
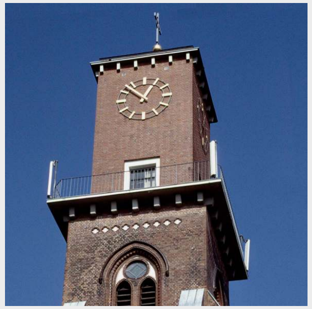
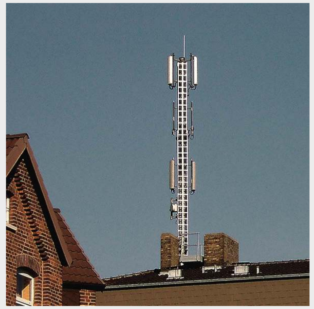

Determination of exposure due to mobile phone base stations in epidemiological studies

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Content

- Inspection of the problem
- Approaches for exposure assessment
- Measurement of RF-EMF in flats
  - Method
  - Results
- Exposure model
  - Basic principles
  - Input data
  - Test of validity
- Conclusions

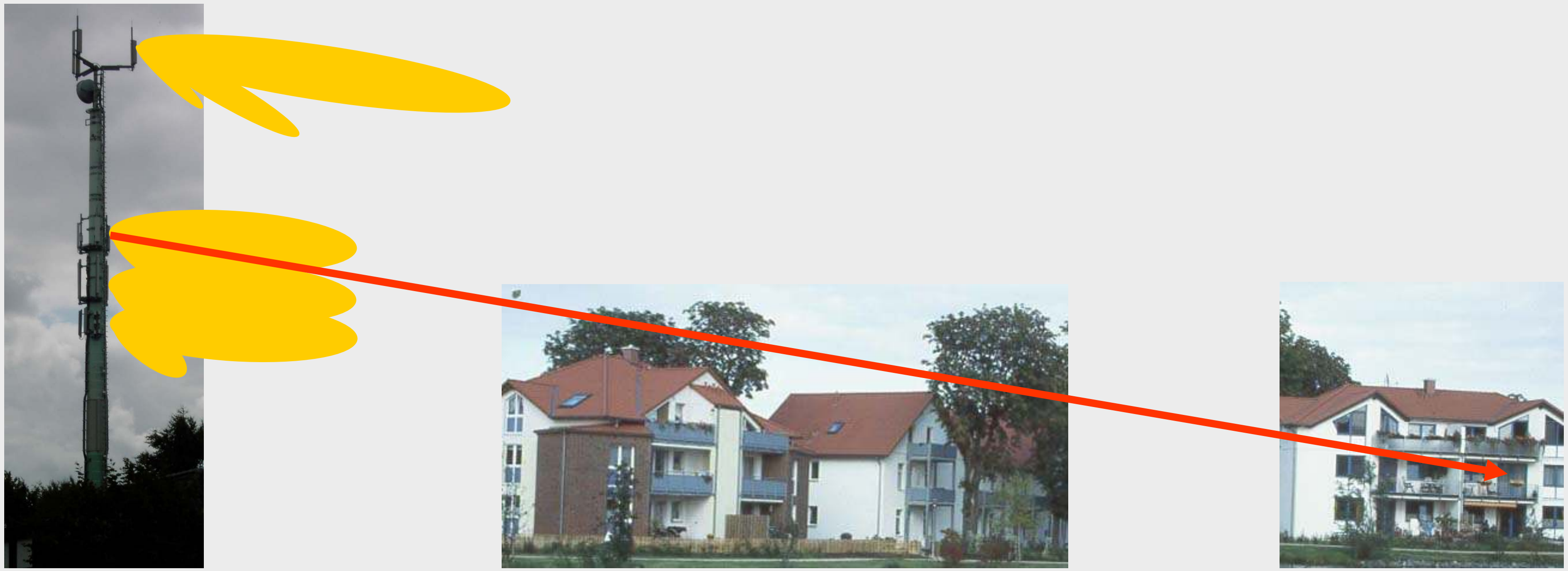
Background

- Epidemiological cross sectional study to test the hypothesis that the electromagnetic fields of mobile phone base stations (MobB-EMF) cause medical disorders for people living in the vicinity of the antennas and that there are people especially sensitive to these fields
- 30,000 participants, randomly selected from the German population

Task

- Develop a method to classify the electromagnetic exposure due to mobile phone base stations

MobB-EMF: RF immissions due to mobile phone base stations



Emission

Technical specification

Propagation

- Reflection
- Scattering
- Diffraction
- Refraction

Immission / Exposure

- Relevant exposure criteria
- Screening

Requirements

Requirements due to the concept of the epidemiological study

- Investigation of medical disorders (headache, sleep disturbances, ….)
  ➔ Determine actual exposures (no exposure history!)
- Investigation of frequent symptoms
  ➔ Determine exposures in a large study group (many flats)
- Hypothesis: A continous exposure for several hours has a stronger effect than varying exposure conditions. (People are possibly very sensitive during the nighttime.)
  ➔ Determine immissions in sleeping rooms
- Hypothesis: The risk for medical disorders increases with increasing average MobB-EMF exposure
  ➔ Determine time and space averages of the MobB-EMF immissions

Determination of MobB-EMF in flats

- Measurements (stat. equipment, pers. expositemeter)
  requ.: equipment, field service personel, access to flats
  + : real immissions
  - : time and effort

  ?

- ‚Exact' calculation: field theoretic solution of Maxwell equations with all boundary conditions
  requ.: detailed technical and environmental data
  + : real immissions
  - : applicable only in simple cases, input data not available

  -

- Approximate calculation: ray optical method
  requ.: detailed technical and environmental data
  +: immissions including effects due to reflection (diffraction))
  - : only approximate immissions, input data not available, time and effort

  -

- Approximate calculation: typical technical data, free space propagation, empirically determined transmission factors
  requ.: technical data, measurement of transmission factors
  + : reduced data input, model applicable in other studies
  - : only approximate^2 immissions

  ?

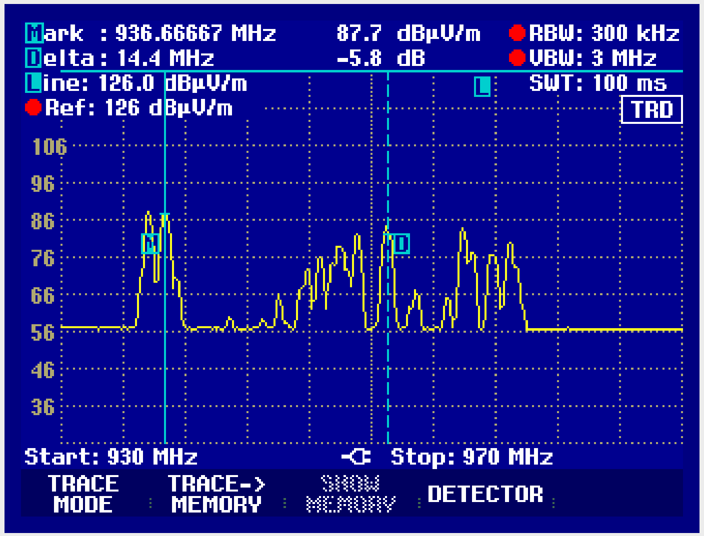
Measurements

Goals of the measurements in this study:

- develop and test a method to measure MobB-EMF in flats
- get information about the RF immissions at indoor locations (true immissions! not maximum possible immissions!)
- find out, which technical and environmental parameters mainly determine MobB-EMF immissions in the vicinity of mobile phone base stations
- determine MobB-EMF propagation parameters for different types of propagation areas
- test the validity of a numerical exposure assessment model

