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The Effect of Limestone in Breast Cancer Detection by Microwaves

Emine AVŞAR AYDIN[*1]

[1]*Adana Bilim ve Teknoloji Üniversitesi, Havacılık ve Uzay Bilimleri Fakültesi, Adana*

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Abstract

Breast cancer is the most widespread type of cancer among women around the world. Initial stage cancer detection is the most important in terms of reproducing of the tumors in an uncontrolled way and spreading to the other organs. Microwave imaging method is relatively effective method compared to other tools which are X-ray mammography, Magnetic resonance imaging (MRI) and ultrasound. They have some shortfalls such as X-ray mammography suffers from high missed-detection and false-detection rates. Also, it is ionizing and uncomfortable compression of the breast. Because of this, microwave imaging method has the potential to overcome the some shortfalls of the X-ray mammography, MRI, and other existing known methods. In addition, Ultra-wide band (UWB) radar technique is a quite attractive technology for many applications, especially for early breast cancer detection. In this paper, both an UWB bow-tie antenna with enhanced bandwidth and a 3D breast model which has varied permittivity and conductivity is designed in CST software simulation tool to solve electromagnetic field values. Return loss and radiation pattern characteristics which are significant antenna parameters are simulated and obtained whether the antenna possess an efficient characteristic or not. Tumor cannot be detected by existing methods since there is limestone layer, which is occurred by milk ducts, surrounding of tumor. Therefore, limestone's effect on the tumor is studied in order to investigate the radiation from the skin with reference to whether there is limestone or not surrounding of tumor. Also, electric field and magnetic field values over the breast tissue with tumor or tumor which is surrounded by limestone, or without tumor, and limestone instead of tumor are evaluated. Limestone's effect is clearly observed when there is limestone surrounding of tumor or not. So, limestone is a crucial factor for breast cancer detection methods.

Keywords: Microwave imaging method, Rounded bow-tie antenna, Breast cancer, Limestone, Dielectric properties

Mikrodalgalarla Meme Kanseri Tespitinde Kireçtaşının Etkisi

Öz

Meme kanseri dünyada kadınlar arasındaki en yaygın kanser türüdür. Kanserin ilk aşamasındaki tespit, tümörlerin kontrolsüz olarak çoğalmasından ve diğer organlara yayılması açısından çok önemlidir. Mikrodalga görüntüleme yöntemi; X-ışını mamografi, Manyetik rezonans görüntüleme (MRG) ve ultrason gibi mevcut görüntüleme yöntemlerine nispeten etkili bir yöntemdir. Mevcut olan bu yöntemler örneğin X-ışını mamografisindeki yüksek-kaçırma ve yanlış algılama oranları gibi bazı eksikliklere

[*]Sorumlu yazar (Corresponding author): Emine AVŞAR AYDIN, *eaydin@adanabtu.edu.tr*

sahiptirler. Ayrıca, radyasyon yayıcı olması ve memeyi sıkıştırması rahatsızlık vericidir. Bu nedenle, mikrodalga görüntüleme yöntemi; X-ışını mamografi, MRG ve bilinen diğer mevcut yöntemlerin bazı eksikliklerinin üstesinden gelme potansiyeline sahiptir. Buna ek olarak, Ultra geniş bant (UWB) radar tekniği birçok uygulamada, özellikle erken meme kanseri tespiti için oldukça ilgi çekici bir teknolojidir. Bu makalede, gelişmiş/ultra bant genişliğine (UWB) sahip bir UWB bow-tie anteni ve çeşitli geçirgenliğe ve iletkenliğe sahip olan bir 3-boyutlu meme modeli, CST yazılım simülasyon programında, elektromanyetik alan değerlerini çözmek üzere tasarlanmıştır. Önemli anten parametreleri olan geri dönüş kaybı ve ışıma örüntü özellikleri simüle edilir ve antenin etkin bir karakteristik olup olmadığı elde edilir. Mevcut olan yöntemlerle, tümör etrafı süt kanallarından dolayı meydana gelen kireçtaşı tabakasından dolayı tespit edilememektedir. Bu nedenle, kireçtaşının tümör üzerindeki etkisi, tümörün çevresinde kireç taşı olup olmadığına bakılarak derideki radyasyonun araştırılması için incelenir. Ayrıca, meme dokusundaki tümörün kireçtaşı ile çevrili olup olmaması, tümörün hiç bulunmaması ya da tümörün yerine sadece kireçtaşının olması gibi tüm senaryoların elektrik alan ve manyetik alan sonuçları değerlendirilmektedir. Tümörün etrafını saran tabakada kireçtaşının olup olmadığı zamanlarda kireçtaşının etkisi açıkça görülmektedir. Sonuç olarak, kireç taşı meme kanseri tespit yöntemleri için çok önemli bir faktördür.

