Wearable Textile Antenna for Glucose Level Monitoring
Asha Ghodake, and Balaji Hogade

Abstract—Wearable antennas are becoming increasingly popular as a result of their wide range of applications, including communication, health parameter monitoring, and so on. If the wearable antenna is built of textile material, it is highly comfortable to wear and has numerous benefits, such as lightweight, compact size, and low cost. A 1.3 GHz microstrip antenna made from jeans substrate is presented in this work. For antenna conducting patch and ground plane copper material is used. The electromagnetic properties of the jean’s substrate are dielectric constant \(\varepsilon_r = 1.7\) and loss tangent \(\tan \delta = 0.01\). In this work the main purpose or application of this antenna is to observe three levels of glucose, i.e., hypoglycemia, hyperglycemia, and normal glucose. The antenna is placed over the arm in the first scenario, while the finger is placed over the antenna patch in the second case. When the glucose concentration in the blood varies, the blood properties change, and the antenna frequency shifts as a result. That frequency shift is used to find out the three glucose levels. The advantage of jeans substrate is that you can wear this antenna very easily over your arm. The antenna is designed using HFSS software and tested using an arm phantom and a finger phantom designed in HFSS.

Keywords—Wearable; textile; microstrip; hypoglycemia; frequency shift; phantom

I. INTRODUCTION

In recent years, the scope of wearable technology has become greater, and there has been a growing need for wearable gadgets in a variety of industries. Wearable antennas for all current applications are often light in weight, cheap in cost, and nearly maintenance-free [1]. Now a day’s one of the most prominent antenna research subjects is wearable textile-based antennas for communications between devices and the human body [2].

Fabric antenna design necessitates an understanding of the electromagnetic properties of the textile material, such as \(\varepsilon_r\) and \(\tan \delta\) [3]. One category of textile material is conductive, and the other is nonconductive. Examples of non-conductive materials are silk, felt, jeans, cotton, and fleece, which are normally used as substrates, and conductive materials like Zelt, Fletron, copper, polyester, and taffeta fabrics. Conducting materials are normally used for conducting patches [4]. Because fabrics have a small dielectric constant, antennas utilizing fabrics as a substrate can provide better performance than traditional antennas [5].

Wearable textile antennas have a variety of uses for military and commercial purposes, but one of the most essential is the observation of various health-related signals when the antenna is worn on the human body [6]. As a result, one of its most important applications is the monitoring of health parameters. In wearable antenna design, microstrip and patch designs are very popular. So, anyone can easily wear or include these antennas in clothing.

There are different methods of fabrication of textile antennas; in general, in the fabrication process, non-conducting textile material is used as the substrate, and copper material is used for the conducting patch. Copper material is directly glued onto textile material using non-conducting glue [7].

Nowadays, glucose level monitoring is very essential for diabetic patients, and it is common in many people. Diabetic patients have face different health problems due to an increase in glucose levels, so it is necessary to monitor glucose levels regularly and, after that, according to glucose levels, patients can change their diet, meditation, and exercise to maintain glucose levels. When a patient can keep proper track of blood glucose, it will be a great help to keep glucose level under control. It is possible only when this tracking is easy, without any pain, without taking blood every time. [8].

Due to different health issues, people can use different medicines. Because of that, a change in glucose level is also observed. Busy life, workload, and stress are responsible for the ups and downs in glucose levels. There are different types of glucose levels. The first is hypoglycemia, means low sugar levels, which are less than 70 mg/dL [9]. The second type is hyperglycemia, which occurs when blood sugar levels exceed 200 mg/dL, and the third type is normoglycemia, or normal glucose, which occurs when blood sugar levels are between 70 and 200 mg/dL [10] [11].

Different methods are available for glucose level monitoring, called invasive methods and noninvasive methods. In the invasive method, devices [enter] are entered into the body, but in the noninvasive method, devices do not enter the body, and the procedure is painless and easy [12]. The most preferred method is to take blood samples from patients and then analyze those samples. Finally, reports are generated [13]. Under the home monitoring concept, different devices and types are used for glucose level monitoring. Two types are available: noncontinuous glucose monitoring and continuous glucose monitoring. [14].

The aim of this paper is noninvasive glucose monitoring. Considering these points, a microstrip antenna is designed to act as a sensor. It senses an increase or decrease in glucose levels. When there is a change in glucose level, then there is a variation in blood properties. This variation is responsible for the shift in output frequency of the antenna. This frequency shift is used to measure glucose level [15].

Authors are with Terna Engineering College, University of Mumbai, India (e-mails: asha.p.ghodake@gmail.com, bghogade@gmail.com).

