Laboratory for EMF and
Microwave Electronics

Annual Progress Report 1997

BIOEM/EMC Group

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Cover page: Smallest Isotropic Probe for Dosimetric Evaluations in Lossy Media (see page 14)

Preface

The great interest and favorable response of industry, universities, governmental agencies and media to our first annual report has inspired us to issue this report.

During 1997 we further consolidated and expanded the scope of our research activities, especially in the area of optimizing personal communications products. We remained committed to developing methodologies and obtaining results employing high standards of scientific rigor to address public concern about the possible health hazards associated with the phenomenal growth of wireless communications applications.

For their support in discharging this task, called for by the public but also of great benefit to industry, we owe our thanks to ETH and the Swiss Confederation for funding our work through the research programs KTI and SPP MINAST.

We are especially grateful to our industrial partners, Motorola Inc. of USA, T-Mobil of Germany and Swisscom, all of whom have generously sponsored our research from the beginning without attempting to influence its outcome. Their continuing support enables us to respond quickly to the numerous challenges that have arisen. Ericsson Radio Systems AB of Sweden has also pledged to sponsor our research in the coming years, which will further enhance and accelerate the outcome of our research. We also wish to thank the other partners listed in this report.

We owe a great debt of gratitude to all our research partners in the engineering, life and medical sciences for their invaluable contributions. We share our successes with them.

My greatest thanks go out to all the members of our group for their commitment and tremendous efforts, and all those individuals at ETH who have continued to support our activities in a multitude of ways.

Niels Kuster

Group Members 1997

Michelle Bunge (Administration, part-time 20%)
Michael Burkhardt (PhD Student)
Nicolas Chavannes (MS Student)
Andreas Christ (PhD Student, since 3/1997)
Jeroen de Keijzer (Mechanical Engineer, part-time 30%)
Benedict de Silva (Copy Editor, part-time 10%)
Jürg Fröhlich, (PhD, Project Leader, since 10/1997)
Georg Klaus (PhD, Lecturer)
Niels Kuster (Professor)
Katja Pokovic (PhD Student)
Karin Rustmeier (Administration, part-time 10%)
Thomas Schmid (Project Leader, part-time 50%)
Frank Schönborn (PhD Student)
Thomas Schwitter (Graphics/Internet, part-time 30%)
Magnus Sundberg (Visiting Scientist)
Roger Tay (External PhD Student at Motorola Inc. USA)
Ondrej Voles (Scientist, until 5/1997)
Former Members: Oliver Egger; Ralph Kästle, PhD;
Klaus Meier, PhD; Yuri Spinelli

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Nortel, Great Britain

Dr. Leonie Ashman
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Mr. Bernhard Eicher
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Ministry of Information & Communications, Korea

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Motorola Cellular, USA

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Mr. Toshiki Kamitani
Mitsubishi Electric Corp., Japan

Dr. Sebastian Kessler
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Prof. Per-Simon Kildal
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Dr. Donald McRee
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Mr. Christophe Rémond
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Dr. Liisa Silvennoinen
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Tokyo Metropolitan University, Japan

Prof. Shoogo Ueno
University of Tokyo, Japan

Dr. Graham Worsley
Department of Trade & Industry, Great Britain

Overview

Our Research Policy

Ever since portable wireless communications became a public health concern, our group has been exposed to the conflicts of interests between the industry, media, governmental agencies and the public. The spotlight became particularly intensive last fall, when "Kassensturz", a Swiss TV consumer show, requested us to perform the dosimetric evaluation of the 15 most popular cellular phones used in Switzerland. This report was relayed by the media in Scandinavia, Germany, USA, England and other countries. As expected, this step was not received with enthusiasm from all quarters. However, our commitment to objectively report the outcome of scientific experiments is crucial to keeping above the fray of conflicting interests. Some of the cornerstones of our policy with regard to ensuring scientific credibility and integrity are:

Independence

As representatives of a publicly funded research institution, we are committed to practising objective independence in our dealings with all outside groups. This is also reflected in the contracts with our industrial partners.

Research

Quality and pertinence are the guiding criteria in our research activities. Our objective is to reach conclusive answers to the most relevant open issues, in a reasonable time, without cutting corners in terms of scientific standards. This is best done by cooperating in multidisciplinary efforts with other groups of outstanding expertise in their particular areas, thereby taking advantage of the most advanced and sensitive techniques available at the time. Quality control always has the highest priority throughout all our studies.
Just as important as our work in risk analysis are our research activities providing solutions in basic science, novel concepts and new tools to enable further technological improvements. These include near-field measurement technology, CAD tools for antenna design, and new concepts for antennas.

Publications

Research results obtained by the group in the area of risk analysis are principally published in the public domain; however, only if they meet rigorous scientific standards. Privileged and unpublished information received from partners is treated as strictly confidential and not included in any publications. This applies in particular to the evaluation of prototypes.

Most of the wireless communications industry has long realized that supporting independent scientific research in laboratories of quality and integrity is by far the best policy in terms of credibility as well as cost, countering the speculations that otherwise sporadically engulf the media.

Near-Field Measurement Techniques

Near-Field Probes

A new generation of isotropic broadband near-field probes has been developed in cooperation with the spin-off company Schmid & Partner Engineering AG (SPEAG) and supported by the Swiss Commission for Innovation and Technology (KTI). This project, which resulted in the first isotropic H-field probe for frequencies above 300 MHz, is outlined in this report.
In a subsequent KTI project with the same partner, we are currently developing novel probes and evaluation techniques with which the pseudo-vector information of the field can be obtained with great precision. This will be especially useful to identify design deficiencies in the near-field of antennas.
A project conducted in cooperation with Motorola focuses on a 0.6 mm sensor probe for highly specialized measurement tasks.

Near-Field Scanners

SPEAG has launched the completely redesigned scanner DASY3, which provides greatly enhanced functionality, based partially on suggestions by BIOEM/EMC. It will enable us to investigate new applications and to efficiently conduct measurements of great complexity with improved precision. One of the new projects planned to be launched in 1998 consists of an extension of the system for spherical radiation measurements.

Calibration Procedures

New calibration procedures have been developed which are significantly more accurate than previous techniques and traceable to international standards.

Computational Electrodynamics

Numerical Platform EMLAB

The numerical platform developed under the auspices of the Swiss Priority Program "Micro- and Nano-System Technology (MINAST)", together with IIS-ETH and several industrial partners, has made considerable progress.

Although the project only started in 1996, the project partner ISE AG plans to release the kernel EMLAB in Spring 1998 as part of its T-CAD platform. Additional extensions, such as subgrids and a module for heat transfer processes, are in progress. Various benchmark tests have been conducted in order to evaluate the performance and limitations of the code. The partner SPEAG has considerably increased its software engineering staff, in order to accelerate the implementation of the high-end user interface of the CAD-tool. The ß-release of this tool is scheduled for the end of 1998.

