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MICROWAVE AND INFRARED THERMOGRAMS OF HOT SPOTS IN TISSUE

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Abstract

The steady-state temperature distribution in the vicinity of hot spots in tissue is investigated using the finite-difference method in a 3-dimensional model. Starting from these results the thermograms from microwave radiometers are computed and compared with those attainable with infrared (IR) thermography.

Introduction

The knowledge of the pattern of subcutaneous temperature anomalies is important for the diagnosis of certain diseases. Therefore, the detection and imaging of hot spots in the human body with non-invasive methods, especially with microwaves, millimeter-waves and IR have been the subject of many investigations. For the interpretation of microwave and IR-thermograms the consideration of heat transfer in tissue is useful. Taking into account thermal conduction, several problems can be answered or may be analyzed more precisely,e.g.

- which frequency for microwave radiometers is advantageous for a compromise between detectability and lateral resolution
- what are the maximum temperature gradients to be expected in real tissue
- for which tissue structures may IR- and millimeter-wave thermography be valuable and where do they fail.

Model

The 3-dimensional model in Fig. 1 is in the form of a cuboid and consists of a layer of air and layers of tissue of different thermal conductivities (fat, muscle). Blood flow in the tissue (far off large blood vessels) and IR-radiation in the air are taken into account by forming 'effective' thermal conductivities. The cover of the model is on a constant room temperature of 20° C whereas the bottom is kept on 37° C, approaching the normal temperature of the human body. Furthermore, for the 4 sidewalls a temperature distribution is assumed, which would result for a structure infinite in xy-direction. To investigate the lateral resolution of microwave and IR-thermographs, two hot spots are placed in the muscular tissue. The hot spots are cubiform with isothermal surfaces of a given temperature. To obtain the temperature distribution, the model is divided into a lattice of 40x20x20 nodes. In these nodes Laplace's equation for heat conduction is solved numerically using the finite-difference method in combination with the successive overrelaxation procedure.

Signals from Radiometers

From the computations mentioned above, the tempeature distribution at the skin, which is assumed to be equivalent to the signals from IR-thermographs, can be achieved directly. Once the spatial temperature distribution is known, the signals received from microwave radiometers can be calculated for dielectrically filled waveguide antennas in contact with the skin. The diagrams for these antennas are developed with reference to (1) for antennas which have quadratic apertures and a filling with a low dielectric constant. With known frequency-dependent properties of the fat and muscular tissue (penetration depth, electrical conductivity) below the antenna (2), (3), (4), the brightness temperature T_r of the antenna can be calculated by summing up the contributions of radiation from various subvolumes (1).

Computed Thermograms

For the examples given in the following figures (Fig. 2 - Fig. 6) the hot spots are at a temperature of 38° C and have the dimensions of $(3\ \text{cm})^3$ with a distance of 6 cm between them. They are situated in a depth of 3 cm under the skin with a fat layer of 1.5 cm thickness. Calculations are carried out for 1 GHz, 4 GHz and 10 GHz with antenna apertures of $(7.5\ \text{cm})^2$, $(1.9\ \text{cm})^2$ and $(.75\ \text{cm})^2$, respectively.

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References

(1) M. Robillard, M. Chive, Y. Leroy, J. Audet, Ch. Pichow, J.Ch. Bolomey: Microwave Thermography - Characteristics of Waveguide Applicators and Signatures of Thermal Structures. Journal of Microwave Power, 17 (2), pp. 97-105, 1982

(2) A. Shitzer: Studies of bio-heat-transfer in mammals. Topics of Transport-Phenomena, Chaim Gutfinger, Ed.: Halsted Press, 1975

(3) M.van Sliedregt: Computer Calculations of a One-Dimensional Model, Useful in the Application of Hyperthermia. Microwave Journal, Vol. 26, No. 6, pp. 113 - 126, June 1983

(4) A.Y. Cheung: Microwave and Radiofrequency Techniques for Clinical Hyperthermia. Br.J. Cancer (1982) 45, Suppl. V, pp. 16 - 24

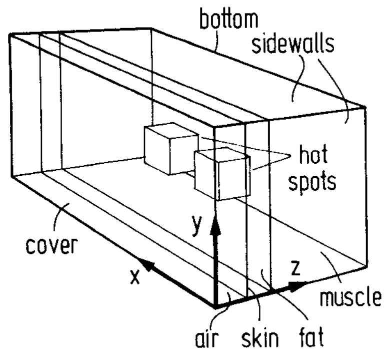

Fig. 1: Perspective view of the model

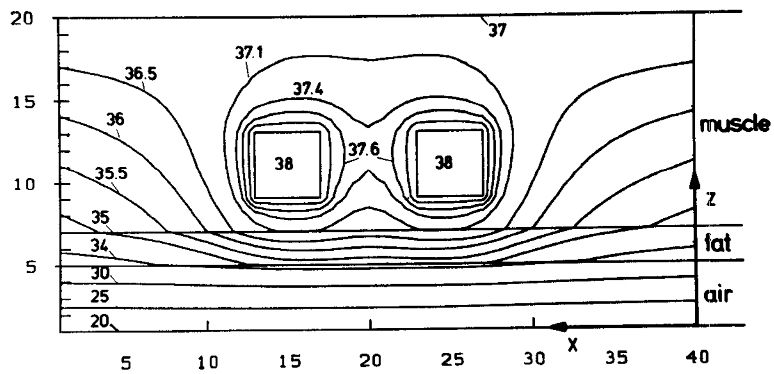

Fig. 2: Isothermal lines (in ^{0}C) in the xz-plane (section through the hot spots)

