Mobile Terminal Antennas

S-72.333, Postgraduate Course in Radio Communications

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Introduction (1)

- What is the purpose of an antenna?
  - Antenna is used for transmitting and receiving radio waves. They are especially designed to transform guided waves into free-space waves, or vice versa. This transformation should be done as efficiently as possible!
- How does a mobile terminal antenna affect on the performance of a communication system?
  - Frii's Equation for a received power in a radio system:

$$P_r = G_t G_r \left(\frac{\lambda}{4\pi r} \right)^2 P_t$$

  - G_t and G_r are the gains of the antennas of the radio system

Introduction (2)

- The antenna gains are typically misunderstood and used wrongly (especially the gains of mobile terminal antennas)
- What does antenna gain actually mean (will be studied later)??

- Why is mobile terminal antenna design so damn difficult?
  - The problem is the interrelationship between the size, efficiency and bandwidth of electrically small antenna. One of these can be improved only at the expense of the others.

    ⇒ small antennas have poor performance!
  - It is not possible (because of physics laws) to construct a small antenna that would cover the frequencies of all communication systems and would in addition radiate efficiently.

Trends in mobile terminal industry (1)

- Trend in mobile terminal industry is to make the terminals more complex and smaller in size (especially thinner). Challenges for an antenna designer:
  - o Multi-system mobile terminals: AM, FM, DVB-H, GSM850/GSM900/GSM1800/GSM1900, UMTS, WLAN, Bluetooth, GPS....etc. ➡ The number of antennas and their volume is increasing!
  - o New modules like cameras are integrated inside the mobile terminal
    ➡ The available space for antennas is decreasing!
  - o Mobile terminals are getting shorter and thinner.
    ➡ The available space for antennas is decreasing even more!
    ➡ Bandwidth decreases and larger antenna would be needed.

Trends in mobile terminal industry (2)

- Clamshell phones are getting more and more popular
  ➡ Antenna designers nightmare! Opening/closing the phone changes the input impedance of the antennas dramatically. Tunability needed?
- Competition in the market puts pressure on the terminal prices
  ➡ The antennas should have a simple structure, they should be **cheap** and suitable for mass production.

- During the last three years, traditional mobile terminal antennas, like PIFAs or monopoles, haven't been developing remarkably. **New, untraditional solutions are definitely needed!!**

The structure of a mobile terminal (1)

- The modules of a mobile terminal that mainly affect the radiation properties of the device:
  - *PCB* (Printed Circuit Board): Is typically well-grounded at least from its other side.
  - *EMC-shields*: Metallic plates located in critical places on top of the PCB.
  - *Antenna module*: Typically a PIFA or a monopole located above the battery.
  - *Screen*: Metallic frames. RF-connection to the ground plane unknown for an outsider (like for a university research engineer).
  - *Battery*: Lots of metal. RF-connection to the ground plane unknown.

The structure of a mobile terminal (2)

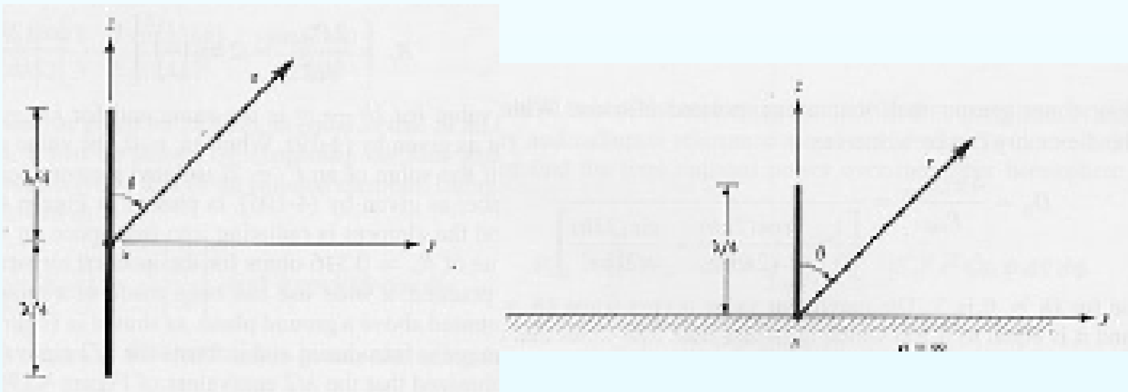
  - *Earpiece*: RF-connection to the ground plane unknown.
  - *Camera and other modules*: RF-connection to the ground plane unknown.
- Due to the unknown connections inside mobile terminals, antenna designers typically model mobile terminals as an antenna module connected to the so-called ”chassis”.
- The length and width of the chassis are chosen from the PCB size, e.g. 100 mm x 40 mm. A good value for the thickness of the chassis is about 3 mm (the thickness of the PCB + the thickness of the EMC-shielding).