Anahtar Kelimeler: Mikrodalga görüntüleme yöntemi, Yuvarlaştırılmış bow-tie anten, Meme kanseri, Kireçtaşı, Dielektrik özellikler

1. INTRODUCTION

Although breast cancer is the most widespread cancer kind among women, initial diagnostic and effectual treatment can substantially improve the survival rate [1-10]. Also, to diminish the morality of this malady, it is to be uncovered starting when both the cancer is comparatively minor and has not diffuse to different organs of the body. Several methods, which are ultrasound, mammography, and magnetic resonance imaging (MRI), are being utilized for breast tumor detection. Nevertheless, there are numerous unsatisfactory features such as high rate of misidentification, ionizing radiation (mammography), high-priced, and so on. For example; mammography is the procedure of utilizing low energy X-rays to check up the human breast and is used as a diagnostic and a screening tool [3-4]. It has problems such as faulty negative ratios, high faulty positive ratios, and the ionizing radiation character of X-rays which exposures a substantial threat of creating intensity of the cancer it tries to identify, and also mammography is very expensive method. Because of this, in order to provide a reliable and more proper method than existing methods, Microwave Breast Imaging techniques have been developed by many researchers [1-9]. Microwave imaging modality proves to show an ability to be both susceptible and distinctive, to identify hidden or minor tumors, and to be cheaper than existing techniques such as MRI, ultrasound. Since microwave breast imaging depends on the electrical property discrepancies of breast tissues, this method has been become significant. Frequency range of the microwave is from 300 MHz to 300 GHz, and so wavelength ranging of microwave signal has from 1m to 1mm in free space. This means that these wavelengths are similar to dimensions of examined object such as tumor in human body. On the other hand, water is an important factor in terms of determining tissue permittivity [3-4]. For example; low water contain tissue has high permittivity than high water contain tissue. Since microwave imaging creates the images involved the dielectric properties of the breast tissue, the tissue with tumor, which contains higher water content than the normal tissue, is identified by using these images. While microwave imaging is easily applied on the breast, it is not applied on internal organs. The breast is outside, and so it is more accessible. At the same time, breast tissue is more diaphanous to microwaves than numerous organs such as muscle, kidney, bowel, lung etc.

According to technical and numerical simulation investigations, microwave imaging for breast cancer has been shown that it is feasible [2-4]. Many practical studies have been done for microwave breast cancer imaging system. One of the biggest challenges is antenna design for the researcher [2, 3, 6, 8]. Various antenna kinds have been designed for breast cancer detection scheme like vivaldi antenna, bow-tie antenna, horn antenna, stacked patch antenna, unipolar antenna, microstrip antenna. There are many merit and demerit of these antennas. Some of them are bulky, non-planar, costly, bidirectional radiation pattern, low efficiency, and low bandwidth.

