Design and Development of Single Layer Microstrip Patch Antenna for Breast Cancer Detection

N. Mahalakshmi and Vijay Jeyakumar

Abstract--- Breast cancer affects many women and early detection aids in fast and effective treatment. Mammography, which is currently the most popular method of breast screening has some limitations and microwave imaging offers an attractive alternative. The objective of this paper is to design a simple and cost effective single layer aperture coupled microstrip patch antenna for breast cancer detection. The radiation characteristics and the performance of the proposed design are compared with double layer patch antenna. The result of this study shows that the designed antenna has excellent performance across the required frequency range. This single layer patch antenna offers better radiation coverage to the breast and provides efficiency of 62.6% (wide slot) and 62.2% (narrow slot) than double layer stacked patch antenna.

Keywords--- Breast Cancer Detection, Microstrip Patch Antenna, Single Layer Patch Antenna, Stacked Patch Antenna

I. INTRODUCTION

Breast cancer is the most common cancer to affect women, often occurring in the prime of their lives. And the incidence of breast cancer has substantially increased over the past 50 years [1], ever since cases have been carefully tracked. The cause of breast cancer disease remains unknown; however, significant progress has been accomplished for the treatment only if the cancer is detected in early stages [2].

There are several methods of screening. Women 20 years of age and older should be told about the benefits and limitations of breast self-exams (BSE). Women should be aware of how their breasts normally feel and report any new breast change to a health professional as soon as they are aware of how their breasts normally feel. Women 20-39 should have a physical examination of the breast clinical breast exam (CBE) at least every three years, performed by health care professional such as a physician. Women 40 and older should have a CBE every year, performed by a physician and they should receive a screening mammogram every year.

The National Cancer Institute recommends women about 40-50 years of age to take mammography twice a year. Beginning at age 50, screening mammography should be performed every year [3]-[4].

Nowadays different techniques are used to detect breast cancer, e.g., X-ray mammography, ultrasound, Magnetic Resonance Imaging (MRI), microwave imaging etc. However, the standard screening technology X-ray mammogram has many unsatisfactory features [5]-[6]. Microwave imaging modality proves to show a potential for detecting malignant tumors in the breast. Since at microwave frequencies the contrast of the electrical properties between normal and malignant breast tissue becomes significant. The basic idea of using microwave imaging system for breast cancer detection is to transmit electromagnetic waves from a transmitting antenna to the breast and receive the scattered waves at a receiving antenna. These received waves contain vital information regarding the tumor location, shape, size and electrical properties.

II. LITERATURE SURVEY

Early work in this area was based on the premise that the structure of the breast is relatively electrically homogeneous and that a contrast of approximately 5:1 exists between malignant and normal tissue. An alternative approach is to solve the problem using a similar architecture to that of GPR in an approach first introduced independently by Hagness et al.

Radar imaging as a means of detecting breast cancer is a technique that is currently being developed by a number of research teams [7]-[10]. In these systems a short pulse, or a synthesized pulse constructed from a frequency sweep, is directed into the breast and the reflected signals are then detected by one or more receive antennas. The sweep is transmitted in turn from a number of different locations and the resulting set of received signals are then time or phase shifted and added in order to enhance returns from high contrast objects and to reduce clutter. Craddock et al [11] designed a patch antenna to radiate into breast tissue. The high contrast between the dielectric properties of a malignant tumor and the normal breast should manifest itself in terms of lower numbers of missed detections and false-positives. Padhi et al [12] developed an intensive algorithm to handle the increasing complexity of electromagnetic problems in biological applications. A high performance hybrid - MoM/FDTD approach is presented for electromagnetic analysis and design applications in microwave breast tumor detection. A critical
part of any detection scheme is the antenna design. In order to obtain high resolution and accurate images, the antennas must be able to radiate signals over a wide band of frequencies while maintaining the fidelity of the waveform over a large angular range. Existing antenna designs either use resistive loading to improve their Ultra Wide Band (UWB) performance, e.g., resistively loaded monopoles dipoles bowtie and horn antennas, which result in low efficiencies. This paper presents a new slot antenna designed for breast cancer detection system. The dimensions of the slot, feed and ground have been chosen so that the antenna operates optimally, with the slot in contact with a matching medium that has electrical properties similar to that of normal breast tissue. The structure of this paper is as follows; the newly proposed single layer aperture coupled microstrip patch antenna is presented along with a slot-fed, double layer stacked patch antenna that was previously designed for the same application. The performance of the two antennas are compared and tabulated.

