# Antennas and health aspects of electromagnetic fields in the near-field region

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***Abstract*—The increase of telecommunication applications such as mobile phones gives rise to concerns about possible health risks caused by the emitted Radio Frequency Radiation (RFR). In order to evaluate possible health risks one refers to RFR exposure limits where the specific absorption rate (SAR) is used as the basic restriction on the thermal effects. Determining compliance with exposure limits, derived quantities such as electric and magnetic field strength are calculated or measured. These values are valid for plane wave conditions. Generally, this approach is sufficient. However, in cases where plane wave conditions are not valid, compliance with the basic restrictions has to be shown. Computational models for solving electromagnetic field interaction problems give a solution approach. In this paper a study on an approach to combine an electromagnetic and a thermal model is reported. For the case of near field interaction by a hand-held mobile phone the proof of concept to establish the link between the SAR and the temperature distribution is given. By using this method it is possible to show compatibility with the basic restrictions as well as to design new safety standards.**

## I. INTRODUCTION

It is generally accepted that at frequencies of operation above 30 MHz, thermal effects form the basis of the RFR safety standards, where the specific absorption rate (SAR) is used as the basic restriction on these thermal effects. Safety factors are applied to account for biological variations and for uncertainties in showing the compliance to the basic restrictions.

For the problem of Radiation Hazard analysis, derived quantities such as electromagnetic field strengths, contact currents or induced currents are determined by measurements and/or calculations. The frequency of operation determines the relevant derived quantity and in general one complies to the basic restrictions if the derived exposure limits are met.

For cases where the basic restrictions (exposure limits) are not met, precautionary measures should be taken to reduce exposure. For example increasing the distance, lowering the emitted electromagnetic power or wearing protective clothing. In certain cases, generally for workers, a more detailed analysis could be performed in order to prove compliance with the basic restrictions or to show that the local temperature rise is within health limits. These cases are particular for near-field interaction problems.

In this paper we report a study on an approach to combine an electromagnetic and a thermal model. This approach applies to frequencies of operation above 30 MHz. Doing so, a proof of concept to establish the link between the SAR and the temperature distribution is given. Although the numerical results pertain to hand-held mobile telephone configurations, it is noted that the methodology applies to a wider range of near-field interaction problems.

The temperature distribution in the human head is calculated from an antenna-generated electromagnetic power absorption distribution using the finite difference time domain technique and a state-of-the-art three-dimensional thermal model, based on advanced hyperthermia treatment prediction tools. The hybrid model shown might be used to justify the basic restriction as well as the safety factors. The complete simulation process, as outlined in Fig. 1, involves three main steps: the construction of a realistic head anatomy, EM modelling to compute the absorbed electromagnetic power, and thermal modelling to obtain the resulting temperature distribution. It is noted that the blood vessels have been included in order to model the blood flow. More details about this study that has been carried out in co-operation with University Medical Centre Utrecht (Netherlands) and Bergen University (Norway) can be found in [1].

Many authors, e.g. [4] and [5], published on SAR calculations for testing the compliance of mobile telephone equipment (MTE) to American and European standards or recommendations ([2] and [3]). In [6] Gandhi et al. mention calculation of the temperature distribution due to RFR exposure. Recently, more research activities are carried out to improve the calculations of temperature changes as presented by Wang et al in [7].