In this paper, bow-tie antenna is designed for microwave imaging over detecting tumors into breast model and also, a simple 3D breast model is designed to characterize tumor tissue. Additionally, limestone's effect on the tumor is studied in order to investigate the radiation from the skin with reference to whether there is a limestone or not surrounding of tumor. Furthermore, tumor cannot be detected by existing methods since there is limestone layer, which is occurred by milk ducts, surrounding of tumor. Different simulations such as breast tissue with tumor or tumor which is surrounded by limestone, or without tumor, and limestone instead of tumor are implemented in CST Microwave Studio. Obtained simulation graphics are evaluated according to electric field and magnetic field values.

2. MATERIAL AND METHOD

2.1. Breast Structure

Throughputs are obtained from numerical breast phantoms which are occurred in CST Microwave Studio simulation tool for the UWB microwave imaging techniques [11, 12]. There have been varied breast phantom designs in the literature survey with the inclusion of cylindrical, hemispherical, and MRI-derived models. In this paper, a hemispherical breast is modeled as shown in Figure 1. There are diameters and thicknesses of breast model in Table 1. Also, the tumor radius size is 4 mm. Tumor is done as a spherical model and is put into the breast tissue (fibro glandular tissue). Structures such as skin, fatty breast tissue, tumor have different dielectric properties (permittivity, conductivity) have different electromagnetic field values. Discrepancies of dielectric properties provide opportunity for detecting of tumor. Table 2 shows the dielectric properties of these tissues [13]. Additionally, the proposed limestone's electrical properties are given as follows: ε_s=85.85 and ε_∞=5.49 [14].

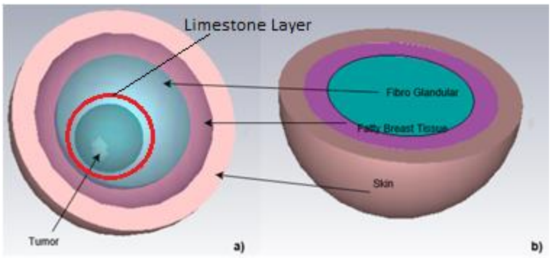

Figure 1. 3D Breast structure, a) top view b) side view

Table 1. Dimensions of breast tissues

Tissues	Radius	Thickness
Skin	8cm	2cm
Fatty Breast Tissue	6cm	2cm
Fibro Glandular	4cm	2cm
Tumor	4mm	-
Limestone	4.5mm	-

Table 2. Debye parameters at 6 GHz UWB centre frequency [13]

Tissues	ε_∞	ε_s	σ_s	τ(ps)
Skin	4.00	37.00	1.10	7.37
Fatty breast tissue	6.57	16.29	0.23	7.00
Fibro glandular	5.28	35.14	0.46	7.0
Tumor	3.99	54.00	0.70	7.23

2.2. Dielectric Properties of Breast Tissues

Microwave imaging depends on the dielectric properties of malignant tumor and surrounding tissues for breast cancer detection [15-22]. The dielectric properties of the tissues consist of two basic parameters called relative permittivity and conductivity. Relative permittivity and conductivity principally related on the electromagnetic properties of the electromagnetic wave interacting with a medium which can be different dielectric tissues such as skin, fat, fibro glandular, tumor for breast. Many investigations have shown that the content of water in a tissue is important owing to identify its relative permittivity. Tumor which has high water ratio has high relative permittivity according to fat tissue which has low water ratio. The storability of electromagnetic energy in the tissue correlates with the relative permittivity value of a tissue. Furthermore, the conductivity value of the tissue demonstrates the attenuation of microwave energy when the microwave interacts with it.

Microwave scanning technique for breast cancer diagnosis depends on large discrepancies in dielectric properties between normal and tumor tissues [15-19]. The dielectric properties of breast tissue in diversified frequency ranges have been studied by many different research groups, demonstrating that differences in the relative permittivity are sufficient for the microwave image.

