https://doi.org/10.36375/prepare_u.iei.a185

A Novel RDRA for Primitive Detection of Breast Cancer in Women for Varying Mammographic Densities

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Abstract
Demand for efficient sensors have increased due to evolution of 5 G and IoT technologies. Sensors are labelled as prominent tools to analyze biological and physiological parameters of breast cancer patients for prognosis and diagnostic purposes. Currently, wide band radio frequency sensor based technology is gaining momentum for primitive stage breast cancer detection. In this research work, a RDRA is proposed as key sensor part which leads to design of smart data acquisition system. Rectangular DRA resonates for a frequency range of 2.9-4.7 GHz (48% Impedance bandwidth) which lies in the Lower European frequency band. Peak gain of 4dB is obtained through proposed antenna. High radiation efficiency, compact size of the antenna makes it perfectly suitable to be employed as a sensor for early breast cancer detection. Proposed antenna can be integrated with wide band wireless communication for Wi-Fi and LTE communication and Wireless Body Area Networks (WBAN) applications as well.

Keywords- *Rectangular Dielectric Resonator Antenna (RDRA), Breast Cancer Detection, Wide band, High Gain, Sensors.*

1. Introduction

Breast cancer is the major cause for mortality in women. WHO has reported that 2.10 million women are being affected each year globally? Breast screening is considered to be one of the most common types of cancers detected among women. Presently, about 2.10 million women are being affected each year globally and having high mortality rate. Breast screening at early stages of bin every four minutes breast tumor, cancer or cyst is a significant step in prognosis. Statistics of India highlights the fact that a woman is diagnosed with breast tumor in every four minutes [2-3]. Prudent early screening systems makes survival rate 90% in USA which is quite high in comparison of 60% in India. Early detection not only provide better healthcare but also ensures well-defined treatment and protocols**.**

Techniques used for the detection of breast cancer are X-ray mammography which suffers from uncomfortable compression of breast and unnecessary follow-ups [4-5]. Moreover, false positive test results make this technique a cumbersome job to perform. Ultra sound is another technique used for breast cancer detection. Low resolution obtained through this process makes it a secondary choice. Magnetic Resonance Imaging is another cancer detection method which is efficient but costly that’s why it is considered as pre-surgery procedure only [6]. PET is the acronym for positron emission tomography in which a radioactive liquid is mixed with glucose or glycoprotein and injected in soft tissues of breast. Nutrients gets absorbed via tumor tissues and positrons are ejected. Mapping of these tissues provides us image for tumor in breast [4]. This process also suffers from low resolution.

Microwave imaging is emerging as a new technique to find location and size of the tumor. It makes use of electromagnetic waves which are transmitted towards the affected area and retrieve those reflected and scattered radio waves to identify shape and size of tumor [7]. Two types of microwave imaging techniques are currently in use. First is Microwave Tomography (MT) which makes use of inverse scattering algorithm to process the affected area image [8]. This process is time consuming and complex due to time taken to produce output. Ground penetrated RADAR based approach is technically the most simple

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and robust way to find out location of tumor in the breast. In this technique, difference between dielectric properties of malign and benign tissue is considered as a key point to form the image. In this process, electro-magnetic waves are impinged, recollected and processed through Focusing Algorithms [11-15] to form image of the affected area and find the position of cysts. In this smart data acquisition system, aerials play a significant role.

Electrical properties of Malignant and Normal tissues determine the efficiency of the system [16]. In early research projects, Breast are considered as homogeneous tissues and contrast between benign and malign tissue was found to be 5:1. Recently it was investigated that this ratio varies only by 10% [17]. Another important fact to be highlighted in previous researches is tissue losses. Human body can withstand a tissue loss of 4dB/cm, which is centered at 6 GHz frequency. All these initial findings lead to the conclusion that resolution of the system should be high so that it can cover small contrasts and at the same time low frequency is a must have to decline the tissue losses in human body. These issues have been mitigated by wearable on body antennas operating in Lower European bands to provide high efficiency and low losses [18-19].