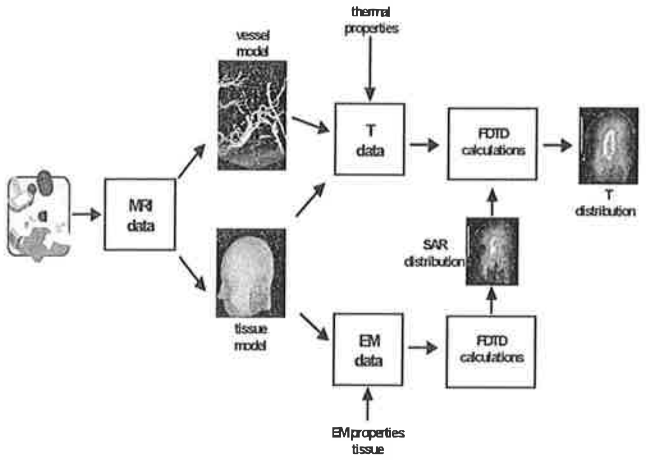


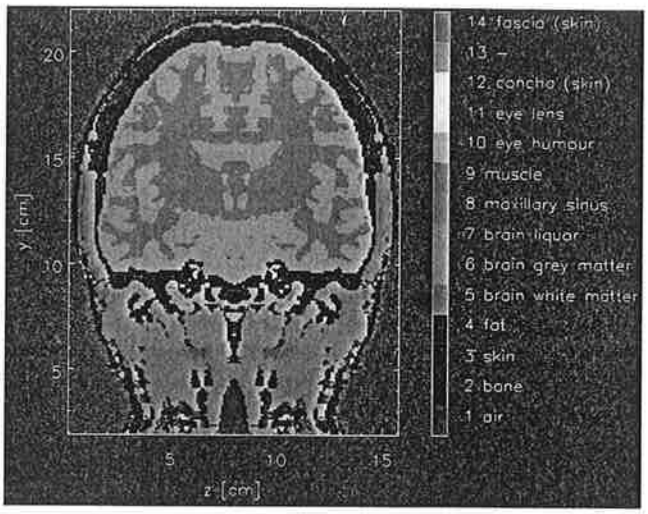

Fig. 1. Flowchart describing the data flow and tools involved

## II. TISSUE MODEL

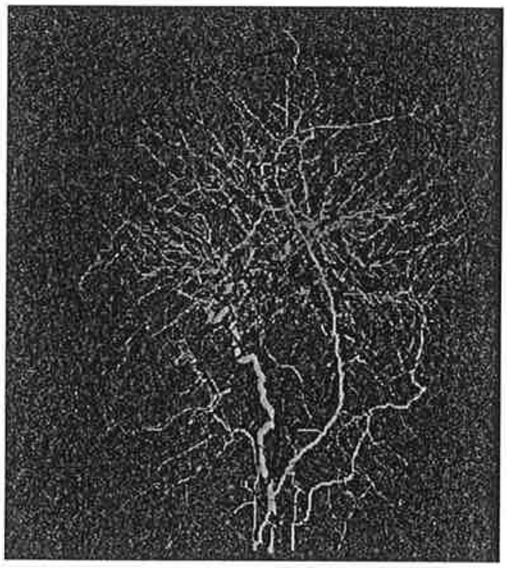
To construct a realistic anatomy 3-D Magnetic Resonance Angiography scans (Philips Gyroscan, resolution better than 1 mm cubic) were made from one side of the head of an adult female volunteer. The three-dimensional anatomy describing the spatial distribution of the tissue types was constructed from a $T_1$ weighted MR image acquired concurrently with the MRA images. The segmentation, Fig. 2a, was carried out using various region operations with ample manual intervention. In the calculations two representations for the anatomy were used: one using voxels of $(2\ \text{mm})^3$ describing a whole head, obtained by means of mirroring in the mid plane; and a high resolution $(1\ \text{mm})^3$ anatomical description only describing the first 4 cm of the head as measured from the antenna. Only in the high resolution thermal calculations the impact of blood flow was modelled by discrete vessels. For the tissue properties, needed in the electromagnetic and thermal calculations, we employed a look-up table relating local tissue type (e.g., bone, muscle) to the required property. The $(2\ \text{mm})^3$ whole head anatomy was used for the calculation of the electromagnetic power density and for the calculation of the fixed boundary temperature used in the high resolution temperature calculation.

