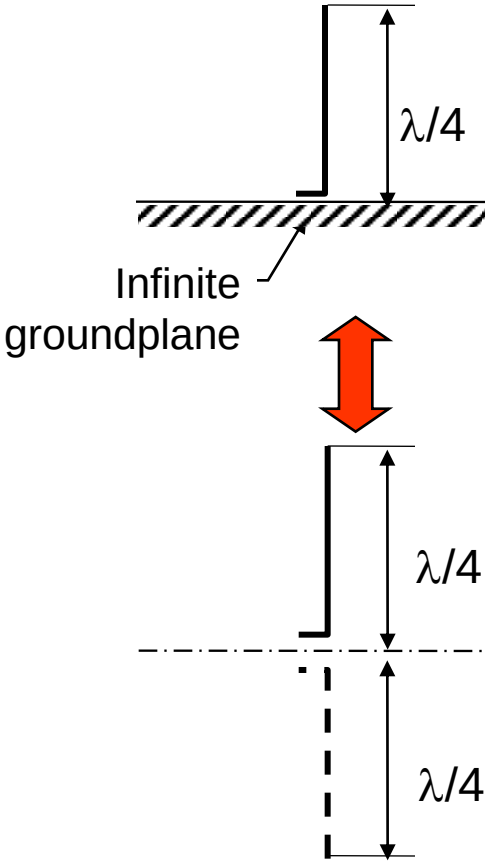
→ Shape adapted to cover

→ Slots and cuts to induce multimode

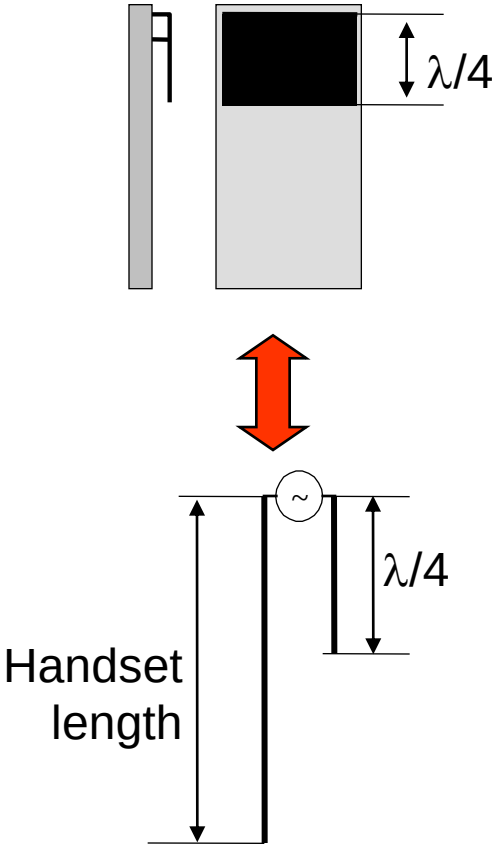
⇒ **individual design for each mobile device!!**

Effect of the finite ground

Monopole over infinite ground

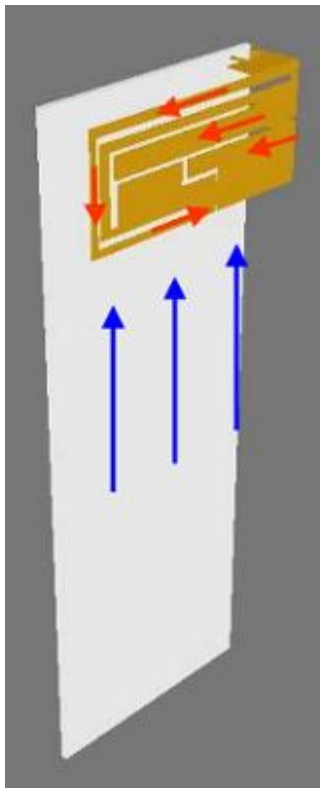


Handset with integrated PIFA

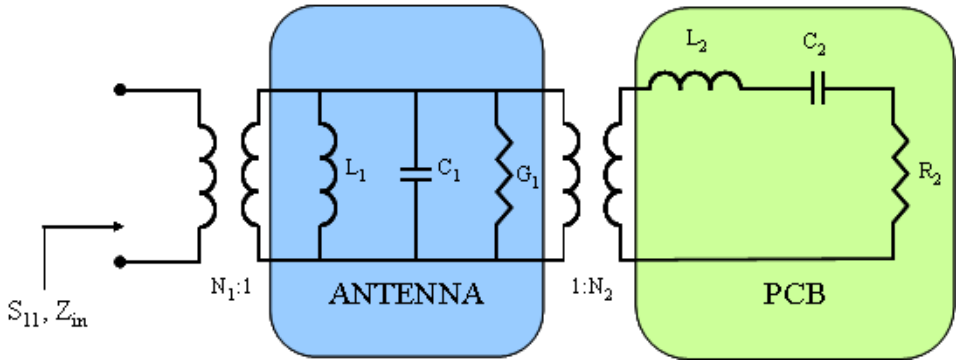


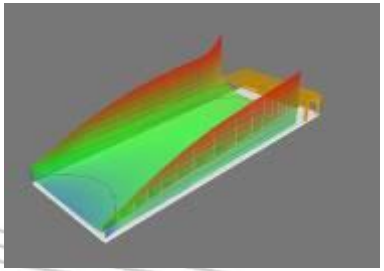
ASSYMETRICAL PROBLEM!

Effect of the PCB

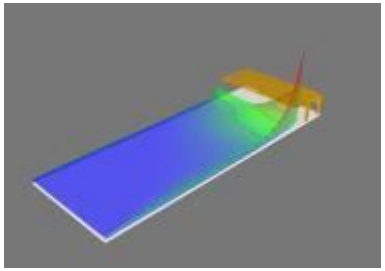


- → Current distribution on the patch induces currents on PCB (frequency related!)
- → PCB contributes to radiation
- → Equivalent circuit model

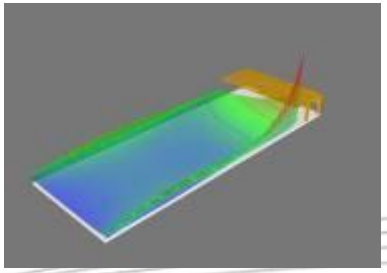




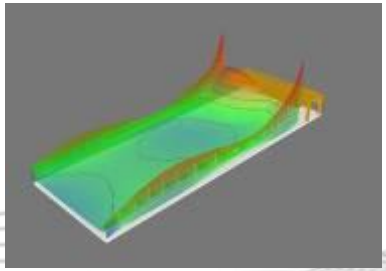
GSM



DCS



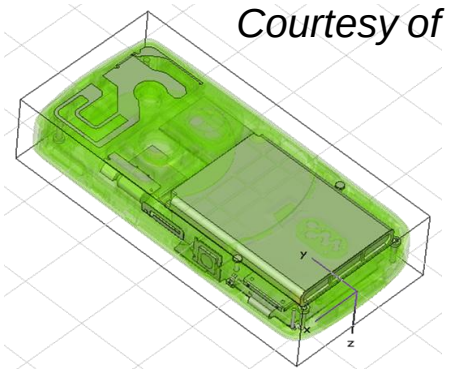
PCS



UMTS

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

Limitations of *em* tools

Reasons:

