Numerical Model For Microwave Induced Thermoacoustic Imaging

Mohand Alzuhiri, Yiming Deng, Mark Golkowski, Ryan Jacobs
Dept. of Electrical Engineering
University of Colorado Denver
Colorado, USA
Mohand.Alzuhiri@ucdenver.edu

Abstract: This paper presents a numerical model to simulate signal generation of near field microwave induced thermoacoustic imaging. The model simulates both of the electromagnetic interaction of microwaves with the imaged target, and the generation of acoustic signals and their propagation. The study investigates the effect of different design parameters on intensity and frequency of generated acoustic signals, focusing on the effect of target's electrical properties, microwave frequency, and microwave pulse width.

I. INTRODUCTION

Breast cancer threatens the life of millions of women around the world [1]. In 2014, more than 232 thousands cases of breast cancer were diagnosed in the United States only [1]. Breast cancer patients have the second highest death rates between other cancer patients [2]. It is well known that the early discovery of the breast cancer decreases the number of fatalities significantly. For this reason a large number of imaging methods has been proposed to detect cancerous tumors in their early stages. The commonly used methodologies are x-ray, MRI, microwave imaging, and ultrasonography. X-ray mammography is most commonly used but it suffers from several drawbacks. Researches shows that about 15% of the cases was detected improperly [2]. This is added to the fact that x-rays rely on ionizing radiation in the process of imaging [2]. On the other hand, MRI is very capable imaging technique that give superior images but it is considered as a very expensive solution [3]. Microwave imaging provides good contrast in biological tissues but it suffers from low spatial resolution due to its long wavelength [2]. Ultrasound has good resolution but it suffers from poor contrast in biological tissues.

Microwave Induced Thermo-acoustic Imaging (MITAI) is a hybrid imaging methodology that combines the high contrast of microwave imaging and fine resolution of ultrasonography. MITAI images are acquired by sending short microwave pulses into the imaged object. The microwave pulses absorption results in a heat gradient inside the object. The heat gradient excites a thermo-elastic expansion that generates acoustic wave in the range of ultrasound. Those acoustic waves are used to reconstruct the imaged object's structure using standard tomography approaches. MITAI is attractive as an imaging solution for breast cancer since it is low cost and combines the advantages of both ultrasound and microwave imaging techniques.

The thermoacoustic signal generation in MITAI is governed by the following equation [4]:

$$\nabla^2 p(r,t) - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}p(r,t) = -\beta\rho\frac{\partial^2}{\partial t^2}T(r,t) \qquad (1)$$

Where p is the acoustic pressure, c is the sound speed in the medium, β is the volume expansion coefficient, and T is the temperature of the medium. The left part of Eq. (1) represents acoustic wave propagation equation. The right part represents an acoustic source that is governed by the amount of microwave absorption inside the imaged target [2]. The temperature rise inside the target medium is governed by the specific absorption rate (SAR) and it is defined as [3] :

$$SAR = \frac{\sigma|E|^2}{2\rho} * I(t)\ . \qquad (2)$$

Where σ, E represent the electric conductivity and the electric field intensity respectively. *I(t)* represents the power envelope of the incident microwave pulse. So the right side of the equation (1) could be rewritten as $-\frac{\beta\sigma|E|^2}{2} * \frac{\partial}{\partial t} I(t)$.

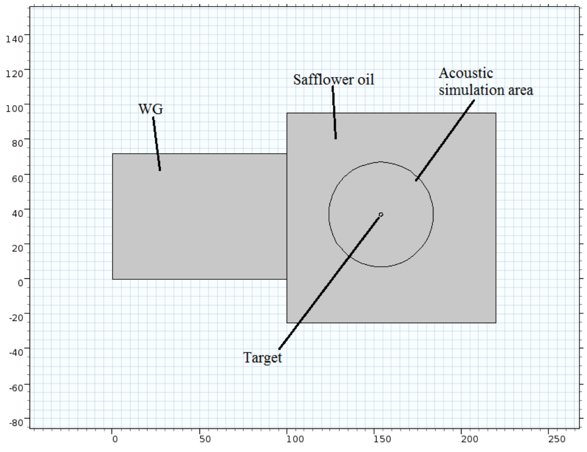

Fig.1: Simulation geometry

II. MODEL SETUP

The present simulation study is motivated by the current experimental setup in our lab and is a continuation of earlier simulation work done by our group [2]. The simulation model is created using a commercial software that is based on the finite element method (COMSOL Multiphysics 5.1). A 2-D approximation of the real experimental geometry is created as shown in Figure 1. The model consists of a WR-284 waveguide with a length of 70mm. This waveguide can operate from 2.6 to 3.95 GHz. The waveguide is fed with a 500 watt power source that can send variable width Gaussian pulses. The open-ended waveguide is used instead of horn antenna due to a narrower main beam in the near-field. The target is an organic compound of circular shape and radius of 1.2mm. The target properties can be found in [4]. It consist of a mixture of ethylene glycol (EG) with different concentrations of microbubbles. The target is immersed in safflower oil to enhance the ultrasound waves coupling to transducer. The safflower oil is chosen instead of water due its low microwave absorption (attenuation constant=0.009m^{-1}). The EM simulation is done for the whole geometry while the acoustic simulation is conducted in the circular area that surrounds the target only. In order to reduce the simulation size, absorbing boundaries are used to shield the simulation geometry of both electromagnetic and acoustic simulations. The simulation is conducted in two steps. The first step is an EM simulation in which microwave losses and absorption are calculated. The results of the first simulation are converted to act as an acoustic source in the acoustic wave simulation. The signals are then recorded by an omni-directional transducer positioned 3mm from the target.

