Microwave Based Medical Imaging

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Abstract—**Our EuMC 2017 contribution is focused on resent research activities in the area of microwaves in medical diagnostics. Projects on microwave differential tomography and UWB radar system (both used both for medical diagnostic and for non-invasive temperature measurement as well) will be described. We will underline international cooperation of Czech researchers with experts from other EU countries.**

Keywords—Microwave Hyperthermia; Noninvasive Temperature Measurement; UWB Radar; Head and Neck Treatment; Delay and Sum;

I. INTRODUCTION

Interactions of EM field with biological systems are utilized in the area of therapy (oncology, physiotherapy, urology, etc.) from late seventieth of last century. Wide utilization of microwave thermotherapy can be observed in the countries of EU, USA, Russia, China, Japan and many others, including the Czech Republic. Important role in development in this area play scientific societies like e.g. ESHO (European Society for Hyperthermia Oncology), which co-operates with STM (Society for Thermal Medicine) and ASHO (Asian Society of Hyperthermia Oncology).

Nowadays the electromagnetic (EM) fields are generally used in several well-established medical applications already. Typical examples are e.g. Computer Tomography (CT) and Magnetic Resonance Imaging (MRI) in medical diagnostics as well as e.g. electro-surgery, radiofrequency (RF) heating in physiotherapy, microwave (MW) hyperthermia and RF + MW ablation in clinical therapy. Therapeutic applications of MWs, e.g. MW hyperthermia and ablation, are being used for the cancer treatment and treatment of some other diseases.

To give a basic overview, we can divide the medical applications of microwaves in following three basic groups according to purpose, how are microwaves used:

- Treatment of patients (with the use of either thermal or non-thermal effects – sometimes both of these types of effects can play its role).
- Diagnostics of diseases (e.g. by aid of permittivity measurements, attenuation measurements and very prospective in the near future can be a microwave tomography).
- "Only" a part of a treatment or diagnostic system (case, when microwave technology is essential for the right function of the medical system, but are not directly used for the treatment or diagnostics – like e.g. in case of linear accelerator, etc.).

As is given above, until now medical applications of microwaves are above all represented by the treatment methods based on thermal effect – i.e. we can speak about the microwave thermotherapy, which can be further divided into three different modalities distinguished according to the goal temperature level or interval:

- Diathermia: heating up to 41 C (physiotherapy).
- Hyperthermia: heating to the interval of 41-45 C (oncology).
- Thermodestruction/thermoablation: over 45 C (urology, cardilology).

First three of the following list of thermo-therapeutical applications are just largely used in many countries around the world, last three instead are in this moment in the phase of very promising projects:

- Oncology (cancer treatment).
- Physiotherapy (treatment of rheumatic diseases).
- Urology (BPH treatment).
- Cardiology (arrhythmia and fibrillations treatment).
- Surgery (growing implants).
- Opthalmology (retina corrections).
- Neurology (stroke identification, brain stimulation).

For here mentioned thermotherapy treatments frequencies from interval from 1 MHz up to 5.6 GHz are mostly used.

Future trends in medical applications of microwave technique and technology can be seen in development of new diagnostic and imaging methods based on high frequency EM field. A significant importance for the future can be identified for the following methods: Microwave differential tomography, Microwave radiometry and Microwave diagnostic radars.

Recent trends in microwave medical applications are to study the possibilities to develop new diagnostics based on EM field resp. on microwave technique. A significant importance for the future can be identified for the next methods:

- MRI,
- Microwave differential tomography,

- Microwave radiometry,
- Microwave diagnostic radar.

We will not talk here about MRI and CT, as it is just well known and broadly used application of EM field in medical diagnostics. We will focus here on other above mentioned methods.

MRI is working mostly in frequency bands from 64 to 299 MHz (upper part of the so called RF band), CT then is working in hard X-ray band. Frequency bands between these two is the MW frequency band, i.e. frequencies from 300 MHz to 300 GHz. Lower part of this frequency band, approx. from 300 MHz till 6 GHz, is very prospective for Microwave Medical Imaging. Upper part of this frequency band, i.e. frequencies above approx. 100 GHz is very prospective for imaging with terahertz waves.

