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Microwave Dielectric Property Based Stage Detection of Skin Cancer

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Abstract

Inherent discrepancy of dielectric properties between biological tissues has drawn considerable interest for the last 30 years. Open-ended coaxial probe is one of the promising methods to measure dielectric properties due to the non-destructive and broadband measurement characteristics. The advances in this method will improve the diagnosis and treatment processes in the medical industry. The aim of this study is not only to determine skin tumors but also to identify the cancer stages with open-ended coaxial probes. This will aid rapid an inexpensive diagnosis of skin cancer. To this end, we simulated a 2.2mm diameter open-ended coaxial probe, which is commercially available, with three-layered breast skin tissue and tumors with fifteen different volumes using Altair FEKO simulation software. The S-parameters of each configuration is simulated in the range of 500 MHz to 2GHz. Based on the simulated S-parameters, the results indicate that the first stage and healthy tissue shows a difference of 11.46 % at 1.5GHz. Similarly, there is a difference of about 39.48 % between the second and third stage. Skin cancer is considered critical at the third stage, therefore having a distinctive difference between dielectric properties and thus between the S-parameter response when the probe is terminated with second and the third stage tumor tissue will help in the detection of early stage skin cancer.

1 Introduction

Many researchers have focused on developing diagnostic and therapeutic methods based on the inherent dielectric property discrepancy between biological tissues [1]. One potential source of discrepancy is the water content of the tissues is elevated due to the rapid metabolism of malignant cells, which leads malignant tissues to have higher dielectric properties than healthy counterparts. This inherent dielectric property discrepancy helped classification of malignant, benign and healthy tissues in various studies [2, 3]. Based on these studies, several microwave applications can emerge as a medical diagnostic equipment [4]. However, such measurements are mostly carried out under controlled conditions often with phantom materials undermining the possible error sources [5, 6]. One such error source is the heterogeneity of the material under test, a realistic scenario for biological tissues. Similarly, the skin cancer tissue is layered, heterogeneous and it grows while changing over time based on the stage of the cancer. Moreover, the dielectric properties can be effected from the surrounding tissue such as fat, muscle, healthy skin, bone. Therefore, there is a need to investigate the sensing depth of open ended coaxial probes and simulate the effect of the surrounding tissues to the response of the open ended coaxial probes. To explore the sensing depth and histology volume of the tissue Open-ended coaxial probe method was investigated in the literature. For instance, [7] used a two-layer structure comprised of a liquid and movable cylindrical part of Teflon and acrylic to determine the sensing depth of the open-ended coaxial probe while measuring the dielectric properties of a multilayered structure. In order to determine the dielectric properties of heterogeneous tissues, [8] examined the histology depth and [9] investigated histology radius. [10] examined the sensing radius with concentrically heterogeneous tissues and found out the increase of contrast in permittivity between the constituent tissues leads to an increase in the sensing radius. These studies indicate that histology volume and surroundings of the targeted sample have a significant effect on gathering correct dielectric property measurements from heterogeneous tissues. [11] studied the sensing volume of open-ended coaxial probes with 2.2 mm and 3.58 mm diameters that is used for measuring dielectric properties of breast tissues with in the frequency range of 1GHz to 20GHz. The minimum thickness and width to obtain accurate results for 3.58 mm-diameter probe were 3.0 mm and 1.1 cm. It was also concluded that the dimensions of sample under test must be 1.5 mm in thickness and 5 mm in width for 2.2 mm diameter probe. Although the reported work indicate some limitations on the dielectric properties, there is still limited consensus on the sensing depth of the open-ended coaxial probe. In this paper, we designed a simulation to examine five cancer stages of basal cell carcinoma (BCC) tumor occurring on breast skin with Altair FEKO. To simulate the breast skin tissue, a three-layered tissue structure consisting of dry skin, wet skin and breast fat was created. The results given in [12] were used to decide the thickness of each layer. During the simulation, the thickness of tumors were determined according to "Breslow Depth of Invasion" [13]. Since skin cancer proceeds in five stages [14], three different tumor depths were selected for each level. Moreover, different tumor widths were used for each stage. As a result, a total of 15 different simulations were performed and the S-parameters were collected. Thus, we aimed to determine the cancer stages by measuring the S-parameters obtained from tumors forming on skin tissue, which is very thin and composed of multiple layers. The rest of the paper is organized as follows; simulation details are explained in Section II, S-parameter results are given in Section III, and conclusions drawn in Section IV.