Resonance phenomenon

- In order for an antenna to work efficienctly, it has to be tuned to resonance

→ the electrical length of the antenna has to be λ, λ/2 or λ/4.

- E.g. at 900 MHz, λ = 33 cm and at 1800 MHz, λ = 16 cm
- E.g. dipole and monopole antennas:



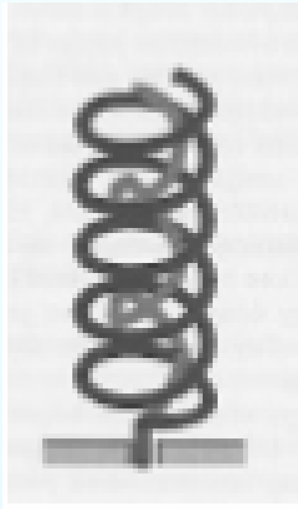
Monopole antennas

- Whip antennas:

- cheap, simple
- good performance
- too long for moder handsets

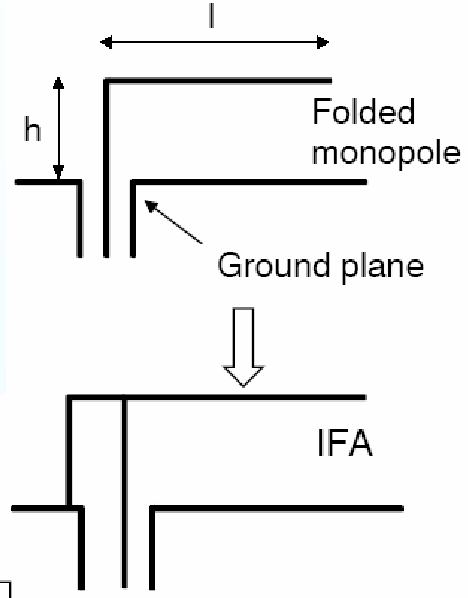
- Helix antennas:

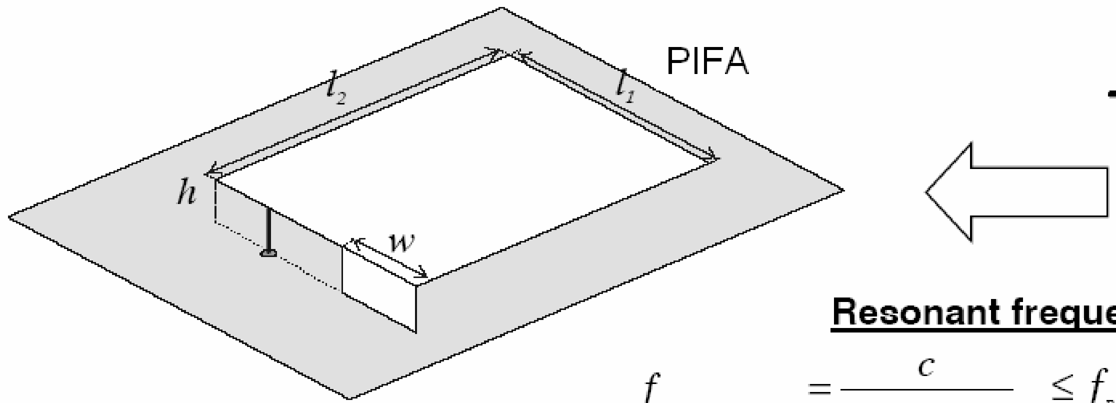
- twisted monopole
- reasonable performance
- compact, strong



Modified monopole antennas (1)

- IFA and PIFA have ”built-in” matching circuits
- IFAs and PIFAs are the most popular internal mobile terminal antennas used nowadays
- Durable, cheap and easy to manufacture



