Antennas for Mobile Terminals; Size, Measurements and Performance

G. Frølund Pedersen, J. Ødum Nielsen, J. Back Andersen
Center for Personkommunikation
Niels Jernes Vej 10
Aalborg University, 9220 Aalborg, Denmark
phone +45 96358660, fax +45 98151583, email gfp@cpk.auc.dk

ABSTRACT

Antennas for small terminals are being developed in large numbers these days. But how to judge if an antenna for a small mobile terminal is performing well or poorly? This paper gives an overview of the work involved in validating the performance of phones both in theory and practise with several examples including the influence of the user, both as a phantom and as live users. The results are based on total radiated power and total receiver sensitivity as well as mean effective gain. Also the coming standards in the area of mobile terminal antenna tests will be addressed.

INTRODUCTION

Antennas for mobile terminals are different to high gain antennas used for fixed communication such as radio and TV broadcast, on satellite or the basestations in the sense that no traditional antenna parameters for the radiation are obvious. Typical parameters describing the traditional fix antennas such as peak gain and co-polarisation cannot be used as the mobile terminal can literally take any position relative to the other end of the communication link. Further the terminal is typically located near or on the human body, which not only lead to losses but also change the radiation significant. To specify the optimum radiation pattern including polarisation knowledge of the likelihood of each position including the nearby objects (say within, one wavelength) is needed together with knowledge of how the signal is distributed in the environment. Then the maximum likelihood or the likelihood weighted by its importance will define the optimum. But even if requirements to the optimum radiation could be established the size allocated for the antenna is often so small, e.g. in a mobile phone, that the whole phone casing acts as antenna and the radiation is then largely given by the shape of the phone. The practical design of the antennas is therefore often reduced to obtaining sufficient bandwidth for a given small size. If the antenna efficiency is not compromised the maximal bandwidth which can be obtained from an antenna it strongly related to the size of the antenna as given by the fundamental limit on antenna size [1].

OVERALL RADIATION EFFICIENCY

To establish the influence a person using a mobile phone has on the transmitted or received signal strength measurements including 200 persons have been made and analysed [2]. The results clearly show that the users add losses but also that the loss can vary from one person to another by up to 10 dB. The loss in the communication cannot

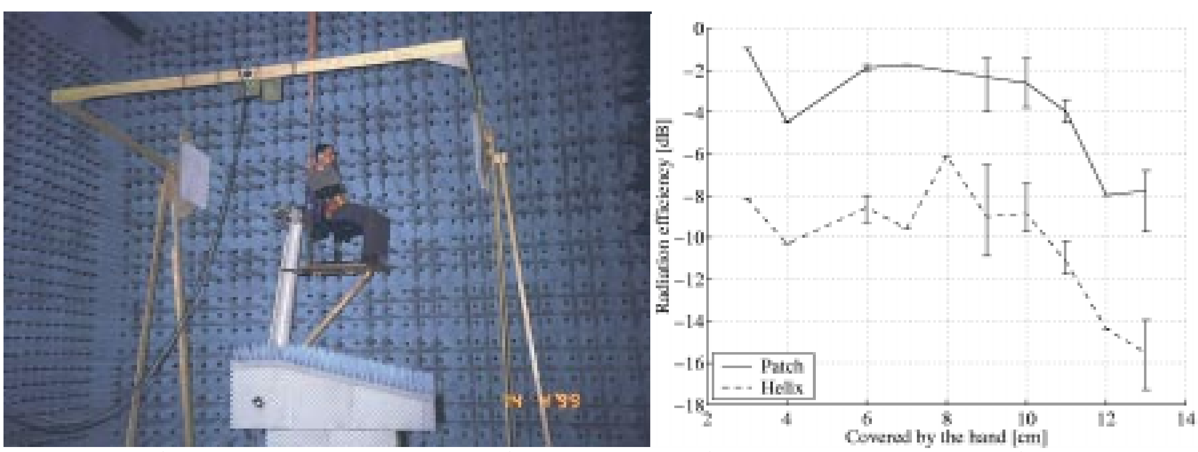

Fig. 1. To the left the setup in the anechoic room for measurements of spherical radiation patterns of a person using a handheld phone. To the right the loss due to the live persons using the phone sorted according to the way they hold the phone. The left most is when the person is holding the phone only at the bottom part whereas at the right most the person covers nearly the entire top of the phone.

only be explained by pure absorption but also additional antenna mismatch and change of the radiation pattern and polarisation [3]. To separate each of the four contributions measurements of the complete radiation from the phone including the user has been measured in an anechoic room [3]. By measuring the radiated or received power on a sphere around the user it is not only possible to obtain the radiation pattern including polarisation but by integrating the transmitted or received power on the sphere and compare it to the power at the antenna terminals also the losses can be found. From the measurements in the anechoic room the loss for each person is compared to the way of holding the phone and a high correlation of 0.7 is found [4] see figure 1.