Medical imaging process is a resultant of the preliminary works done in the field of scattered waves in 1960 by Jack. H. Raymond who postulates the theory of scattered waves that can identify the properties of dielectric material. At later stages, Toro Uno[20], Luk and Lueng, Mongia et all [21], Tie Jun Cui[22] and Mikhinev et al[23] carry forward his work by working on dielectrics and scattered wave and recollection methods. Franceschini investigated an iterative technique for image reconstruction from the scattered TE waves. These investigations open new door of opportunities for medical image reconstruction in combination of Dielectric Resonators. Various designs on BAVA (Balanced Antipodal Vivaldi antennas and arrays [25-28], Slot antennas and arrays [29-34], TWTLTA (Travelling Wave Tapered and Loaded Transmission Line Antennas [35,36], Metamaterial based microstrip patch antenna [37] have been proposed in literature hitherto. Currently DRA is emerging as an efficient and viable replacement of the patch antennas [38,39]. Numerous designs of DRA have been reported by several researchers for medical imaging applications like L-shape, H-shape, cubical shape and ring shape DRA's [40-43]. This paper presents a novel partial ground structure base antenna which operates in Lower European Band frequency. This antenna provides an impedance bandwidth of 48% ranging from 2.9-4.7 GHz. High gain and radiation efficiency are the key factors for this design in order to employ proposed antenna design as Monostatic breast cancer detection sensors.

2. Method and Materials

In this research work, rectangular geometry is chosen due to the flexibility offered in dimensions of DRA. Antenna dimensions are selected in such a manner that desired response can be achieved. Length (L_2), width (W_2) and height (H_2) and Q-factor of RDRA depends upon aspect ratio of the structure. Presented antenna makes use of lowest order mode of RDRA i.e., TE^{x}_{111} mode. Resonant frequency for this particular mode can be determined with the following transcendental equation

$$k_x \tan\left(\frac{k_x d}{2}\right) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_x^2} \quad (1)$$

where

$$k_o = \frac{2\pi}{\lambda_0} = \frac{2\pi f_0}{c}, k_y = \frac{\pi}{W_2} \text{ and } k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2$$

Selection of aspect ratio $\frac{W_2}{H_2}$ and $\frac{d}{H_2}$ along with dielectric constant (ε_r), is important in determining the resonant frequency of antenna. The expression used for the determination of above parameter consisting of normalized frequency (F), is taken from [45] and is given by equation (2):

$$F = \frac{2\pi f_0 W_2 \sqrt{\varepsilon_r}}{c} \quad (2)$$

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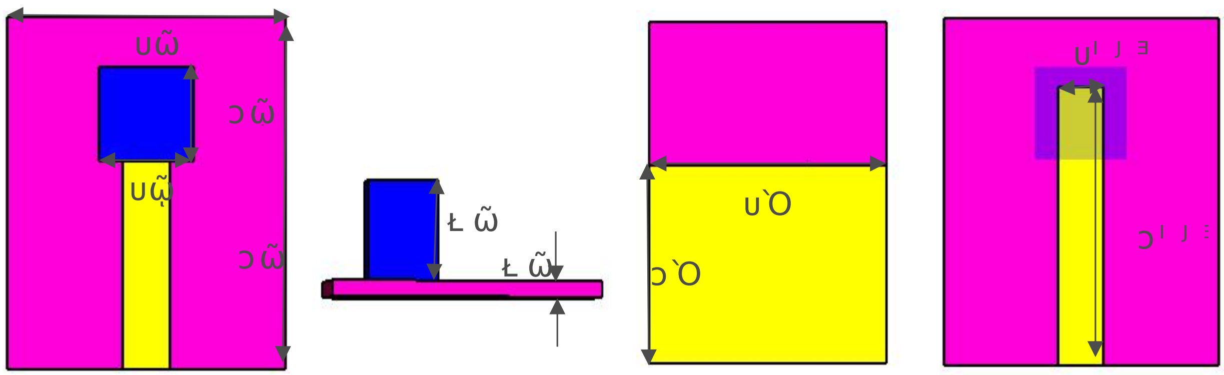
With eq^n (2), the resonant frequency is calculated in close approximation without solving the transcendental equation (2). Fig.1 represents the geometrical aspects of the antenna. Presented structure is implemented with FR4 substrate $\epsilon_r = 4.4$ with substrate dimensions of 37.5 mm x 30 mm x 1.6 mm. In this design, Wide bandwidth response is achieved with the application of partial ground structure of dimension 22.5 mm x 30 mm x 0.018 mm. A Rectangular Ring Dielectric resonator antenna of material Gallium Arsenide (GaAs) ceramic having the relative permittivity of 12.8 is instituted upon the substrate having dimensions as per the Table 2. Simple microstrip feed mechanism is presented in this paper to excite lower order modes so that operating bandwidth between the frequency 2.9-4.7 GHz is obtained. Fig. 1(a) represents Top view of antenna with DRA and feed implementation of structure. Fig. 1(b) represents the side view of the antenna with proposed heights of substrate and DRA. Fig. 1(c) Ground structure of antenna and 1(d) represents the feed structure of the antenna.