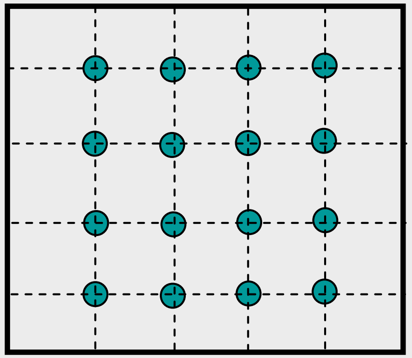
Measurements: Methods

- Spektrum analyser R&S FSH 3, Software RFEX
- Isotropic measuring probe R&S TS EMF (80 MHz to 2.5 GHz)
- Directional antenna R&S HE 200



Measurements: Methods

- Point grid method
- Spatial averaging
- Long time measurements
- Standard measuring packets:
  - FM Radio
  - TV VHF
  - TV UHF
  - GSM 900 downlink
  - (GSM 900 uplink)
  - GSM 1800 downlink
  - (GSM 1800 uplink)
  - DECT
  - (UMTS downlink)

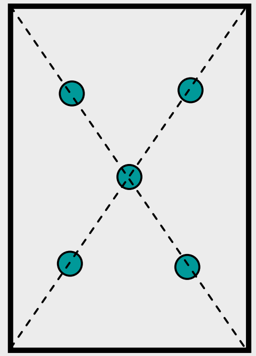


large rooms

1.0 m x 1.0 m - grid
height 1.0 m

0.1 m x 0.1 m - grid
heigth: 0.75 m, 1.5 m

Minimum distance to
walls and objects: 0.5 m



smaller rooms

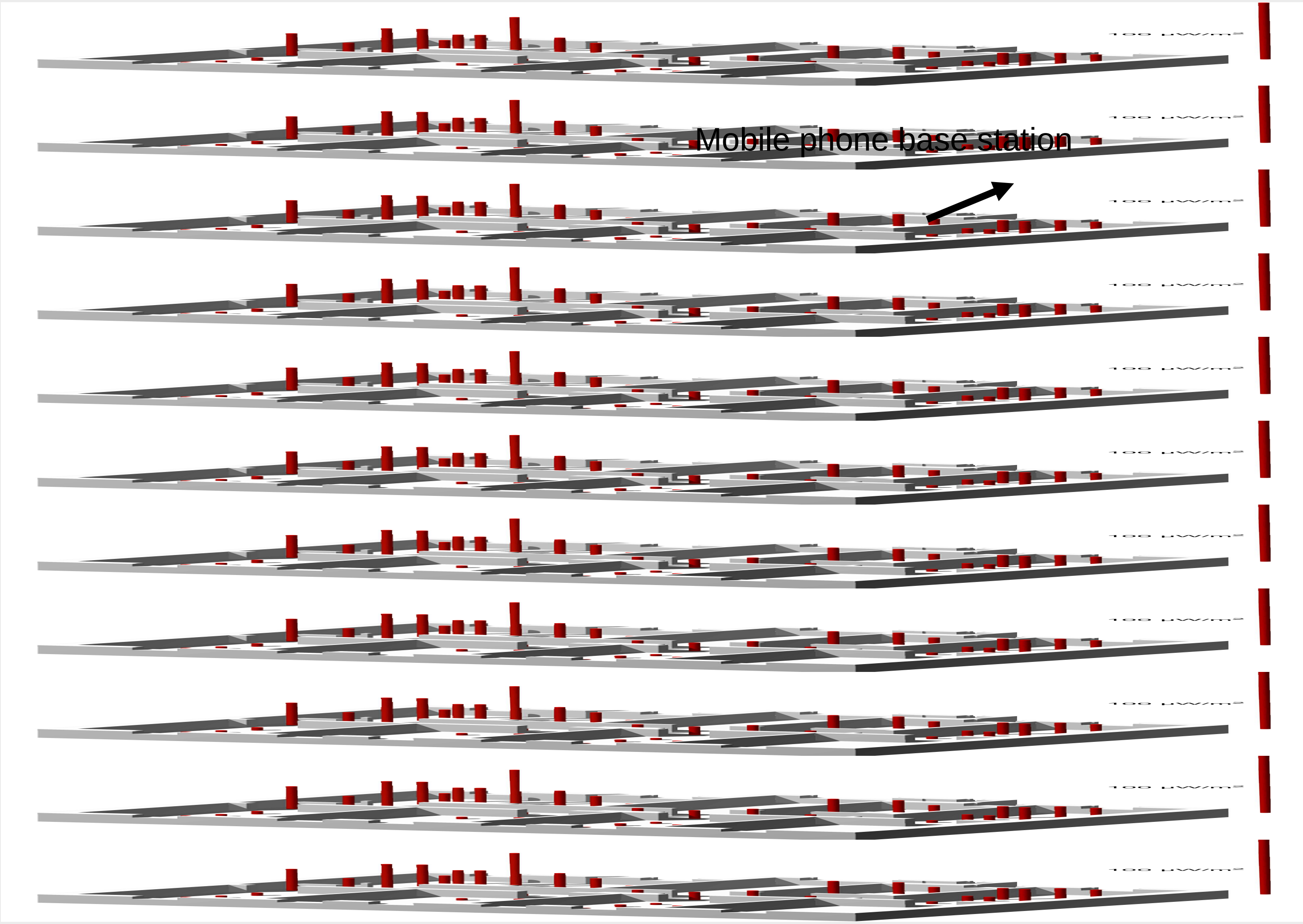
5 point - grid

Measurements: Methods

Measurements of RF-EMF immissions

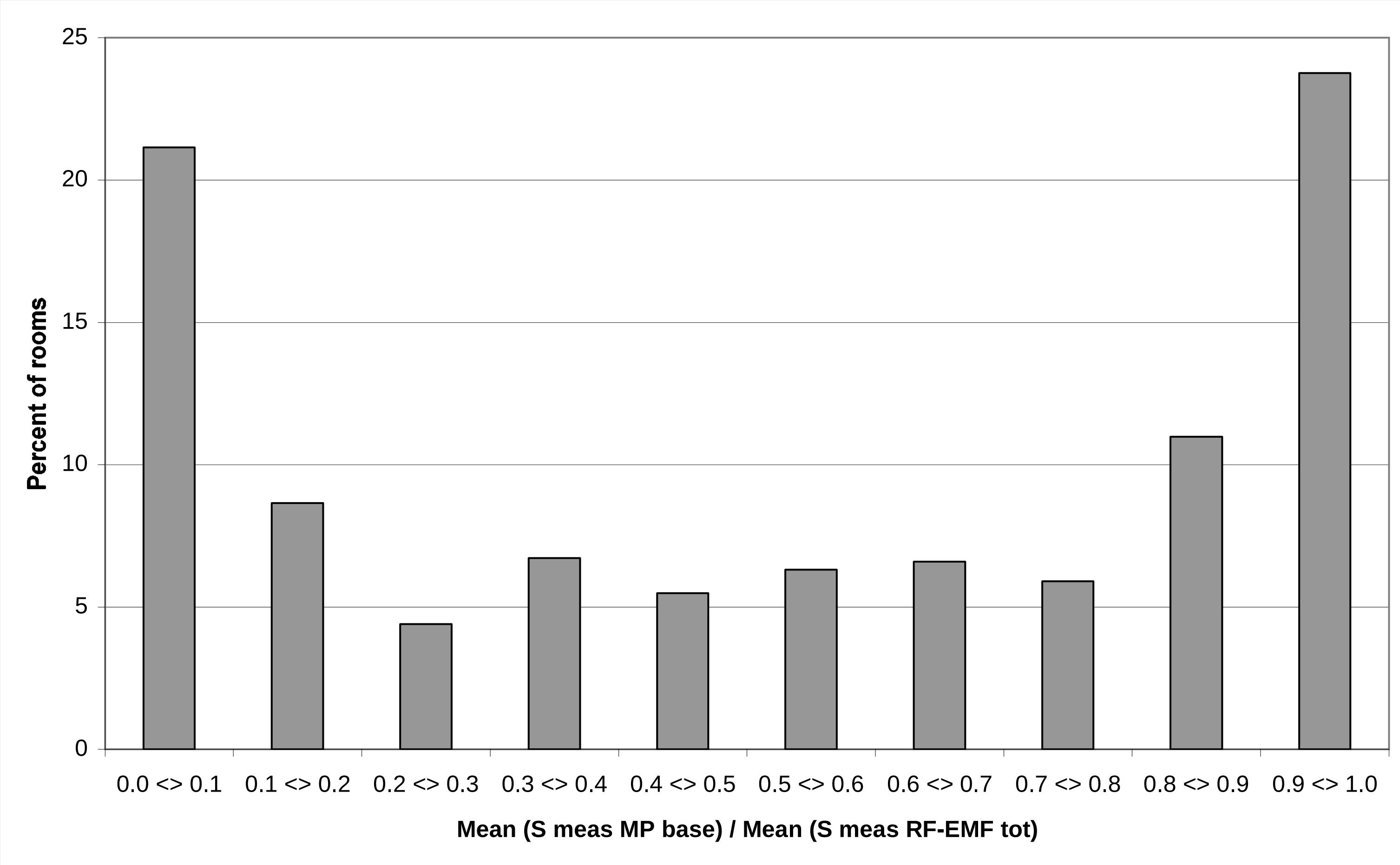
- - in 1100 rooms
  - at 120 outdoor-locations (balcony, patio, garden)
  - additionally in the vicinity of 60 mobile phone base stations
- in four types of residential areas
  - closed high-density areas
  - high-density areas with courtyards and/or small greens
  - low-density areas with houses with more than three floors
  - low-density areas with houses with up to three floors
- in different magnitudes of communities (1000 to 1,000,000 inhabitants)
- for different types of terrain (flat, hilly)
- for different constellations of RF-transmitters
  - GSM 900- and GSM 1800-base stations (UMTS: limited validity)
  - one to eleven base station sites within a distance of 500 m
  - base station sites with one to 24 antennas
  - radio- and TV-broadcasting stations at a distance from 200 m to 20 km
  - flats with and without cordless telephones
  - flats far from and near to places with high use of mobile phones (urban places, shopping centres, railway stations)

