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DEVELOPMENT OF FLEXIBLE MICROWAVE ANTENNAS FOR BREAST CANCER IMAGING SYSTEM

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MARYAM LIAQAT

TÍTULO

"DEVELOPMENT OF FLEXIBLE MICROWAVE ANTENNAS FOR BREAST CANCER IMAGING SYSTEM"

A comissão examinadora composta pelos professores: FREDERICO DIAS NUNES, DEN/UFPE; JULIANO BANDEIRA LIMA, DES/UFPE; EMERY CLEITON CABRAL CORREIA LINS, DEB/UFPE; HÉLIO MAGALHÃES DE OLIVEIRA, DE/UFPE e ODILON MAROJA DA COSTA PEREIRA FILHO, CIN/UFPE, sob a presidência do primeiro, consideram a candidata **MARYAM LIAQAT** **APROVADA**.

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A mother is a real blessing of Allah Almighty. My work is dedicated to my mother who did all the efforts for me from day one of my study till Doctorate.

(MARYAM LIAQAT)

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“God does not forbid you from being good to those who have not fought you in the religion or driven you from your homes, or from being just towards them. God loves those who are just.”

(Surat al-Mumtahana, 8)

ABSTRACT

To diagnose the breast tumor, Microwave Imaging techniques are used as an alternative to X-ray Mammography. Radar-based Microwave imaging is non-ionizing , a non-invasive technique which usesback scattering rays for reconstruction of ima ges of the targeted tumor in the breast. Antennas are designed for a microwave frequency of 2GHz. Three different kinds of substrate material that are FR4, polyester and pyralux polyimide are analyzed in this project with respect to three different designs like, Rectangular Patch antenna, Bow-Tie, and Split Rectangular Patch. S-parameters, Radiation pattern and magnitude of the electric field are analyzed to determine the performance of the antenna in the air and in the presence of 3D phantom (healthy and diseased). On the bases of dielectric properties of cancerous tissues, embedded tumors are analyzed in breast phantom which is designed in HFSS. By the careful analysis of the three designs of antenna and material, a split patch antenna with pyralux polyimide substrate is the most suitable type due to compact size and efficient in performance that means high directivity and gain. Mutual coupling of the antenna is also analyzed by simulation. Two face-to-face antennas on y-axis at 72mm apart produce the best mutual coupling that is difference of S11 and S12 is -20 dB. Therefore, in array of antenna, the mutually coupled antennas are placed at 180^0 to each other. Further, 3D breast phantom is simulated with array of two antennas using HFSS. The magnitude of electric field is 163V/m for normal breast tissues and 133.23 V/m with 10mm tumor.

Keywords: Imaging, Flexible Antenna, Pyralux Polyimide, S-Parameters, Magnitude of Electric Field, Phantom, Tumor.

RESUMO

Para diagnósticar tumors cancerígenos, a geração de imagens por técnicas baseadas em de Micro-ondas têm sido usadas como uma alternativa à mamogragrafia por Raios-X. Imageamento por Micro-ondas baseado em Radar é uma técnica não invasiva que usa os raios do retro espalhamento para a reconstrução da imagens do tumor de mama sob irradiação. Neste trabalho, as antenas foram projetadas para a frequência de 2GHz. Tres diferentes tipos de materiais são usados para os substratos sendo FR4, poliéster e pyralux polyimide foram analisadas neste trabalho segundo três diferentes topologias, como antena Retangular , "Bow-Tie" e Abertura Retagular. Foram analisadas grandezas como Parâmetros-S, Perfil de Radiação e Magnitude do Campo elétrico para ser determinado o desempenho das antenas no ar e irradiando um fantoma 3D (fantoma saudável e fantoma patológico).A interação da radiação com os tumores foi analisada a partir das propriedades dielétricas dos tumores, situação simulada nos fantomas da mama. Entre os diferentes tipos de topologia a antena com abertura linear foi a que se mostrou mais apropriada por conta do seu tamanho compacto e alto ganho e direcionalidade. Foi tema de análise o acoplamento entre antenas, via simulação numérica. Duas antenas posicionadas de frente uma a outra à uma distancia de 72mm entre si produziram o melhor acoplamento mutuo, com a diferença entre o S11 e S12 de -20 dB, portanto num arranjo de antenas elas foram posicionadas com 180^0 entre si. Ademais, foi simulado um fantoma 3D com um arranjo de duas antenas utilizando o HFSS. O campo elétrico é de 163V/m para uma mama com tecido saldável e 133.23 V/m para uma mama com um tumor de 10mm.

Palavras-chave: Imageamento medico, Antenas flexíveis, Poliamida Pyralux, Parâmetros de espalhamento, Magnitude do campo elétrico, Fantoma, Tumor

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1 INTRODUCTION

Out of three cancer patients, one has breast cancer in the United States [1][2], in Pakistan and Brazil, the proportion of a number of patients is one out of 4 [2]. The risk of death for breast cancer patient is approximately 12.8% (1 out of 8 breast cancer patient) in Pakistan and USA[1][2].

According to American Cancer Society, cancer is the uncontrolled reproduction of the cells with damaged DNA. If the breast cancer is not cured at early stages then the mortality risk rises up to 100% [4]. Therefore, the focus on detection and treatment of the breast cancer is developed day by day. The death rate can be minimized by early detection and postoperative care. The patient who has a family history of breast cancer has 20% more chances to be diagnosed with disease [5].

Table 1.1:Statistics of Breast Cancer Screening with X-Rays Mammography

Age	In Situ Cases	Invasive Cases	Deaths (%)
<40	1,610	11,160	2
40-49	12,440	36920	9
50-59	17,680	58,620	19
60-69	17,550	68,070	23
70-79	10,370	47,860	20
80+	3,760	30,080	27
All ages	**63,410**	**252,710**	**40,610**

Source: Breast Cancer Fact and Figures, 2017-2018

Different medical imaging techniques like X-ray mammography, Magnetic Resonance Imaging (MRI), and Computed Tomography are used in radiology to see the internal structure of the body and to detect and locate the tumor. Computed Tomography (CT) also known as “X-ray Computed tomography” is another imaging technique, that by using computer processed programming, produces the image of the specific areas of the body. Positron Emission Tomography (PET) is another technique used for three-dimensional imaging [6] for breast cancer [7]: the illumination source are gamma rays emitted indirectly by a positron-emitting tracer, which is biologically active molecules. The image is constructed by the computer analysis. In X-Raymammography,the most commonly used technique, low-energy X-rays (usually around 30 kVp) is used which is specifically designed for the examination of the breast screening. The most commonly used technique is X-ray mammography. Advancement of mammography is

Digital Mammography (full-field digital mammography, FFDM) but it is recommended only for patient of age group of 50 years and above or for dense breast patient [10][11][12],It has many advantages it still have many drawbacks due to low contrast image [13] and other disadvantages [14] as mention in next paragraph.

X-ray Mammography is restricted to specific age groups, false results, high dose level for dense breast for mammography and for different age groups [14].Along with this, an additional biopsy (or MRI or Ultrasound) needed for the verification of results [14]. False result ratio of Mammography is very high, every fifth patient has false result/report (especially for a person of 30-40 years) [15][14];

- False-Positive results [13];
- False-Negative Results [15].

The statics of different research groups shows that the x-rays mammography is good for the patients for the age group of 70-79 years. Whereas, 69% of screening results are wrongly diagnosed as healthy and about 33% as having breast cancer [16]. The false positive results affect the person economically and mentally because of biopsy test [16].

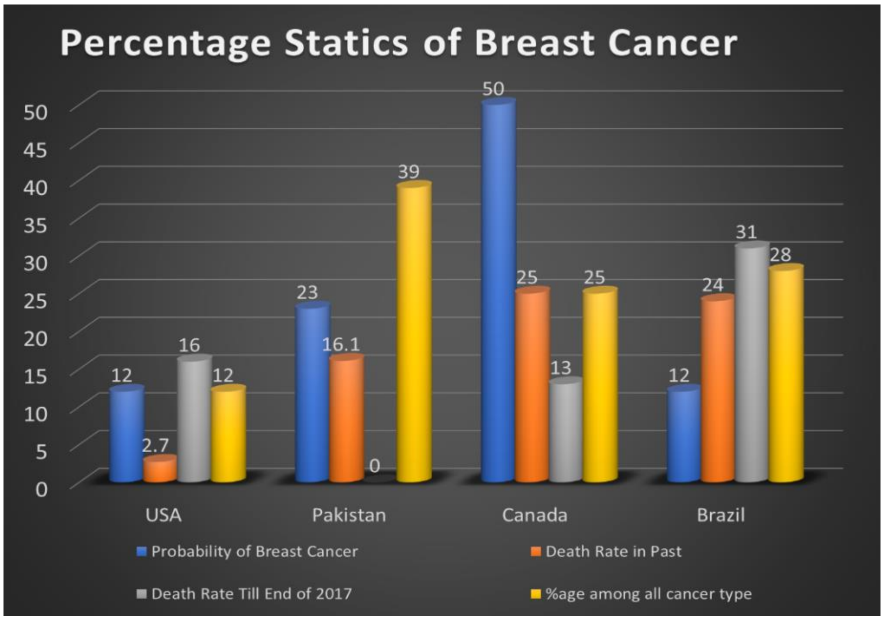
An underdeveloped [16] technique for diagnosis of breast cancer is Microwave Imaging (MI) [17][4]. Microwave Imaging is advantageous over the other techniques as stated before because it is non-ionizing, non-invasive, cheap and sensitive in nature [4]. It alsoprovidesimages of the fluid tissues (soft tissues) and can be used for imaging at earlier stages at which the disease is curable and hence one can be able to save the patient's life. Microwave scattering is significantly high for high contents of water [18] therefore malignant tumor can be detected with microwave imaging [19] as malignant tissues have high water contents as compare to normal tissues [19]. Also, worthwhile to mention that MWI technique improves the resolution of the images [4] making this technique more and more attractive as a tool for breast cancer detection because it makes possible to detect tumors at earlier stages in a better way.

1.1 Death Rate of Breast Cancer Patients

American cancer society reported in April 2016 that the second leading cause of death in cancer patients is breast cancer (one out of 36) reported [1]. Survival rate at different stages mentioned above shows that if diagnosed and treated timely the death rate can be controlled. In

Brazil, mortality rates due to breast cancer remain high, most likely because the disease is still diagnosed at advanced stages [20].Relatively rare before age 35, above this age, the incidence is growing fast and steadily.

Figure 1.1:Statistical Analysis of Breast Cancer of Different Countries in 2017



Source:http://www.who.int/cancer/detection/breastcancer/en/index2.html.
http://www.who.int/cancer/detection/breastcancer/en/index2.html.

The statistics of the four different countries shows that probability of having breast cancer in Canada is 50% which is very high but the death rate of Canada is reduced from 25 to 13%. In Pakistan, breast cancer is highly diagnosed cancer (30%) type among all types of cancers as shown in figure 1.1.According to the World Health Organization (WHO), the rate of breast cancer in developing countries during 1960 and 1970 is 10 times greater than now [23].

1.2 Microwave Imaging

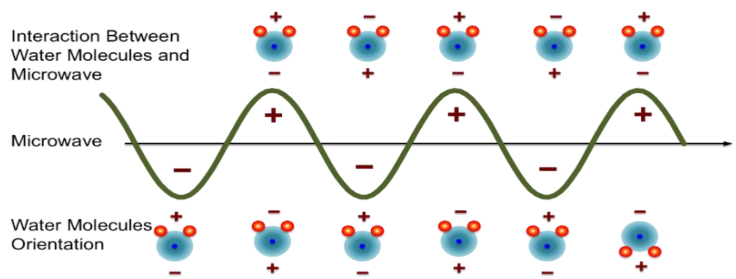
In microwave imaging, backscattered rays are used to identify and locate the tumor in the body, therefore this technique also called radar-based microwave imaging (microwave imaging). Advantages of this technique over mammography are, early stage detection, non-ionizing nature of the source, non-invasive, low cost and more comfortable for patients [24]. Ultra-wideband

(UWB) Radar imaging of the breast uses the difference in dielectric strengths of normal and cancerous tissue, in microwave frequency ranges [24].

1.2.1 Background of Microwave Imaging

In microwave range, the dielectric properties of malignant and healthy breast tissues are in contrast. The low-loss nature of breast tissues (fatty) is used for breast image reconstruction [25].The interaction of microwave and tissue has an important element. Tissues are full of water, being the main interacting material. Water molecules (H_2O) are polar and electric charges on the molecules are not symmetric because dipole structure is present.

Figure 1.2: Schematically illustrates the interaction between water molecules and microwaves



Source: http://www.who.int/cancer/detection/breastcancer/en/index2.html

These dipoles will interact with electromagnetic radiation and will flip as schematically shown in Figure 1.2, being possible to achieve resonant conditions. Microwave radiation specially tuned to the natural frequency of water molecules to maximize the interaction of electromagnetic waves with the water contents inside the breast tissues. Temperature rises because the resonance of microwave in dipole oscillation meets scattering and absorption of microwave energy. Due to overheating, coagulation of cancer is produced. If the field radiation and electrical properties of tissues are known, then its interaction can be studied easily because it's a frequency dependent behavior.

1.3 Objectives

The development of breast cancer imaging system is important for the perspective to bring improvements for earlier detection and diagnose. The objective of this project was to improve the microwave imaging technique.

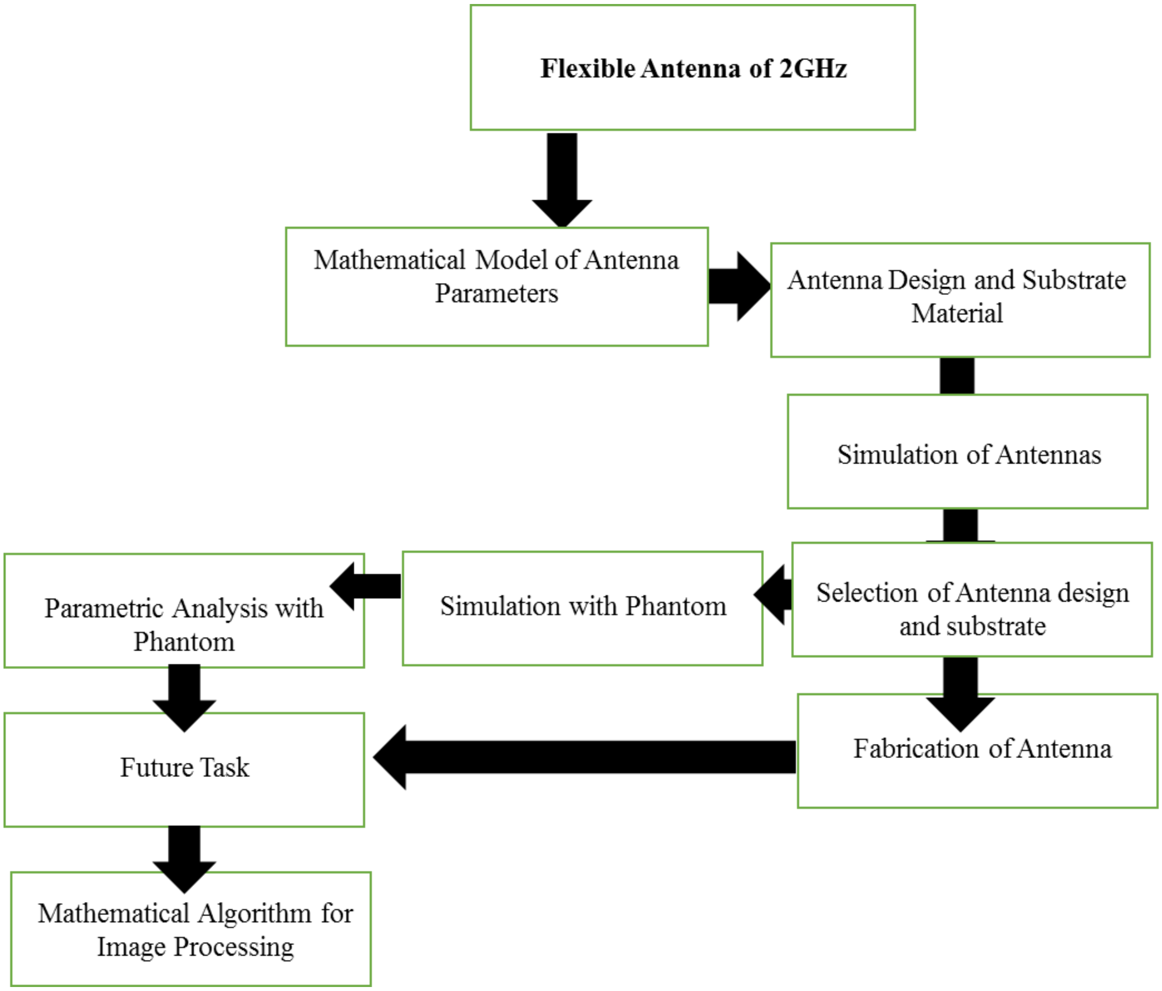
Low photon energy is one core property of MI, therefore, no need of safety hazards due to non-ionizing nature [27] to apply at human for detection of cancer tumors at very early stages. The purpose of this work is to develop the flexible antennas of 2GHz for breast cancer detection technique.

Antennas will be tested using healthy and cancerous inhomogeneous breast phantom. Three antennas of different designs with three different types of substrate material will be simulated and fabricated for the current project. The chosen substrate materials were FR4, polyester and pyralux Polyimide. They were laminated with a copper layer of 35μm thickness. Those laminated substrates were modeled in computer simulation software for finite element method (FEM) using the software named HFSS, from Ansys Software.

The results of this project are divided into three categories,

- Design and Material of Antenna from Parametric Analysis;
- Simulation of Antennas;
- Parametric Analysis of Antennas with Phantoms;

Figure 1.3:Flowchart of the Project and Future Task



2 REVIEW OF LITERATURE

A review of UWB microwave imaging [12] was published by Li, X.; et al., in 2005 to emphasize the importance and advantages of this technique for breast imaging for malignant tumors. Microwave Imaging via space-time (MIST) beamforming using signal processing algorithm. From scattered signals, the location of malignant lesions traces. A numerical algorithm was designed using FDTD to detect a very malignant tumor in heterogeneous breast tissues (phantom). The experimental feasibility of the MIST beamforming approach was also demonstrated in three dimensions, using an initial imaging prototype and a multilayered breast phantom containing one or more small synthetic tumors. Low-power UWB microwave radar-imaging technique proved a potential tool for clinical diagnosis of breast tumor.L. WANG and B. Huang [28] presented in this article on ultra-wideband (UWB) MIMO Antenna consist of the circular slot and rectangular patch. The low value of mutual coupling of the antenna in the air was detected for early-stage detection of breast cancer. The antenna simulated and designed over the range of 2.3-12.2 GHz with return loss less than -15 dB. Out of two antennas, antenna 1 was vertically polarized whereas antenna 2 was polarized horizontally. A rectangular patch of 10 mm and 12 mm was good for impedance matching. Antenna performance was measured for a different circular slot for 4 mm, 5 mm and 6 mm, but more prominent results were recorded at 5 mm radius.

F. Yang and A. Sangavarapu [29] in 2012 mentioned that the radar-based UWB microwave imaging has more potential to localize the breast tumor or tumors. The frequency range of this antenna is 1-9 GHz with a return loss of -40 dB (experimental) and -50 dB (in simulation) reported. In UWB imaging process, antenna characterizes the receiving signals and distort the radiated signal by behaving as a spatial-temporal filter. Image reconstruction is also performed in an article for detecting the tumor at early stages. An array of a prototype-Vivaldi antenna located at hemisphere pattern to shine the target (inhomogeneous breast phantom). To reconstruct the image Finite-Difference Time-Domain (FDTD) mathematical approach was used to localize the targeted place (tumor location). Then experiment work also performed and was concluded from both results that signal distortion was very low for pulse transmission for an array of antenna. Tumor successfully located by three-dimensional FDTD image reconstruction for this array of antenna.

P. K. Singh et al., [30] worked on the worldwide problem of malignant neoplasm, a death causing cancer and proposed early detection techniques, based on dielectric properties of biological tissues (breast tissues). They proposed that microwave imaging (with low power and longer signals) as compared to X-ray Mammography was accurate and safer technique. In that article, a rectangular patch antenna and a phantom of 2 mm was simulated. Rectangular patch antenna with 32mm x 28.1mm dimensions of the substrate (Rogers RT/ Duroid 5880 mm) was designed. The phase shift of phantoms was a function of electrical properties of the breast with tumor and was analytically calculated. This helped to locate the tumor at a specific position with bulk electrical properties (depends on the volume) of breast were used. The current density was the main parameter, which was studied in the present working using radiated signals of the antenna. The resonating frequency was reported by simulation was 7.5 GHz. Tumor of 2 mm was placed at 10 mm distance from a patch of the antenna within a conical shielding. The maximum current density was 109.5 A/m^2 without tumor and with the tumor was 275.61 A/m^2, which was an evidence of detection of the tumor. Then tumor with 2 mm radius was added and current density distribution of the Tumor of Breast was observed. The maximum current density of the breast/ Tumor was 275.61 A/m^2 and the minimum current density of the Breast/ Tumor was 1.16 A/m^2observed by Singh and group.

Radar-based microwave imaging with ultrawide-band antennas was used to investigate the tumor at early stage by Hagness and his group [31]. By using the finite-difference time-domain methodology was developed for three-dimensional imaging using array of bow-tie antenna. By study of scattered properties of electromagnetic radiations, it was concluded that microwave imaging system is an adequate technique to detect tumor at early stage which can not be possible with x-rays mammography. The simulated initial results for embedded tumor of size 1.5-5.3mm in breast, copolarized spherically within the range -80 to -115 dB with back scattered radiation.

Inset fed Rectangular Microstrip Patch [32] antenna was designed by S. Pundir and his group. Proposed mathematical tools to calculate the parameters of design measurement. To get the best results, electrical properties were measured by varying the inset fed gap and width. Simulated results using computer simulation technology (CST) and got resonate frequency at 2.4

GHz. On the bases of results, it was concluded that gap between inset fed and patch fed line effects the performance of the antenna.

