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INSET-FED MICROSTRIP PATCH ANTENNA FOR GLUCOSE DETECTION USING LABEL-FREE MICROWAVE SENSING MECHANISM

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Abstract

In this work, a real-time label-free microwave sensing mechanism for glucose concentration monitoring using a planar biosensor configured with an inset fed microstrip patch antenna has been demonstrated. A microstrip patch antenna with the resonating frequency of 1.45 GHz has been designed and is fabricated on the Flame Retardant (FR-4) substrate. Due to the intense electromagnetic field at the edges of the patch antenna, edge length has been used as the detecting area where the sample under test (SUT) interacts with the electromagnetic field. The Poly-Dimethyl-Siloxane (PDMS) with the trench in the centre has been employed as the sample holder. Here, the SUT is the glucose dissolved in DI (de-ionized) water with the concentration range of 0.2 to 0.6 g/mL. The dielectric constant dependency on the glucose concentration has been used as the distinguishing factor which results in a shift in the S-parameter. The experimentally measured RF parameters were observed closely which showed the shift in S11 magnitude from –40 to –15 dB and resonant frequency from 1.27 to 1.3 GHz w.r.t the SUT solution of 0.2 to 0.6 g/mL with linear regression coefficient of 0.881, and 0.983 respectively.

Keywords: microwave sensor, patch antenna, glucose monitoring, PDMS.

1. Introduction

Recently, biosensors have been utilized progressively for continuous monitoring of biological processes, predominantly in the field of agriculture and food industries [1]. Glucose is the key ingredient of many food beverages. Because of its essential responsibility in organic and physiological processes, much effort has been committed to the improvement of the technique to identify glucose in beverages and drinks [2]. Evaluation of glucose fixation with high affectability, selectivity and exactness are required in widespread applications. Detecting the actual concentration of glucose is very important to maintain the quality of preserved foods in the food industries [3]. Most of glucose biosensors are based on the amperometric [4] or potentiometric electrode [5].

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They have also taken several forms based on the electrochemical [6], optical [7,8], and thermal [9], *etc* sensors. Many other technologies have been utilized to implement the biosensor, *e.g.*, infrared spectroscopy [10], fluorescence spectroscopy [11], Raman spectroscopy [12], fluid chromatography [13], polarimetry [14] and impedance spectroscopy [15] *etc*. Various designs such as the microwave microfluidic sensor based on *split ring resonators* (SRRs) [16], metamaterial-inspired coupled *complementary SRR* (CSRR) based microwave microfluidic sensor [17], *metamaterial* (MTM)-infused planar microwave sensor for sensitivity improvement [18], microstrip transmission line loaded with an LC resonator [19], open ended microstrip transmission line loaded with CSRR [20], complementary electric LC resonator coupled with a microstrip line [21], co-planar waveguide with the micro-fluid channel created on the top [22], microwave resonator integrating passive device technology [23], IDC with an inter-twined spiral inductor [24], 3D rectangular shaped wave guide cavity [25], microwave sensor based on a split ring resonator [26] and microstrip transmission line sensor [27] for the quantitative detection of glucose level have already been reported. Our group is working on microwave biosensors using a CPW transmission line [28], IDCs embedded with the CPW [29] and meander inductor embedded with the CPW [30]. These designs are configured with two-port radio-frequency devices. Several single-port sensors such as a microstrip patch antenna for the glucose detection have been reported in [31] where the antenna is completely submerged in the sample, and in [32,33] the patch top-side needs to be completely covered with the SUT. Hence, the required sample quantity is very high. In this work, we have proposed a single port glucose sensor implemented using an inset fed microstrip patch antenna where the sample is confined only to the edge length. Hence, the sample required is comparatively very low. This paper is organized with sensor design, sensor fabrication and its experimental set up under Section 2, experimental results under Section 3, discussion as well as comparison of the proposed work with the reported work under Section 4, and conclusions under Section 5.

2. Sensor Design

2.1. Working principle

The electromagnetic wave interacts with the SUT which is glucose solution with varying concentration, resulting in a shift in the RF parameter of the glucose sensor. Dielectric constant for varied glucose concentration was reported in [34], which showed that an increase in the concentration of glucose from 0.2 to 0.6 g/mL, causes the decrease in the dielectric constant from 73.11 to 61.9. Therefore, a decrease in the dielectric constant with a rise in the concentration of glucose cause the increase in the crest frequency. This shift in the RF parameters can be observed closely enough to use the microstrip patch antenna for glucose level detection. The microstrip patch antenna sensor design details are discussed below.

