Investi
into the power
under real

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Introduction

During the use of mobile phones the human head is exposed to electromagnetic fields. Mobile phone manufacturers have to prove that their products comply with applicable limits with regard to radio frequency exposure of the user.

The Specific Absorption Rate (SAR) is the appropriate quantity used to describe the immission in the near field of mobile phones. The SAR is the basic quantity for the assessment of radio frequency immissions. The SAR of a mobile phone is established by a standardized measurement method and indicates the energy input into the body tissue of the person making the phone call (unit: Watt/kilogram). The relevant limit for the part-body SAR at local exposure of the head/body is 2 W/kg, averaged over a 10 g mass of coherent tissue volume. This standardized SAR measurement method is a worst case consideration, as the mobile phone transmits well-defined at the highest power level during measurement. Under normal conditions, mobile phone transmission power is controlled depending on the quality of the connection with the base station. The aim is to use the minimum power required for maintaining the connection.

gations

control of a GSM mobile phone operating conditions

Data on maximum exposure of the user are, however, not sufficient to answer certain questions. This relates to:

- Epidemiological studies investigating possible effects of radio frequency exposure on user health require exact data on average exposure during a call: Information provided by the maximum SAR is insufficient.
- Information about the control performance of mobile phones is also of interest for precautionary minimization of exposure. For it is only the exact knowledge about factors that exert an influence on the real exposure of the user that allows e.g. to give recommendations for the behaviour of phone users. Above all, there must be clarity about which parameters exert a strong influence on real exposure and which ones are of subordinate relevance.

There are few studies available dealing with the issue of actual exposure during the use of a mobile phone and related influencing factors [WIART 00, ARDO 04]. In some studies, results were not obtained from individual measurements, but from supplementary evaluation of data of many calls stored by mobile radio operators [LÖNN 04].

At present, a study on this issue is underway within the “German Mobile Radio Research Program”, titled “Determination of SAR values occurring during daily use of mobile phones”. The completion of this study

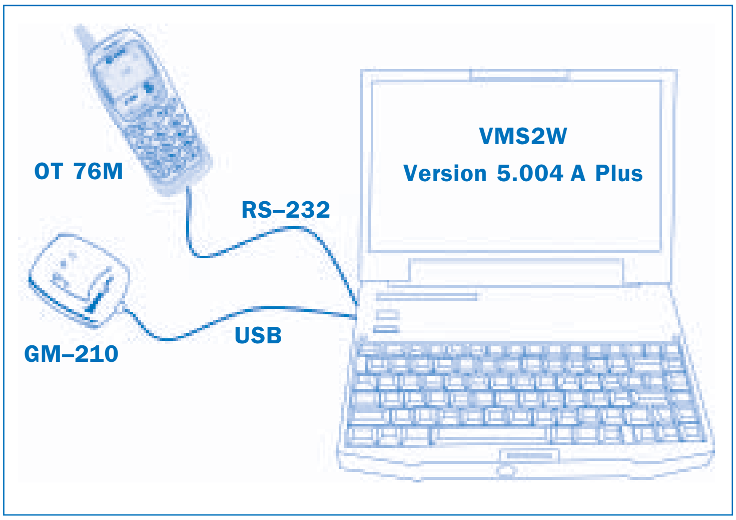
Fig. 1: SAR meter ESM 120

is planned for mid-year 2005. Two interim reports on the project are already available [GEORG 04-1, GEORG 04-2].

In the context of a diploma thesis written at the "University of Applied Sciences" at Deggendorf, extensive investigations were performed in the summer of 2004. The aim was to verify published knowledge about mobile phone power control and to obtain additional results [WUR 04]. Special attention was given to the graphic depiction of results. The following basic aspects related to mobile phone transmission power were investigated in the project:

- the dependency of transmission power levels on the network structure and quality of supply
- the influence of the human body on transmission power control
- reproducibility of measurement results
- differences between average transmission power needed by moving phone users and area-related evaluation of phone transmission power
- transmission power control on underground lines with tunnel supply.

Measurements were mainly performed outdoor. Additional measurements were, however, conducted in underground trains and during the use of a phone by motor vehicle passengers (without external antenna). Investigations into control performance of mobile phones in closed spaces are planned in future projects. Some very concrete results of the investigations for the thesis are briefly described in the following.



