DOUBLE-LAYERED METAMATERIAL-BASED RESONATOR OPERATING AT MILLIMETRE WAVE FOR DETECTION OF DENGUE VIRUS

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To my beloved parents, thank you.

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ABSTRACT

The interest in microwave technology for biological applications using metamaterial as sensing element is increasing due to strong electric field compared to traditional microwave sensors. The operation at millimetre-wave frequencies further enhances the field intensity leading to increased sensitivity, which can be used in the detection of the dengue virus and it can be vital in controlling the disease. The millimetre-wave metamaterial-based resonators are presented in this thesis to characterise blood's dielectric properties in the case of the dengue virus. The correlation coefficient, t-test, and cross-correlation were applied on S_{11} phase responses. During measurements, tap water was used instead of blood, and methylated alcohol was added to the water to lower its permittivity, mimicking the dielectric response of infected blood. First, a single-layered design with an engraved space to hold blood samples is presented as a proof of concept for blood-sensing and the application of statistical models. This sensor showed a resonance shift of 0.22 GHz due to an 8 unit decrease in blood's permittivity. In contrast, three (3) designs of two-layered sensors are proposed with replaceable sensing layers suitable for repeated measurements. Double-layered Sensor 1 showed resonance at 36.28 GHz for normal blood. The perturbation observed was 0.88 GHz when the blood's permittivity was reduced by 8 units. Sensor 2 showed a resonance shift from 27.22 GHz to 29.82 GHz with the 8 unit change in blood's permittivity. Sensor 3 showed a lesser resonance shift, which is 0.44 GHz. However, the double-layered Sensor 3 has the edge over other designs in terms of its performance in all statistical methods. In double-layered sensors, the replaceable sensing layer provides quick and accurate results. As a result, the sensors presented here can detect the dengue virus using a simple finger-prick blood extraction method.

ABSTRAK

Teknologi gelombang mikro untuk aplikasi biologi menggunakan bahanmeta sebagai elemen penderiaan semakin diminati dan meningkat disebabkan mempunyai medan elektrik yang kuat berbanding dengan penderia gelombang mikro tradisional. Operasi pada frekuensi gelombang milimeter meningkatkan lagi keamatan medan yang membawa kepada peningkatan kepekaan, yang boleh digunakan dalam pengesanan virus denggi dan penting dalam mengawal penyakit ini. Penyalun berasaskan bahanmeta gelombang milimeter dibentangkan dalam tesis ini untuk mendapatkan ciri sifat dielektrik darah dalam kes virus denggi. Pekali korelasi, ujian-t, dan korelasi silang digunakan pada tindak balas fasa S_{11}. Air paip digunakan sebagai pengganti darah semasa pengukuran, dan alkohol metilasi dicampurkan ke dalam air untuk menurunkan kebertelusan air bagi mimik tindak balas dielektrik darah yang dijangkiti. Pertama, rekabentuk penderia selapis dengan ruang terukir untuk menyimpan sampel darah direkabentuk sebagai bukti konsep untuk penderiaan darah dan penerapan model statistik. Penderia ini menunjukkan anjakan salunan 0.22 GHz disebabkan oleh penurunan 8 unit dalam kebertelusan darah. Sebaliknya, tiga (3) rekabentuk penderia dua lapis dicadangkan dengan lapisan atas yang lebih sesuai untuk pengukuran berulang. Penderia dua lapis 1 menunjukkan salunan pada 36.28 GHz dalam darah normal. Gangguan yang diperhatikan ialah 0.88 GHz apabila kebertelusan darah berkurangan sebanyak 8 unit. Penderia 2 menunjukkan anjakan salunan daripada 27.22 GHz kepada 29.82 GHz dengan perubahan 8 unit dalam kebertelusan darah. Sensor 3 menunjukkan anjakan salunan yang lebih rendah, iaitu 0.44 GHz. Dalam rekabentuk ini, korelasi silang didapati meningkat dengan penurunan kebertelusan. Penderia 3 berlapis dua mempunyai kelebihan berbanding reka bentuk lain dari segi prestasinya dalam semua kaedah statistik. Lapisan penderiaan yang boleh diganti dalam penderia dua lapis menawarkan hasil yang cepat dan tepat. Oleh itu, penderia yang dibentangkan boleh digunakan dalam pengesanan virus denggi dengan kaedah perahan darah tusukan jari yang mudah.