(a) (b) (c)

Fig. 1(a) Top View (b) Side View (c) Ground Structure of antenna (d) Feed structure of Antenna

Table 1. Dimensions of the Proposed Structure

Parameter	**Dimension(mm)**	**Parameter**	**Dimension(mm)**
ɔῶ	37.5	ɔᴵ ᴶ ᴲ	3.25
ʋῶ	30	ʋᴵ ᴶ ᴲ	3.5
Ꝉ ῶ	1.6	Ꝉ ῷ	10
ɔῷ	10	ɔÒ	22
ʋῷ	10	ʋÒ	20

3. Results and Discussion

Optimization of the ground

Fig. 2 represents optimization of ground plane of proposed antenna design. 2(a) shows full ground plane of antenna with dimension Lg=37.5mm. Antenna does not for this dimension of ground plane. Fig. 2(b) shows partial ground plane of dimension Lg= 22mm. In this configuration, an impedance bandwidth of 48%is achieved. Fig. 2(c) and 2(d) shows varying ground dimensions. For Lg=17.5 mm length of ground, antenna resonates for dual band. Resonant frequency of 5.2 GHz and 7.6 GHz is obtained for this ground dimension. At reduced ground plane length (5.5 mm), antenna operates at the frequency of 5.29 GHz only.