## III. VESSEL MODEL

Blood flow plays an important role in living body heat transfer. A thermal model, DIVA (DIscrete VAsculature), has been developed for use in hyperthermia treatment planning [8]. In this model the vasculature is described in a separate data structure additional to the rectangular tissue grid from the MR images. The geometry of the vessels is described by smooth curves with an associated diameter. Vessels with diameters smaller than the tissue voxel size can be accurately modelled [9]. This enables the modelling of the majority of the thermally significant vessels. The premise is that a detailed description of the geometry of the vasculature is available, Fig. 2b. Using the anatomy data, tree structures were interactively built, describing the visible vessels in the vasculature. Smaller vessels were added in order to obtain a better description of heat transfer in the anatomy. The manually traced vasculature has been expanded using a home-developed program that adds smaller vessels according to the typical branching pattern, while also accounting for different perfusion levels and impenetrable tissue types [10]. The smallest diameter in the traced vasculature was 0.7 mm, that in the expanded vasculature 0.3 mm. Where the discrete description of the vasculature stops, the thermal model accounts in a small volume for the remaining difference in temperature between blood and tissue. The combination of the DIVA thermal model and the vessel network expansion method has been validated in experiments on isolated bovine tongues [11].




(a)



(b)

Fig. 2. tissue model (a) and vessel model (b)

## IV. ELECTROMAGNETIC MODEL

An electromagnetic power density distribution in the head was calculated for a half-wavelength dipole antenna using the (2 mm)$^3$ anatomy by using the finite difference time domain (FDTD) method [12]. The antenna was modelled 2 cm from the head, oriented vertically and operating at 915 MHz. The output of the FDTD program, a SAR distribution in [W kg$^{-1}$] is converted to an absorbed electromagnetic power distribution $P$ in [W m$^{-3}$], Fig. 3a, to be used in the temperature calculations. For the temperature calculations the total emitted power of the antenna was scaled to 0.25 Watt, the maximum effective power of commercial equipment. Assuming there is no physiological reaction, temperature elevations induced by the antenna scale linearly with emitted power. Analysis of the SAR distribution learned that the highest SAR value for a single voxel was 4.0 W kg$^{-1}$, occurring in muscle. The average SAR in a cubic volume of 1 g was 1.53 W kg$^{-1}$ maximum, in a cubic volume of 10 g it was 0.91 W kg$^{-1}$ maximum. Maximum values for arbitrary volumes of 1 g and 10 g were considerably higher, at 2.22 W kg$^{-1}$ and 1.66 W kg$^{-1}$ respectively. For the general public, the European PreStandard ENV 50166–2 [3] gives a SAR limit of 2 W kg$^{-1}$, averaged over any 6 minutes time interval and any cubic volume of 10 g of tissue other than hands, wrists, feet and ankles.

## V. THERMAL MODEL

One way of modelling the living body heat transfer by blood flow is by using the Pennes' bio heat transfer equation [13]

$$\rho_{tis} c_{tis} \frac{\partial T}{\partial t} = k_{tis} \nabla^2 T - c_b W_b (T - T_{art}) + P \qquad (1)$$

where $\rho_{tis}$, $c_{tis}$ and $k_{tis}$ are the tissue density, specific heat and thermal conductivity, $c_b$ is the specific heat of blood, $W_b$ the perfusion [kg m$^{-3}$ s$^{-1}$], $T_{art}$ the temperature of the blood entering the volume, and $P$ the electromagnetic power density. The equation is based on the assumption that all blood-tissue heat exchange takes place in the smallest vessels of the circulation. Actually, exchange also takes place in the larger vessels, causing cold tracts and an apparent increase in tissue thermal conductivity [14]. Individual modelling of blood vessels is needed to account for this. High resolution temperature simulations were done with the DIVA and the detailed vasculature, with boundary conditions determined by the (2 mm)$^3$ temperature distribution, which was calculated using the Pennes equation to account for the blood flow.