2 Methodology

The simulated geometry of the open-ended coaxial probe is based on the geometry of RG405 semi-rigid coaxial cable [7] with inner conductor diameter: 0.51 mm, dielectric material diameter: 1.68 mm (Teflon with relative permittivity ($\varepsilon_r = 2.08$)), and outer conductor diameter: 2.2 mm. The length of the probe is 200 mm and its designed to match around 50 Ω. Note that his probe is also commercially available. The probe was then terminated with only breast fat, dry skin, and wet skin. The probe was then terminated with a three layered tissue composed of a combination of skin and fat tissues. It can be seen from Fig. 1 the S_{11} response is effected from the permittivity and conductivity of the tissue terminating the probe.

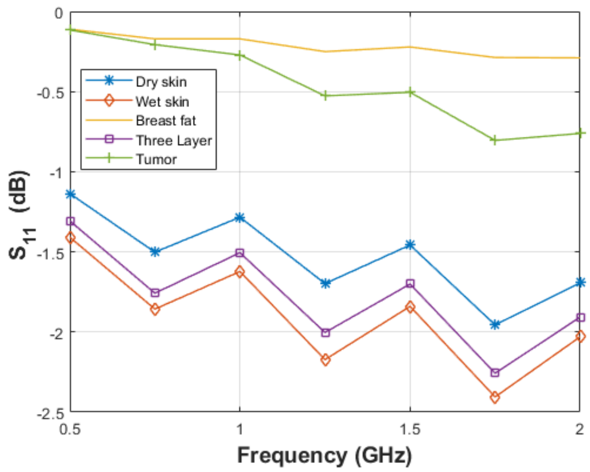

Figure 1. S_{11} response of the probe collected from the different simulated breast skin layers including breast fat, dry and wet skin as well as three layered tissue composed of skin and fat tissues.

A three layered tissue consisting of dry skin (epidermis), wet skin (dermis) and fat is designed to replicate some of the fundamental tissues present in the human skin. The thickness of the three layers was kept constant at 0.0769 mm for the dry skin (upper layer), 4.7171 mm for the wet skin (middle layer) and 9.4352 mm for the fat (bottom layer) as shown in Fig. 2b. To replicate the tumor growth in the skin, a conical shaped structure with varying diameters and lengths is inserted in the three layered structure from the dry skin to fat layer with different dimension representing various stages of skin tumor. The simulation is performed for five different stages of skin cancer. The diameters and lengths representing the five stages are given in Fig. 2a and Fig. 2b, respectively. The simulation configuration is shown in Fig. 2c . In each stage, three different lengths were selected while keeping the diameter of the tumor constant as the tumor grows from the dry skin layer towards the fat layer. A total of fifteen simulations were performed for the five stages with three simulation per stage.

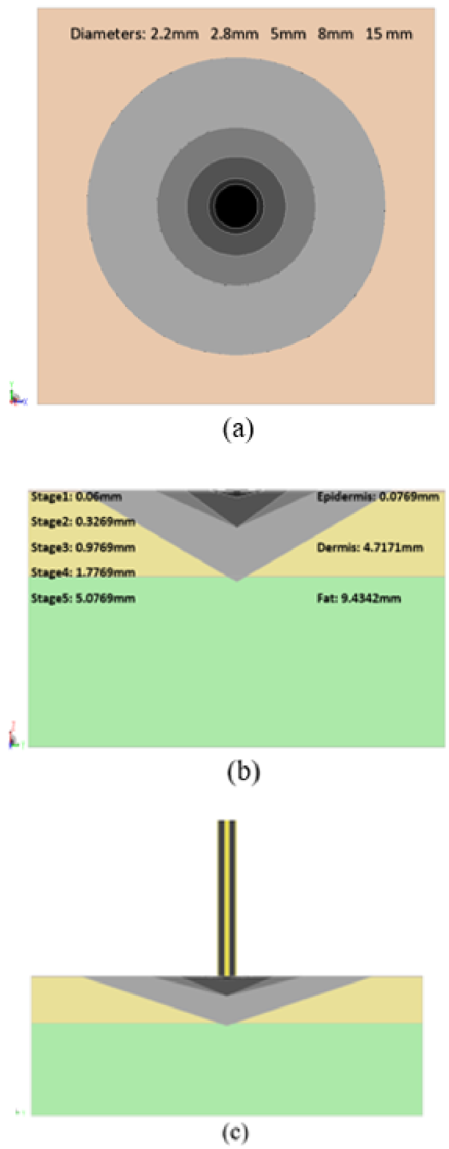

Figure 2. Simulation methodology: the three layer configuration of dry skin (epidermis), wet skin (dermis), fat layer and tumor stages; (a) top view of the tumor dimensions, (b) side view of the three layers with tumor stages, (c) position of the probe on the three layer configuration.