The use of MWs for medical diagnostics is relatively new but rapidly developing area. The main advantages of MW technology are as follows: MWs belong to a nonionizing radiation and for diagnostics purposes low power levels (1-20 mW) are used only. Furthermore, since the MW technology is being massively used in mobile telecommunication the MW diagnostic systems have potential to be one order of magnitude less expensive than MRI.

II. Microwave Medical Diagnostics

A. Microwave differential tomography

Microwave differential tomography is in Prague developed by people from Dept. of Biomedical Technique in cooperation with Prof. Andrea Massa from Eledia Research Center (Trento, Italy).

Theoretical works are focused on a theory of a differential microwave imaging (DMI) in real time. In the near future, this research could contribute to significant development in the area of microwave tomography, which is supposed to be able to bring some additional diagnostic information to those obtained by MRI and CT. In details - reconstruction algorithms for differential real-time MWI were described and implemented. They were applied and tested both numerically and experimentally within the feasibility studies on microwave tomography.

It seems to be realistic that the DMI methods can be used for 3D non-invasive temperature monitoring of the treated volume during thermotherapy in oncology. Existing suitable reconstruction algorithms, which allow quasi-real-time monitoring of changes of dielectric properties due to change of temperature, were implemented. Reconstruction algorithms were tested on different 2D models and one 3D model. The obtained results using Distorted Born Algorithm (DBA) and Born Algorithm (BA) were compared in terms of algorithms ability to reconstruct shape and position of the target and flatness of the obtained object function in regions without change in dielectric properties. Furthermore, influences of different TSVD-threshold values, number of pixels and normalization were tested. Demands on RAM for 3D inversion for desired spatial resolution was performed. Although BA with low TSVD-threshold value leads to clear pictures of difference in relative permittivity but we lose information about difference in conductivity. Described algorithms were tested with sphere virtually homogeneously heated and resulting pictures have no clear boundary of the object function: the predicted changes of object function are smooth. In this way the spatial resolution in 3D will be approx. 2 x 2 x 2 mm^3. Even though the implemented algorithms show several deficits they represents state-of-the-art and are therefore suitable starting point in development of the combined system. Such non-invasive temperature monitoring, when it will be available, would mean a significant improvement of Quality Assurance for hyperthermia treatment of oncological patients in real clinics. And for the comfort of their treatment as well.

Other prospective possibility to use DMI is the very quick detection, identification and classification of strokes (SDI), which would be very essential for quick qualified decision of what kind of treatment is necessary to give to the stroke patient already in ambulance car when he/she is being transferred to the hospital. Pioneer research group in this area is a team of Prof. Mikael Persson from Chalmers University in Goeteborg, Sweeden.

A simplified laboratory microwave system for the detection and identification of strokes was designed and built at Dept. of Biomedical Technique. All necessary MATLAB scripts for automatization of measurements, acquisition and saving of measured data, reconstruction were implemented. Numerical model of the forward problem necessary for the reconstruction algorithm was created. At the same time preliminary evaluation of the system based on both numerical as well as measurement results was performed. It is necessary to point out, that reconstruction results obtained here with the first simplified laboratory MWI system built for SDI at Dept. of Biomedical Technique should be taken as preliminary. In near future it is therefore possible to analyze the suitability of various types of antennas, their size, number and different placements by means of numerical simulations. Furthermore, we believe, that the main resolution limit of the current here described system is a low number of antennas. We plan to extend the system to the maximum possible number of antenna elements of our current measurement equipment (i.e. up to 24) and therefore there is considerable potential for improvement.

B. UWB radar

Microwave UWB radar technology for noninvasive microwave imaging and/or noninvasive temperature monitoring is in Prague developed by people from Dept. of EM Field in cooperation with Dr. Marko Helbig and Dr. Juergen Sachs from TU Ilmenau in Germany.

The detection principle of temperature change via UWB radar signal is based on a fact that the complex permittivity is changing with temperature (like it was stated for microwave differential tomography) and with the distance. In [5] we have demonstrated that it is possible to detect these changes by UWB microwave radar. The antenna array for noninvasive differential temperature change detection is composed of 8 dipole antennas (21 x 11 mm). These antennas are excited by the UWB pulse in the frequency band 1-8 GHz. The values of relative permittivity and specific conductivity of all considered tissue temperature (at starting temperature 37 °C) have been taken from IT'IS Foundation database [7].

