UWB Sierpinski Fractal Antenna for Breast Tumour Detection Using SAR

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Abstract — Breast tumour is the most common tumour in the world and one in eight women is likely to develop breast tumours. Survival rate is higher only when the tumour is detected at the early stages. The various methodologies currently available to detect breast tumour are ultrasound, MRI, X-ray mammography etc. But these methods are not cost effective and have other reliability issues. In this paper, tumour is detected by passing microwave signals into the homogeneous breast model by designing an Ultra-Wideband (UWB) Sierpinski fractal micro strip patch antenna (MSA) with reduced ground. SAR (Specific Absorption Rate) calculation helps to find the presence of tumour. The antenna characteristics are studied using CST studio suite 2017 software. Sierpinski fractals and reduced ground are used to achieve UWB and enhance bandwidth. The preferred antenna provides a bandwidth width of 9.71 GHz (2.79 - 12GHz).

Keywords: Breast tumour; women; microwave imaging; microstrip patch antenna;

1. Introduction

Breast Tumour is the most common disease in Women. Though we have various techniques to diagnose it, several researchers are attracted towards UWB Microwave Imaging because it is non-ionizing, non-invasive and safe for patient in detecting the Breast tumours[1,2] When a microwave signal is exposed to breast tumour tissue it reveals the electrical properties that are different from healthy tissue. Scattering parameter of the normal and malignant tissue exhibits huge variation and it collects the tumour size, location, shape and electrical properties[3,4]. When a normal tissue is affected by tumour it increases the water content level in the tumour and it is proportional to the electrical energy stored in the tissue[9,10].

This work deals with the design of a breast model and an UWB Sierpinski fractal antenna designed and simulated. EM waves are passed through the breast tissues and identifying the tumour using Specific Absorption Rate (SAR) [5,6,11]. The fractal antenna operating at Ultra-wide band can be used for diagnosing breast cancer there by eliminating the currently used clinical methods[7,8]. Since the proposed method is of low cost, does not involve harmful ionising radiations, radiation efficiency is more, the antenna size used is small it can be considered as a potential replacement for the existing methods[13]. Here the focus is given only on the design of the antenna. The UWB Sierpinski Fractal antenna with the breast phantom consisting of tumour is designed and the SAR values for various positions of the tumour and various distance between the breast phantom and antenna is obtained.

2. Models

2.1. Antenna Design
The proposed antenna is designed and simulated using computer simulation Technology (CST) software. We have considered circular patch and its radius is been calculated using the Equation (1) and (2).

\[ a = \sqrt{1 + \frac{2h}{\pi r^2} \left[ \ln\left(\frac{2h}{\pi r^2}\right) + 1.7726\right]} \quad \text{(1)} \]

where \( a \) is radius of the circular patch in cm, \( h \) and \( \varepsilon_r \) are thickness and dielectric constant of substrate in cm and

\[ F = \frac{0.791 \times 10^9}{f_r \varepsilon_r} \quad \text{(2)} \]

\( f_r \) - Resonant frequency of the antenna

By substituting the values in above equations, the calculated radius is 10mm and \( f_r \) is 8.7 GHz. The width of the ground is reduced to 9mm. The antenna parameters are listed below in the table 1.

| Antenna parameters | Material used | Dimensions (mm) | Thickness (mm) |
|--------------------|---------------|-----------------|----------------|
| Ground plane       | Copper (annealed) | L=9, H=40      | 0.036          |
| Substrate          | Fr-4 (lossy)  | L=9, H=40      | 1.6            |
| Circular patch     | Copper (annealed) | R=10           | 0.036          |

where \( L \) is length, \( H \) is height and \( R \) is radius of the antenna parameter. The dielectric constant of the substrate material is 4.3.

Further to increase the antenna performance, Sierpinski fractals is been introduced in the circular patch. Due to the presence of repeating or iterating structures of various sizes in the patch, the current circulating path increases which in turn increases the amount of radiation from the antenna. Thereby the gain of the antenna increases. In our design we have included three iterations of fractals, i.e., there are three sizes of fractals present in the circular patch. The shape of the fractal is also circular, and the radius of the first iteration is 2.5mm in the centre, the radius of the second iteration is 2mm and the third is 1mm. The resulting antenna is shown in figure 1.

