An Overview of Electromagnetic Methods for Breast Cancer Detection and A Novel Antenna Design for Microwave Imaging

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***Abstract* - There are several techniques that are used for early stages detection of breast cancer which is important to decrease the higher percentages of death cases. This paper focuses on summarizing the electromagnetic techniques for disease detection such as X-ray mammography, ultrasonography, tomosynthesis, magnetic resonance and the other emerging electromagnetic techniques. Using microwave techniques in the imaging system have recently attracted considerable attention. In this study, categories of the microwave imaging system is examined, especially radar-based ultrawideband microwave imaging technique is explained in detail. A key component of this imaging system is the antenna that is used to radiate and receive the UWB pulses. In this paper, a compact-size, UWB and directional planar antenna is developed for this aim. Analysis and the performance optimization of the proposed antenna is performed by High Frequency Structural Simulator (HFSS) software. Simulation results show that the designed antenna is suitable for using in radar-based microwave imaging systems.**

***Keywords* – Breast cancer detection, electromagnetic imaging methods, microwave imaging, ultra-wideband, directional antenna.**

I. INTRODUCTION

ACCORDING to the World Health Organization, breast cancer is the most common cancer among women worldwide [1]. Statistics clearly demonstrate the importance of this disease and its impact on the health. The early diagnosis of the disease could help to decrease the higher percentages of death cases. Malignant cells can multiply uncontrolled and spread to other tissues. Hence, detecting the cancer tumor at the early stage plays a crucial role in the treatment of disease.
An ideal breast cancer detection technique should have the following properties:

- has low health hazard,
- is sensitive to malignant tumor issue,
- determine breast cancer at a medicable stage,
- screening as fast as possible,
- is affordable, widely available, non-destructive and simple to perform,
- involve minimal discomfort, so the procedure is acceptable to women [2-4].

There are various techniques that are used for early stages detection of breast cancer such as; X-ray mammography, ultrasound technique, digital tomosynthesis and magnetic resonance imaging (MRI). However, even with the combined use of these techniques, the current method of screening for breast cancer does not meet the ideal requirements. Therefore, researchers are actively searching for alternative methods of breast imaging [5]. Some of the emerging electromagnetic techniques are electrical impedance tomography (EIT), diffuse optical tomography (DOT), biomagnetic and microwave imaging (MI). Among these techniques, MI methods have recently attracted considerable attention because it uses nonionizing radiation which is safer than ionizing radiation, i.e. X-rays used in mammography. It is noninvasive so there is no compression in MI and making the exams more comfortable than the other techniques [6].The low illumination power levels used in MI also make regular screening possible. Another advantage is that the system is low cost.
The present study aims to find out the type of techniques for tumor detection and mention about the merits and drawbacks of them clearly. The informations about the number of methods will be summarized and detailed informations about the MI methods will be provided in the paper.

II. BREAST CANCER SCREENING TECHNIQUES

Since the early diagnosis and treatment are the hot keys to survive from the breast cancer, there are many techniques that are used for detection of early stages of the breast cancer such as; mammography, ultrasound, tomosynthesis, MRI and other emerging electromagnetic techniques under development [7].

A. Mammography

Currently, the standard and frequently used technique for breast cancer screening and detection is X-ray mammography where is it being quite sensitive to the lesions in the breast by compressing the breast on X-ray image. Mammography is not sensitivity for early-stage tumor detection but only for the best and effective medical treatment. Although the X-ray mammography provides high resolution images, it's not highly reliable [8,9].

The most widely used X-ray mammography also requires painful and uncomfortable breast compression and exposes the patient to ionizing radiation. X-radiation is a form of electromagnetic radiation. Most X-rays have a wavelength ranging from 0.01 to 10 nanometers, corresponding to frequencies in the range 30 to 30.000 petahertz and energies in the range 100 eV to 100 keV, so they are in ionizing radiation class and they may be harmful for body. X-ray mammography has another limitation, especially when dealing with younger women who have dense breast tissues, because there is a few percent contrast between healthy and diseased breast tissues at X-ray frequencies [5]. One of the other drawbacks is the high miss detection which can reach 30 per cent [10] due to high false positive and negative detection.

Consequently, X-ray mammography, currently the most common imaging method for early breast cancer detection, is not highly reliable, requires painful breast compression, and exposes the patient to low levels of ionizing radiation. All of these limitations and their potential for harm, provide plenty motivation for the development of alternative methods of breast imaging.

