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Feasibility Study of Non Invasive Blood Glucose Monitoring using Wideband Antenna

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Abstract— **Blood glucose monitoring is difficult to manage the diabetes as continuous monitoring is required. There are many new noninvasive measurement techniques developed and still research is going on these techniques. The present work focuses on the possibility of non-invasively measures blood glucose levels using electromagnetic waves. This technique is based on relating an antennas resonant frequency to the permittivity and conductivity of blood which is then related to the glucose levels. The proposed wideband antenna is designed to operate over 500 MHz to 6 GHz. Good return loss up to -33 dB which is less than -10 dB and radiation pattern characteristics with 2.21 dB gain at 1.6 GHz resonant frequency are obtained in the frequency band of interest.**

Index Terms— **Non-Invasive, Glucose Monitoring, Diabetic, Biological tissues, wideband, SAR.**

I. Introduction

In 2014, there were 382 million people had diabetes and there is a possibility that up to the year 2035 the 592 million people will suffer from diabetes. More than 11% of healthcare institutes spending their time to study the treatment of diabetes [1]. Chemical, Biochemical, and Glucometer are some of the invasive monitoring techniques available to monitor blood glucose level. The invasive monitoring procedure for diabetes is very tedious and painful so that nearly one-third of the population with diabetes goes undiagnosed. For this reason, a noninvasively monitoring glucose levels method is having high demand because it is desirable for diabetes patient which would allow for more frequent and continuous monitoring of blood without pain. So, we are the concern with that noninvasive blood glucose monitoring technique which is inexpensive.

The non-invasive methods include infrared Spectroscopy, Optical Coherence Tomography, Raman Spectroscopy, Polarization Change, Ultra-sound, Fluorescence, Thermal spectroscopy, Ocular spectroscopy, Impedance spectroscopy, Breath Chemical Analysis, Temperature-modulated localized reference etc. and already a number of research groups and companies developing noninvasive blood glucose monitoring systems based on these methods[2]-[4]. This frequently monitoring reduces hypoglycemia, and also we can determine diet as per the glucose level in the blood, physical activity, and insulin doses.

This paper gives the possibility of monitoring blood glucose levels non-invasively. The method consists of antenna which would change its resonant frequency depending on the dielectric properties of the human body tissues present in its near fields. We have selected the performance of antenna in the near field because the antenna can be kept on the arm or leg of the human body. The antenna has been designed such as to meet the standards of Institute of Electrical and Electronics Engineers which concern with acceptable SAR levels that make the devices harmless to human tissues [5]. If blood glucose levels changes, it will affect the dielectric properties of blood and it will shift the resonant frequency of an external antenna [6]. This frequency shift in the antenna can be used to characterize blood permittivity, conductivity, and ultimately the blood glucose levels.

Caduff et al. [7] have been presented a non-invasive method to determine blood glucose concentration by using impedance, spectroscopy from 1 MHz to 200 MHz with a resonant circuit. This frequency range had been selected to fall within blood region of -dispersion. Part of the resonant circuit contained in a wristwatch as to hold it on the users arm. The device was working well but some limitations occurred. In the present work, an antenna has been designed to provide the same effect. For our purpose, the resonant frequency of the antenna is used as a measurement parameter.

II. THEORETICAL BACKGROUND

The dielectric properties of any material can be obtained from their complex relative permittivity $\hat{\varepsilon}$ and it is expressed as [8]

$$\hat{\varepsilon} = \varepsilon' + j\varepsilon'' \quad \text{(i)}$$

Where j=$\sqrt{-1}$ ε' is the relative permittivity which is a measure of charge displacement and energy stored in the material, and ε'' is the out-of-phase loss factor which is a measure of the electrical energy dissipated. In biological material external field induces ionic and displacement currents. The corresponding losses with his currents are in proportion with ionic conductivityσ_i. The total conductivity is given by

$$\sigma = \sigma_d + \sigma_i \quad \text{(ii)}$$

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And it is related to the loss factor

$$\varepsilon'' = \frac{\sigma}{\varepsilon_0 \omega} \tag{iii}$$

But in real it is only possible to measure total conductivity σ. The dielectric properties can be determined as ε' and ε'' or ε' and σ values, as a function of frequency. The dielectric properties of human tissues are characterized in the studies of previous research group [9] which is described by (iv). The frequency-dependent relative permittivity and conductivity [9] of dry and wet skin, fat, muscle, and blood has been shown in Fig. 1 and Fig. 2 respectively.

$$\hat{\varepsilon} = \varepsilon_r + \frac{\sigma(\omega)}{j\omega\varepsilon_0} \tag{iv}$$

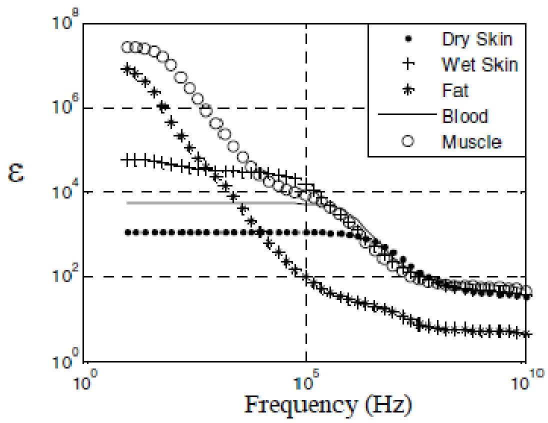

Fig. 1 Biological tissue model with relative permittivity [9]