Çaliskan et al., [33] designed another inset fed Microstrip antenna and concluded that microwave imaging is a promising method for malignant tumor detection at early stages. An FR4 substrate patch antenna was made with 2.45 GHz frequency to enhance the quality of imaging. By changing the ground plane dimensions, current density, electric field,andthe magnetic field were evaluated. Spherical Breast phantom of 20mm was designed using HFSS with dielectric properties of 50 (F/m) and 4 (S/m) for cancerous tissues and for normal breast tissue 9 (F/m) and 0.4 (S/m) permittivity and conductivity respectively. The recorded results for Electric field was 137.36 V/m, for the magnetic field was 0.786 A/m and current density 54.946 A/m^2 phantom model with the tumor. Without tumor the respective values were higher, that is 170.38 V/m, 0.84634 A/m and 68.15 A/m^2, respectively.

Klemm and his group add his contributions in the development of radar-based breast cancer detection using UWB antennas by experimental working [34]. 3D breast phantom with tumor of 4 to 6 mm diameter as well as the real breast samples from the clinical trials was under investigation. An array of 16 stacked-patch antennas used to scan the breast. To obtain 3 D image two beamforming algorithms followed which are Delay-and-sum (DAS) and multistatic adaptive microwave imaging (MAMI) for results. Results proved that the signal-to-clutter ratio for MAMI is higher than DAS that means MAMI was more efficient in working.

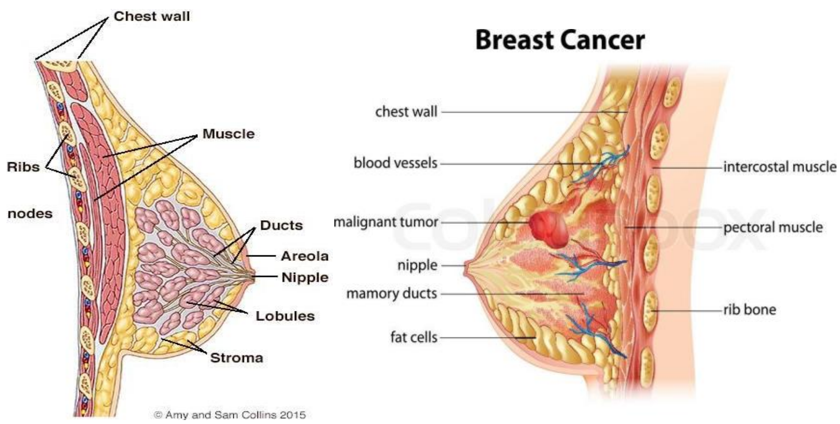
3 BREAST ANATOMY AND TECHNIQUES OF SCREENING

To understand the breast cancer properties and way of screening, the breast anatomy is very important to know. Till the day, there are many techniques, for treatment and diagnosis of breast cancer. This Chapter is about the anatomy of the healthy and cancerous breast, properties of healthy and diseased breast tissues and screening techniques.

3.1 Anatomy of Breast

The breast is consisting of skin, fatty tissues, connective tissues, adipose tissues and glandular tissues [35], which is illustrated in Figure 3.1 [36].

Figure 3.1: Anatomy of Normal Breast (on left) and Cancerous Breast (on right)



Source: http://www.guands.com/cancer/breast-cancre/breast-cancer.html

The shape and size vary for everyone due to different proportion of fatty tissues and connective tissues [35]. Whereas, the proportion of glandular tissues also varies during pregnancy for lactation process [37]. The main function of the connective tissue (Copper‘s ligament) is to maintain the structure of the breast [74]. The anatomy of a healthy breast is shown in Figure 3.1. It should be noted that although lymph nodes are not constituents of the breast per se, they are represented in this figure as breast cancer can be diagnosed through detection of metastasized tumor cells particularly in the axillary lymph nodes, where approximately 50% of breast cancer occur [74].

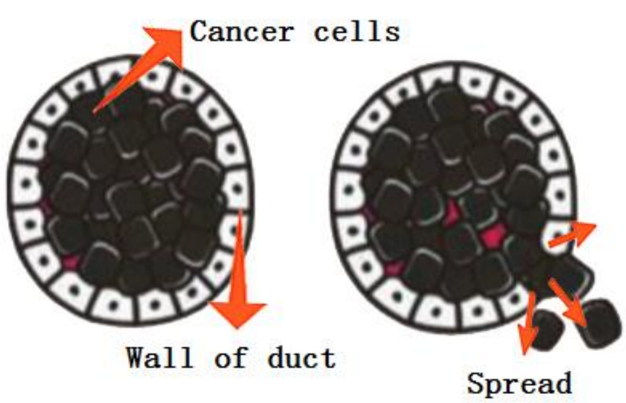
3.2 Anatomy of Cancerous Breast

Uncontrolled growth of breast lump cells causes cancerous tissues [74] due to gene mutations. Figure 3.2 shows that the anatomy of a cancerous breast. Breast tumors [39] are classified asa benigntumor and malignant tumor.

A benign, also known as non-invasive,the tumor grows with a controllable speed and does not become a malignant tumor. Cancer cells only stay within mammary lobule and milk ducts; these cancer cells do not invade normal tissues beyond mammary lobule and milk ducts. Non-invasive breast cancer further divided into LCIS (lobular carcinoma in situ) and DCIS (Ductal carcinoma in situ). Non-invasive breast cancer is an early sign of early breast cancer [41].

A malignant tumor or invasive invadebeyond mammary lobule and milk ducts. It destroys healthy cells and grows at a high rate of spread to other adjacent organs. It is unfortunate that most breast cancers are invasive breast cancer [41].

Figure 3.2: Types of Cancer in Breast, non-invasive (on left) and invasive (on right)



Source: Haoyu Zhang, Microwave Imaging for Ultra-Wideband Antenna Based Cancer Detection. The University of Edinburgh, 2015.

3.2.1 Discrimination between Benign and Malignant

The discrimination between benign and malignant tumors is mainly based on the content of water within the tumor [25]. An increase in water content in tumor indicates the deterioration of cells, and this increases the values of the dielectric constant and conductivity of the tumor.

Morphologically, [25] both types are distinguished by size, surface and packing density. A malignant tumor usually has an irregular surface and speculated periphery and a benign tumor has a smoother surface and roughly spherical shape. These two major criteria are often used in medical diagnoses, such as when using MRI and ultrasonic imaging. Breast cancer is common cancer in women which usually originates from the lactiferous ducts. Genetic mutation, family history or environmental effects could increase the chances of appearing in breast cancer [42].

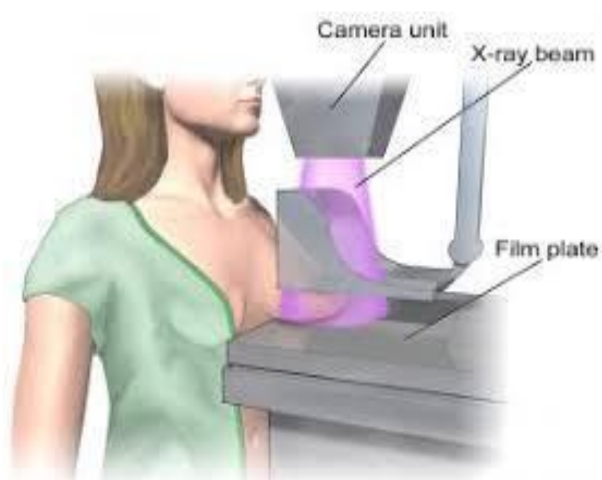
3.3 Clinical Diagnostic Methods

For the diagnosis of invasive and non-invasive tumors, different techniques are used in medical diagnoses such as x-ray mammography, MRI and ultrasonic imaging etc [52]. The principles of these three methods are summarized as follows,

3.3.1 X-ray Mammography

Ionizing x-rays of 30 kVp are used to diagnose breast cancer and this technique is known as X-ray Mammography [9]. Low contrast images of the breast are then recorded on film for diagnosis [9].

Figure 3.3: X-Rays Mammography



Source: https://www.topdoctors.es/en/articulos-medicos/diferencias-entre-la-ecografia-y-la-mamografia

This process is beneficial with respect to process time whereas, it’s painful and has a high ratio of false results [14]. Due to ionizing nature of the source of x-rays, it may be harmful tohealthy tissues in the surrounding of cancerous tissues. The resolution of the resulting images is sufficient for the most diagnostic requirement, but not enough for a high dense breast [41].

3.3.2 Ultrasound imaging

Only the expert doctors can detect breast cancer using ultrasound imaging. Ultrasound Imaging System figure 3.4 is based on the use of ultrasonic wave ranging from 1MHz to 15MHz. Whereas, the deep and solid tumor cannot be detected using this technique. The resulting images can be in any orientation due to real-time screening [42].

Figure 3.4: Ultrasound Imaging

http://medgadget.com/2007/03/esie_touch_elas.html

3.3.3 Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) [44] is based on the use of magnets to generate a very strong magnetic field for the creation of a pathological image. The patient lies on an examination table with several small scanner devices placed around the breast to examine, as shown in Fig 3.5. The high sensitivity of MRI provides extremely high-resolution images for soft tissues, and especially for small tumors. However, its high cost and the time-consuming diagnosis process are major shortcomings. The advantages and disadvantages of the diagnostic method can be classified as cost, safety, accuracy,and scope of application [44].

Figure 3.5: Magnetic Resonance Imaging (MRI)

Source: https://www.healthcare.siemens.dk/clinical-specialities/oncology/cancer-types/breast-cancer/patient-information/diagnostics/magnetic-resonance-imaging

3.3.4 Microwave Imaging for Breast Cancer Detection

The limitations of these three methods have motivated researchers to develop a more effective, lower ionizing and low-cost diagnosis method for cancer detection. For this purpose, microwave imaging has become a potentially significant method which will be discussed in detail in next section.

3.4 Conclusion

This chapter discusses the background of breast cancer and currently used breast cancer diagnosis methods. The anatomy of the breast and classification of tumors are discussed first. Tumors can be mainly classified as benign, potentially malignant and malignant tumor. The benign tumor grows with a controllable speed and does not invade or destroy the surrounding cell or tissues. The malignant tumor invades and destroys healthy cells and grows at a high rate or even spreads to other adjacent organs. The discrimination of benign and malignant tumors is mainly based on their electrical properties and morphology. The most commonly used clinical diagnostic methods for breast cancer are X-ray Mammography, Ultra-sound and Magnetic Resonance Imaging (MRI). These three methods are painless compared with the medical biopsy.

Their advantages and disadvantages are classified in terms of cost, ionizing radiation, accuracy,and scope of application.

4 MICROWAVE IMAGING

Almost 15% screening tests are failed to detect breast cancer using x-ray mammography[45]. Due to the limitation of mammography, it is necessary to develop this non-clinical technique. Due to ionizing nature of x-rays, eight out of 1,00,000 patients dies due to yearly screening for a 10years [62].

Microwave Imaging (MWI) for breast cancer is non-ionizing technique. The principle of Microwave Imaging techniques is based on the contrast between dielectric properties, that is, conductivity and permittivity, of healthy and cancerous tissues [46]. Few advantages of microwave imaging over mammography are: the ratio of dielectric properties which are of few percentages with mammography whereas with MWI ratio is 2:1 [48]. MWI also helps to detect the size and stage of the tumor as well as locate the tumor position [45].

There are two types of MWI:

- Active Microwave Imaging
- Passive Microwave Imaging [2][4]

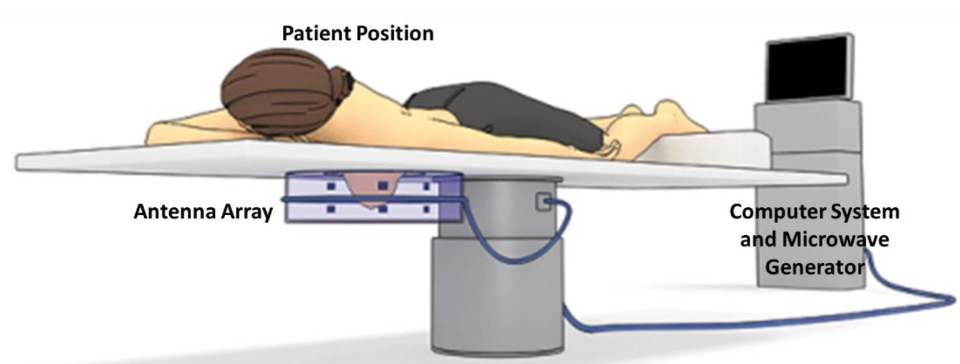
As in the current project, only the active microwave imaging will be under consideration, therefore it will be discussed in detail here. It will be further divided into two categories like Radar Based Imaging or Microwave Tomography approach. The microwave tomography seeks to reconstruct the electrical profile inside the breast by solving inverse scattering problem. This procedure involves the solving of non-linear functions of mathematical algorithms which causes difficulties in signal processing and reconstruction the image. The radar-based imaging method originates from ground-penetrating radar (GPR) and was proposed for breast cancer detection [41]. This method focuses on the detection of objects such as tumors by creating images based on the high dielectric difference between a tumor and surrounding healthy tissues.

4.1 Basic Working Principle:

For typical microwave tomography, the patient lies on an examination table with the breast through a hole and surrounded by a tank, as shown in Fig 4.1. An antenna array configured in the tank is immersed in coupling liquid to reduce noise and the discontinued electrical boundaries which cause multi-reflections. This the antenna array is composed of several antennas to transmit and receive microwave The contrast in electrical properties of healthy and tumor tissues can be used to determine the tumor's position. Normally, a small antenna such as a monopole antenna is used in a microwave tomography prototype to maximize the number of configured antennas. The antenna array rotates vertically in a small step to scan the breast. At each stop position, one antenna is used as transmitting antenna to transmit incident wave and the rest antennas are as receiving antenna to receive scatter wave [41]. These received signals are normally processed by the solving of non-linear functions, and this is the most difficult part of microwave tomography. It is worth noting that microwave tomography attempts to reconstruct a map of all electrical properties of the breast,

whereas radar-based microwave imaging only focuses on imaging the tumor rather then the whole breast.

Figure 4.1: Microwave Tomography



Source: http://www.chalmers.se/en/projects/Pages/Microwave-tomography-for-breast-cancer.aspx.

4.2 Radar-based Microwave Imaging

The basic working of radar-based imaging is on the reconstruction of imaging from the collection of scattered signals in the far field using transmission and receiving antennas of the microwave. Radar-based technique locate the position of the tumor and focused on the image of tumor instead of complete breast. It works well with low frequencies as at a low frequency of electromagnetic radiation penetrates deeper.

4.2.1 Advantages of Microwave Imaging (MWI)

Due to poor efficiency and cost of mammography, a cheap, more sensitive and precise solution for breast cancer screening, microwave imaging may be that required technique in near future due to following reasons

- Microwave Imaging is non-invasive and non-ionizing in nature [62]
- Early stage detection: The concentration of water is higher in the malignant cells as compared to normal cells [19]. Therefore, MWI can detect cancer at very early stages and the images produced by MWI are also high in the resolution [42]
- High dielectric contrast for malignant breast tumor [62]
- Probably inexpensive [62]

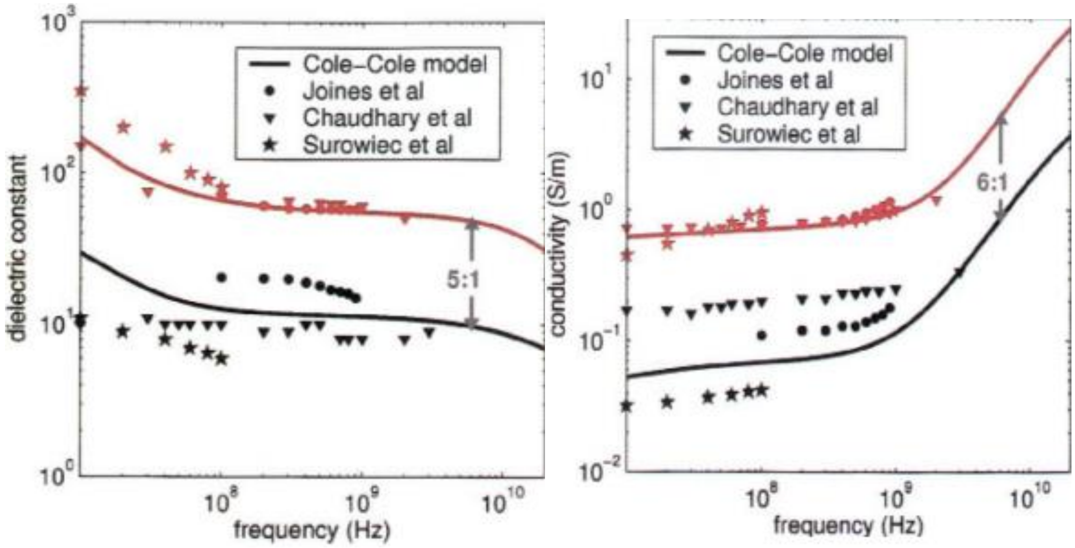
4.3 Electrical properties of Tissues

Microwave imaging for cancer detection was based on the electrical properties of cancerous and surrounding tissues [62]. Cancerous cells or tissues have high water contents as compare to the healthy tissues like fatty tissues [19] [41] [62]. Attenuation of microwaves is related to the conductivity of tissues whereas, storability linked with the permittivity when electromagnetic microwaves are interacting with tissues [41]. The contrast for relative permittivity and conductivity of malignant to normal breast tissues across 3MHz to the 3GHz range is of 4.7:1 and 5:1 respectively [63]. The relative permittivity and conductivity of normal, benign and malignant tissues have also been measured in the range between 500MHz to 20 GHz [51]. From measurements of dielectric properties with respect to specific frequency, A Cole-Cole model has been developed based on relative permittivity and conductivity of tissues, as given in Equation 4.1 [41].

$$\varepsilon_{\omega} = \varepsilon_{\infty} + \frac{\varepsilon_{s} - \varepsilon_{\infty}}{1 + (i\omega\tau)^{1-\alpha}} \qquad 4.1$$

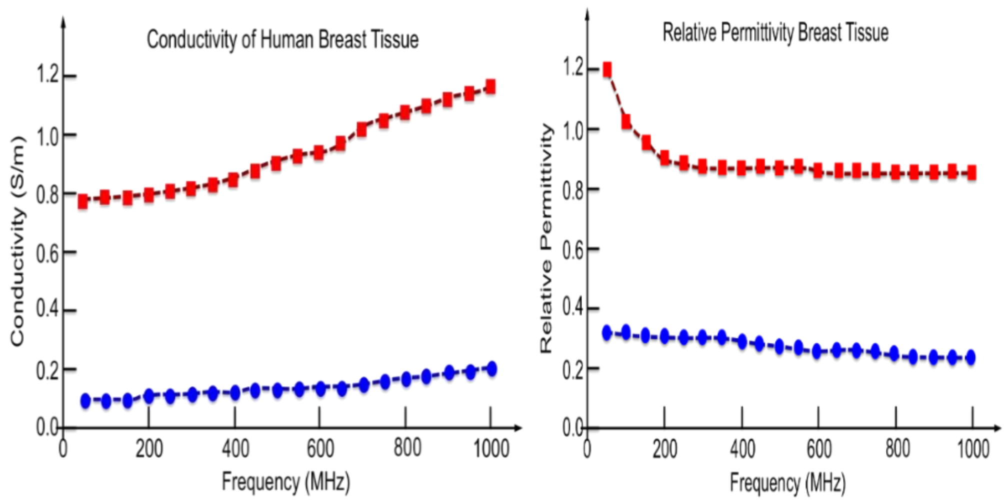
where ω and α are the angular frequency and exponent parameter, ε_s, τ *and* ε_{∞} are static frequency permittivity constants, time constant and infinite frequency permittivity constants respectively. Fig 4.2 shows that the Cole-Cole model of several studies of the relative permittivity and conductivity of benign and malignant tissues.

Figure 4.2: Measured Relative Permittivity and Conductivity. Black: Benign tumor, Red: Malignant tumor



Source: LAZEBNIK, M.; L. McCartney; D. POPOVIC; C. B. WATKINS; M. J. LINDSTROM; J. HARTER; S. SEWALL; A. MAGLIOCCO; J. H. BOOSKE; M. OKONIEWSKI and S. C. HAGNESS, A Large -Scale Study of the Ultrawideband Microwave Dielectric Properties of Normal Breast tissue Obtained from Reduction Surgeries‖, Physics in Medicine and Biology, Vol. 52, pp. 2637–2656, 2007.

Figure 4.3: Dielectric Properties of malignant (red line) and healthy (blue line) of human Breast Tissues.



Source: Ybarra, G.A; Liu, Q. H.; Stang, J.P.; Joine, W.T. Microwave Breast Imaging. Emerging Technology in Breast Imaging and Mammography, p. 1-12, 2007

5 ANTENNA THEORY

The antenna is an electrical device which converts electrical power/current into radio waves and vice versa [52]. Antenna efficiently radiates and receive electromagnetic waves. The antenna can also be defined as, "Transducer designed to transmit and receive Electromagnetic Wave" [52].

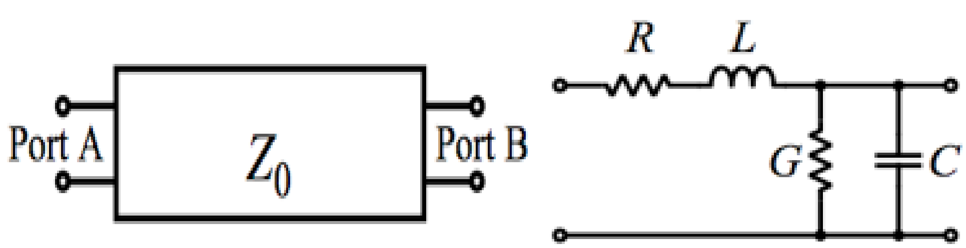
To provide better results for MWI antenna design and features are really important. Antennas are selected by analyzing antenna parameters like dimensions, shape, material, and bandwidth of antennas [49] [19]. For better understanding, the working of antenna few parameters like radiation pattern, transmission lines, matching and reflection, directivity, antenna gain,and polarization have to be understood completely.

5.1 Antenna Parameters

5.1.1 Transmission Lines

Transfer of power from the input port to the output port through transmission lines which described as characteristic impedance $Z_0$and losses in free space [52]. In figure 5.1, a two-port transmission line is shown, where port A is for input and port B is for output. Depending on the type of antenna and the application of antenna, the value of characteristic impedance is different. Usually, for medical application, Z_0 is 50 ohms or 75 ohms with coaxial cable.