Measurements: Results



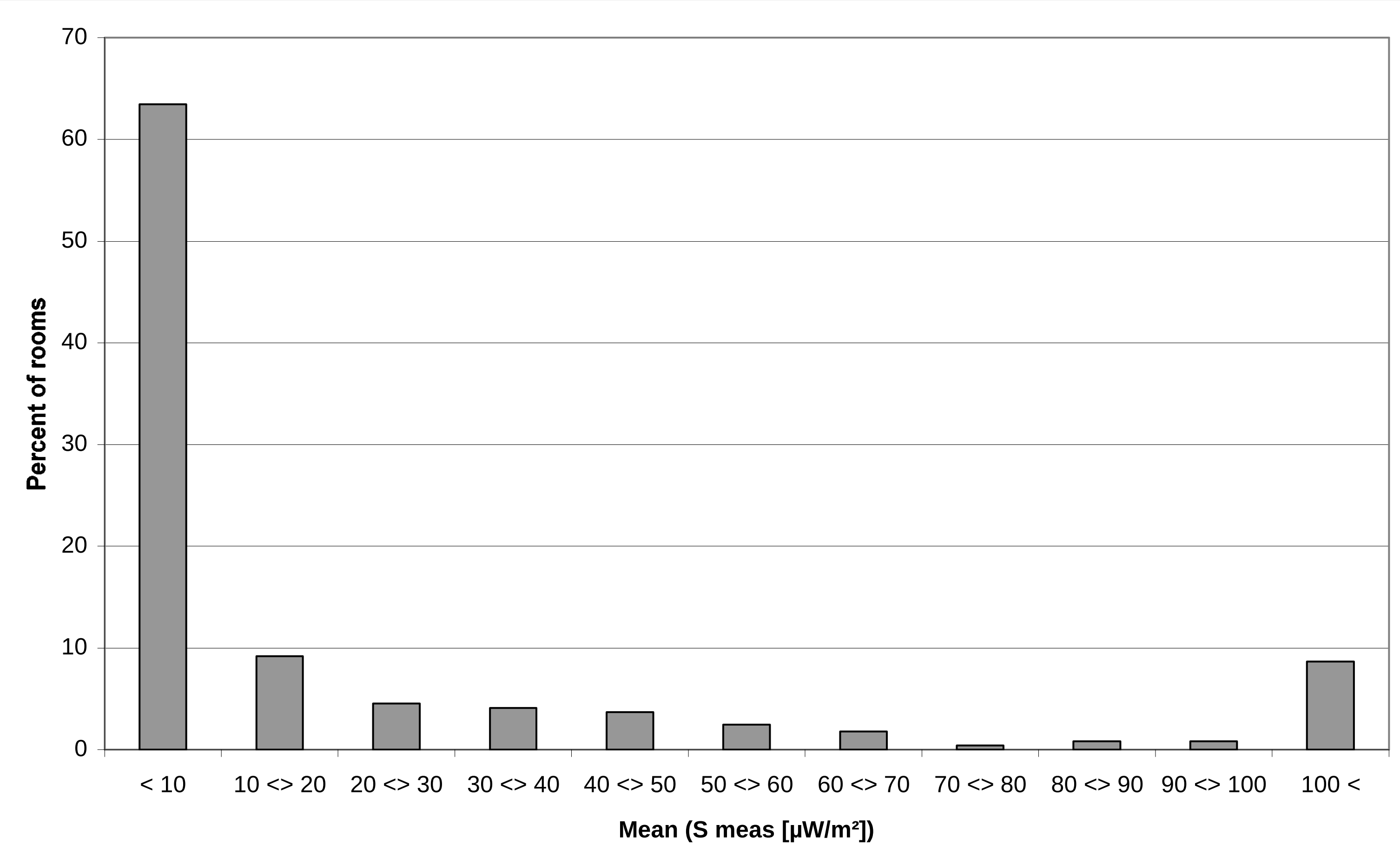
MobB-EMF immissions in rooms: Distribution of measured values