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LIST OF SYMBOLS AND ABBREVIATIONS

ε	–	Permittivity
μ	–	Permeability
n	–	Refractive index
σ	–	Conductivity
Q	–	Quality factor
J	–	Current density
z	–	Impedance
S_{11}	–	Reflection coefficient
S_{21}	–	Transmission coefficient
ΔS_{11}	–	Reflection coefficient phase
WHO	–	World health organisation
hCG	–	Human chorionic gonadotropin
HIV	–	Human immunodeficiency virus
POCT	–	Point-of-care testing
MM-W	–	Millimetre-wave
SRR	–	Split ring resonator
EM	–	Electromagnetic
RF	–	Radio frequency
NRW	–	Nicholson-ross-weir
VNA	–	Vector network analyzer
WGM	–	Whispering gallery mode
MTL	–	Microstrip transmission line
PCB	–	Printed circuit board
DPS	–	Double positive medium
MNG	–	Mue-negative
DNG	–	Double negative medium
MTM	–	Metamaterial

SIW	–	Substrate integrated waveguide
CRA	–	Compressive reflector antenna
FIT	–	Finite integration technique

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CHAPTER 1

INTRODUCTION

1.1 Background

Dengue is a deadly mosquito-borne virus spreading throughout the world. In the last five decades, the prevalence of the dengue virus has climbed 30-fold with its emergence into new countries, and it has also expanded from urban to rural areas in the last decade [1]. This rate is still increasing despite vector control efforts and the widespread use of clinical guidelines. According to World Health Organisation (WHO), an estimated 390 million dengue infections occur every year, in which Asian countries account for 70% of the total cases [2]. Currently, there is an increasing trend of mortality rate due to dengue infection in Malaysia [3]. The number of reported dengue infections in Malaysia was 130,101 in 2019, which is 60% more than the cases in 2018. In addition, 182 deaths were also reported in Malaysia related to dengue infections during the same year [2]. The forecasted rate of infections per 100,000 Malaysian population for 2030 and 2040 is 798 and 940, respectively [3]. A primary intervention and prevention plan is essential to evade the predicted prevalence of dengue, as this will impose a huge burden on the country's people and its economy. According to WHO, if disease cases are detected early in an epidemic, emergency space spraying and increased larviciding can benefit reduction measures [1].

The biosensors in this aspect are vital because of their portability and remote sensing ability. Biological investigations can be carried out using portable sensors with the help of microelectrodes as well as conventional electrodes [4]. A measurable signal is obtained from the device called a biosensor which senses biological response. Various biosensors used in the detection of tuberculosis, human chorionic gonadotropin (hCG), human immunodeficiency virus (HIV), cancer, glucose, and

malaria are based on optical or electrochemical methods [5]. However, apart from being accurate and providing high precision, these sensors also suffer from some limitations. These sensors are based on invasive operation and require purification of the samples. Moreover, some sensing methods are based on laboratory investigations [4].

The biosensors generally can be categorised into a couple of classes, one includes those which are cheaper and easier to use and the other includes those providing accurate results. Among these, those cost low, and are easy to detect have sought more attention despite being less accurate and less sensitive [4]. Figure 1.1 shows the commercially available portable biosensing device used in the detection of glucose, HIV, tuberculosis, etc.

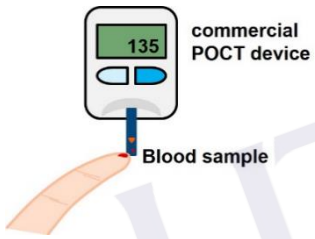

Figure 1.1: Point-of-care testing (POCT) device for home-based sensing [5]

The sensor's suitability in biomedical applications can be assessed depending on certain performance indicators, such as accuracy, precision and portability. The rising interest in the development of microwave biosensors has grown to a new level that they will be potentially made available in the commercial market very soon. This is certainly because high-frequency waves can pass through the cell membrane and interact with the cytoplasm, eventually interacting with γ-dispersion.