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

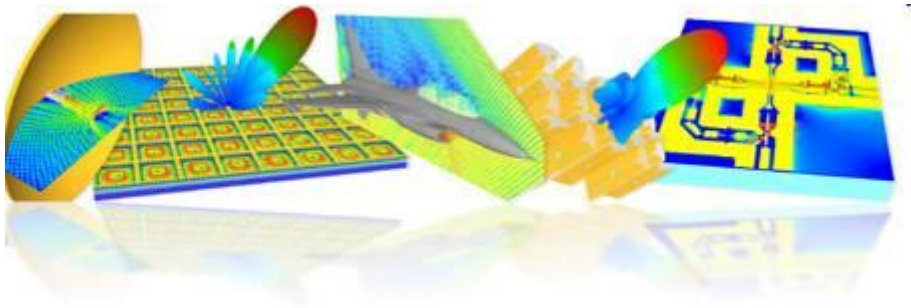
→ Mathematics
- Model limits
- System complexity
- Numerical stability

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

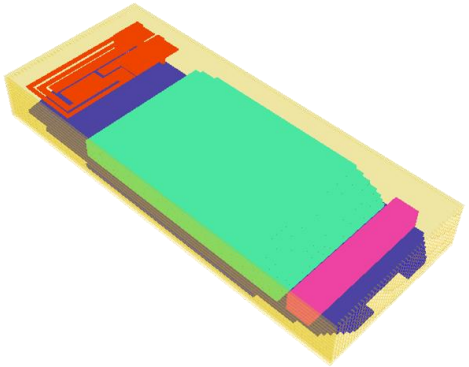
Influence of:

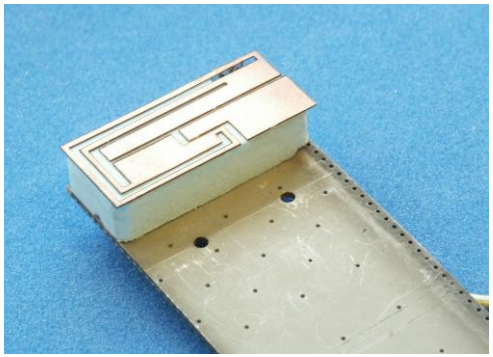
→ Hardware
- Memory requirements
- Processing capabilities
- Simulation time

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



From concept to prototype





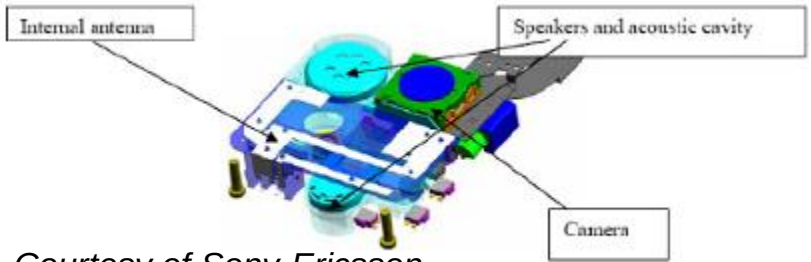
Simulation model

→ Simplified structure

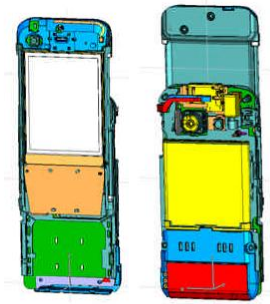
→ Metallic patch

Implementation (demonstrator)

→ Antenna with foam carrier: mechanical stability

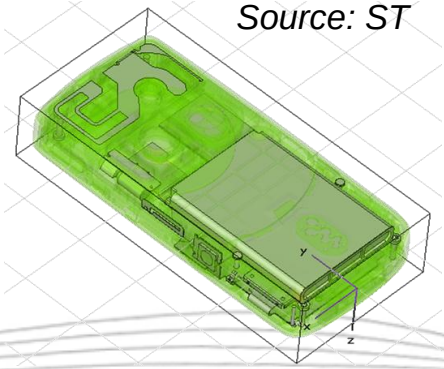


Courtesy of Sony-Ericsson



Courtesy of Nokia

Source: ST



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

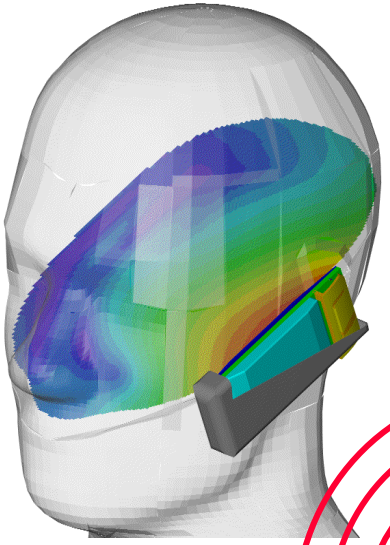
Mismatch (including user)

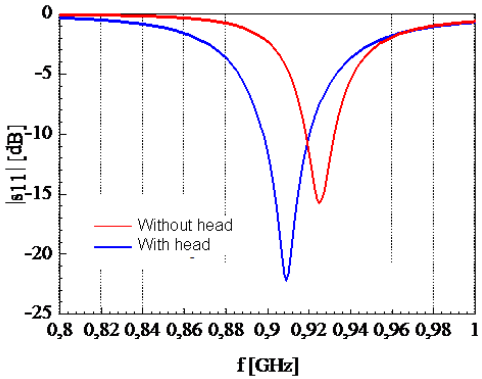
Delivered

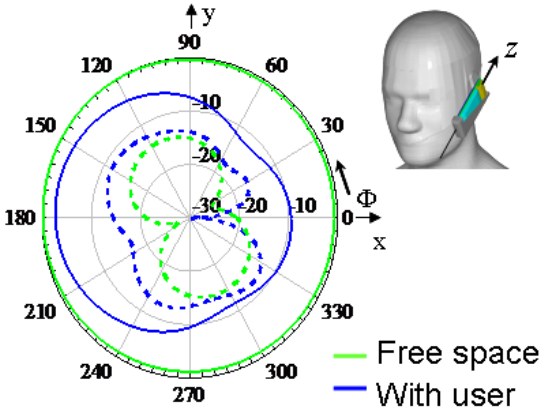
Antenna

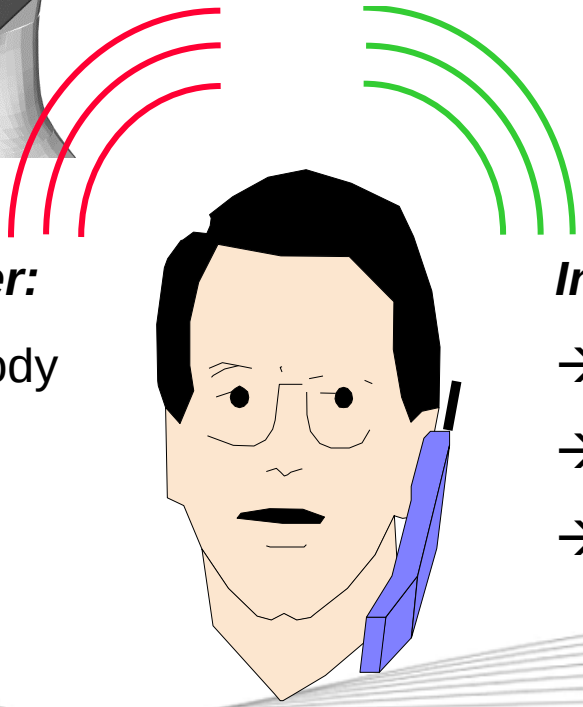
Absorption

Human-mobile interaction









Influence on the user:

→ EM fields in the body

→ Biological effects?