2.2. Design Analysis

The rectangular microstrip patch antenna is intended for the resonant frequency (f_r) of 1.45 GHz. The design parameters of the rectangular microstrip patch antenna are calculated analytically using the antenna modelling formulae [35–37]. The analytical modelling has been done in MATLAB and further optimized by carrying out a 3D *electromagnetic* (EM) simulation with the *Computer Simulation Technology* (CST) tool. The 3D view of the microstrip patch antenna designed in the CST is shown in Fig. 1.

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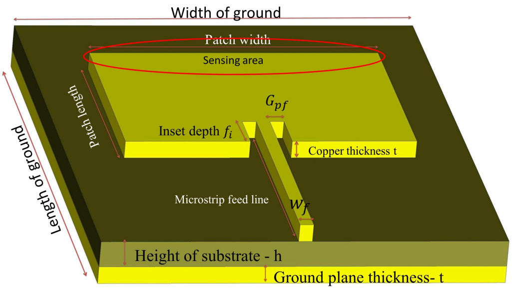

Fig. 1. Geometrical configuration of the antenna with the sensing area encircled.

The design parameters obtained from the analytical model and further optimized with the CST tool are listed in Table 1. In the conventional rectangular microstrip patch antenna, the top of the patch is surrounded with air only. But in the proposed solution, the fringing field along the patch edge length is partially covered with the sample from the top, as shown in Fig. 2. Hence, the dielectric constant of the varied glucose affects the RF performance parameter. The field distribution on the patch is presented Fig. 3, which shows that the field is highly intense at the

Table 1. Antenna design parameters.

Description	Parameters from the analytical model (in mm)	Parameters from the CST simulation (in mm)
Width of the patch (W)	61.43	62
Length of the patch	47.88	47
Microstrip feed line width (W_f)	2.95	2.9
Inset feed depth (f_i)	12.69	10.4
Notch gap (G_{pf})	0.1219	0.8
Ground length (L_g)	122.86	122
Ground width (W_g)	95.76	114

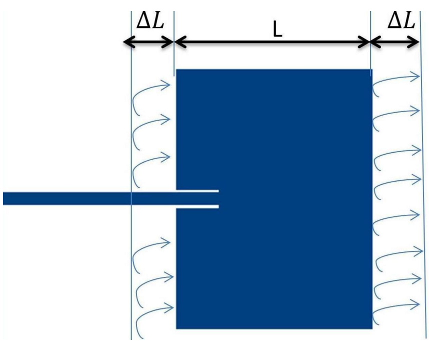

Fig. 2. Fringing fields along the patch edge length.

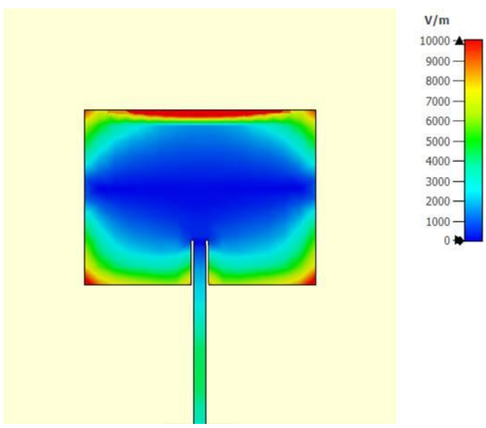

Fig. 3. Electric field distribution on the patch.

edges of the patch compared with its centre. To utilize the intense electric field at the patch length edges, the sensing area is confined to the length edge with the PDMS cavity.

2.3. Fabrication of the Inset fed Patch Antenna

FR-4 substrate with ε_r of 4.3, height of 1.6 mm, and copper clad with the thickness of 0.035 mm on both sides, was used as the substrate. The microstrip patch antenna with optimized dimensions, tabulated in Table 1, was fabricated utilizing the PCB screen printed technology. To realize the glucose sensor, a PDMS of cavity size 83 mm × 36 mm with thickness 5 mm is integrated on the top, along the edge of the patch, as shown in Fig. 4. The PDMS cavity is fixed on the antenna patterned PCB using a thin layer of uncured liquid PDMS, which subsequently is cured to bond the PDMS cavity on the PCB. Therefore, the SUT will cover the length edge of the patch for a more prominent shift in the RF parameter.