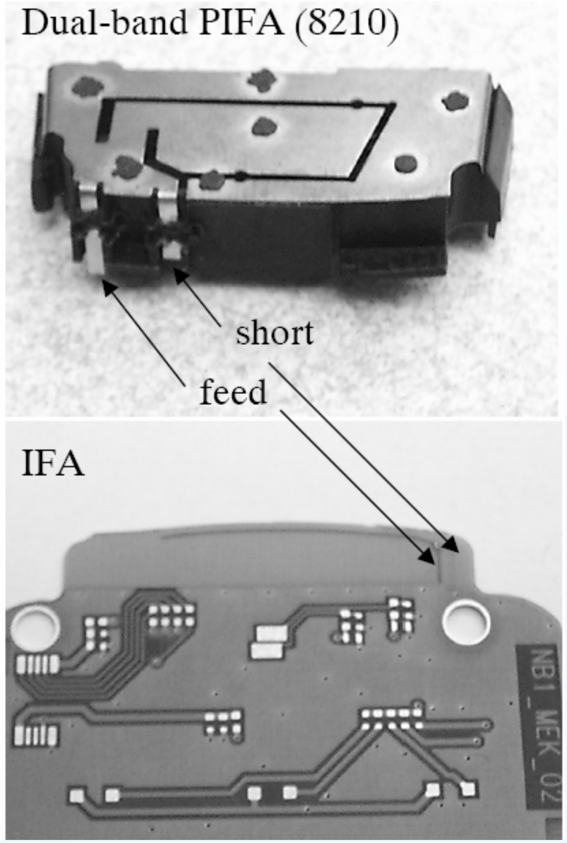


Resonant frequency

$$f_{L(w\approx 0)} = \frac{c}{4(l_1+l_2+h)} \le f_R \le f_{H(w=l_1)} = \frac{c}{4(l_2+h)}$$

Modified monopole antennas (2)

- PIFA and IFA examples from Nokia's phones:



Antenna terms

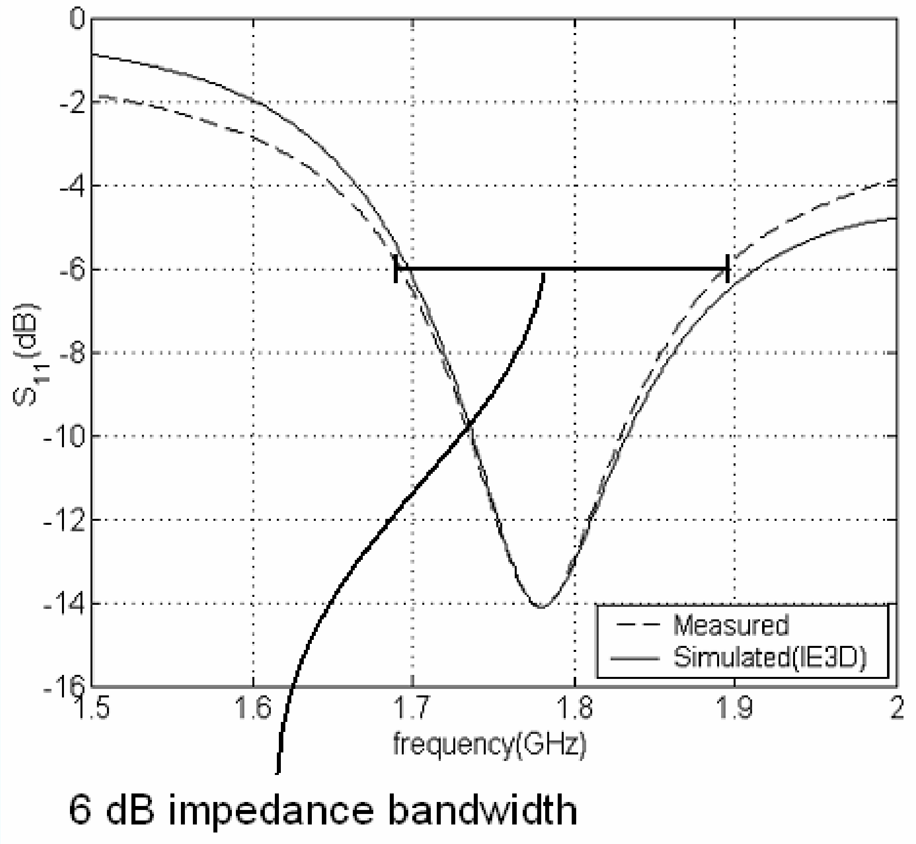
- The most important terms for a mobile terminal antenna designer are:

- Impedance bandwidth
- Radiation efficiency
- Total efficiency
- Directivity and Gain
- *MEG* (Mean Effective Gain)
- Polarization
- *SAR* (Specific Absorption Rate)

(7. Antenna dimensions and volume)

Impedance bandwidth (1)

- The impedance level after the mobile terminal antenna is typically 50 Ohms.
- If the input impedance of the mobile terminal antenna differs from 50 Ohms at some frequency, part of the power is reflected back.
- The input impedance (varies rapidly) of an antenna typically can be 50 Ohms only at some single frequency, called resonant frequency of the antenna.
- Impedance bandwidth: the frequency range, in which the reflected power stays below some value. E.g. the most used reflection coefficienct criterion $S_{11} = -6$ dB => 25 % of the power is reflected.