Ill. 2: Measurement set-up

Ill. 3: The spatial distribution of transmission power levels and their average values were determined for the shown routes in the city centre of Passau. The arrows point to the walking direction.

Basics of power control of GSM mobile phones

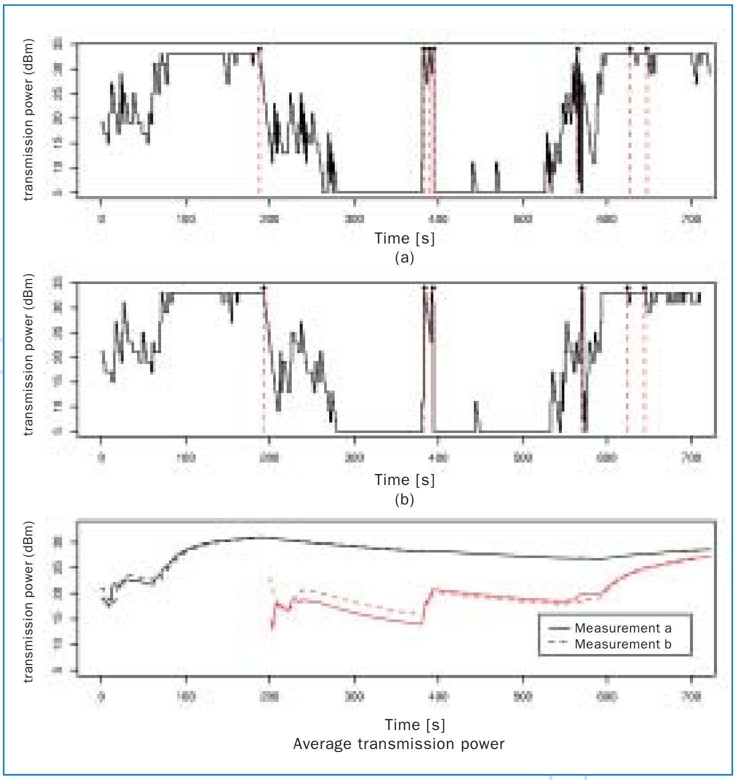
The transmission power of GSM mobile phones is constantly controlled during connection in order to minimize energy consumption resp. improve network quality (minimization of interference). The power of GSM 900 phones can be reduced in 15 steps from 2 Watt (33 dBm; power level 5) to 3.2 milliwatt (5 dBm; power level 19). Power is reduced by 2 dB per level. There are 16 levels for GSM 1800, in steps of 2 dB between 1 Watt (30 dBm; level 0) and 1 milliwatt (level 15). The differential factor, i.e. the difference between maximum and minimum transmission power, is thus about 1,000 both for GSM 900 and GSM 1800.

The transmission power is controlled by the base station through constant observation of the level and the bit error rate of the received signal. The phone is made to increase or decrease transmission power according to the changes in the quality of the connection. Power control commands are sent to the phone every 0.5 seconds (actual power adjustment, however, is distinctly faster: the phone can change its power level every 60 ms). Required phone power levels are not specified in numbers in the GSM standard; network operators are free to define optimal control algorithms. In general, however, it can be observed that, if connection quality is insufficient, power levels are significantly increased very quickly e.g. to prevent connection breakdowns. Typical is a command to increase power by 6 dB. Power reduction, in contrast, is for the most part performed rather slowly. Typical is a request for a decrease by one level, i.e. 2 dB.

Of great importance for the analysis of average transmission power is the fact that GSM mobile phones always operate with the maximum power level when a connection is first established. It takes some time (typically a few seconds up to 20 seconds, dependent on the quality of the connection) to reduce the level to the sufficient amount due to the commands of the base station. The same behaviour is usually observed in mobile phones after a change of cell (hand-over): At first, transmission power is at its maximum, possibly followed by a reduction of power where appropriate.

Another mechanism for the reduction of average transmission power is the DTX mode (discontinuous transmission) where, during pauses in speech, the phone ceases to send 217 transmission pulses per second. Instead, there is a combination of 8 Hz and 2 Hz pulse sequences. This operation mode is, however, not affected by external quantities, but only by the speech characteristics of the user (frequency of breaks) and was therefore not included in the experiments.

UMTS phones are also power-controlled; control is distinctly faster, and the dynamic range is considerably larger than that of GSM. However, UMTS phones were not that closely examined in the project.