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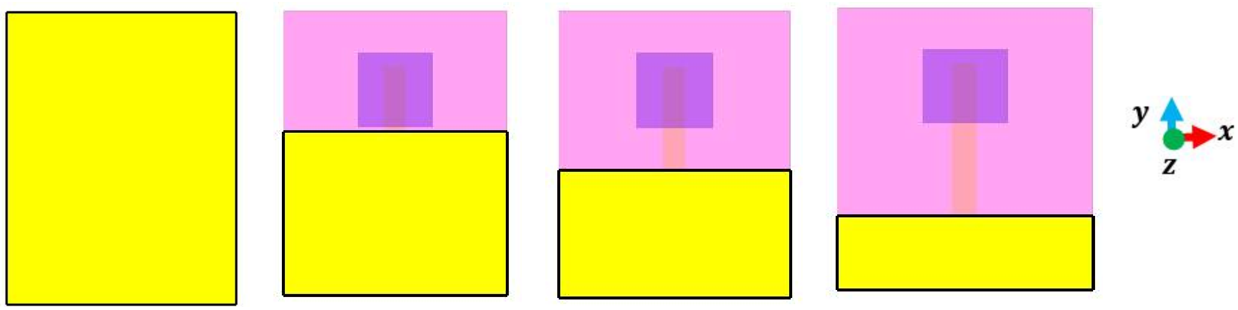
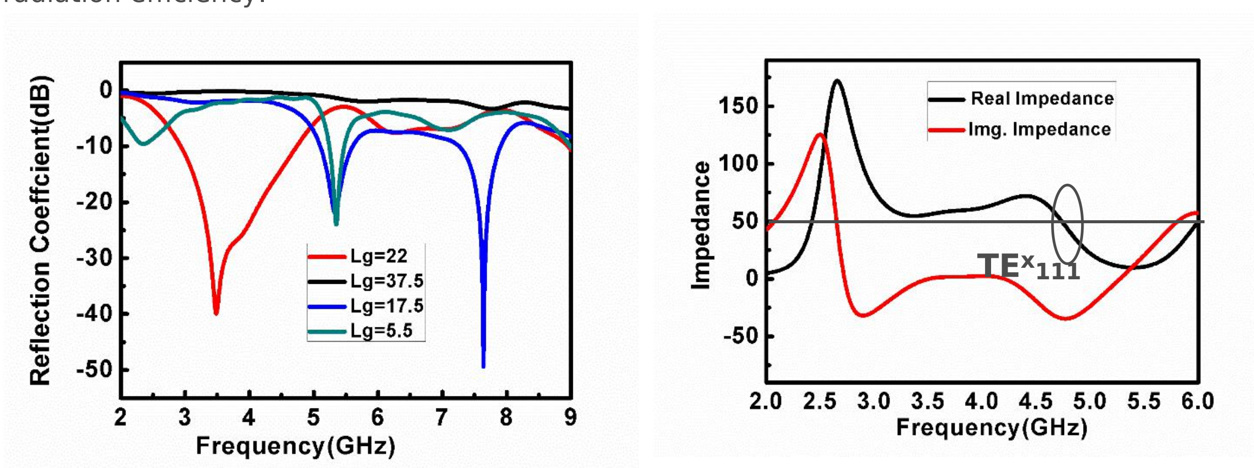


(a) (b) (c) (d)

Fig. 2(a) Lg=37.5 (b) Lg= 22 (c) Lg=17.5 (d) Lg=5.5mm

Fig. 3(a) shows comparative reflection coefficient of the antenna. It is observed that the bandwidth characteristics of the proposed design have been shifted to lower frequency by reducing the dimensions of ground structure. Dual band response for 17.5 mm ground dimension is shown in Fig. 3(a). Lg=5.5 mm dimension of ground plane dimensions are shown as a single band response for 5.2 GHz frequency. Wide band response is achieved at a ground length of 22 mm. Bandwidth of 1.8 GHz is achieved with high gain and high radiation efficiency.



(a) (b)

Fig. 3(a) Comparative reflection coefficient of various ground stages (b) Real and Imaginary impedance of the antenna

Reflection coefficient determines the quantity of power coupled into space on account of impedance discontinuities. Fig. 4(a) represents the obtained simulated reflection coefficient response of the proposed design with ground plane of dimension 22 mm. Further it can be seen that the reflection coefficient plot lies below -10 dB within the frequency range of 2.9 to 4.7 GHz. Fig. 4(b) represents comparative Voltage standing wave ratio (VSWR) of the antenna. It can be observed from the figure 4(b) that a classic 2:1 ratio of VSWR has been achieved thereby indicates good tuning of the antenna design.