Measurements: Results



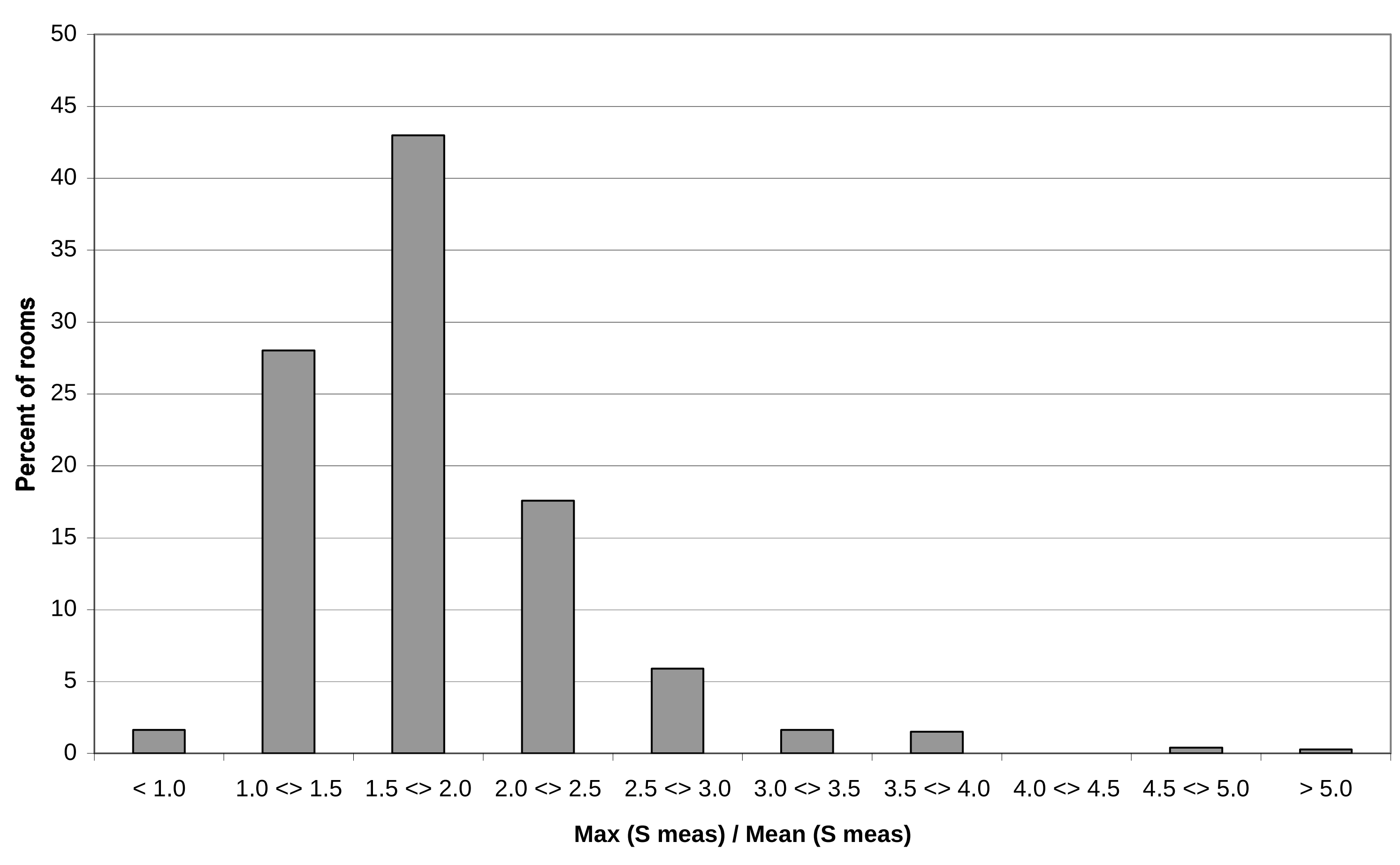
MobB-EMF immissions in rooms: Contribution of MobB-EMF to total RF-EMF

Measurements: Results



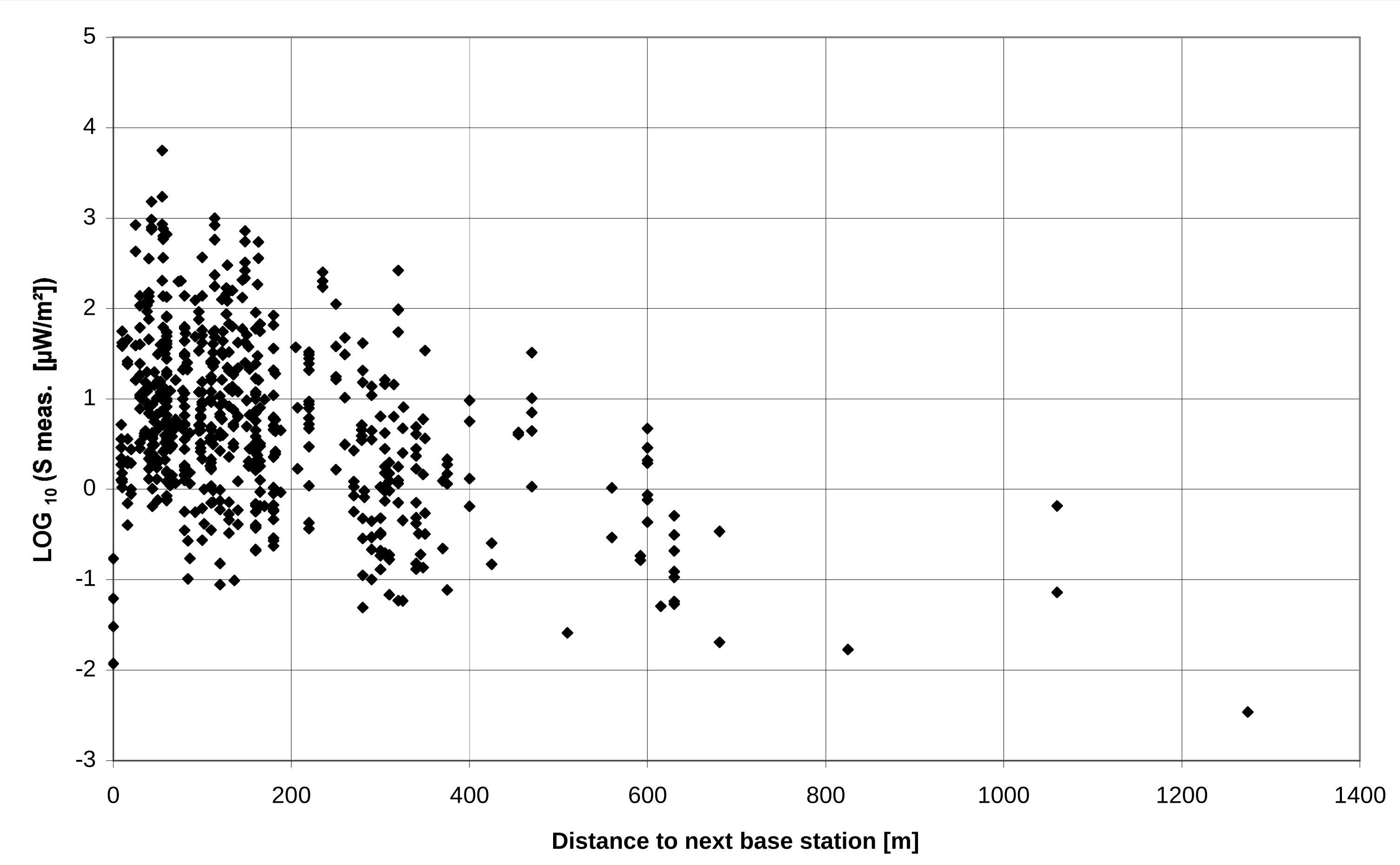
MobB-EMF immissions in rooms: Room averages of measured power densities