Ill. 4: Time course of mobile phone transmission power levels for measurement route 1 in Passau (two measurements for the validation of reproducibility). Handovers are marked by vertical red lines. The third graph shows two different courses of average power started at different times. Note: Recordings at the starting point of the route begin only a few seconds after connection was established, after the phone power level was down regulated to the sufficient amount.

Methods for the determination of phone user exposure

The Specific Absorption Rate (SAR) occurring in the head is used as a physical quantity for the description of exposure related to the use of a mobile phone. It indicates how much power is absorbed per gram of body tissue and thus is transformed into heat. There are complicated measurement set-ups with head models filled with tissue-simulating fluid for the standardized determination of the SAR during mobile phone use. Such apparatuses are not an appropriate tool for SAR measurements performed in normal living surroundings, since measurements would be very time-consuming and mobile use of these devices would not be possible with reasonable expenditure.

But for quite some time now, a simplified "SAR measurement device" has been available [MASCH 03]. It cannot be used for standardized SAR determination for the type approval of mobile phones, but can be effectively applied in qualitative studies. As is shown in figure 1, this "SAR measurement head" is at least an appropriate tool for measurements performed in interiors or for mobile measurements in motor vehicles (mounted on the passenger seat) Measurements done while walking longer distances are still quite strenuous to do with this system.

A system for direct measurement of the SAR was therefore not used in this study. Instead, measurements were performed with a modified mobile phone (Sagem OT 76M) that transmits important signalling data of the air interface (among other things, the current transmission power level) via an interface to a laptop (fig. 2). In addition, the current position is determined by a GPS receiver and combined with the mobile phone data. This portable measurement system is thus not capable to determine the current SAR, but only the current transmission power that, however, is directly proportional to the SAR. Thus, by recording the time course of the phone's transmission power, also the temporal change in SAR is determined. As a consequence, the measurement technique cannot indicate absolute SAR values but only relative quantities. Moreover, findings relate only to the phone that was used in experiment. A comparison of different phones was not possible. The big advantage of this measurement set-up is the easy handling (measurements done on foot are fairly unproblematic, the laptop can e.g. be carried in a rucksack); furthermore, additional parameters can be recorded, aside from the current transmission power level (reception level, bit error rate, ID of the corresponding base station, etc.). Thus, further evaluations are made possible.

The presented measurement system was used to perform extensive measurements in a GSM 900 network in different surroundings. Some of the results of the investigations will be briefly presented in the following.

Measurements performed in the Passau city centre

Extensive measurements were performed in the city centre of Passau. Downtown Passau is characterized by relatively densely built-up areas with, in part, quite narrow streets and alleys, i.e. the topography makes it rather difficult to provide supply. Figure 3 shows the course of the individual measurement routes.

Measurement route 1 was walked twice to draw conclusions on reproducibility (call duration approx. 12 minutes). The results of the two measurements are compared in Figure 4. Reproducibility of the measurement was very good (average transmission power 0.71 resp. 0.68 Watt). The time course shows areas with maximum, and part-routes with minimum transmission power levels. It can also be clearly seen that, after a hand-over, maximum power is always used before power control engages. Figure 5 depicts the current transmission power of the phone in a coloured map. The small area with maximum transmission power during the hand-over can be clearly seen, about halfway along the route. (The call is only handed over from one sectorial antenna of the close-by transmitter to another antenna of the same site.)

In principle, there are two different possibilities to determine average exposure:

- The obvious thing to do is to calculate the average transmission power from the measurement results. This quantity is representative of the average exposure of a caller who moves along the observed route during the phone call (e.g. a pedestrian). The resulting average power level, however, strongly depends on the duration of the call, the number of handovers and the selected route.
- In reality, mobile phone calls are not always made while moving. There are at least as many phone calls of persons who do not move much, i.e. who are standing (e.g. at a bus stop) or sitting somewhere (e.g. in a café) during the phone call. In such cases average transmission power levels obtained from (such) measurement courses are not very meaningful. The cartographic depiction of transmission power is more informative, as shown in figure 6 for the city centre of Passau. The obvious thing to do is to depict the probability of the occurrence of a certain transmission power level by percentiles. The median e.g. shows which transmission power level is fallen below at 50 percent of the tested points.

