Single Fold Microstrip Ring Resonator Antenna for Glucometer

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Abstract— **Blood glucose measurement is vital for diabetes management. Blood glucose measurement technologies are both painful and costly. A microwave sensor can be useful for non-invasive determination of blood glucose levels. As a step towards developing a microwave based non-invasive blood glucose measurement technique, a microwave antenna or sensors are designed and tested with aqueous glucose. In this paper, a single fold microstrip ring resonator with compact structure is designed for use as a glucometer. As the dielectric constant of the superstrate material placed above ring resonator antenna changes, resonant characteristic of antenna varies and shift in the frequency is observed. The proposed microstrip antenna resonators are designed using Advanced Design System. As low frequency microwave signal penetrates deep into tissues and has potential for practical applications, a low profile low cost microstrip ring resonator antenna is proposed for better frequency resolution. A high frequency resolution is desired for glucometer i.e. for a small change in glucose concentration there should be a large frequency shift. The proposed ring resonator gives 10-20 MHz shift in frequency for every 10% change in glucose concentration.**

***Keywords**: Ring Resonator, Aqueous Glucose, Resonant Frequency, Permittivity, Glucometer*

I. INTRODUCTION

The disease Diabetes afflicts millions of people worldwide. It is an abolic disease concerned with the inability of the body to achieve sufficient glucose regulation. Improper insulin regulation is the main cause of diabetes. Insulin hormone breaks down glucose, which is the primary energy source of living organism as glucose enters into body cells and energizes them. The body's glucose concentration level must be between 70 mg/dL (milligram of glucose in 100 milliliters of blood) to110 mg/dL for a person to be healthy. However, right after food consumption, blood sugar concentration may rise upto 140 mg/dL and blood glucose above 150 mg/dL for prolonged time indicates diabetes or its onset. According to World Health Organization (WHO), by 2030, the number of diabetes patients is likely to rise to 101 million in India making it the world's seventh largest killer. Hence, we have to utilize technology to eradicate this disease. We can make use of WBAN (Wireless Body Area Networks) systems to monitor blood glucose concentration of a diabetic patient. Regular glucose level measurement in a diabetic patient and administering insulin are the keys to keep the patient safe. The device used to measure blood glucose level is called Glucometer.

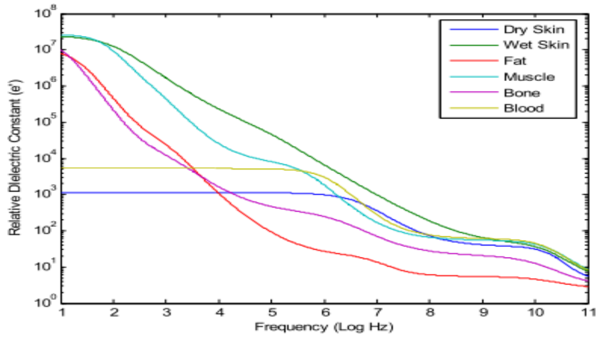
Presently, glucose can be measured using two techniques, invasive and non-invasive, also known as in-vivo and in-vitro respectively. In invasive technique, a blood drop is taken from the patient's finger tip onto a test strip which is further inserted into a glucometer for blood glucose measurement[1]. This technique is both costly and painful with an added risk of infection. Therefore, a non-invasive glucose measurement is desirable.

In non-invasive technique, various technologies are used such as near Infrared spectroscopy, Optical coherence tomography, Raman spectroscopy, Ultrasound technology, Thermal spectroscopy, Fluorescence technology, Impedance spectroscopy, etc. [2]. These methods have limitations like size, calibration problems, discontinuous monitoring, etc. Hence, a microwave ring resonator antenna is used in this paper for non-invasive blood glucose measurement. Another application found in this paper[3] is measuring dielectric constant of superstrate (olive oil) using microstrip meander resonator sensor.