Measurements: Results



MobB-EMF immissions in rooms: Maximum to mean value of measured power density

Measurements: Results

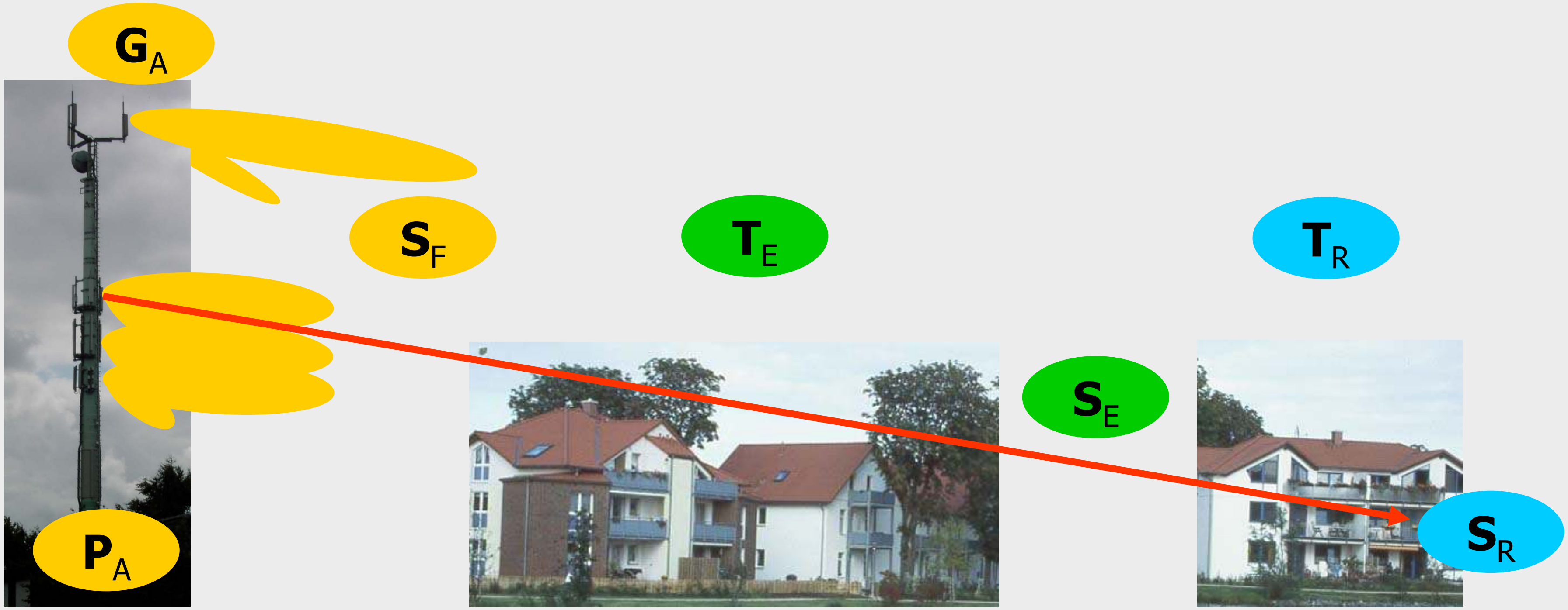


MobB-EMF immissions in rooms: Room averages of measured power densities as a function of the horizontal distance to the next mobile phone base station

Measurements: Results

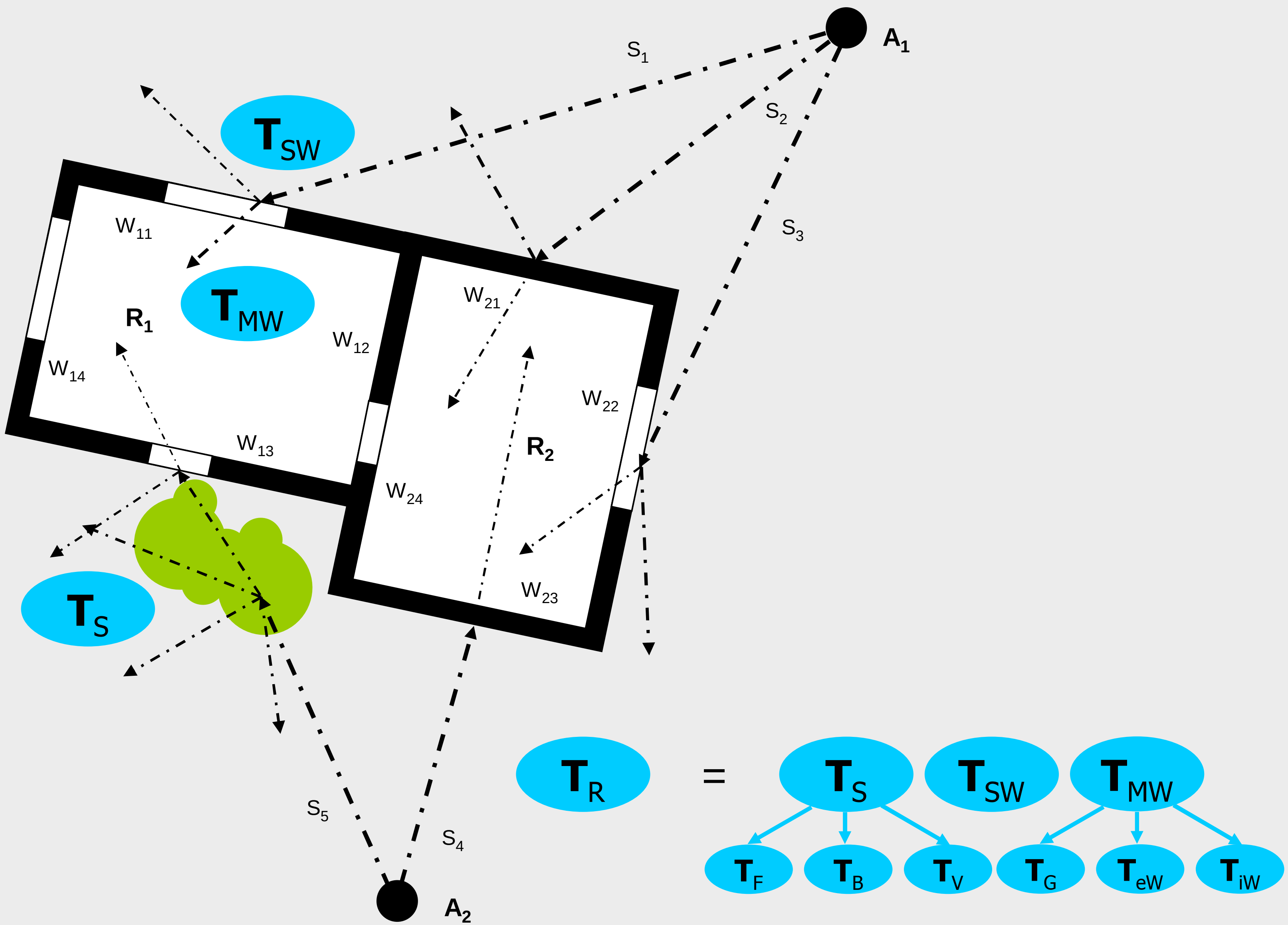
- measurements in flats at distances from the next mobile phone base station site not exceeding 1000 m → measured immissions not representative for the exposure of the population in Germany
- only in a few cases measured power densities above 0.1 % of maximum allowable values in Germany (ICNIRP recommendations)
- sum of the mobile phone immissions (GSM 900, GSM 1800, UMTS) below 10 µW/m² in more than 60 % of the rooms, only in about 9 % of rooms averages of more than 100 µW/m²
- contributions from mobile phone base stations to the total RF-immissions dominate, but occasionally other sources may contribute substantially (DECT-phones)
- 24 h-variations of the mobile phone immissions caused by additional traffic channels normally below 20 %.
- immissions strongly dependend on the spatial orientation of windows with respect to the direction from the room to the base station
- strong damping of RF-EMF due to buildings and vegetation in the LOS, exterior and interior walls
- immissions at places with free sight on a mobile phone antenna strongly dependend on the angle between the LOS and the main radiation direction of the antenna
- distance only a very bad indicator for exposure (it can at best be used to identify flats that are probably less exposed)

Exposure model



Emission	Propagation	Immission
$P_F(\boldsymbol{\theta}, \boldsymbol{\varphi}) = P_{A,\ EIRP}\ G_A(\boldsymbol{\theta}, \boldsymbol{\varphi})$	Free space: $S_F = P_A\ G_A(\boldsymbol{\theta}, \boldsymbol{\varphi}) / (4\pi\ r^2)$	$S_R = T_S\ T_{SW}\ T_{MW}\ S_E$
	Real environment: $S_E = T_E\ S_F$	
	$T_E = \exp(\mathbf{a}\ \mathbf{d})$	

Exposure model: Damping at immission site



Exposure model: Input data

Input data	**Sources**	**Qual.** this study / Epi study
Location of base stations	Maps / Geo coordinates	A / B
Type of mobile phone nets	Site declaration	A / A
Mounting heights of antennas	Site declaration	A / A
Orientation of antennas	Site declaration	A / A
Radiated Power	Typical values (net, type of area)	B / B
Radiation characteristics of antennas	Typical values (net, type of area)	B / B
Downtilts of antennas	Typical values (net, type of area)	B / B
Type of propagation area	Knowledge of place / Epi Questionnaire	B / C
Transmission coefficient: Environment	Measurement	B / B
Location of flat/room	Maps / Geo coordinates	A / B
Height of room/flat above ground	Knowledge of place / Epi Questionnaire	A / B
Orientation of windows	Knowledge of place / Epi Questionnaire	A / B
Sight conditions in front of windows	Knowledge of place / Epi Questionnaire	A / B
Transmission factor: Visibility	Measurement	B / B
Transmission factor: Wall surface	Reflection model, Data from literature	B / B
Transmission factor: Wall substance	Absorption model, Data from literature	C / C