The overall result of the evaluation of measurements performed in the city centre of Passau with regard to average power and median can be seen in table 1. An analysis of table 1 leads to the following results:

- Both median and average transmission power strongly depend on the selected measurement route. Due to the dense build-up, areas with very low transmission power levels are found only in close proximity to the base station site (within a radius of about 100 meters). When turning round the corner of a building, the immediate visual contact to the site is interrupted; the phone distinctly increases its power.
- The average transmission power (0.75 Watt) is below the maximum value of 2 Watt only by a fac-

Measurement no.	1a	1b	1c	2	3	4	5	6	total
Average power[Watt]	0.71	0.68	0.51	0.34	0.13	0.77	1.82	0.18	0.75
Median [Watt]	0.08	0.08	0.02	0.05	0.03	0.5	2	0.03	0.13

Table 1: Results of measurements performed in the city centre of Passau (average transmission power levels and median) for the different part-routes. In all measurements, the phone was held to the right ear. An exception was measurement 1c: The phone was inside the breast pocket.

Route no. Nr.	**average distance to base station site**	**average transmission power (phone pointing to the base station)**	**average transmission power (head between phone and base station)**
1	482 Meter	6.7 dBm	11.3 dBm
2	951 Meter	14.3 dBm	10.6 dBm
3	1594 Meter	25 dBm	15.2 dBm
4	1802 Meter	29.7 dBm	13.4 dBm

Table 3: Average transmission power levels dependent on the phone's position relative to the base station (average values from all performed measurements)

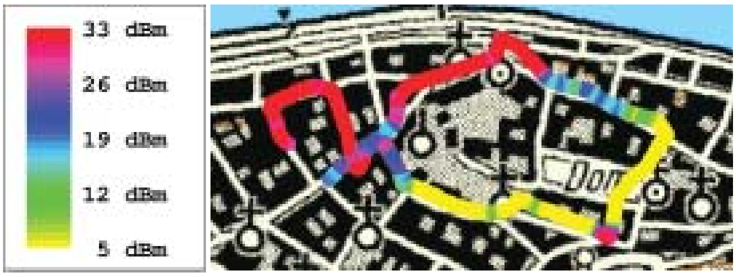


Fig. 5: Local distribution of transmission power along the measurement route 1 in Passau (measurement 1a)

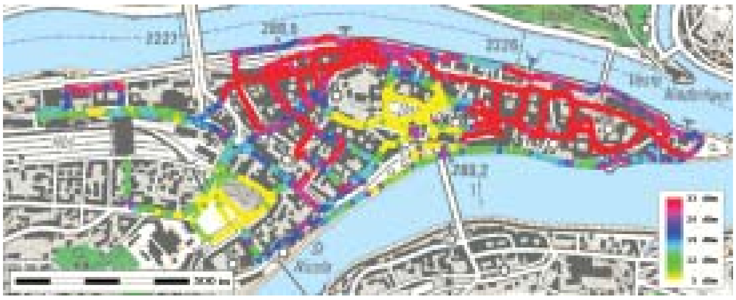


Fig. 6: Local distribution of transmission power in the Passau city centre

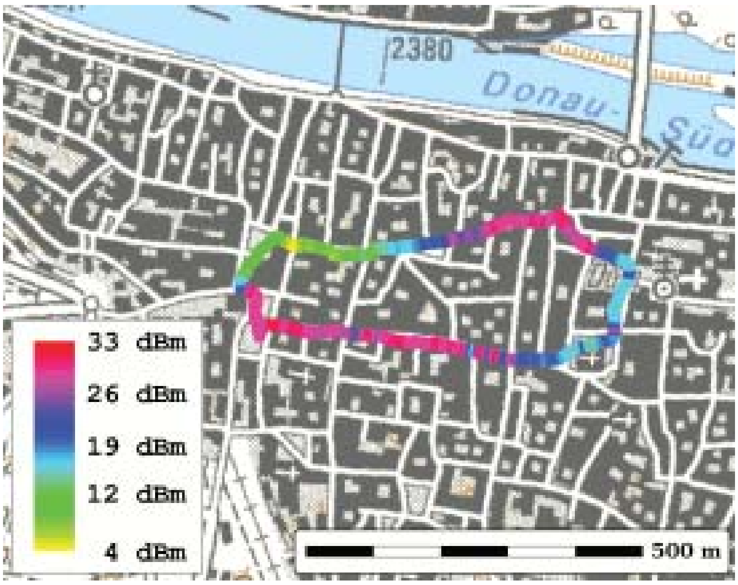


Fig. 7: Local distribution of transmission power in the Regensburg city centre (left: conventional network with rooftop sites; right: micro cell network)

tor 2.5 (about 4 dB). There is no extreme power reduction during phone calls made by moving persons due to the densely built-up areas and relatively frequent handovers.

