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An Off-diagonal Feed Elliptical Patch Antenna with Ring Shaped Slot in Ground Plane for Microwave Imaging of Breast

S. Shekhawat[1,*], Pawan Kumar Jain[2], B.R. Sharma[2], V.K. Saxena[1], D. Bhatnagar[1]

[1] *Microwave Lab, Department of Physics, University of Rajasthan, Jaipur 302004, India*
[2] *Department of Physics, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur 302017, India*

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Being planar and having many applications of microstrip patch antennas, nowadays these also have applications in biomedical field (for detection of cancer). As EM radiations are hazardous so direct experiments on human body and EM radiation are impossible. So this paper is focused on a breast model to detect the presence of tumor inside it along with antenna structure as a radiation source. HFSS simulation software is used for designing and simulation part. Antenna is resonating at 2.46 GHz in frequency range 2.41-2.5 GHz of ISM band suitable for medical purpose. Two models, one of which has microstrip patch antennas along with breast model without tumor and the other with tumor, are designed and simulated, and their radiation properties are compared. For cancer detection near E-field results are important, so near E-field plots for both models are shown in this paper. The differences in these results of two models can be used to diagnose tumor.

Keywords: MIS, Diagnostic of Breast Tumor, Patch antenna.

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1. INTRODUCTION

Breast cancer is the most threatening disease occurring in the lives of women, also leads to a large number of deaths. But it can be cured if it is diagnosed early. The screening of breast cancer is a key to successful cure. Modern methods used for the diagnosis and treatment of breast diseases are based on the action on the tissue from radiation of various types: laser, ultrasonic waves, high-frequency current, and others, and include x-ray mammography, MRI, ultrasound, etc. [1-3]. X-ray mammography is commonly used for early breast cancer diagnosis but has many errors. A number of published reports deliberate that it gives direct exposure of radiation to patient; and false results are also very common in this technique [4-6]. During recent scenario microwave imaging is finding place as one of the most promising techniques in diagnosis as well as screening of breast cancer. It has many advantages like the use of non-ionizing radiation, non-invasive, sensitive to tumors, and low in cost. The principle behind the diagnosis of tumor in microwave imaging system consists in differences in electrical properties (conductivity, permittivity or dielectric parameters) of healthy and cancerous tissues at microwave range [7, 8].

In microwave breast imaging (MBI), low power and low frequency signals (compared to X-ray mammography) are used to obtain for ordered breast scanning. In the imaging systems based on microwave, an antenna is a significant element to irradiate the body under test with microwaves which travel through the body and then are detected by the other antenna working as a receiver. The receiver antenna contains the reflected information from tumors which are recorded and analyzed using suitable signal processing technique to get three-dimensional images of body under test. Microstrip antenna is one of the suitable types of antennas for use in Microwave Imaging System (MIS) as they are compact, conformal, low cost, light, easily designed and ease to fabricate. Several research groups from all over the world are working in this field. The performance of double layer and single layer patch antennas is checked, and it is proved that single layer patch structure is better candidate to be used in microwave imaging of breast return loss [9]. The inset fed antenna structure as a rectangular microstrip patch antenna is used, and a simple 3*D* breast structure is modelled for better understanding of cancer detection model [10]. A novel Multi-Ring Slots Ultra-Wide-Band (MRS-UWB) patch antenna that can be used for breast tumor detection is presented [11]. For radar based microwave imaging wide slot double sided microstrip antenna with fork feed has been presented [12]. A review on various geometries of microstrip patch antenna using FR-4 substrate resonating at various frequencies for MIS is also discussed [13].