The design parameters for the skin layers, tumors and stages at 1.5GHz is tabulated in Table 1. Note that the simulations were perform from 500 MHz to 2 GHz with 250 MHz increments using FEKO simulation software. In order to reduce the simulation time, standard mesh sizes were implemented during the simulations.

Table 1. Design parameters of breast skin and skin tumor at 1.5GHz.

Tissue type	ε_r	σ (S/m)	Thickness (mm)	Area (mm^2)
Dry skin	38.86	11.49	0.0769	1600
Wet skin	47.12	8.97	4.7171	1600
Breast fat	4.93	0.8858	9.4342	1600
Tumor Stage1 Stage2 Stage3 Stage4 Stage5	45.89	2.56	0.06 0.3269 0.9769 1.7769 5.0769	3.80 6.15 19.63 50.26 176.71

3 Results

After the stage 3 of skin cancer the cancer spreads to other tissues named metastasis which is mostly irreversible; therefore, malignant tumor must be diagnosed before metastasis occurs. To enable a possible skin cancer diagnostic technology based on open-ended coaxial probes, there is need to account the size of the tumor which will affect the measured S_{11} response and thus the measured effective dielectric property. One of the main reasons for this is that the dielectric properties of the surrounding tissues affects the measurement results due to the sensing depth of the probe.The aim of this study was to analyze S_{11} response of the open-ended coaxial probe when terminated with thin layered and heterogeneous tissues. Therefore, three-layered breast skin tissue was simulated with 15 different tumor volumes. The dimensions of the tumors were decided based on cancer stages. Each level has three different thicknesses and a unique radius. The median of S_{11} response collected from three thicknesses at each level were obtained and shown in Fig. 3.

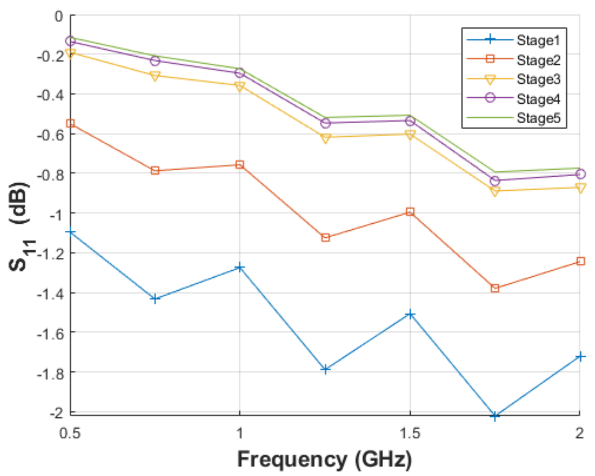

Figure 3. S_{11} measurements performed with each step of simulated breast skin layers.

The results indicate that the first stage and second stage BCC tumor tissue display different S_{11} response from dry skin, wet skin and tumor itself. The discrepancy between consecutive stages was calculated in Table 2. Even though last three stages have similar S_{11} response results, for these three levels, discrepancy in dielectric properties must be examined as well in the future work. Furthermore, the obtained S_{11} response will be used to calculate the relative permittivity and conductivity in future analysis.

Table 2. S-parameters of stages and discrepancy of each stage from the next stage at 1.5GHz.

Stages	S-parameters (dB)	Discrepancy (%)
Healthy	-1.701	11.46
Stage 1	-1.506	33.9
Stage 2	-0.995	39.48
Stage 3	-0.6021	11.34
Stage 4	-0.5338	4.98
Stage 5	-0.5072	-

4 Conclusion

Early detection of skin cancer is necessary to enable a successful treatment. One alternative technology is to measure the inherent dielectric property discrepancy between biological tissues which can be utilized to determine the malignancy of skin tumors as well as their stages. Skin cancer diagnosis is especially difficult since tumors occur on thin and multi-layer tissue. Moreover, it is quite difficult to determine the stages of these tumors. For this reason, we performed 15 simulations on 5 skin cancer stages on the breast skin, then collected S-parameters with the 2.2 mm open-ended coaxial probe method. The results indicate that first and second stages of malignant skin tumors were distinguished from other stages. Furthermore, discrepancy between malignant tumor at first stage and healthy tissue is 11.46% at 1.5 GHz. Therefore, successful implementation of open-ended coaxial probes can be utilized for determining both the malignant skin tumors and their stages. The future work includes performing experiments with phantom materials.

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