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II. ANTENNA DESIGN

The antenna is designed at 1.3 GHz using a jeans substrate having a dielectric constant $\varepsilon_r = 1.7$ and a loss tangent of 0.025 [16] [17]. An antenna is simulated using HFSS software. A dielectric layer on the ground surface supports a rectangular patch element [18]. The front side and back side of the antenna are given in Fig 1. The antenna operates at 1.3 GHz with a patch length of 45.25 mm and a width of 53.75 mm. Partial ground plane concept is used in this design.

![Antenna Design](image)

(a) Front side (b) back side of proposed antenna

For feeding, the microstrip feed line method is used. The patch and ground are made of copper material.

A. Simulation Results

It is clear to see that the return loss for the antenna is to be -48.06 dB at a frequency of 1.3 GHz, as shown in Fig 2. A good value of reflection coefficient is obtained, and it is required for antenna design. Because the reflection coefficient is the ratio of incident to reflected power [19].

![Return Loss of Antenna](image)

Fig. 2. Return loss of antenna

The obtained voltage standing wave ratio is 1.01, as shown in Fig 3. Normally, the value of VSWR falls between 1 and 2.

![Voltage Standing Wave Ratio](image)

Fig. 3. Voltage standing wave ratio

The obtained radiation pattern of the antenna is shown in Fig 4. Radiation patterns are very important to find out the quality of radiated power. There are two different plots of the radiation pattern; one is 2D and the other is 3D.

![Radiation Pattern of Antenna](image)

Fig. 4. Radiation pattern of antenna

An antenna’s gain is another important component. It is related to how an antenna effectively converts input into RF output. The obtained gain of the designed antenna is 2.27 dB, as shown by the 3D polar plot given in Fig 5.

![Gain of Antenna](image)

Fig. 5. Gain of antenna
The electric field at the feeding point is 1.0120 e + 002, at the patch center electric field is 2.5307 e + 001, and at the patch age, it is 7.5903 e + 001.

B. Specific absorption rate (SAR)

In wearable antennas, the main significant parameter is the specific absorption rate (SAR). Because human beings can wear these antennas on their bodies, so what is the effect of electromagnetic radiation on the human body? This can be found out using SAR results. SAR is nothing but how much RF power is absorbed by the human body when an antenna is placed near to it [20]. The SAR value also depends on the distance between the antenna and the human body [21]. The obtained value of SAR for the designed antenna is 0.487 w/kg, as shown in Fig 7.

C. Arm and finger phantom design

In the testing procedure, two steps are considered. In the first step, the antenna is placed over the arm phantom and observations are to be taken. In the second case, a finger is placed over the antenna patch and observations are to be taken.
III. RESULTS

The antenna is placed over the arm phantom in the first case. At 1.3 GHz, the blood properties are, \(\varepsilon_r = 60.3\) and \(\sigma = 1.73\) s/m. These values are for normal glucose levels. When glucose levels increase, there is a decrease in the value of \(\varepsilon_r\) and increase in output frequency of antenna [27]. So, by keeping \(\sigma\) value constant and the variation in \(\varepsilon_r\), output frequency shift is observed. If the glucose level rises, the value of \(\varepsilon_r\) falls, resulting in hyperglycemia. Similarly, if the glucose level decreases the value of \(\varepsilon_r\) rises, resulting in hypoglycemia.

For normal glucose levels, \(\varepsilon_r\) is 60.3 at 1.3 GHz [28]. When glucose levels increase, \(\varepsilon_r\) decreases. Table III shows when \(\varepsilon_r\) = 54.3, 52.3, and 50.3, which represent decreased values of \(\varepsilon_r\) i.e high glucose levels, and for these values high output frequency is obtained. This condition is considered hyperglycemia. When \(\varepsilon_r\) = 62.3 and 64.3, which represent increased values of \(\varepsilon_r\) i.e low glucose levels, and low output frequency. This is considered hypoglycemia. So, according to \(\varepsilon_r\) values, Table III is divided into hypoglycemia, normoglycemia, and hyperglycemia levels, which are summarized in Table IV and shown in Fig 10 (b).

Similarly, output frequency shift is also measured in the second case, when a finger is placed over the antenna. Fig 11 (a) illustrate the frequency change and change in return loss. The height of the blood layer is greater in the finger phantom than in the arm phantom. So, the frequency shift is maximum in the case of the finger, which is shown in Table V.

