

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.

CONTENTS

TITLE	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
ABSTRAK	vi
CONTENTS	vii
LIST OF TABLES	xii
LIST OF FIGURES	xiv
LIST OF SYMBOLS AND ABBREVIATIONS	xxi
LIST OF APPENDICES	xxiii
CHAPTER 1 INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	3
1.3 Aims and objectives	4
1.3.1 Aims	4
1.3.2 Objectives	4
1.4 Scope	4
1.5 Key contributions to research	5
1.6 Organisation of thesis	6
CHAPTER 2 LITERATURE REVIEW	8
2.1 Introduction	8
2.2 Dielectric materials and permittivity measurement	8
2.2.1 Permittivity	8

2.2.2	Debye equation	9
2.3	Review of conventional and resonator-based biosensors	11
2.3.1	Biosensor	11
2.3.2	Detection of dengue virus	11
2.3.3	Resonator	12
2.3.4	Resonator-based biosensors	15
2.4	Review of metamaterials and metamaterial-based sensors	17
2.4.1	Common metamaterial resonators	18
2.4.2	Metamaterial sensing mechanism	20
2.4.3	Metamaterial applications in biosensing	21
2.5	Review of millimetre-wave metamaterial sensors	36
2.6	Statistical models	41
2.7	Summary	42
CHAPTER 3	RESEARCH METHODOLOGY	44
3.1	Introduction	44
3.2	Design methodology	44
3.3	Design and simulation	46
3.3.1	Conventional metamaterial-based resonators	47
3.3.2	Components of a single-layered structure	49
3.3.3	Proposed single-layered sensor design	50
3.3.4	Components of a double-layered structure	55
3.3.5	Proposed double-layered Sensor 1 design	57
3.3.6	Proposed double-layered Sensor 2 design	62

3.3.7	Proposed double-layered Sensor 3 design	67
3.4	Characterisation of metamaterial	72
3.5	Dielectric characteristics of blood	74
3.6	Effect of dengue infection on blood permittivity	74
3.7	Correlation coefficients, t-test and cross-correlation analysis	76
3.8	Fabrication	79
3.9	Measurement and verification of results	79
3.10	Summary	81
CHAPTER 4	SINGLE-LAYERED METAMATERIAL RESONATOR SENSOR	83
4.1	Introduction	83
4.2	Simulation and analysis for single-layered sensor	83
4.2.1	Resonant frequency before and after placement of MUT	83
4.2.2	Characterisation of the metamaterial structure	84
4.2.3	Perturbation in reflection coefficient	85
4.2.4	Estimation and correlation of different samples	86
4.2.5	T-test	88
4.2.6	Cross-correlation	89
4.3	Summary	90
CHAPTER 5	DOUBLE-LAYERED METAMATERIAL RESONATOR SENSOR	92
5.1	Introduction	92
5.2	Simulation, analysis and measurement for Sensor 1	92
5.2.1	Resonant frequency before and after placement of MUT	92

5.2.2	Characterisation of the metamaterial structure	93
5.2.3	Impact of potential position error	94
5.2.4	Perturbation in reflection coefficient	95
5.2.5	Estimation and correlation of different samples	97
5.2.6	T-test	98
5.2.7	Cross-correlation	99
5.2.8	Fabrication and validation of sensing	100
5.3	Simulation, analysis and measurement for Sensor 2	102
5.3.1	Resonant frequency before and after placement of MUT	102
5.3.2	Characterisation of the metamaterial structure	103
5.3.3	Impact of potential position error	104
5.3.4	Perturbation in reflection coefficient	105
5.3.5	Estimation and correlation of different samples	106
5.3.6	T-test	107
5.3.7	Cross-correlation	108
5.3.8	Fabrication and validation of sensing	109
5.4	Simulation, analysis and measurement for Sensor 3	111
5.4.1	Resonant frequency before and after placement of MUT	111
5.4.2	Characterisation of the metamaterial structure	111
5.4.3	Impact of potential position error	112
5.4.4	Perturbation in reflection coefficient	113
5.4.5	Estimation and correlation of different samples	114
5.4.6	T-test	115
5.4.7	Cross-correlation	116