2. EXPERIMENTAL DETAILS

It is a big challenge for researchers to design a compact size, low profile broadband antenna which can be efficiently used for imaging human body. In this paper, an off-diagonal microstrip line fed elliptical shaped microstrip antenna is proposed for microwave imaging system and for further check of its performance in active imaging system. A simple 3D breast structure with and without tumor is also modelled to diagnose cancerous tissue. HFSS simulator is employed for simulations. Antenna is designed for ISM band allotted for biomedical application. The designed antenna is resonating at 2.46 GHz in free space which is kept below breast model, and simulated maximum volume current density and maximum electric field results have been analyzed for cancer diagnosis. Step by step discussion

* sumita10shekhawat@gmail.com

is presented in this article. Section 3 explains basic antenna design with breast model with and without tumor, simulation and results of cancer diagnosis model and section 4 presents conclusions.

3. RESULTS AND DISCUSSION

3.1 Antenna Geometry

Off-diagonal feed elliptical patch antenna with defected ground plane structure is shown in Fig. 1 and Fig. 2 (top and bottom views). Microstrip feed line is applied for excitation of this antenna. Epoxy FR4 substrate of relative permittivity $\varepsilon_r = 4.4$, substrate thickness $h = 1.6$ mm and loss tangent of 0.025 is used to design antenna structure. The operating frequency of the antenna with complete ground is 2.9 GHz, a square shaped slot is cut on ground plane to shift operating frequency from 2.9 GHz to 2.46 GHz in Industrial Scientific Medical (ISM) band for medical applications. The performance of this elliptical patch antenna is simulated in free space by using HFSS simulator.

The dielectric properties of biological tissues are greatly influenced by change in the frequency spectrum because different tissues will absorb different quantities of microwaves [14, 15].

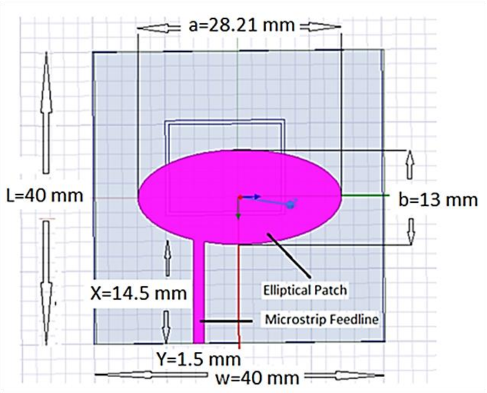

Fig. 1 – Elliptical patch with off-diagonal feeding (top view)

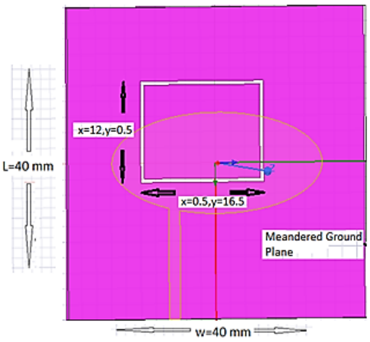

Fig. 2 – Geometry of meandered ground (bottom view)

Such electrical properties such as the electric conductivity (σ) and relative permittivity constant (ε) are also different for different tissues. Table 1 gives the dielectric properties of breast structure and tumor [16].

The dependency of permittivity and conductivity on frequency can be calculated by using following formulas [17]:

$$\varepsilon_r = 1.71.f^{-1.13} + 4 + \frac{\varepsilon_s - 4}{1 + \left(\frac{f}{25}\right)^2}, \qquad (3.1)$$

$$\sigma = 1.35.f^{0.13}.\sigma_{0.1} + \frac{0.0222.(\varepsilon_s - 4).f^2}{1 + \left(\frac{f}{25}\right)^2}. \qquad (3.2)$$

Table 1 – Dielectric and conductivity values of breast tissue at 2.45 GHz frequency

Tissue type	Permittivity	Conductivity, S/m
Normal breast tissue	9	0.4
Breast skin	36	1.46
Cancerous breast tissue	50	2.1

3.2 Diagnose Models

Using the above mentioned dielectric properties we have designed breast model implemented in HFSS simulator. Breast model is designed in the form of conical shape having two cones. Outer cone is designed taking lower radius 0 mm, upper radius 90 mm and height 70 mm which acts as breast skin. Inner cone is designed taking lower radius 0 mm, upper radius 85 mm and height 70 mm which acts as normal breast tissues without tumor which is placed at 11.67 mm distant from microstrip antenna. In order to diagnose tumor we have modelled breast structures with tumor. To design tumor we have embedded a sphere of radius 5 mm with the same dielectric properties as tumor (relative permittivity 50 and conductivity 2.1).