![Graph](image1)

**Table III**

<table>
<thead>
<tr>
<th>(\varepsilon_r)</th>
<th>(\sigma) s/m</th>
<th>(f) GHz</th>
<th>(S_{11})</th>
</tr>
</thead>
<tbody>
<tr>
<td>64.3</td>
<td>1.73</td>
<td>1.1760</td>
<td>-15.92</td>
</tr>
<tr>
<td>62.3</td>
<td>1.73</td>
<td>1.1780</td>
<td>-16.37</td>
</tr>
<tr>
<td>60.3</td>
<td>1.73</td>
<td>1.1790</td>
<td>-16.64</td>
</tr>
<tr>
<td>58.3</td>
<td>1.73</td>
<td>1.1800</td>
<td>-16.75</td>
</tr>
<tr>
<td>56.3</td>
<td>1.73</td>
<td>1.1810</td>
<td>-16.92</td>
</tr>
<tr>
<td>54.3</td>
<td>1.73</td>
<td>1.1810</td>
<td>-16.98</td>
</tr>
<tr>
<td>52.3</td>
<td>1.73</td>
<td>1.1840</td>
<td>-17.24</td>
</tr>
<tr>
<td>50.3</td>
<td>1.73</td>
<td>1.1850</td>
<td>-18.05</td>
</tr>
</tbody>
</table>

**Table IV**

<table>
<thead>
<tr>
<th>Blood Sugar Levels</th>
<th>(f) GHz</th>
<th>(S_{11})</th>
</tr>
</thead>
<tbody>
<tr>
<td>hyperglycaemia</td>
<td>1.1810</td>
<td>-16.98</td>
</tr>
<tr>
<td>Normal range</td>
<td>1.1790</td>
<td>-16.64</td>
</tr>
<tr>
<td>hypoglycaemia</td>
<td>1.1760</td>
<td>-15.92</td>
</tr>
</tbody>
</table>

![Graph](image2)

Fig. 10. (a) Frequency shift (b) frequency shift at three different glucose levels using arm phantom at different values of \(\varepsilon_r\)

Fig. 11. (a) Frequency shift (b) frequency shift at three different glucose levels using finger phantom at different values of \(\varepsilon_r\)
Table V shows the variation in frequency according to the Er values. When the glucose level falls, Er rises and the frequency falls; when Er is 64.3, the output frequency is 1.4040 GHz, indicating hypoglycemia. Similarly, when glucose levels increase and Er decreases, there is an increment in output frequency. When Er is 54.3, then the output frequency is 1.4350 GHz. This is the condition of hyperglycemia.

<table>
<thead>
<tr>
<th>Er</th>
<th>σ (s/m)</th>
<th>f (GHz)</th>
<th>S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>64.3</td>
<td>1.73</td>
<td>1.4040</td>
<td>-13.94</td>
</tr>
<tr>
<td>62.3</td>
<td>1.73</td>
<td>1.4250</td>
<td>-14.40</td>
</tr>
<tr>
<td>60.3</td>
<td>1.73</td>
<td>1.4260</td>
<td>-14.45</td>
</tr>
<tr>
<td>58.3</td>
<td>1.73</td>
<td>1.4330</td>
<td>-14.49</td>
</tr>
<tr>
<td>56.3</td>
<td>1.73</td>
<td>1.4340</td>
<td>-14.48</td>
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</tr>
<tr>
<td>52.3</td>
<td>1.73</td>
<td>1.4440</td>
<td>-14.85</td>
</tr>
<tr>
<td>50.3</td>
<td>1.73</td>
<td>1.4510</td>
<td>-14.94</td>
</tr>
</tbody>
</table>

Table VI shows the variation in frequency according to glucose levels. When the glucose level is 1.4350 GHz, this is the condition of hyperglycemia.

<table>
<thead>
<tr>
<th>Blood Sugar Levels</th>
<th>f (GHz)</th>
<th>S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperglycaemia</td>
<td>1.4350</td>
<td>-14.95</td>
</tr>
<tr>
<td>Normal range</td>
<td>1.4260</td>
<td>-14.45</td>
</tr>
<tr>
<td>Hypoglycaemia</td>
<td>1.4040</td>
<td>-13.94</td>
</tr>
</tbody>
</table>

Using finger, we can also measure three glucose levels, which are mentioned in Table VI. Fig 11(b) shows the response of three glucose levels.

CONCLUSION

As a function of blood dielectric characteristics, a link between blood glucose level fluctuation and matching resonating frequency shift is seen. If the blood glucose level increases, then there is an increment in output frequency. Results are observed in both cases; one is the antenna placed over the arm and the second is the finger placed over the antenna patch. A maximum frequency shift is obtained when a finger is placed over the antenna patch. A specially designed antenna should be used as a sensor to sense variations in glucose levels and find out hyperglycemia and hypoglycemia levels.

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