5.4.8	Fabrication and validation of sensing	117
5.5	Comparison with previously reported sensors	119
5.6	Summary	120
CHAPTER 6	CONCLUSION AND RECOMMENDATIONS	121
6.1	Introduction	121
6.2	Concluding remarks	121
6.2.1	Single-layered sensor	122
6.2.2	Sensor 1	123
6.2.3	Sensor 2	124
6.2.4	Sensor 3	124
6.3	Recommendation for future works	126
	REFERENCES	127
	APPENDICES	137
	LIST OF PUBLICATIONS	141
	LIST OF AWARDS	142



LIST OF TABLES

2.1	Famous dielectric characteristics measurement techniques [30]	14
2.2	Shift in the resonant frequency on different samples [46]	27
2.3	Summary of metamaterial biosensors	33
2.4	Summary of metamaterial millimetre-wave sensors	40
3.1	Dimensions of the conventional microstrip ring resonator for resonance at 36 GHz	49
3.2	Optimised dimensions of a single-layered sensor	51
3.3	Optimised dimensions of Sensor 1	58
3.4	Dimensions of Sensor 2	62
3.5	Dimensions of Sensor 3	68
3.6	Dispersion characteristics of blood	74
3.7	Dispersion characteristics of samples created	76
3.8	Statistical models	78
3.9	Indices of statistical models	78
4.1	Summary of correlation coefficients obtained from a single-layered sensor	87
4.2	Summary of t-test for single-layered sensor	89
5.1	Summary of correlation coefficients obtained from Sensor 1	97
5.2	Summary of t-test for Sensor 1	99
5.3	Summary of correlation coefficients obtained from Sensor 2	106

5.4	Summary of t-test for Sensor 2	108
5.5	Summary of correlation coefficients obtained from Sensor 3	115
5.6	Summary of t-test for Sensor 3	116
5.7	State-of-art biosensors	120
6.1	Features of single-layered and double-layered designs	125
6.2	Performance indicators of designs	125



LIST OF FIGURES

1.1	Point-of-care testing (POCT) device for home-based sensing [5]	2
2.1	Schematic structure of an electrochemical biosensor [24]	11
2.2	Classification methods based on resonators for the study of material properties [30]	13
2.3	Sensing method of microwave glucose sensor [31]	15
2.4	Layout of the high-sensitivity dielectric sensor (a) top view and (b) bottom view [37]	16
2.5	Classification of materials [4]	18
2.6	Metamaterial (unit cell) topologies: (a) split ring resonator (SRR) and (b) complementary split ring resonator (CSRR) [7]	19
2.7	Spiral resonator-based structures (a) simple spiral resonator, (b) spiral resonator with 8 loops, (c) two-layer multi-spiral resonator (TL-MSR) and (d) broad-side coupled spiral resonator with four turns (BS-SR) [41]	20
2.8	(a) SRR with integrated antennas on a dielectric substrate and (b) process of affinity binding of heparin to immobilised basic fibroblast growth factor (FGF-2) bioreceptor on the split ring [5]	22
2.9	(a) S_{21} and (b) S_{11} split-ring resonator's parameter response before and after the affinity binding [58]	23

2.10	(a) Substrate integrated waveguide chemical sensor and (b) Simulated reflection coefficients of ethanol-filled, deionised water-filled and an empty state of the microfluidic channel [20]	24
2.11	(a) Transmission line metamaterial-based sensor and (b) variation in S_{21} due to permittivity changes [52]	24
2.12	(a) Single complimentary omega particle and (b) resonant frequency shift between normal tissue (green dashed line) and malignant tissue (red solid line) [9]	26
2.13	Slotted ring resonator design [46]	26
2.14	(a) Single unit cell, (b) three unit cells of different dimensions and (c) aperiodic array [59]	28
2.15	Simulation results for the scanning setup (a) the transmission behaviour and (b) the phase change [59]	28
2.16	(a) Schematic design of closed-loop enclosed split ring biosensor and (b) shift in the resonant frequencies of S_{11} during in-vitro measurements [14]	29
2.17	Perspective view of SRR [12]	30
2.18	Frequency shift as the biological process for free cortisol detection (a) 10 ng/ml and (b) 100 ng/ml [12]	30
2.19	Schematic of THz nano-gap metamaterial sensing of viruses [61]	31
2.20	Normalised THz transmission amplitudes for (a) PRD1 and (b) MS2 [61]	31
2.21	Fabricated design of $\lambda/2$ -line sensor [65]	37
2.22	Comparison of the experimental data after the de- embedding process [65]	37
2.23	(a) 8×8 array structure of Maltese-cross cells, (b) inhomogeneity near the edge (1) versus at the centre (2) [53]	38
2.24	(a) Fabricated meander-line monopole antenna on a polyimide substrate and (b) simulation and	