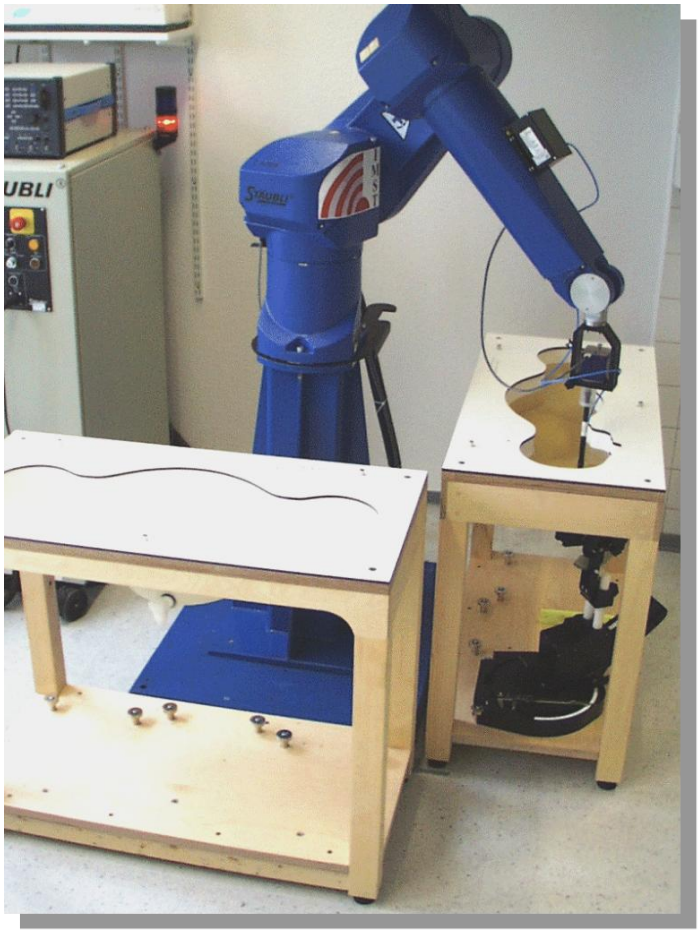
Influence on the performance

→ Losses in the tissues

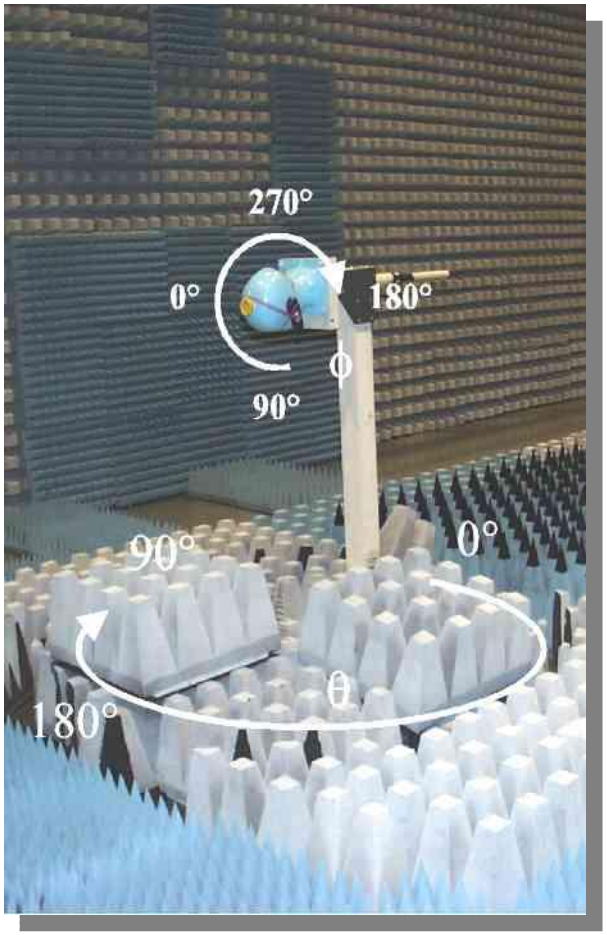
→ Changes in radiation pattern

→ Antenna mismatch

Characterisation of the interaction



SAR-measurements
DASY III setup



Radiated power in presence of user
3D measurement setup

Specific Absorption Rate (SAR)

Different limits according to:

→ CENELEC (Europe)

→ FCC (USA)

→ ACA (Australia)

Human tissue parameters

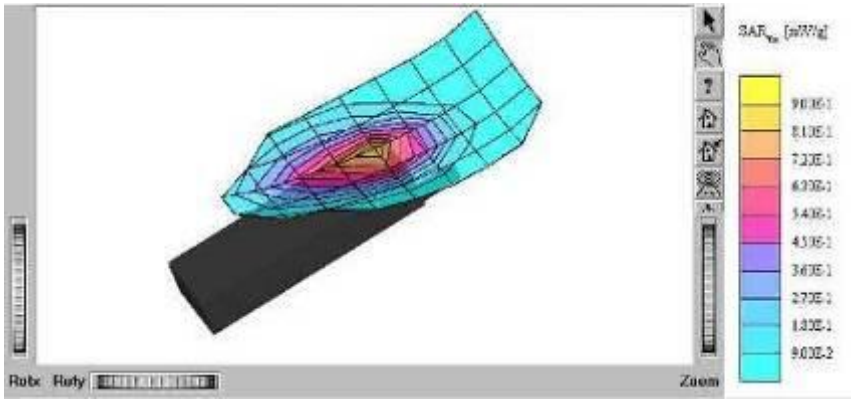
Frequency	ε_r	σ (S/m)	ρ (kg/m^3)
900 MHz	42.5	0.86	1040
1800 MHz	41	1.69	

SAR recommended limits

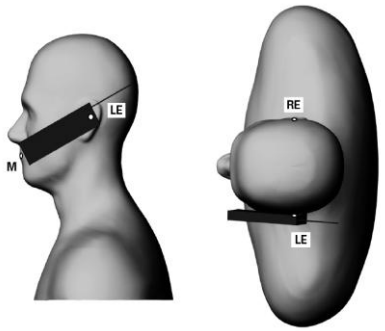
	Max. local SAR (W/kg)	Averaged over (g)
Europe	2	10
USA	1.6	1

Measurements according to EN 50361

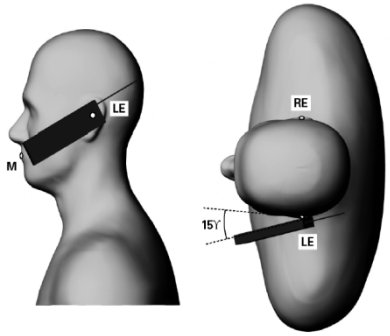
- → 4 standard positions: Cheek and Tilted, left and right side
- → Phone in transmit mode, maximum power
- → SAR at 3 different frequencies: band centre, upper and lower limits
- → Different liquids needed in different bands