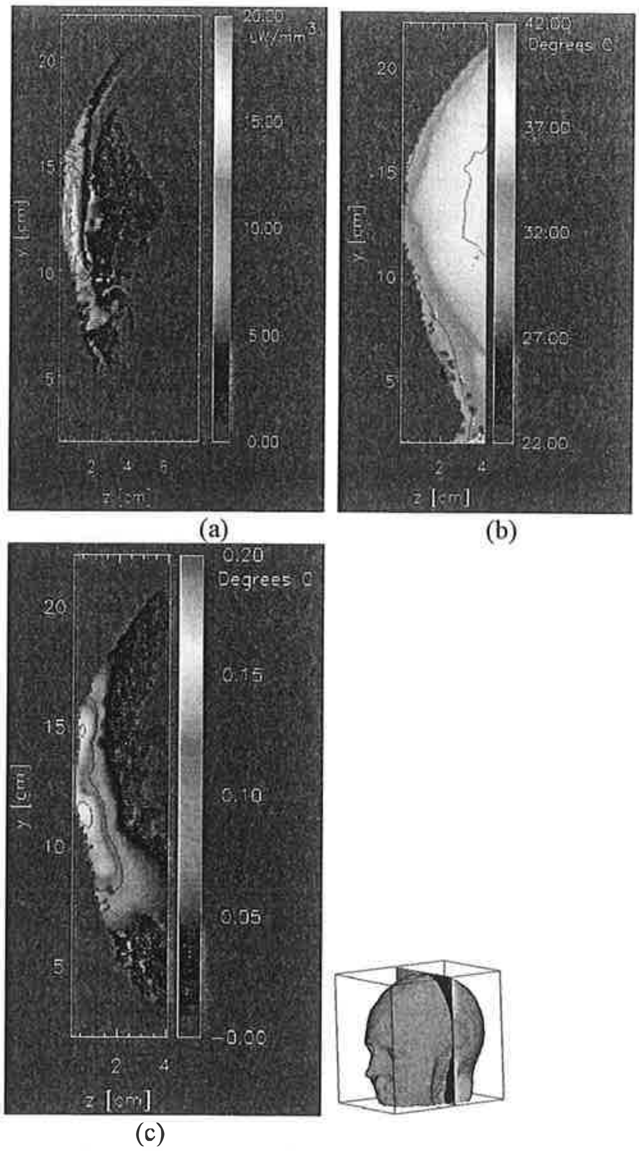



Fig. 3. (a) EM power distribution, (b) temperature distribution and (c) temperature rise

The electromagnetic power density distribution used in the high resolution calculations was obtained after trilinear interpolation of the (2 mm)$^3$ result.

Skin cooling was modelled by fixing the temperature of the air voxels and adjusting the thermal conductivity of air to the voxel size such that in effect a heat transfer coefficient between skin surface and air of 8 [W K$^{-1}$ m$^{-2}$] was modelled [15].

## VI. RESULTS

In order to show the feasibility of the proof of concept to the problem of near-field interaction of a hand-held mobile telephone, temperature calculations were done with zero emitted EM-power to determine the (non-homogeneous) base temperature distribution. From this and the stationary temperature distribution, calculated with electromagnetic power absorption, the temperature rise everywhere in the region of interest is determined. The maximum temperature rise calculated in the skin was 0.16 °C, in the skull 0.13 °C, and in the brain 0.11 °C.

It is noted that for this near-field interaction problem the local SAR values are not exceeded.

We also calculated the maximum allowable emitted RF-power if we maximise the temperature rise in the brain to 3.0 °C. The total emitted power of the antenna may not increase 6.8 W in this case.

## VII. Conclusion

We have demonstrated that combining numerical electromagnetic and thermal modelling in order to calculate the temperature rise induced by a mobile phone leads to a better understanding of safety issues. A systematic program of combined electromagnetic / temperature modelling can be instrumental in designing new safety standards or radiation hazards analysis for near field interaction problems.

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