III. SIMULATION RESULTS

Different system parameters are tested to achieve the best experimental setup. Figure 2 shows the effect of using different micro bubbles concentrations on the acoustic signal intensity, i.e. the effect of changing the permittivity and conductivity on signal intensity. As the bubbles concentration increases (permittivity and conductivity decrease), the signal intensity decreases. This happens because the microwave absorption is increased as the conductivity increases as shown in Eq. (2). Figure 3 shows the effect of changing the frequency from 2.8 to 3.9 GHz. The results shows that the signal increases as we increase the frequency but then start decreasing. The initial increment is due to the increase in microwave absorption with the microwave frequency. While the later drop in intensity is related to the fact that the microwave signal penetration ability is decreased with the increase of the frequency. The decrease is related to the increase of losses along the path of propagation. Figure 4 gives normalized results of the effect of changing the microwave pulse width on acoustic signal frequency. The results show that the acoustic wave's frequency is inversely proportional to pulse width, i.e. using shorter microwave pulses will result in higher acoustic frequencies.

IV. SUMMARY AND FUTURE WORK

A complete model of the generation of microwave-induced thermoacoustic signals was created. The results shows that acoustic signals intensity is increased with the increase of the microwave pulse frequency, but with a tradeoff that the penetration depth decreases as we increase the frequency. Increasing the material conductivity will result in an increase in the acoustic signal which mean good contrast for the material with high conductivity. So the image contrast is related to the contrast of electrical properties inside object. The results also shows that the decrease of the pulse width results in an increase in the frequency of the acoustic signal, which means better spatial resolution for shorter microwave pulses. Future work will focus on 2- D image reconstruction from observed signals from more complicated targets.

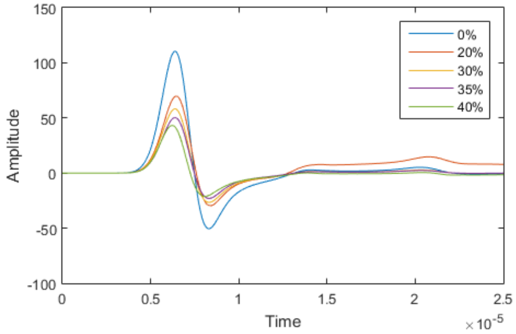

Fig.2. Signal variation with microbubbles concentration

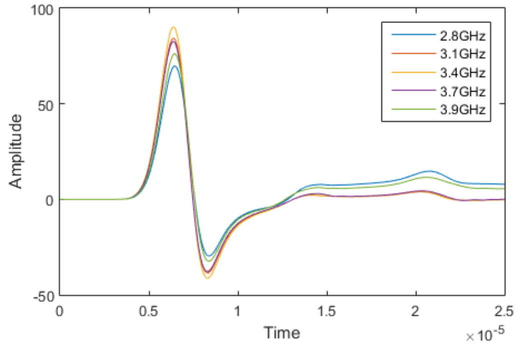

Fig.3. Signal variation with MW frequency

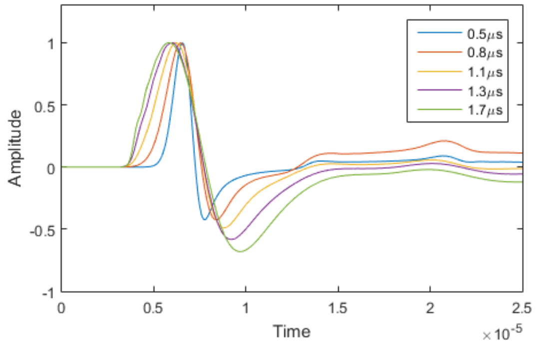

Fig.4. Signal variation with MW pulse period

REFERENCES

[1] Who.int, 2015. [Online]. Available: http://www.who.int/cancer/country-profiles/usa_en.pdf?ua=1. [Accessed: 22- Sep- 2015].

[2] Y. Deng and M. Golkowski, 'Innovative biomagnetic imaging sensors for breast cancer: A model-based study', *J. Appl. Phys.*, vol. 111, no. 7, pp. 07B323, 2012.

[3] Xiong Wang, D. Bauer, R. Witte and Hao Xin, 'Microwave-Induced Thermoacoustic Imaging Model for Potential Breast Cancer Detection', *IEEE Transactions on Biomedical Engineering*, vol. 59, no. 10, pp. 2782-2791, 2012.

[4] A. Mashal, J. Booske and S. Hagness, 'Toward contrast-enhanced microwave-induced thermoacoustic imaging of breast cancer: an experimental study of the effects of microbubbles on simple thermoacoustic targets', Physics in Medicine and Biology, vol. 54, no. 3, pp. 641-650, 2009.