- Area-related evaluation provides a median value that is clearly below average transmission power (about 7.5 dB lower). At 50 percent of the measurement points located in the Passau city centre, transmission power is less than 0.13 Watt. That is about 12 dB less than the maximum power level.
- Both the evaluation of average transmission power and the area-related evaluation demonstrate that, on average, the minimum possible transmission power is by far not achieved in the Passau city centre.

Average immissions in a city centre with micro cells

Occasionally, in city centres densely packed with shops, cafés, public squares and bus stops and corresponding great numbers of phone calls, networks consisting of many adjacent, low-mounted micro cell antennas (e.g. on building fronts or advertising columns) are installed in support of the additional rooftop sites in order to increase capacity. A GSM 900 operator in the historic Old Town of Regensburg has implemented such a micro cell network. The second German GSM 900 operator has installed a conventional network with rooftop sites in the city centre of Regensburg. Average transmission power levels of both network structures were measured along a circuit in the Old Town of Regensburg. The results are compared in figure 7 and in table 2.

Obviously, the micro cell network provides a distinctly improved supply quality along the route. On average, lower transmission power levels are needed than within the conventional network structure. When taking a look at the median, it can even be seen that the phone operates at its lowest power level at more than 50 percent of the measurement points.

This finding is relative though: On the one hand, a route optimally oriented to the micro cell sites was selected; the measurement result thus reflects an "optimum condition". For further measurements performed in Regensburg, also routes without orientation to the local sites of micro cell antennas were selected. In these cases, very quickly the same average results were reached as for rooftop sites, due to the small reach of micro cell sites.

It must be noted that the micro cell network in Regensburg is a highly cost-intensive alternative (6 micro cell sites plus one rooftop site in an area of about 60 x 200 meters, compared to three rooftop sites for the "conventional network"). Thus, the use of this network structure will scarcely be economic for larger areas.

Influence of different positioning of base stations on average transmission power

Measurements performed in smaller towns were aimed at examining the influence of site selection for mobile radio base stations on the exposure of phone users. Figures 8 and 9 exemplarily show the results from measurements conducted in two communities of Lower Bavaria (Bad Griesbach and Ruhstorf).

In towns supplied by external sites, as is the case in Bad Griesbach, phones nearly everywhere have to transmit with maximum power, since the quality of supply, although sufficient for maintaining the connection, does not allow an observable reduction in transmission power. This effect should be even more

Network structure	average power [Watt]	median [Watt]
Rooftop sites	0.44	0.2
Micro cells	0.14	0.003
Differential factor	3.1	66.7
Differential factor in dB	5.0	18.2

Table 2: Results of measurements performed in the city centre of Regensburg (average transmission power and median)