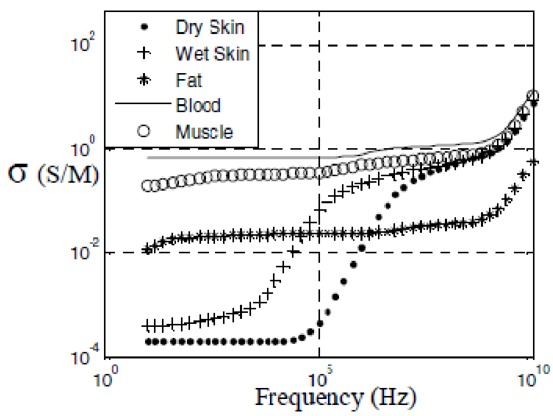

Fig. 2 Biological tissue model with relative conductivity [9]

If the wave is passing through the skin and fat layers at frequency 1 GHz, only 50% of its intensity is transmitted and if the same wave passes through skin and muscle layers it can be transmitted in a 93% of its intensity. Thus, the antenna has to be in touch with more blood i.e. on muscle tissues. But as the thickness of tissue layers increased, it is difficult to measure the biological parameters as each layer of tissues has different dielectric and it varies through person to person, gender and age difference etc. So it can be placed on the forearm as only blood vessel has been found in the arm is a branch of the Subclavian Artery, which is very small and surrounded by bone and muscle[10].

III. ANTENNA DESIGN CONSIDERATIONS

The starting of design process of an antenna is to select the operating frequency. Two parameters should be considered to select the frequency of operation is the relative permittivity and penetration depth.

The relative permittivity and depth of penetration of blood have been shown in the Fig. 3 and Fig. 4 respectively.

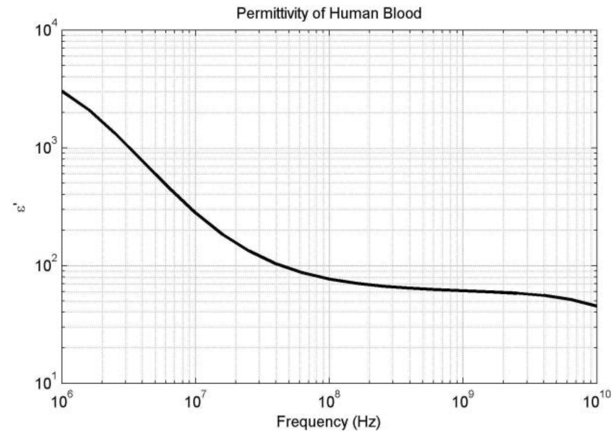

Fig. 3 Permittivity of Blood[11]

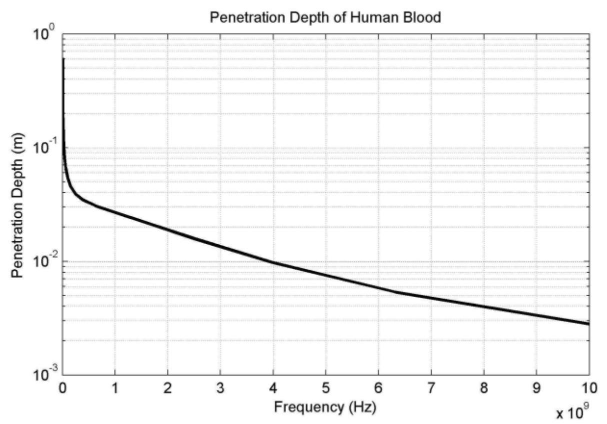

Fig. 4 Penetration depth of Blood[11]

It can be seen that from Fig. 3, below 100 MHz, permittivity rises exponentially. This very high permittivity can provide almost complete reflection, so it will be difficult to measure the minor changes in the dielectric properties if tissues. Also from Fig. 4 we can conclude that at 4 GHz, penetration depth falls to minimum desired level of 1 cm. For our design penetration depth of approximately 1 cm is sufficient as we have to observe a blood glucose level and not tumors. Here we have modified the ultra-wideband antenna [12] to operate 1.3 to 6 GHz.

IV. ANTENNA DESIGN

Fig. 5 shows the configuration of the proposed wideband antenna in which rectangular patch with two notches at the two lower corners of the rectangular patch exists. Also, there is truncated ground plane has been included with the notch and slot structure. The proposed antenna has dimension of 48 mm X 68 mm (Wsub X Lsub) and it is constructed on the FR4 substrate having a thickness of 1.6 mm and relative dielectric constant of 4.4. The width (Wf) of the Microstrip feed line is fixed at 2 mm. On the upper layer of substrate a rectangular patch with size of 21 mm X 31 mm is printed. With the help of truncated ground with notch and slot we have achieved good impedance matching.