B. Ultrasound Technique

Ultrasound technique is harmless but it is less effective than mammography and it is used as a supporting imaging method for mammography. Ultrasound imaging is based on high frequency sound waves which reflect with changing intensity from different tissues. In the breast, ultrasound is able to differentiate skin, fat, glandular tissue, and muscle. Unfortunately, it has a limitation that fat issue and tumor issue have similar acoustic features and for this reason detecting many tumors is impossible with ultrasound. Ultrasound has also been utilized in breast cancer detection with a false negative rate of 17% [11]. The other drawback of ultrasound is its disability to provide high resolution for deep and condensed tissue structure such as fatty tissues. Also ultrasound imaging requires high skill and longer time, and that is why the technique is not used commonly [12].

C. Digital Tomosynthesis

Breast tomosynthesis is based on the acquisition of three-dimensional digital image data, could help solve the problem of interpreting mammographic features produced by tissue overlap. Breast tomosynthesis has the potential to help reduce recall rates, improve the selection of patients for biopsy, and increase cancer detection rates, especially in patients with dense breasts [13]. Advantages and disadvantages of the tomosynthesis can be listed as below:

- 3-D imaging is available,
- It is able to detect the tumor which is hidden behind the dense breast tissue,
- It has less X-ray radiation according to mammography,
- It decreases the biopsy rates and increases the ratio of true diagnosis,
- It is not required more compression and provide less pain,
- It has long application and evaluation time,
- It uses big detectors and has difficulty in giving positions.

D. Magnetic Resonance Imaging (MRI)

MRI for breast cancer has been proposed since the late 1970s but until the 1980s it did not show sufficient benefit. However, the use of gadolinium as a contrast agent in MRI significantly enhanced breast cancer detection. In almost all studies, MRI has exhibited high sensitivity and it often detected small tumors missed by mammography and ultrasound [14]. MRI showed particular advantage in dense breasts where mammography typically fails to detect tumors. However, the elevated sensitivity of MRI came at the expense of modest specificity [15].

MRI has several advantages such as a high sensitivity, no ionizing radiation, and the ability to image radio graphically dense breast. However, the prime limitation of MRI is the high cost of imaging [7]. Also, MRI suffered from a higher false positive rate than any of the other screening methods. In one study [16], MRI had a specificity of only 95.4 percent, compared to 96, 99.3, and 99.8 percent for ultrasound, clinical breast exam, and mammography, respectively. This low specificity, along with the high costs associated with MRI, severely limits MRI's usefulness as an alternative or complement to mammography as a widespread screening method [5]. Some advantages and disadvantages of the different imaging techniques mentioned up to this point can be summarized as in Table 1.

Table 1: This caption is centered

Imaging Technique	Advantages	Disadvantages
X-Ray Mammography	Cheap. Availability of copying and archiving the images. Provide high resolution images.	Not convenient for women with dense breasts. Ionizing radiation, dangerous. Compressed breast, pain.
Ultrasonography	Used as scanning for women with dense breasts. Cheaper than mammography. No danger, no ionizing radiation.	More negative false rate than mammography. Cannot image the whole breast at the same time and deep locations in the breast. Cannot diagnosis malign tumors.
Tomosynthesis	3-D Image reconstruction by getting data from different angles. Increased imaging feature of lesions.	Less compression than mammography but still painful.
Magnetic Resonance Imaging	High sensitivity. No ionizing radiation	High negative false rate, high cost. Increased biopsy rates.

E. Emerging Electromagnetic Techniques

Even with the combined use of the current methods for breast cancer, screening does not meet the ideal requirements. Researchers are actively searching for alternative modalities of diagnostic breast imaging. Electrical impedance tomography, diffuse optical tomography, biomagnetic and microwave imaging techniques are some alternative techniques. EIT, a 2-D or 3-D reconstruction of the impedance of the breast, is turned out through the frequency between 100 Hz and 1 MHz [17]. EIT is achieved by placing sensors on the surface of the breast with each sensor performing a current and then voltage differences between the sensors are measured. DOT of breast cancer can be defined as the use of light to screen the optical features in the chest. DOT uses significantly higher frequencies in the near infrared range from about 650 to 950 nm in wavelength with respect to the other breast cancer detection modalities [18]. Biomagnetic technique is based on the elevated magnetic fields were detected from malignant breast tumors in comparison to benign tumors [19]