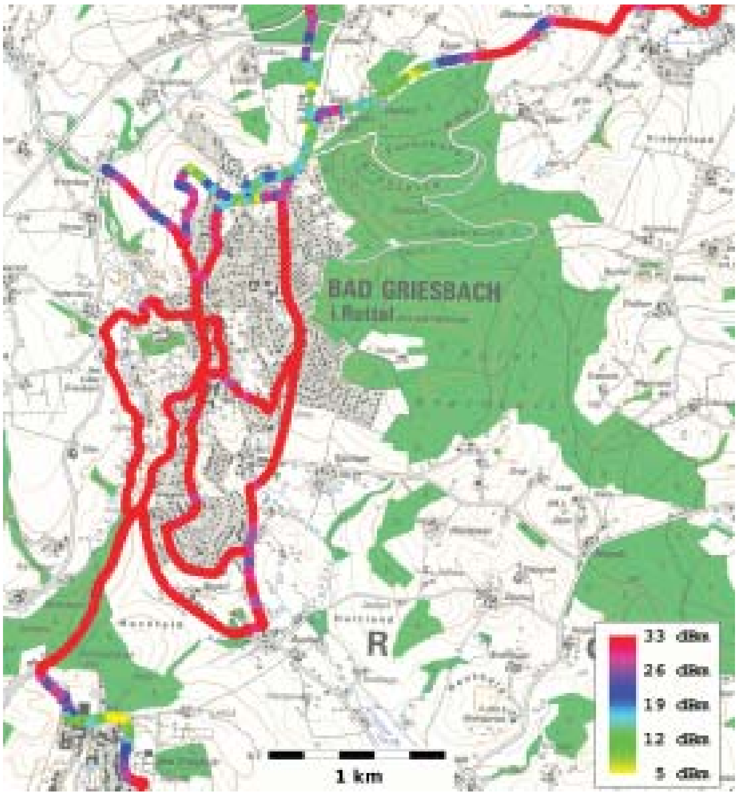


Fig. 8: Local distribution of transmission power in Bad Griesbach

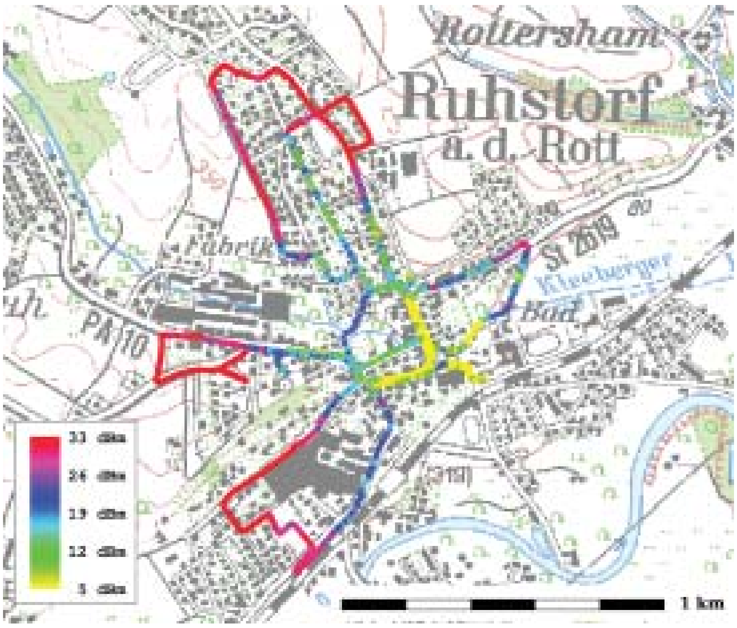


Fig. 9: Local distribution of transmission power in Ruhstorf

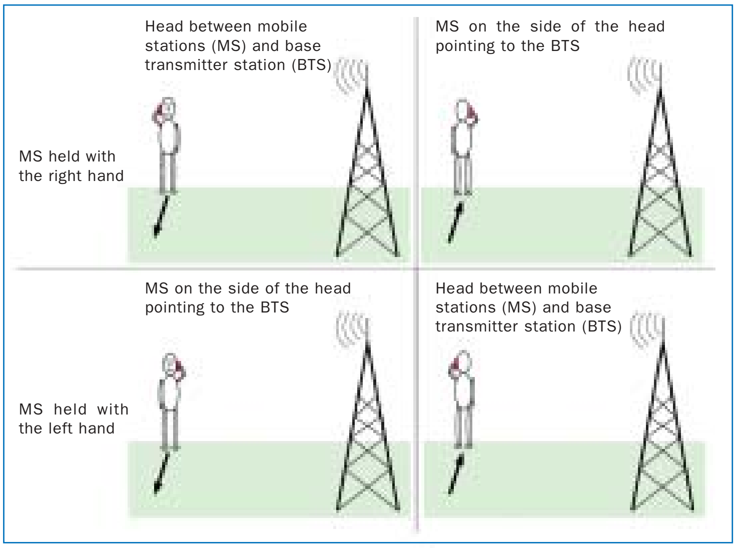


Fig. 10: Simple measurements on user influence

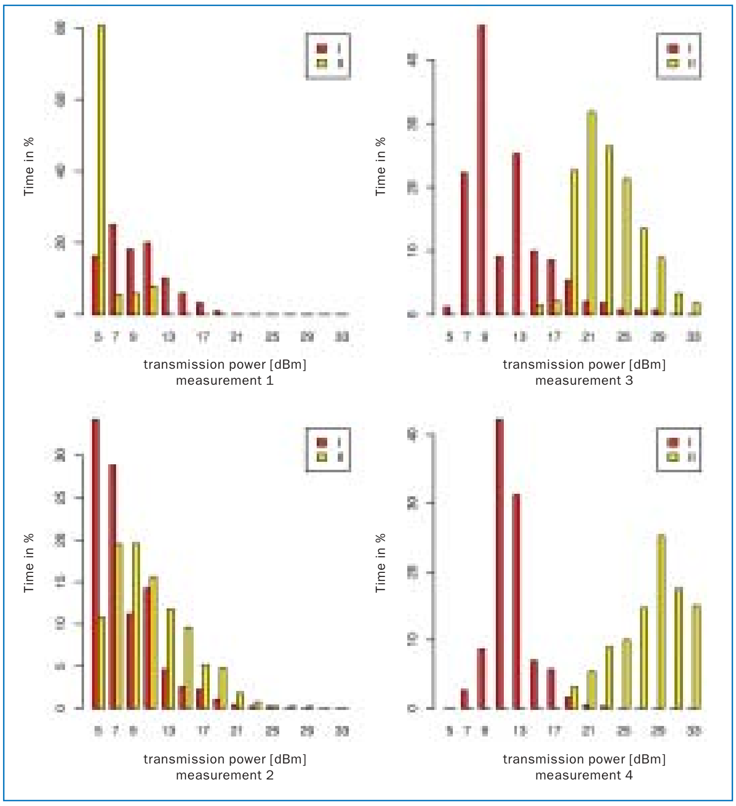


Fig. 11: Histograms of the measurements with the phone held to the right side of the head (red: phone pointing to the transmitter; yellow: head between phone and transmitter)

pronounced inside buildings; however, measurements were only performed outdoor.

Obviously, selection of sites located in a town's centre is more favourable with regard to the exposure of phone users, as is the case in Ruhstorf. One can see here that, at least in the town's centre, phones can considerably reduce their transmission power levels.

Influence of the user on transmission power control

Besides network structure, the influence of the user on transmission power control was examined. Measurement routes located at different distances to a mobile radio site were walked several times in both directions. The phone thus was held both on the side of the head pointing to the base station and on the side pointing away from it (figure 10). The measurements were conducted in a flat rural area with direct visual contact to the base station site so that influences of reflections would be as small as possible. The base station was equipped with an omni directional antenna and thus there were no handovers. The results of the measurements are depicted in figure 11 and table 3.

The following insights were obtained from the results:

- As expected, there was an increase in average transmission power with increasing distance to the station, when the phone was held to the side of the head pointing to the base station. When holding the phone to the side of the head pointing away from the base station, this trend was less pronounced.
- With the exception of route 1, the influence expected due to the shadowing effect of the head is well observable. Moreover, it is more pronounced with increased distance: The phone needs distinctly less power if held to the side of the head that points to the station.
