

# Study on possible of cm-/mm waves on the human

by J. Waldmann, F. Landstorfer,  
R. Wisniewski, K.P.Hadeler,  
J. Müller, V. Müller, F. Lang



STUDYS

## Part I: Concept, experimental set-up and results

### 1.1. Introduction

In recent years commercial use of electro-magnetic fields has increasingly extended to the higher microwave range. Apart from traditional telecommunication services such as directional radio, satellite links or wireless networks (f.e. 60 GHz), these frequencies also are used in road traffic. Here, the main emphasis lies on applications of radar technologies (for example distance radar in intelligent tempomates at 77 GHz or lateral radar for side impact protection system at 94 GHz). With the increased use of these frequencies we have to consider possible effects of the involved electromagnetic fields on human organism, particularly of those which could have health-impairing consequences.

Several studies commissioned by the Forschungsgemeinschaft Funk e.V. (FGF; Association for Radio Applications) examined potential effects of microwaves. A study of the IMST (1) (2) dealt with the subject of thermal effects. A second study (3) focused on potential non-thermal effects based upon the hypothesis that potential non-thermal effects can be observed in spite of microwave power flux density being in the range where thermal effects do yet not occur. This article is based on this study.

### 1.2. Experimental set-up

Potential effects of microwaves on the human autonomic nervous system were

examined via field exposure experiments in healthy subjects. Aimed to obtain relevant experimental results on actually used systems operating within this frequency range, a commercially available distance radar system (figure 1) with a radio frequency of 77 GHz was applied. Power flux density at the site of the test subject (exposed were breast and stomach areas) amounted to about 3  $\mu\text{W}/\text{cm}^2$ . In a double-blind experiment (see part II) subjects were exposed/sham-exposed during different time intervals. During the test a series of important physiological parameters controlled by the autonomic nervous system were continuously observed and later compared applying methods of evaluating statistics (see part II).

### 1.3. Medical background

In our study, the identification of potential effects of microwaves on the human organism is based upon the observation of the autonomic nervous system. As this also includes control and functioning of the circulatory system, i.e. fundamental functions of the human organism, an observation of the autonomic nervous system may lead to quite reliable insights into potential nonthermal effects of microwaves. For identifying possible effects on the autonomic nervous system, the following parameters were used: the electrocardiogram (ECG) in order to observe heart activity, blood pressure, respiratory frequency, as well as skin conductivity and

# effects

## autonomic nervous system

skin temperature among other things giving evidence of temperature control in the human organism. Blood pressure and electrocardiogram are the parameters most strongly influenced by the autonomic nervous system; nevertheless, the other parameters were of importance, too, since measurements are uncomplicated and may provide additional information for statistical evaluation. In short, by observing these parameters possible nonthermal effects of microwaves on the human autonomic nervous system may be identified.

### 1.4. Measurement system and proceedings

As the observed parameters of the autonomic nervous system very quickly (within some 10 seconds) respond to stimuli, no lengthy observation intervals are required. Therefore, a field exposure interval of 15 minutes was selected. During this period possible effects of microwaves can be observed quite clearly. However, since the mentioned parameters may also be influenced by other external stimuli, the experiment began with a 30-minutes resting period during which no exposure occurred. For identifying possible effects the total of 50 experiment subjects was randomly divided into two equally numbered groups.

Here, neither the test subject nor the testing scientist knew to which group the individual subject belonged. Table 1 shows the measurement schedule. During the 60-minutes measurement period following to the resting period the experiment subjects of the first group were exposed for the first 15 minutes, the second group for the third 15 minutes. To each field exposure period followed a rest aimed to put possible effects to rest and to prevent carry-over effects in the next field exposure period. The recording of observation data as well as the control of field exposure set-ups was automated to prevent measurements from being influenced by the activities of the scientists responsible for the tests. Further, subject data were administered by the computer system to guarantee the anonymity. Figure 2 shows the measurement site with an experiment subject. In the foreground one sees the antenna of the applied radar system. The measurement site is located in a shielded absorber measurement chamber to minimize the impact of external fields.

### 1.5. Statistical evaluation

The applied statistical methods, as well as the evaluation of measurement results by means of statistics and the statistical

Measured parameters:  
 electrocardiogram (ECG)  
 respiratory frequency  
 blood pressure  
 skin temperature  
 skin conductivity



fig. 1: Applied radar system

resting period	field exposure group 1	rest	field exposure group 2	rest
----------------	------------------------	------	------------------------	------

table 1



fig. 2: Measurement site

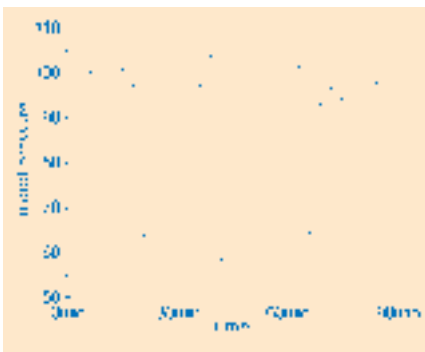


fig. 3: Measurement data of subject 4.0 (blood pressure)

verification of the drawn conclusions are presented in part II of this article.

