Design of a Flexible Microstrip Antenna for BAN Applications

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Abstract: A flexible microstrip antenna is a compact antenna that can be coupled with the skin. However, such antennas require to be coupled with an intermediate matching liquid medium which makes the antenna bulky, complicated, and expensive. Body area network devices are wearable wireless devices/sensors that are used to get the information of a patient’s health in terms of physiological changes irrespective of location. A flexible layer made of Polyethylene is chosen as the substrate and a copper patch is levied upon it. This substrate layer lies in between two adhesive layers (GIL GML 1000). In this paper, flexible antennas are designed and simulated for Body area networks (BANs). The S11 parameter, VSWR value, Gain, and the radiation pattern of the antennas are compared. The polyethylene substrate is highly flexible and lightweight; therefore it would be an ideal material to be used as the substrate of the required antenna.

1. Introduction
The primary objective of recent research in the field of microstrip antenna is to reduce the size and complexity which is utilized in various medical applications. Many such applications use antennas that are bulky in size and this impedes the overall efficiency of the antenna and its applicability despite high application potential. Detecting the tumour tissue at an early stage without using any harmful radiation is important in the treatment of breast cancer and this possibility is offered by microwave imaging and is becoming increasingly popular in the last decade [1-4].

The primary objective of this project is to detect breast cancer tumours by observing the differences in their relative permittivity or conductivity concerning the other cells. The secondary objective of this antenna is to provide a base for body area network devices. Body area network devices are wearable devices that provide the biomedical data of any person using wireless sensors. These devices require a flexible antenna for them to be considered “wearable” and practical and this antenna aims to provide just that. [3]

Techniques like Mammogram, X-Ray, and Ultrasound, etc often provide undesired results and false-negative and are reported to be painful as they involve breast compression and it exposes the patients to ionizing radiation which have serious repercussions on the health of the patient [5]. Therefore the objective of this project is to provide an alternative to these which inflicts less or no pain by the usage of body area network (BAN) devices. These are implemented into/onto our body as implants and are small-sized. They consist of a flexible patch antenna. Previous research, although have brought about changes in the design of such an antenna, however, the antennas presented so far has been dense, heavy, and somewhat uncomfortable. This project aims to improve upon these qualities and also to increase the efficiency of the antenna.
The paper is organized as follows: the related work described in section 2, the proposed design methodology of an antenna explained in section 3 and its results are shown and described in section 4 and section 5 conclude the paper.

2. Literature Survey
Thus far the antennas that have been used require a matching medium to make contact with the skin which increases the overall weight of the antenna and it renders the antenna bulky and impractical[7]. The planner form factor of an antenna is often sought after in the medical industry for a variety of medical applications and therefore a continuous evolution of the substrate is required to attain the desired flexibility while reducing cost. [6-10].

However, some much-needed progress is made in this field the formation of a microstrip antenna that utilizes Kapton (Polyimide) [Thickness: 0.25mm; Dielectric constant, $\varepsilon_r = 3.5$] as its substrate. The design of the antenna as it was observed that the performance of normal antennas gets hindered when they are coupled with the skin and hence a liquid medium is often used between the skin and the antenna [3]. This method is seen in many applications concerning a microstrip antenna [11]. The design of the formulated antenna was changed for an optimized operation with the skin layer as shown in Fig. 1. It was also observed experimentally that there were no significant changes when multiple antennas were used in place of a single antenna. [12]

While Kapton provides useful results, it is much denser than polyethylene. The density of polyethylene ranges from 0.857 g/cm$^3$ to 0.975 g/cm$^3$ whereas the density of Kapton is 1.42 g/cm$^3$ [13-15]. Using a half-ground also increases the overall efficiency of the antenna as it converts it into a monopole antenna. A monopole antenna has twice the directivity of that of a dipole antenna. In this project several changes are made in the design, a half ground is used to convert the antenna into a monopole antenna which has lower losses and makes the antenna significantly lighter. Polyethylene has been chosen as a suitable substrate for this antenna after experimental observation from several other materials that were tested for a possible match for the substrate. These changes have been made to overcome the disadvantages of the antenna being denser and relatively less efficient in terms of radiation losses. The lesser dense polyethylene has an advantage over polyimide which is denser.