	measurement comparison of the magnitude of the S_{11} [66]	39
2.25	Fabricated metamaterial aperture [67]	39
3.1	Flowchart of research methodology	46
3.2	Basic components of microstrip line	47
3.3	Conventional microstrip ring resonator	49
3.4	Concept of proposed single-layered structure (a) front side and (b) backside	50
3.5	Placement of blood sample in the substrate defect of single-layered sensor design	50
3.6	Single-layered sensor design (a) dimensions and (b) perspective view	51
3.7	Modifications for designing single-layered sensor	52
3.8	Reflection coefficient of single-layered sensor configurations	53
3.9	Reflection coefficient on different values of “R” in single-layered sensor	53
3.10	Resonant frequency on different values of “d” in single-layered sensor	54
3.11	Resonant frequency on different values of “w” in single-layered sensor	55
3.12	Bottom layer of double-layered structure (a) Feed Transmission Line (FTL) on the front side and (b) full ground on the backside	56
3.13	Top layer of double-layered structure (a) resonator on the front side and (b) backside	56
3.14	Integrated two-layered structure (a) side view and (b) perspective view	56
5.15	Placement of blood sample on the front layer of a double-layered sensor	57

3.16	Sensor 1 (a) structure on top layer (b) bottom layer and (c) integrated top & bottom layer	58
3.17	Modifications for designing Sensor 1	59
3.18	Reflection coefficient of Sensor 1 configurations	60
3.19	Resonant frequency on different values of " T_0 " in Sensor 1	60
3.20	Resonant frequency on different values of " L_2 " in Sensor 1	61
3.21	Resonant frequency on different values of " W " in Sensor 1	62
3.22	Sensor 2 (a) structure on top layer (b) bottom layer and (c) integrated top & bottom layer	62
3.23	Modifications for designing Sensor 2	65
3.24	Reflection coefficient of Sensor 2 configurations	65
5.25	Resonant frequency on different values of " R_0 " in Sensor 2	66
5.26	Resonant frequency on different values of " L " in Sensor 2	66
5.27	Resonant frequency on different values of " W " in Sensor 2	67
3.28	Sensor 3 (a) structure on the top layer (b) bottom layer and (c) integrated top and bottom layer	67
3.29	Modifications for designing Sensor 3	69
3.30	Reflection coefficient of Sensor 3 configurations	70
3.31	Resonant frequency on different values of " R_1 " in Sensor 3	70
3.32	Resonant frequency on different values of " R_2 " in Sensor 3	71
3.33	Resonant frequency on different values of " W " in Sensor 3	72

3.34	Relative permittivity of normal blood in the frequency range of 20-40 GHz [56]	74
3.35	Complex permittivity curves of the samples	76
3.36	Measurement setup	80
3.37	Measured (a) real and (b) imaginary permittivity of liquid samples	81
4.1	Resonant frequency with and without blood sample for single-layered sensor	84
4.2	Permeability, permittivity and refractive index of a single-layered structure	85
4.3	Perturbation under different MUTs on the single-layered sensor	86
4.4	Phase shift in response to different MUTs on the single-layered sensor	86
4.5	(a) Pearson, (b) Spearman and (c) Kendall correlation coefficients obtained from the single-layered sensor	87
4.6	Confidence interval of the samples in single-layered sensor	89
4.7	Delay obtained in cross-correlation for a single-layered sensor	90
5.1	Resonant frequency with and without blood sample for Sensor 1	93
5.2	Permeability, permittivity and refractive index of Sensor 1	94
5.3	Error in the positioning of the top layer to (a) right, (b) left, (c) up and (d) down	95
5.4	Reflection coefficient on different positions of the top layer on centre of the bottom layer in Sensor 1	95
5.5	Perturbation under different MUTs on Sensor 1	96
5.6	Phase shift in response to different MUTs on Sensor 1	96