Exposure model: Technical input data

	low-density areas with houses with up to three floors	low-density areas with houses with more than three floors	high-density areas with courtyards and/or small greens	closed high-density areas
EIRP [W]				
GSM 900	165	205	285	365
GSM 1800	165	330	460	460
Downtilt [°]				
GSM 900	-3.5	-6.0	-3.5	-6.0
GSM 1800	-1.0	-2.5	-3.0	-6.0
Antenna charact.	horizontal		vertical	
GSM 900	$G_R = 0{,}005 + 0{,}495 \cos(\phi/2)^{14} + 0.5 \cos(\phi/2)^{6}$		$G_R = 0{,}002 + 0{,}984 \cos(\theta/2)^{850} + 0{,}014 \cos(\theta/2)^{8}$	
GSM 1800	$G_R = 0{,}005 + 0{,}595 \cos(\phi/2)^{20} + 0{,}4 \cos(\phi/2)^{6}$		$G_R = 0{,}001 + 0{,}989 \cos(\theta/2)^{1800} + 0{,}01 \cos(\theta/2)^{8}$	

Exposure model: Transmission factor input data

Transmission factors	ext. wall with window	ext. wall without window	int. wall	
Reflection at surface $T_{SW}(\varepsilon_r)$				
GSM 900	$\varepsilon_r = 5.0$	$\varepsilon_r = 5.0$	-	
GSM 1800	$\varepsilon_r = 5.0$	$\varepsilon_r = 5.0$	-	
Absorption in material T_{MW}				
GSM 900	0.2	0.02	0.003	
GSM 1800	0.1	0.01	0.002	
Sight T_S	free	buildings, walls	vegetation	
GSM 900	1.0	0.5	0.4	
GSM 1800	1.0	0.2	0.4	
Environment $T_E = \exp(a\ d)$	low-density areas with houses with up to three floors	low-density areas with houses with more than three floors	high-density areas with courtyards and/or small greens	closed high-density areas
GSM 900	a = 0	a = 0	a = -0.0003	a = -0.0025
GSM 1800	a = 0	a = 0	a = -0.0003	a = -0,006

Exposure Model: Tests

Methods to test the agreement of calculated and measured immissions

- Correlation Analysis
- Bland-Altman-Plot
- **κ**-Test
- Analysis of Sensitivity and Specifity

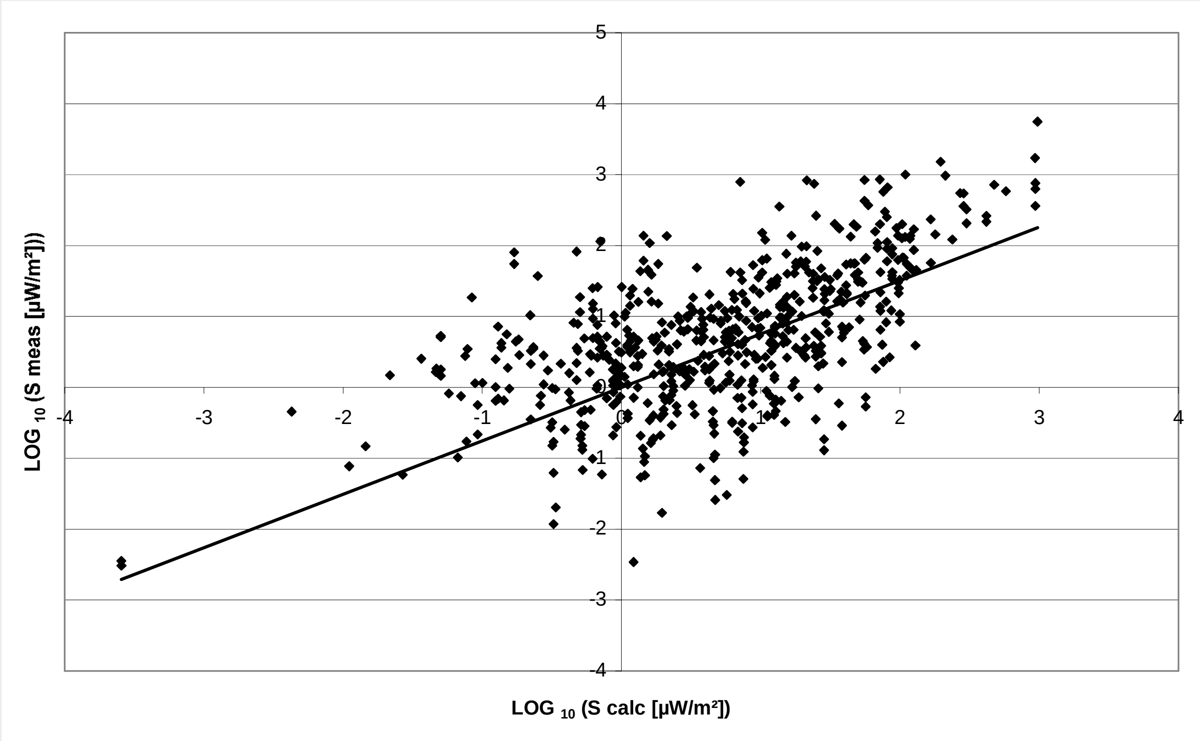
Exposure Model: Tests

Correlation-Analysis

statistical method to test the correlation of two sets of data

Result

Correlation coefficient: 0.64 (0.48 – 0.86) ☞ acceptable to good correlation



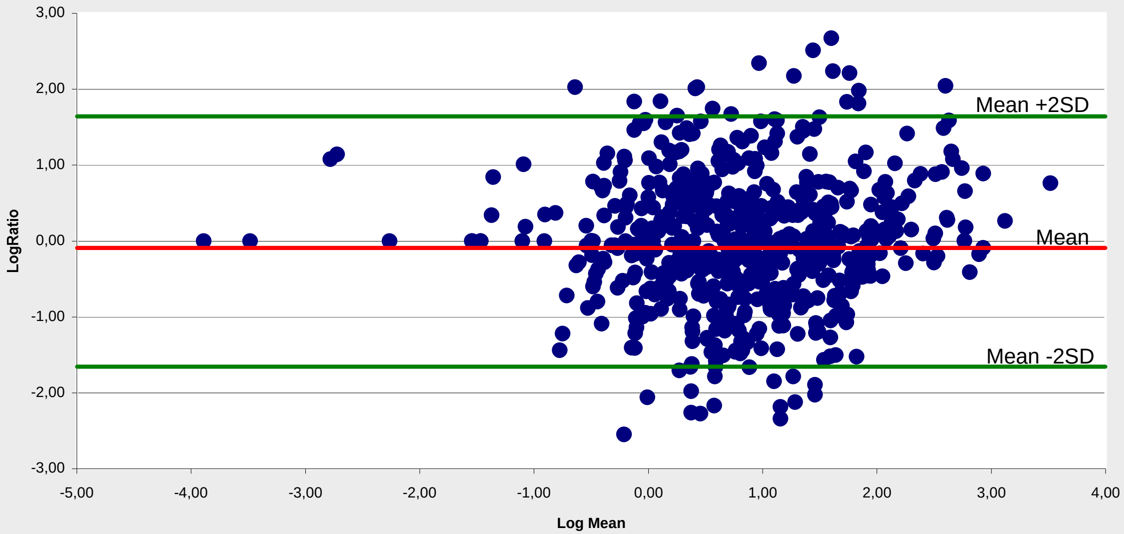
Exposure Model: Tests

Bland-Altman-Plot

statistical method to compare two measurements techniques; in this graphical method the differences (or alternatively the ratios) between the two techniques are plotted against the averages of the two techniques