Impedance bandwidth (2)

- The following chart is the starting point for designing antennas for mobile terminals

Network	**Uplink** (fl , fh)		**fc (u)**	**BW**	**Downlink** (fl , fh)		**fc (d)**	**BW**	**fc (u+d)**	**BW**	**Rel. BW**
	MHz	MHz	MHz	MHz	MHz	MHz	MHz	MHz	MHz	MHz	%
GSM450	**450.4**	457.6	454	7.2	460.4	**467.6**	464	7.2	**459**	**17.2**	3.7
GSM850	**824**	849	836.5	25	869	**894**	881.5	25	**859**	**70**	8.1
EGSM900	**880**	915	897.5	35	925	**960**	942.5	35	**920**	**80**	8.7
PGSM900	**890**	915	902.5	25	935	**960**	947.5	25	**925**	**70**	7.6
PDC	940	**956**	948	16	**810**	826	818	16	**883**	**146**	16.5
	1477	**1501**	1489	24	**1429**	1453	1441	24	**1465**	**72**	4.9
GSM1800 (PCN)	**1710**	1785	1747.5	75	1805	**1880**	1842.5	75	**1795**	**170**	9.5
GSM1900 (PCS)	**1850**	1910	1880	60	1930	**1990**	1960	60	**1920**	**140**	7.3
IMT-2000	**1885**	1980	1932.5	95	2110	**2170**	2140	60	**2027.5**	**285**	14.1
UMTS / FDD	**1920**	1980	1950	60	2110	**2170**	2140	60	**2045**	**250**	12.2
+ TDD	1900-1920(TDD1) &2010-2025(TDD2)										

Bluetooth	2400 - 2483.5	2441.8	83.5	Short range (<10m) RF link connection
GPS	1575.42 MHz +/- 10.23 MHz			Global Positioning System

Radiation efficiency (η_r)

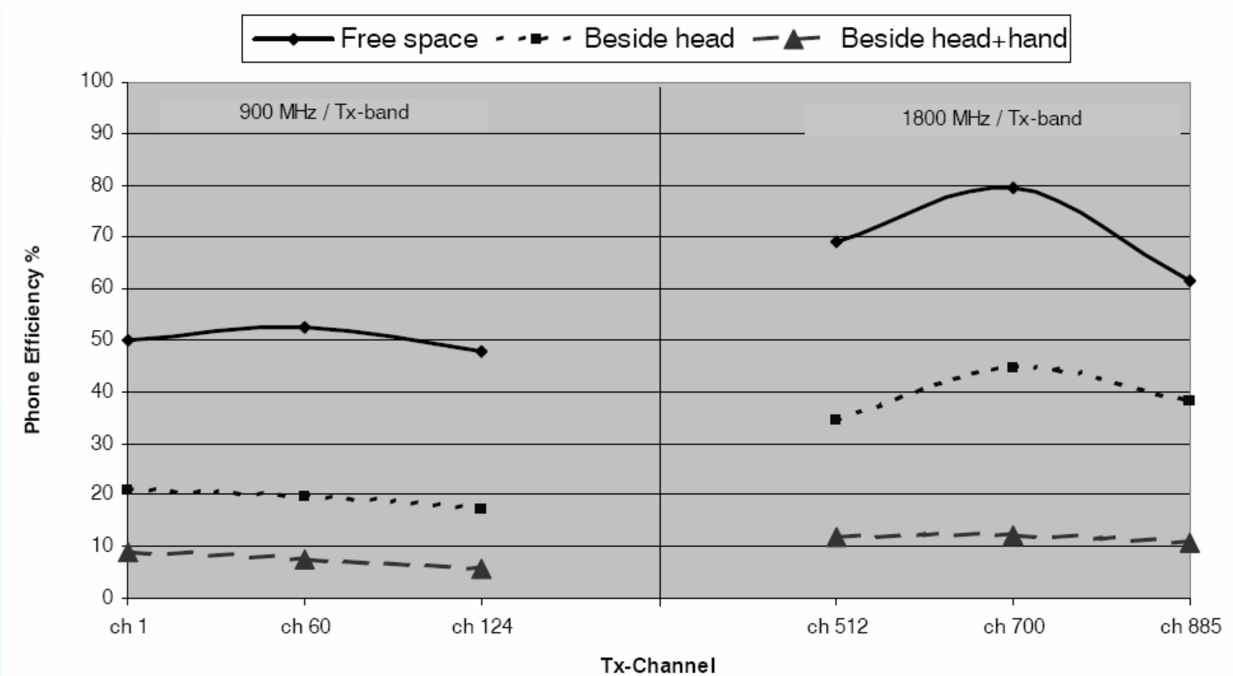
- The ratio of the total radiated power to the total input power:

$$\eta_r = \frac{P_r}{P_{in}}$$

- In free-space, most of the losses come from the metal parts of the antenna structure (finite conductivity) and from other lossy material inside the mobile terminal.
- In use-position, operators head, hand or other body parts can cause significant losses.