Minimization of the Uncertainty of FDTD Simulations

A new project, supported by Swisscom and T-Mobil, has been launched with the objective of evaluating the uncertainties intrinsic to FDTD and modeling uncertainties, as well as possible strategies for error minimization for the problem class of antennas operating in complex environments.

Exposure Assessments

Human Modeling and Phantoms for Compliance Testing

The phantom presented in the 1996 progress report has already become a worldwide quasi-standard. The data on the shape of the phantom is being made publicly available for use by other groups.
In current proposals for compliance testing procedures, the ear is modeled as a lossless spacer of 4 mm to 6 mm thickness. This approach has been questioned by several scientists and regulatory agencies. A new project, supported by several partners, has been launched to investigate this problem in detail. The study will be conducted using MRI data sets with increased spatial resolution in the ear region.

Procedures for Compliance Testing

A new consortium consisting of MCL of Great Britain, the University of Gent of Belgium, SPEAG and BIOEM/EMC has been built to develop procedures for compliance testing under the auspices of EUREKA. The main objectives of the project to be started in Spring 1998 are accuracy, reproducibility and suitability.

Dosimetric Evaluation

In 1997 the group performed several near-field evaluations of base station antennas, prototypes and commercial cellular phones for manufacturers, service providers, research laboratories as well as for public institutions in Europe, North America and Japan.

Health Risk Assessment

Cancer Promotion and Cell Growth Regulation Studies

The group has further intensified its collaboration with different research groups in the area of risk assessment and replication studies. The group is currently involved in new large scale *in vivo* and *in vitro* studies to test the RF exposure of the newest cellular systems. Dosimetric evaluation will be performed for a replication study at 900 MHz to be conducted in Australia. Several studies on cell growth in test cultures of normal and cancer cells are in preparation. BIOEM/EMC will be responsible for the development of the exposure systems.

Basic Research

A new project has been prepared together with the IPK of Gatersleben in Germany, which aims to study the interaction mechanism of extremely low frequency amplitude modulated HF exposure on the differentiation of embryonal stem cells. This two year study will be supported by the VERUM Foundation in Germany.

Other Activities

Commissions

Quick translation of scientific findings into global standards benefits both technology and society. We therefore provide standardization agencies and commissions in Europe, USA, and Japan with appropriate data, and actively participate in the deliberations of these organizations.

Consulting

We provide our expertise in dosimetric assessments, near-field measurements and antenna design to various companies in Europe, North America and Japan.

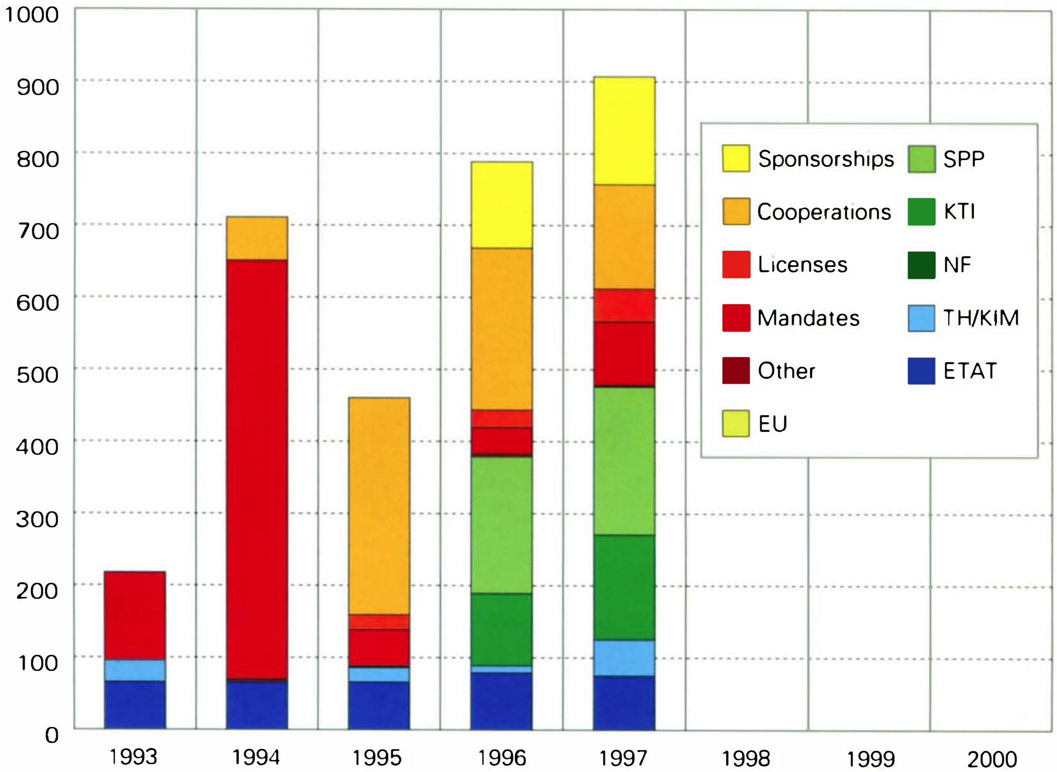
Publications

The volume of publications remained at the same high level as in previous years. Several invitations for book chapters and reviews are close to completion and scheduled for publication in the coming months.

Courses

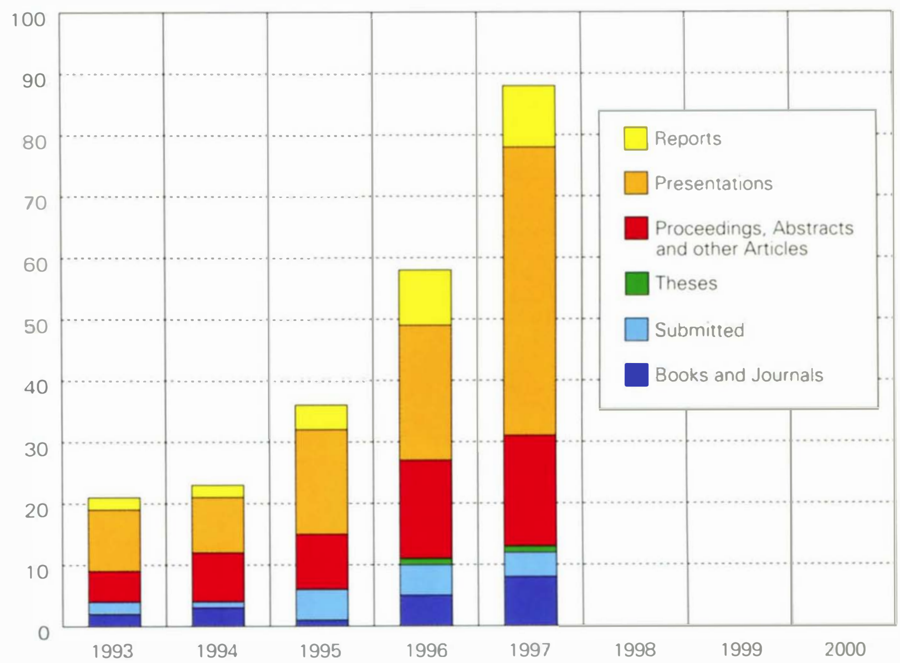
The two semester course on Electromagnetic Compatibility, dealing with all classical concepts of EMC and the concept of safety standards, has increasing attendance despite being an optional course.