Cheek-Position



Tilted-Position

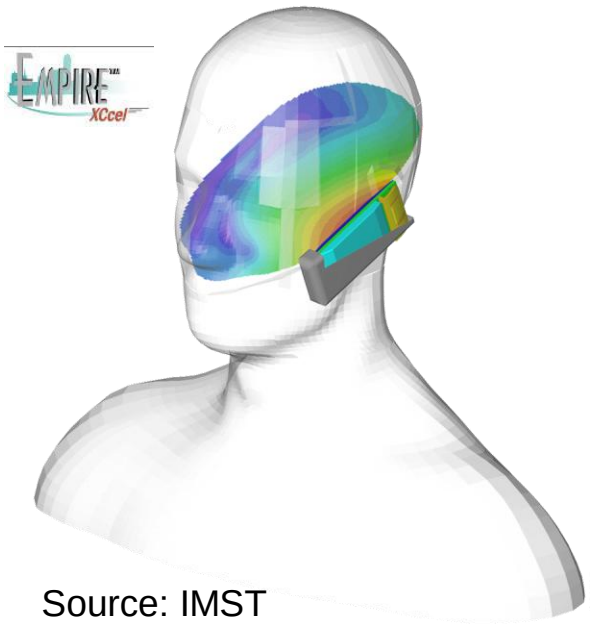


3-band mobile phone:

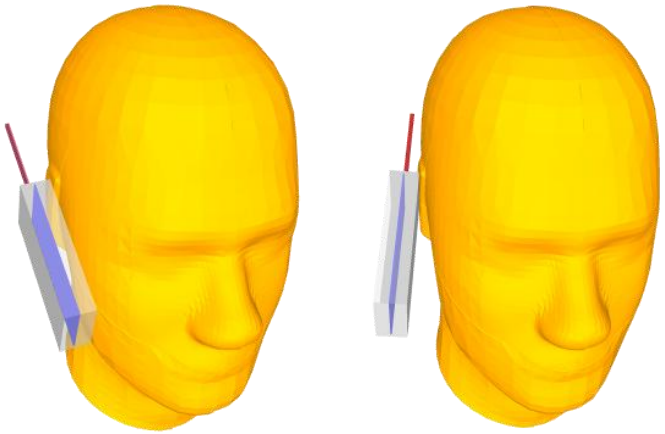
3 bands x 3 frequencies/band x 4 positions

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

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

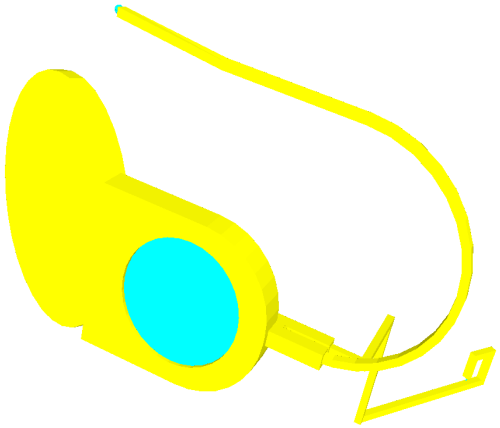
→ cells= 170 x 170 x 315

Simulation time: ~ 5 min

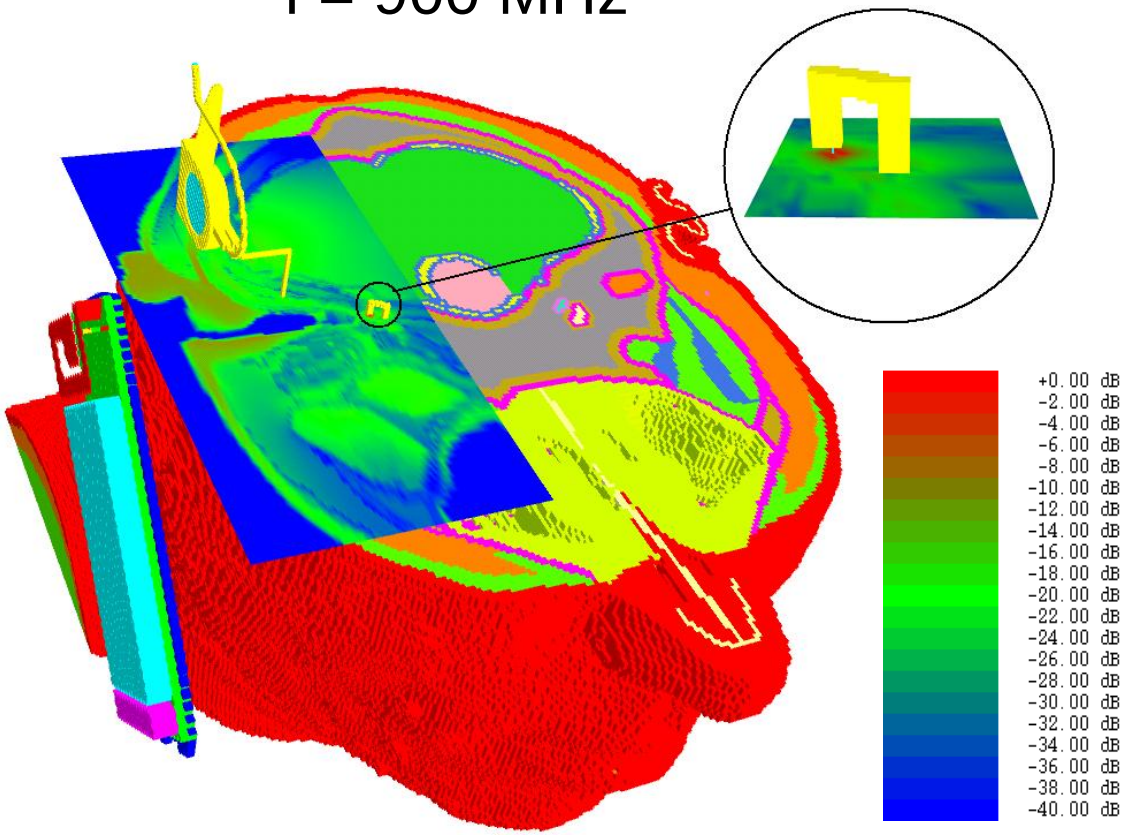
→ (2 x Xeon 5350, 2.66 GHz)

Dosimetric Assessment

f = 900 MHz



Cochlea implant



Normalised local SAR-distribution (1W input power)

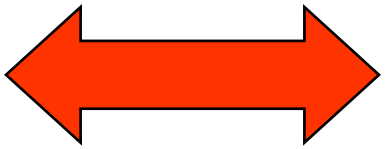
Scope of the talk

→Introduction & historical review

→Practical considerations & design flow

→State of the art

Integrated vs. external antennas



✓PROS

→Aesthetical design

→Lower cost

→Mechanical robustness

✘CONS

→Small available volume

→Interaction with other components

→Shadowing

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

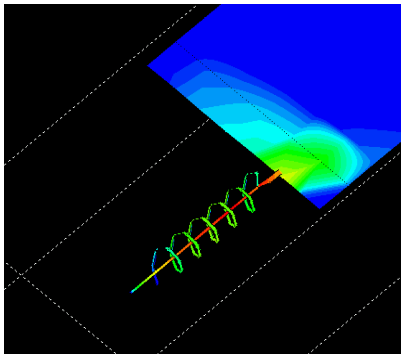
Some examples:

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.