It is known that the dielectric properties of the tissue such as permittivity and conductivity depend on frequency [23, 24]. To analyze the impact of an incident field in a body, it is needed to have models that describe the dependency on frequency of these parameters. There are many models such as Debye [13] and the Cole-Cole models [23, 24] which are frequently employed models. Debye model interests the dielectric behavior of water on the tissue at microwave frequencies and is modeled as a lossy resonant circuit. It is clear that the effect of dispersion is not taken into account from Debye model. The dispersion of the relaxation constant of the material has to take into consideration because of the complexity of the structure and composition of biological tissues. Therefore, a Cole-Cole model has been developed and is presented in Equation 1.

$$\varepsilon_r = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1+\left(j\omega\tau\right)^{1-\alpha}} \qquad (1)$$

where, α, ε_∞, ε_s and τ, are exponent parameter, infinite permittivity constant, static permittivity constant, and time constant.

2.3. Antenna Structure

The geometry of proposed UWB configuration is presented in Figure 2 [25]. The proposed antenna is printed on FR-4 substrate with dielectric permittivity 3.34 and thickness h=0.794mm. The length and width of proposed antenna equal to respectively 44mm and 24mm for perfect radiation efficiency. The antenna is fed by a coplanar waveguide, the width of the coplanar lines is wa=1.5mm, separated by a distance of 1mm. Additionally, the other geometrical parameters of the proposed antenna are shown in Figure 2: R2=1.7mm, O2 (3.7, 3.7), R3=6mm, and O3 (3.5, 6.6)mm. Any changes in antenna size affect the performance of antenna parameters. Therefore, any antenna size should be fixed by varying another antenna size in order to obtain bandwidth enhancement. The design parameters such as arm length, substrate width, feed gap, permittivity and flare angle are optimized to obtain better bandwidth and gain characteristics by antenna designers as in [13]. The bowtie antenna presented in this section has been designed using dimensions in Figure 2. CST Microwave Studio is used to simulate the model with bow-tie antenna and breast structure.

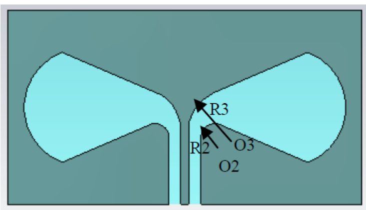

Figure 2. Proposed bow-tie antenna geometry with rounded ends and progressive feed line

Analysis of proposed antennas are carried out and presented in this section. Parameters which are analyzed are return loss and radiation patterns. The proposed antenna presents a multiband behavior. However, the simulated result for this antenna shows an impedance bandwidth from 2.05 to 2.11 GHz. These frequency ranges meet the requirements for UWB imaging systems which are especially used for early breast cancer detection. Additionally, the antenna patterns and S_{11} parameter, which is return loss, are the most important results. Figure 3 presents the matching interval of the designed bow-tie antenna. While Figure 4 shows the simulated 3D antenna pattern at the far field, Figure 5 shows the simulated gain radiation pattern.