![Figure 1. UWB Sierpinski fractal antenna with reduced ground (a) Front view (b) Back view](image)

The S11 reflection coefficient plot for the designed antenna is shown in figure 2.
Here we have considered the regions with the return loss less than -10dB so that the VSWR value is between 0 to 2 which is ideal for an antenna operation.

2.2. Breast Model with Tumour

The breast model used here is a homogenous consisting of two layers. Usually the actual breast consists of many layers like skin, fat, glandular tissues, nerves, mucous etc. [12,14]. Since it is difficult to model all the layers of the breast and still researches are being carried out regarding the modelling of breast with all the layers with their exact properties for microwave imaging purpose, we have chosen only the homogenous model of 40mm radius consisting of only skin and fat. The thickness of the outer layer skin is 2mm and remaining 38mm is fat.

In figure 3, The homogeneous breast model of radius 40mm with tumour of 6mm radius located 10mm away from the antenna is shown. The structure which is denoted in red colour is the tumour or malignant tissue and its electrical and dielectric properties are given in table 2 along with skin and fat layer.
Table 2. Electrical properties of Skin, Fat and Tumour

| Layers  | σ (S/m) | ρ (kg/m³) | ε  |
|---------|---------|-----------|----|
| Skin    | 0.003   | 1059.9    | 3.5|
| Fat     | 0.012   | 900       | 2.36|
| Tumour  | 2.57    | 1559.23   | 23 |

From the table 2, σ is conductivity, ε is permittivity (F/m) and ρ is material density of each layer of the phantom.

The electrical and the dielectric properties of the breast model chosen here are similar to the electrical and dielectric properties of the actual breast tissues.

3. Results and Comparisons

3.1. Tumour Detection

SAR (Specific Absorption Rate) is a parameter that is the basis for the maximum permissible exposure in biological tissue under electromagnetic field. It is a measure of maximum electromagnetic energy absorbed by breast tissue, such as skin, fatty breast tissue. SAR values for the normal breast model and for the abnormal breast model with tumour can be calculated and compared to find the presence of tumour in the breast with its exact location.

The 1g averaged SAR values for breast model of radius 40mm without tumour at various frequencies where the distance between the antenna and the breast model is 10mm is given in table 3.

Table 3. 1g averaged SAR values at different frequencies for homogenous breast model without tumour

| Frequency [GHz] | Total SAR [W/kg] | Max. SAR [W/kg] | Maximum at (x, y, z) | Absorbed power [W] |
|-----------------|------------------|------------------|----------------------|--------------------|
| 3.5             | 0.127            | 0.366            | -0.125, 1.625, 17.744| 0.0423             |
| 5.5             | 0.124            | 0.413            | 0.125, 6.875, 17.744 | 0.0564             |
| 6               | 0.121            | 0.397            | 8.125, 7.875, 19.512 | 0.0632             |
| 7.8             | 0.0869           | 0.266            | 19.864, 19.615, 35.419| 0.0743             |
| 8.7             | 0.067            | 0.202            | -13.673, 7.875, 21.279| 0.0824             |
| 10              | 0.0567           | 0.173            | 14.4181, 23, 31      | 0.0986             |

Table 4. 1g averaged SAR values at different frequencies for homogenous breast model with tumour at position (0,0,20)

| Frequency [GHz] | Total SAR [W/kg] | Max. SAR [W/kg] | Maximum at (x, y, z) | Absorbed power [W] |
|-----------------|------------------|------------------|----------------------|--------------------|
| 3.5             | 0.225            | 9.152            | -0.125, -0.375, 18.833| 0.0547             |
| 5.5             | 0.221            | 12.964           | 0.125, 0.125, 20.5   | 0.0695             |
| 6               | 0.206            | 10.357           | -0.125, 0.375, 20.833| 0.0738             |
| 7.8             | 0.123            | 4.321            | 0.125, 0.875, 20.833 | 0.0792             |
| 8.7             | 0.0872           | 2.336            | 0.125, 0.375, 20.5   | 0.0846             |
| 10              | 0.0731           | 1.777            | 0.125, -0.375, 20.5  | 0.101              |
Similarly, the 1g averaged SAR values for breast model of radius 40mm and with tumour of size 6mm placed at position (0,0,20) from the UWB antenna for various frequencies is given in table IV. By comparing the table, there is an increase in the SAR values at the location of tumour in abnormal breast model since the dielectric constant of the tumour is higher than the dielectric constant of the normal breast tissues. This indicates that due to the presence of tumour the absorption rate increases.