Figure 1: Representation of antenna, breast tissue, and tumour (a) normal breast tissue and (b) breast tissue with cancer tumour [4]

In this paper, we have changed the substrate from polyimide to polyethylene and used a half ground plate for the antenna model. The alteration in the substrate was made owing to the lesser density of polyethylene along with better electrical properties as shown in Table 2. The half ground employed in this antenna converts it into a monopole antenna which further enhances the functioning of the antenna by reducing reflection losses. The simulated results of the aforementioned antenna were observed and compared with an antenna of the same dimensions consisting of a polyimide substrate layer. Afterward, a sea-water layer was placed over the substrate which emulates the skin layer and the properties of this skin-antenna model were also observed.
3. Proposed design methodology

A polyethylene layer of 0.25 mm is used as the substrate. This substrate is layered with a flexible copper patch. The patch and ground will be combined by the substrate using an adhesive layer on both ends (GIL GML 1000) \( \varepsilon_r = 3.1 \). A 1.5mm skin layer [Dielectric coefficient: \( \varepsilon_s = 39 \) and conductivity: \( \delta_s = 1.1 \text{ S/m} \)] is used to combine the substrate to the ground as shown in Fig. 2. The skin layer, which is considered to be a part of the substrate [3-12]. A skin layer phantom made of seawater is used in place of the skin during simulation. As shown in Fig. 3. The frequency of operation is 2.45 GHz and impedance for the inset fed antenna is 50 \( \Omega \).

Therefore mentioned approach used to detect the cancerous tissue works by differentiating between the values of various parameters such as relative permittivity and conductivity of the normal tissue and the cancerous tissue. This method can also differentiate between malignant tumour tissue and benign tumour tissue. The permittivity and conductivity of these issues vary according to the frequency as they are a function of frequency. The relative permittivity was considered to be 50 F/m and conductivity was 2.1 S/m for attaining accurate detection for frequencies ranging from 2.45 to 2.7 GHz.

![Figure 2: Schematics of skin-antenna stack [1]](image)

![Figure 3: Detection of Tumor cell [2]](image)

4. Simulation Results and Analysis

Using the parameters given above, three antennas are designed without the skin layer. For each antenna, the \( S_{11} \), VSWR, and Gain are plotted. The change in the resonant frequency in the simulated results can be due to the change in the number of meshes. Antenna 1 is a microstrip antenna that uses full ground and a polyimide substrate as shown in Fig. 4 and Fig.5 respectively, Antenna 2 is a half ground antenna with polyimide substrate, Antenna 3 is a half ground antenna that has polyethylene as the substrate, both shown in Fig. 6 and Antenna 4 is the skin phantom – antenna model which has a half ground, polyethylene substrate and a skin phantom made of seawater which will emulate the skin layer as shown in Fig.7 and its bottom view shown in Fig.8. Patch dimensions for all antennas is \( X = 32 \text{mm}, Y = 31 \text{mm} \). The resonant frequency for the various antennas is 2.45 GHz.

It is observed that the microstrip antenna with polyethylene substrate has a better \( S_{11} \) parameter value than an antenna with a polyimide substrate with better radiation. The phantom skin model is...
superimposed over the antenna the gain increases significantly while there is a minor change in the $S_{11}$ parameter.

In most antenna applications the ideal value of VSWR should be less than 2 dB for it to be considered a good match. As it is apparent in the results of both of the antennas with polyethylene substrate are good matches for this particular application. A microstrip antenna with a half ground is an improvement over a microstrip antenna because the half ground converts the antenna into a monopole antenna.

The microstrip antenna with polyethylene substrate shows improvement over the previous two antennas due to two primary modifications being made. Firstly, it employs a half ground contrary to the full ground used in an ordinary microstrip antenna. Secondly, the substrate of this antenna is made of polyethylene unlike the polyimide substrate used in monopole antenna. In addition to polyethylene being a better alternative to polyimide in terms of various properties of the antenna is also more lightweight and durable. Therefore, the presented antenna has a polyethylene substrate, and its comparison is shown in Table 1.

| Design Value       | Antenna 1 (Flexible Microstrip) | Antenna 2 (Microstrip with the half ground) | Antenna 3 (Microstrip, half ground, polyethylene substrate) | Antenna 4 (Skin-Antenna model) |
|--------------------|--------------------------------|---------------------------------------------|-------------------------------------------------|--------------------------------|
| Substrate          | Polyimide Thickness(t) = 0.25 mm $\varepsilon_r = 3.5$ | Polyimide $t = 0.25$ mm $\varepsilon_r = 3.5$ | Polyethylene $t = 0.25$ mm $\varepsilon_r = 2.25$ | Polyethylene $t = 0.25$ mm $\varepsilon_r = 2.25$ Sea water(Skin Phantom) ; $t= 1.5$ mm ; Conductivity = 4 s/m |
| Additional Layers  | Adhesive layer (GIL GML 1000) ; $t = 0.10$ mm; $\varepsilon_r = 3.1$ | Adhesive layer (GIL GML 1000) ; $t = 0.10$ mm; $\varepsilon_r = 3.1$ | Adhesive layer (GIL GML 1000) ; $t = 0.10$ mm; $\varepsilon_r = 3.1$ | Adhesive layer (GIL GML 1000) ; $t = 0.10$ mm $\varepsilon_r = 3.1$ |