III. Microwave Imaging System

One of the leading alternative methods for breast cancer detection is to use microwave techniques in imaging. MI methods are non-invasive imaging methods. The quantities imaged in MI are the dielectric properties. The main principle of this technique is based on the significant difference in dielectric properties of malignant breast tumors and normal breast tissue in the microwave frequencies [6]. Microwave signals are the non-ionizing form of the electromagnetic waves and there is no risk to health hazard when used at low levels. Microwave detection is less expensive and safer than other modalities of detection. MI is done mainly in three category as passive, hybrid and active systems [20]. The passive method involves microwave radiometry uses radiometers to obtain the temperature differences in the breast as temperature rises in the presence of tumor than with normal breast tissue [21]. The hybrid methods use microwave energy to heat tumors and they expand and generate pressure waves which are detected by ultrasound transducers [22]. The active methods involve illuminating the breast with microwaves and then measuring transmitted or backscattered signals. Active MI can be classified as microwave tomography, microwave microscopy and ultra-wideband (UWB) radar technique.

A. Microwave Radiometry

Passive MI is usually termed as microwave radiometry and is based on the measurement of the electromagnetic field emitted by warm bodies. Temperature is the main parameter that is used here to estimate the presence of malignancy [23]. There are various causative factors to the temperature elevation related to the tumor presence: the malignant cells are more metabolically active and produce more heat, they have a reduced thermoregulatory capacity, and it is recognized that localized increases in blood volume can be associated with early tumor growth [24].

B. Microwave-Induced Thermal Acoustic Imaging

Microwave-induced thermal acoustic imaging provides two properties that high contrast in the conductivity of malignant tissues at microwave frequencies and the high spatial resolution of ultrasound imaging. The generated acoustic waves carry the information about the microwave energy absorption properties of the tissues under irradiation. The microwave energy absorbed by tumor and normal breast tissues will be significantly different and a stronger acoustic wave will be produced by the tumor. The majority of challenges are referred to inhomogeneity of the breast tissue. This leads to a nonuniform microwave energy distribution, strong interference from the skin and chest wall, and consequently, to complicated image reconstruction algorithms [24]. The biological tissues should be heated by the microwave source in a uniform manner, otherwise thermal acoustic signals will be induced by a nonuniform microwave energy distribution, resulting in images difficult to interpret.

C. Microwave Microscopy

The working principle of the microwave microscope is based on the changing in the resonant frequency of an open-ended microwave cavity resonator, which results from the interaction of the electromagnetic field of the resonator and objects positioned under the skin. This technique provides a high spatial resolution since it is based on the near-field wave tissue interaction, which is not limited by the diffraction limit [25]. Microwave microscopy for the breast cancer detection offers a number of important advantages: it avoids special processing of skin tissues and implementation of complex inverse scattering algorithms; it operates in a very narrow frequency range, thus there is no need of complex dispersive dielectric models of the breast tissues; a priori knowledge of the dielectric properties of the tumor is not critical to the success of the detection; the method can be used for detecting breast cancer in men.

D. Microwave Tomography

In tomography, image is reconstructed using a forward and inverse scattering to enhance the spatial distribution of the complete dielectric properties in the breast. The reconstruction of the electrical properties of the breast at each pixel is calculated in this system [26]. In this method, a coupling medium between the antennas and the body is used in order to refuse high reflections from the air and skin interface. Therefore, the patient orientation for these systems is different from one in microwave radiometry with the patient lying in a prone position with her breast suspended down into the tomography. The electrical properties of the medium are chosen to be close to the properties of the body to achieve the coupling of electromagnetic energy into the breast [27]. In practice however, the electrical properties of the medium depends on temperature, and any temperature drifts and unpredictable local temperature gradients affect the measurement accuracy of the system.

E. Ultrasound-Guided Microwave Imaging

Ultrasound-guided MI is such a combination of two modalities, where microwave image reconstruction is guided by ultrasonography. The ultrasound imaging is used to assemble a priory data about the breast structure and presence and shape of embedded objects. This helps to generate an optimal mesh with well refined target region for effective numerical analysis of the electromagnetic problem [28]. Consequently, the spatial resolution of ultrasound-guided microwave imaging can be enhanced resulting in more accurate imaging of tumors.

F. Ultra-wideband Radar Technique

The principle of the radar-based MI of breast is illuminating the breast with an UWB pulse and detect the reflections. The reflected signals are the data for processing to obtain images that indicate the size and location of the tumor(s) in the breast. A key component of the system is the antenna that is used to radiate and receive the ultra-wideband pulses. This method has been increasingly recommended as a regular examination and detection tool for early breast cancer detection but it is under research and investigation stage till today [7]. The detailed information will be given in the next Section.