In this section the effect of radiation on breast model is discussed. We have simulated the complete model with and without tumor at a frequency of 2.46 GHz. The reflection coefficient of the microstrip antenna without breast model, with breast model having tumor and without tumor is shown in Fig. 3. It can be clearly observed that there is no change in operating frequency, it is almost the same in all three cases, but the reflection coefficient decreases from – 41 dB to – 17.46 dB which is considerable.

Volume current density for breast in the absence of tumor and with tumor in breast is shown in Fig. 4 and

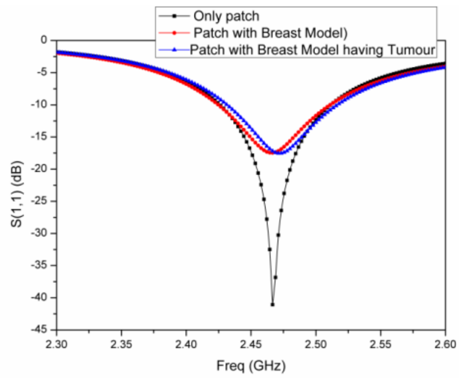

Fig. 3 – Variation of reflection coefficient with frequency

Fig. 5 respectively. The maximum volume current density of the breast with tumor increases as compared to that without tumor from 160.14 A/m² to 276.49 A/m² respectively. Also the maximum electric field is also measured for both cases. The results for maximum electric field and volume current density for both cases are mentioned in Table 2.

From Table 2 it is clear that the maximum volume current density and maximum electric field for the breast with tumor are more in comparison to without tumor. In both cases the near electric (E) field of 2*D* pattern for azimuth plane is shown in Fig. 6.

It was found that at all angles near E-field for breast with tumor is more than that for breast without tumor. Thus, radiation properties of both models differ a lot and give a clue to detect the presence of tumor inside breast.

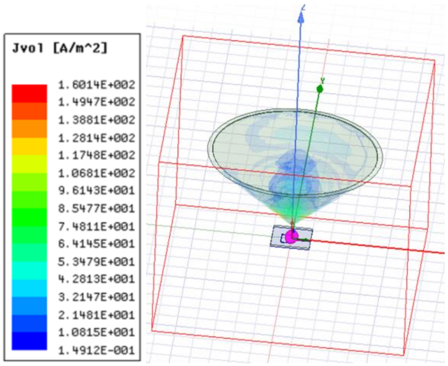

Fig. 4 – Volume current density distribution in breast without tumor

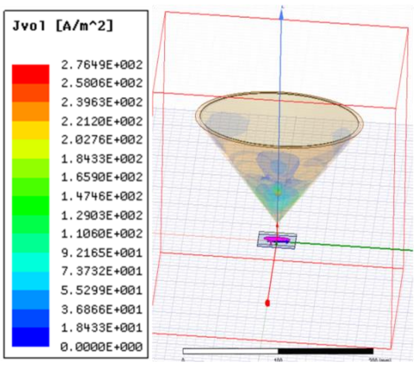

Fig. 5 – Volume current density distribution in breast with tumor

Table 2 – Comparison of electric properties for designed cancer diagnosis model with and without tumor

Model	Resonating frequency, GHz	Maximum electric field, V/m	Maximum volume current density, A/m²
Antenna with breast model without tumor	2.4667	202.63	160.14
Antenna with breast model having tumor	2.4733	264.25	276.49

It is important to measure the Specific Absorption Rate (SAR) value, which was calculated using the simulation software and is shown in Fig. 7. The maximum SAR value for this antenna is 0.843 W/kg at 2.46 GHz frequency which is below the desired range of allowed SAR value (1.6 W/kg).