3.2. Varying the tumour size and location

By varying the tumour size, the 1g averaged SAR is calculated for breast model of radius 40mm containing the tumour located at (-20,0,20). The size of the tumour taken for calculating the 1g averaged SAR are 4 mm, 5 mm, 6 mm. The frequency range considered for SAR calculation is ultra-wide band frequency 3GHz to 12 GHz. Here the distance between the antenna and breast model is 10 mm. Table 5 shows the SAR calculation for the above parameters.

Table 5. Detection of different sizes of tumour located at (-20,0,20) in 40mm homogeneous breast model at different frequencies

| Frequency [GHz] | 4 mm Tumour max. SAR [W] | 4 mm Tumour max. SAR at (x, y, z) | 5 mm Tumour max. SAR [W] | 5 mm Tumour max. SAR at (x, y, z) | 6 mm Tumour max. SAR [W] | 6 mm Tumour max. SAR at (x, y, z) |
|-----------------|--------------------------|-----------------------------------|--------------------------|-----------------------------------|--------------------------|-----------------------------------|
| 3.5             | 0.830                    | 22.2, -14.5, 34.2                 | 1.96181                  | 22.8, -15.2, 34.8                 | 3.721                    | 22.8, -15.2, 33.8                 |
| 5.5             | 1.121                    | 22.2, -14.2, 34.5                 | 3.265                    | 23.2, -14.8, 34.8                 | 3.687                    | 23.5, -14.8, 35.5                 |
| 6               | 0.748                    | 22.8, -14.2, 34.2                 | 1.715                    | 23.2, -14.8, 35.2                 | 2.061                    | 23.2, -14.5, 36.2                 |
| 7.8             | 2.237                    | 22.5, -14.8, 35.8                 | 2.963                    | 22.8, -14.8, 35.2                 | 3.098                    | 22.5, -14.8, 34.8                 |
| 8.7             | 1.771                    | 23.2, -14.2, 35.8                 | 2.743                    | 22.8, -14.8, 35.2                 | 3.019                    | 22.5, -14.5, 35.5                 |
| 10              | 1.285                    | 23.8, -13.9, 34.2                 | 2.186                    | 23.2, -14.8, 35.2                 | 2.206                    | 23.5, -14.2, 34.2                 |

Table 6. Detection of different sizes of tumour located at (23, -15, 35) in 40mm homogeneous breast model at different frequencies

| Frequency [GHz] | 4 mm Tumour max. SAR [W] | 4 mm Tumour max. SAR at (x, y, z) | 5 mm Tumour max. SAR [W] | 5 mm Tumour max. SAR at (x, y, z) | 6 mm Tumour max. SAR [W] | 6 mm Tumour max. SAR at (x, y, z) |
|-----------------|--------------------------|-----------------------------------|--------------------------|-----------------------------------|--------------------------|-----------------------------------|
| 3.5             | 1.636                    | -19.1, -0.4, 20.7                 | 3.448                    | -19.9, -0.1, 19.5                 | 6.144                    | -19.01, -0.4, 18.5                |
| 5.5             | 3.522                    | -19.1, 0.9, 20.7                  | 10.675                   | -19.9, 0.1, 19.8                  | 10.256                   | -19.6, 0.6, 20.2                  |
| 6               | 4.617                    | -19.1, 0.9, 20.1                  | 10.002                   | -19.9, 0.1, 19.8                  | 10.997                   | -19.9, 0.6, 20.2                  |
| 7.8             | 4.924                    | -19.4, 0.4, 20.7                  | 7.618                    | -20.1, -0.1, 19.8                 | 8.364                    | -20.1, -0.4, 19.8                 |
| 8.7             | 4.040                    | -19.9, 0.6, 20.7                  | 6.289                    | -19.9, -0.1, 20.2                 | 6.999                    | -19.6, -0.4, 20.5                 |
| 10              | 4.431                    | -19.1, -0.1, 20.1                 | 5.284                    | -19.9, -0.1, 20.2                 | 5.302                    | -19.1, -0.6, 19.1                 |
Now the location of the tumour in the breast model is changed and the corresponding SAR values for the respective tumour sizes are calculated. The table 6 shows the 1g averaged SAR for tumour sizes 4 mm, 5 mm and 6 mm located at (23,-15,35) when the distance between the antenna and breast model is 10 mm. From this, we can infer that the SAR values have been reduced, when the tumour is located at (23,-15,35) compared to when located at (-20,2,20) for the same frequency. This is due to the increase in distance between antenna and the tumour.

