Contributions of the Engineering Sciences to the Research on Possible RF-related Health Effects

by Gernot Schmid

During the last two decades the research activities on possible RF-related health effects caused by modern mobile communication technologies ("EMF research") have been increasingly recognised as a complex interdisciplinary science, essentially requiring a high degree of both biological/medical as well as engineering expertise. Unfortunately, this kind of recognition was not always given in the past, as can be seen on the basis of several "early" investigations.

I many of these studies focusing on various biological endpoints, including in vitro, in vivo and human studies, sophisticated biological/medical protocols and methodologies were applied. However, many important technical aspects related to the exposure of the test samples/subjects were only poorly addressed, although the basic physical interaction mechanism between radio frequency radiation and biological tissues are known and documented in the scientific literature since the 1950s (even though only based on rather simple models). Intuitively, devices such as commercially available radio handsets or mobile phones or antennas fed by generic RF sources in the „switched on" or "switched off" state, "close to" the test objects/subjects were used as "exposure facilities" without any clear definition of the actual exposure conditions. Mainly driven by the partly inconclusive results provided by many of these early studies, the demand of engineering knowledge in this field of research has been increasingly realised and it became clear that providing well defined exposure conditions for specific test samples or test subjects within a given biological study design requires a considerably high degree of engineering know how. This understanding triggered what one could call a "boom of EMF research related engineering science" in the early 1990s. Experimental methods for measuring the dielectric properties of body tissues have been optimised and enabled the dielectric tabulation of many important body tissues over the entire frequency range relevant in practice. Methodologies for measuring RF absorption in simplified homogeneous body phantoms have been developed and reached production stage within only a few years, such that standardised compliance testing of mobile phones was available almost simultaneously to their steeply increasing world wide propagation. Moreover, the spreading and the advances of personal computer technology, taking place in the same time period, enabled reasonable software implementations of known numerical methods for computational electrodynamics. Especially in this field of „computational dosimetry" the rapid progress, which could be observed in recent years, is impressive. While at the end of the 1980s computational dosimetry was still

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limited to body models consisting of a few thousand voxels having dimensions of a few centimeters, one decade later, body models consisting of several million cells of size in the range of millimeters were ready and could be handled by the available computational hardware resources. But not only human body models have been developed, but also voxel models of test animals were made available which has to be seen as a milestone with respect to the design of exposure facilities for animal experiments. With these achievements, a tissue specific absorption analysis in test animals and a comparison between the absorption pattern in test animals and in humans under practically relevant exposure conditions were made possible for the first time. Today, a further decade later, a series of CAD-based high resolution body models, developed from MRI scans of both male and female children and adults are available. More than 100 tissue regions can be distinguished in some of these models, and based on currently available personal computer technology, computations with a spatial resolution in the sub-millimeter range and several hundred million voxels are possible. Using appropriately equipped high performance computer or computer cluster computations with more than a billion voxel are feasible today.

Mainly this amazing progress in computational dosimetry led to a significant improvement with respect to the engineering aspects of biological studies in recent years. On the one hand it has become possible to provide evidence for the weaknesses of the exposure concepts and dosimetric methodologies used in many of the early studies, and on the other hand the development of highly sophisticated exposure facilities for specific biological/medical study designs has been enabled, providing not only a qualitative indicator but also a quantitative tissue specific measure of the actual exposure during the experiments. Therefore, since the late 1990s, it is generally accepted that EMF-related biological/medical studies can only provide reliable and scientifically acceptable results, if competent scientist of both the biological/medical and the engineering sciences are working closely together. As a consequence, a tight co-operation of biologists and engineers becomes an essential condition by most EMF research funding agencies, which further led to the development of many highly sophisticated exposure facilities for a variety of studies (in vitro, in vivo, as well as human studies) in recent years. Defined exposure conditions within known boundaries of uncertainty, (double) blinded application of multi-level exposure with high flexibility regarding the time course of the applied RF signal and at the same time keeping the impairment of the test samples/subject at a minimum under precisely controlled environmental conditions have become basic requirements, and are acting as a robust physical basis of state of the art study designs.

A further aspect, not only closely related to the progress of the dosimetric methodologies described above, but also of general importance for the EMF-related research, is the question of achievable (exposure-) uncertainties in typical RF exposure situations. The awareness about the range of uncertainty, the way how its boundaries are quantified, and the derivation of its consequences with respect to the study outcome is frequently used as an important measure of the quality level of a scientific study. Moreover, the definition of uncertainty ranges with respect to exposure assessment in electromagnetic fields plays an essential role in view of setting safety standard for personal exposure. Also in the field of RF exposure-related uncertainty assessment it was again the progress on computational dosimetry, which enabled

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many essential insights. Besides the well known basic propagation properties of electromagnetic fields and the complex spatial and temporal inhomogeneous field distributions connected to them, as well as the complex interaction mechanisms in the near field of antennas, the biological variance of the human anatomy and tissues has been identified as an important uncertainty contributor. When additionally taking into account, as usual in daily life situations, "uncontrolled" exposure conditions, in which additional variations of the resulting exposure are caused by transmit power control, complex medium access- and duplex schemes as implemented in modern mobile communication devices, it becomes obvious that the total uncertainty in exposure assessment (with respect to power absorption) can reach easily more than one order of magnitude under general conditions. Even higher uncertainties must be expected, if the RF-induced temperature elevation in the tissue, which is currently seen as the biologically relevant quantity, is of interest. In this case further significant uncertainty contributors as thermal tissue properties and, most important, the active thermoregulatory response of the organism need to be additionally taken into account. Today, under controlled conditions, as it is the case in well designed biological/medical studies using one of the above mentioned high tech exposure facilities, the resulting uncertainties can at least be kept within a range required for a serious interpretation of the study results. A reliable exposure assessment with a known minimum uncertainty under uncontrolled conditions including multi source exposure, as usual in practice, however, is still one of the present challenges of the EMF research-related engineering science.

From the above it can be recognised that the uncertainty assessment in RF dosimetry is not a problem to be solved straightforward, but that its scope has been shifted during the last two decades. While at the beginning the focus was on uncertainties due to simplified body models and limited computational resources, the progress in computational dosimetry led to an decrease of its inherent uncertainties on the one hand and to the identification of other significant uncertainty contributors on the other hand. Not only this situations shows that there is still demand for further engineering activities in EMF related research. Despite of extending the currently available methodologies to new frequency ranges and exposure conditions to be expected in future, the issue of a reliable analysis of complex (i.e., real) exposure situations based on the biologically relevant quantities appears to be one of the most challenging fields for future EMF research related engineering tasks. For example, embedding the classical electrodynamics-based RF-dosimetry into multi-physics models in connection with statistical methods might be one of the next steps, which can bring benefits to the macroscopic exposure assessment and, moreover, which might also bring new insights in the area of microdosimetry, i.e., the assessment of possible interaction mechanisms on the cellular level.

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