Development of Funding (kSFr)

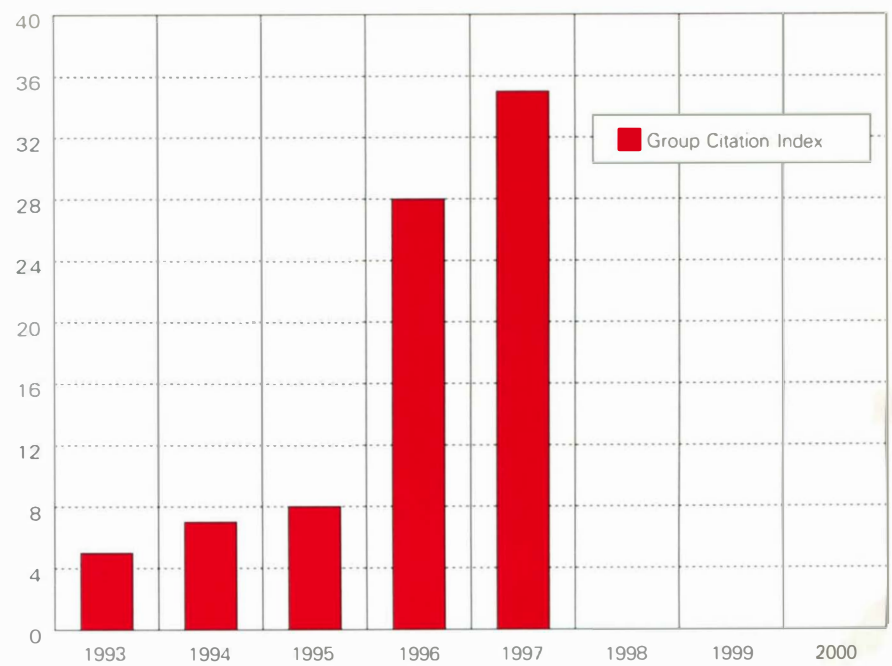


Included is funding received through: sponsorships, cooperations, mandates and other assignments from industry; research projects of the European Union (EU); research funds of the Federal Government: Swiss Priority Program (SPP), Commission for Technology and Innovation (KTI) and the Swiss National Fund (NF); the ETH research programs (TH/KIM), as well as the basic support provided by the university (ETAT).

Development of Publications



Group Citation Index



Selected Projects 1997

CAD Tool for Antenna Analysis and Optimization

Funds
Swiss Priority Program in Micro- and Nano-Systems Technology (SPP MINAST)

Partners
Integrated Systems Laboratory
ISE AG
SPEAG
Huber & Suhner AG
Swisscom

Background

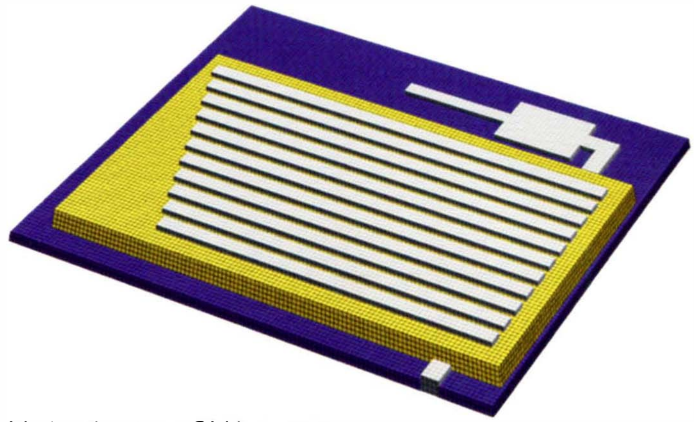
Continuously shrinking development cycles of consumer communications products create high demand for computer-aided modeling and simulation tools to reduce development time and costs.
Recent years have seen a dramatic development toward smaller and lighter transceivers. In conjunction with this development, antenna engineers are faced with the need for smaller antennas equaling the performance of longer antennas, even when operated in complex environments.
The future is likely to see strong development and growth of personal communications systems similar to that of cellular communications. The simultaneous use of different systems operating in the near-field of other sources will greatly increase the likelihood of malfunctions due to EMC and EMI problems. Systems optimized with respect to reliability will be crucial in case of life support and enhancement systems.
Powerful numerical simulation tools combined with a near-field scanner would provide the necessary tools for RF engineers responsible for developing antennas embedded in complex environments.

Objectives

The objective of this project is to develop a robust and reliable CAD platform for the analysis and optimization of antennas in complex environments. Special emphasis will be put on the development of a powerful and user-friendly modeling tool, as well as provision of a CAD data import feature. The simulation platform will share a common interface with the DASY evaluation software, in order to facilitate rapid comparison between near-field measurements and simulations.

CAD Tool

The kernel is based on the Finite-Difference Time-Domain simulation technique (FDTD) and has been developed in collaboration with the Integrated Systems Laboratory (ETH) and industry partners within the SPP MINAST project EMSIM. The current kernel includes various simulation modes (2D/3D transient simulation, 2D/3D harmonic simulation and 2D static simulation), various sources (hard and added sources, voltage source with internal resistance, TEM excitation, excitation via total field/scattered field interface, etc.), various boundary conditions (1st and 2nd order Mur, Higdon operator up to 4th order, Perfectly Matched Layer PML, Periodic Boundary Condition) and postprocessing features (voltage, current, impedance and energy calculation, spectrum extraction, far-field computation, etc.). Extensions such as subgrids and a module for heat transfer processes are currently in progress.



Model of a planar QMA-antenna

Various predefined MRI based heads, including the data set of the generic phantom have been prepared. These will become an integral part of the CAD tool. For hand-held transceiver simulations, the placement of the phone with respect to the auditorial channel of the head will be possible using simple commands. This software will be integrated into the GENESIS simulation environment, which has been developed by the MINAST industrial partner ISE AG and which enables semi-automated optimization of structures.
The code is continuously tested on the bases of different benchmark structures.