- There is a reason for the fact that this effect does not occur on measurement route 1. The station is very close here, so the phone, on average, nearly

always operates on the lowest power level. This is also true on the side of the head pointing away from the station, since the body shielding is obviously compensated for by sufficiently strong reflected signals.

Comparison between median and average transmission power for all measurements

Besides the measurements presented in this article, a variety of other measurements done on foot or by car were conducted in diverse surroundings. Fig.. 12 and 13 show all average transmission power levels and the percentiles drawn from area-related observations. The results were as following:

- Measurements done on foot in cities and smaller communities indicated average transmission power levels of about 0.4 to 0.8 Watt. The median value reached 0.1 to 0.2 Watt. Only micro cell supply in the city centre of Regensburg, as an extreme case, yielded distinctly reduced power levels compared to the rest of the measurements.
- Different average power levels resp. median values were found during measurements performed on highways and motorways, depend on the quality of supply. The measurement results of Bad Griesbach are discussed above; they are due to the large average distances to the base stations.
- Of special interest are the measurement results in the area of the Nuremberg underground. The supply of the tunnel is not ensured by radiating cables (slot cables), but by directional antennas that are mounted in the tunnel, near the stations, radiating from both sides into the tunnel. For the most part, the radiation of the antenna back lobe is sufficient for the supply of the stations. The measurements (covering several rides in the individual tunnel sections) demonstrated that such a tunnel supply can provide a very good connection quality so that, compared to the other measurements, the most favourable average power levels of the phone were found here.