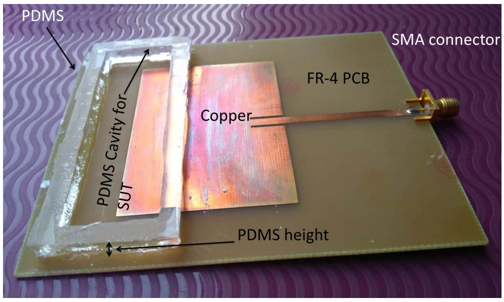

Fig. 4. Fabricated microwave sensor with PDMS cavity integrated on the length edge of the patch antenna to hold the SUT.

2.4. Experimental Set-Up

Experimental studies of the rectangular microstrip patch antenna for the S-parameters were performed utilizing a Rohde & Schwartz ZNB20 Vector Network Analyser displayed in Fig. 5. The aqueous solutions with varying glucose concentrations had been prepared by mixing the required amount of D-Glucose (Dextrose $C_6H_{12}O_6$ by Fisher Scientific) in 20 mL DI water.

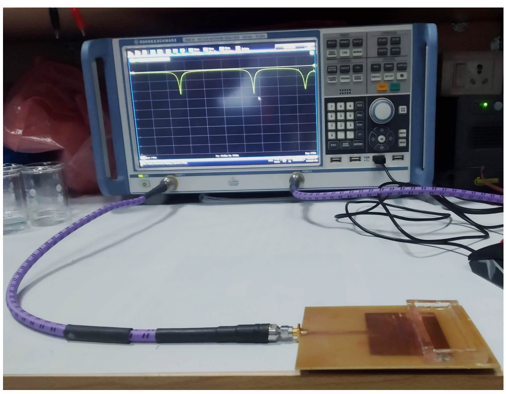

Fig. 5. Experimental setup of the microwave sensor.

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The solution was stirred thoroughly to avoid any precipitation. In each measurement, a glucose sample of 7.5 mL was measured and poured into the PDMS cavity with the help of a pipette and then was settled down for 2 min before taking the measurement. The measurements were performed at 30°C temperature and 40% humidity. To reuse the sensor, the cavity was altogether washed with DI water and completely dried. The subsequent RF measurements were performed changing the concentration of glucose from 0.2 to 0.6 g/mL with the step of 0.1 g/mL.

3. Results

The simulated results of the patch antenna (without the PDMS cavity on the top) are compared with the experimentally measured results, as illustrated in Fig. 6. It is observed that the experimental results are in accordance with the simulation results, with a slight difference which may be due to the manufacturing error, unavoidable parasitic effects, SMA connectors *etc*. The RF measurements were carried out with SUTs of different glucose concentration from 0.2 to 0.6 g/mL range. The measured S_{11} parameter with varying concentration of glucose was presented in Fig. 7, which showed the significant shift in the crest frequency and S_{11} magnitude

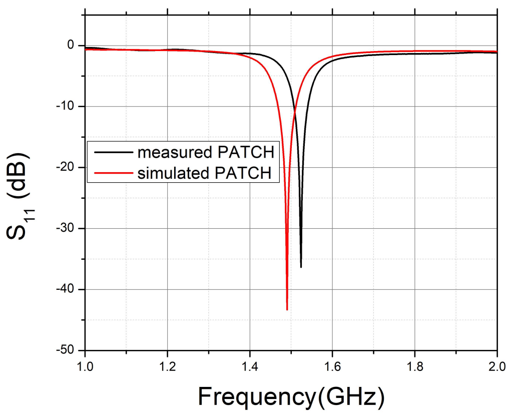

Fig. 6. Measured result vs. simulated result for the microstrip patch antenna.