Outlook

A software upgrade to DASY3.x will provide common interfaces with the simulation tool, enabling efficient comparison of near-field scans with simulations. The combination will provide an excellent design tool for analysis and optimization of antenna structures in complex environments. The CAD tool will be officially released next year.

Optimization of Industrial Microwave Ovens

Funds
SKI
SEK

Partners
Swedish Institute for Food and Biotechnology (SIK)
Chalmers University of Technology

Background

Microwave sterilization of packaged foods was the subject of a COST project within the Agricultural and Agro-Industrial Research (AAIR) program. The primary interests were microbiological safety, product quality and equipment and packaging design. One study of the project involved electromagnetic modeling and design of the microwave ovens.

Objectives

The objectives of this study were implementation and performance evaluation of simulation tools suitable for optimization of microwave applicators used for food sterilization. The basic requirements such applicators must satisfy are: (1) the heating pattern should be uniform such that microbial safety can be guaranteed without sacrificing the overall quality of the product; (2) the edge overheating should be minimized (a common problem in most microwave heating applications, caused by electric fields parallel to sharp dielectric edges); (3) the heating pattern should be robust toward changes in product geometry and properties; and (4) the cost of the oven should be low. The latter rules out many high-tech designs, except for very exclusive products.

Numerical Methods

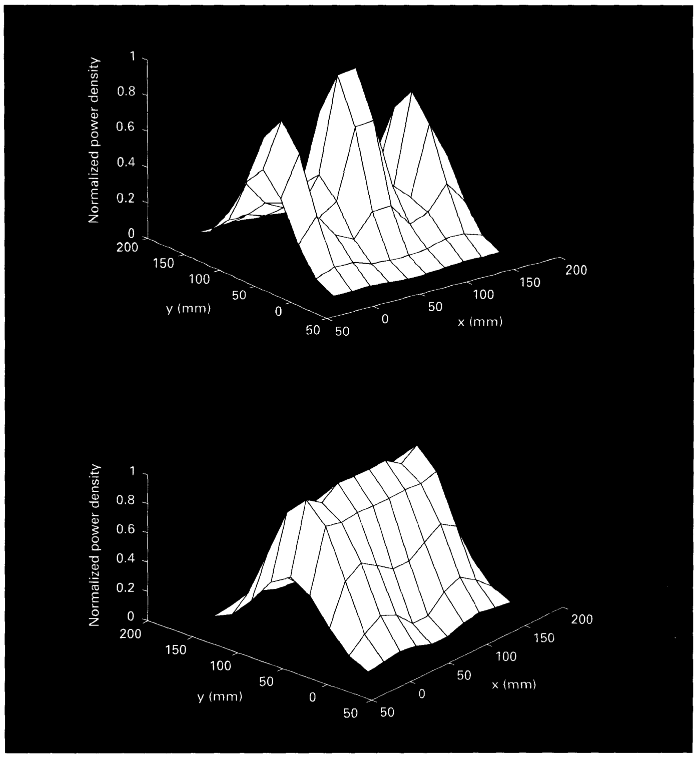
FDTD, the most obvious technique to be applied for analyzing such applicator systems, has indeed proven to be a very powerful tool. It enables the simulation of almost any structure relevant for microwave heating. Unfortunately, this versatility entails the disadvantage of being rather slow, from several minutes to several hours on workstations, and even minor changes of the structure require a completely new simulation. Since the initial simulation with FDTD showed that a number of separate food packages can be sufficiently approximated by a homogeneous dielectric plate, the applicability of faster semi-analytical techniques was investigated for optimization purposes. In this context, a Method of Moments (MoM) code highly optimized for this particular type of structure was implemented and tested, thereby reducing computational expenses by a factor >100 compared to the FDTD method.

Optimization

The suitability of numerical optimization of microwave applicators has subsequently been tested on the basis of this MoM code, whereby different quality and cost functions have been used. For example, a cost function which minimizes the difference in the power density between different parts of the food has been used to create a maximally uniform field. The parameters in the optimization were the dimensions of the applicator and the location of the waveguide feed.

Results

The use of numerical methods offers great scope for optimization of the design of microwave applicators for the food industry. The FDTD method is very powerful and universal but also computationally expensive, so that only semi-automated optimization is currently possible. Fully automated optimization can only be performed with much faster methods, e.g., MoM, requiring considerable simplification of the physical setup. In this case, the optimization can be automated by choosing a suitable quality function for the performance of an applicator and using a numerical search algorithm. It should be noted that an optimization procedure as described here cannot generate a totally new type of applicator; it can, however, significantly increase the level of performance of an already sound initial design.



Initial heating pattern in the surface of the food (top). Heating pattern optimized for maximally uniform field (bottom). The parameters in the optimization are the dimensions of the applicator and the location of the waveguide feed.

New Generation of Isotropic Broadband E- and H-Field Probes

Funds
KTI

Partner
Schmid & Partner Engineering AG

Background

Thanks to the commercialization of the measurement techniques developed at BIOEM/EMC, the spin-off company Schmid & Partner Engineering AG has been able to provide the best near-field probes from the beginning in terms of frequency range, isotropy and linearity. In order to keep this market position, E-field probes with significantly improved performance was striven for in a joint project. Early studies had also revealed the desire and considerable potential for isotropic H-field probes for the analysis of deficiencies in transmitters embedded or operated in complex environments.

Objectives

Development of a new generation of electric and magnetic near-field probes optimized for the frequency range of mobile communications and providing significantly improved isotropy, spatial resolution, frequency range and secondary mode rejection without impairing sensitivity.