The optimum antenna radiation depends therefore not only on the likelihood of use and the environment as discussed above but also on the different users. The losses in the phone itself is mainly caused by dielectric losses and matching losses will of course also enter the equation but here it is clear that the optimum is to keep the overall efficiency as high as possible. Even though the target of high overall antenna efficiency is clear it is not straightforward to measure the overall antenna efficiency. First of all the mobile terminal is often small and by adding a conductive cable to the small casing acting as the antenna for traditional antenna measurement will change the radiation and possibly also the overall efficiency [5]. Secondly, the antennas for mobile terminals radiate in all directions and the requirements for mounting the antenna and to the reflection level in a traditional antenna room is largely different. This has lead to a measuring setup in an anechoic room whereby both the transmitted and received power can be measured for each frequency channel, see figure 2.

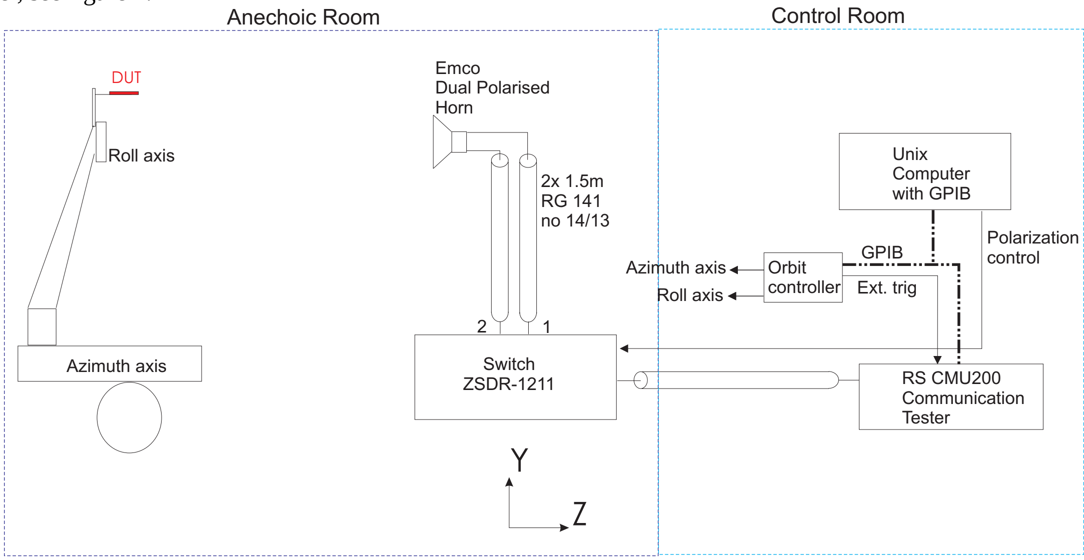

Fig. 2. Block diagram showing major components of the measurement system for measuring radiated power as well as received power. The received power can either be measured directly or by means of Bit Error Rate (BER).

The measurements are taken over a sphere around the phone in both polarisations by using a basestation simulator. The power received by the mobile terminal can be measured as either signal strength or as the Bit Error Rate (BER) for the new digital systems. By measuring the BER the measuring accuracy is increased and the measurement is not only including the antenna but also the interaction with the receiver. The interaction between the antenna transmitter and receiver can often cause self-interference on certain frequency bands or channels and it is therefore needed to measure at least one direction at each frequency channel. Results from measurements on several mobile phones on the market has shown that even though the transmitted and received power is specified and measured just before the antenna within small limits the variation when including the antenna can vary up to 10 dB [6]. Note that this is without any person using the phone. This can cause problems in normal operation and new requirements to the radiation and reception of the mobile terminal is demanded by the network operators. The most promising tests for both second-generation phones as well as third generation mobile terminals are based on spherical radiation and reception.