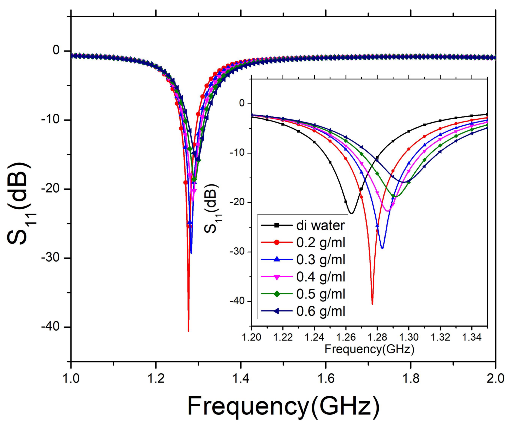

Fig. 7. Shift in frequency and magnitude for varying glucose concentrations.

with varied glucose concentration. The S_{11} magnitude and resonant frequency for solutions of different glucose concentration are listed in Table 2. As we can see in Table 2, there is an increase in frequency with a rise in the concentration of glucose, the same happens with the phase, as shown in Fig. 8.

Table 2. Measured peak frequency for varying glucose concentration.

Glucose concentration (g/mL)	S_{11} magnitude (dB)	**Peak frequency (GHz)**
0 (DI water)	–22.2349	1.26
0.2	–40.5951	1.276
0.3	–29.3128	1.283
0.4	–21.7310	1.286
0.5	–18.7938	1.291
0.6	–15.8992	1.297

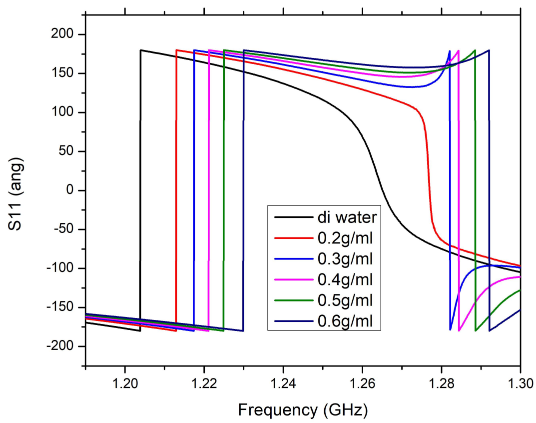

Fig. 8. Phase shift with respect to frequency for different glucose concentrations.

To find out the sensitivity of the patch antenna sensor, the linear regression coefficient is analysed, as presented in Fig. 9. The sensitivity in terms of S_{11} frequency and magnitude are 50 MHz/g/mL and 59.91 dB/g/mL as expressed in (1) and (2), respectively.

$$Y(\Delta S_{11}\text{frequency}) = 50X + 3.6; \qquad R^2 = 0.983, \tag{1}$$

$$Y(\Delta S_{11}\text{magnitude}) = 59.9X - 26.9; \qquad R^2 = 0.881. \tag{2}$$

The regression analysis with R^2 value near to 1, indicating a linear relation between the concentration of glucose and the change of S_{11} parameter as well as the crest frequency. To confirm the re-usability, the experimentally measured results for the empty cavity after each measurement were compared, as shown in Fig. 10. The experiment was repeated to check the repeatability and stability of the sensor. The stability graph of magnitude and frequency is presented in Fig. 11 and Fig. 12 respectively, which show that the results are repeatable with minor change.

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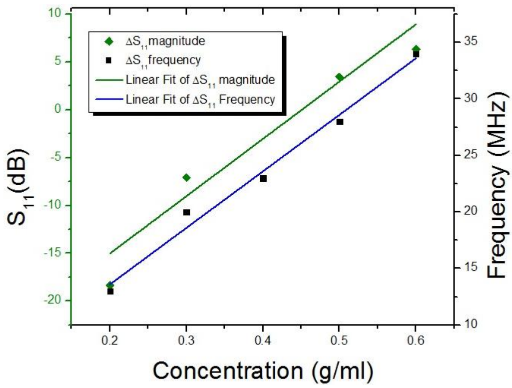

Fig. 9. Regression analysis of S_{11} frequency and magnitude with respect to glucose concentrations.