3.3. Varying the radius of breast model

Table 7 shows the SAR1g calculated for the breast model with tumour at different frequencies by varying the radius of the breast like 40mm, 50mm and 60mm. The tumour is located at (0,0,20) for all the radii. We can infer from the table 7 that the absorbed power increases as the size and mass of the breast increases at various frequencies.

Table 7. 1g averaged SAR for abnormal breast by varying its radius

| Frequency [GHz] | Radius 40mm | Absorbed power [W] | Radius 50mm | Absorbed power [W] | Radius 60mm | Absorbed power [W] |
|----------------|-------------|--------------------|-------------|--------------------|-------------|--------------------|
| 3.5            | 9.152       | 0.0547             | 8.436       | 0.0567             | 9.073       | 0.0669             |
| 5.5            | 12.964      | 0.0695             | 13.799      | 0.0778             | 11.391      | 0.0826             |
| 6              | 10.357      | 0.0738             | 12.480      | 0.0812             | 13.909      | 0.0905             |
| 7.8            | 4.321       | 0.0792             | 4.050       | 0.0846             | 3.393       | 0.0896             |
| 8.7            | 2.336       | 0.0846             | 3.667       | 0.0916             | 5.116       | 0.0996             |
| 10             | 1.777       | 0.101              | 1.592       | 0.104              | 2.288       | 0.1112             |

3.4. Varying the distance between the antenna and breast model

Table 8 shows the SAR1g calculated for the breast model with tumour at different frequencies by varying the distance between antenna and the abnormal breast model. The various distances between the antenna and breast model taken for calculation is 10 mm, 15 mm, 20 mm. Here the tumour is placed at centre and the coordinates of the tumour is (0,0,30) and the radius of the tumour is 4 mm. The radius of the abnormal breast is 40 mm.

Table 8. 1g averaged SAR for abnormal breast by varying the distance between antenna and the breast model

| Frequency [GHz] | Distance 10mm | Absorbed power [W] | Distance 15mm | Absorbed power [W] | Distance 20mm | Absorbed power [W] |
|----------------|---------------|--------------------|---------------|--------------------|---------------|--------------------|
| 3.5            | 1.52          | 0.0433             | 1.456         | 0.0403             | 1.229         | 0.0374             |
| 5.5            | 3.004         | 0.0583             | 2.427         | 0.0544             | 1.652         | 0.0599             |
| 6              | 2.639         | 0.0657             | 1.758         | 0.0602             | 1.153         | 0.0556             |
| 7.8            | 0.720         | 0.0749             | 0.464         | 0.0703             | 0.347         | 0.0674             |
| 8.7            | 0.293         | 0.0826             | 0.251         | 0.0787             | 0.442         | 0.0768             |
| 10             | 0.604         | 0.0993             | 0.783         | 0.0947             | 0.602         | 0.0926             |

4. Conclusion

The designed UWB Sierpinski fractal antenna is used to detect the breast tumour. Since the size of the antenna is just 40 mm that is just 4 cm, it can be concluded that it is the best antenna for breast tumour detection. With the simulated data, it can be clearly seen that the SAR and the absorbed power values are higher in a tumour infected breast and these values increase as the mass of the breast
increases. The maximum SAR values also decrease if the tumour is located deep inside the breast. The coordinates of the maximum SAR values can be used as an indication for the location of a tumour. Further with the increase in the distance between the antenna and the breast model, the absorbed power also decreases. In future, the proposed work can be expanded and studied under various potential areas such as increasing the number of iterations, using heterogeneous breast model, and increasing the number of tumours.

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