MEAN EFFECTIVE GAIN

Above only the amount of radiated power, or equivalent the amount of received power, was investigated. But in a mobile environment where the phone can take virtually any orientation with respect to the basestation not only the amount of radiated power but also the direction and polarisation of the radiated power is affecting the power received at the other end of the link. Basically, the radiation pattern is a recording of the power received or transmitted in all directions to or from the mobile, as measured on the surface of a sphere centred at the mobile. Given the uplink spherical radiation pattern the total power transmitted from the mobile can be obtained by an integration of the radiation patterns for the two polarizations. This is called the Total Radiated Power (TRP). While the TRP may be used for evaluating the efficiency of the antenna, the TRP result does not necessarily indicate how well the mobile works in practice. Due to the nature of the radio wave propagation in the mobile environment, the amount of power that actually reaches the receiver (base station) generally depends on the launching direction from the mobile antenna. As a simple example, for a mobile in an outdoor environment, any power transmitted upwards is not likely to reach the receiver. However, the TRP includes all the power transmitted from the mobile, and therefore the TRP may be misleading in the real situation.

A measure that takes the propagation channel into account is the so-called Mean Effective Gain (MEG) [7,8]. The MEG computation can be seen as weighted integration of the transmitted power, where the weights for the different directions depend on the mobile channel, i.e. the environment. Hence, the MEG takes into account the mobile channel whereas the TRP assumes a special or ideal channel. Further the MEG also weight the co-polarisation and cross-polarisation by the cross Polarisation Discriminator (XPD). The TRP and the MEG, as explained above, are performance measures for the uplink. Similarly to the uplink case, the MEG may be defined for the downlink where also the Total Receiver Sensitivity (TRS) is defined.

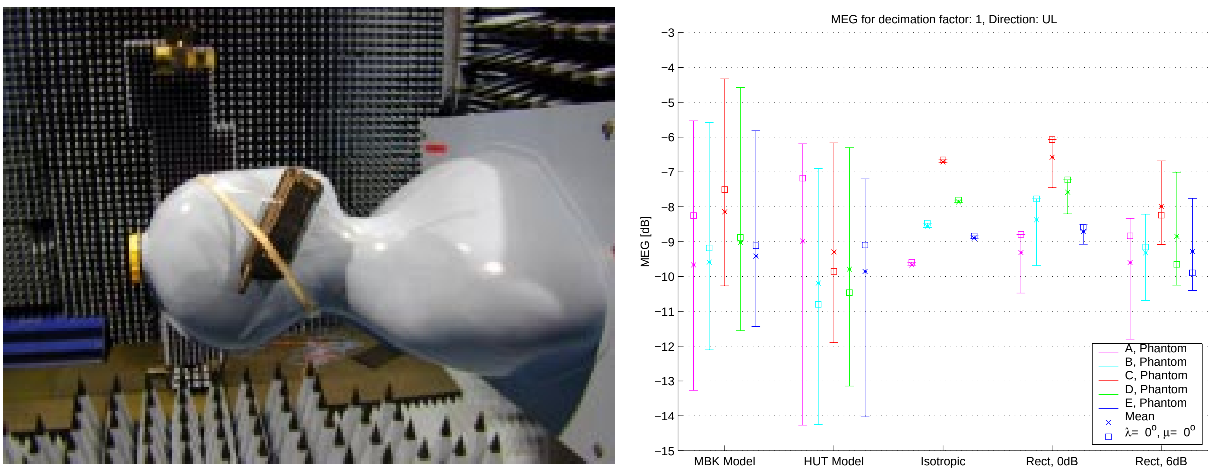

Fig. 3. Left the measurement setup in the anechoic room, note the "live" phone on the phantom where no cable or other modifications has been made. To the right the MEG values for different orientations of the phone and phantom for each phone model. Also the TRP is shown under the label `Isotropic'. As can be seen the MEG varies significantly vs. Orientation of the phone and phantom and also that the correlation between MEG and TRP is weak [9].

This investigation includes [9]

- Measurements of 5 different handsets/antennas
- Free space and phantom
- Different environments
- Uplink and downlink
- Different orientations of the handset
- MEG in different environments