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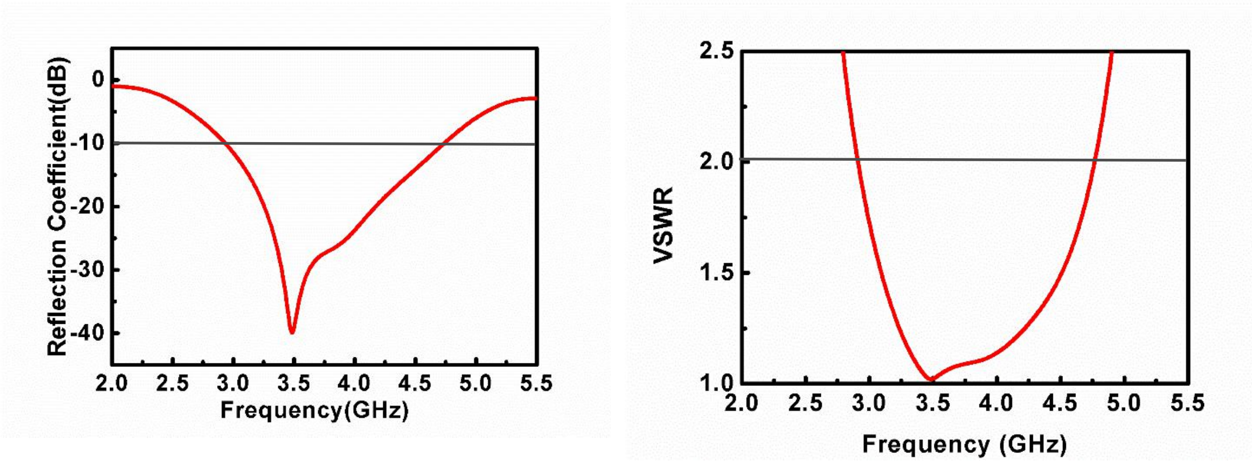
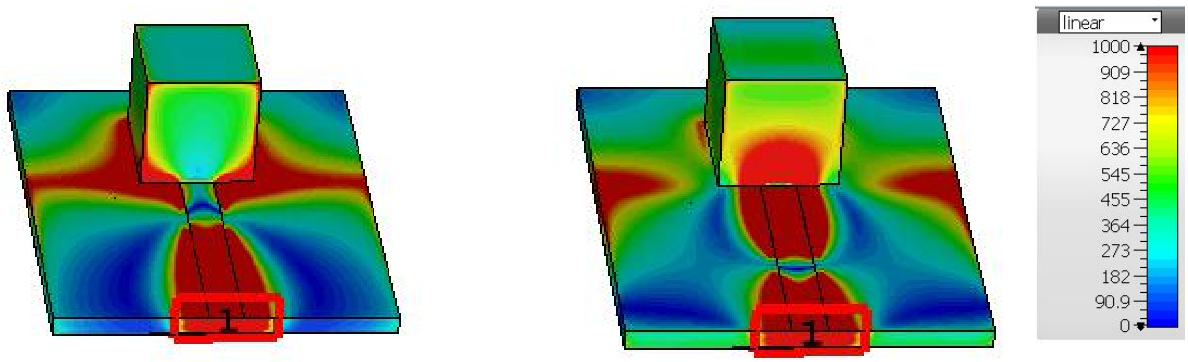


(a) (b)

Fig. 4(a) Reflection Coefficient (b) VSWR of the antenna

Fig. 5 depicts the dielectric resonator electric field vector distribution inside the proposed design. Distribution of dominant modes is visible in Fig. 5(a) and 5(b). Fig. 5(b) represents TE^{x}_{111} mode at 4.7 GHz. At lower frequency of 2.9 GHz lower order degenerative mode exists. The radiating mode generation plays a vital role in bandwidth enhancement up to 1.8 GHz.



(a) (b)

Fig. 5(a) E-field at 2.9 GHz (b) 4.7 GHz

Fig. 5(b) represents the dominant TE^{x}_{111} mode of antenna at frequency 4.7 GHz. Due to partial ground structure, degenerative mode exists at lower 2.9 GHz. Fig. 5(a) shows the E-field distribution of the antenna. Fig. 6(a) represents simulated gain of proposed antenna design with respect to frequency. The positive gain curve is obtained and is stable across entire operating frequency range earning the prerequisite for early breast cancer detection application. The proposed design provides a peak gain of 4 dBi. Fig. 6(b) shows the simulated radiation efficiency plot. The Radiation efficiency is a significant parameter, which signifies the role of antenna as a sensor in the entire system. The proposed DRA design provides high radiation efficiency within operating bandwidth. An average radiation efficiency of 90% is obtained with this sensor**.**