Where are the antennas?

Internal antennas

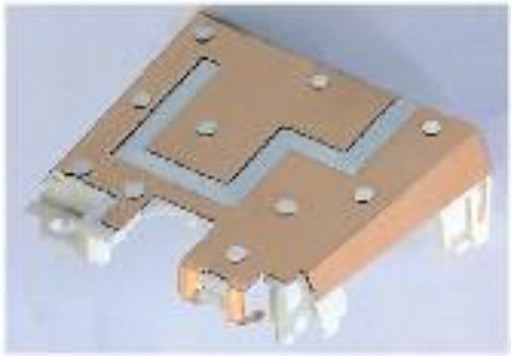
→Small, compact terminals

→External design independent of antenna

→More robust handsets

→Easy to produce, cost effective

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

Multiband patch antennas

→Coupled resonators (fed / coupled)

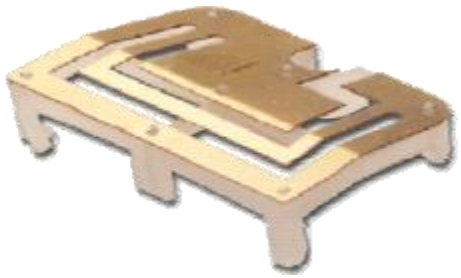
→Small in size, low production cost

→Centre frequency and bandwidth can be controlled to some extent

→Bandwidth for lower bands limited

→Require experienced engineers and reliable CAD tools

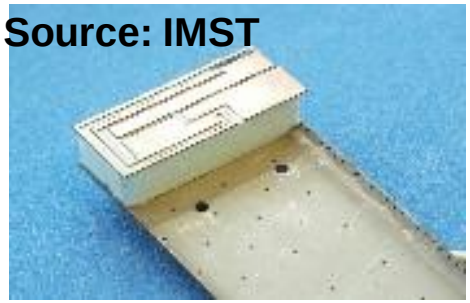
Source: IMST



3 bands:
GSM 900/1800/1900

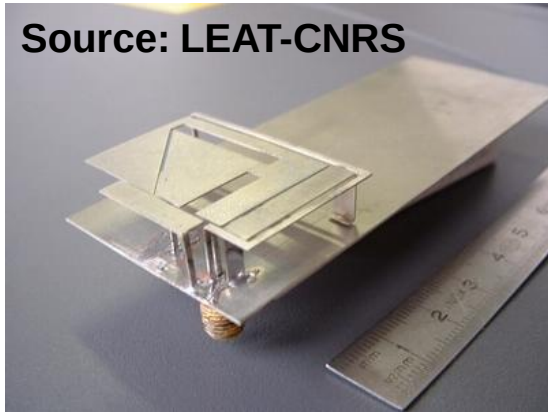
Combination patches / slots

Source: IMST



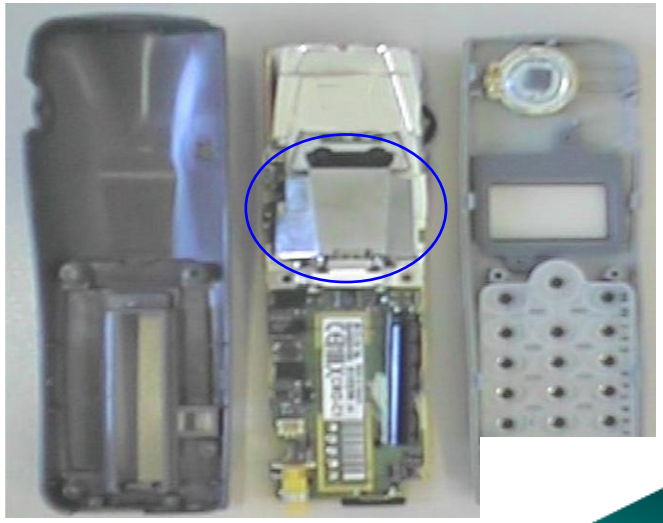
4 bands:
GSM 900/1800/1900/UMTS

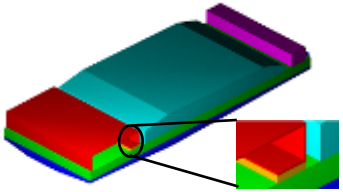
Source: LEAT-CNRS



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

Integrated patch antennas





Sony CMD-C1

→Patch Antenna

→Air-filled

→Capacitive end to reduce size

Nokia 8810

→C-patch antenna

→Air-filled

Integrated patch antennas

Nokia 3210: planar Antenna

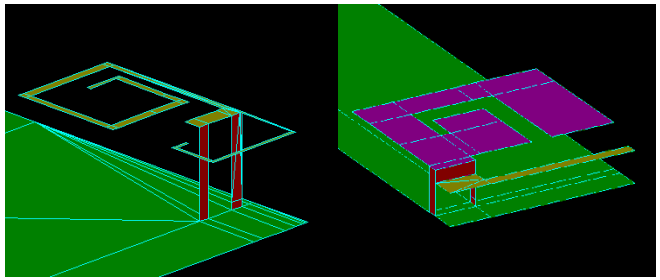
→3D-MID-Technology

→3-D flexibility

→High tooling costs: production volume must be high

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

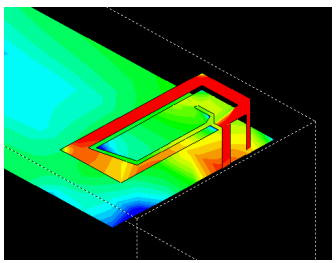
→Very popular in Nokia, Siemens, Ericsson products.

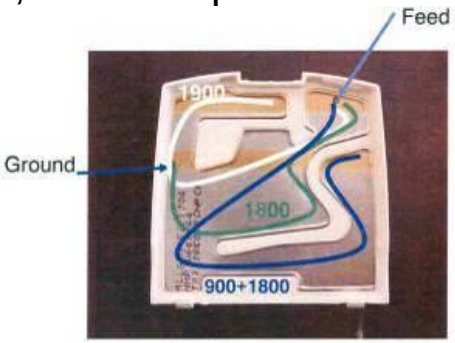
Branch PIFA

→First used in Nokia 8210 (1999)