The radiation patterns are measured in the anechoic room in an upright position. However, in practice the mobiles are used in many different orientations with respect to the environment, and this must be included in the MEG computations. In this work different combinations of tilt angles from vertical of the mobile and azimuth rotation angles were used. The tilt angle varied from -60 to 60 degrees and the azimuth rotation angle varied from 0 to 345 degrees, both in steps of 15 degrees. As an example of the results that have been obtained, Figure 3 shows the MEG values computed for the uplink. The MEG values are computed for different mobile environments with two models based on measurements of the mobile channel (MBK and HUT [10,11]). The TRP can be seen as special a case of the MEG, where all the power radiated in the different directions is received, regardless of the direction and polarization. Similarly, the TRS for the downlink is a special case of the downlink MEG. The special environment where all the power transmitted by either the mobile or the base station is received in the other end has been labelled `isotropic' in the figure. Thus, the results for the isotropic environment are the TRP and TRS results. In addition, results for two `Rect' environments are included. As for the isotropic environment, these environments also have uniform weighting versus direction, but only within an area of 45 degrees above and below the horizon. Outside this area no power is included. The difference between the two `Rect' environments is the cross Polarisation Discrimination (XPD) values of 0 dB and 6 dB, respectively. The XPD value is the difference in power between the polarisation in which the signals were transmitted and the power in the cross polarisation. The rectangular model with an XPD of 0 dB was suggested in [12] and therefore included in this work. On inspecting the results obtained with this model, another rectangular model with an XPD of 6 dB was included, as a possible simple improvement. For each of the five environments the MEG values are shown for all 5 mobile handsets, each mobile represented by a vertical line. The endpoints of each line are the minimum and maximum MEG values, respectively, obtained for the environment/mobile combination. From the figure two general observations can be made: Firstly, the MEG performance may vary widely for a mobile, depending on the orientation of the mobile with respect to the environment. For both the MBK and the HUT model the variation in more than 5 dB. The performance variation cannot be detected with the isotropic environment, since the TRP/TRS measure is insensitive towards the orientation of the mobile. A second important observation is that the MEG for the isotropic environment, i.e., the TRP, only shows a small variation among the mobiles as compared to the variation seen when the environment is taken into account, e.g., the HUT model. Thus, the TRP results are very different from the MEG results.

CONCLUSION

Both for third generation terminals and also for second generation terminals a test including the antenna will be required as already investigated by e.g. 3GPP. As shown it is not a trivial task to establish the communication performance including the antenna and more knowledge is needed but as shown it is possible to validate the communication performance of a mobile phone. Shortly standards based on solid technical knowledge will appear in e.g. 3GPP and it can be expected that the requirements for testing including the antenna will be adopted also by the existing mobile systems.

REFERANCES

[1] J. S. McLean, “A Re-examination of the Fundamental Limit on the Radiation Limits on the Radiation Q of Electrical Small Antennas”, IEEE Trans. On Antennas and Propagation Vol. 46 no 11, November 1996, pp 1629 – 1633

[2] G. Frølund Pedersen, J. Ødum Nielsen, K. Olesen, and I. Z. Kovacs, “Measured Variation in Performance of Handheld Antennas for a Large Number of Test Persons”, Proceedings of Vehicular Technology. Conference, Ottawa 1998, pp.505-509.

[3] G. Frølund Pedersen, K. Olesen, S. L. Larsen, “Factors Comprising the Bodyloss for Handheld Phones”, In the VTC Conference proceedings pp 1580-1584, Houston Texas, 1999.

[4] G. Frølund Pedersen ” Phantoms for Radiation Measurements of Mobile Phones”, In the PIMRC 2001 Conference proceedings pp C95 to C99, San Diego, Californian, 2001.

[5] W. A. Th. Kotterman, G. Frølund Pedersen, K. Olesen, P. Eggers, ”Cable-less Measuremen Setup for Wireless Handheld Terminals ”, In the PIMRC 2001 Conference proceedings pp B112 to B116, San Diego, Californian, 2001.

[6] “*Wireless Flexible Personalised Communications”*, Edited by Luis M. Correia, John Wiley & Sons, ISBN 0 471 49836X.

[7] J. Back Andersen and F. Hansen, “Antennas for VHF/UHF personal radio: A theoretical and experimental study of characteristics and performance”, IEEE Transactions on Vehicular Technology, Vol. 26 no. 4 pp 349-357, November 1977.

[8] T. Taga, “ Analysis for mean effective gain of mobile antennas in land mobile environments”, IEEE Transactions on Vehicular Technology, Vol. 39 no. 2 pp 117 – 131, May 1990.

[9] J. Ødum Nielsen, G. Frølund Pedersen. ”Comparison of Total Received Power and Mean Effective Gain for Mobile Handsets”, COST 273 document, TD(02)021.

[10] M. Bergholz Knudsen, ” Antenna Systems for Handsets”, Ph. D. theses, Aalborg University, September 2001. Can be reached at http://home1.stofanet.dk/grenen7

[11] K. Kalliola and H. Laitinen “Statistical distribution of incident waves to mobile antenna in microcellular environment at 2.15 GHz” COST 259 document, TD(99)045.

[12] “CTIA Wireless Subscriber Station Certification Program. Method of Measurement for Radiated RF Power and Receiver Performance.” Draft revision 1.0, May 2001. Cellular Telecommunications & Internet Association Certification Programs, 1250 Connecticut Ave. NW, Suite 800, Washington, DC 20036.