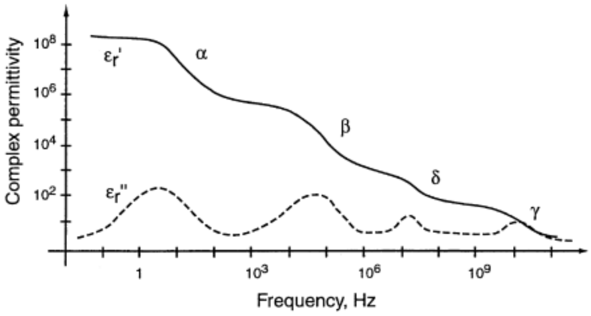
In this paper a low profile microstrip ring resonator antenna for glucometer is proposed.

II. MICROWAVE PROPERTIES OF BIOLOGICAL TISSUES

In electromagnetic waves spectrum, the waves with radiation wavelength ranging from one meter to one millimeter and with frequencies between 300 MHz (100 cm) and 300 GHz (0.1 cm) are known as Microwaves. To understand microwaves, it is important to understand the dielectric properties of tissues in presence of different microwave frequency ranges [4], [5], [6]. Fig. 1 depicts that bloods permittivity does not change much if the frequency is below 1 MHz. Hence, a sensor can be designed above 1 MHz band where resonant frequency changes with change in glucose concentration in the blood.



(a)



(b)

Fig. 1. (a) Relative dielectric constant of certain tissues from 10 Hz to 100 GHz [7], (b) Dispersion regions of an ideal biological tissue

The complex permittivity of any material is written as [8]

$$\varepsilon = \varepsilon_{r'} - j\varepsilon_{r''} \quad (1)$$

where $\varepsilon_{r'}$ is dielectric constant or relative permittivity and it is a measure of the amount of energy from an external electrical field stored in the material and $\varepsilon_{r''}$ is loss factor and it is a measure of the amount of energy loss from the material due to an external electric field and is written as

$$\varepsilon_{r''} = \frac{\rho}{\omega\varepsilon 0} \quad (2)$$

where ρ is the conductivity of the material and ω is the angular frequency, ε_0 =8.85x10^{-12} F/m is permittivity of free space.

Table I [10] shows the various dielectric constants of Aqueous Glucose..

TABLE I. DIELECTRIC CONSTANT OF AQUEOUS GLUCOSE SOLUTION [10]

Concentration of glucose in water by weight percent	**Dielectric constant**
0%	77.37
10%	76.14
20%	73.43
30%	70.46
40%	67.11
50%	63.39

III. Antenna Design

The design formulas relating to the dimension and the resonant frequencies are as follows [9]

$$L_R = 2\pi r = n\lambda_g \quad (3)$$

where, L_R = Total Length of resonator, r is the radius, λ_g is guided wavelength, n is the number of modes, here n=1.

Assuming resonant frequency as 1 GHz using following formula for assuming length of ring resonators [9]

$$\lambda g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \text{ and } \lambda_0 = \frac{c}{f} \quad (4)$$

where $\lambda_0$wavelength in air and f is resonant frequency and c=3x10^8 m/s is speed of light in air, given as [9].

Effective dielectric constant is calculated as [10]

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{\frac{-1}{2}}. \quad (5)$$

Dielectric constant of substrate FR4 is ε_r = 4.6 and h is height of substrate and w is width of microstrip antenna. Hence, for designing a Ring Resonator antenna, assuming f = 1 GHz and h= 1.6 mm, from (5) and (6), $\boldsymbol{\lambda}_0$=300 mm, w=1.6 mm, and Again using ε_r=4.6 (FR4), h= 1.6 mm, w=1.6 mm and ε_{eff}=3.299. Thus from (3) and (4) the length of the total resonator id obtained as L_R=165.16, r=26.5 mm, and λg =165.16 mm.

IV. Geometry Analysis of Antennas

Two microstrip antenna structures are designed using Advanced Design System software. Microstrip resonator width=1.6 mm, coupling gap between feed and resonator =0.32 mm, feed line width=3 mm, feed line length=10 mm are used as design parameters for the antennas:

A. *Ring Resonator*

Fig.2 shows a Ring Resonator for Glucometer [8]. From (3), it is seen that total length of the resonator is integral multiple of the guided wavelength of antenna. When signal enters into the ring of the ring resonator through coupling gap, the energy coupled into ring splits equally over the top and bottom of the ring producing standing waves [8].