IV. Ultrawideband Radar-Based Microwave Imaging For Breast Cancer Detection

Since the authorization of the unlicensed using of the UWB technology in the range of 3.1 GHz to 10.6 GHz by the Federal Communication Commission (FCC) in the USA [29], UWB technology has become very popular in different areas. One of these applications of this technology is UWB microwave imaging technique for breast cancer detection. In UWB applications, it is desirable for impedance bandwidth to be at least 50% to cover the lower UWB band of 3.1–5 GHz or the upper band of 6–10.6 GHz or 110% to cover the entire UWB band of 3.1–10.6 GHz [30].

UWB radar imaging, as proposed by Hagness et al. [31,32] uses an UWB pulse which involves low to high frequencies. The lower frequency band provides sufficient depth of penetration while the higher frequency band ensures the adequate resolution of the creating images. Hence, both the deeply buried and small size tumor can be detected based on the lower and higher frequency of the UWB bands [33]. From this point of view, this system is very important and candidate to become popular. The system is a similar imaging procedure to that used in surface-penetrating radar rather than using the tomographic approach of reconstructing the entire dielectric profile of the breast. In this system, there are three main system configurations: monostatic, bistatic and multistatic. The same antenna performs the task of both sending microwave signals and receiving the reflected signals in monostatic system. Bi-static system has two antennas and the target material is positioned between the receiving and transmitting antennas. Finally, in multi-static system, antenna arrays are used.

For example, experimental study of monostatic MI system for making measurement on breast phantom which has been used in [7] is shown in Figure 1.

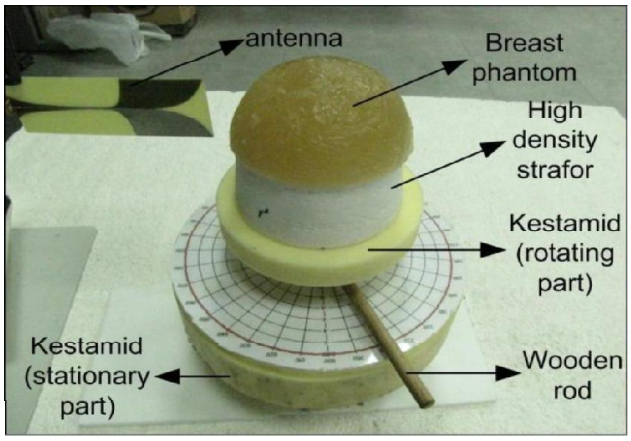


Figure 1: Experimental setup of the monostatic MI system.

There are a lot of MI systems under development for breast cancer detection. An UWB microwave imaging system was developed by Klemm et al. at the University of Bristol [34]. This system operated at higher frequencies (3-10, 4-8, 4.5-9.5 GHz) which were achieved by employing different very small UWB antennas in a hemi-sphere array encircling the breast, instead of using monopole antennas. Consequently, some attention has been directed towards the microwave tomography and UWB radar imaging for breast cancer detection because these techniques are still under development. In addition, most of the histological methods applied UWB radar imaging.

Classification of the microwave imaging systems for breast cancer diagnosis mentioned up to this point can be seen clearly in the Figure 2.