→Different variants in the following years

→2-/3-band solutions





Source: Sony-Ericsson

Multiband folded monopole antenna

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

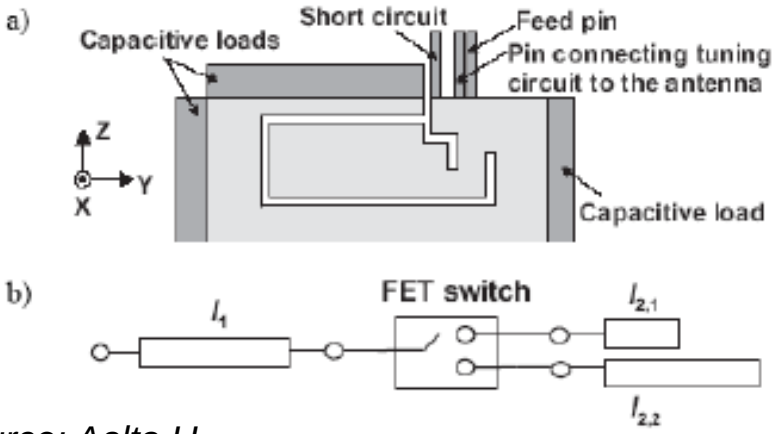
Frequency-Tuneable Antennas

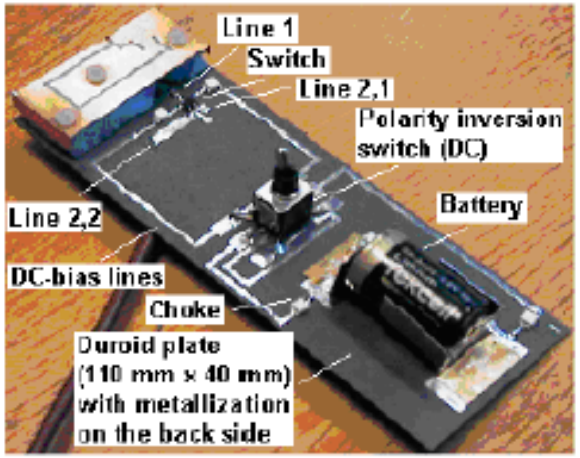
→Frequency agility to cover different bands

→Use of switches and matching networks

→Use of FET transistors, PIN diodes

→In the future: MEMs





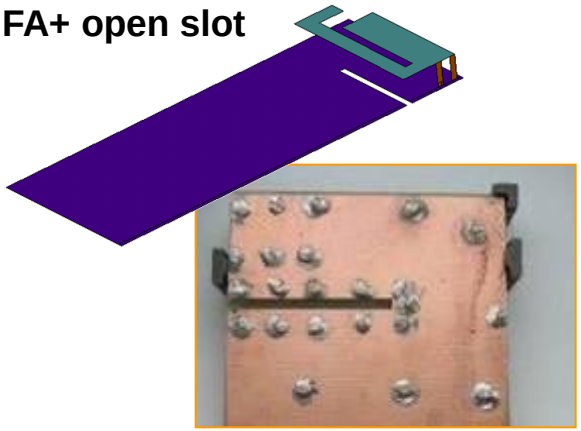
Source: Aalto U.

Antennas with slotted PCB

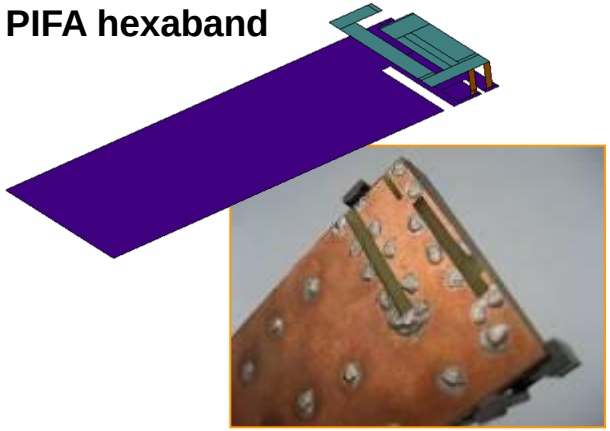
Universitat Ramon Llull

fractus
Optimised Antennas for Wireless Devices

PIFA+ open slot



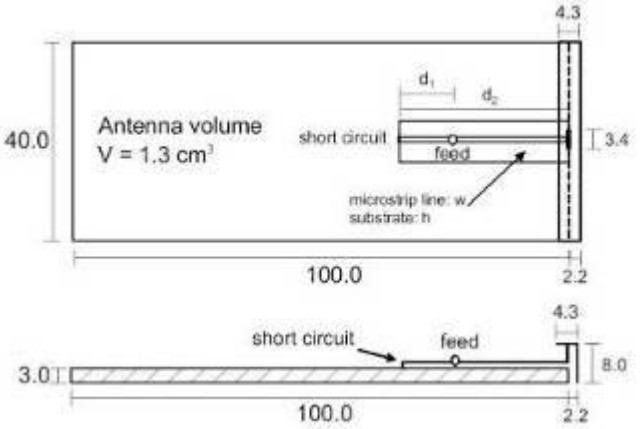
PIFA hexaband



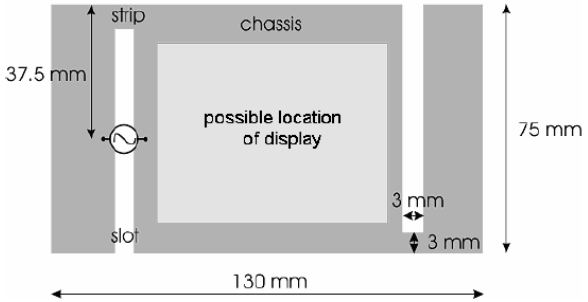
Patent app. WO 03/023900

Coupling structures

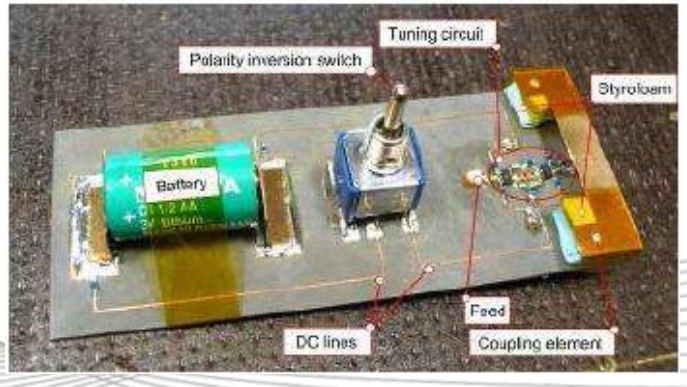
- → Small-size + bandwidth difficult to meet simultaneously with self-resonant antennas
- → 900 MHz: power radiated by surface currents on ground plane
- → Small non-resonant, non-radiating structures: couple power into the characteristic wavemodes of the chassis
- → Necessary resonances created by matching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