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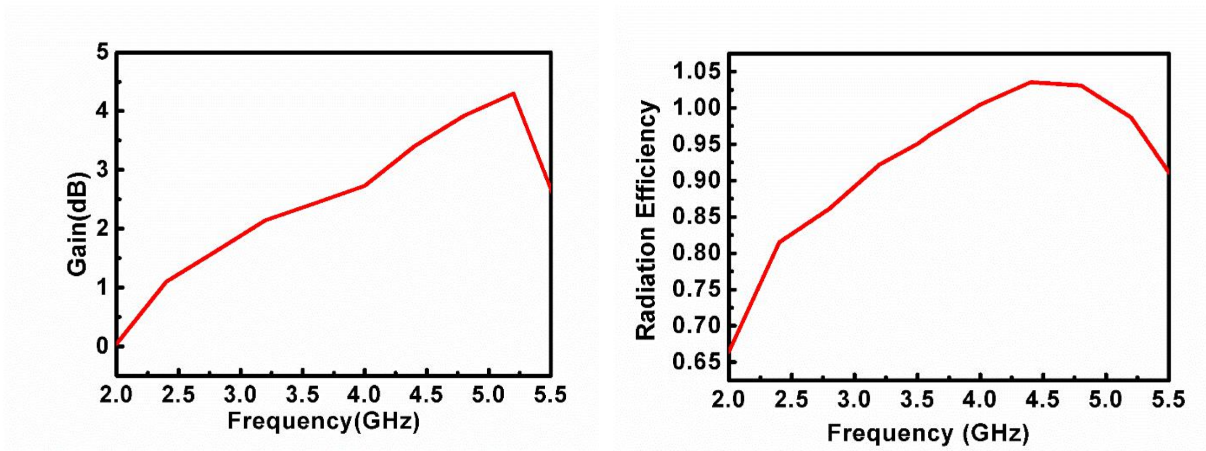
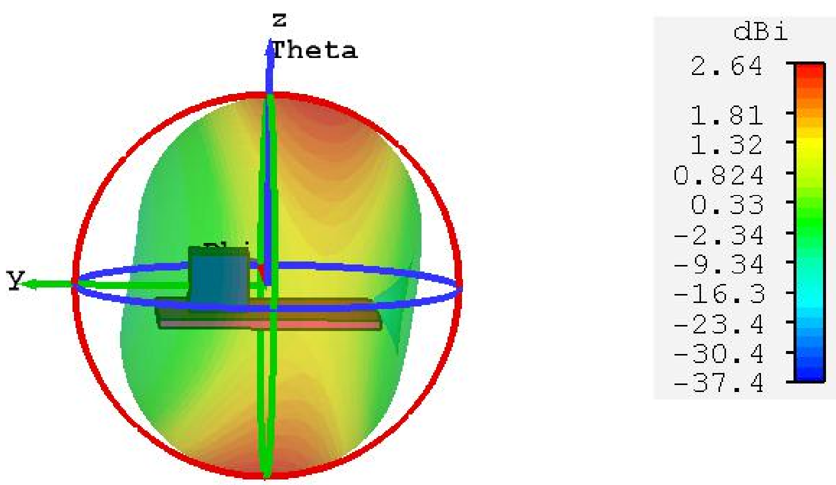