### 1.6. Results

The experimental design was based on the assumption that the observed parameters initially would decrease considerably (resting), but for the rest of the time would remain constant. Thus, a possible impact of microwaves would be clearly identifiable. However, a pretest showed that this was not the case. The decrease of parameters is not limited to an initial phase, but continues for the whole 90 minutes (see fig. 3). During evaluation of the experimental data of all 50 test subjects this result could be confirmed as highly significant (see part II). The evaluation of the parameters' time series in view of a possible impact of microwaves on the autonomic nervous system no significant effect could be proven. The study did not find evidence for any effect whatsoever on the autonomic nervous system.

### 1.7. Conclusion

During the study 50 test subjects were exposed to a 77 GHz microwave signal of low intensity ( $3 \mu\text{W}/\text{cm}^2$ ); simultaneously, relevant autonomic parameters were observed. The subject was exposed for 15 minutes in a double-blind experiment with

a total duration of 90 minutes. The field exposure randomly occurred within two possible time intervals. Subsequently, these two intervals were compared during statistical evaluation. The total of experiment subjects was divided into two groups being differentiated by the order of intervals with and without field exposure. Though evaluation showed that the activity of the autonomic parameters during the second interval (min 60 through 75) generally was lower than during the first interval (min 30 through 45), no difference between exposed and non-exposed intervals could be identified. Thus, the investigation did not observe any impact of microwave radiation at 77 GHz on the autonomic nervous system.

### Literature

- (1) U. Kullnick: Biological Effects in the cm/mm Wave Range Part 1 – Literature Survey, Abschlußbericht des Instituts für Mobil- und Satellitenfunktechnik GmbH, Kamp-Lintfort, April 1998.
- (2) F. Gustrau, A. Bahr: Biological Effects in the cm/mm Wave Range Part 2/3 – Determination of Material Parameters and Analysis of Field Strengths in Human Tissue, Abschlußbericht des Instituts für Mobil- und Satellitenfunktechnik GmbH, Kamp-Lintfort, June 1998.
- (3) J. Waldmann, F. Landstorfer, R. Wisniewski, K.P. Haderler, J. Müller, V. Müller, F. Lang: Investigation of Possible Non-Thermal Effects of cm/mm-Waves on the Autonomic Nervous System, Abschlussbericht, Stuttgart, July 2000.

# Part II: Statistical Evaluation

## 2.1. Introduction

The first part of this article presented the aims of our study on possible effects of cm/mm waves on the human autonomic nervous system, as well as the medical background, measurement methods and the evaluation of results from a medical point of view. As is always the case in such studies, tests were performed in a small sample in proportion to the total population meaning that results have to be confirmed by statistics. It is to be expected that industrially applied signals at most can cause slight effects; on the other side, the autonomic nervous system which for example responds to emotional stimuli may be expected to show considerable variations in different subjects in due time. Insofar, the aim of the study was to detect very small effects at possibly great variations or to exclude such effects. Therefore, it was necessary to minimize variations between test subjects and observation intervals as far as possible to already by means of the test design.

Statistics operate as follows: In view of the relation between effects, disturbances and observations a model is assumed. Based on the data it is tested whether the conditions for applying the model are fulfilled. Subsequently, on the basis of such a model for example parameters can be assessed, confidence intervals can be calculated, hypotheses can be examined or options can be found. In the end, results have a certain probability factor.

It is not sufficient to transfer data into formula or to computer programs and then to gather mentioned probability factor from tables or from the desktop. Model development and testing are very important el-

ements of experiments; but as important are the interpretation and evaluation of the results, i.e. drawing the connection between statistical model and practical application, a step that should be taken with great care.

In the following, the test design will be described; after that we will point to the problem of fatigue effects. Next, the statistical model will be introduced complemented by a description of the conditions required for its use. The ensuing chapter once more presents the characteristics of statistical analysis illustrated by an example. We will show how respective conditions were tested. Finally, we will deal with the test performance itself and validation of results.

## 2.2. Test design

The study participants were subjected to a resting period, followed by two observation intervals separated by a rest. During one interval they were exposed, during the other one there was no exposure. Here, neither the testing scientist nor the test subject knew during which interval exposure occurred (double-blind experiment). Such set-ups reduce variation compared to a theoretical set-up that exposes one half of the test subjects leaving out the other half. This is called 'crossover design'. The sample size of 50 subjects was set in cooperation with the physiologists according to their experience concerning magnitude and variation of physiological quantities.

## 2.3. Fatigue effects

Pretests showed that in spite of resting in due course of observations resting or fatigue effects could overlie possible field exposure effects. Since fatigue effect and

possible field exposure effect could not be separated during experiment, they had to be statistically analysed together. Ultimately, the occurrence of fatigue effects proved advantageous for the test, as they allowed assessments as to which magnitude effects can be detected by the statistical model.