The results from our numerical experiments show the potentiality of this approach that it is possible to detect low changes in tumor permittivity (caused by temperature change). For simulation purposes two numerical models with frequency and temperature dispersive parameters of biological tissues were used. We presented an experimental antenna setup for UWB temperature change detection within the microwave hyperthermia treatment. To avoid the interference between hyperthermia system and UWB radar signal the differential temperature measurement will be done at the moment when the microwave heating will be turned off.

The numerical experiment with homogenous phantom shows that we can detect layers of different temperature. From reconstructed image, we are partially able to reconstruct the shape and position of the simulated inhomogeneity. From this experiment we establish the maximum distance between antennas and inhomogeneity when we are still able to detect the inhomogeneity (for head and neck the distance is 10 cm due to the attenuation in tissues). For real measurements scenarios, this distance will be lower.

To approach to the real measurement the heterogeneous numerical phantom of real patient of large tumor was implemented. According to the results, the maximum reconstructed signal intensity was detected in the position of tumor, but the reconstructed signal intensity is spread in surrounding area, where the temperature increase did not occur. This is caused by the EM wave dispersion and it is decreasing possible spatial resolution.

The way how to improve the chance for more accurate differential temperature reconstruction is in the higher number of antennas closer to the heated area utilization and in the attenuation correction improvement.

C. Microwave radiometry

Microwave radiometry is based on measurement of a very weak EM signal, which radiates any object (e.g. people), whose temperature is superior to absolute zero [1]. It is based on utilization of so-called Planck radiation law. Interest in microwave radiometry is given by possibility of its utilization at diagnostics of cancer and also of inflammatory disorder (e.g. appendicitis, arthritis, atp.) because tumors and inflammatory processes causes temperature rise. Microwave radiometer as a tool for biomedical imaging applications has the possibility to „monitore" a thermal noise produced by all objects with the temperature over absolute zero. Next figure gives a basic idea about experimental setup. Advantage of microwave radiometer is ability to „see" the temperature increase under the surface of human body. Therefore wee need to scan studied area of the tissue with a sensor and to evaluate the results of temperature measurements.

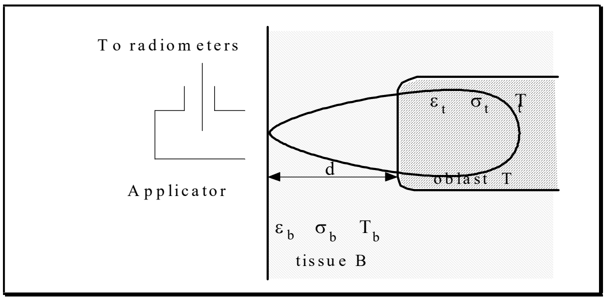

Fig. 1. Imaging by radiometer

In the next figure we can see relation between discussed quantities for the case, when T_b = 310 K and T_t = 312 K and sensitivity of a radiometer is 0,5 K so we can detect increase in temperature for levels of 310,5 K. Temperature measured by radiometer is in this figure a function of L_b.

According to this figure attenuation in region B can be only 6 dB at maximum, othervise radiometer "will not see" increased temperature in region T.

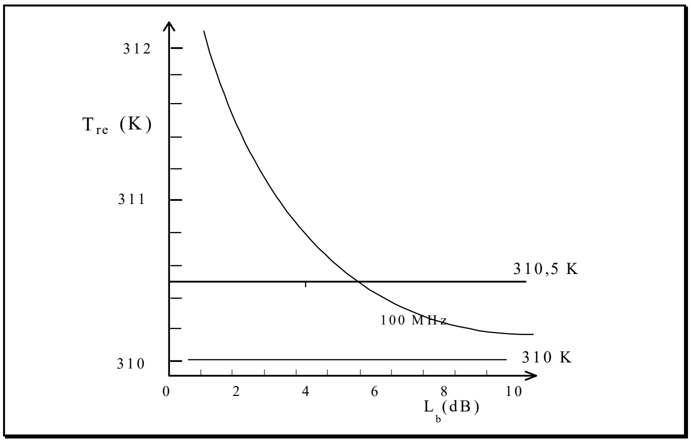

Fig. 2. Temperature measured by radiometer with respect to tissue attenuation L_b .

ACKNOWLEDGMENT

This work has been supported by two grants of the Czech Science Foundation, numbers XXXX and YYYY, as well as by the COST Action TD1301.

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