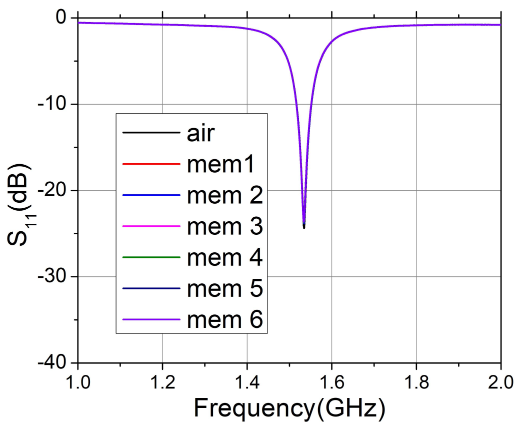

Fig. 10. S_{11} parameters for an empty cavity followed by each measurement.

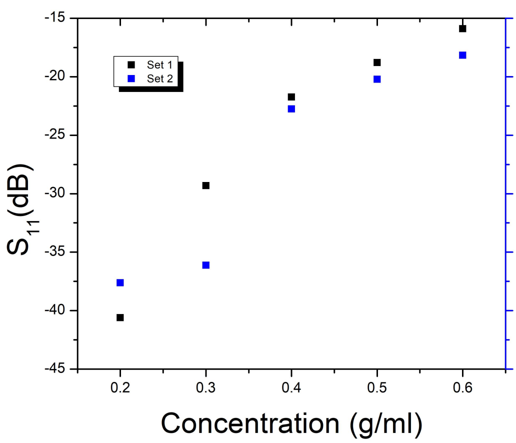

Fig. 11. Stability graph of magnitude for the repeated experiment.

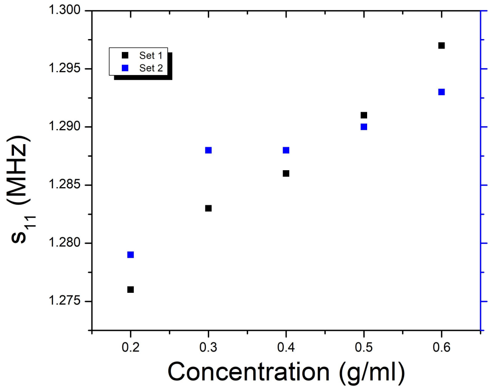

Fig. 12. Stability graph of frequency for the repeated experiment.

4. Discussion

The proposed microwave sensor was compared with the reported work from various aspects including number of ports, sample quantity, sensitivity, and linearity factor, as listed in Table 3.

Table 3. Comparison of the proposed design with the work reported in literature.

Ref	No. of port	Frame-work	Sample holder	SUT	Sample Volume	Sensitivity		R^2	
						|S| (dB)	Frequency (MHz)	ΔS	ΔFreq.
[20]	1-port	Open ended microstrip transmission line with CSRR	Integrated sample holder	Glucose–water sample	–	0.5	–	0.9985	0.995
[21]	2-port	Complementary electric LC resonator	Integrated sample holder	Glucose–water sample	–	–	–	–	0.995
[26]	2-port	Split ring resonators	Not integrated sample holder	Glucose–water	7.5 mL	0.0076 (mmol/L) (S_{11})	–	–	–
[27]	2-Port	Microstrip line	Integrated sample holder	Glucose–water	160 µL	2.6×10^{-3} mg/dL (S_{21})	3.2×10^{-2} mg/dL	–	–
[31]	1-Port	Microstrip square patch antenna	Integrated sample holder	Synthetic blood–glucose	50 mL	–	–	–	–
[32]	1-Port	Microstrip patch antenna	Not integrated sample holder	(Saline–glucose) (Pig blood–glucose)	–	–	1.091e-6/ mg/dL 0.0003/ mg/dL	–	0.0039 0.9219
[33]	1-Port	Circulated Psi-shaped patch	Not integrated sample holder	(NaCl–DI water) (Sucrose–DI water)	–	–	–	–	–
This work	1-Port	Microstrip rectangular patch antenna	Integrated sample holder	Glucose–DI water	7.5 mL	59.9/ g/mL	50/ g/mL	0.881	0.983

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It can be observed from Table 3 that designs reported in [21, 26–28] are two-port designs thus add an additional cost of port and RF cables. The required SUT volume in the proposed design is significantly smaller as compared with the reported single port designs [31–33]. The design reported in [20] is single-port but the design is complex as compared to our design. The proposed design was fabricated on cost-effective and less complex PCB fabrication technology, it has improved sensitivity and the linear coefficient over the reported devices when characteristics like design complexity, cost-effectiveness and smaller SUT requirements are taken into consideration. Glucose concentrations used for our proposed sensor are from 0.2 g/mL to 0.6 g/mL with a step of 0.1 g/mL. Glucose concentrations of various soft drinks that are present in the market are in the range of 0.1 g/mL. Thus, we can clearly see that the concentrations of soft drinks lies in the range which can be easily detected by our device with the sensitivity of 59.9 dB/gm/mL and 50 MHz/gm/mL.