Due to the aforementioned constraints of conventional biosensors, the scientists' focus has diverted to some methods that analyse electrical parameters. In these developments, the metamaterial is considered an exceptionally suitable candidate due to its extraordinary properties. This is due to the highly concentrated fields provided by metamaterial structures that result in enhanced sensitivity [6]. Split Ring Resonator (SRR) and its complementary version are the two most researched configurations of metamaterials [7]. Metamaterial exhibit negative values of permittivity, permeability, and refractive index at different microwave frequency ranges, which is not possible in commonly available materials. These subwavelength resonators in biosensing are used to achieve a significant response against small

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APPENDIX B

MATLAB KEYWORDS FOR STATISTICAL METHODS

MATLAB keyword used to apply correlation coefficient:

[rho, pval]=corr(x,y,’type’,’name’)

‘type’: 'Pearson' ‘spearman’ ‘kendall’

MATLAB keyword used to apply t-test:

[h,p,ci,stats]=ttest2(x, y, 'alpha',0.1)

MATLAB code to apply Cross-correlation:

[c,lags] = xcorr(x,y);

[pks,locs] =findpeaks(c,lags,'SortStr','descend');

LIST OF PUBLICATIONS

1. S. A. Qureshi, Z. Z. Abidin, A. Y. I. Ashyap, S. H. Dahlan, H. A. Majid, and C. H. See, "Liquid-Sensing Metamaterial Ring Resonator in Millimeter-wave band for 5G Applications," in 2020 *IEEE Student Conference on Research and Development (SCOReD)*, Sep. 2020, pp. 55–58, doi: 10.1109/SCOReD50371.2020.9250999.
2. S. A. Qureshi, Z. Z. Abidin, AY. I. Ashyap, H. A. Majid, M. R. Kamarudin, M. Yue, M. S. Zulkipli, J. Nebhen, "Millimetre-Wave Metamaterial-Based Sensor for Characterisation of Cooking Oils," *Int. J. Antennas Propag*., vol. 2021, pp. 1–10, Mar. 2021, doi: 10.1155/2021/5520268.
3. Z. Z. Abidin, S. A. Qureshi, A. Y. I. Ashyap, H. A. Majid, "Unorthodox Technique in Sensing with the Metamaterial-Based Resonator Sensor at Millimetre Frequencies," *Journal of Sustainability Science and Management* (Accepted).
4. S. A Qureshi, Z. Z Abidin, N. I.M Elamin, H. A. Majid, Adel Y.I. Ashyap, Jamel Nebhen, MR Kamarudin, C. H. See, R.A. Abd-Alhameed "Continuous Glucose Level Monitoring Using Millimetre-Wave Metamaterial-Inspired Resonator," *PLoS ONE* (Submitted).
5. S. A Qureshi, Z. Z Abidin, H. A. Majid, Adel Y.I. Ashyap and C. H. See, "Double-layered Metamaterial Resonator Operating at Millimetre Wave for Detection of Dengue Virus," *AEUE - International Journal of Electronics and Communications* (Submitted).

LIST OF AWARDS

1. GOLD MEDAL for “MM-Wave Metamaterial-based Sensor for Blood-Sensing Application” in The International Research and Symposium and Exposition (RISE) 2020.
2. BRONZE MEDAL for “Millimetre-Wave Metamaterial-Based Resonator as a Glucometer” in International multidisciplinary Innovation Competition (IMIC) 2021.
3. SILVER MEDAL for “Non-invasive Low-cost and Portable Sensor to Detect Anaemia” in Innovative Research, Invention and Application Exhibition (I-RIA) 2021.
4. SILVER MEDAL for “Non-invasive Sensing of Anaemia Using a Low-cost, and Portable Millimetre-wave Resonator” in International Malaysia-Indonesia-Thailand Symposium on Innovation and Creativity (iMIT SIC) 2021.