Figure 5.1: Two-port transmission Lines(TL) (on left) and TL elements (on right)



Source: JENSEN, S. Microstrip Patch Antenna. Northern Arizona University, 2010

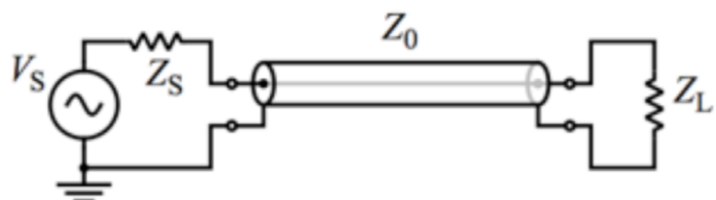
The equivalent circuit components of transmission lines are, resistance R, inductance L, capacitance C and Inductance G as shown in figure 5.1 [53]. For the better working of the antenna, the input impedance must be equal to the characteristics impedance of antenna [52].The mathematical relation for this is;

$$Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}} \qquad 5.1$$

5.1.2 Matching and reflection

For the transmission of power between the input port and output port (load which is an antenna) the characteristic impedance of transmission line must be equal to load impedance that is $Z_L = Z_0$ [52]. Characteristic Impedance is a frequency dependent parameter, to avoid back reflection the $Z_L = Z_0$condition must satisfied for required frequency [52].

Figure 5.2: Transmission line between source and load



Source: JENSEN, S. Microstrip Patch Antenna. Northern Arizona University, 2010

Mismatch cause heating up of the system or damaging of the system due to back reflection, therefore, the impedance matching is a very important factor to pay attention to power flow [52]. The reflection coefficient is a factor to calculate the back reflection of the source, mathematically [72];

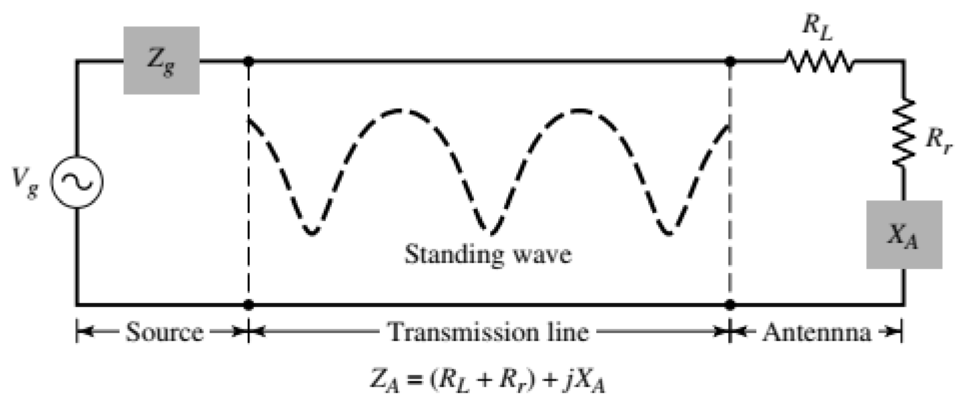
$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} \qquad 5.2$$

Whereas Z_L and Z_S are load and source impedance respectively and Γ is reflection coefficient. Reflection coefficient is a complex function, if imaginary part is zero then Γ =-1 and cithe rcuit is referred as short, for $\Gamma = 0$ is casa e of perfect matching and $\Gamma = +1$ is conda ition for open circuit [52].

5.1.3 Scattering Parameters (S-parameter)

Normally, scatter parameters are used to describe the reflected energy. Consider a black box with port 1 and port 2, where port 1 is the energy input port and port 2 is the output port. S_{11} represents reflected energy from port 1 while S_{21} shows the transferred energy from port 1 to port 2. S_{11} and S_{21} are known as the reflection coefficient and forward transmission coefficient, respectively. The loss or gain of the transmission line can be calculated by s-parameters which refer as an output voltage to the input voltage and can be measured in dB [54].

Figure 5.3: S-parameters in a two-port network S parameter



Source: BALANIS, C. A., Antenna Theory Analysis,and Design. A John Willey and Sons, Inc., 3rd Edition, 2005.

S_{11} input port voltage reflection coefficient, S_{12} reverse voltage gain, S_{21} forward voltage gain,and S_{22} are output port voltage reflection coefficient. S-parameters measured by Vector Network Analyzer [52].

5.1.4 Directivity and Gain

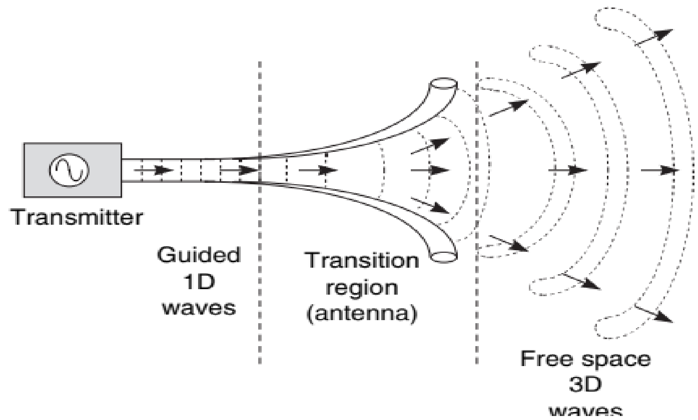
Fundamental parameter of antenna which measure the degree to which the radiation emitted is concentrated in a single direction. Directivity has a directrelation with a gain of the antenna. Directivity enhances the efficiency of antenna/gain of the antenna [52]. Gain is a value of antenna, which depends on directivity. Mathematically,

$$G = \eta \bullet D \qquad 5\text{-}3$$

5.1.5 Antenna radiation

Due to the flow of current radiation is produce around the antenna which is shown in figure 5.4 below. The electric field is created in the transmission line which creates the flow of electric current [55]. With time-varying, electromagnetic waves produced due to movement of free electrons. Electromagnetic waves radiate within the transmission lines and approaches to open air whereas closed loop in free space [52].

Figure 5.4: Antenna Radiation Propagation



Source: SAUNDERS, S. R.; ZAVALA, A. A. Antennas and Propagation for Wireless Communication Systems, Willey, 2nd Edition, 2007.

5.1.6 Near Field and Far Field

The radiation field can be represented by three regions: the reactive near field (Rayleigh Zone), radiating near field (Fresnel Zone) and far field (Frauenhoffer Zone), as shown in Fig 5.5. Hence, the calculation of the power flow density is too complex, since the phase and angle relationship of E and H changes with the radiation direction. The boundary of this region [53] is given by

$$R < 0.62\sqrt{\frac{D^3}{\lambda}} \qquad 5.4$$

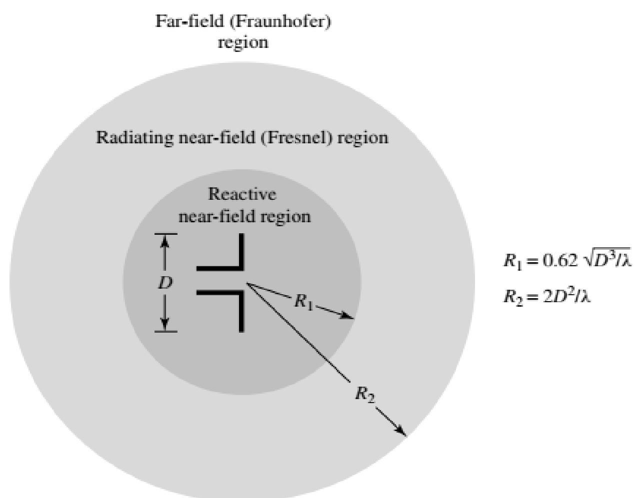
In the radiating near field, the progressively reduces along thedistance. However, the radiationfield also changes with the radiation direction. The boundary of the radiating near the field is given by:

$$0.62\sqrt{\frac{D^3}{\lambda}} < R < \frac{2D^2}{\lambda} \qquad 5.5$$

In the far field, the radiation pattern does not change with radiation distance and can be approximated as a plane wave or spherical wave. The E field and H field are orthogonal to each other. The boundary of the far-field region is given by

$$\begin{cases} R > \frac{2D^2}{\lambda} \\ R \gg D \\ R \gg \lambda \end{cases} \quad 5.6$$

Figure 5.5: Definition of Radiation Field Regions



Source: BALANIS, C. A., Antenna Theory Analysis,and Design. A John Willey and Sons, Inc., 3rd Edition, 2005.

The targeted object can place beyond the limit of Fraunhofer region (far-field region)for better response of the antenna. In near field, the reactance energy can observe properly whereas in far-field radiation energy focused [55].

5.1.7 Array of Antenna

To enhance the overall gain and directivity of the antenna systems for specific applications, more than one element of the same antenna is used without the change of design and dimensions of the antenna element. In this way, individual antennas elements assembled electrically and geometrically and form a new antenna which is called antenna array [64]. The current in each element is assumed to be same [53] but the overall radiation pattern of the array of antenna or antenna array is changed [64]. Array factor is a factor to measure the radiation pattern of an array of the antenna [64]. There are five parameters or the conditions which can help to attain the required radiation pattern of the antenna array which is given below [53];

- Geomaterial Arrangement of antennas to for an Array;
- The relative position of Array Elements;
- Relative pattern of individual elements;
- Excitation phase of individual elements;
- Excitation amplitude of individual elements;

In the present case, the circular array is used for the scanning of the breast through 360^0. Furthermore, the antenna array is represented by two parts that are geometric array and pattern array [53]. The physical location of elements defined as a geometric array which can be uniform or non-uniform in the arrangement. All elements in an array are assumed to be isotropic and the combination of all pattern of each element is known as array pattern which is a function of array geometry [53].

5.1.8 Mutual Coupling

For an array of antenna, one element is transmitting and other is receive the signals which are intrinsic nature of antennas even for the transducers, one antenna acts like either transmission or receiver antenna. The amount of receiving the energy (in term of signals) depends on the relative position and separation of antennas from each other. Each antenna re-scatter some energy also. That means antennas interchange energies either by direct scattering (direct path) or re-scattering (indirect path) which is due to mutual coupling of antennas. Mutual coupling f antennas are acceptable in some specific range and to attain that two factors need to be maintained carefully that is i) radiation characteristics for a specific application and ii) position with respect to elements and orientation of each element [53]. In the circular array, that is in the present case, the factors which affect the mutual coupling depends on i) type and required parameters to be studied, ii) relative position, iii) feed of array and iv) volume of the antenna [53].

6 METHODOLOGY OF PROJECT

This chapter will cover the methodology and technical details of the project. The simulation of antennas is done using High-Frequency Structure Simulator (HFSS) software of ANSYS. Three designs of antennas were made. Antennas were tested with multilayered phantom with breast dielectric properties. This chapter focuses on phantom design, experimental setup,and signal collection. Antenna parameters were simulated and manufactured for this project. The project proceeded from four steps of analysis like;

- Optimization of Antenna Design
- Optimization of Antenna Substrate Material
- Experimental analysis of designed antennas
- Antenna performance with Breast Phantom

A microwave imaging system is composed of the microwave source, a network of computer-controlled switches, transmission lines feeding an array of transmitting and receiving antennas, chamber whose interior contains the breast to be imaged, detector, and computer for data post-processing/image formation.

For imaging, different physical parameters like radiation gain, resonant frequency return loss and power gain of the antennaare of great importance, which depends on the antenna geometry (width, length, height,and shape). The shape of the antenna is one important parameter to be designed for the illumination of the phantom (artificial objects of human tissues or organs) from all the directions [61]. This analysis will require powerful processing computer to carry out theoretical analysis and simulations by HFSS.

In summarized form, the study will follow the following steps:

- Microwave Antenna Design
- Microwave and tissue interaction theoretical analysis
- Device fabrication and characterization
- Simulation of Antenna using Phantom
- Experimental analysis of microwave and tissue interaction

Microwave devices should be designed in spectrum range from 2GHz and different shapes likea rectangular patch antenna, bow-tie patch and split rectangular patch antenna analyzed to improve performance.

6.1 Simulation of Antenna

To make the transmission/receiving antenna with suitable frequency range (1-3 GHz) and minimum return loss (>-10dB), we must focus on the following parameters,

- The shape of the Antenna
- Required Frequency
- Substrate Material

To check all these parameters, antennas will be designed using High-Frequency Simulation Structure (HFSS).

6.2 Inhomogeneous Breast Phantom

The breast as a communication media is modeled by several biological tissues and each biological tissue is defined as a dispersive dielectric in a homogeneous medium using three electric parameters: relative permittivity, loss tangent and mass density. By stacking several homogenous layers to mold an inhomogeneous environment using HFSS. The multilayer model that is used to design the antenna array includes skin, breast tissues, and tumor. An inhomogeneous hemisphere phantom of the breast is made with the following properties. Tumor of 2mm and 5mm with permittivity of 13.1 and 16.1 which is the dielectric property of the malignant type of cancer. Skin layer of 36 and breast tissues of 10.0 permittivity.

6.3 Vector Network Analyzer

In this project, a portable miniVNA tiny network analyzer is used for antenna analysis. It works in the frequency range from 1 MHz to 3GHz. It’s a low power device with 5V and 370mA current consumption. There are two ports DUT (device under test) and DET (detector) port and S11 and S21 parameters can be observed with this device.

Figure 6.1: miniVNa tiny (1MHz-3GHz frequency range)

7 DESIGN OF MICROWAVE ANTENNAS

The focus of this thesis is to work on the development of antenna for breast cancer detection technique. For the development of antennas, substrate material and design of antenna are very important to investigate for the development of MWI system. For this purpose, the required scattering parameters like return loss, impedance, gain directivity are carefully investigated for selection of design and material for the medical application. Therefore, the scattering parameters are strongly affected by geometric parameters like width, length, height and shape of the patch for required frequency. Substrate material also allows best coupling and propagation of electromagnetic field inside the antenna.

The microwave imaging system can detect the tumor of the small or large size of tumors. The present work provides the simulated results of microwave breast cancer detection technique integrating of a wideband oscillator, a source of energy and a number of compact microwave antennas in the array configuration. To get the suitable characteristics of microstrip patch antenna three designs are simulated and designed for this project which further use for the detection of breast cancer.

7.1Types of Antenna

Microstrip patch antennas are designed with microwave frequency range[66] [65], Three designs of the patch are analyzed in this present project which are;

- Microstrip Rectangular Patch Antenna;
- Bow-Tie Antenna;
- Rectangular split patch Antenna.

In this project, along with the specific design, the material of substrate also analyzed. Some basic parametric behavior will mention in design optimization section of this chapter. These types are chosen because of its ease of manufacturing [30], low cost and high reliability to detect at a curable stage of the tumor [30] [55].

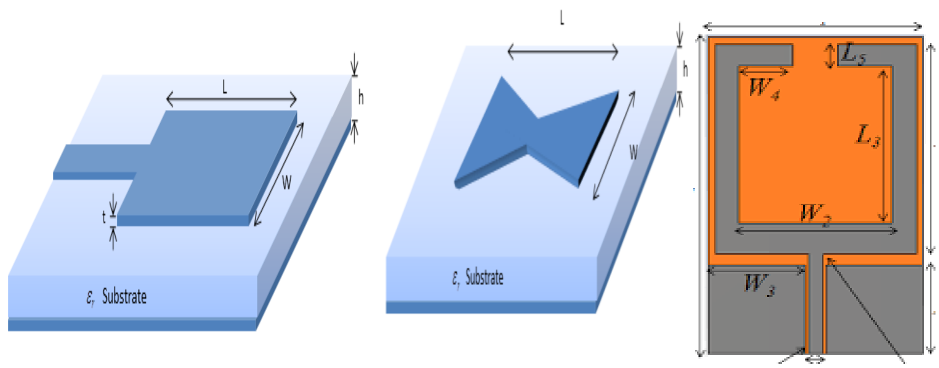
7.1.1 Microstrip Patch Antenna

Microstrip patch antenna has a frequency range from 100 MHz to 100 GHz. A Patch antenna consists of at least three layers, the first layer of metal ground, second dielectric substrate and third of metal again [56]. Microstrip patch is designed on the metal surface and feed by either feed line or coaxial cables. Three different shapes of microstrip patch antennas use in this project are shown in the figure below;

Table 7.1: Geometrical Parameters of Patch Antenna

Layer	Material	Reference
Ground Layer	Metal	[56] [65]
Layer 2 (Substrate)	Dielectric	[56]
Upper Layer	Metal	[56] [65]

Figure 7.1: Microstrip Patch Antenna design, a) Rectangular Patch, b) bow-Tie and c) split rectangular Patch Antenna



(a) (b) (c)

Source: [53] BALANIS, C. A., Antenna Theory Analysis,and Design. A John Willey and Sons, Inc., 3rd Edition, 2005. [58] Haider R. Khaleel, Hussain M. Al-Rizzo and Ayman I. Abbosh. Design, Fabrication,and Testing of Flexible Antenna. INTECH, 2013. ODI: 10.5772/50841. http://dx.doi.org/10.5772/50841

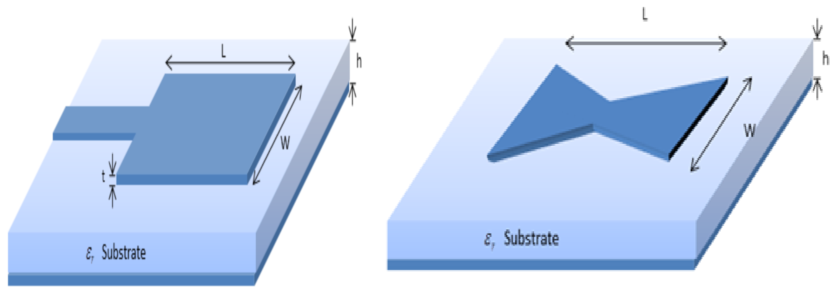
The length, L (in Figure 7.1 (a) of the patch is almost half of the wavelength [55]. The electric field is approximately perpendicular to the patch whereas the magnetic field is approximately parallel to the patch [55]. The resonant frequency is fed by a feed line to the antenna patch [55].

All the above types of antennas, there importance and applications are briefly discussed in next section below.

7.3 Design Optimization of Microstrip Patch Antenna

Antennas are designed for a specific frequency, in present project antenna for 2GHz frequency are designed because of the penetration of radiation ability at low frequency. To get the desired frequency, geometric parameters like length width etc. of the antenna of specific shape are required. For a currentproject, we have three different shapes, the characteristic impedance is set at 50 Ohms because the antennas used for medical applications have 50 ohms impedance [53]. For Patch antenna, the mathematical expressions shown below in table 7.2 for design measurements of patch antenna [67] [68].

Figure 7.2: Microstrip Patch Antenna



Source: BALANIS, C. A., Antenna Theory Analysis,and Design. A John Willey and Sons, Inc., 3rd Edition, 2005.

7.4 Mathematical Relation to Microstrip Patch Antenna Design

Figure 7.2 present schematics for both Bow-Tie patch (right) and Rectangular patch (left) pointing out major geometry parameters necessary to design. Geometric parameters affected by the substrate material because effective permittivity of the substrate is differenct for different material and therefore the thickness of substrate changes and characteristic impedance (Z_0) as mention in table 7.2 [68] [57] for bow-tie patch and rectangular patch.

These parameters help to obtain Z_0 nearby 50 ohms, once for both designs, Z_0 is strongly dependent on the width (w) of patch and height of substrate (h). The High-Frequency Structure Simulator software (ANSYS HFSS) simulated and calculated Return Loss, Gain and Electromagnetic Field Distribution of antennas.

Table 7.2: Effective Permittivity, Parameters, and Impedance

Effective Parameters	**Characteristic Impedance**
For Patch antenna when w/h≥1 $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[[1+12h/w]^{-\frac{1}{2}} + 0.4(1-w/h)^2\right]$	$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} ln\left[\frac{8h}{w} + \frac{w}{h}\right]$
For Patch Antenna when w/h<1 $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[[1+12h/w]^{-1/2}\right]$	$Z_0 = \frac{1}{\sqrt{\varepsilon_{eff}}} \frac{120\pi}{\left[\frac{w}{h} + 1.393 + \frac{2}{3} ln\left[\frac{w}{h} + 1.444\right]\right]}$
For Bow-Tie $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[[1+12h/a]^{-1/2}\right]$	$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} ln\left[\frac{8h}{a} + \frac{a}{h}\right]$

Source: M. K. A. Rahim, M.Z.A. Abdul Aziz, C.S.Goh. Bow-tie microstrip antenna design. 2005. IEEE, doi: 10.1109/ICON.2005.1635425.

Source: Priyadarshi Suraj 1 and Vibha Rani Gupta; Analysis of a Rectangular Monopole Patch Antenna, International Journal of Recent Trends in Engineering, Vol 2, No. 5, November 2009.https://www.researchgate.net/publication/229036248

7.5 Material of Antenna

Different substrate materials are studied for these three types of antennas with 2 GHz operating frequency and the results are published [69]. Traditional non-flexible and flexible antennas are designed. The material selected for flexible and non-flexible antennas are;

- FR4;
- Polyester;
- Pyralux Polyimide;

The size of the antenna is dependent on the thickness of the substrates and the required frequency [70]. Flexible antennas are basically designed to make some wearable device to reduce the pain of the patient suffered during mammography. Flexible antennas are designed using polyester and pyralux polyimide substrates and the performance of antennas are comparable to traditional FR4 non-flexible antennas.

7.6 Advantages and Disadvantages of Patch Antennas

Microstrip patch antennas are increasing in popularity for use in medical applications [33] [69] due to their low-profile structure;

- Lightweight and low volume [69];
- Low profile planar configuration which can be easily made conformal to hostsurface [69];
- Low fabrication cost, hence can be manufactured in large quantities [69].

Microstrip patch antennas suffer from several disadvantages as compared to conventional antennas. Some of their major disadvantages [69] below:

- Narrow bandwidth [67];
- Low efficiency [67];
- Low Gain [67];

But the low gain and efficiency can improve using the array of antennas [69] [70] [71] for which the compact antennas must design to increase the number of antennas. In this chapter,various materials of flexible and non-flexible with different designs of antennas are investigated and discussed which will further be used to diagnose a tumor in breast phantom.