E-GSM & DCS

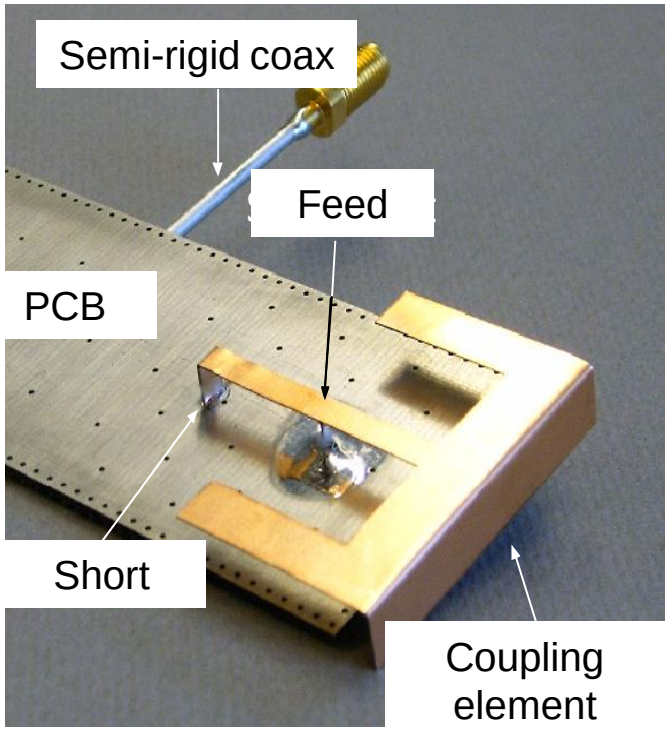


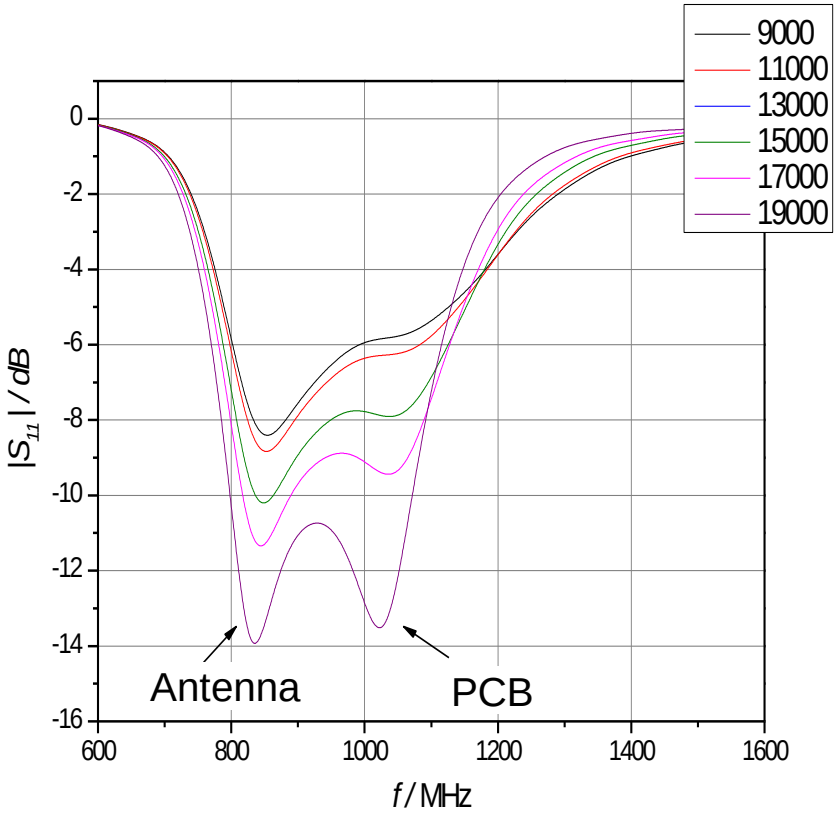
DVB-H



Source: Aalto U.

Coupling elements



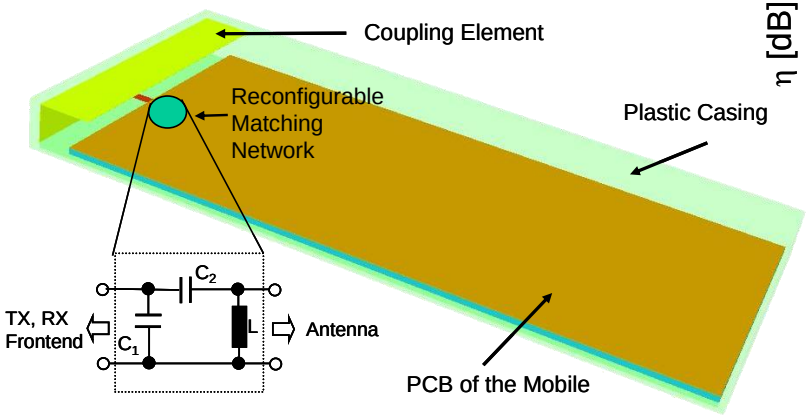


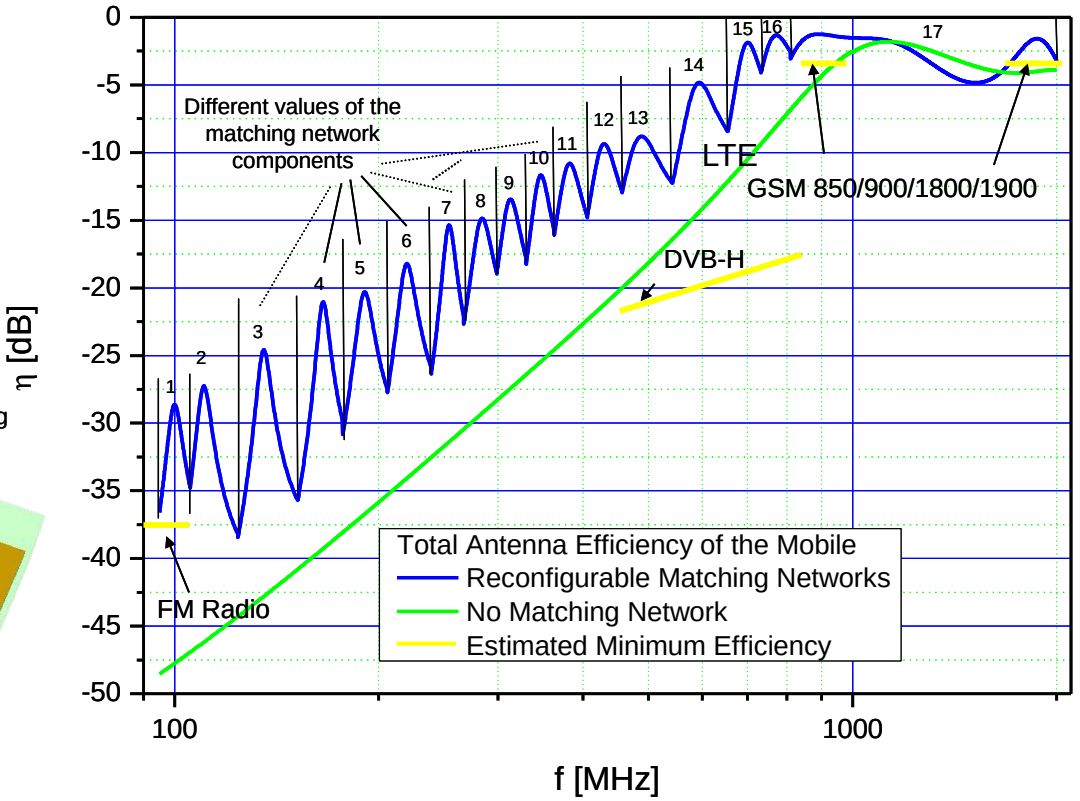
→ Optimised coupling to the PCB

→ Optimised bandwidth

→ High efficiency (whole device acts as antenna)