Total efficiency (η_{tot})

- The same as radiation efficiency but matching losses taken into account. Expresses all the possible losses caused by the antenna structure.
- Measured total efficiencies in free-space typically 35 - 75 % (1.3 - 4.6 dB loss) , beside head 10 – 40 % (4 - 10 dB loss) and beside head+hand 5 – 25 % (6 – 13 dB loss) .



Directivity and gain

$$\text{Directivity } D = \frac{\text{maximum radiated power density from an antenna}}{\text{total radiated power averaged over all directions}}$$

- Directivities of mobile terminals at 900 MHz typically around 2.2 dBi.
- Realized gain $G = \eta_{tot}D$ (matching losses taken into account).
- The directivity and realized gain are different in different directions and can vary dozens of decibels depending on the direction....Be carefull when using Free's formula!
- With the total efficiencies given in the previous slide, realized gain (D = 2.2 dBi) beside head+hand can vary from -3.8 dBi to -10.8 dBi (in radiation pattern maximum direction)!!

MEG (Mean Effective Gain)

- The gain of an antenna varies significantly depending on the direction
- The orientation of a mobile terminal is quite random.
- Multipath component arrive from different angles

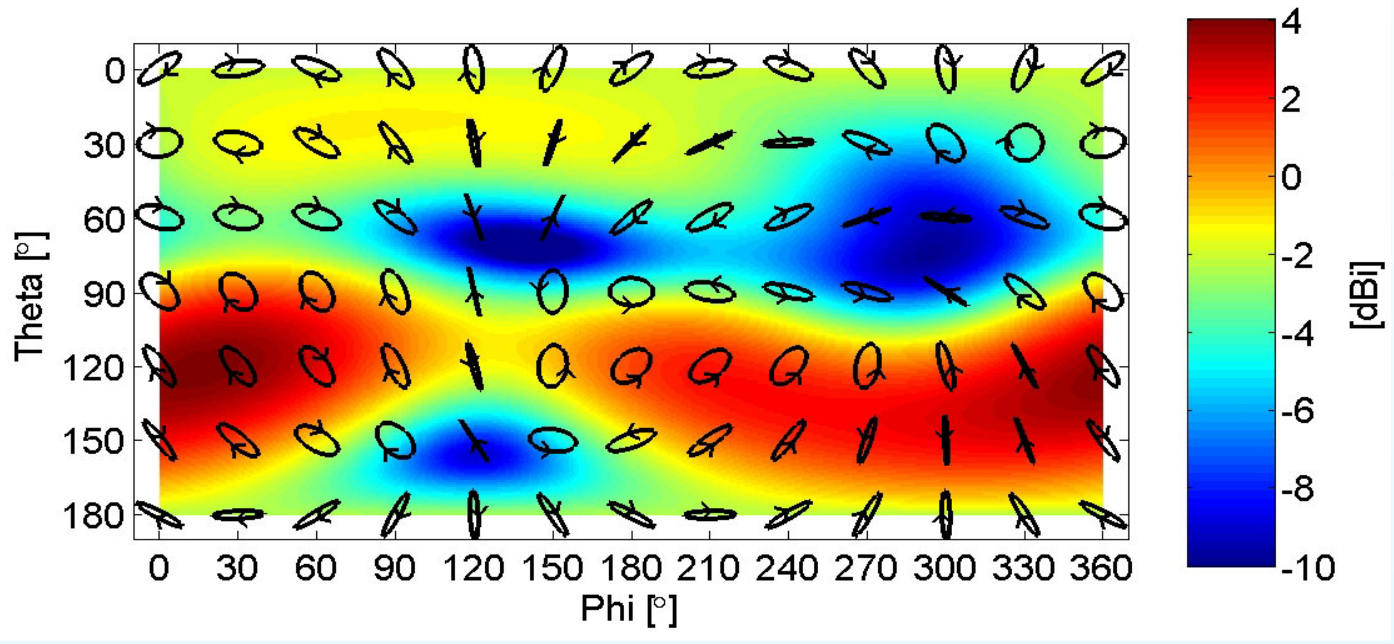
→ Gain as a number does not tell actually anything about mobile terminal ability to receive power in multipath environment and should not be used in Free’s formula (in my opinion)!!

- Closest to the truth is MEG (Mean Effective Gain), which takes into account the effect of multipath environment and the orientation of the mobile terminal (slow fading has to be normalized away):

$$MEG\,[dBi] = E\left\{\frac{\text{Power received by an antenna along some route}}{\text{Power received by an isotropic radiator along the same route}}\right\}$$

Polarization

- The polarization of a mobile terminal varies from circular to horizontal and vertical polarizations depending on the angle. Also, the orientation of the mobile terminal is typically quite random. The polarization cannot be much affected by the antenna designer.