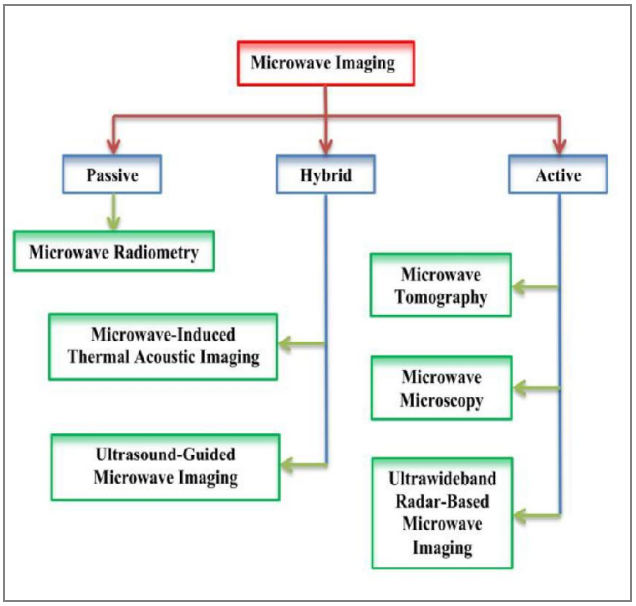


Figure 2: Microwave imaging methods

V. Antenna Design For Ultrawideband Radar-Based Microwave Imaging System

Microstrip antennas are compact and have low-profile but they have narrow bandwidth. However, microwave broadband systems, for example MI system, need UWB signal to transmit short pulses for obtain sufficient range resolution. The modified microstrip antennas which has partial ground plane is called monopole planar antenna and they are the most choosen antennas in the UWB applications because of their wide bandwidth. They are named according to their radiation patch shapes such as elliptical, square circular, rectangular or any session of these shapes. In this study, firstly a L-shaped monopole antenna with gap and T-shaped slot is examined. The geometry of the antenna and the detailed design parameters are given in Figure 3 and Table 2, respectively. Design and analysis of the antenna has been performed by HFSS software.

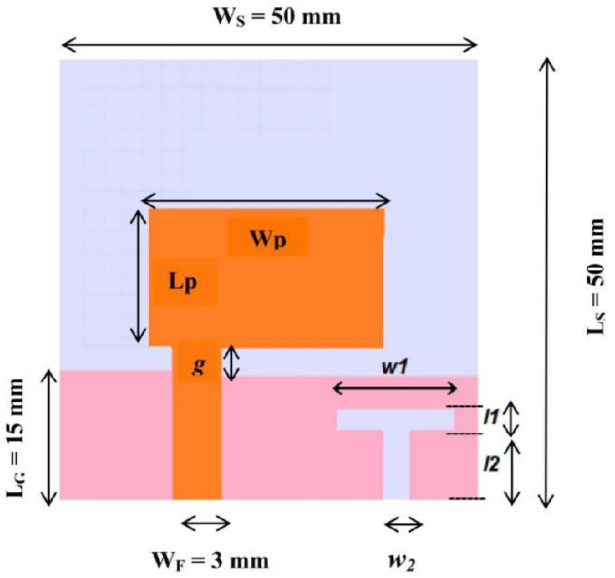


Figure 3: L-shaped monopole antenna with gap and T-shaped slot

Table 2: Design values of the L-shaped monopole antenna.

Antenna Design Parameters	Values (mm)
Length (Ls) and width (Ws) of the substrate	50 x 50
Length (Lp) and width (Wp) of the patch	15 x 22
Length (Lf) and width (Wf) of the feedline	15 x 3
Length (Lg) and width (Ws) of the ground plane	15 x 50
Gap (g) between the ground and patch	1
Length (l_1) and width (w_1) of the horizontal part of the slot	1 x 4
Length (l_2) and width (w_2) of the vertical part of the slot	4 x 1

The return loss graph of the L-shaped planar monopole antenna with T-shaped ground slot is given in Figure 4.

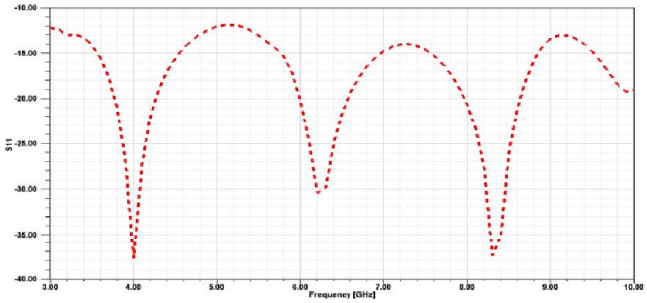


Figure 4: Return loss result of the L-shaped monopole antenna.

The return loss result shows that the antenna shown in Fig. 1 can be used for the UWB MI system from the points of bandwidth and impedance matching. However, for the radar-based UWB MI system, the antenna not only needs large bandwidth but also it should have directional radiation pattern. As it is seen from the Figure 5, this antenna has nearly omnidirectional pattern.

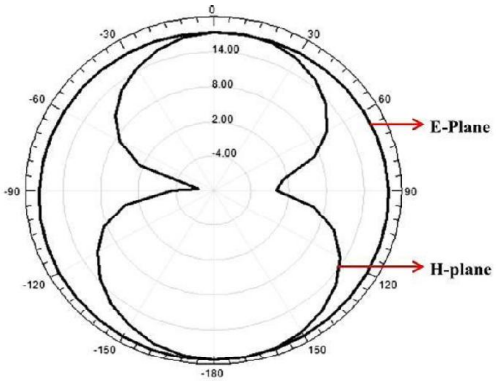


Figure 5: Radiation pattern of the antenna shown in Fig. 1 for 6 GHz frequency

After this point, we force the antenna to be directional in the desired frequency band. For this aim, a three-quarter circle conductor is added to top right-hand corner of the patch. Also a parasitic element is added to left side of the substrate. The radius (*r*) of the circle is 3 mm, the length (*l3*) and width (*w3*) of the rectangular parasitic element are the 10 mm and 3 mm, respectively. The new geometry of the antenna is shown in Figure 6.