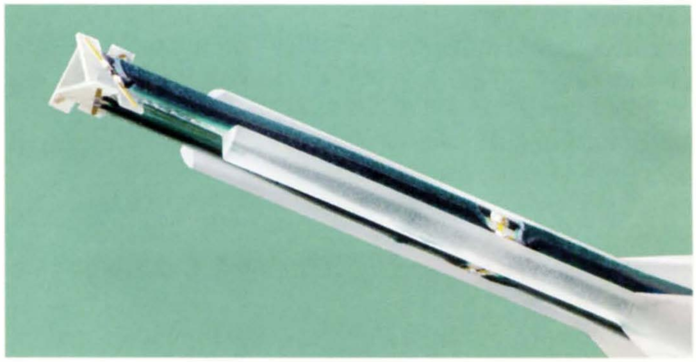
Methods

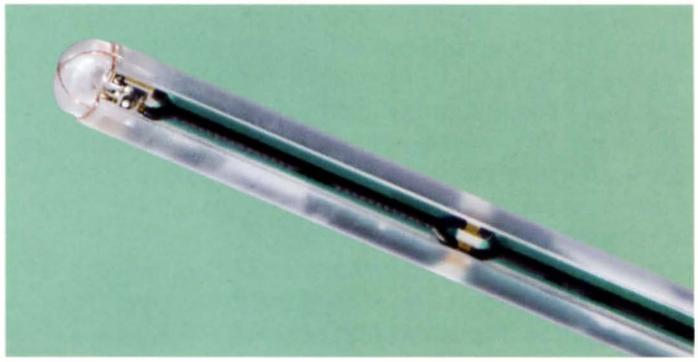
Most of the scientific investigations were carried out simultaneously using both experimental and numerical tools. Basic studies included investigations on secondary modes of reception, mutual coupling and spherical probe isotropy. A new sandwich construction of the lines on epoxy substrates was developed, which solved three problems at once: 1) the interlead capacitance was greatly increased, decreasing the RF signal pick-up by more than 20 dB; 2) the width of the substrate was reduced by almost a factor of two, which is essential for smaller probes; 3) ceramic substrates were replaced by epoxy substrates, improving the robustness of the probes and permitting thinner substrates (< 0.1 mm).

Results

The latest generation of dosimetric E-field probes provides considerably improved isotropic response inside tissue simulating liquids and increased bandwidth over probes based on older designs. This has been accomplished through compensation of the field distortion inside the probe and increased decoupling of the sensos from the line. The fine tuning of the dipole angle led to a spherical isotropy of better than ±0.25 dB, which constitutes a marked improvement compared to the ±2 dB of other commercially available probes. Since the new feature for surface detection has been incorporated in the data acquisition unit of the DASY3 system, the optical cable could be removed from the probe core, enabling reduction of the spatial distance of the dipole centers to 0.6 mm, whereby the dipole arms are interleaved (length 3 mm). The probe diameter was reduced from 6.8 mm to 3.9 mm, therefore significantly reducing the uncertainty of measurements at higher frequencies and in strongly non-homogeneous field distributions. Probes optimized for dosimetric as well as free space measurements have been realized.

The newly developed isotropic 3-dimensional H-field probe consists of three concentric loop sensors, each with a diameter of 3.8 mm. The shunt resistance and the layout have been optimized to achieve excellent isotropy (< ±0.2 dB) and minimal E-field sensitivity in the bandwidth of greatest interest, ranging from 300 MHz to 2.5 GHz. The dynamic range of the probe spans from 10 mA/m up to 2 A/m at 1 GHz.





Isotropic E-Field Probe (top) with interleaved dipole sensors optimized for dosimetric measurements (frequency range: 30 MHz - 3 GHz)
Isotropic H-Field Probe (bottom) consisting of three concentric loop sensors (frequency range: 200 MHz - 2.5 GHz)

Broadband Calibration Procedures Providing Greatest Precision

Funds
T-Mobil
Swisscom
Schmid & Partner Engineering AG

Partners
Research & Technology Center Telekom

Background

The accuracy of classical calibration procedures for E-field probes in tissue simulating liquids is not better than ±1 dB. Although this has been sufficient for applications to date, the dosimetric evaluations of handheld transmitters require significantly improved accuracy.

Objective

Evaluation and development of calibration procedures covering the frequency range 30 MHz to 3 GHz and optimized with respect to accuracy, traceability to standards, robustness and ease of use.

Transfer Calibration with Temperature Probes

In lossy media, the E-field can be measured indirectly by measuring the temperature gradient at the same location ($SAR = \sigma E^2/\rho = c dT/dt$). Non-disturbing temperature probes with high spatial resolution (< 1 mm), fast reaction time (< 1 s) and excellent sensitivity (< 1 mK) are a prerequisite. For this purpose, a thermistor based probe was developed providing a hundredfold enhanced signal-to-noise ratio when compared to commercially available non-disturbing optical probes. Several problems limit the available accuracy: (1) position uncertainty between E-field and temperature probe; (2) distortion of the temperature gradients due to energy equalizing effects or convection currents in the liquid; (3) limited accuracy in assessing the heat capacity (c) and the conductivity (σ) of the medium; (4) non-linearity of the system (dT/dt must be assessed at higher power levels than the actual measurements). In a carefully designed setup, the achievable standard uncertainty is about ±6%. This approach has the advantage that the performance is hardly dependent on the exciting source or frequency if sufficiently steep temperature gradients can be induced (e.g., dipoles). At lower frequencies (< 300 MHz), this is more difficult to accomplish. The disadvantages of this approach are that it is tedious and time consuming, as well as sensitive to shortcomings in the setup and the applied protocol.

Numerical Simulation

FDTD enables straightforward modeling of the probe inside any medium for which the sensitivity change between different media (e.g., medium and air) can be assessed. The limitation of this approach is that the mechanical and material tolerances as well as impedance change of the sensor network cannot be adequately accounted for. The achievable precision is not better than ±10 - 20% (standard uncertainty). However, this approach is applicable for any medium and frequency.

Calibration with Analytical Fields

Rectangular waveguides are self-contained systems in which the cross-sectional field distributions are not dependent on reflections. This was utilized to generate an analytically known field inside tissue simulating liquids with the following setup:
The upper part of a standing open waveguide is filled with liquid. A dielectric slab at a distance > λ from the feeding coupler provides an impedance match (> 10 dB return loss) between air and liquid. The symmetry of the construction and high losses in the liquid ensure that the field distribution inside the tissue simulation liquid follows the TE_{01} pattern, although higher modes could theoretically exist. This was carefully validated through means of a complete volume scan in the liquid using the ER3DV5 probe, which showed a deviation from the theoretical TE_{01} pattern of only < 1 - 2%.
Inside the liquid, the field nearly propagates as a TEM wave, because of low cutoff frequency. The medium depth (> 3 skin depths) was chosen so that the reflections at the upper surface of the liquid are negligible. The power absorbed in the liquid is assessed by measuring forward and reflected power inside the waveguide. The attenuation in the liquid can be assessed with high precision by measuring at different distances from the dielectric slab and by exponential curve fitting. This is sufficient to determine the SAR distribution in any highly lossy liquid.
This technique provides excellent accuracy, with a standard uncertainty of only < 3.5% (depending on the frequency and media). The calibration of the setup is reduced to power measurements traceable to standard calibration procedures. In addition, it is a robust and easy-to-use technique. However, in practice it is limited to discrete frequencies between 800 MHz and 2.5 GHz. Three systems based on R9, R14 and R22 have been realized for calibration purposes.