Reconfigurable coupling elements



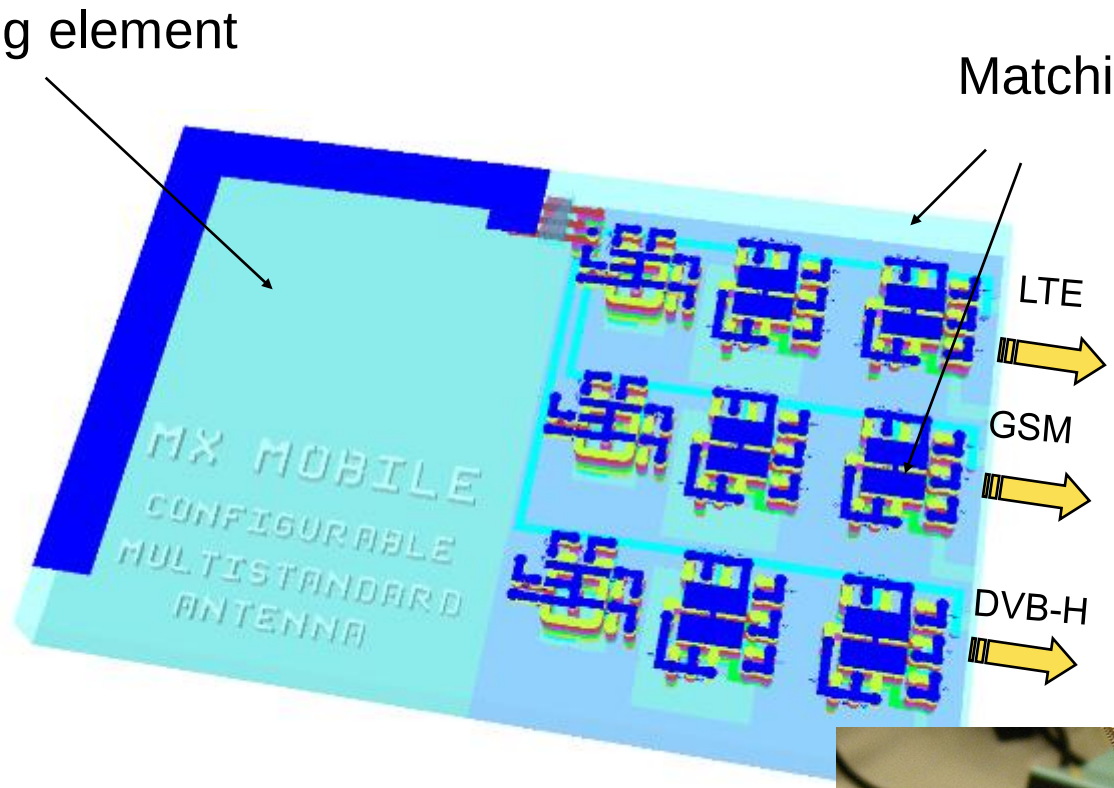


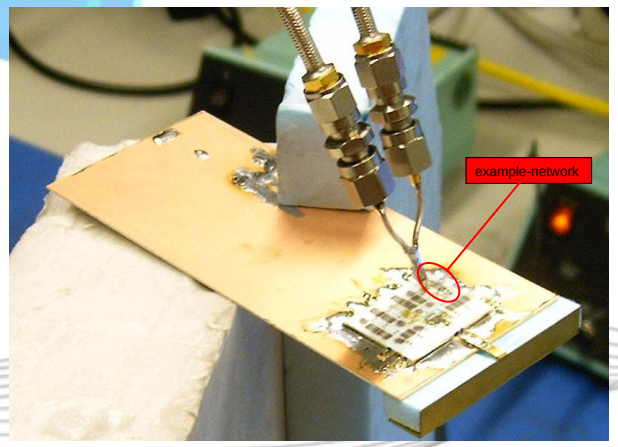
→ Reconfigurable matching network

→ 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.

Reconfigurable multistandard antenna



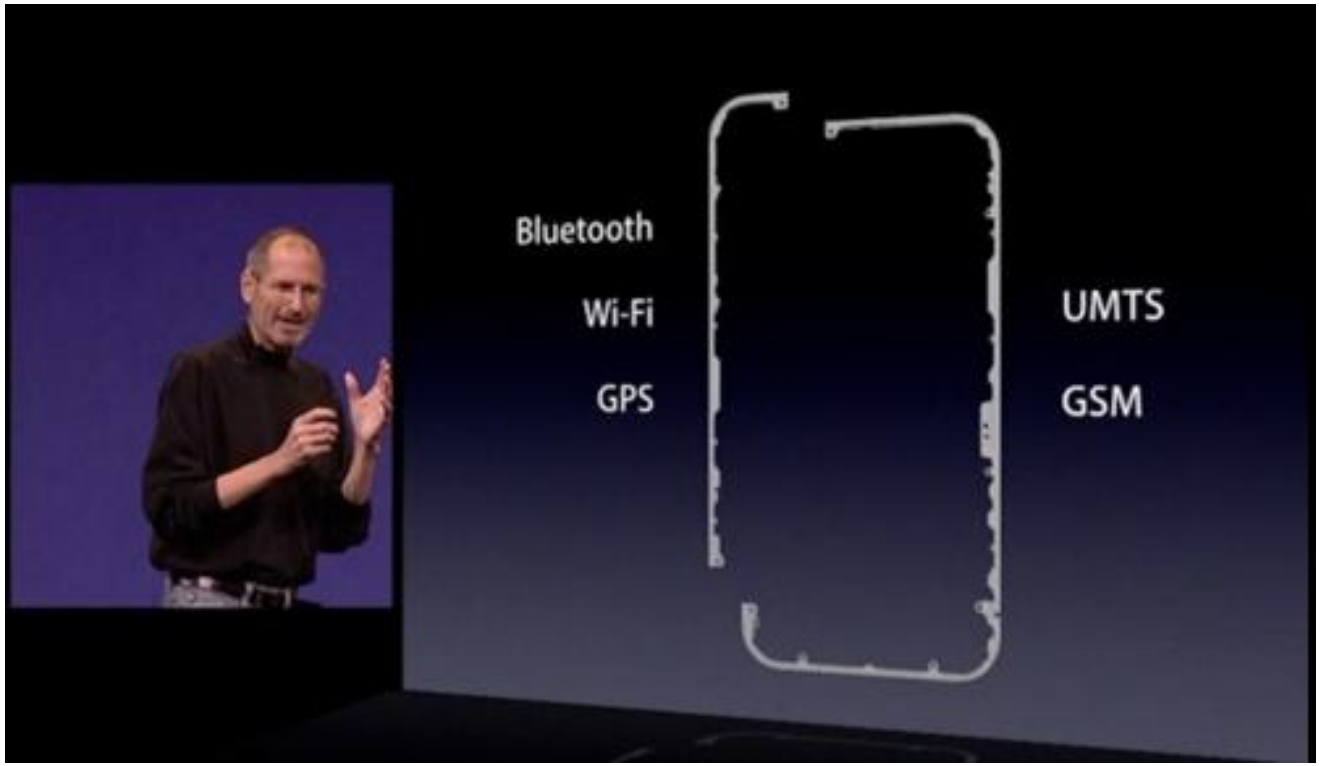


→ Multistandard operation, single module

→ LTCC technology

Looking again at the iPhone…

iPhone 4 antennas



The future?

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

→ Nanoscale technologies, flexible and transparent materials, …

Thank you for your attention!

For more information please visit:

http://www.imst.com