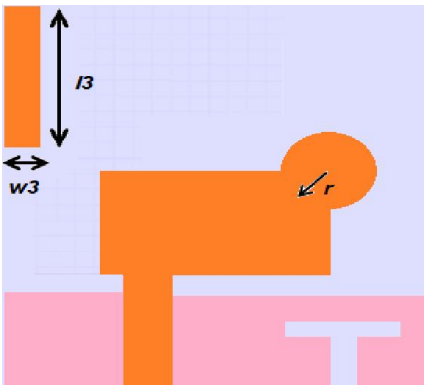


Figure 6: Proposed antenna with new geometry

VI. Results

Indeed, modification of the patch and adding parasitic element improved the directionality. Radiation patterns at the three different frequency points are shown in Figure 7. It is important to maintain the large bandwidth when making some modifications to obtain directional radiation pattern. The return loss result of the proposed antenna is also given in Figure 8.

It is clearly seen that, it still has broad frequency band and good impedance matching. The aim of the UWB and directional antenna design, which is valid for the radar-based UWB microwave imaging application, is accomplished according to these results.

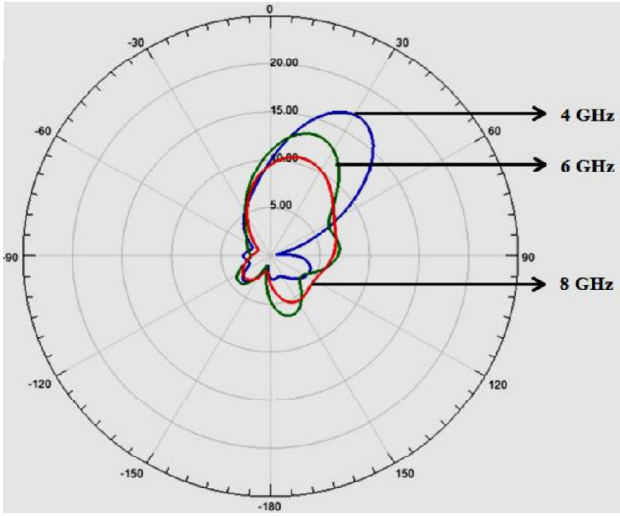


Figure 7: Radiation patterns of the proposed antenna for 4, 6 and 8 GHz.

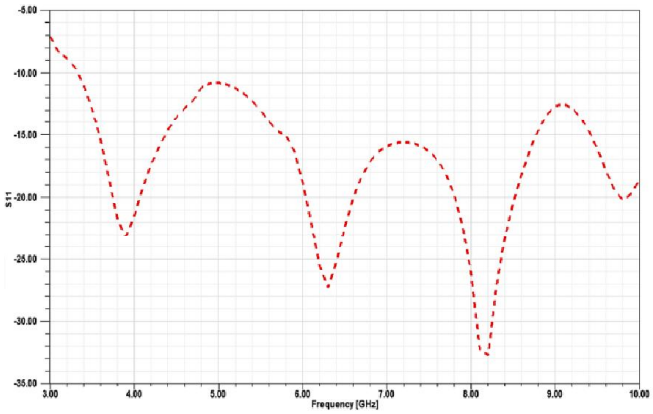


Figure 8: Return loss result of the proposed antenna.

VII. Conclusion

There are various techniques that are used for early stages detection of breast cancer such as; X-ray mammography, ultrasound technique, digital tomosynthesis and MRI. However, even with the combined use of these techniques, the current method of screening for breast cancer does not meet the ideal requirements.

One of the emerging electromagnetic methods is microwave imaging technique. This technique has recently attracted considerable attention because it uses nonionizing radiation which is safer than ionizing radiation, it is comfortable and low cost. The most important element of the system is antenna to transmit and receive the microwaves. The antenna should be UWB, compact, stable and directive. In this study, a planar monopole antenna is designed and analysis by using HFSS software. Simulation results show that the proposed can be used for the radar-based microwave imaging system.

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E-ISBN: 978-605-67535-4-1