SAR (Specific Absorption Rate)

- *SAR* = the amount of radiated power absorbed by a unit mass of a human tissue [W/kg].
- E.g. in European Union, the maximum allowable *SAR* is specified in terms of average *SAR* inside a 10 g cube of tissue.
- According to current knowledge, the only biological effects caused by mobile terminal radiation are due to the temperature rise of the tissue.

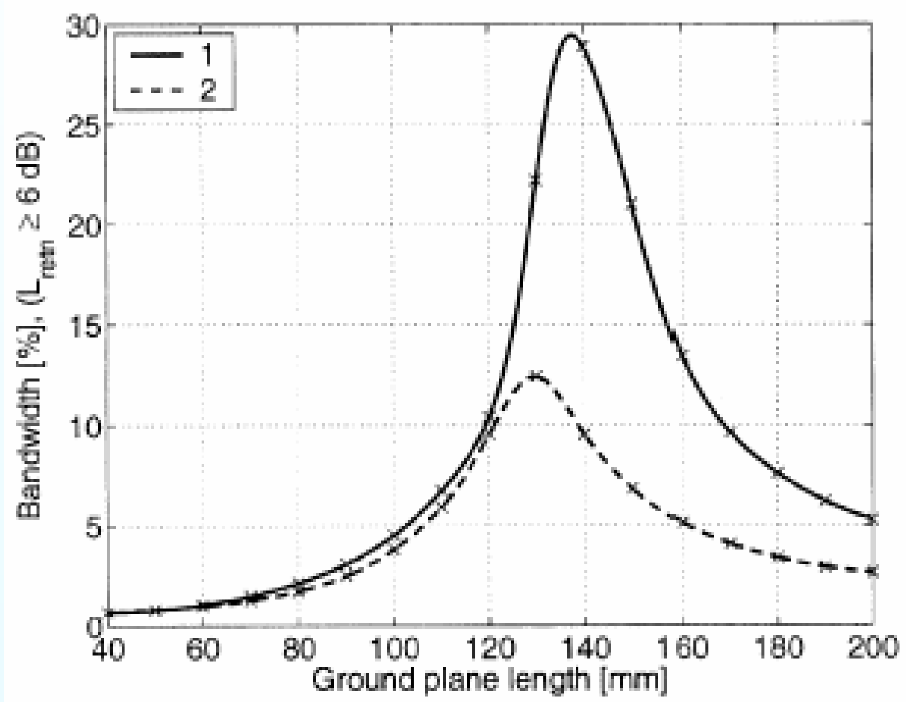
International Standard	*Averaging time [min]*	*Restrictions for averaged SAR [mW/g]*		
		Whole body	*Head and body*	*Hands, wrists, feet,…*
Europe CENELEC EN50360 (2001)	*6*	*0.08*	*2.0 (10 g)*	*4.0 (10 g)*
United States IEEE C95.1 (1999)	*30*	*0.08*	*1.6 (1 g)*	*4.0 (10 g)*

Effect of the chassis on mobile terminal radiation properties (1)

- During the last four-five years, the chassis effect have been investigated in several good publications.
- According to the published results, the power radiated by a typical self-resonant antenna element (e.g. PIFA) at E-GSM900 frequencies is less than 10 % of the total radiated power !!
- 90 % of the power is radiated by the dipole type current distribution of the mobile terminal chassis.
- The antenna element works mainly as a coupling element and matching circuit, whereas the mobile terminal chassis is the main antenna!!
- At 1800 MHz, the power radiated by the antenna element is larger, about 50 %.

Effect of the chassis on mobile terminal radiation properties (2)

