Microwave radiometer for medical application

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The microwave radiometer receives and evaluates the natural electromagnetic radiation from the patient’s internal tissues at microwave frequencies.
Basic principle of microwave radiometry

Frequency range - 3.5 to 4.2 GHz

\[ P = k \cdot T_{rad} \cdot \Delta f \]

- \( P \) – noise power at the output antenna;
- \( T_{rad} \) – brightness temperature; \( k \) – Boltzmann constant;
- \( \Delta f \) – receiver bandwidth.

Volume under investigation

- \( W_z = 30\text{-}70 \text{ mm} \)
- \( W_x = 10\text{-}40 \text{ mm} \)
- \( P = 10^{-12} \text{ W} \)
- \( \Delta f = 700 \text{ MHz} \)
The French scientist M. Gautherie made dynamic observation on 1,245 patients with temperature changes of breasts, without clinical and X-ray mammography breast cancer symptoms during 12 years.

X-ray mammography and clinical examination were carried out annually.

Breast cancer was detected in 501 patients (40.2%) during 8 years of tests.
Metabolic heat production as a function of doubling time of tumor volume

Metabolic heat production (mWt/cm³)

Doubling time of tumor volume (days)

Without lymph node metastases

With lymph node metastases

M. Gautherie
The tumor growth dynamics is characterized by the doubling time of a tumor (mass or number of cells). The doubling time can vary widely (from 3 days to hundreds of days), but it is constant for a specific patient, and can be represented by an exponential curve. Also tumors with short doubling time can have a high specific heat generation (Watt/cm$^3$). When the tumor grows rapidly, energy consumption increases and heat generation rises. Therefore, most of dangerous tumors (short DT, i.e. rapid growth) can be detected by thermal methods. These cases are about a quarter of all breast cancer patients.
Mathematical model of microwave radiometry

\[ T_\mathcal{R} = \int_{-\infty}^{\infty} T(r) \cdot W_n(r) \, dV \]

\[ W_n(r) = \frac{\sigma |E(r)|^2}{\int_{-\infty}^{\infty} \sigma |E(r)|^2 \, dV} \]

\( \sigma \) – electroconductivity

\( E(r) \) – the vector of the electric field created by the antenna in tissues.
Methodology for designing antenna applicators for medical purposes
1а – antenna-applicator, 1б – excitation system of electromagnetic waves, 1в – IR-sensor; 2 – skin; 3 – fat layer, 4 – skull bones; 5 – cerebrospinal fluid layer; 6 – proper brain

<table>
<thead>
<tr>
<th>Electrophysical simulation parameters 3.6 GHz</th>
<th>Skin</th>
<th>Fat</th>
<th>Bones skull</th>
<th>CSF</th>
<th>Brain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permittivity</td>
<td>52.0</td>
<td>5.164</td>
<td>5.16</td>
<td>61.83</td>
<td>50.56</td>
</tr>
<tr>
<td>Conductivity, [Sm/m]</td>
<td>2.76</td>
<td>0.161</td>
<td>0.163</td>
<td>3.22</td>
<td>3.03</td>
</tr>
<tr>
<td>thickness of the layer of biological tissue h, mm</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1.5</td>
<td>93.5</td>
</tr>
</tbody>
</table>
Efficiency of the antenna applicators

Brightness temperature measurements of brain

Typical thermal field of brain healthy person (25 years)

Scheme for measuring the internal temperature human brain

Typical thermal field of the human brain in the presence of cerebral infarction in middle cerebral artery (left hemisphere)
Creating a mathematical model of microwave radiometry

Solving equations of heat and mass transfer:

$$\nabla \cdot k \nabla T + Q_{\text{met}} - \rho_b c_b \omega_b (T - T_b) = 0$$

- $k$ – thermal conductivity of tissue $[\text{W/m} \cdot \text{°C}]$
- $Q_{\text{met}}$ – specific heat $[\text{Bt/m}^2]$,
- $\rho_b c_b \omega_b$ – blood flow parameters $[\text{W/m}^3 \cdot \text{°C}]$,
- $T_b$ – arterial blood temperature $[\text{°C}]$,
- $h_a$ – heat transfer coefficient $[\text{W/m}^2 \cdot \text{°C}]$,
- $T_a$ – ambient temperature $[\text{°C}]$.

$$k \nabla T \cdot n + h_a (T - T_a) = 0$$

$n(k_1 \nabla T)_1 = n(k_2 \nabla T)_2$

$T_1 = T_2$

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External boundary conditions for continuity of biological layers

Analyzed about 30 different models.