5.7	(a) Pearson, (b) Spearman and (c) Kendall correlation coefficients obtained from Sensor 1	97
5.8	Confidence interval of the samples in Sensor 1	99
5.9	Delay obtained in cross-correlation for Sensor 1	100
5.10	Fabricated design of Sensor 1	100
5.11	Simulated and measured reflection coefficient of Sensor 1 (a) without top layer and (b) with the top layer	101
5.12	Measured reflection coefficients for liquid samples on Sensor 1	102
5.13	Simulated and measured reflection coefficient for liquid samples on Sensor 1	102
5.14	Resonant frequency with and without blood sample for Sensor 2	103
5.15	Permeability, permittivity and refractive index of Sensor 2	104
5.16	Reflection coefficient on different positions of the top layer on centre of the bottom layer in Sensor 2	105
5.17	Perturbation under different MUTs on Sensor 2	105
5.18	Phase shift in response to different MUTs on Sensor 2	106
5.19	(a) Pearson, (b) Spearman and (c) Kendall correlation coefficients obtained from Sensor 2	107
5.20	Confidence interval of the samples in sensor 2	107
5.21	Delay obtained in cross-correlation for Sensor 2	108
5.22	Fabricated design of Sensor 2	109
5.23	Simulated and measured reflection coefficient of Sensor 2 (a) without top layer and (b) with the top layer	109
5.24	Measured reflection coefficients for liquid samples on Sensor 2	110
5.25	Simulated and measured reflection coefficient for liquid samples on Sensor 2	110

5.26	Resonant frequency with and without blood sample for Sensor 3	111
5.27	Permeability, permittivity and refractive index of Sensor 3	112
5.28	Reflection coefficient on different positions of the top layer on centre of the bottom layer in Sensor 3	113
5.29	Perturbation under different MUTs on Sensor 3	114
5.30	Phase shift in response to different MUTs on Sensor 3	114
5.31	(a) Pearson, (b) Spearman and (c) Kendall correlation coefficients obtained from Sensor 3	115
5.32	Confidence interval of the samples in Sensor 3	116
5.33	Delay obtained in cross-correlation for Sensor 3	117
5.34	Fabricated design of Sensor 3	117
5.35	Simulated and measured reflection coefficient of Sensor 3 (a) without top layer and (b) with the top layer	118
5.36	Measured reflection coefficients for liquid samples on Sensor 3	119
5.37	Simulated and measured reflection coefficient for liquid samples on Sensor 3	119



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
<i>WHO</i>	–	World health organisation
<i>hCG</i>	–	Human chorionic gonadotropin
<i>HIV</i>	–	Human immunodeficiency virus
<i>POCT</i>	–	Point-of-care testing
<i>MM-W</i>	–	Millimetre-wave
<i>SRR</i>	–	Split ring resonator
<i>EM</i>	–	Electromagnetic
<i>RF</i>	–	Radio frequency
<i>NRW</i>	–	Nicholson-ross-weir
<i>VNA</i>	–	Vector network analyzer
<i>WGM</i>	–	Whispering gallery mode
<i>MTL</i>	–	Microstrip transmission line
<i>PCB</i>	–	Printed circuit board
<i>DPS</i>	–	Double positive medium
<i>MNG</i>	–	Mue-negative
<i>DNG</i>	–	Double negative medium
<i>MTM</i>	–	Metamaterial

<i>SIW</i>	–	Substrate integrated waveguide
<i>CRA</i>	–	Compressive reflector antenna
<i>FIT</i>	–	Finite integration technique



LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	MATLAB Code for Extraction of Metamaterial Constitutive Parameters	137
B	MATLAB Keywords for Statistical Methods	140
C	List of Publications	141
D	List of Awards	142



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

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.

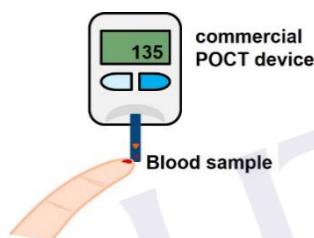


Figure 1.1: Point-of-care testing (POCT) device for home-based sensing [5]

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.