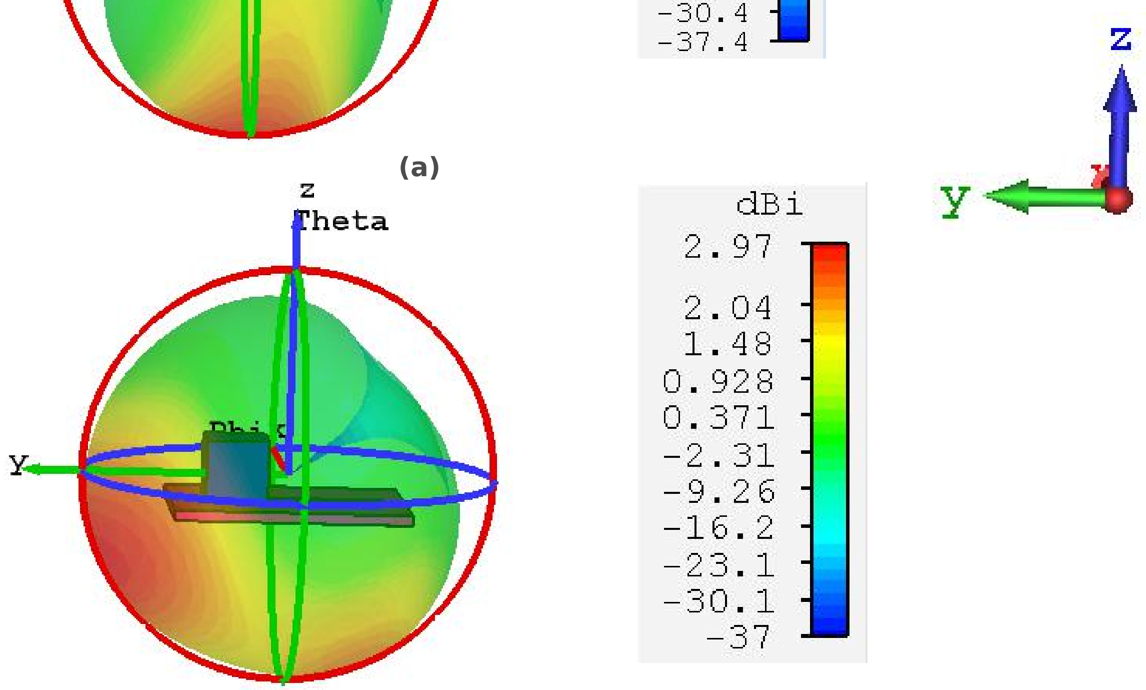
(a) **(b)**

Fig. 6(a) Gain (b) Radiation Efficiency of Antenna

Fig. 7(a and b) shows the simulated 3D polar radiation patterns of proposed antenna structure operating at 2.9 GHz and 4.7 GHz respectively. The radiation field patterns are broadband in nature and are stable (without ripple) throughout the entire frequency band.



(a)



(b)

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Fig. 7(a) 3-D Radiation pattern of antenna at 2.9 GHz (b) 4.7 GHz

4. Phantom design and SAR calculation

SAR (Specific Absorption Ratio) defined as the measure of electromagnetic (EM) energy absorbed inside biological tissue mass, when it has been exposed to microwave imaging radiating device.

$$SAR= \frac{P}{\rho} = \frac{\sigma E^2}{2\rho} = \frac{J^2}{2\rho\sigma}$$

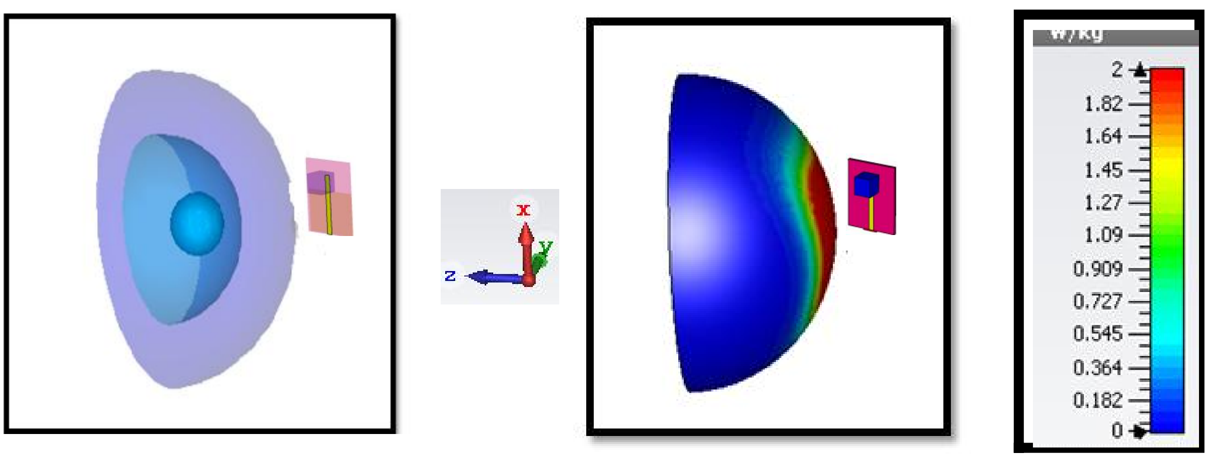
Where P = Power loss density, E= Electric field strength