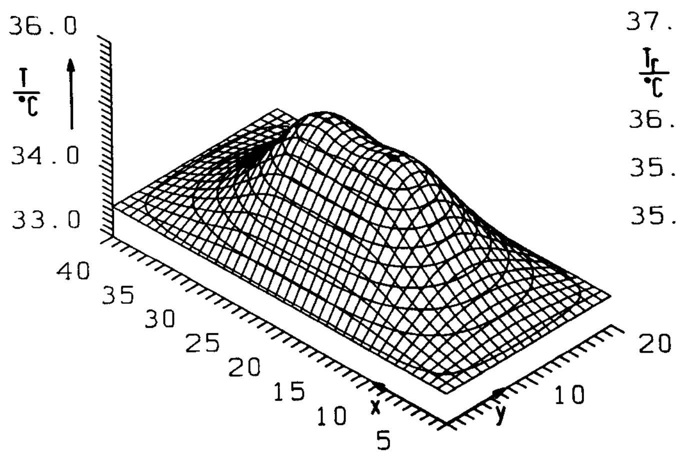

Fig. 3: Temperature distribution at the skin (IR-thermogram)

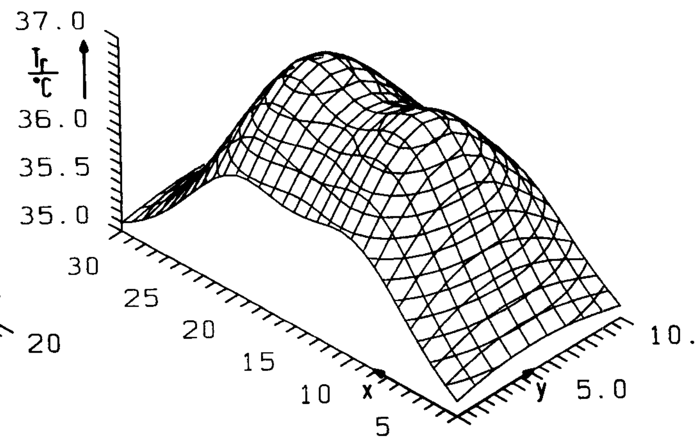

Fig. 4: Computed thermogram for a 1 GHz-radiometer

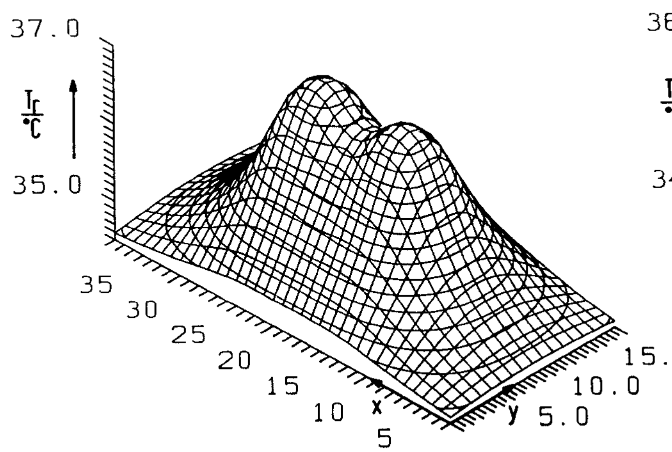

Fig. 5: Computed thermogram for a 4 GHz-radiometer

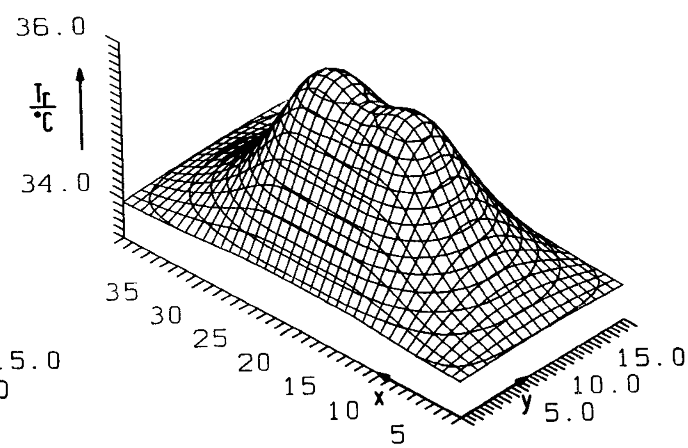

Fig. 6: Computed thermogram for a 10 GHz-radiometer