Procedures	Standard Precision	Frequency Limitations	Comments
Temperature Probe	~ 6%	~ 100 MHz - 3 GHz[1]	tedious; time consuming; sensitive to shortcomings in setup and protocol
Numerical Simulations	> 10 - 20%	none	fast but of limited accuracy; requires accurate calibration in another media, e.g., in air
Waveguide Setup	< 3.5%	800 MHz - 2.5 GHz	robust; easy-to-use; traceable; discrete frequency bands only

Summary of advantages and disadvantages ot the three procedures ([1]for flat phantom setup with external wire antennas as exciting sources; the frequency range can be extended with other setups).

Studies of Brain Cancer Promotion by Cellular Phone Exposure

Funds
Motorola Inc.

Partners
Department of Veterans Affairs, Research Center
University of California at Riverside
University of California at Davis
FEML of Motorola Inc.
Texas A and M University

Background

Since CNN's report on the Raynard case in early 1993, public concern about health hazards posed by wireless applications has focused on whether or not the use of cellular phones may enhance brain tumor incidence. Our current interaction models rule out RF exposure as a tumor initiator. They are less conclusive regarding promoter effects. Experimental animal models of tumorigenesis generally induce tumors by the sequential use of an 'initiator' and a 'promoter'. The initiator is usually a mutagen which has irreversible effects and must be administered before the promotor. Promoters alone do not have carcinogenic properties, but can stimulate cell proliferation.

Objectives

The main objective of the studies performed was to test the hypothesis that the electromagnetic fields of mobile communication systems promote brain tumors. The tested signals were those of the TDMA North American Digital Cellular (NADC) standard (824 - 849 MHz, 50 packets/s, duty cycle 1:3) and the analog AMPS standard (824 - 849 MHz).

Study Consortium

The experiments were performed at the J.L.P. Memorial Veterans Administration Medical Center in Loma Linda, California. UC Riverside and VA measured the ODC activity. UC Davis conducted the Histopathology and Texas A and M University the toxicology of ENU. Motorola Inc. provided the antennas and the signal generation equipment. Detailed numerical and experimental dosimetry of the exposure setups was performed by our research group. W.R. Adey of the Department of Veterans Affairs had the overall responsibility.

Methods

The design of the NADC *in vivo* study was as follows: Pregnant Fischer 344 rats were randomly assigned to 4 groups. They received either a single tail-vein injection of the carcinogen ENU (Initiator) or inert buffer solution on the 18th day of gestation. The RF exposure began on Day 19 and continued after parturition until weaning at age 23 days. Offspring (n=236) of the 4 maternal groups then became treatment cohorts: 1) ENU/field (n=56), 2) ENU/sham (n=60), 3) sham/field (n=60) and 4) sham/sham (n=60). Until day 35, the pregnant rats and pups were exposed under far-field conditions in the apperature of a horn radiator. Although it results in large variations of the SAR values in the animals, far-field exposure was chosen for this phase of the experiments, since it allows exposure of the pups together with their mothers at minimal stress levels. Starting from day 36 for the next 22 months, the rats were exposed 2 hours a day, 4 days per week in the near-field. The carousel setup used was similar to the one described in our report of last year, providing very well characterized exposure parameters. A comprehensive dosimetric evaluation was performed by our group using FDTD and experimental verifications after completion of the project. The AMPS study had a very similar design.
The first *in vitro* study looked for the expression of c-fos and c-jun in nerve growth factor (NGF) treated PC12 cells. These two genes were chosen because their response to various agents is an immediate event following cell stimulation. Expression was measured by hybridizing the mRNA with specific cDNA for c-fos and c-jun. The second *in vitro* study investigated the induced ODC activity in C3H10T1/2 cells, because ODC has shown to be sensitive to a wide variety of extracellular signals. ODC overexpression alone in initiated cells is sufficient for tumor formation, in the absence of a promotor. ODC activity was induced by changing the medium from basal BME medium with 10% FBS to basal BME medium with bovine serum albumin (BSA, 1 mg/ml).

Results and Discussion

As expected, the carcinogen ENU showed a significant effect in both *in vivo* studies (e.g., NADC: 11 tumors for ENU/sham and 4 for ENU/field compared to 7 for sham/sham and 2 for sham/field). The RF exposure did not result in a statistically significant alteration of the tumor incidence. The observed tendency in the NADC study that the RF exposure reduces the incidence of malignant glial tumors (4 in the group ENU/field compared to 13 in ENU/sham and 2 in sham/field compared to 7 in sham/sham) was not statistically significant.

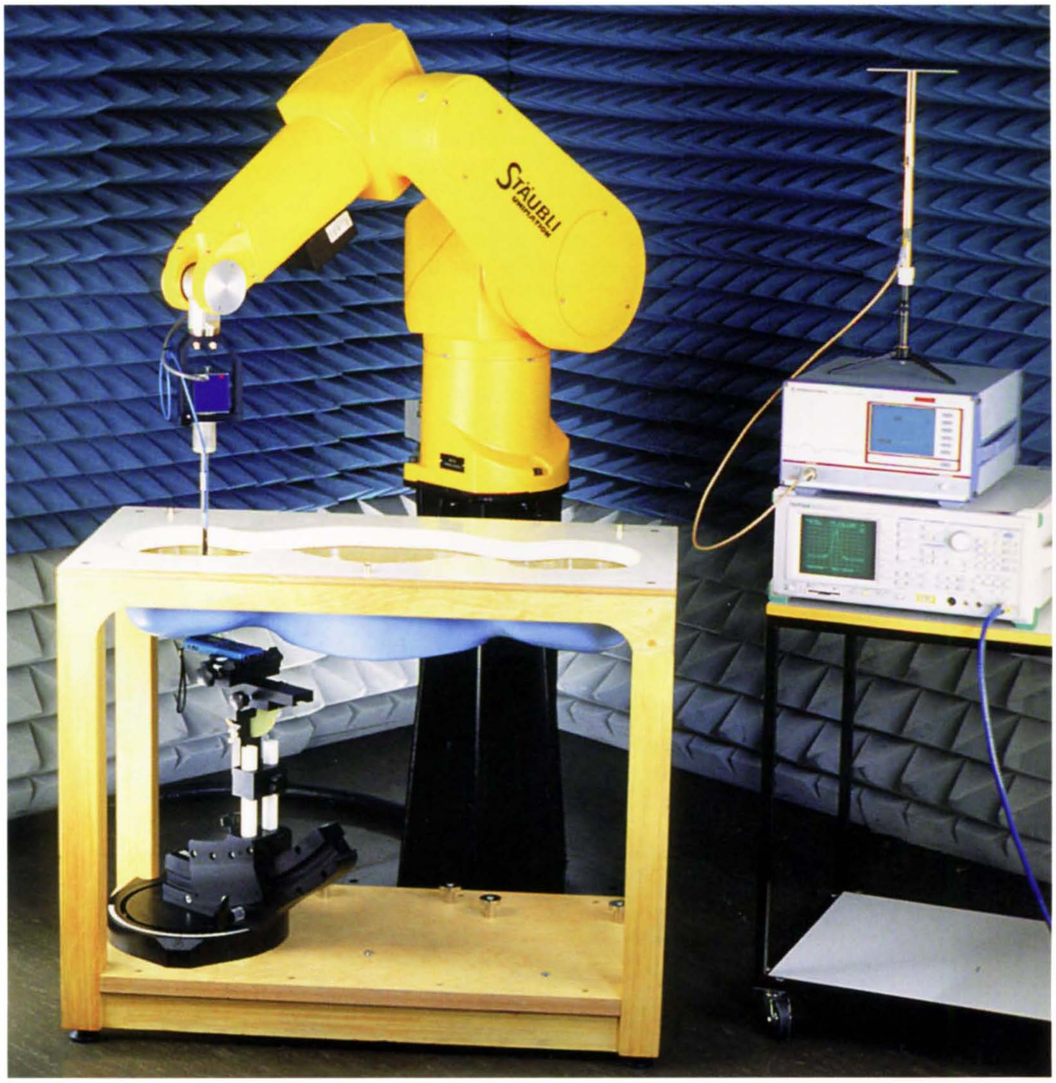
The results of the *in vitro* study on gene expression indicated no consistent alteration in the expression of either c-fos or c-jun in exposed cells as compared to unexposed cells under any condition of NGF concentration or exposure level. NADC exposure did not effect the ODC activity response 2 hours after change-of-medium. However, at 3 and 4 h after change-of-medium, the exposure inhibited the ODC activity by 50%. This effect was only found at the higher exposure level of 77 µW/g and not at 0.77 µW/g.