Result

☞ **no systematic error**



Exposure Model: Tests

κ-Test

Kappa is a measure of interobserver or methodical agreement

κ = 1: perfect agreement
κ > 0.6: very good agreement
κ > 0.5: good agreement
κ = -1: perfect disagreement

Result

κ = 0.52 (0.41 – 0.68) ☞ acceptable to very good agreement

Κ-Test		Test 1		
		+	-	
Test 2	+	a	b	a + b
	-	c	d	c + d
		a + c	b + d	N

$$K = \frac{(a + d)/N - [(a + c)*(a+b) + (b + d)*(c+d)] / N^2}{1 - ([(a + c)*(a+b) + (b + d)*(c+d)] / N^2}$$

Exposure Model: Tests

Analysis of Sensitivity and Specifity

Sensitivity ST: ratio of the number of all exposed subjects correctly identified to the number of all exposed subjects

Specifity SP: ratio of the number of all non-exposed subjects with correct negative exposure prognosis to the number of all non-exposed subjects

Result

ST = 0.56 (0.43 – 0.76) ☞ low to high sensitivity

SP = 0.93 (0.89 – 0.97) ☞ high specifity

In an epidemiological study misclassification leads to an underestimation of the observed risk!

Example:

Assumption:	30,000 participants in study	
	exposed cases: 2000	non-exposed cases: 1000
	exposed controls: 13,500	non-exposed controls: 13,500
Correct risk	OR = 2.0 (CI: 1.9 – 2.2)	
Observed risk due to misclassification:	OR = 1.5 (CI: 1.2 – 1.7)	

Exposure Model: Conclusions

Agreement between the calculated and the measured immissions

Good agreement for

- low-density areas with houses with up to three floors

Acceptable agreement for

- low-density areas with houses with more than three floors
- high-density areas with courtyards and/or small greens
- closed high-density areas

Model used for the estimation of exposure in an epidemiological cross sectional study

- exposure classification of 30,000 participants
- preselection of 3,000 propably higher/lower exposed subjects
- independent verification of exposure classification by point measurements

Acknowledgment

- Federal Radiation Protection Office, Dirk Geschwentner et al.
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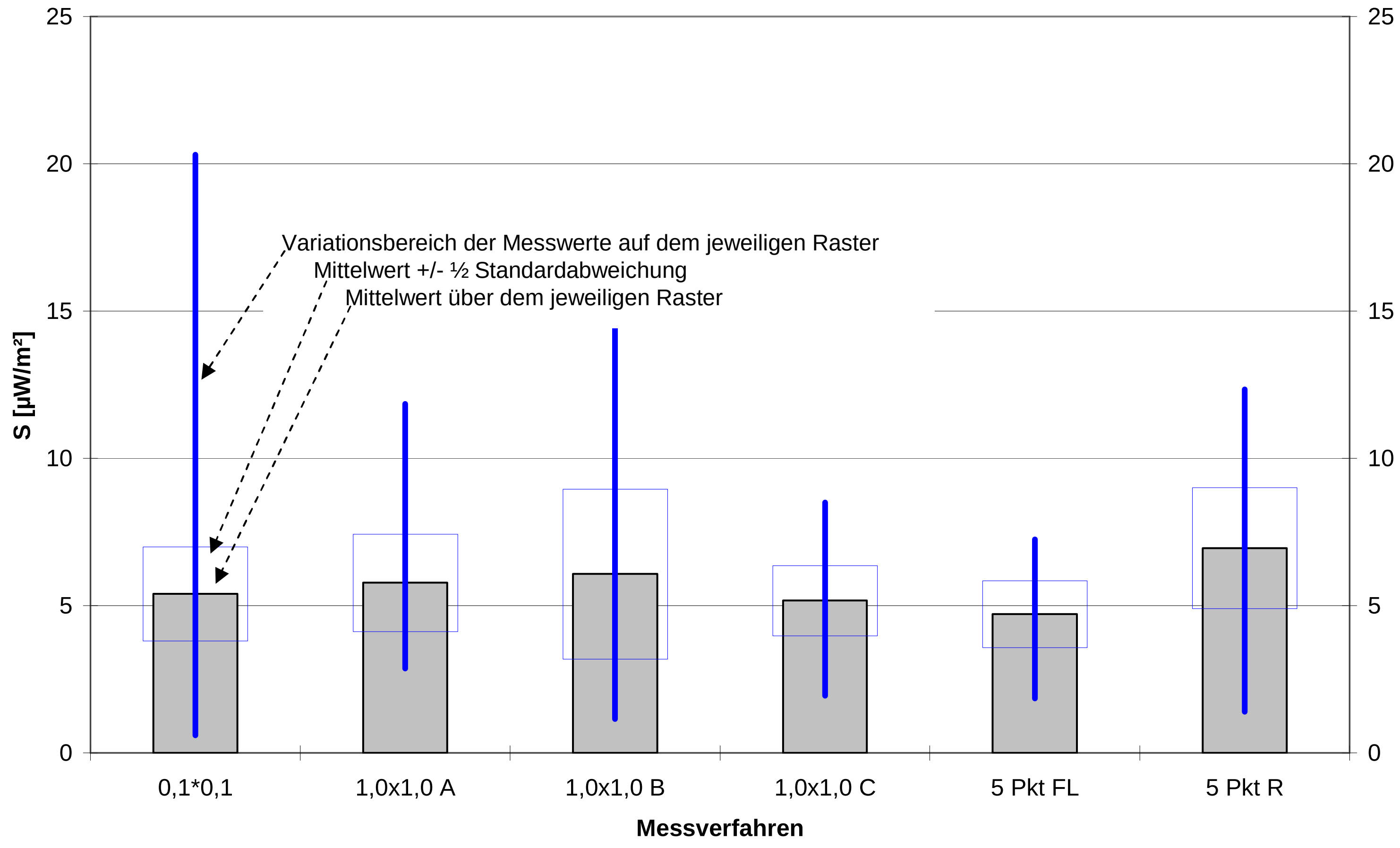
- IMST, Dr. Christian Bornkessel
- Lower Saxony Office of Ecology, Dr. Hauke Brüggemeyer



Vergleich der Ergebnisse der Vermessung der GSM 900-Felder in einem Innenraum anhand verschiedener Messraster