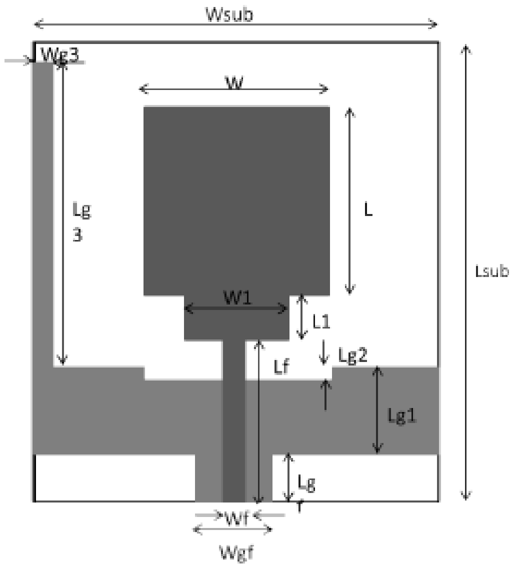

Fig. 5 The configuration of the proposed wideband antenna.

The optimal dimensions of the designed antenna are: Wsub = 48 mm, Lsub = 68 mm, W = 21 mm, L = 31 mm, W1 = 15 mm, L1 = 7 mm, Wf = 2mm, Lf = 26mm, Wg1 = 48 mm, Lg1 = 14 mm, Wg2 = 21 mm, Lg2 = 1 mm, Wg3 = 2 mm, Lg3 = 42 mm, Wgf = 8 mm, Lgf = 10 mm. It is found that the designed antenna satisfies the requirements in wideband frequency band ranging 1.3 GHz to 6 GHz.

V. RESULTS AND DISCUSSION

The wideband antenna with various parameters has been constructed using bandwidth-enhancement technique. The simulated results are obtained using the CST Microwave studio.

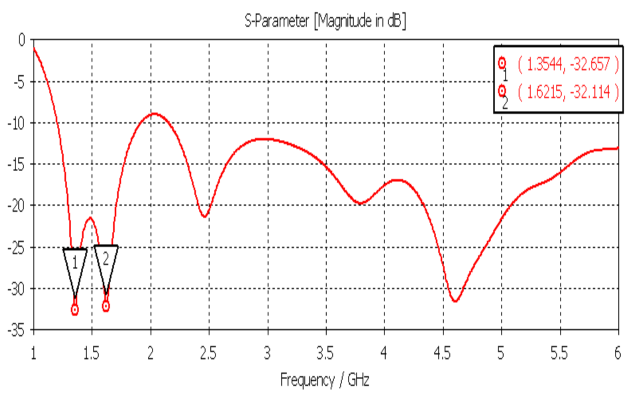

Fig. 6 Return loss of the proposed wideband antenna.

Fig. 6 shows the simulated return loss curve in free space which is below -10 dB over the frequency range 1 GHz to 6 GHz. The antenna is resonating for different frequencies giving large bandwidth and good impedance matching.

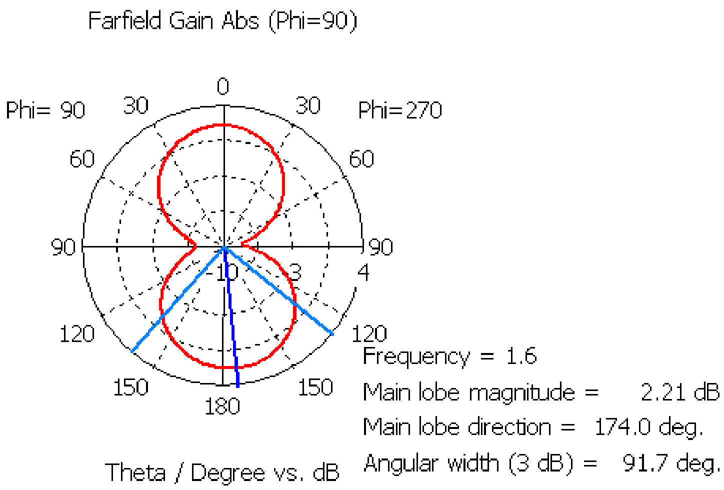

Fig. 7 Radiation pattern of the proposed wideband antenna at 1.6 GHz.

Fig. 7 shows the radiation pattern of the antenna at resonating frequency 1.6 GHz. We are getting much better antenna gain is 2.21 dB at 1.6 GHz which is more than acceptable value.

Previous work by the research group has shown that a resonant frequency shift is relative to free space and can be used to characterize biological tissues [5] which is then can be used characterize blood glucose levels.

VI. CONCLUSION

From the simulated result of antennas at frequencies of 1.35 GHz, 1.62 GHZ, 2.43 GHz and 4.58 GHz we observed that the frequency 1.62 is more suitable as we are getting sharp result with return loss -32.114 dB and the gain is 2.21 dB. The designed antenna will give the frequency shift on VNA as a change in glucose concentration occurs. With the help of this observation, we will create the database of blood glucose level of diabetes patient having same age and gender. In this way we can frequently monitor glucose of diabetic patients as here we are not going to make direct contact with the blood.

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