<table>
<thead>
<tr>
<th>Thermal parameters of biological tissue</th>
<th>Tumor</th>
<th>Glandular tissue</th>
<th>Skin</th>
<th>Fat</th>
<th>Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>specific heat ($Q_{\text{met}}$, [W/m^2])</td>
<td>65400</td>
<td>700</td>
<td>1620</td>
<td>400</td>
<td>700</td>
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<tr>
<td>blood flow parameters ($\rho_b c_b \omega_b$, W/m^3. °C)</td>
<td>48000</td>
<td>2400</td>
<td>9100</td>
<td>800</td>
<td>2400</td>
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<tr>
<td>thermal conductivity ($k$, [W/m·°C])</td>
<td>0.511</td>
<td>0.3</td>
<td>0.376</td>
<td>0.21</td>
<td>0.55</td>
</tr>
</tbody>
</table>
Fixing labs. animal  
TUMOR

Register thermogram

Examples of application

Two-channel signal recording

- Muscle with tumor
- Healthy muscle

Features reception signal (broadband microwave radiation biological object own), allows you to get a fundamentally new information about the processes of metabolism, perfusion (microcirculation) and cell kinetics malignancies.
Examples of applications

Noninvasive measurement brightness temperature breast

The temperature field of breast

Noninvasive measurement radiobrightness temperature on the projection carotid

Temperature field on the projection of the carotid artery: an increase in temperature 1.5 °C
Thermal changes start at a stage that is previous to malignant growth, i.e. at the stage of the expressed proliferation and an atypical hyperplasia.
Patients survival with IIIb stage breast cancer depends upon thermal indications

Thermonegative tumors (without increase of temperature)

Hot tumors
The method efficacy is confirmed by clinical trials, carried out on more than 3500 patients
Results of the measurements can be displayed as a temperature field and thermograms.
Patient Б.
Mastitis of right breast before treatment

Mastitis after treatment
Features of thermal process in breast

**Temperature reduction**
- Hypothermia

  - Adipose involution
  - Blood circulation reduction
    - fibrosis
    - scars
    - lipoma
    - other

*No temperature changes*
- Isothermy
  - Benign changes without proliferation

**Temperature increase**
- Hyperthermia
  - Proliferation and atypia
  - Malignant growth
  - Inflammation
Healthy breast
Breast cancer
Mastitis
Mastopathy with proliferation

Шаг изотерм - 0.120°C

Правая МЖ

Левая МЖ

Температура[°C]: минимальная - 31.4, средняя - 32.0, максимальная - 34.8

Norm: 34.0
Fibroses
<table>
<thead>
<tr>
<th>№</th>
<th>Clinical trials sites</th>
<th>Year</th>
<th>Sensitivity %</th>
<th>Specificity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oncological Hospital # 40, Moscow, Russia</td>
<td>1997</td>
<td>94.2</td>
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<td>2</td>
<td>Mammological dispensary, Moscow, Russia</td>
<td>1998</td>
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<td>3</td>
<td>Oncological centre, Moscow, Russia</td>
<td>1998</td>
<td>89.6</td>
<td>81.8</td>
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<tr>
<td>4</td>
<td>Main military Hospital (Burdenko), Moscow, Russia</td>
<td>2001</td>
<td>98</td>
<td>76</td>
</tr>
<tr>
<td>5</td>
<td>Mammological dispensary, Moscow, Russia</td>
<td>2002</td>
<td>95</td>
<td>57</td>
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<tr>
<td>6</td>
<td>Medical College, Arkansas, USA</td>
<td>2003</td>
<td>85</td>
<td>70</td>
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<tr>
<td>7</td>
<td>Russian Scientific Center for X-ray radiology, Moscow, Russia</td>
<td>2006</td>
<td>96.6</td>
<td>76</td>
</tr>
</tbody>
</table>
Advantages of microwave mammography

- Lack of radiation exposure. It is possible to perform measurements many times with no effect
- High method sensitivity
- Detection of pathologies at an early stage
- Visual display of the results
Use on different organs

- Prostate Gland
- Scar
- Skin Neoplasm
- Skin Neoplasm (short)
- Skin Neoplasm (symmetric pair)
- Spine
- Sternum
- Stomach
Temperature Fields

Healthy person

Ischemic stroke in the left side of the brain
First In Vivo Application of Microwave Radiometry in Human Carotids
A New Noninvasive Method for Detection of Local Inflammatory Activation

Figure 1  Microwave Radiometry
(A) Photograph of the antenna for microwave radiometry measurements placed at a 90° angle. (B) Schematic presentation of the system of microwave radiometry. The antenna of the microwave sensor is in contact with the skin above the volume under investigation.
Thermographic profile of internal temperature and shank anatomy in normal
Nodal melanoma of skin in the left deltoid region $pT2N0M0$ 1cm
Liver and kidney

Healthy

Inflammation
Spine

Healthy

Inflammation
Internal temperatures field of thyroid cancer
Thank you for your kind attention