5. Conclusions

In this paper, the development of an inset fed micro strip patch antenna glucose sensor has been presented. RF measurement results showed a prominent shift in S_{11} magnitude and the frequency with very good sensitivity for glucose detection. The experimentally measured RF parameters w.r.t the SUT solution with different glucose concentrations showed a shift in S_{11} magnitude from –40 to –15 dB and resonant frequency from 1.27 to 1.3 GHz for glucose concentration 0.2 to 0.6 g/mL, with linear coefficient of 0.881, and 0.983 respectively.

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References

[1] Zhang, S., Wright, G., & Yang, Y. (2000). Materials and techniques for electrochemical biosensor design and construction. *Biosensors and Bioelectronics*, *15*(5-6), 273-282. https://doi.org/10.1016/S0956-5663(00)00076-2

[2] Jafari, F., Khalid, K., Hassan, Y. J., Zulkifly, A., & Salim, N. S. M. (2015). Variation of microwave dielectric properties in the glucose biosensor system. *International Journal of Food Properties*, *18*(7), 1428–1433. https://doi.org/10.1080/10942912.2011.619293

[3] Bababjanyan, A., Melikyan, H., Kim, S., Kim, J., Lee, K., & Friedman, B. (2010). Real-time noninvasive measurement of glucose concentration using a microwave biosensor. *Journal of Sensors*, *2010*. https://doi.org/10.1155/2010/452163

[4] Liu, X., Hu, Q., Wu, Q., Zhang, W., Fang, Z., & Xie, Q. (2009). Aligned ZnO nanorods: a useful film to fabricate amperometric glucose biosensor. *Colloids and Surfaces B: Biointerfaces*, *74*(1), 154–158. https://doi.org/10.1016/j.colsurfb.2009.07.011

[5] Liao, C. W., Chou, J. C., Sun, T. P., Hsiung, S. K., & Hsieh, J. H. (2007). Preliminary investigations on a glucose biosensor based on the potentiometric principle. *Sensors and Actuators B: Chemical*, *123*(2), 720–726. https://doi.org/10.1016/j.snb.2006.10.006

[6] Heller, A. (1999). Implanted electrochemical glucose sensors for the management of diabetes. *Annual Review of Biomedical Engineering*, *1*(1), 153–175. https://doi.org/10.1146/annurev.bioeng.1.1.153

[7] Choudhury, B., Shinar, R., & Shinar, J. (2004). Glucose biosensors based on organic light-emitting devices structurally integrated with a luminescent sensing element. *Journal of Applied Physics*, *96*(5), 2949–2954. https://doi.org/10.1063/1.1778477

[8] Jerónimo, P. C., Araújo, A. N., & Montenegro, M. C. B. (2007). Optical sensors and biosensors based on sol-gel films. *Talanta*, *72*(1), 13–27. https://doi.org/10.1016/j.talanta.2006.09.029

[9] Subramanian, A., Oden, P. I., Kennel, S. J., Jacobson, K. B., Warmack, R. J., Thundat, T., & Doktycz, M. J. (2002). Glucose biosensing using an enzyme-coated microcantilever. *Applied Physics Letters*, *81*(2), 385–387. https://doi.org/10.1063/1.1492308

[10] Hertzberg, O., Bauer, A., Küderle, A., Pleitez, M. A., & Mäntele, W. (2017). Depth-selective photothermal IR spectroscopy of skin: potential application for non-invasive glucose measurement. *Analyst*, *142*(3), 495–502. https://doi.org/10.1039/C6AN02278B