**Figure 4: Top view**
Figure 5: Bottom view

Figure 6: Top view of an antenna with half ground and microstrip antenna with half ground and polyethylene substrate

Figure 7: Top view of microstrip antenna with the half ground, polyethylene substrate and skin layer substitute (Seawater)

Figure 8: Bottom view of microstrip antennas with the half ground, polyethylene substrate, and skin layer substitute
The analysis of the $S_{11}$ parameter is shown in Fig 9 to Fig. 12. The microstrip antenna with a polyimide substrate is only able to provide the $S_{11}$ parameter reading equal to 7.7346 dB, where a monopole antenna with the same substrate provides a reading of 12.3322 dB, a microstrip antenna with a polyethylene substrate provides an $S_{11}$ parameter of 21.4665 dB and the skin-antenna model which consists of a skin layer substitute as a part of the polyethylene substrate gives an $S_{11}$ parameter reading of 20.6492 dB. From the given data, we can conclude that the antenna that has a polyethylene substrate and the half ground has lesser radiation losses than a microstrip antenna with a polyimide substrate keeping the dimensions of the antenna and patch the same. Another useful observation here is that the performance of the antenna is enhanced when a half ground is utilized.

The VSWR value under 2 is suited best for most antenna applications. By observing the given results shown in Fig. 13 to Fig. 16, it is seen that while keeping the dimensions of the antenna and the patch constant, the VSWR plot given by the microstrip antenna with polyethylene substrate has a VSWR value that is close to ideal at 1.4708 dB along with the skin-antenna model which gives a VSWR value of 1.6167 dB. Also, when a half ground is used in the microstrip antenna with polyimide substrate, the VSWR value almost halves itself from 7.57 dB to 4.287 dB.
The significant improvement has been seen when we observe the gain plot of four antennas shown in Fig 17 to Fig 20. The gain value for microstrip antenna with a polyimide substrate reads -0.4925 dB, for the microstrip antenna with polyimide substrate with half ground reads -1.8285 dB, for microstrip antenna with polyethylene substrate the gain is -2.2052 dB, and the gain value for the skin-antenna model is -18.6426 dB. These results can be verified by the physical fabrication of the four antennas. The increase in the gain value across the four antennas can be explained by the usage of a half ground, the change of substrate from polyimide to polyethylene, and the superimposing of seawater layer over the microstrip antenna with the polyethylene substrate as a part of the substrate. The comparative analysis between different antennas is given in Table 2.
5. Conclusion

The technology employed so far uses a bulky and complex antenna to detect breast cancer. Techniques like Mammography are coarse and primitive and are often cause discomfort and pain to a patient. A flexible microstrip antenna is designed that is approximately 0.45 mm thick. Its lightweight design allows it to avoid the use of a matching medium. Then a skin 1.5 mm thick layer of skin is superimposed over the antenna and its properties are observed. The skin tissue is differentiated from the tumour tissue by comparing the difference in the values of relative permittivity and dielectric coefficient and thus the tumour is located.

After observing simulation results, it can be concluded that a monopole antenna coupled with a polyethylene substrate can be used for achieving the objective mentioned. In this paper, the microstrip antennas are designed for microwave imaging for body area applications. Further, the results with developed antennas shown enhanced results.

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Table 2: Comparative analysis between the different antennas

| Simulation Parameters | Antenna 1 Microstrip Antenna | Antenna 2 Microstrip Antenna with half ground | Antenna 3 Microstrip antenna with Polyethylene substrate | Antenna 4 Microstrip antenna |
|----------------------|-------------------------------|-----------------------------------------------|--------------------------------------------------------|----------------------------|
| S11 Parameter (dB)   | 7.7346 dB                     | 12.3322 dB                                    | 21.4665 dB                                              | 20.6492 dB                 |
| VSWR (dB)            | 7.57 dB                       | 4.287 dB                                      | 1.4708 dB                                               | 1.6167 dB                  |
| Gain (dB)            | -0.4925 dB                    | -1.8285 dB                                    | -2.2052                                                 | -18.6426 dB                |
| Frequency (GHz)      | 2.4 GHz                       | 2.4GHz                                        | 2.74 GHz                                                 | 2.1 GHz                    |
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