III. MATERIALS AND METHODS

3.1 Antenna Design

Microstrip antennas are attractive due to their light weight, conformability and low cost. These antennas can be integrated with printed strip-line feed networks and active devices. In its most fundamental form, a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

![Figure 1: Structure of Microstrip Patch Antenna](image)

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 2.

3.2 Feed Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories: contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer the power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

![Figure 2: Common Shapes of Microstrip Patch Elements](image)

The antennas being examined in this paper are:

1. A cavity backed version of a double layer stacked patch antenna with a fork-fed wide-slot antenna presented in [13].
2. A single feed with reduced layer of stacked patch antenna is intended to replace the double layer stacked patch antenna in this application.

Both the antennas are constructed using the easily available materials FR4-Glass Epoxy having a dielectric constant of $\varepsilon_r=4.5$ and its radiation characteristics are analyzed. The antenna design and the performance characteristics of both double layer and single layer antennas were done by Advanced Design System (ADS) software. It is the leading electronic design automation software for RF, microwave and high speed digital applications.

3.3 Double Layer Patch Antenna

Each microstrip patch antenna consists of at least one feed line and one radiating element. To increase the bandwidth of a microstrip antenna, additional parasitic radiators, placed in the same or in different layers are used. In the case of different layers, the radiators (patches) as well as feed lines (in aperture-coupled antennas) are etched on different dielectric substrates with a relative permittivity larger than one. Some additional dielectric layers are usually needed to support the etched patches and a quarter-wavelength reflector. Thus, up to 6 and more dielectric layers are commonly used in a microstrip antenna. This makes such antennas expensive and therefore unsuitable for production. Figure 3 shows a typical structure of the aperture-coupled double layer stacked-patch antenna.

This stacked patch antenna consists of a microstrip line feeding a slot, which in turn excites an arrangement of stacked patches. The slot feed is used in order to eliminate the inductance associated with a probe feed. The patches sandwich a lower permittivity substrate and their size has chosen so that a lowest order resonance is achieved at either end of the desired frequency band. The antenna is manually optimized by using a MoM computer simulation and the dimensions are given in the Table 1. The efficiency of this
antenna is 51% at 2.44 GHz.

![Diagram of Double Layer Aperture Coupled Antenna](image)

Figure 3: Double Layer Aperture Coupled Antenna

### Table 1: Dimension of Double Layer Aperture Coupled Patch Antenna

<table>
<thead>
<tr>
<th>Element</th>
<th>Narrow Slot</th>
<th>Wide Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patch – 1</td>
<td>21.35</td>
<td>30</td>
</tr>
<tr>
<td>Patch – 2</td>
<td>18.35</td>
<td>25</td>
</tr>
<tr>
<td>Slot</td>
<td>2</td>
<td>14.5</td>
</tr>
<tr>
<td>Feed</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Ground</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

### Table 2: Dimension of Single Layer Aperture Coupled Patch Antenna

<table>
<thead>
<tr>
<th>Single Layer Aperture Coupled Patch Antenna</th>
</tr>
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<tbody>
<tr>
<td>Element</td>
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<tr>
<td>---------</td>
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<tr>
<td>Slot</td>
</tr>
<tr>
<td>Feed</td>
</tr>
<tr>
<td>Ground</td>
</tr>
</tbody>
</table>

3.4 Single Layer Patch Antenna

A single layer aperture coupled design is proposed for microstrip slot antenna to improve its radiation pattern as well as bandwidth. It is based on coupling of an aperture between the patch antenna and the microstrip slot line. The geometry of the proposed method is shown in figure 4. It consists of two substrates bonded together, with a ground plane between. The radiating patch is printed on the top of the substrate; while a microstrip feed line is printed on the bottom of the substrate.