7.7 Review of Microwave Imaging

Microwave breast cancer imaging using microwave antennas is an underdevelopment diagnostic tool for breast cancer. From last one and half decade this technique developed with more strength due to the high contrast of dielectric properties of cancer tissues [30] in microwave frequency range. This technique can be an alternative technique to x-ray mammography due to tissue characterization capability. Mammography has some drawbacks likethe low-resolution image, painful diagnostic way, high risk of death due to false results as well as late diagnosis and expenses of diagnosis.

To overcome these issues, MWI technique is quite feasible due to high proficiency, cost-effective technique[68] [70] [70] but still underdeveloped. To add in the development of microwave breast imaging the present project is designed.This is a cost-effective technique with manufacturing advantages like easy fabrication, lightweight and compact size with flexibility [69].

7.8 Microstrip Patch Antenna

For frequency higher than 6 GHz the penetration of the radiation through the skin is reduced but the resolution gets higher [69]. Therefore, for the medical application, 1-6 GHz frequency is good [69] for high penetration through skin and microstrip patch antennas with 2 GHzfrequency are designed with a narrow band, high gain and directivityfor this purpose. The resolution can be improved by having a large number of antennas of same frequency and design per unit area [69]. Microstrip patch antennas are easy to fabricate and easy to make antenna array. Microstrip patch antennas are simulated using HFSS. Microstrip Patch antennas are also a good selection of antennas due to its parametric features likes,

- Flexible selection of Position of Feedline;
- Compact size;
- Radiate into the half plane;
- S-Parameters;

- Impedance matching;

Three materials like FR4, Polyester,and Pyralux Polyimide substrates are used to design three different microstrip antennas. The FR4 material is used as a reference antenna as FR4 is a standard material used for compact antenna manufacturing. Whereas, polyester and pyralux polyimide substrates are used to make flexible antenna [71].

The rectangular patch antenna is fed by a feed line whereas; other two are fed by coaxial cable. To check the performance of antenna few important characteristics parameters have been analyzed for the required properties of the antenna for specific applications. Therefore, the antennas are simulated using HFSS to optimize the characteristics properties like return loss, gain,and directivity of the antenna.

The Performance of antenna for breast cancer detection was also tested in simulations using the breast phantom with dielectric properties of the breast with a malignant tumor.

7.9 Rectangular Patch Antenna

Rectangular Microstrip Patch antenna of approximately 2GHz resonating frequency is designed for FR4, polyester,and Pyralux Polyimide substrate material. The inset-fed gap design is designed for FR4 with 2.5 GHz frequency using HFSS [33] for medical applications as shown in figure7.3 [33]. The modified dimensions of the antenna for three types of substrates are given in table 7.3 for all substrate materials. The relative permittivity of FR4 is 4.4,relative permittivity of flexible substrate that is pyralux polyimide is 3.5 and of polyester is 3.2. The parametric properties of antennas are showing in figure 7.3. For the medical application, the acceptable antenna has S-parameters of antenna less than -10dB with specific resonance frequency [59]. In table 7.3, the geometric parameters for 2 GHz frequency for three substrates, that is, FR4 the standard non-flexible material, Pyralux polyimide (PP) and Polyester which are flexible materials of the substrate are shown.

Figure 7.3: Inset-Fed Patch Antenna Design

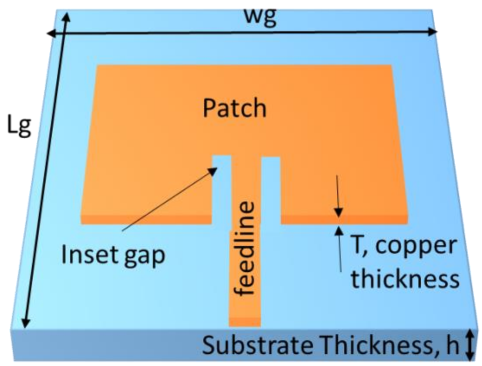


Table 7.3: Dimensions of Rectangular Microstrip Patch Antenna

Dimensional Parameter (mm)	**Substrate of Rectangular Patch**		
	FR	**PP***	**Polyester**
Lg, ground and substrate	60	65	65
Wg, substrate width	72.	90	92
T, Copper thickness	0.0	0.035	0.03
h, Substrate thickness	1.6	0.0508	0.36
W, width of patch	36	36	49
G, length of patch	35.	35	38
Wf, Feedline width	3.1	2.896	4
Lp, Feed line length	35	55	55
Fi, length of Inset fed	11	12.82	29.9
Gap	1	1.5	1.5

7.9.1 Antenna Geometry

The size of traditional FR4 substrate antenna is 72.041 x 60mm^2 and for flexible patch antenna is 90 x 65 mm^2 and 92 x 65mm^2 for pyralux polyimide and polyester respectively. FR4 is a standard non-flexible antenna material which is used to fabricate using printed circuit board (PCB). Ground and patch of the antenna are made of copper of 35µm thickness. In the present case, the antenna is vertically polarized, therefore, propagation of radiation antenna is along the y-axis.

The factors which affect the performance of the antenna are ground plane, inset fed gap and substrate material [72] [73]. The geometrical parameters which generate impedance mismatching are;

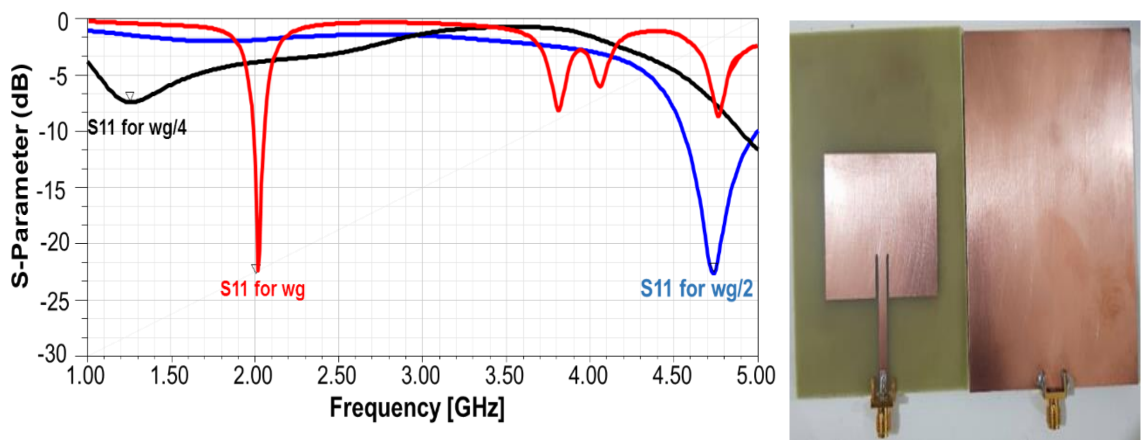
- Ground Surface of Antenna;
- Inset Fed Gap;
- Substrate Material;

Effect of width and length is already mentioned in the section of antenna theory whereas the effect of ground surface and inset fed will be done in the next section. The ground surface size is changed from wg/4 towg and the inset fed from 0.5-1.5mm. Whereas for the required frequency the width and height of the patch are calculated by formulas of antenna theory.

7.9.2 Effect of Ground Surface of Antenna

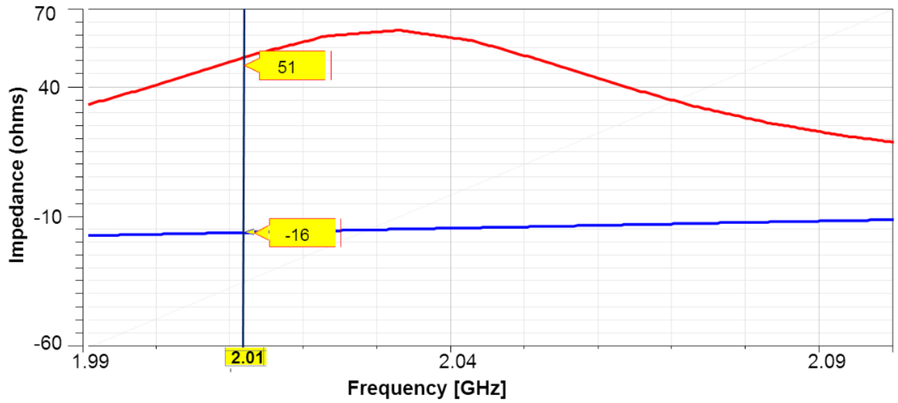
The ground plane affect the impedance and resonance frequency of rectangular patch antenna [65] which is also analyzed presently for selection of better dimensions of the ground antenna. The size of ground is very important parameter which effects the impedance of the antenna and the resonance of frequency.

Figure 7.4: S-Parameter for Different Lengths of Ground Plane



By changing the size of the ground plane, the resonating frequency of antenna changes as shown in figure 7.4. As currently, the antenna of 2 GHz is using which obtained only by the complete length of the ground. The characteristic impedance also satisfied with this configuration of the antenna as shown in figure 7.5.

Figure 7.5: Impedance of Patch Antenna for full copper ground

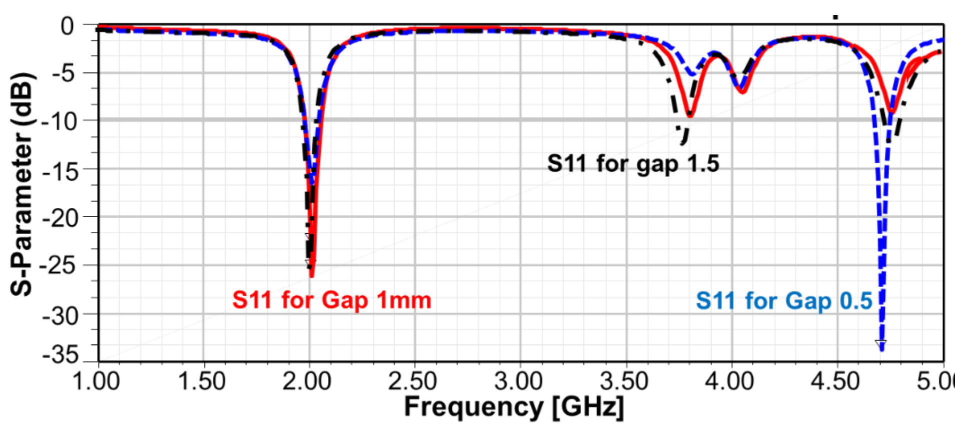


For the acceptable configuration of the antenna, the impedance must be about 50 Ohm and s-parameter of <-10dB. Therefore, for the required impedance of the antenna, the best design for this type of antenna must be covered with a complete ground of copper material.

7.9.3 Effect of Inset Fed Gap

For microstrip patch antenna, feed line help to reduce the impedance. If the coaxial cable directly connectsto the patch the impedance is very high but using feed line,

Figure 7.6: Simulation result of S11 for Rectangular Patch antenna with different values of Inset fed gap (0.5-1.5mm)



impedance reduces [73] to 50ohms or 75 ohms as per requirement of the system. In addition to the feedline, inset fed is advantageous to help the distribution of same impedance in an array of the antenna [73].

Figure 7.7: Simulation Impedance of Patch antenna with different values of Inset fed gap (0.5-1.5mm)

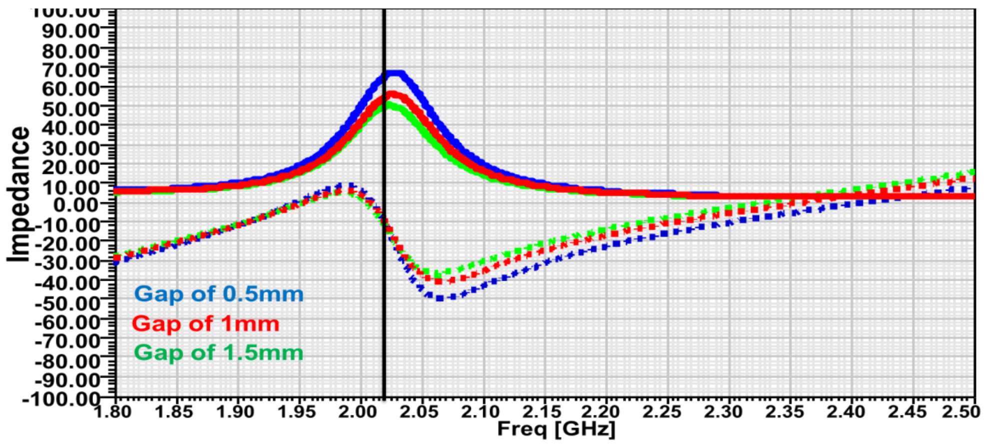
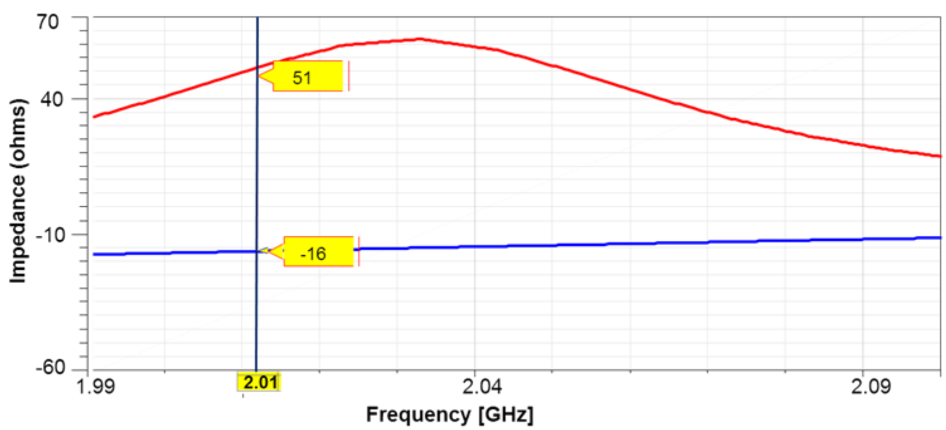


Figure 7.8: Simulation Impedance of Patch antenna at a 1mm gap of inset



Therefore, inset fed gap is also a very important parameter to study. Figure 7.6 and 7.7, shows S11 of a patch antenna for different inset feed gaps that are from 0.5-1.5mm and characteristic impedance respectively. The other parameters of antennas remain the same, to analyze the effect of a fed gap on return loss with respect to impedance matching of the circuit. The observation of s-parameter shows that the patch antenna is no more single band for a gap of 0.5mm and 1.5mm as shown in figure 7.6. Figure 7.7 shows that the impedance also not match to 50 Ω for multiband frequency antenna. It is clear from figures7.6-7.8 that the s- parameter and impedance both parameters are affected by changing the gap of inset feed, only at 1mm gap the impedance is about 50 ohms which are showing in figure 7.8.

7.9.4 Effect of Substrate Material

From the antenna theory, dimensions of the antenna depend on the relative permittivity of substrate material [53] [71], therefore by changing the substrate material the size of antenna changes [71]. Table 7.3 gives the dimensions of patch antenna with different substrates with 2 GHz frequency and in figures 8.8, the s-parameter is given for all substrates that are, FR4, pyralux polyimide,and polyester. The resonance frequency of all substrates is, 2.01 GHz for FR4, 2.00 GHz for polyester and 2.13 GHz for pyralux polyimide (PP).

Figure 7.9: S-Parameter in dB of Rectangular Patch Antenna for all substrates

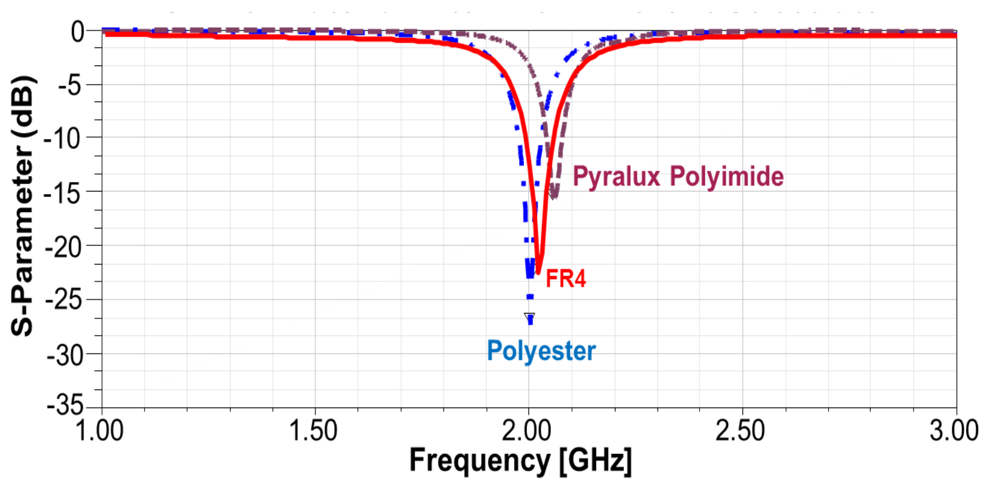
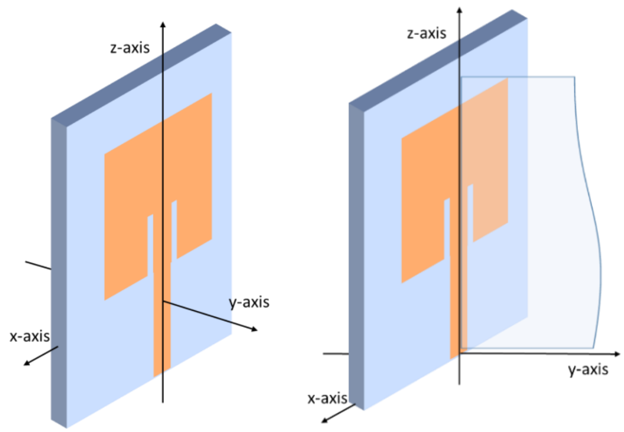


Figure 7.9 shows that the three substrates that are FR4, polyester,and pyralux polyimide are suitable for rectangular patch antenna for breast cancer imaging as all these have S11 than -10dB. Printed monopole antenna simulates using HFSS for all substrate sandwich between two layers of copper matel. The antenna is fed via a 50 ohms microstrip feed line. The plane of ground has its own importance as mismatching of impedance is occurred by removal of the ground plane.

7.9.5 Propagation of Radiation in Antenna

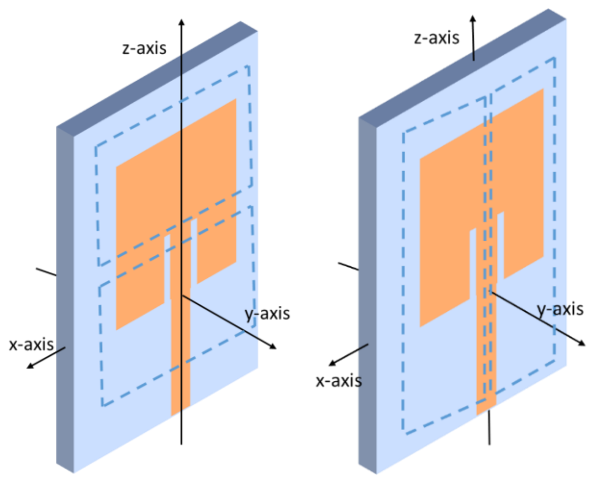
The antenna configuration is shown in the figure 7.10 (a) below. The excitation field is along the edge of the feed line. Propagation of radiation of patch antenna is at a perpendicular to the patch of the antenna, which is along the y-axis as shown in figure 7.10 (b). The

Figure 7.10: Propagation of radiation in Rectangular Patch Antennas



(a) (b)

Figure 7.11: Propagation of radiation in Rectangular Patch Antennas

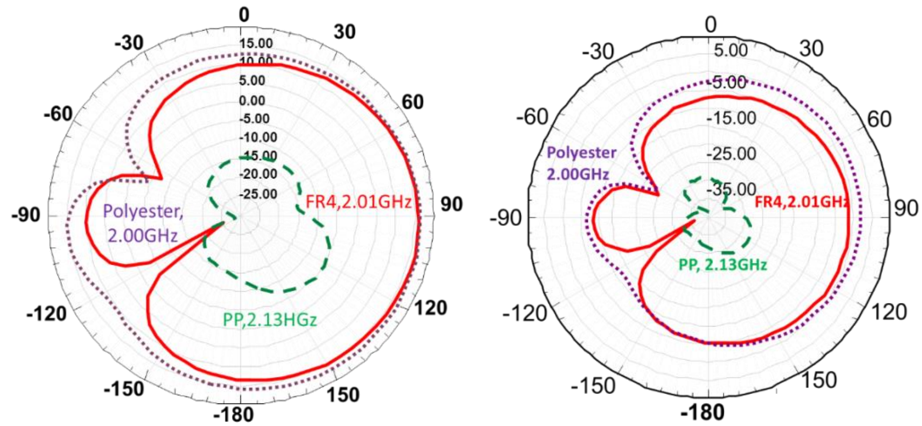


(a) (b)

Excitation field is along the z-axis and propagation of the field in along y-axis due to the property of perpendicular propagation of radiation. The electric field is perpendicular to the patch and magnetic field is parallel to the antenna. There are two sections of the propagation field as shown in figure 7.11. In Figure 7.11 (a) propagation in feed line along the z-axis, the left and right sections of the antenna are identical but the top and bottom of the section of the patch have a different pattern as shown in figure 7.11 (b).

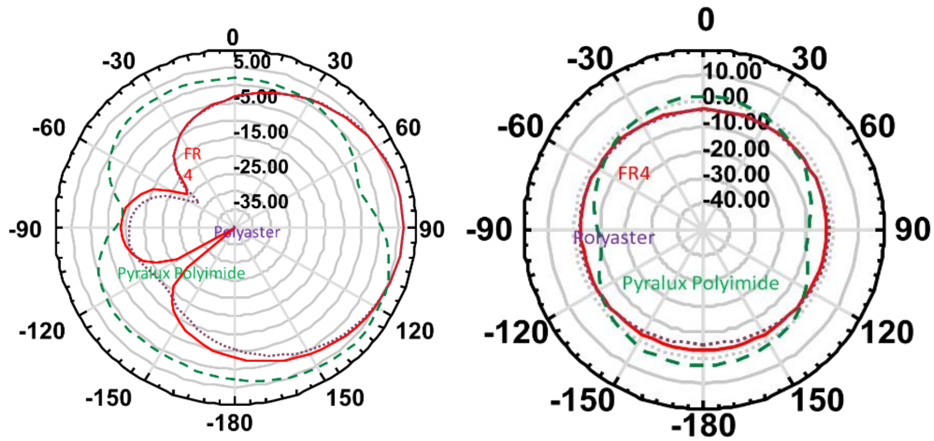
Whereas in the present case, the radiation pattern as shown in the figures in the radiation section shows that the propagation of radiation is along the y-axis, in my plane the radiation pattern is different as compare to yz-plane but same in xy- and –xy plane. This difference of radiation pattern is due to feed line in xy-plane and the flat edge of patch along yz-plane.