Outlook

Studies with similar designs are currently in progress to test the signals of other systems.

Spin-Off Schmid & Partner Engineering AG

Schmid & Partner Engineering AG (SPEAG), founded in December 1994 as a ETH spin-off of BIOEM/EMC, has greatly increased its R&D efforts in 1997. With only a moderate delay of two months, SPEAG launched the third generation of the near-field scanner DASY3, a complete hardware and software redesign of the first commercial system DASY2. Since DASY3 is equipped with the latest generation of probes, developed in collaboration with BIOEM/EMC and financially supported by KTI, it not only provides enhanced functionality but also greatly improved precision. By marketing this advanced product, SPEAG has been able to consolidate its leading position in near-field measurement technology. Its customer base consists of the R&D departments and quality-control units of the major players in the mobile communications industry, including service providers and testing organizations. New extensions and products, some of which have been developed in cooperation with BIOEM/EMC, are scheduled to be introduced in 1998. Currently more than 25 percent of turnover is reinvested in research and development of new products. The synergy which is generated by intensive cooperation between pacemakers in research and leaders in technology creates a dynamism of fast innovation cycles, which is essential for young high-tech enterprises. BIOEM/EMC greatly benefits from its collaboration with SPEAG through financial and professional support, access to the latest technology, market input, and the production of high quality prototypes in very short times.



Research Partners and Consulting Activities

Industry Partners

AT&T, USA
Cetelco, Denmark
CRL, Japan
E-Plus, Germany
Ericsson Radio Systems AB, Sweden
Huber & Suhner AG, Switzerland
Integrated System Engineering AG, Switzerland
Lucent Technologies, USA
Matsushita Communications Industries, Japan
MCL, Great Britain
Mitsubishi, Japan
Moteco AB, Sweden
Motorola Cellular, USA
Navstar Systems Ltd., Great Britain
Nokia Research Center, Finland
Nortel, Great Britain
Rosenberger HF-Technik GmbH, Germany
Sagem, France
Schmid & Partner Engineering AG, Switzerland
Swisscom, Switzerland
T-Mobil, Germany

Commissions

WHO
ICNIRP
IEC Task Force
IEEE Standards Coordinating Committee 28
IEEE Standards Coordinating Committee 34
CENELEC TC211
MCCC of COST244
Chair of the Swiss TK211
Commission for Medical Issues of the Swiss Electrical Power Association
Delegate of the Swiss Academy of Science in Commission K of URSI
Chair of Module 4 of the Swiss Priority Program MINAST
Editorial Board of the Bioelectromagnetics Journal
Board of Directors of the Bioelectromagnetics Society

Universities & Research Labs

Institut für Integrierte Systeme, ETHZ, Switzerland
Institut für Biomedizinische Technik, ETHZ, Switzerland
Institut für Geophysik, ETHZ, Switzerland
Institut für Lebensmittelmikrobiologie, ETHZ, Switzerland
Neurologische Klinik und Poliklinik, UNIZ, Switzerland
Institut für Mikrobiologie, UNI Bern, Switzerland
Forschungs- und Technologiezentrum der Telekom, Darmstadt, Germany
Max Planck Institute for Neurological Research, Cologne, Germany
Max Planck Institute for Neuropathology, Ruprecht-Karls University, Germany
IPK Gatersleben, Germany
Institute for Mobile and Satellite Technology, Germany
CSELT, Research Center, Italy
Center for Personal Communications, Aalborg University, Denmark
Department of Information Technology, University of Gent, Belgium
Finnish Center for Radiation and Nuclear Safety, Finland
Chalmers University of Technology, Sweden
University of California, Davis, USA
University of California, Riverside, USA
Motorola's Corporate Electromagnetics Research Laboratory, Ft. Lauderdale, USA
Department of Veterans Affairs, Research Center Loma Linda, USA
Washington University, USA
Metropolitan University of Tokyo, Japan

List of Publications 1997

Journals

[1] Niels Kuster, Ralph Kästle and Thomas Schmid, "Dosimetric evaluation of mobile communications equipment with known precision (invited paper)", *IEICE Transactions on Communications*, vol. E80-B, no. 5, pp. 645–652, May 1997.

[2] K. Fritze, C. Wiessner, Niels Kuster, C. Sommer, P. Gass, D. M. Hermann, M. Kiessling and K.-A. Hossmann, "Effect of GSM microwave exposure on the genomic response of the rat brain", *Neuroscience*, vol. 81, no. 3, pp. 627–639, 1997.

[3] C. Sommer, K. Fritze, C. Wiessner, N. Kuster, D. Hermann, K. A. Hossmann and M.Kiessling, "Effects of Electromagnetic Field Exposure on the Genomic Response and Blood-Brain Barrier Permeability in the Rat CNS", *Clinical Neuropathology*, vol. 16, p. 289, 1997.

[4] Klaus Meier, Ralf Kästle, Volker Hombach, Roger Tay and Niels Kuster, "The dependence of EM energy absorption upon human head modeling at 1800MHz", *IEEE Transactions on Microwave Theory and Techniques*, vol. 45, no. 11, pp. 2058–2062, Nov. 1997.

