Design of antennas for mobile communications devices: practical aspects.

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IMST GmbH
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IMST GmbH: facts & figures

- **Foundation:** 1992
- **Staff:** 150 employees (110 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**
Library for multilayered elements
Integrated in Agilent ADS™

**COPLAN**
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
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

Internet users: 1.4bn
TV sets: 1.5bn
Dayly newspapers: 480m
Mobile phones: 4bn

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

Number of mobiles for every 100 people

Source: i-strategy
Market Evolution

Source: IMS Research 2011

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Size</th>
<th>Weight</th>
<th>Price</th>
<th>Functionality</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
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<td></td>
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<td>2000</td>
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<td></td>
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<tr>
<td>2010</td>
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</table>

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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**!
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 mm³
- Weight: 248 g.

Source: www.apple.com
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Mobile handset development

CONCEPT
Marketing & sales
Concept & preliminary design
Development

INTEGRATION
Optimisation & integration
Industrialisation
Hard tool go
Qualification
Ramp up

PRODUCTION
Mass production
Product upgrade
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 $a$:

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

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

$\rightarrow$ Relation bandwidth - antenna volume
$\rightarrow$ Goal: optimising this relation
Handset antennas

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)

Result: handset antenna

\[ L + H \approx \frac{\lambda_0}{4} \] Resonance frequency

\[ Z_{\text{in}} = f(S) \] Input Impedance

\[ BW = f^*(H, W) \] Bandwidth

⇒ 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
Antenna analysis

*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

\[ \text{SAR} = \frac{c}{dt} \]

\[ \text{SAR} = \frac{\sigma}{2\rho} |E|^2 = \frac{\sigma}{\rho} E_{\text{eff}}^2 \]

Effect **of** the user: losses

Radiated power

\[ P_{\text{rad}} = P_{\text{in}} - P_a - P_L - P_{\text{abs}} \]

Radiated (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

<table>
<thead>
<tr>
<th>Frequency</th>
<th>$\varepsilon_r$</th>
<th>$\sigma$ (S/m)</th>
<th>$\rho$ (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 MHz</td>
<td>42.5</td>
<td>0.86</td>
<td>1040</td>
</tr>
<tr>
<td>1800 MHz</td>
<td>41</td>
<td>1.69</td>
<td></td>
</tr>
</tbody>
</table>

### SAR recommended limits

<table>
<thead>
<tr>
<th></th>
<th>Max. local SAR (W/kg)</th>
<th>Averaged over (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>USA</td>
<td>1.6</td>
<td>1</td>
</tr>
</tbody>
</table>
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

3-band mobile phone:
3 bands x 3 frequencies/band x 4 positions
= 36 measurements!!! (~ 18 hours!)
SAR simulation during the design phase

**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)
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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 antenna**
- 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

**Branch meander multi-band antenna**
- Z. Ying (Ericsson, 1997)
- Flexible and easy to manufacture
- Volume over 15 millions.
Where are the antennas?

- A-GPS
- 3G
- GSM
- Bluetooth
- WLAN
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

Combination patches / slots

Source: IMST

3 bands:
GSM 900/1800/1900

Source: LEAT-CNRS

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

Source: IMST

4 bands:
GSM 900/1800/1900/UMTS
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

Multiband folded monopole antenna
- Branch or non-uniform meander line for multi-band operation

Source: Sony-Ericsson
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

PIFA+ open slot

PIFA hexaband

Patent app. WO 01/22528

Patent app. WO 03/023900
References


**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.

*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
Reconfigurable multistandard antenna

- Coupling element
- Matching circuits (L, C)

→ 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!

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For more information please visit:

http://www.imst.com