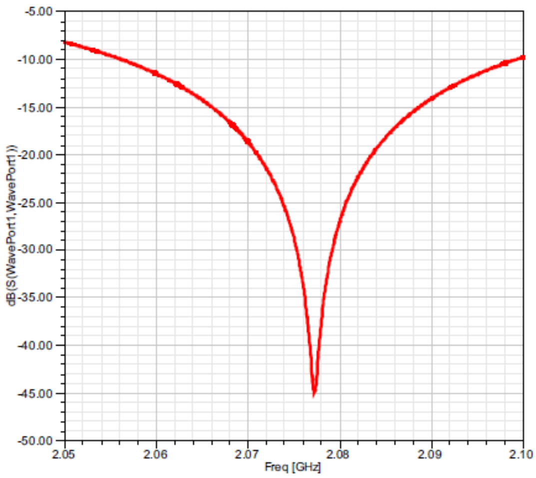

Figure 3. S11 parameter (return loss) of designed bow-tie antenna

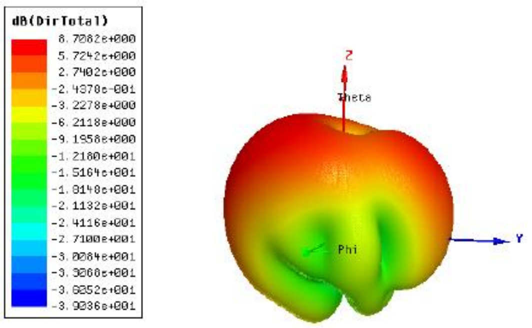

Figure 4. The simulated 3D antenna pattern at the far field

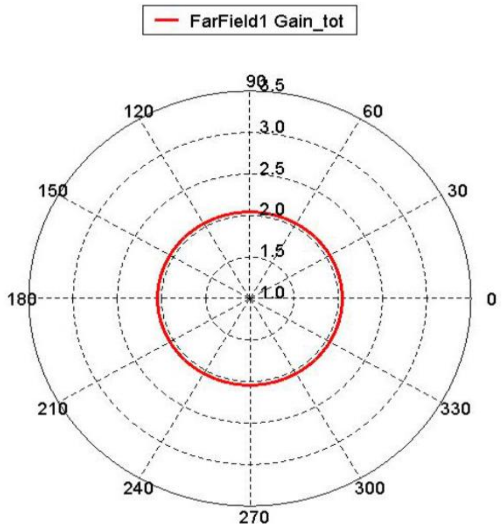

Figure 5. The simulated gain radiation pattern

3. SIMULATION RESULTS

The breast structure is simulated with an excitation signal from the bowtie antenna and the electric field and magnetic field values are obtained for tumor size which is 4mm in order to detect the cancerous cells. Additionally, it is observed that breast tissues with tumor or tumor which is surrounded by limestone, or without tumor, and limestone instead of tumor have slightly difference in the electric field and magnetic field. While Figure 6 illustrates the maximum electric field value of the breast tissue with tumor at given position (0, 5, 10.95), Figure 7 illustrates the maximum magnetic field value of the breast tissue with tumor. While Figure 8 illustrates the maximum electric field value of the breast tissue with tumor which is surrounded by limestone at given position (0, 5, 10.95), Figure 9 illustrates the maximum magnetic field value of the breast tissue with tumor which is surrounded by limestone. Figure 10 illustrates the maximum electric field value of the breast tissue with tumor which is surrounded by limestone at given position (0, 10, 12). On the other hand, probe position is not inside tumor. Figure 11 illustrates the maximum electric field value of the breast tissue with limestone instead of tumor at given position (0, 5, 10.95), Figure 12 illustrates the maximum magnetic field value of the breast tissue with limestone instead of tumor. Also, while Figure 13 illustrates the maximum electric field when the tumor structure is not inserted into the breast structure, Figure 14 illustrates the maximum magnetic field when the tumor structure is not inserted into the breast structure. Discrepancies between values of breast structure with tumor or tumor which is surrounded by limestone, without tumor, and limestone instead of tumor are clearly shown in graphics. After all, tumor in the breast model can be identified due to the electric field and magnetic field difference. Nevertheless, tumor cannot be detected by existing methods since there is limestone layer, which is occurred by milk ducts, surrounding of tumor. Limestone's effect on the tumor is seen when there is limestone surrounding of tumor or not. Therefore, microwave imaging is more effective method than existing methods in terms of limestone's effect. Additionally, the electric field and magnetic field values are obtained as possible as small.

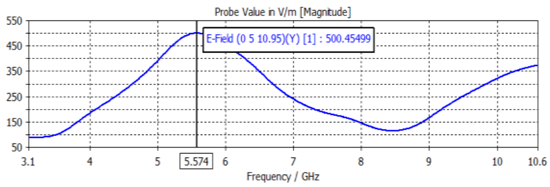

Figure 6. Graphic of electric field of breast tissue with tumor

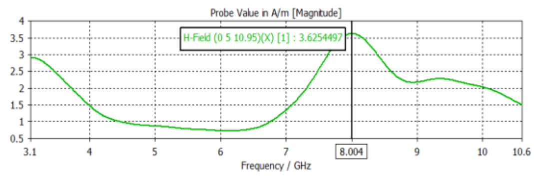

Figure 7. Graphic of magnetic field of breast tissue with tumor

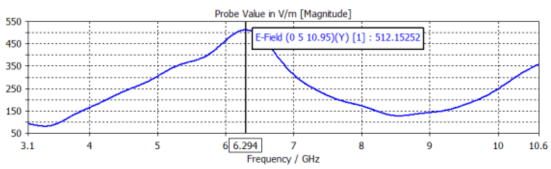

Figure 8. Graphic of electric field of breast tissue with tumor which is surrounded by limestone (Probe is inside tumor)