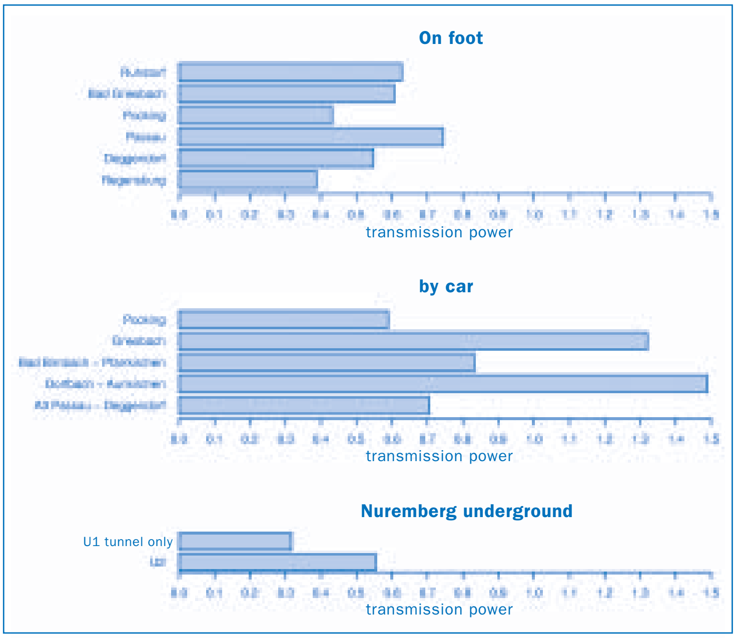


Fig. 12: Average transmission power levels of all recorded measurements done on foot resp. by car

Summary

Power control in a GSM mobile radio network was investigated by means of a specially configured GSM 900 phone. The average transmission power of the phone can be used as a measure of the exposure of the phone user. Measurements were done outdoor on foot or by car. Average power levels for persons moving on foot or by car during a phone call remain clearly above the theoretical minimum limit of the phone. Instead, due to unfavourable connection quality and frequent handovers, average power levels of several hundred milliwatts up to, in part, even more than one Watt are to be expected.

But area-related evaluation also shows that power levels within the minimum range of the phone can be reached in areas with favourable supply, if the phone call is made by a stationary resp. scarcely moving participant.

Site selection and site density of mobile radio base stations can exert a considerable influence on the average transmission power of the phone.

Even most simple measurement sequences can reveal a distinct influence of the user on average transmission power during phone calls.

Obviously, tunnel supply for underground and rapid trains can be designed so as to ensure not only uninterrupted connection, but also a relatively large reduction in transmission power during phoning.

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References

[ARDO 04] L. Ardoino, E. Barbieri, P. Vecchia „Determinants of Exposure to Electromagnetic Fields From Mobile Phones“, Radiation Protection Dosimetry, Vol. 111 (4), S. 403-406, (2004)

- [GEORG 04-1] R. Georg „Bestimmung der SAR-Werte, die während der alltäglichen Nutzung von Handys auftreten: Literaturstudie“, BfS-Forschungsprojekt M8810, (03/2004), www.deutsches-mobilfunk-forschungsprogramm.de
- [GEORG 04-2] R. Georg „Bestimmung der SAR-Werte, die während der alltäglichen Nutzung von Handys auftreten: Vorstellung der Mess- und Berechnungsverfahren“, BfS-Forschungsprojekt M8810 (08/2004), www.deutsches-mobilfunk-forschungsprogramm.de
- [LÖNN 04] S. Lönn, U. Forssen, P. Vecchia, A. Ahlbom, M. Feychting „Output Power Levels from Mobile Phones in Different Geographical Areas; Implications for Exposure Assessment“, Occup. Environ. Med., Vol. 61 (9), S. 769-772, (2004)
- [MASCH 03] Firma Maschek Elektronik Datenblatt SAR Meter ESM 120
- Kaufering, (2003) www.maschek.de
- [WIART 00] J. Wiart, C. Dale, A. Bosisio, A. Cornec „Analysis of the Influence of the Power Control and Discontinous Transmission on RF Exposure with GSM Mobile Phones“, IEEE Transactions on Electromagnetic Compatibility, Vol. 42, S. 376-385, (11/2000)
- [WUR 04] T. Wurstbauer „Untersuchung der Leistungsregelung eines GSM-Mobiltelefons unter realen Betriebsbedingungen“, Diplomarbeit, Fachhochschule Deggendorf, Fachbereich Elektrotechnik und Medientechnik, (2004).