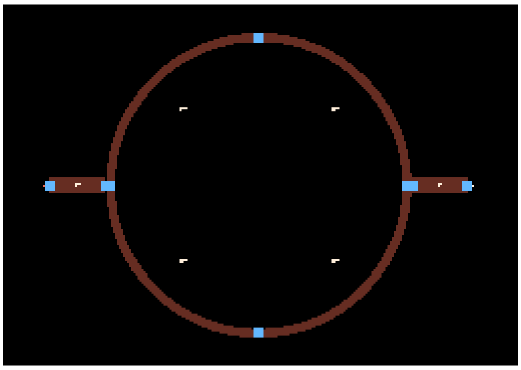


Fig.2. Ring resonator [8]

B. Proposed Single Fold Ring Resonator

The base for this antenna design is microstrip Ring Resonator, from which the single fold ring resonator is derived as shown in Fig.3. The symmetrical inner folds at the centre have radius of 27 mm, while radii of extreme left and right curves are 26.5 mm. Hence total optimized length of resonator L_R becomes 168 mm. As seen in Fig. 3 , radii of extreme left and right curves are taken as 26.5 mm so as to have same basic ring shape intact.

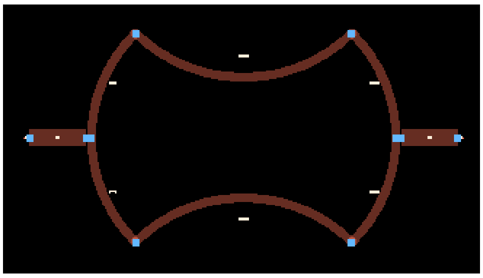


Fig.3. Proposed Single Fold Ring resonator

Table II shows that the area of proposed single fold ring resonator is reduced by 38% as that of ring resonator.

TABLE II. COMPARISON OF PHYSICAL AREA COVERED BY ANTENNAS

Antenna Type	**Area (sq. mm)**
Ring	2206
One Fold	1375

V. SIMULATION RESULTS

Both the microstrip antenna structures are simulated using Advanced Design System software and tested by vector network analyzer on a standard FR4 substrate with $\varepsilon_r = 4.6$ for measurement of S_{21} parameter with air and aqueous glucose as superstrate.

I. Simulation Results using air as a superstrate

Both the antennas are simulated with air as the superstrate as shown in Fig.4. S_{21} parameters for both the antennas are plotted as in Fig. 5.As can be seen from Fig.5, both antennas are having similar S_{21} parameters.

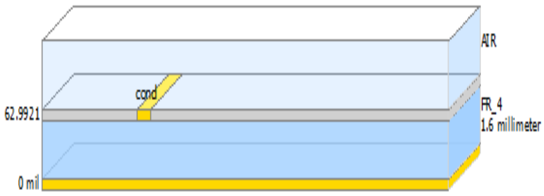


Fig.4. Air as superstrate for both the antennas

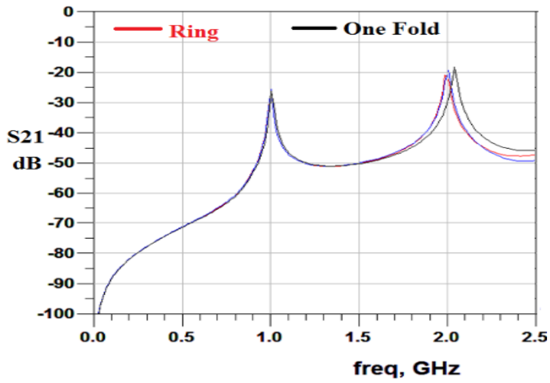


Fig.5. S_{21} (dB) Vs Frequency plot

II. Simulation Results using Aqueous Glucose as Superstrate

To have a significant shift in frequency aqueous glucose is introduced as a superstrate, as shown in Fig.6. This proposed antenna is simulated for various concentration of aqueous glucose which can be maintained with different dielectric constants as given in Table I.The S_{21} parameters for both the antennas are plotted as in Fig. 7.