Figure 7.12: Elevation plane radiation distribution of Rectangular Patch Antenna for all substrates a) rEtotal and b) Gain



(a) (b)

Figure 7.13: Elevation plane radiation distribution of Rectangular Patch Antenna for all Substrates a) Directivity and b) H-plane directivity



(a) (b)

Figure 7.12-7.13 shows the electric field, gain,and directivity of the antenna for three different substrate materials at resonance frequency for phi=90^0. The Gain of pyralux polyimide antenna is very low as compare to Fr4 and the size of the antenna with pyralux polyimide is too large. But the directivity of the antennas at phi=0^0 and 90^0 shows that the type of flexible substrate can be used for the medical application. Due to low gain and large size of the flexible antenna as compared to the FR4 material, more designs have to analyzed for the compatc sizewith high efficiency in this project.

Printed monopole antenna of planar monopole is affected by changing the size of ground plane, by changing the inset-fed gap and by changing the substrate material which is shown in figure 7.7 to 7.13. The results show that FR4 and pyralux polyimide both types of substrates are highly directive in nature with the same design of the antenna. The gain of pyralux polyimide antenna is low as compare to Fr4 but it can be overcome by array of antenna. But the size of the antenna with pyralux polyimide is too large which forced to test some more antenna design.

7.2 Bow-Tie Antenna

The second design for this antenna for the current project is Bow-Tie antenna. The figure below shows the standard design of bow-tie and modified design of bow-tie. Parameters which affect the characteristics parameters for this antenna are already shown above.

Figure 7.14: Bow-Tie Antenna a) Standard structure of Bow-Tie b) Modified design of Bow-Tie and c) Fabricated Bow-Tie

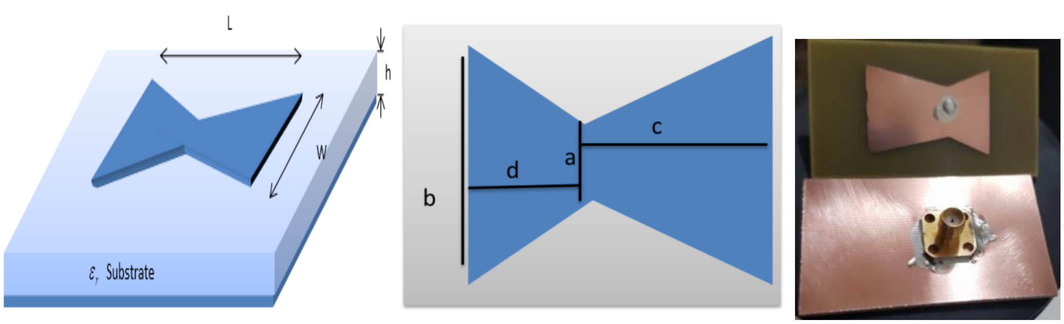
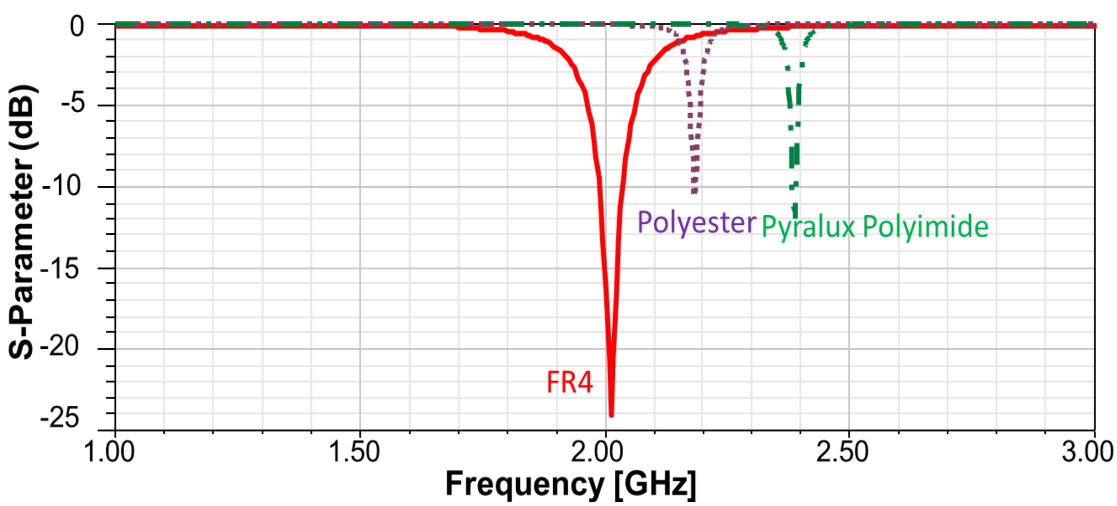


Table 7.4: Dimensions of Parameters of Bow-Tie Antenna

Parameter (mm)	Parameter (mm)	FR4	Polyester	PP
Ground	Patch Width	15	25	20
	Patch Length	40	35	30
	Thickness	0.035	0.035	0.035

Substrate	Thickness	1.6	0.36	0.0508
	Width	35	25	50
	Length	60	50	58
		Bow-Tie Dimensions		
Bow-Tie	a	12	12	14
	b	22	20	27
	c	21	2	24
	d	11	12	5

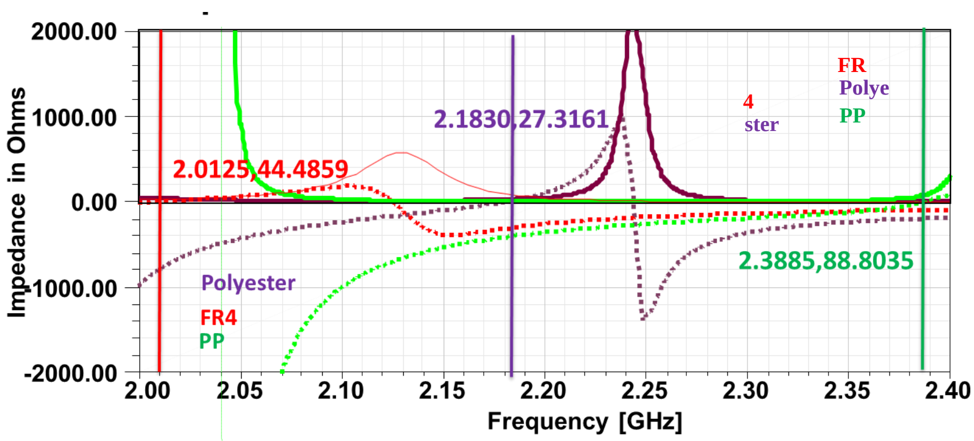
Figure 7.15: Return Loss in dB of Bow-Tie Antenna for both substrates



The rectangular patch antennas are fed by microstrip feed line whereas bowtie antenna is fed by coaxial feedline directly to from ground to tie patch. Before going to the next parametric analysis, the impedance of the antenna is more important to simulate. Figure 7.15 shows the impedance of bow-tie antenna for all substrates. In figure 7.15, the shows the s-parameter satisfied the definition of antenna that is -10dB to use for the medical application.

Above figure, shows that the Bow-tie antenna cannot be suitable for the present project since the required impedance is 50 ohms,

Figure 7.16: Impedance (ohms) for all the substrates of Bow-Tie Antenna



which cannot be achieved for this design within the frequency range of 2-2.5. Figure 7.16 shows that with the FR4 material, the impedance is about 44 ohms. Because of the mismatching of impedance within the required range of frequency, this design of the antenna is not suitable, therefore no need to explain the other parameters like directivity and gain of the antenna.

7.3 Rectangular Split Patch Antenna

By the results analysis of the last two designs that is rectangular patch antenna and bow-tie antenna, there is a need to design some other design which will be more suitable for flexible substrates. As noticed from the results of patch antenna that polyester and pyralux polyimide substrates are acceptable for a required range of frequency but the size of the antenna is very large which effects the resolution of the image due to the low signal ratio in the per unit area. Therefore, a compact dipole antenna is designed with λ/4 rectangular split patch dimensions with 50 Ω impedance. A different dimension of the antenna affects the performance of antenna which will go to discuss in detail. The following characteristics are measured in present working:

- Scattering Parameter;
- E-field, Directivity,and Gain;
- Characteristic Impedance;

7.9.6 Design of Split Rectangular Patch Antenna

The geometric design of the antenna is shown in figure 7.17 below; Ground of antenna is also on the same surface as the patch. The feed line is used for the input of the source which directly connected to the split ring of the patch. Coaxial cable is used to feed the antenna vertically to the feed line. Dimensions of the antenna are given in table 7.5.

Figure 7.17: Geometric Parameters of Split Rectangular Patch Antenna

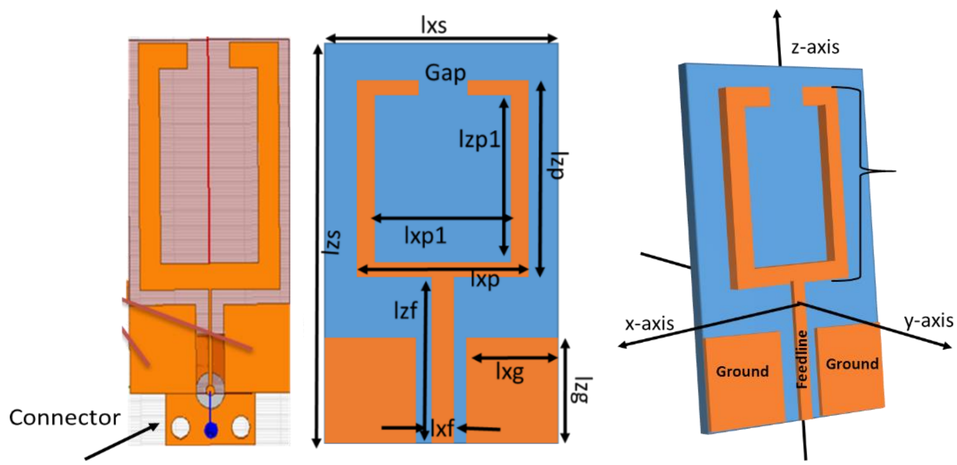


Table 7.5: Geometrical Parameters of Split Ring Patch Antenna

Parameters		Fr4	Polyester	PP
	Lzs	18	16	23
Substrate	Lzs	52	52	48
	Lys	1.6	0.36	0.0508
	Lxf	2.2	1.8	0.6
Feedline	Lzf	12	12	8.6
	Lyf	0.035	0.035	0.035
	Lzp	38.65	39.65	33.65
Split Rectangular Patch	Lxp	17	15	20
	Lzp1	13	11	14
	Lxp1	4.65	36.65	28.65
	Gap	6	6	6

Ground	Lzg	6.5	4	9.5
	Lyg	10.25	10.25	10.25

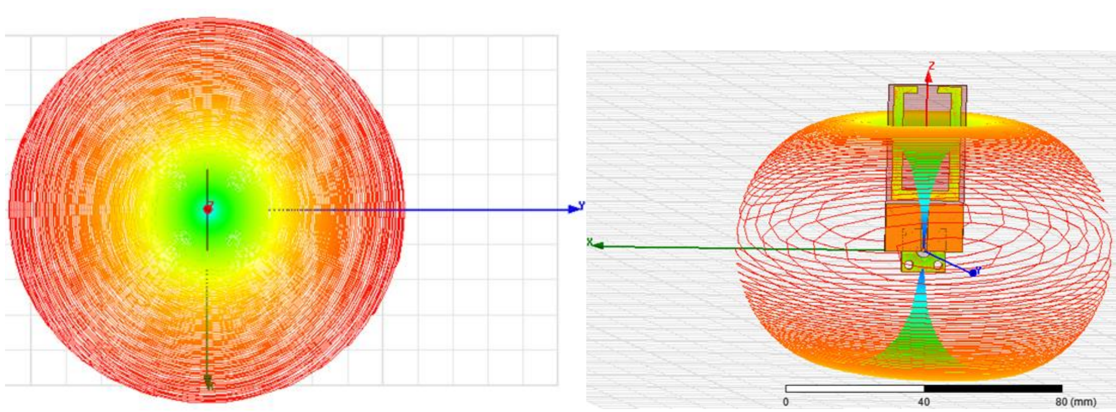
The factors affect the characteristics will discuss here which are:

- Dimension of Ground
- A gap of Split Rectangular patch
- Substrate Material

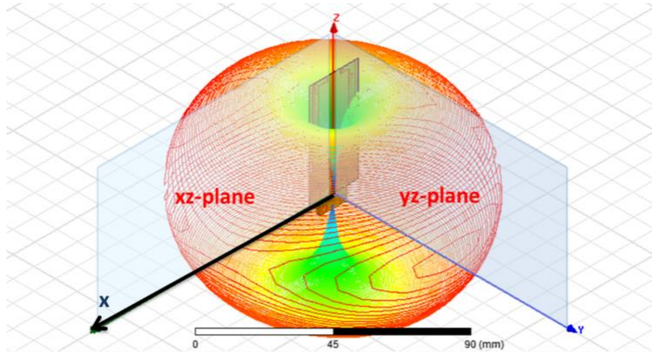
7.9.7 Propagation of Radiation

The antenna is vertically polarized.The radiation pattern of the split antenna is shown in the figure 7.18 below, the E-plane is vertical, and H-plane is along horizontal axes. The top view of an antenna with logarithmic radiation distribution shows that the antenna power reduces by moving away from the antenna in far-field region.

Figure 7.18: Radiation Pattern of Split Rectangular Antenna



Top View Side View



Elevation Plane with phi=90

7.9.8 Effect of Ground Dimension

Dipole split patch antenna has the ground plan on the same side of the substrate as the split patch. The ground plan is working as the impedance matching parameter. The size of the ground plan also affects the resonance frequency as in figure 7.19 shown for the FR4 material of the substrate. One more thing in this structure is the bandwidth of the antenna. As compare to rectangular patch and bow-tie antenna the bandwidth of split patch antenna is different.

Figure 7.19: Effect of Ground size of Resonance Frequency of Split Patch Antenna

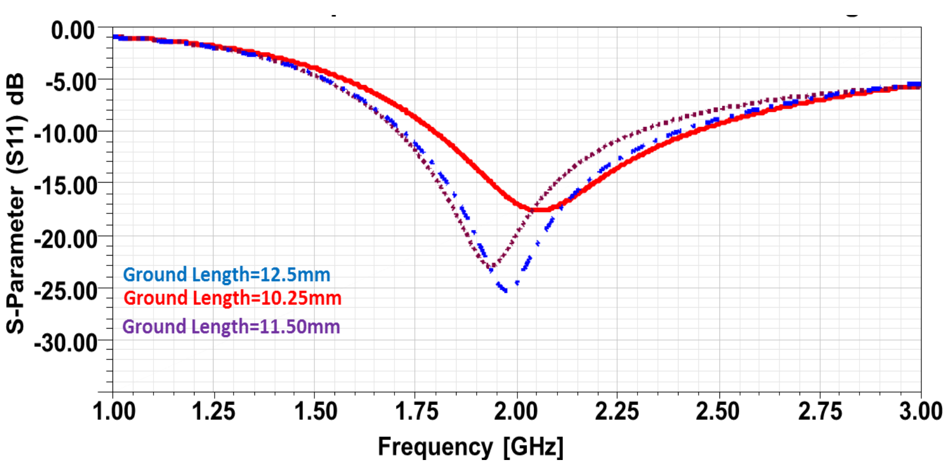
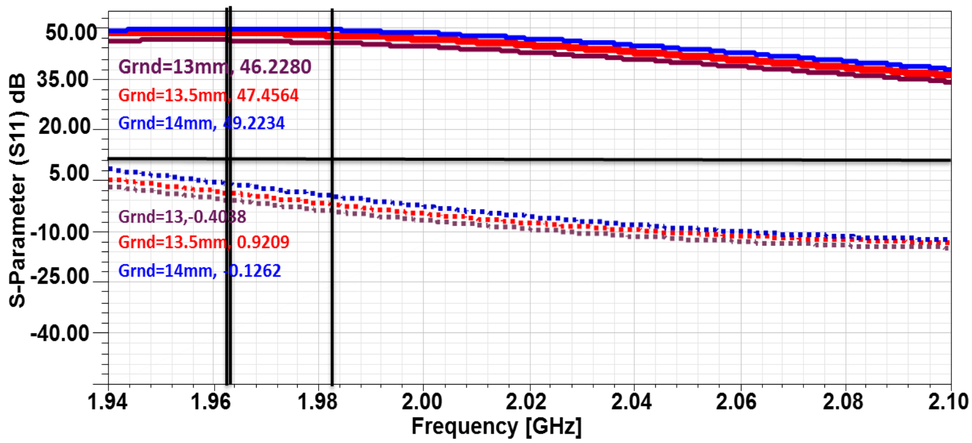


Figure 7.20: Impedance of FR4 Substrate with respect to Ground Size of Split Patch Antenna

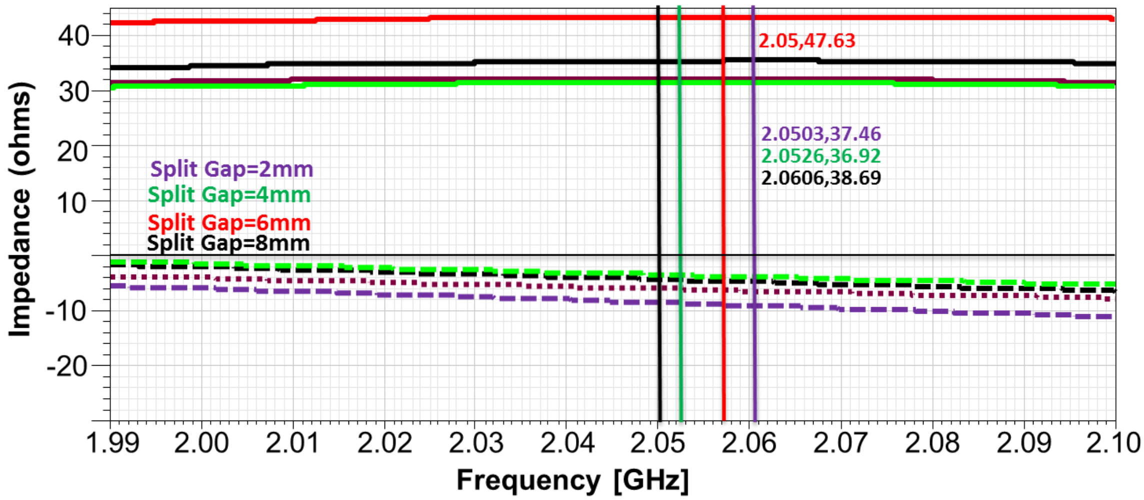


As the antennas are designed for the impedance of 50 Ω but in figure 7.20, it's clear that FR4 is not a suitable material for the current project due to mismatching of impedance even for the different sizes of the ground. Whereas, this design of the antenna is very suitable for flexible substrates like pyralux patch antenna in the required frequency. Figure 7.20 shows the impedance matching of PP split antenna for flexible antennas.

7.9.9 Effect of Split Gap

Figure 7.21 below shows return loss of patch antenna for different split gaps that are from 2-8mm. The other parameters of antennas remain the same to analyze the effect of a split gap on S11 with respect to impedance matching of the circuit. It is clear from figure 7.21 that the impedance is affected by changing the split gap of the rectangular ring only. For 6mm gap, only the flexible antennas are the suitable as shown in figure 7.21.

Figure 7.21: Impedance of FR4 split substrate for different Gap



7.9.10 Effect of Substrate Material on Split Rectangular Patch Antenna

The factor effects of antenna performance, it was clearly mentioned that FR4 is producing mismatch of impedance for but the flexible antenna is well suited for this type of antenna. Figure 7.22 and 7.23 shows the effect of substrate on the antenna behavior.