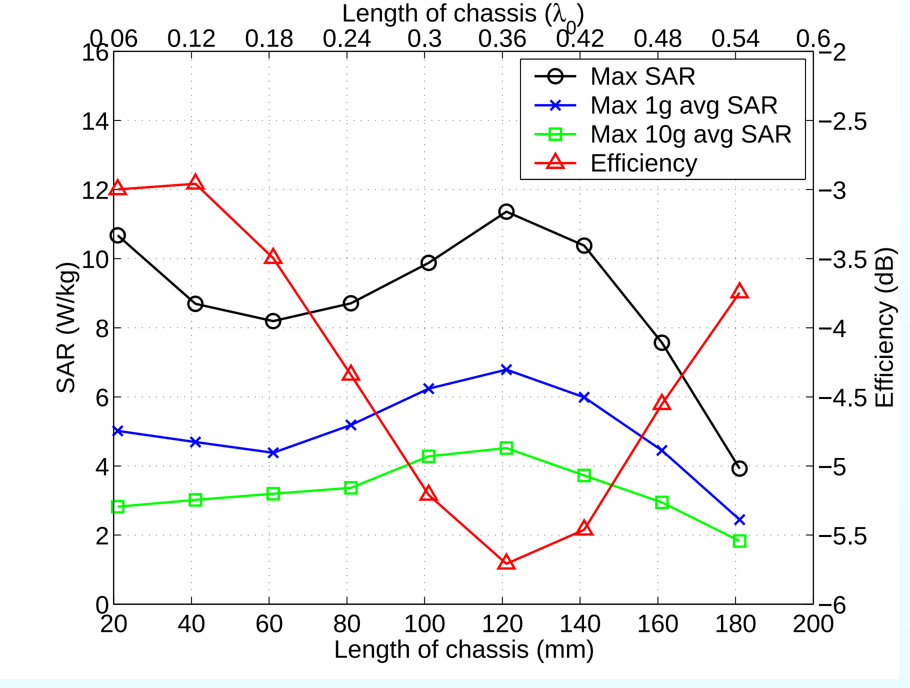
- The relative bandwidth of a mobile terminal antenna is strongly dependent on the chassis dimensions.
- Maximum bandwidth achieved when the chassis is at resonance at the operating frequency
- Without the radiation from the chassis, it would be impossibel to implement the low-profile antenna elements curretly used in mobile terminals.



Typical PIFA, 900 MHz

Effect of the chassis on mobile terminal radiation properties (3)

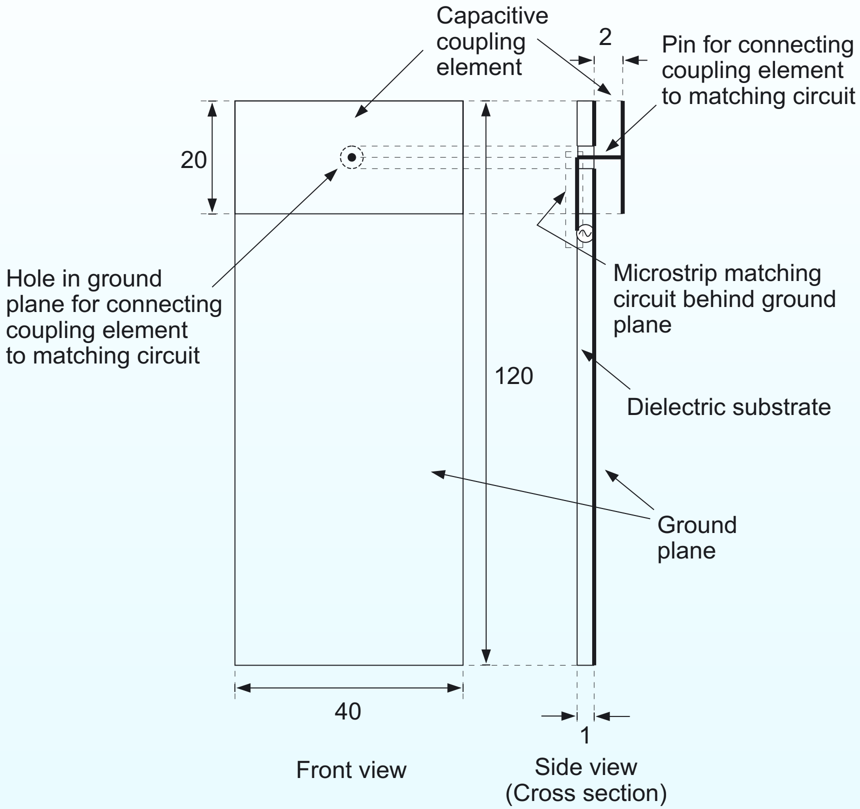
- *SAR*s and radiation efficiencies as a function of the chassis length at 900 MHz (typical PIFA, XFDTD simulations).



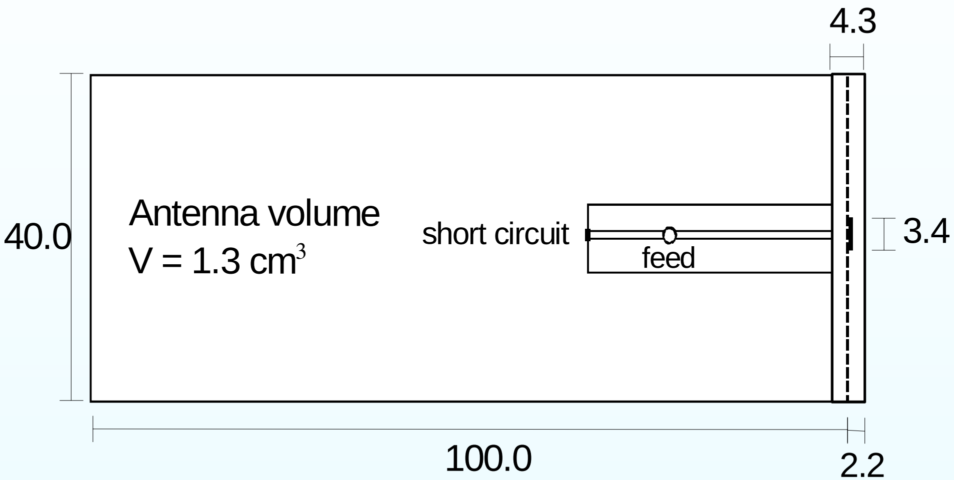
Coupling elements (1)