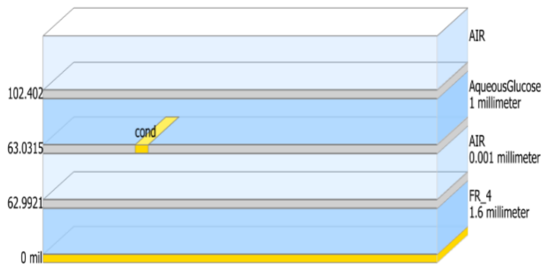


Fig. 6. ADS Simulation Substrate

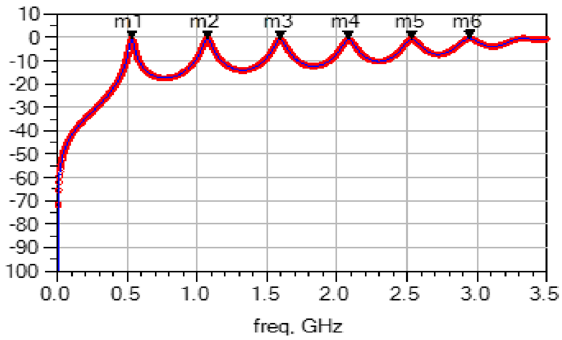


Fig. 7. Ring Resonator for 40% aqueous glucose

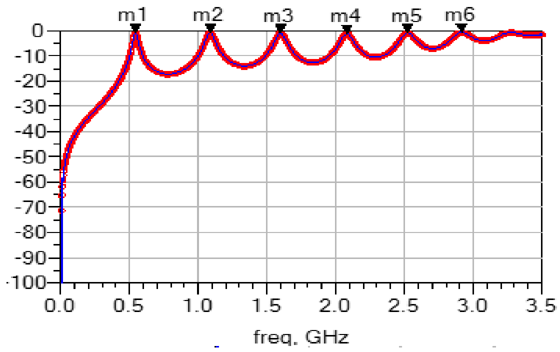


Fig. 8. One Fold Ring Resonator for 40% aqueous glucose

Though there is no significant difference with air as a superstrate, the aqueous glucose as a superstrate shows significant shift in frequency. The simulation results are tabulated in Table III. For different frequencies such as1 GHz (M1), 2 GHz (M2) and 3 GHz (M3). The shift in frequency is calculated by subtracting the resonant frequency obtained with aqueous glucose as a superstrate through the resonant frequency obtained with air as a superstrate. Thus the frequency resolution is obtained by finding the gap between two successive shifts in frequencies. Thus the proposed ring resonator gives 10-20 MHz shift in frequency for every 10% change in glucose concentration.

TABLE III. MEASURED FREQUENCY FOR RING RESONATOR CORRESPONDING TO CHANGE IN GLUCOSE CONCENTRATION AS PER SIMULATION

% Glucose	M1			M2			M3		
	Centre (MHz)	Shift (MHz)	Resolution (MHz)	Centre (MHz)	Shift (MHz)	Resolution (MHz)	Centre (MHz)	Shift (MHz)	Resolution(MHz)
0	515	485	0	1037	963	0	1535	1465	0
10	515	485	0	1041	959	4	1542	1458	7
20	522	478	7	1051	949	10	1556	1444	14
30	525.5	474.5	3.5	1058	942	7	1573	1427	17
40	532.5	467.5	7	1072	928	14	1594	1406	21
50	539.5	460.5	7	1086	914	14	1615	1385	21

VI. CONCLUSIONS

The proposed single fold microstrip ring resonator antenna gives maximum shift in frequency for small change in glucose concentration. Therefore, the single fold ring resonator gives better resolution. As it requires lesser physical area, the proposed single fold ring resonator has good scope to be used as a sensor in compact non-invasive glucometer. The resolution between two successive frequency shift is in the range of 10-20 MHz for every 10% change in concentration of aqueous glucose as a superstrate.

VII. REFERENCES

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