J=Current density, σ = Conductivity, ρ= Sample Density σ=Electrical conductivity

Table 2. Material properties of the multilayer human tissue model

Parameter	**Skin**	**Fat**	**Tumor**
ϵ_r	36.8	4.84	54.9
σ(S/m)	2.34	0.262	4
Density(kg/m3)	1109	911	1058

The breast mimic (phantom) was also designed for measuring the SAR using presented antenna structure is shown in Fig. 10. The material properties of mimic are as tabulated in Table 2. It is a tri-layered structure depicting Skin, Fat and tumor layers distinctly. Mass Averaged SAR principle is used to carry out SAR study of proposed design. In this method 1.6W/kg averaged over 1g of tissue. Simulated averaged mass ratio is obtained with phantom is 0.6 W/kg, which is quite effective for early detection of breast cancer.



(a) **(b)**

Fig. 10 Breast Phantom for calculation of SAR

In Table 3, a brief comparison of proposed design is depicted along with existing references. The compared parameters in the below mentioned table, show that the proposed design is competitive among its peer designs.

Table 3 Comparison of proposed design with existing research

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Ref No.	Shape of DRA	BW (GHz)	Ground Plane (GP)	Antenna size(B B O)	Observations
38	Stair shaped	7-12	Choked GP	20 x 20 x 10.77	Complicated structure design
39	L shape DRA	2.6-5.52	Full ground	122.6 x 122.6 x 2.5	High backlobe radiation and co/cross polarization
40	H-shape DRA	3.47-9.62	Partial GP with slot	30 x 30 x 5.8	Fail to denote the tumor size and position
41	Rectangular DRA	22.5-27	Full GP	30 x 30 x 4.8	Circularly Polarized, full ground plane however complex structure
42	Cubicle shaped	4.3-12.6	Partial slotted GP	20 x 15 x 5.64	Dominant mode resonant above 10 GHz which may cause rippling in radiation pattern leading to inaccuracy.
43	Ring Shaped DRA	5.4-15	Partial slotted GP	26x18x12	Proposed DRA reduces SAR, Low frequency detection of tumor causing less ripples, lowered surface-wave losses with high accuracy.
44	Ring Shaped DRA	3.7-7.4	Partial GP	26 x 20 x 11.6	Compact/minimized design, Single radiating with SAR reduction, wideband, and reduced ground plane.
Presented Antenna	Rectangular DRA		Partial GP		Compact design, Lower operating frequency of antenna ensures minimal tissue loss, suitable for compact wearable design

5. Conclusion

The proposed design is presented as a sensor element in Monostatic-Radar-based-microwave-imaging technique for Breast Cancer Detection. The microstrip line fed proposed (RDRA) UWB antenna structure is explicitly designed to operate in the Lower European Band so that the non-ionizing tissue losses can be constricted. One of the vital characteristics of proposed designed is its obtained peak radiation efficiency of 99% thereby nominating the design as a suitable contender in high resolution sensor classification. A wideband fractional bandwidth of 48% along with stable isotropic gain of 4 dBi is achieved. Subsequently, based upon these characteristics the proposed design attracts a perfect choice for “On-Body and wearable sensors” category.

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