[5] Michael Burkhardt, Yuri Spinelli and Niels Kuster, "Exposure setup to test effects of wireless communications systems on the CNS", *Health Physics*, vol. 73, no. 5, pp. 770–778, Nov. 1997.

[6] N. Kuster, "Dosimetric Needs for Laboratory and Epidemiological Research in Non-Thermal Effects of RF Electromagnetic Fields, eds J. H. Bernhardt, R. Matthes and M. H. Repacholi", *ICNIRP Publication*, pp. 27–34, 1997.

[7] C. Sommer, K. Fritze, C. Wiessener, N. Kuster, D. Hermann, K. A. Hossmann and M. Kiessling, "Acute Effects of GSM Electromagnetic Field Exposure on the Genomic Response of the Rat CNS", *Journal of Cerebral Blood Flow and Metabolism*, vol. 17, p. 486, 1997.

[8] M. Sundberg, P.-S. Kildal and T. Ohlsson, "Moment method analysis of a microwave tunnel oven," *J. Microwave Power and Electromagn. Energy*, vol. 33, no. 1, in press.

[9] F. Schönborn, M. Burkhardt and N. Kuster, "Differences in energy absorption between heads of adults and children in the near-field of sources", *Health Physics*, in press.

[10] Roger Yew-Siow Tay, Quirino Balzano and Niels Kuster, "Dipole configurations with strongly improved radiation efficiency for hand-held transceivers", *IEEE Transactions on Antennas and Propagation*, 1998, in press.

[11] M. Sundberg, "An investigation of the edge overheating effect for high-permittivity dielectrics." *J. Microwave Power and Electromagn. Energy*, submitted.

[12] A. Bahr, R. Kästle, S.-G. Pan, T. Schmid, T. Becks and N. Kuster, "Numerical and experimental near-field evaluation of a DCS1800 mobile telephone", *Radio Science*, submitted.

Proceedings and Abstracts

[13] M. Sundberg, "Semi-automated design of microwave applicators for sterilization of packaged foods," in *Proc. of First World Congress on Microwave Processing*, Orlando, FL, Jan. 1997.

[14] M. Sundberg and P.-S. Kildal, "Moment method and FDTD analysis of industrial microwave ovens," in *Proc. of the Nordic Antenna Conference ANTENN97*, Göteborg, Sweden, May 1997.

[15] Katja Pokovic, Thomas Schmid and Niels Kuster, "Specialized E-field probe for RF exposure evaluation of *in vivo* and *in vitro* experiments", in *The 2nd World Congress for EMBM*, Bologna, Italy, June 8–13, 1997, p. 117.

[16] M. Burkhardt, K. Pokovic, F. Schönborn and N. Kuster, "Evaluation and design of an optimized *in vitro* exposure setup for the mobile frequency range of 1.5 – 1.9 GHz", in *The 2nd World Congress for EMBM*, Bologna, Italy, June 8–13, 1997, pp. 166 – 167.

[17] Frank Schönborn, Michael Burkhardt and Niels Kuster, "Variation in energy absorption between heads of children and adults at 900MHz and 1800GHz", in *The 2nd World Congress for EMBM*, Bologna, Italy, June 8–13, 1997, p. 165.

[18] Thomas Schmid and Niels Kuster, "A new phantom for compliance testing", in *The 2nd World Congress for EMBM*, Bologna, Italy, June 8–13, 1997, p. 275.

[19] Niels Kuster, "Dosimetry of RF laboratory equipment (invited)", in *The 2nd World Congress for EMBM*, Bologna, Italy, June 8–13, 1997, p. 33.

[20] Paola P. Schultheiss-Grassi, Jon Dobson, Heinz. G. Wieser and Niels Kuster, "Magnetic properties of the heart, spleen and liver: evidence for biogenic magnetite in human organs", in *The 2nd World Congress for EMBM*, Bologna, June 8–13, Italy, 1997.

[21] W. R. Adey, C. V. Byus, C. D. Cain, W. Haggren, R. J. Higgins, R. A. Jones, C. J. Kean, N. Kuster, A. MacMurray, J. L. Phillips, R. B. Stagg and G. Zimmerman, "Brain tumor incidence in rats chronically exposed to frequency–modulated FM cellular phone fields", in *The 2nd World Congress for EMBM*, Bologna, Italy, June 8–13, 1997, p. 109.

[22] Robert. A. Jones, J. L. Olivares, N. Kuster and W. R. Adey, "Two exposure systems for *in vivo* frequency-modulated RF field studies at 836.55 MHz", in *The 2nd World Congress for EMBM*, Bologna, Italy, June 8–13, 1997, p. 331.

[23] Frank Schönborn, Michael Burkhardt and Niels Kuster, "Variation in energy absorption between heads of children and adults at 900 MHz and 1800 GHz", *The 2nd World Congress for EMBM*, Bologna, Italy, June 8–13, 1997.

[24] Niels Kuster, "Mobile Handsets & Health Risks (invited)", in Handset '97 Technology, *IBC Meeting*, London; June 17–18, 1997.

[25] Ondrej Voles, Katja Pokovic, Michael Burkhardt and Niels Kuster, "Limitations of precise simulations of handheld mobile phones with FDTD", in *1997 North American Radio Science Meeting*, Montreal, Canada; July 13–18, 1997, p. 134.

[26] Michael Burkhardt, Frank Schönborn and Niels Kuster, "EM-absorption in human heads depending on age, size and shape", in *1997 North American Radio Science Meeting*, Montreal, Canada; July 13–18, 1997, p. 651.

[27] Frank Schönborn, Michael Burkhardt and Niels Kuster, "Experimental requirements for RF laboratory experiments", in *World Congress on Medical Physics and Biomedical Engineering*, Nice, France, Sept. 14–19, 1997, p. 83.

[28] M. Sundberg, "Moment method and FDTD analysis of industrial microwave ovens," in *Proc. of the 6th International Conference, Microwave and High Frequency Heating*, Fermo, Italy, Sept. 1997.

[29] Katja Pokovic, Thomas Schmid and Niels Kuster, "Robust setup for precise calibration of E-field probes in tissue simulating liquids at mobile communications frequencies", in *ICECOM7*, Dubrovnik, October 15–17, 1997, pp. 120–124.

[30] Michael Burkhardt, Nicolas Chavannes, Katja Pokovic, Thomas Schmid and Niels Kuster, "Study on the FDTD performance for transmitters in complex environments", in *ICECOM7*, Dubrovnik, October 15–17, 1997, pp. 83–86.

Thesis

[31] Roger Tay, "Contribution Towards the Optimization of Hand-held Mobile Telecommunication Equipment by Computational Electromagnetics", PhD Thesis, Diss. ETH No. 12311, 1997.

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