Figure 7.22: Return Loss of Split antenna for all substrates

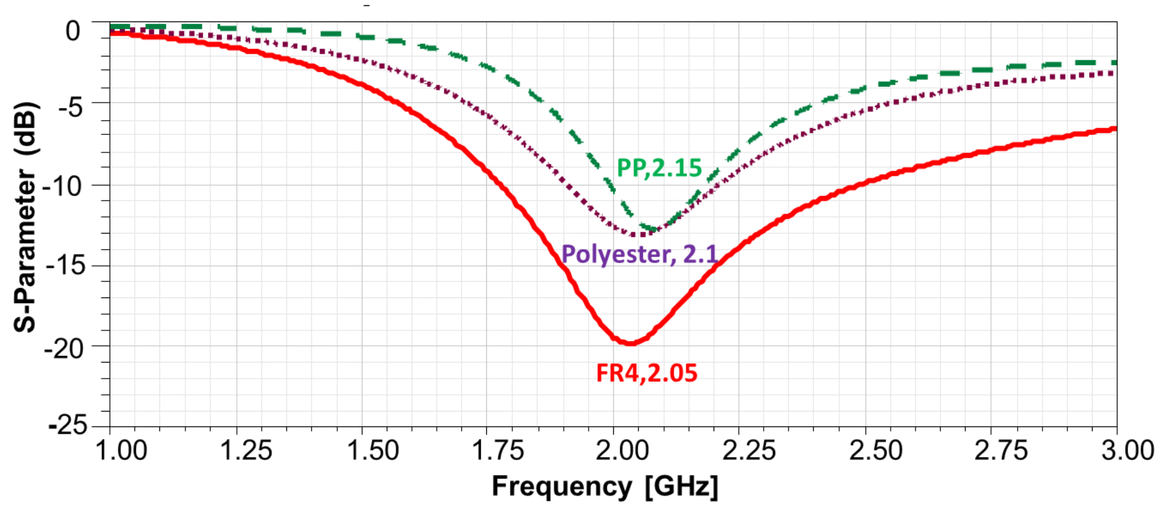
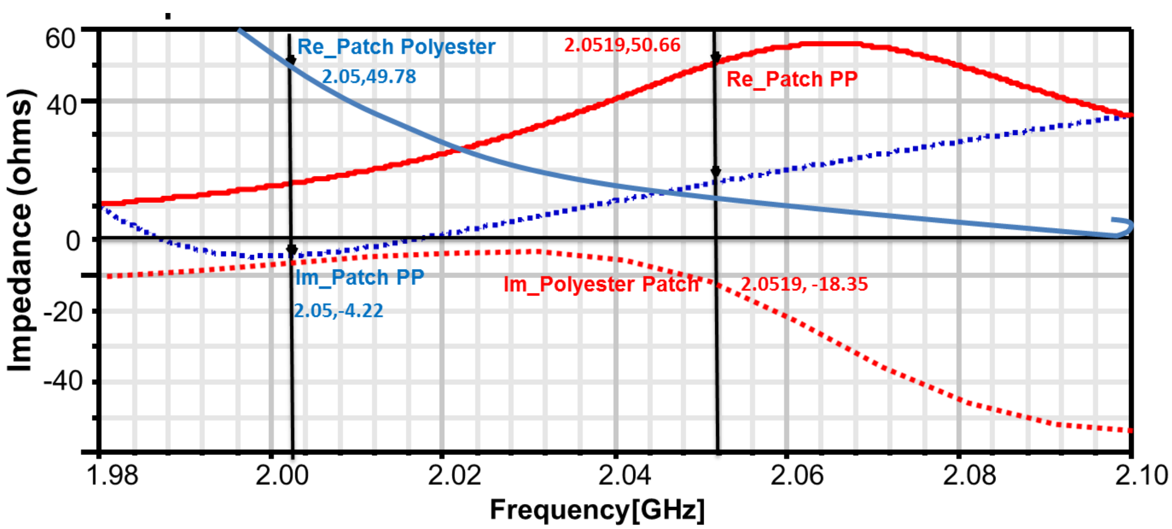
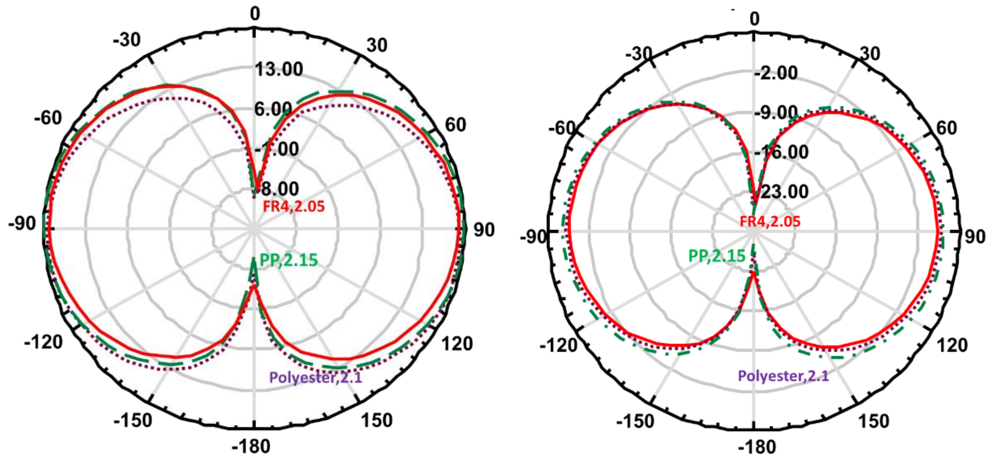


Figure 7.23: Impedance of Split Antenna with respect to Flexible Substrate Material



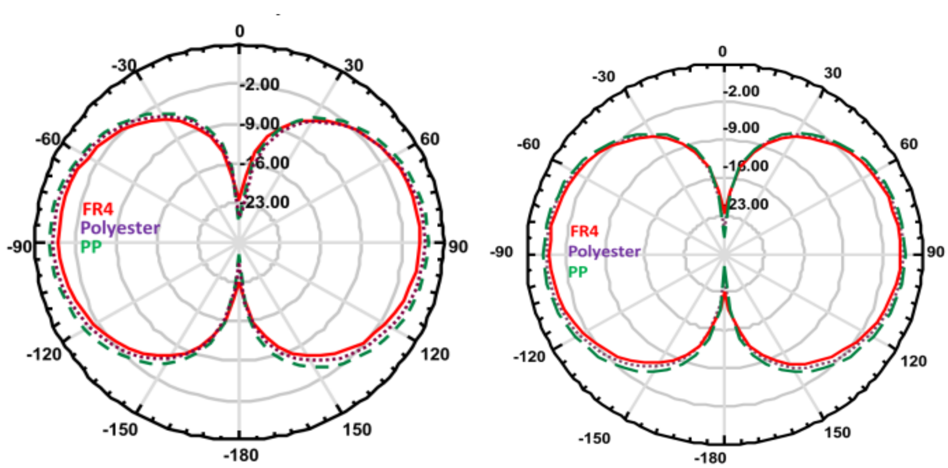
The other factors which are important to talk about are electric, gain and directivity in the far field region. The Figure 7.24 and 7.25 shows that the split antenna is dipole antenna and has a great performance in term of the electric field, gain and directivity in E and H-plane. As compared to the patch antenna the gain of pyralux polyimide is improved a lot for the split patch antenna.

Figure 7.24: Electric Field in Far Region and Gain of Split Antenna at Phi=90



The size of the split patch antenna is less than half of the rectangular patch antenna. Therefore, using pyralux polyimide material or polyester, the 8 to 12 antenna arrays can be made to increase the signals which help to improve the resolution of an image using reverse imaging technique.

Figure 7.25: Directivity of Dipole antenna



7.4 Comparison of Antenna Performance

The table 7.6, below shows the comparison of scattering parameters of the Rectangular patch antenna and split patch antenna. For the selection of an accurate design for the microwave imaging system with high efficiency from designed three antennas is easy from this table. Bow-tie antenna is an antenna with high values of impedance therefore, it's not going to be discussed here in this section but the parametric analysis of split and rectangular patch antennas is in agreement in all aspects for the processing of this project. The size of the antenna and the directivity range in dB for the split antenna is more suitable to proceed. The compact size and directivity for split flexible patch antenna make is suitable in all aspects. Because the gain can be increased using an array of antenna and as much as the size of the antenna is small then more and more antennas can be used in an array. The pyralux polyimide split patch antenna less than half from the non-flexible FR4 antenna. As per requirement of the antenna project that the antennas must be compact in size and flexible, then the Split patch antenna with pyralux polyimide will test with breast phantom in HFSS simulation.

Table 7.6: Comparison of Size and Different Parameter for all Substrate of Antennas

Antenna Type	Substrate	Size of Antenna (cm)	Thickness (mm)	R. Freq. (GHz)	S-Parameter (dB)	Directivity (dB)
	FR4	60 x 72	1.6	2.01	-17	
Rectangular Patch	Pyralux polyimide	65 x 90	0.0508	2.13	-22	-1.63-1.98
	Polyester	65 x 92	0.36	2.00	-28	
	FR4	18 x 52	1.6	2.05	-20	-8.77
Split Patch	Pyralux polyimide	23 x 48	.0508	2.15	-13	-6.77
	Polyester	16 x 52	0.36	2.1	-14	2.5

8 EXPERIMENTAL RESULTS

In the previous section of this chapter, three designs of antennas were discussed that is, the rectangular patch, bow-tie patch and split rectangular patch antenna. Let's recall the behavior of three designs; Rectangular patch antenna is suitable in characteristic behavior for FR4 and pyralux polyimide (PP) but the size of the flexible patch antenna is too big as shown in figure 8.1.

Whereas, bow-tie antenna cannot simulate for the required frequency range due to mismatching of impedance for all kind of substrates. A split antenna which is actually dipole in nature and compact in size (shown in figure 8.1) is quite up to the requirement for the flexible antenna in all parametric properties. Basically, the selection of patch antennas for MWI is not just due to a compact size and cost-effectiveness but also due to manufacturing technique also. Patch antennas are manufactured using simple etching and thermal techniques. Below in figure 8.38 shows the manufactured antennas with dimensions of simulated antennas for FR4 material and pyralux polyimide antenna.

Figure 8.1: Comparative Size of Antennas for FR4 and Pyralux Polyimide

Only two designs of antennas are manufactured for experimental analysis that is rectangular patch antenna and split rectangular patch antenna as shown in figure 8.2 and 8.3. S-parameter and directivity of both antennas are analyzed using miniVNA.

For measurements, antennas with the FR4 substrate are made in Laboratory for both shapes. The operating frequency and s-parameter of the antenna are shown in the figures belowfor standard non-flexible (that is FR4) and flexible antennas (Pyralux polyimide) are shown below in figure 8.2-8.3. A slight difference of radiated frequency might be because of the fringing effect. Fabricated antennas are fabricated with the FR4 substrate, whereas, the etching of copper material of 35µm thickness is used to make the design of the antenna.

Figure 8.2: Experimental and Simulated Results of S-Parameter for FR4 Patch antenna

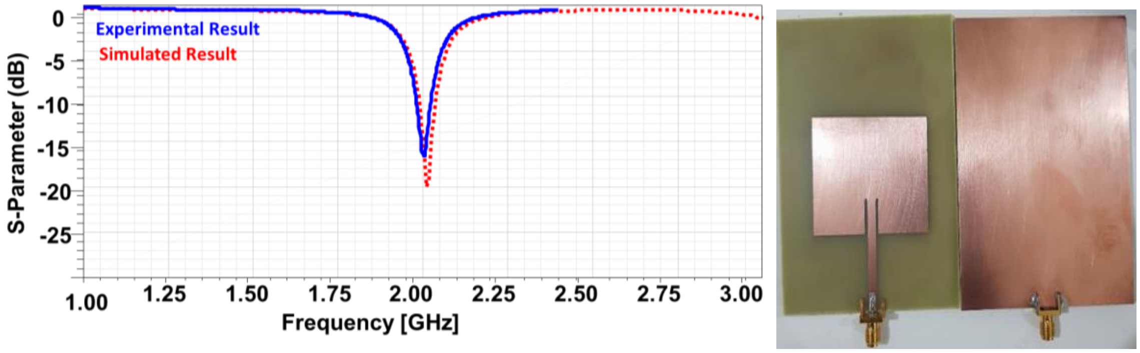


Figure 8.3: Experimental and Simulated Results of S-Parameter for Pyralux Polyimide

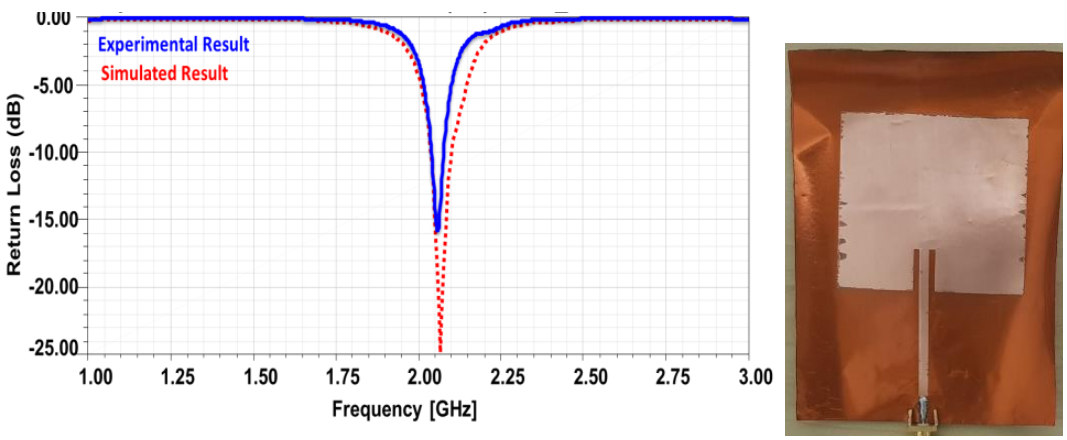
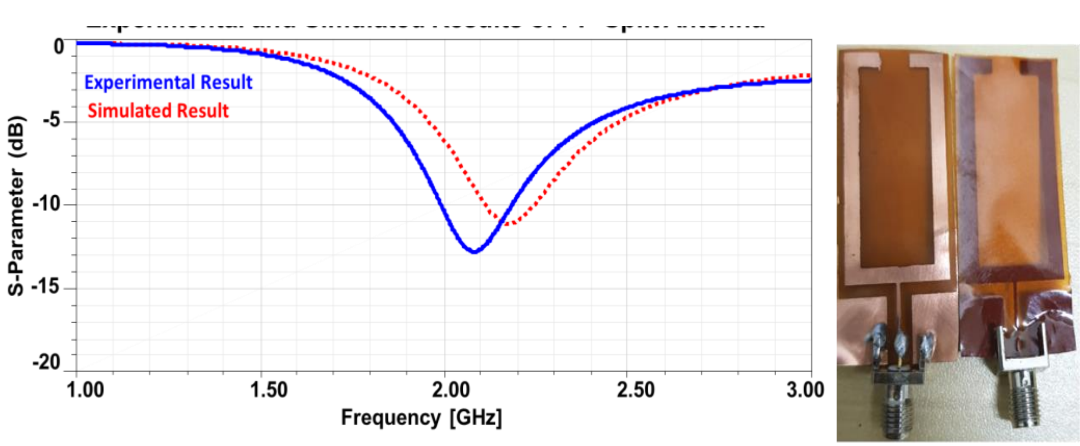


Figure 8.4: Split Patch Antenna of FR4 and Pyralux Polyimide



The split patch antenna is a dipole antenna, the difference of resonance frequency in the simulated and experimental results might be due to fringing effect or due to a manufacturing error. The scattering parameter of antennas shows that both the substrate material is full fill the condition of S11 for microwave imaging system, but the size of the flexible rectangular patch antenna is too large. Therefore, the split antenna is designed for the same substrate with small size. The S11 at the 2GHz frequency is less than -10 dB which is in verified experimentally as shown in figure 8.4. The difference of 100 MHz in frequency shift is due to fringing effect of antenna.

9 AN ARRAY OF SPLIT ANTENNA AND SIMULATION WITH PHANTOM

The antenna is a key element of any microwave imaging system. It radiates and receives signals to or from nearby scattering objects exactly like the technique of a radar [65]. The previous studies during the development of this technique, literature made few points very clear for the performance of the antenna, like directionality and gain of the antenna for breast cancer technique that is; omnidirectional and high in gain [41]. The previous two sections of the result shown that the polyester and pyralux polyimide substrate is good for microwave imaging for breast cancer detection. As well as the design of antenna well-defined and carefully analyzed that the split dipole antenna is a suitable design for this application of antenna. The polyester and pyralux polyimide are flexibletypes of substrates [71] which make it more feasible for this technique as mammography is a very painful technique [4] which can be overcome by developing a compatible wearable antenna device for diagnosis of breast cancer. In the previous section, the configuration of antennas was discussed, now in this section arrangements of the antenna are going to analyzed by placing the multiple antennas of the same configuration at different positions using the HFSS software.

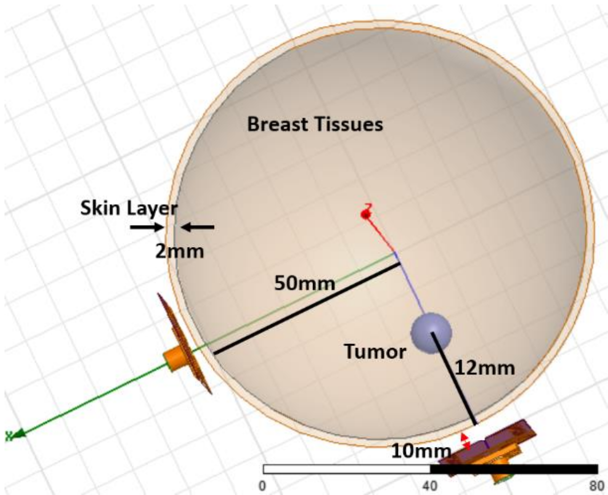
9.1 Simulation Setup for Split Antenna

The antenna is fabricated in microstrip with an air medium. A rectangular split antenna was mounted between two vertical planes. The performance of antenna will be assessed from different locations. The effect of mutual coupling is very important for investigation. Three cases are examined for two antennas like; Case I: the transmit antenna (TX) and receive antenna (RX) are positioned at 0^0 apart from each other, Case II: TX and RX positioned at 90^0 and Case III apart at 180^0. The simulation of antenna analysis is showing the return loss in an air medium. The literature shows that the -20dB is the coupling level for imaging process [60].

9.1.1 Antenna Arrangement Around Phantom

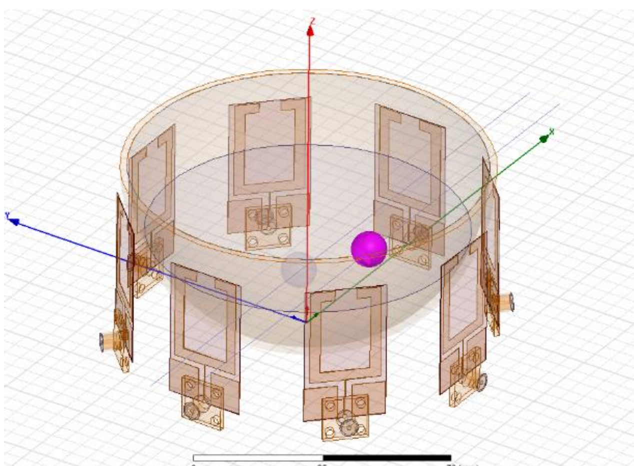
The arrangement of the antenna around the phantom is showing in figure 9.1below. The geometrical arrangement for simulation shows that the healthy breast tissues are of 50mm and thickness of 2mm of the skin layer. Whereas, the tumor of the different radius from 2mm to 10mm is embedded 12mm inside the normal tissues.

Figure 9.1: Geometrical Arrangement of Breast with Antennas



The distance of antenna from the breast skin is 10mm. Total of 8 or 16 arrays of the antenna will design but for the best transmission and receive paring the three different positions of two antennas will be analyzed to get mutual coupling of less than -20 dB for image processing [60]. The figure below shows the arrangement of 8 antennas around diseased breast phantom.

Figure 9.2: Simulation Arrangement of Array of 8 Antennas around Diseased Breast Phantom



9.2 Antennas Array

9.2.1 Casa I: Antenna Apart 0^0

The two split patch antennas are arranged at 0^0 about 25mm far from each other in an air medium. The return loss and transmission signal are shown in figure9.3.

Figure 9.3: Two Antenna at 0^0 with 30mm Distance Apart

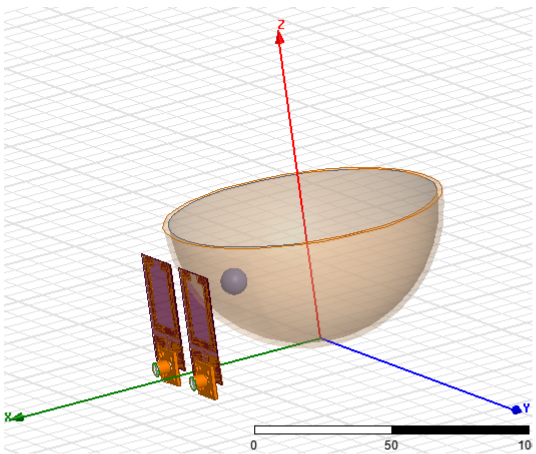
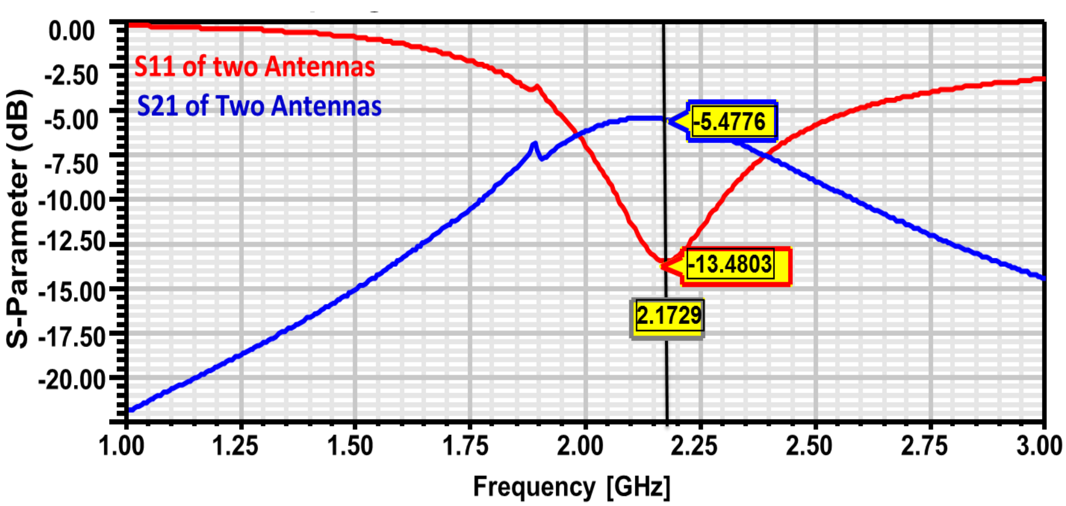


Figure 9.4: Array of Two Antennas aside (at 0^0) of each other at 30mm



The two antennas are at 25mm and transmission coefficient (S_{21}) is showing below in graph 9.3. The S11 and S21 parameters show that the difference of return loss for both is about -7dB which is not acceptable for the current application as mention in the literature [7]. This resultshows that the antenna strongly transmits signals.

9.2.2 *Case II: Antennas at 90^0*

By placing the antennas at 90^0 apart from each other, the difference of return loss of coupling is about -10dB which is better the aside coupling but still not acceptable for the required applications.