## 2.4. Statistical Model

The basis was a linear model, i.e. the assumption that fatigue effect and possible field exposure effect additively overlie: For each measurement the observed value is an addition of the average value, the fatigue effect, the field (sham) exposure effect, as well as random disturbance. The latter is assumed as normally distributed with an expected value equalling zero. Linearity is adequate for relatively small effects. Deviations from the average value equalling zero are seen as effects. An approximately normal distribution is to be expected when disturbances are caused by a great number of independent influences. The conditions for the application of the linear model have to be reviewed (see chapter 6).

In our case, the zero hypothesis means that no field exposure effect is identifiable. In regard to the model it means that for each observed variation the difference between the values of field exposure/sham exposure equals zero and that all deviations from zero must be seen as random disturbances.

Based on the zero hypothesis via methods of linear algebra a test variation with known distribution is developed (2). That enables us to describe in detail the probability of observed effects being caused

by random variation. In other words, we can identify the probability of erroneous rejection of the zero hypothesis (based on the assumed model).

## 2.5. Graphic interpretation

What does this proposition mean in practice? An illustrative example may be the situation of a producer and a consumer who have to judge a product's quality. Both are interested in symmetrical quality and wish that no 'effects' occur. The zero hypothesis claims that there are no effects; certain differences may be explained by the usual variations. Both opponents wish the hypothesis to prove correct. At a practically conducted sample deviations may occur. If  $p$  is the probability that according to the zero hypothesis an effect observed in experiment is due to random deviations and not to a true physical effect. Thus,  $p$  is the probability of an erroneous rejection of the zero hypothesis 'no effect'. The producer prefers the selection of a small  $p$  to prevent unnecessary reservations; the consumer rather tends to a big  $p$ , since he expects that it would diminish the probability of an existing physical effect remaining undetected. In many concrete situations a big  $p$  will indicate a slight probability of an erroneous rejection of the zero hypothesis. But this 'mistake of second degree' is not quantifiable within this model.

## 2.6. Control of conditions

After completing measurements the data were made available to statistical evaluation as ASCII files. Data were examined for bad mistakes and inconsistencies. As a matter of fact, it showed that measurements of a subject's skin temperature contained mistakes, presumably because the measurement probe had been misplaced.

This demonstrates clearly that such an experiment can not be fully automated. All data of this subject were excluded from the study.

In the following, applying methods of mathematical statistics we examined whether the conditions for use of a linear model were fulfilled. The condition of approximately normal distribution was tested by two methods. For one thing, a Mahalanobis test on statistical strays was applied (3). During this procedure the linear model is adapted to the data, variation is assessed, a confidence ellipsoid (for the multi-dimensional normal distribution) is determined and, finally, individual data outside the ellipsoid are classified (3). There was one subject requiring classification as a stray.

On the other hand, a Shapiro/Wilk test was performed to determine whether each variable was approximately normally distributed (3). The result was that from the measured variables only skin temperature showed a significant deviation. This divergence could be put down to a single subject. The influence of this subject was traced back during computation.

Further, homogeneity of covariance matrices was to be examined (1). Considering all remaining subjects, there was a satisfying homogeneity; without the mentioned stray covariances even were definitely homogeneous.

The reader may find these details quite unimportant; a thorough investigation, however, requires an examination of test conditions, an analysis of each deviation and particularly, tracing back deviation effects on the final result.

## 2.7. Test conduction

After all this preliminary work the actual test could be carried out. The test variable corresponds to a field distribution with

known free gradients (naturally depending on the size of the actual sample (49) and on the number of observed measurement variables (9)) (1, 2). Considering all 49 test subjects  $p$  was = 0.71; leaving out the stray the result was  $p = 0.80$  (calculated by means of the statistics package (3)). This means that the existence of physical field exposure effects can be excluded even allowing that in about 70% of all experiments the proposition 'There is no field exposure effect' is erroneously rejected. Thus, the hypothesis 'There are no field exposure effects' (in regard to the measured parameters, at the selected frequency and intensity) statistically verified.

It is of interest to do also a statistical evaluation of the (from a medical point of view quite small) fatigue effect. Here, the result is a  $p$ -value of around 0.0001 to 0.0005 (depending on the consideration of strays). That means that the hypothesis 'There is no fatigue effect' is rejected with extremely good significance. We may conclude that the selected test set-up principally is able to detect very small effects.

## Literature

- (1) J. Hartung, B. Epelt, *Multivariate Statistik*. R. Oldenbourg Verlag, München, Wien 1995
- (2) H. Pruscha, *Angewandte Methoden in der Mathematischen Statistik*, Teubner Verlag, Stuttgart 1996
- (3) J. Sall, A. Lehman, *JMP V3.2.2*. SAS Institute Inc. 1996

*Dipl.-Ing. J. Waldmann,  
Prof. Dr. F. Landstorfer,  
Dipl.-Ing. R. Wisniewski, Institute of High-Frequency Technologies, University Stuttgart;  
Prof. Dr. K.P. Hadeler, Dr. J. Müller, Chair of Biomathematics, University Tübingen;  
Dr. V. Müller, Prof. Dr. F. Lang, Steinbeis Transfer Center of Molecular Pathophysiology and Pathopharmacology, Tübingen*