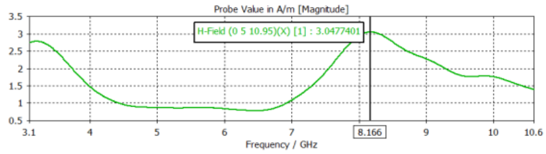

Figure 9. Graphic of magnetic field of breast tissue with tumor which is surrounded by limestone (Probe is inside tumor)

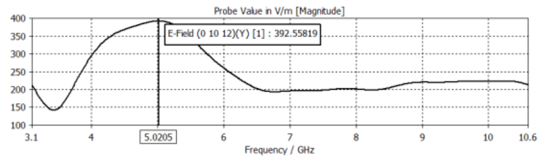

Figure 10. Graphic of electric field of breast tissue with tumor which is surrounded by limestone (Probe is not inside tumor, outside from tumor)

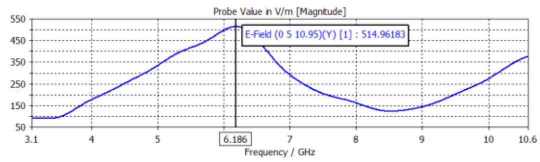

Figure 11. Graphic of electric field of breast tissue with limestone instead of tumor

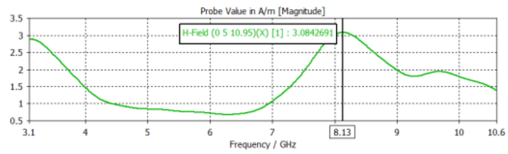

Figure 12. Graphic of magnetic field of breast tissue with limestone instead of tumor

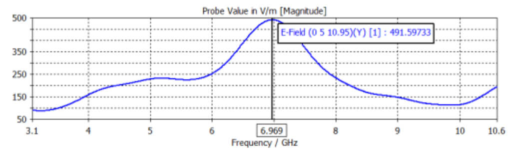

Figure 13. Graphic of electric field of breast tissue without tumor

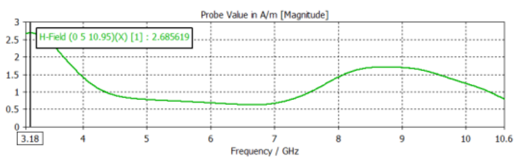

Figure 14. Graphic of magnetic field of breast tissue without tumor

4. CONCLUSION

In this paper, a bow-tie antenna is used to diagnose tumor due to its low profile, high bandwidth and omnidirectional radiation pattern. Firstly, a bow-tie antenna is designed in order to cover UWB frequency range (3.1-10.6 GHz). Secondly, a 3D breast structure, which is made up of skin layer, fatty layer, fibro glandular layer, limestone layer, and tumor is obtained. Then, this antenna structure and breast structure are simulated in CST software simulation tool both to diagnose the tumor cells and to investigate limestone's effect on the tumor. Finally, the electric field and magnetic field values are obtained with tumor or tumor which is surrounded by limestone, or without tumor, and limestone instead of tumor via CST commercial package. The values are acceptable for detecting breast tumor because of difference between them. Also, limestone's effect on the tumor is clearly shown when there is limestone surrounding of tumor or not. Therefore, microwave imaging is more effective method than existing methods in terms of limestone's effect. Consequently, limestone is an important factor in term of detecting tumor.

5. ACKNOWLEDGEMENT

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