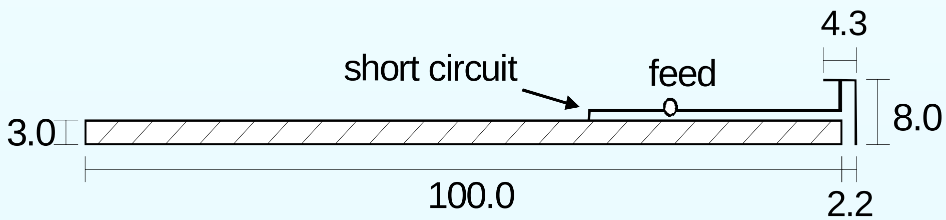
Finnish patent No. 114260, ”Modular Coupling Structure for a radio device and portable radiodevice”, Pertti Vainikainen, Jani Ollikainen, Outi Kivekäs and Ilkka Kelander:

- Modular coupling structure for a radio device comprises at least one essentially nonresonant electromagnetic coupling unit for coupling the signals to the wavemodes of the ground plane of the device and at least one matching circuit unit for impedance matching
- The coupling element located on the surface or close to the surface of the ground plane has a form of a conformal plate, probe or several probes in parallel, one loop or several loops in series, or an aperture or several apertures, or, optionally, the coupling element is implemented with direct galvanic contact to electrically separated parts of the chassis.



Coupling elements (2)





- Prototypes for the E-GSM900 and GSM1800 systems manufactured
- 6 dB bandwidth requirements fulfilled
- Radiation efficiencies ≥ 82.2 %
- *SAR* (Specific Absorption Rate) requirements fulfilled

Conclusions

- Mobile terminals are getting smaller and smaller. Size reduction is needed also for mobile terminal antennas while more systems have to be covered.
- Internal PIFA-type antennas are becoming more and more popular.
- There are many different kinds of terms describing the performance of mobile terminal antennas. Communications people should make sure to use the terms correctly with realistic values.
- The chassis is the main and essential radiator of a modern mobile terminal.
- Coupling elements can be used to more efficiently couple to the chassis wavemode and thus, to minimize the antenna volume.

References

[1] P. Vainikainen, J. Ollikainen, O. Kivekäs and I. Kelander, ”Resonator-based analysis of the combination of mobile handset antenna and chassis”, *IEEE Transactions on Antennas and Propagation*, Vol. 50, No. 10, October 2002, pp. 1433-1444.

[2] O. Kivekäs, J. Ollikainen, T. Lehtiniemi and P. Vainikainen, “Bandwidth, *SAR*, and Efficiency of Internal Mobile Phone Antennas”, *IEEE Transactions on Electromagnetic Compatibility*, Vol. 46, No. 1, February 2004, pp. 71-86.

[3] D. Manteuffel, A. Bahr, D. Heberling and I. Wolf, “Design considerations for integrated mobile phone antennas”, *Proc. 11th International Conference on Antennas and Propagation*, Boston, Massachusetts, April 2001, pp. 252-256.

[4] J. Villanen, J. Ollikainen, O. Kivekäs and P. Vainikainen, ”Compact Antenna Structures for Mobile Handsets”, *IEEE VTC2003 Fall Conference*, Orlando, Florida, October 2003, CD-ROM (0-7803-7955-1), paper 08A_02.pdf.

[5] O. Kivekäs, *Small Mobile Terminal Antennas with Low User Interaction*, Licenciate thesis, Helsinki University of Technology, Espoo, August 2001, 105 p.

[6] J. P. Louhos, *Antenniluento (Antenna lecture, in Finnish)*, Lecture material for course S-26.142 Tietoliikenteen radiolaitteet II, TKK/04.04.2002, 42 p.

Homework

1. Search IEEE-explore for compact mobile terminal antennas.
2. Choose one publication
3. Write a summary of the publication.
4. Are all the relevant measures of quality (bandwidth, radiation and total efficiency, gain and *SAR* in free-space and in use-position (head+hand)) of a mobile terminal antenna reported in the publication??