[11] del Barrio, M., Moros, M., Puertas, S., de la Fuente, J. M., Grazú, V., Cebolla, V., ... & Galbán, J. (2017). Glucose oxidase immobilized on magnetic nanoparticles: Nanobiosensors for fluorescent glucose monitoring. *Microchimica Acta*, *184*(5), 1325–1333. https://doi.org/10.1007/s00604-017-2120-8

[12] Pandey, R., Paidi, S. K., Valdez, T. A., Zhang, C., Spegazzini, N., Dasari, R. R., & Barman, I. (2017). Noninvasive monitoring of blood glucose with Raman spectroscopy. *Accounts of Chemical Research*, *50*(2), 264–272. https://doi.org/10.1021/acs.accounts.6b00472

[13] Zhang, T., Zhang, C., Zhao, H., Zeng, J., Zhang, J., Zhou, W., ... & Chen, W. (2016). Determination of serum glucose by isotope dilution liquid chromatography-tandem mass spectrometry: a candidate reference measurement procedure. *Analytical and Bioanalytical Chemistry*, *408*(26), 7403–7411. https://doi.org/10.1007/s00216-016-9817-0

[14] Phan, Q. H., & Lo, Y. L. (2017). Stokes-Mueller matrix polarimetry system for glucose sensing. *Optics and Lasers in Engineering*, *92*, 120–128. https://doi.org/10.1016/j.optlaseng.2016.08.017

[15] Valiūnienė, A., Rekertaitė, A. I., Ramanavičienė, A., Mikoliūnaitė, L., & Ramanavičius, A. (2017). Fast Fourier transformation electrochemical impedance spectroscopy for the investigation of inactivation of glucose biosensor based on graphite electrode modified by Prussian blue, polypyrrole and glucose oxidase. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *532*, 165–171. https://doi.org/10.1016/j.colsurfa.2017.05.048

[16] Vélez, P., Su, L., Grenier, K., Mata-Contreras, J., Dubuc, D., & Martín, F. (2017). Microwave microfluidic sensor based on a microstrip splitter/combiner configuration and split ring resonators (SRRs) for dielectric characterization of liquids. *IEEE Sensors Journal*, *17*(20), 6589–6598. https://doi.org/10.1109/JSEN.2017.2747764

[17] Ebrahimi, A., Withayachumnankul, W., Al-Sarawi, S., & Abbott, D. (2013). High-sensitivity metamaterial-inspired sensor for microfluidic dielectric characterization. *IEEE Sensors Journal*, *14*(5), 1345–1351. https://doi.org/10.1109/JSEN.2013.2295312

Metrol. Meas. Syst., Vol. 30 (2023), No. 2, pp. 211–222
DOI: 10.24425/mms.2023.144867

[18] Ebrahimi, A., Scott, J., & Ghorbani, K. (2019). Ultrahigh-sensitivity microwave sensor for microfluidic complex permittivity measurement. *IEEE Transactions on Microwave Theory and Techniques*, 67(10), 4269–4277. https://doi.org/10.1109/TMTT.2019.2932737

[19] Abdolrazzaghi, M., Daneshmand, M., & Iyer, A. K. (2018). Strongly enhanced sensitivity in planar microwave sensors based on metamaterial coupling. *IEEE Transactions on Microwave Theory and Techniques*, 66(4), 1843–1855. https://doi.org/10.1109/TMTT.2018.2791942

[20] Ebrahimi, A., Scott, J., & Ghorbani, K. (2020). Microwave reflective biosensor for glucose level detection in aqueous solutions. *Sensors and Actuators A: Physical*, 301, 111662. https://doi.org/10.1016/j.sna.2019.111662

[21] Ebrahimi, A., Withayachumnankul, W., Al-Sarawi, S. F., & Abbott, D. (2015, November). Microwave microfluidic sensor for determination of glucose concentration in water. In *2015 IEEE 15th Mediterranean Microwave Symposium (MMS)* (pp. 1–3). IEEE. https://doi.org/10.1109/MMS.2015.7375441

[22] Grenier, K., Dubuc, D., Poleni, P. E., Kumemura, M., Toshiyoshi, H., Fujii, T., & Fujita, H. (2009). Integrated broadband microwave and microfluidic sensor dedicated to bioengineering. *IEEE Transactions on microwave theory and techniques*, *57*(12), 3246–3253. https://doi.org/10.1109/TMTT.2009.2034226