Figure 9.5: Array of Two Antennas at 90^0 with each other

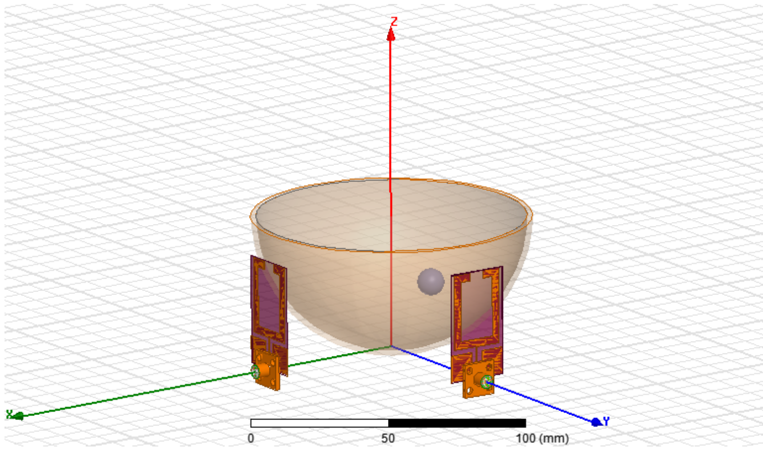
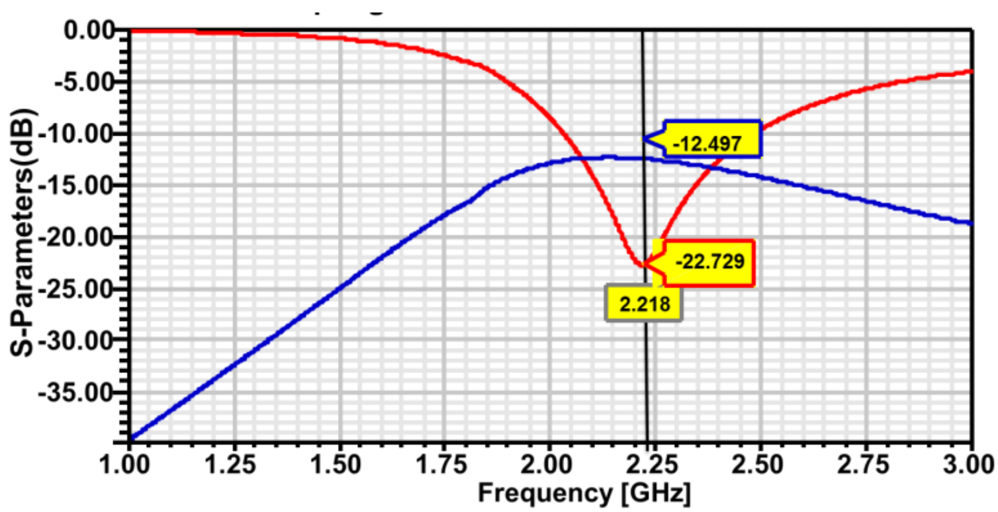


Figure 9.6: Array of Two Antennas side to side with each other



9.2.3 *Case III: Antennas at 180^0*

Two split antennas are arranged at 180^0 to each other at 80mm distance between each other. The figure 9.7 shows that the coupling is in the acceptable range for this arrangement. The difference of S11 and S21 are of -20dB.

Figure 9.7: Array of Two Antennas at 180^0 along axes to each other

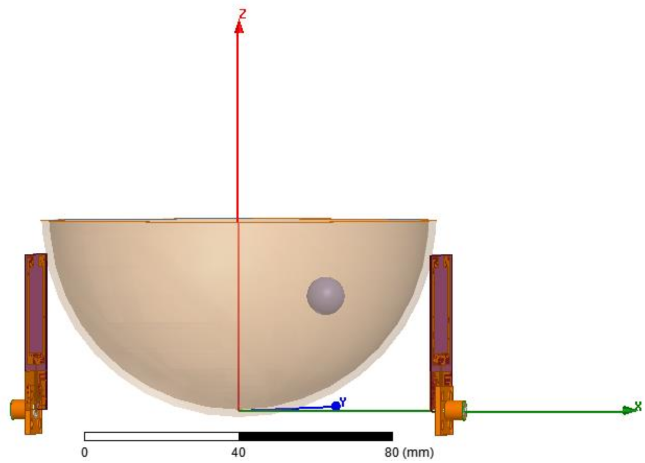
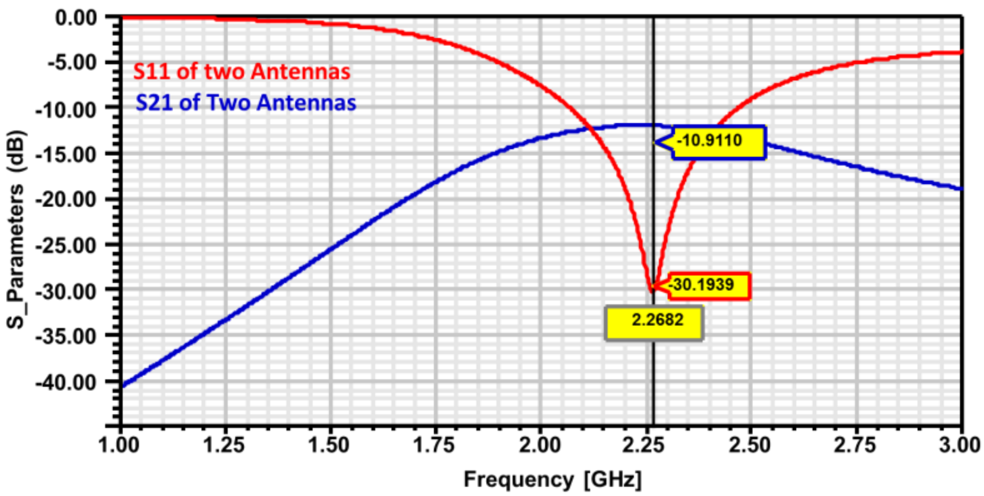


Figure 9.8: Array of Two Antennas at 1800 along axes to each other



From the results of this arrangement shows that, in an array of antennas of more than two antennas, the best coupling is between the antennas at 180^0 to each other. They are at low-dispersive behavior which is acceptable for the breast cancer imaging system.

Basically, the array of antennas is used to increase the mutual gain of the system and the directivity of the antenna. Figure 9.9 and 9.10 shows the gain of the antenna for 2, 4 and 8 antennas in an array.

Figure 9.9: Gain of single (on left) and two antennas (on right)

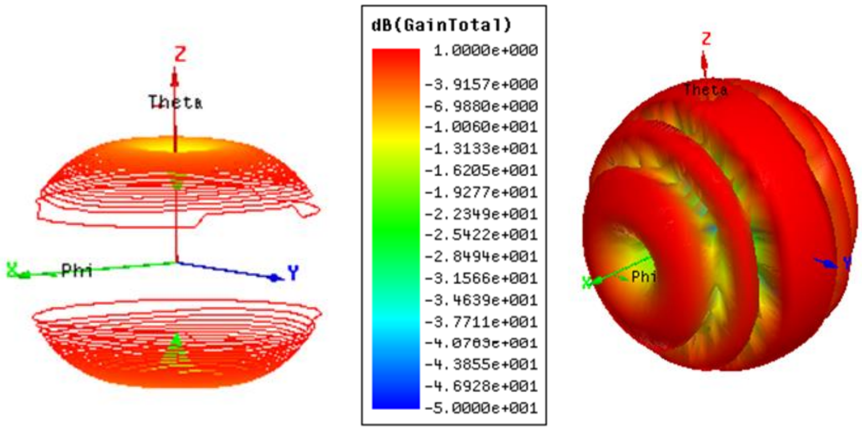
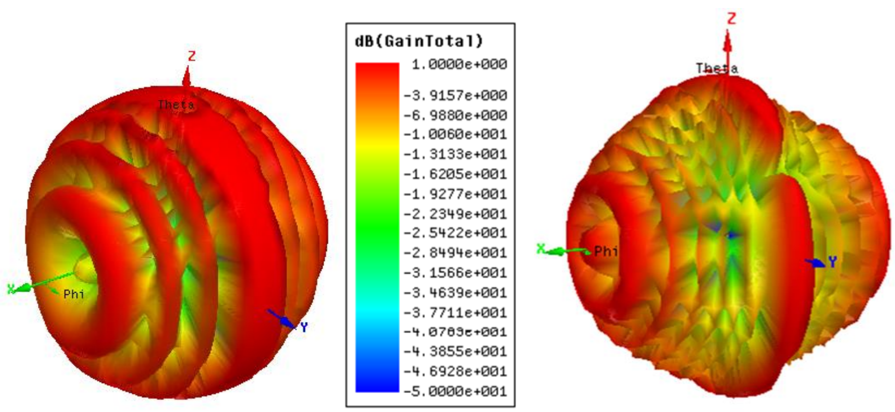


Figure 9.10: Gain of Four Antenna Array (on right) and Eight Antenna Array (on left)



The figure shows that the antennas are highly directive and increase for an array of antennas as directivity is linked with gain.

Now in the final section of results, the performance of the antenna is tested in simulation by simulating and breast phantom of normal and cancerous properties of inhomogeneous breast phantom. From the value of scattering parameters and electric field magnitude analyzed.

9.3 Inhomogeneous Breast Phantom

The breast as a communication media is modeled by several biological tissues and each biological tissue is defined as a dispersive dielectric in a homogeneous medium using three electric parameters: relative permittivity, loss tangent and mass density. By stacking several homogenous layers to mold an inhomogeneous environment using HFSS. The multilayer model that is used to design the antenna array includes skin, breast tissues and tumor. An inhomogeneous phantom of the breast is made with the dielectric properties of breast tissues. The dielectric properties of breast tissues are taken from the literature [41]. Malignant tumor with different dimensions from 2mm to 10mm diameter is placed inside the skin and normal breast tissue layers. Whereas, other two layers are skin layer and breast tissues. Two types of the phantom are designed one is with tumor tissues and another is a normal healthy phantom.

Table 9.1: Dielectric Properties and Geometrical Properties of Inhomogeneous Phantom

Tissue Type	**Permittivity**	**Conductivity**	**Skin Thickness**	**Radius of Breast**
Skin	36	4	2mm	52mm
Normal Tissues	10	0.3	-	50mm
Tumor	13.1	0.5	-	2-10mm

Source:

In present section of results is based on the performance of antennas in the presence of a 3-D inhomogeneous phantom. Therefore, the results and discussion will be divided into

- Antenna Design and parametric analysis;
- The magnitude of Electric Field for Tumor of different size;
- The magnitude of different Parameters of Antenna with Phantom;

The selected antenna is split rectangular patch antenna with pyralux polyimide substrate of 0.0508 mm thickness.

Figure 9.11Response of an S11 parameter of Split Pyralux Polyimide Antenna with healthy and tumor phantom

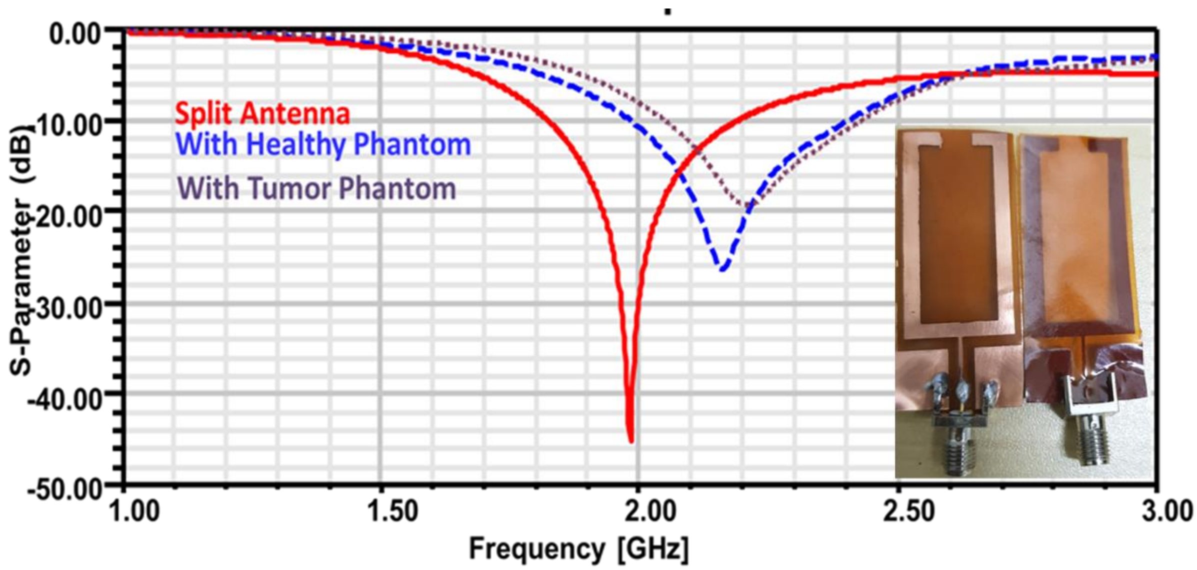


Figure 9.11 shows that the S11 of split patch antenna with and without the phantom with respect to diseased phantom also.

Figure 9.12: Electric Field (V/m) using four Split Flexible Antenna with Healthy Breast Phantom

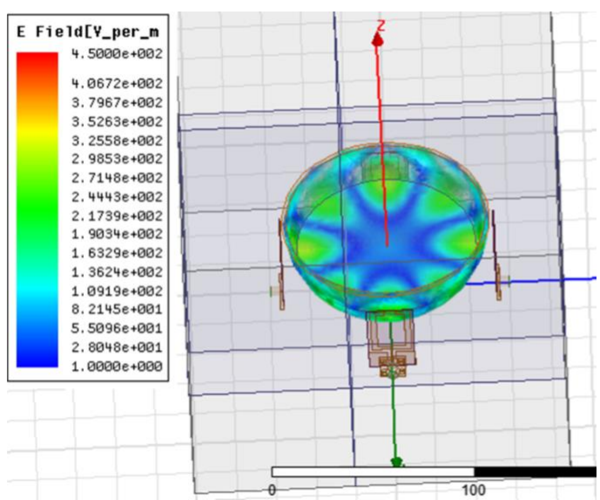
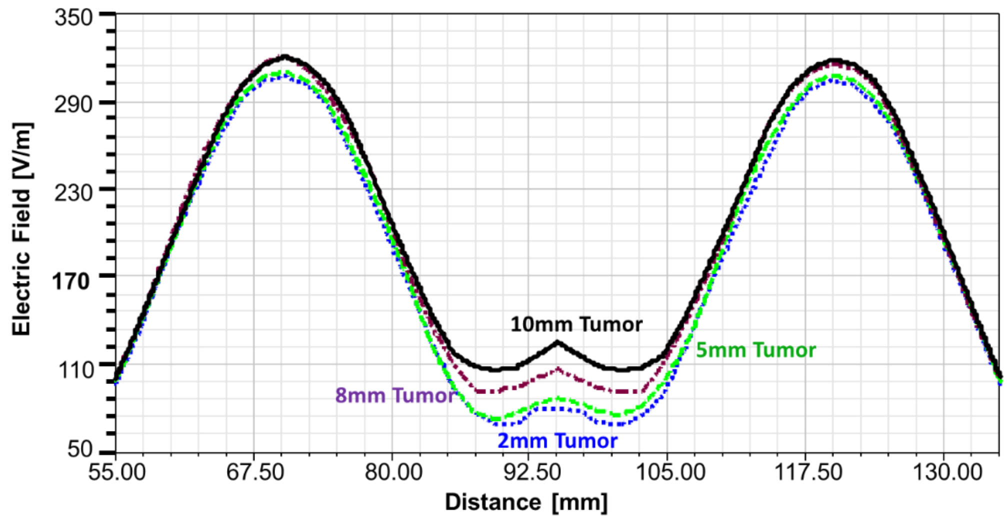


Figure 9.13: Electric Field Magnitude in dB with Healthy and Tumor Phantoms Using Split Flexible Antenna



In this section, the antenna and parametric behavior of split patch antenna of flexible material are going to explain. It's clear that split patch antenna is more good design for tumor size analysis as with patch antenna only the information of the tumor presence can be taken whereas with split antenna even the size of the tumor can also get from scattering parameter and magnitude of electric field which is shown in figure 9.11-9.14.

Figure 9.14: Electric Field Magnitude in dB with Tumor Phantoms Using Split Flexible Antenna

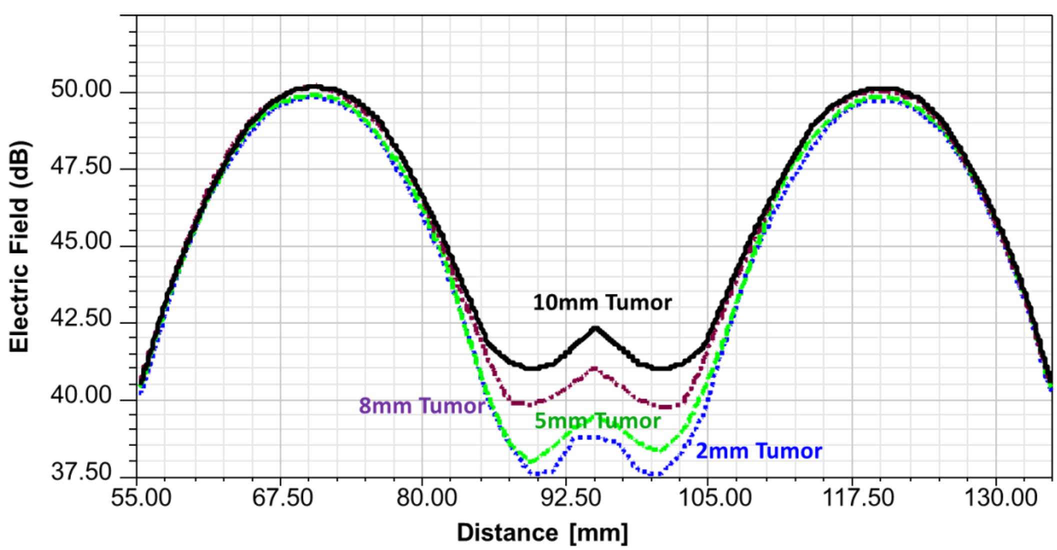


Table 9.2: S-Parameters, Radiation Gain, and Magnitude of E-Field Split Antenna with Healthy and Tumor Phantom

Phantom Type	**E-Field**		**Literature**
	In dB	**In V/m**	**V/m**
Normal	39.97	163	177
With Tumor 2mm	38.92	88.35	No Data
5mm	39.61	95.63	
8mm	41.22	115.15	
10mm	42.46	133.23	137

The table 9.3 below shows the values of electric field in dB and v/m. The magnitude of the electric field of healthy tissue with four antennas is 163 v/m as shown in figure 9.12 above which is very close to 177v/m as calculated by another research group using rectangular patch antenna [33]. For diseased breast phantom with 10mm tumor size, the value of electric field is 133.23 v/m which is analyzed with split patch antenna in simulated results also near about the value of 10mm tumor by the same group which is 137 V/m [33]. Comparison of Antenna From the simulation results of 4 different size of Tumor shows that

- Very small tumor, like 2mm (10 times less than 2cm) can detect with MWI;
- E-field is quite different for different size of antennas;
- E-field Magnitude trend is completely different for Normal phantom;
- The electric field in v/m is low for diseased phantoms;
- The value of normal phantom and dieseased phantom of 10mm tumor are very close to the values given in literature [33];

10 Conclusion and Future Task

This chapter is concluding the thesis and the results. Basically, the current thesis was based on the development of breast cancer imaging. For this, the flexible antennas are designed and manufactured for the frequency of 2GHz.

Microwave imaging technique is non-invasive in nature which is can be used to diagnose and reveal the internal biological structure of the targeted object like breast in our case. The scope of these techniques is still to be determined, and the broader issue of the interaction of electromagnetic waves in vivo drives several major areas of cross-disciplinary research. Breast cancer is the most common type of malignancy in women and a leading cause of female mortality, the most effective route to the reduction of risk is early detection.

X-ray mammography is the only technique which is used for the detection and locates the breast cancer but has many limitations and disadvantages. Some major limitations of x-ray mammography are

- Lake of early-stage detection;
- Limitation over the age group;
- Dense Breast;
- Yearly Screening of Patient;
- High Rate of false-positive and false-negative Results ;
- Painful;
- Expensive for a common person;

Those limitations forced to develop some new technique which can help to diagnose the breast cancer. These are the main features to follow for the development of new technology for breast screening.

Microwave Breast Cancer Imaging is a technique which is cost effective and more precise in results. Early stage detection of breast cancer is possible with MWI which reduce the death rate due to breast cancer. Non-ionizing nature of this technique allows yearly screen as recommended by American and Canadian cancer society. There is a huge contrast of dielectric properties of cancerous and healthy breast tissues in microwave frequency range. MWI is working on the interaction of electromagnetic radiations with tissues. The diseased tissues havea high concentration of water therefore, the scattered radiations have strong signals to generate a clear image using different mathematical algorithms. MWI is a cost-effective, more efficient and user-friendly technique but it's still under developingtherefore, the current project was a contribution to the development of this technique.

The present thesis is focused on the simulation of theoretically designed antennas for 2 GHz and manufacturing of flexible antennas. Low frequency is used for medical application as up to 6 GHz, the penetration of radiation through the skin is considerably high but low in the resolution which can be improved using an array of antennas. The project is proceeding in three sections, which leads to helping in the development of microwave imaging system and these sections are;

- Antenna Design;
- Substrate Type;
- Investigation with Phantom;

The first section of results is based on the selection of antenna design and the second section was based on the selection of suitable substrate material to make a wearable device. Three different designs are analyzed in the project which is basically the patch antennas. That are, Rectangular patch, bow-tie and split patch antenna which was simulated using HFSS software. For manufacturing, the photo-etching technique was used. A very careful analysis was done on the base on characteristic properties of antennas for the high demand of antennas to use for medical applications.

Rectangular patch antenna and split patch antenna are feed by feedline whereas, bow-tie antenna is feed using coaxial cable. The antennas are designed for 50Ω. Analysis of antenna design on the basis of design and substrate material mainly due to the resistance of the antenna, return loss and bandwidth of the antenna.

For medical applications, the required return loss is less than -10dB and bandwidth must be greater than 0.2. Whereas, the antenna must be high in gain (either individual or array of the antenna) and omnidirectional. The low frequency of the antenna makes the radiation penetrate deeply up to several centimeters whereas, wideband of antenna radiation cause high resolution. Out of these three designs, split rectangular antennas has full fill all these requirements for flexible and non-flexible antennas. Three kinds of substrates is used here in this project which iscategories as flexible and non-flexible in nature. Fr4 are traditional substrate material for non-flexible antennas whereas, polyester and pyralux polyimide antennas are flexible antennas.