0,1x0,1 0,1 m x 0,1 m-Raster

1,0x1,0 A, B, C 1,0 m x 1,0 m-Raster mit unterschiedlichen Lagen im Raum

5 Pkt FL, R 5 Punkt-Raster mit unterschiedlichen Lagen im Raum

Approach

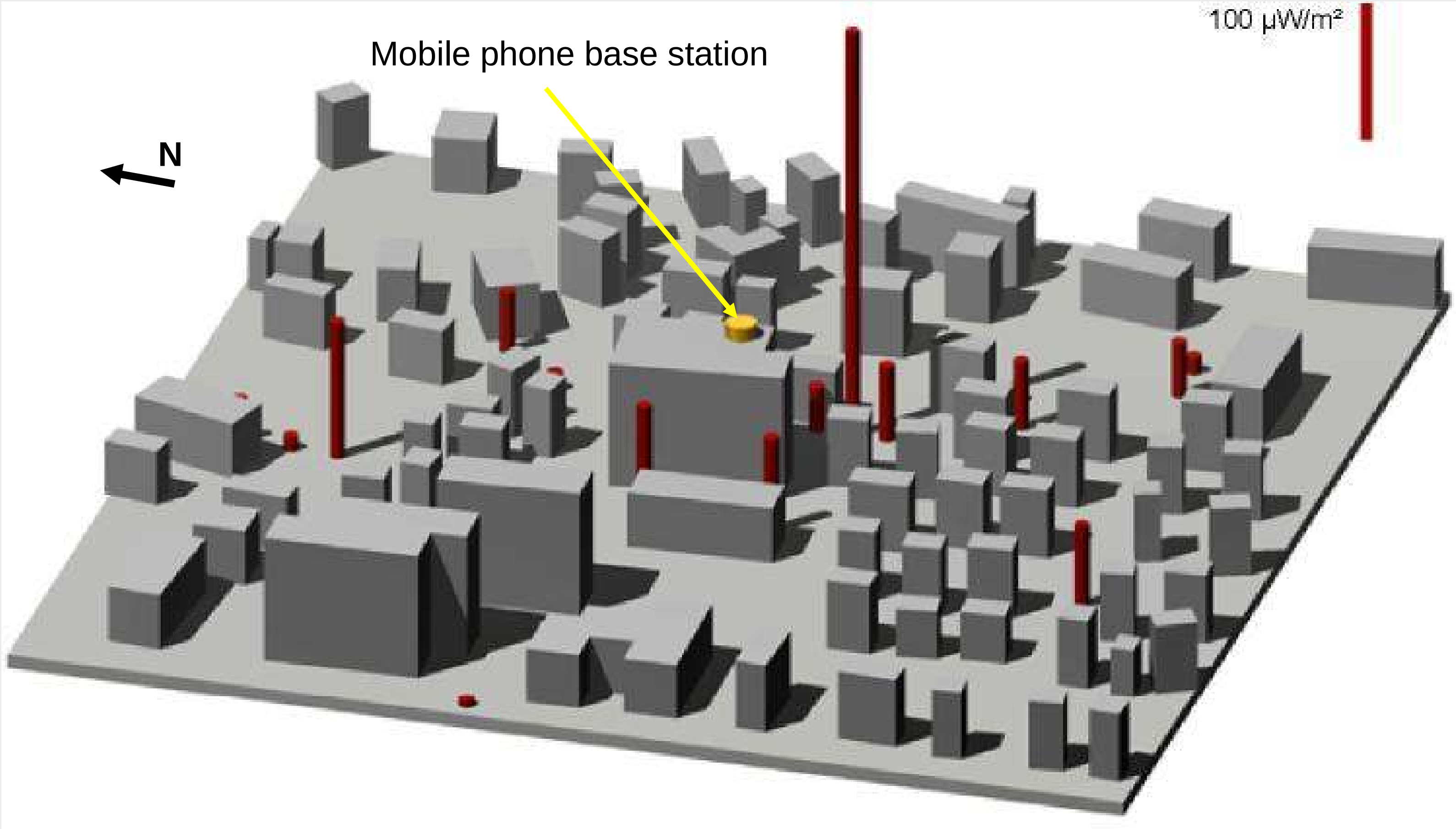
a) measure high frequency immissions in flats in the vicinity of mobile phone base stations
b) determine typical emission patterns and radiation power (informations from the mobile phone industry)
c) extract information about actual base stations from the site declarations (German Regulatory Authority for Telecommunications and Posts)
d) calculate the emissions of mobile phone antennas under the condition of free space propagation (b & c)
e) compare measured with calculated immissions (a & d)
f) determined transmission factors for the propagation of electromagnetic waves in different types of residential areas and visibility conditions in front of windows
g) calculate transmission factors for radio waves entering rooms through walls and windows (kind of walls, spatial orientation - especially for walls with windows)

Aim

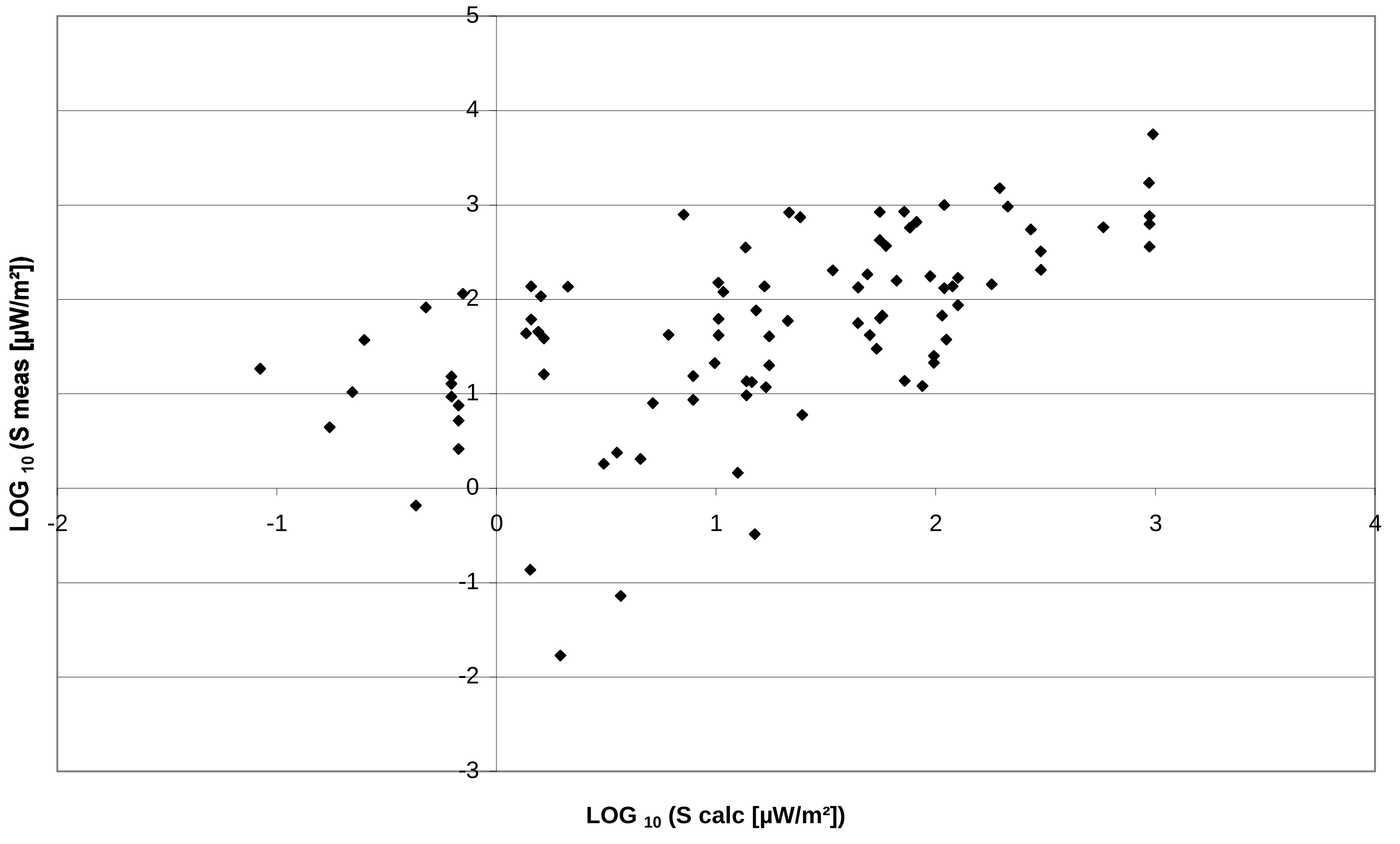
Develop a **method to estimate electromagnetic immissions due to mobile phone base stations in flats** on the basis of

- geographical informations about all base station sites within a distance of 500 m to the flat to be tested
- technical data for all base station antennas at these sites (number, mounting height and orientation, typical emission patterns and radiated power of mobile phone base station antennas)
- informations about location of the flat (geographical coordinates, height)
- information relevant for the propagation of electromagnetic waves from the point of emission to the point of immission

Measurements: Results



MobB-EMF immissions at outdoor locations in the vicinity of a mobile phone base station


5
4
3
2
1
0
-1
-2
-3
-2
-1
0
1
2
3
4
LOG 10 (S meas [µW/m²])
LOG 10 (S calc [µW/m²])