[23] Kim, N. Y., Dhakal, R., Adhikari, K. K., Kim, E. S., & Wang, C. (2015). A reusable robust radio frequency biosensor using microwave resonator by integrated passive device technology for quantitative detection of glucose level. *Biosensors and Bioelectronics*, *67*, 687–693. https://doi.org/10.1016/j.bios.2014.10.021

[24] Kim, N. Y., Adhikari, K. K., Dhakal, R., Chuluunbaatar, Z., Wang, C., & Kim, E. S. (2015). Rapid, sensitive and reusable detection of glucose by a robust radiofrequency integrated passive device biosensor chip. *Scientific Reports*, *5*(1), 1–9. https://doi.org/10.1038/srep07807

[25] Gennarelli, G., Romeo, S., Scarfì, M. R., & Soldovieri, F. (2013). A microwave resonant sensor for concentration measurements of liquid solutions. *IEEE Sensors Journal*, *13*(5), 1857–1864. https://doi.org/10.1109/JSEN.2013.2244035

[26] Zidane, M. A., Rouane, A., Hamouda, C., & Amar, H. (2021). Hyper-sensitive microwave sensor based on split ring resonator (SRR) for glucose measurement in water. *Sensors and Actuators A: Physical*, *321*, 112601. https://doi.org/10.1016/j.sna.2021.112601

[27] Shahri, A. A., Omidvar, A. H., Rehder, G. P., & Serrano, A. L. (2021). A high sensitivity microwave glucose sensor. *Measurement Science and Technology*, *32*(7). https://doi.org/10.1088/1361-6501/abe1e3

[28] Sameer, M., & Agarwal, P. (2019). Coplanar waveguide microwave sensor for label-free real-time glucose detection. *Radioengineering*, *28*(2), 491. https://doi.org/10.13164/re.2019.0491

[29] Abedeen, Z., & Agarwal, P. (2018). Microwave sensing technique based label-free and real-time planar glucose analyzer fabricated on FR4. *Sensors and Actuators A: Physical*, *279*, 132–139. https://doi.org/10.1016/j.sna.2018.06.011

[30] Todi, S., & Agarwal, P. (2022). Mediator-Free and Rapid Glucose Sensing Using 5-Turn Meandered Signal Coplanar Sensor (MSCS) with Rectangular PDMS Cavity for the Sensitivity Enhancement. *IETE Technical Review*, 1–11. https://doi.org/10.1080/02564602.2022.2067082

[31] Khadase, R., & Nandgaonkar, A. (2016, December). Design of Implantable MSA for Glucose Monitoring. In *International Conference on Communication and Signal Processing 2016 (ICCASP 2016)* (pp. 625–629). Atlantis Press. https://doi.org/10.2991/iccasp-16.2017.90

[32] Vrba, J., Karch, J., & Vrba, D. (2015). Phantoms for development of microwave sensors for non-invasive blood glucose monitoring. *International Journal of Antennas and Propagation*, *2015*. https://doi.org/10.1155/2015/570870

[33] Rahman, M. N., Islam, M. T., & Samsuzzaman Sobuz, M. (2018). Salinity and sugar detection system using microstrip patch antenna. *Microwave and Optical Technology Letters*, *60*(5), 1092–1096. https://doi.org/10.1002/mop.31108

[34] Malmberg, C. G., & Maryott, A. A. (1950). Dielectric constants of aqueous solutions of dextrose and sucrose. *Journal of Research of the National Bureau of Standards*, *45*(4), 299-303. https://doi.org/10.6028/JRES.045.030

[35] Balanis, C. A. (2015). *Antenna Theory: Analysis and Design*. John Wiley & Sons.

[36] Ramesh, M., & Kb, Y. I. P. (2003). Design formula for inset fed microstrip patch antenna. *Journal of Microwaves, Optoelectronics and Electromagnetic Applications (JMOe)*, *3*(3), 5–10.

[37] Prabhakar, D., Rao, P. M., & Satyanarayana, D. M. (2016). Characteristics of Patch Antenna with Notch gap variation for Wi-Fi Application. *International Journal of Applied Engineering Research*, *11*(8), 5741–5746.

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