The rectangular patch antenna is suitable for all three substrates but the size of pyralux polyimide antenna is very large in size with the required frequency that is 2GHz in the present project. Whereas, bow-tie antenna did not satisfy the equivalent circuit theory as 50Ω resistance did not achieve in simulation within this frequency range. The split rectangular patch antenna is highly suitable for medical application with polyester and pyralux polyimide substrate for flexible antennas. With pyralux polyimide, the gain is low for patch antenna whereas for split antenna is very high and increased using an array of antennas.

The subsection of the result depends on the manufacturing results of the antenna, split and patch antennas are manufactured using a photo-etching technique which is in agreement with the simulated results for patch antenna and pyralux polyimide antennas. But the polyester antennas cannot be fabricated due to unavailability of pure polyester in the local market of Recife, Brazil.

The array of the antenna also analyzed with a combination of 2, 4 and 8 antennas. The arrangement of two antennas at three different configuration that is, side to side (at $0^{0)}$, at 90^{0} and face to face (apart 180^{0}) shows that antennas placed at 180^{0} angle to each other are mutually coupled. The minimum difference between S11 and S21 return loss is -20dB for medical applications.

The last section of the project was to analyze the antenna performance in the presence of breast phantom. Two types of breast phantoms are used in this project one is based on the dielectric properties of healthy breast and another one is with phantom of the breast with tumor of different diameters (from 2 to 10mm). The return loss of antenna is affected in the presence of healthy phantom as well as a diseased phantom. The magnitude of electric field in dB and in V/m shows that the performance of the antenna is affected in the presence of different size of tumor embedded in breast phantom. There was a prominent difference of magnitude of the electric field from normal to diseased samples. Numerical values are shown in table 9.5.

The project is concluded that the flexible antenna of split rectangular design is highly recommended for the analysis if breast cancer embedded in the breast within the frequency range of 2 GHz. Whereas, due to the very small size of the split antenna, an array of 8 to 16 antennas can use for the single side of a wearable device which enhances the directivity, gain,and resolution of the image.

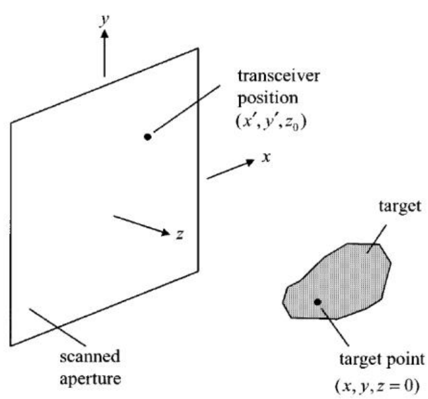
10.1 Future Task

The next steps to this project are to develop the system of 8 to 16 array of the antenna in the laboratory for the analysis with heterogenous breast phantoms. The phantom with the dielectric properties of healthy and diseased tissues will make in laboratory by the technique mention by M. Lazebnik and her group in 2005 [76].Then a mathematical algorithm will design for the reconstruction of 2D and 3D image using the backscattered radiations.

10.2 Mathematical Algorithms

Linear Born Approximation is use for reconstruction of image in 3D back scattering of radiations [77]. Information of wideband frequency of microwave is obtain in quasi-real time for 3D image of object.

Figure 10.1: Holographic Imaging system for 2D configuration

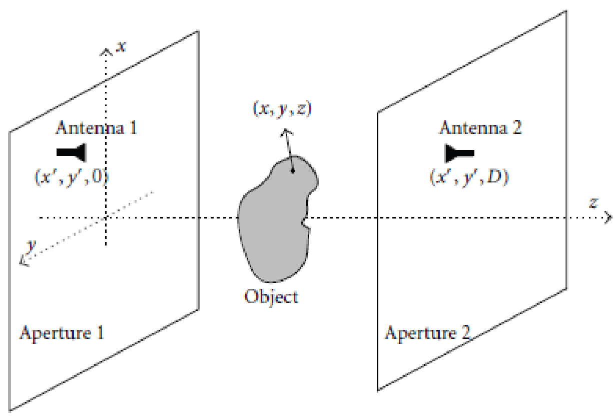


Source: RAVAN, M.; ANMINEH, R. K.; NIKOLOVA, N. K.; Two-Dimensional Near Field Microwave Holography. Inverse Problems, v., 26, p. 055011-055032, 2010.

Whereas for single frequency 2D image is produce on acquisition plane, which is parallel to objective plane as, shown below [78]. Using back-scattering [78] 2D single-frequency image reconstruct to near-field microwave imaging. The inverse imaging use Green’s function in the form of 3D inverse Fourier transformation (FT) and 3D imge is produced as a set of 2D image in parallel planes [79]. Actual principle of inverse imaging is to solve the equations for spatial frequency along x and y-axis (i.e., *kx*, *ky*) under the area of interest. Smaller dimensions of the equaltions as compare to regular microwave technique reduced the ill-posed nature of problem [79].

By adding some processing in holographic algorithms the non-point-wise antenna' function can be calculated by using inverse procedure of image reconstruction. The figure 16 below, shows the antenna positions with different configuration partner like

Figure 10.2: Arrangement of Antenna and Object for Inverse Image Reconstruction



Source: RAVAN, M.; ANMINEH, R. K.; NIKOLOVA, N. K.; Two-Dimensional Near Field Microwave Holography. Inverse Problems, v., 26, p. 055011-055032, 2010.

The proposed technique is validated with the range localization and the 2D image reconstruction of a predetermined target in simulations. Resolution limits are derived and validated. The effect of noise will also study.

The next step of the present research project is to make the microwave imaging system by fabricating flexible antennas and test in the laboratory. Another thing parallel to this is development of an imaging algorithm as mention in the above section.

REFERENCE

[1] American Cancer Society. (2013). Retrieved from American Cancer Society:https://www.cancer.org/research.

[2] YU, C.; FAN, S.; SUN,; PICKWELL-MACPHERSON, E. Review Article: The potential of terahertz imaging for cancer diagnosis: A review of investigations to date. **Quant. Imaging Med Surg**, v. 2, p. 33-45, 2012.

[3] http://www.cancer.ca/en/cancer-information/-type/breast/statistics/?region=bc.

[4] BERTRAM,M,J.; YANG,D.; CONVERSE,M.C.; WEBSTER, J.G.; MAHVI,D.M.; Antenna design for microwave hepatic ablation using an axisymmetric electromagnetic model. **BioMedical Engineering OnLine** , 5:15 2006.

[5] www.Komen.org/BreastCancer/BreastMRI.html.

[6] ZIEGLER, S.I.; Positron Emission Tomography: Principles, Technology and Recent Developments. **Nuclear Physics A,** v.752, p.679-687, 2005.

[7] GRANOV, Antatoliy.; TIUTIN, Leonid.; SCHWARZ, Thomas.**Positron Emission Tomography:** Springer,2008.

[8] FEIG, S.; HENDRICK, R.; Radiation risk from screening mammography of women aged 40–49 years. **J Natl Cancer Inst Monogr.,** v.22, 119–24, 1997.

[9] ETZIONI, R.; URBAN, N.; RAMSEY, S.; MCINTOSH,M.; SCHWARTZ, S.; REID, B.; RADICH, J.; ANDERSON, G.; HARTWELL,L. Review: The Case for Early Detection. **Nature Review|Cancer,** v.3, p. 1-10, 2003.

[10] JOY, E. Janet; PENHOET, E.Edward; PETITTI, B.Diana; Saving Women's Lives: Stategies for Improving Breast Cancer Detection and Diagnosis:**The National Academies Press.** ISBN: 0-309-53209-4, 2005.

[11] Mammography. copyright@2016. RadiologyInfo.org for patients. Page:1-7. American Cancer Society. Breast Cancer Facts and Figures 2013-2014. Atlanta, Ga:

[12]LI, X.; BOND, E.; VAN VEEN, B.; HAGNESS, S. An Overview of Ultra-Wideband Microwave Imaging via Space-Time Beamforming for Early-Stage Breast-Cancer Detection.**Antennas and Propagation Magazine, IEEE,** v. 47, p. 19–34, Feb 2005.

[13] OSEPCHUK, J. M.; PETERSEN, R. C.; Full Spectrum Consulting, Concord, Massachusetts, USA. **Lucent Technologies, Inc./Bell Labs,** Murray Hill, New Jersey, USA.2001.

[14] KOBRUNNER, H.; HACKER, A.; SEDLACEK, S.; Advantages and Disadvantages of Mammography Screening. **Breast Care,** 6:199-207, 2011.

[15] CHERRY, N.;**Cataract as a Side Effect of Unprotected Exposure to Microwave Hyperthermia Treatment of Breast Cancer:**Thesis (Doctorate) - Environmental Health Lincoln University. New Zealand, 2002.

[16] PENDRY, J. B.; SCHURIG, D.; SMITH, D. R. Controlling electromagnetic fields. **Science** 312(5781), 1780–1782 ,2006.

[17] BINDU, G. **Development of Active Microwave Imaging Techniques For Applications in Mammography:** Cochin University of Science and Technology, 2007.

[18] CAMPBELL, A. M.; LAND, D. V. Dielectric Properties of Female Human Breast Tissue Measured in Vitro at 3.2 GHz. Phys. Med. Biol. V.37, p. 193–210, 1992.

[19] BINDU, G.; LONAPPAN, A.; THOMAS, V.; AANANDAN, C. K.; MATHEW, K. T. Active Microwave Imaging for Breast Cancer Detection. **Progress In Electromagnetics Research, PIER**, v. 58, 149–169, 2006.

[20] Yu, C.; Fan, S.; Sun, P. M. E. Review Article: The potential of terahertz imaging for cancer diagnosis: A review of investigations to date. **Quant Imaging Med Surg,**v. 2, p. 33-45, 2012.

[21] http://www.who.int/cancer/detection/breastcancer/en/index2.html.

[22] PLOSONE | DOI:10.1371/journal.pone.0168950 January 2017.

[23] http://www.who.int/cancer/detection/breastcancer/en/index2.html.

[24] SATTAR, A.ZUBAIDA.**Experimental Analysis on Effectivness of Confocal Algorithm for Radar Based Breast Cancer Detection.**Durhum University, United Kingdom, 2012.

[25] DETLEFSONN, J.; DALLINGER, A.; SCHELKSHORN, S. Reconstruction Approaches to Millimeter-Wave Imaging of Humans. **XXVIIIth General Assembly of Int. Union of Radio Science (URSI),** p. 23-9, 2005.

[26] LEACH, E. M. M.; SKOBELEV, S.; SMITH, D. A Modified Holographic Technique for Antenna Measurements and Object Imaging. **IEEE Int. Symp. On Microwave, Antenna, Propagation and EMC Technologies for wirless communications,** p. 966-9, 2007.

[27] STANG, P. John.**A 3D Active Microwave Imaging System for Breast Cancer Screening.** Thesis (Doctorate) - Department of Electrical and Computer Engineering,Duke University, 2008.

[28] WANG, D.; RAN, L.; WU, B. I.; CHEN, H.; HUANGFU, J.; GRZEGORCZYK, T. M.; KONG, J. A. Multi-frequency Resonator Based on Dual-Band S-shaped Left-Handed Material. **Optical Express, v.** 14(25), 12288–12294, 2006.

[29] YANG, F.; SANAGAVARAPU, A. M. Microwave imaging for breast cancer detection using Vivaldi antenna array. **Antennas and Propagation (ISAP), International Symposium,** p. 479 – 482, 2012.

[30] SINGH, P. K.; TIRPATHI, S. K.; SHARMA, R.; KUMAR, A. Design and simulation of Microstrip Antenna for Cancer Diagnosis. **IJSER,** v. 4 (11), p. 1821-1815, 2013.

[31] HAGENSS, S. C.; TAFLOVE, A.; JACK, E.B. Three-Dimensional FDTD Analysis of a Pulsed Microwave Confocal System for Breas Cancer Detection. **IEEE, Transactions on Antennas and Propagration**, v. 47, p. 783-791, 1999.

[32] PUNDIR , S.; ARYA, D.; BANSAL, A. Analysis of Electrical Paramaters of Inset Fed Rectangular Microstrip Patch Antenna (RMPA) by Varying Inset Gap and Inset Width. **IJETAE,** v. 3 (7), 2013.

[33] CALISKAN, R.; GULTEKIN, S. S.; UZER, D.; DUNDAR, O. A. Microstrip Antenna Design for Breast Cancer Detection. **Procedia Social and Behavioral Sciences,** v. 195, p. 2905-2911, 2015.

[34] KLEMM, M.; IAN, J. C.; JACK, A. L.; ALAN, P.; RALPH, B. Radar-Based Breast Cancer Detection Using a Hemispherical Antenna Array- Experimental Results.**IEEE, Transactions on Antennas and Propagration,** v. 57, p. 1692-1704, 2009.

[35] SEER Training: Breast Anatomy". National Cancer Institute. Retrieved 9 May 2012.

[36]http://www.cancer.ca/en/cancer-information/cancer-type/breast/anatomy-and-physiology/?region=on.

[37] BLAND, K. I.; COPELAND III, E. M.; DAVIDSON, N. E.; PAGE, D. L.; RECHT, A.; URIST, M. M.The Breast: Comprehensive Management of Benign and Malignant Disorders, **Elsevier,** Vol. 1, 2004

[38] SAUNDERS,M. Christobel; JASSAL, Sunil.**Breast cancer:** Oxford University Press, 2009.

[39] COOPER,M. Geoffrey.**Elements of human cancer**: Boston: Jones and Bartlett Publishers. p. 16, 1992.

[40] http://www.guands.com/cancer/breast-cancre/breast-cancer.html

[41] ZHANG, Haoyu. **Microwave Imaging for Ultra-Wideband Antenna Based Cancer Detection.**Department of Electrical Engineering. The University of Edinburgh, 2015.

[42] KUHL, C. K.; SCHRADING, S.; LEUTNER, C.; MORAKKABATI-SPITZ, N.; WARDELMANN, E.; FIMMERS; SCHILD, H. H.; Mammography, Breast Ultrasound, and Magnetic Resonance Imaging for Surveillance of Women at High Familial Risk for Breast Cancer‖, **Journal of Clinical Oncology,** Vol. 23, No. 33, pp. 8469-8476, 2005.

[43] http://medgadget.com/2007/03/esie_touch_elas.html

[44] healthcare.siemens.

[45] BOND, E. J. B.; LI, X.; VEEN, B. D. V.; Microwave Imaging via Space-Time Beamforming for Early Detection of Breast Cancer. **IEEE Transactions on Antennas and Propagation,** 51:1690-1705. 2003.

[46] SALLEH, S. H. B. M.; OTHMAN, M. A.; ALI, N.; SULAIMAN, H. A.; MISRAN, M. H.; AZIZ, M. Z. A. A.; Microwave Imaging Technique using UWB Signal for Breast Cancer Detection. ARPN, **Journal of Engineering and Applied Sciences,** 10(2):723-727. ISSN 1819-6608. 2015.

[47] CAMPBELL, A. M.; LAND, D. V.; Dielectric Properties of Female Human Breast Tissue Measured in Vitro at 3.2 GHz. **Phys Med Biol,** vol. 37, pp. 193–210, Jan 1992.

[48] HAGNESS, S. C.; TAFLOVE, A.; BRIDGES, J.E.; Two-Dimensional FDTD Analysis of a Pulsed Microwave Confocal System for Breast Cancer Detection: Fixed-focus and Antenna-Array Sensors. **IEEE Trans. Biomed.Eng.,** 45(12):1470–1479.1998.

[49] SON, S.; SIMONOV, N.; KIM, H.; LE, J.; JEON, S.; Preclinical Prototype Development of a Microwave Tomography System for Breast Cancer Detection. **ETRI Journal,** v. 32, n.6, 2010.

[50] https://www.cancer.org/cancer/breast-cancer.html

[51] YBARRA, A. Gary; LIU, H. Qing; STANG, P. John; JOINES, T. William.**Microwave Breast Imaging. Emerging Technology in Breast Imaging and Mammography:** American Scientific Publishers, 2007.

[52] JENSEN, Steve. **Microstrip Patch Antenna**: Northern Arizona University, 2010.

[53] BALANIS, A.Contantine.**Antenna Theory Analysis and Design**: A John Willey and sons, Inc., 3rd Edition, 2005.

[54] Antenna Basic Concepts. By Pulse Electronics/ Larsen Antennas.

[55] SAUNDERS, R. Simon; ZAVALA, Alejandro Aragon.**Antennas and Propagation for Wireless Communication Systems:** Willey, 2nd Edition, 2007.

[56] FR-4. (2013, March 21). In Wikipedia, The Free Encyclopedia. Retrieved 17:54, March 31, 2013, from http://en.wikipedia.org/w/index.php?title=FR-4&oldid=545928339.

[57] RAHIM, M. K. A.; ABDUL AZIZ, M.Z.A.; GOH, C.S.; Bow-Tie Microstrip Antenna Design. 2005. **IEEE,** doi: 10.1109/ICON.2005.1635425.

[58] HAIDER, R. K; AL-RIZZO, H. M.; AYMAN, I. A.; Design, Fabrication and Testing of Felexible Antenna. **INTECH,** 2013. ODI: 10.5772/50841. http://dx.doi.org/10.5772/50841.

[59] MOHAMMED, Beadaa Jasem.**Design and implementation of Microwave Imaging System for Medical Applications.** Thesis (Doctorate) - School of Information Technology and Electrical Engineering, The university of Queensland, 2014.

[60] RUBAEK, Tonny.**Microwave Imaging for Breast Cancer Screening.**Thesis (Doctorate) - Department of Electrical Engineering, Technical University of Denmark, 2008.

[61] KLASER,Jacob.**Wide-band Antenna Designfor Use in Minimal Scan, Microwave Tomographic Imaging.** Thesis (Doctorate) - Department of Electrical Engineering, Michigan State University, 2013.

[62] Henriksson T.; Contribustion to Quaitative Microwave Imaging Technoligy for Biomedical Applications (Thesis # 73), Malaedalen University Sweden, ISSN: 1651-4238, 2008.

[63] http://www.chalmers.se/en/projects/Pages/Microwave-tomography-for-breast-cancer.aspx.

[63] LAZEBNIK, M.; L. McCARTNEY; D. POPOVIC; C. B. WATKINS; M. J. LINDSTROM; J. HARTER; S. SEWALL; A. MAGLICCO; J. H. BOOSKE; M. OKONIEWSKI and S. C. HAGNESS, A Large -Scale Study of the Ultrawideband Microwave Dielectric Properties of Normal Breast tissue Obtained from Reduction Surgeries‖, **Physics in Medicine and Biology**, Vol. 52, pp. 2637–2656, 2007.

[64] Dhayalini, Ramamoorthy.**Impact of Mutual Coupling among Antenna Arrays on the Performance of the Multipath Simulator System.**Thesis (Master's) - Program in Electronics/Telecommunications, University of Gavle, 2014.

[65] ADNAN, Shahid. **Ultra-Wideband antenna Design for Microwave Imaging Applications.**Thesis (Doctorate) - University of Bradford, 2012.

[66] BAHRAMIABARGHOUEI, H.; ADAM, S.; BENOIT, G.; MILICA, P.; LESLIE, A. R.; Flexible 16 Antenna Array for Microwave Breast Cancer Detection, **IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING,** VOL. 62, NO. 10, OCTOBER 2015.

[67] SURBHI, M.; Manasi, J.; An Overview: Various Slots Shapes of Micro-Strip Patch Antenna.**International Conference on Multidisciplinary Research & Practice,** v. 1, p. 175, ISSN 2321-2705.

[68] PRIYADARSHI, S.; VIBHA, R. G. Analysis of a Rectangular Monopole Patch Antenna. **International Journal of Recent Trends in Engineering,** Vol 2, No. 5, November 2009. https://www.researchgate.net/publication/229036248.

[69] NEHA; AMRITJOT, K.**Wearable Antenna for Skin Cancer Detection:** 2nd International Conference on Next Generation Computing Technologies (NGCT-2016), IEEE, 2016.

[70] KAUSHAL, A.; SACHIN, T. Microstrip Patch Antenna its Types, Merits, Demerits and its Applications.**IJESRT,** ISSN: 2277-9655, 2015.

[71]LIAQAT, M.; COSTA, L. G.; VASCONCELOS, T. C.; LESSA, P. S.; LINS, E. C; A Feasible Novel Technique for Breast Cancer Imaging Using UWB-Microwave Antennas. **J Clin Exp Oncol.** 6:6. 2017.

[72] SINGH, L. L. K.; B. GUPTA; P. P. SARKAR.; A REVIEW ON EFFECTS OF FINITE GROUND PLANE ON MICROSTRIP ANTENNA PERFORMANCE, **International Journal of Electronics and Communication Engineering & Technology (IJECET),** ISSN 0976 – 6464(Print), ISSN 0976 – 6472 (Online) Volume 3, Issue 3, 2012.

[73]ORBAN, D.; MOERNAUT G. J. K.; The Basics of Patch Antennas. **Orban Microwave Products,** 2006.

[74] RAQUEL,Cruz Conceicao.**The development of Ultra-Wideband Scanning Techniques for Detection and Classification of Breast Cancer:** National University of Ireland Galway, 2010.

[75]https://www.topdoctors.es/en/articulos-medicos/diferencias-entre-la-ecografia-y-la-mamografia.

[76] LAZEBNIK, M.; ERNEST, L. M.; GARY, R, F.; Tissues-Mimicking Phantom Materials for Narrowband and Ultrawideband microwave Applications, **Phys. Med. Biol.**, 50, p. 4245-4258, 2005.

[77] WANG, D.; RAN, L.; WU, B. I.; CHEN, H.; HUANGFU, J.; GRZEGORCZYK, T.M.; KONG, J.A. Multi-Frequency Resonator Based on Dual-band S-shaped Left-Handed Material. **Opt. Express, 14** (25), 12288–12294 ,2006.

[78] TURKMEN, M.; AKSU, S.; CETIN, A. E.; YANIK, A. A.; ALTUG, H. Multi-Resonant Metamaterials Based on UT-shaped Nano-Aperture Antennas. **Optics Express,** Vol. 19, No. 8 / 7922, 2011.

[79] RAVAN, M.; ANMINEH, R. K.; NIKOLOVA, N. K.; Two-Dimensional Near Field Microwave Holography. **Inverse Problems,** v., 26, p. 055011-055032, 2010.