![Diagram of Single Layer Aperture Coupled Antenna](image)

Figure 4: Single Layer Aperture Coupled Antenna

The proposed wide-slot antenna consists of an approximately square slot set in a ground plane on one side of a substrate with a relative permittivity of 4.5. Instead of using fork feeding technique, a single feed aperture coupled just below the slot of 50 Ω is used. The antenna with only one layer of stacked patch (Dimensions are shown in Table-2) reduces complex design of stacked patch antenna.

The single layer aperture coupled patch antenna is designed with simple structure gives better performance and efficiency of 62% is achieved at 2.45GHz. The double layer patch antenna offers 3.6 Steradians of effective angle with 2.3dB of gain but the proposed methodology offers 3.709 Steradians of effective angle with 3.2dB of gain. The return loss of single patch aperture coupled antenna is shown in figure 5.
3.5 Breast Model

The breast is modeled as a finite cylinder cone of breast tissue surrounded by an outer layer of skin shown in Figure 6. This cylindrical cone model is not realistically shaped, but a reasonable approximation for feasibility studies of tumor detection in 2-D cross sections. The breast models have diameter of 8 cm and length of 5 cm. Tumors are modeled as spheres of 8 mm diameter, and are located at the center of the cylindrical cone at a depth of approximately 3 cm. The properties of the breast model are similar to those selected by Hagness et al.

Figure 6: Patch Antenna with Breast Phantom Model

The electrical parameters for breast tissue are chosen as permittivity  is 4.49 and conductivity  = 0.59 S/m; for skin the parameters are  = 39.0 and  = 1.1 S/m and for chest wall, the parameters are  = 53.0 and  = 0.8 S/m respectively. A spherical tumor of radius 4 mm with  = 50.0 and  = 4.0 S/m is placed at a distance of 1 cm from skin. The entire breast model is immersed in a liquid with the same dielectric constant as either breast tissue or skin, but with very low conductivity.

IV. RESULTS AND DISCUSSION

The double layer and single layer patch antennas are simulated and its return loss, Gain, Efficiency and its effective angles are evaluated in this paper as shown in Table 3. The optimized antenna model is used to simulate with the breast models developed. The simulation is performed for the cases where the antenna is placed away (3 cm) from the Breast Simulation models are analyzed for both healthy breast as well as for a breast with a tumor at the center.

Table 3: Comparative Analysis of Antenna Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Double Layer Aperture Coupled Patch Antenna</th>
<th>Single Layer Aperture Coupled Patch Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiated Power (Watts)</td>
<td>1.235e-9</td>
<td>1.040e-9</td>
</tr>
<tr>
<td>Effective Angle (Steradians)</td>
<td>3.109</td>
<td>3.698</td>
</tr>
<tr>
<td>Directivity (dB)</td>
<td>6.0</td>
<td>5.3</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>3.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Efficiency</td>
<td>51%</td>
<td>50.4%</td>
</tr>
</tbody>
</table>

The final field distributions inside the breast phantom with and without tumor are shown in Figure 7. The microwave imaging technique for breast cancer relies on the fact that normal and pathological tissues have different permittivity and therefore respond differently to incident EM field. From the field profiles the tumor can be seen clearly. There are some computational errors found near the skin wall which may be due to the reflection at the tissue-air interface.

Figure 7: Field Distribution of the Breast with and Without Tumor

V. CONCLUSION AND FUTURE ENHANCEMENT

A single layer microstrip patch antenna intended for use in breast cancer detection system has been presented and compared to a double layer stacked patch antenna which was previously designed for the same application. Return loss measurements show that both antennas have suitable bandwidths for use in an ISM band (2.4 – 2.48 GHz) detection system and good agreement has been found between simulated results for both narrow slot and wide-slot antenna. Due to higher radiation pattern and directivity of single layer patch antenna the geometry and electrical properties of breast cancer can be measured accurately for early diagnosis. In future, the antenna will be adopted in the biotelemetry imaging system and the experimental results will be tested with the simulated results using network synthesizer. The overall performance of the single layer aperture coupled stacked patch antenna will be improved further.
REFERENCES


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