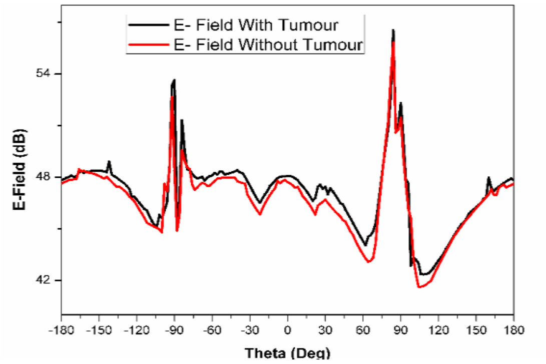

Fig. 6 – Near E-field variation with theta at *phi* = 0 for the two models

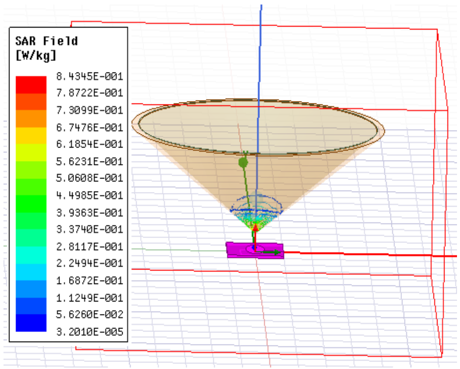

Fig. 7 – Simulated SAR value for the proposed antenna at 2.46 GHz when it exposed breast model

4. CONCLUSIONS

In this study we have designed a cancer diagnosis model of tumor present in breast by using HFSS simulator. The simulated results explain that in spite of having small more variation in resonating frequency, the maximum volume current density and maximum electric field for breast model with tumor are more than breast model without tumor. It is also shown that for all values of theta the near E-field result for tumor breast is more than that for tumor free breast. These results have a good approach to the detection of tumor inside the breast. Also, the SAR value is well below the allowed range. So, from these results we can say that the designed antenna structure can be used as a suitable candidate for active microwave imaging system as a transceiver as well as a receiver. But in spite of having good simulation results, it is very difficult to test the antenna performance practically as we have to make human phantom with three different dielectric layers (breast skin, normal tissues and cancerous tissue), and human phantoms are generally in the form of jell or liquid. So, more studies have to be planned to obtain the measured results for this cancer diagnosis model.

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Вертикальна еліптична смугова недіагональна антена з кільцевим отвором для мікрохвильового зображення молочної залози

S. Shekhawat[1], Pawan Kumar Jain[2], B.R. Sharma[2], V.K. Saxena[1], D. Bhatnagar[1]

[1] *Microwave Lab, Department of Physics, University of Rajasthan, Jaipur 302004, India*
[2] *Department of Physics, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur 302017, India*

На сьогоднішній день мікросмугові антени також мають застосування в біомедичній галузі (для виявлення раку). Оскільки електромагнітне випромінювання небезпечне, то прямі експерименти на людському тілі неможливі. Таким чином, ця стаття зосереджена на моделі молочної залози, щоб виявити наявність пухлини всередині неї, разом зі структурою антени як джерела випромінювання. Програмне забезпечення HFSS використовується для проектування та моделювання. Антена резонує на частоті 2,46 ГГц у діапазоні частот 2,41-2,5 ГГц , що підходить для медичних цілей. Дві моделі, одна з яких має мікросмугові накладні антени разом із моделлю молочної залози без пухлини, а інша з пухлиною, розроблені та моделюються, і порівняно їх радіаційні властивості. Для виявлення раку є важливими результати поблизу електричного поля, тому в роботі показані графіки поблизу електричного поля для обох моделей. Відмінності в цих результатах двох моделей можуть бути використані для діагностики пухлини.

Ключові слова: MIS, Діагностика пухлин молочної залози, Смугова антена.