

DESIGN AND ANALYSIS OF DUAL BAND T-RESONATOR MICROWAVE SENSOR FOR MATERIAL CHARACTERIZATION

MUHAMMAD AMIR IS'AD BIN MD KAMAL



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**DESIGN AND ANALYSIS OF DUAL BAND T-RESONATOR
MICROWAVE SENSOR FOR MATERIAL
CHARACTERIZATION**

MUHAMMAD AMIR IS'AD BIN MD KAMAL

**This report is submitted in partial fulfilment of the requirements
for the degree of Bachelor of Electronic Engineering with Honours**



**Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka**
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

**BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II**

Tajuk Projek : Design and Analysis of Dual Band T-Resonator
Microwave Sensor For Material Characterization
Sesi Pengajian : 2021/2022

Saya MUHAMMAD AMIR IS'AD BIN MD KAMAL mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

SULIT*

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD*

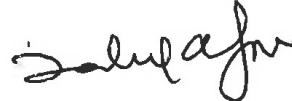
(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan.)

TIDAK TERHAD

Disahkan oleh:



(TANDATANGAN PENULIS)



(COP DAN TANDATANGAN PENYELIA)

Alamat Tetap: No 11, Jln Sari
Ilmu 1/1 Taman
Alam Sari 43000
Kajang Selangor

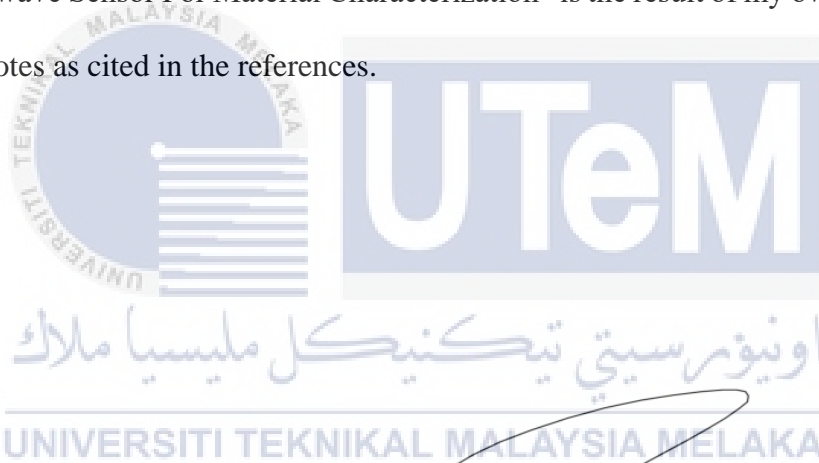
PROFESOR DR. ZAHRLADHA BIN ZAKARIA
Profesor
Fakulti Kejuruteraan Elektronik Dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
764100 Durian Tunggal, Melaka

Tarikh : 21 JUN 2022

Tarikh : 21 JUN 2022

DECLARATION

I declare that this report entitled “Design and Analysis of Dual Band T-Resonator Microwave Sensor For Material Characterization” is the result of my own work except for quotes as cited in the references.



Signature

:

A handwritten signature in black ink, appearing to be 'Amir', written over the watermark.

Author

:

Muhammad Amir Is'ad Bin Md Kamal

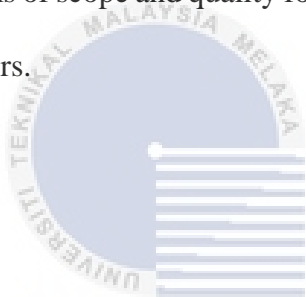
Date

:

21 JUN 2022

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.



اونيفورستي تكنولوجي ملایسيا ملاک

Signature

:

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Supervisor Name

:

Prof. Dr. Zahriladha Bin Zakaria

Date

:

21 JUN 2022

PROFESOR DR. ZAHRIADHA BIN ZAKARIA
Profesor
Fakulti Kejuruteraan Elektronik Dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
764100 Durian Tunggal, Melaka

DEDICATION

I dedicated this thesis to my beloved parents, Md Kamal Bin Abdul Manaf and Roslinda Binti Ramli for always be my backbone to complete the research.



ABSTRACT

Microwave sensor which is known as resonant sensor are design that is the most popular for sensor application in detecting material characterization. This design can be seen in food industry, biomedical and material industrial application. Measurement of dielectric constant on any material is important in those respective industry by using microwave resonant technique which is used at single or discrete frequency. Conventionally, there are many kinds of resonant sensor, and has been realized in the respective industry such as waveguide, coaxial and dielectric resonator. Nevertheless, their traditional technique produces them in bulky size and high cost for manufacturing the resonator. Thus, past research conclude that planar resonant technique has the advantages due to their size comparably smaller resulting low costs manufacturing process. However, by comparing the most important perspective which is sensitivity and Q-factor, the planar technique is definitely lower than the others and limited by the range of resonant it produced. Therefore, this thesis introduces a different implementation of the same planar technique which is dual band metamaterial to overcome the disadvantages of sensitivity. The dual band sensor operates in two different frequencies in range of 1GHz to 5 GHz. It can be used with either solid, liquid, gas or powder, depends on the sensor structure and design with

Polydimethylsiloxane (PDMS) as a container for the material under test (MUT). The design will be simulated in computer simulation technology (CST) and as a result, produces narrow resonance and high Q-factor comparable to previous researchers' thesis. This proof that the proposed sensor can be one of the solutions to characterize material dielectric constant for determining its properties and quality level.



ABSTRAK

Penderia gelombang mikro yang dikenali sebagai penderia resonan adalah reka bentuk yang paling popular untuk aplikasi penderia dalam mengesan pencirian bahan. Reka bentuk ini boleh dilihat dalam industri makanan, aplikasi industri bio-perubatan dan bahan. Pengukuran pemalar dielektrik pada sebarang bahan adalah penting dalam industri masing-masing dengan menggunakan teknik resonan gelombang mikro yang digunakan pada frekuensi tunggal atau diskret. Secara konvensional, terdapat pelbagai jenis sensor resonan, dan telah direalisasikan dalam industri masing-masing seperti pandu gelombang, sepaksi dan resonator dielektrik. Namun begitu, teknik tradisional mereka menghasilkannya dalam saiz yang besar dan kos yang tinggi untuk pembuatan resonator. Oleh itu, kajian lepas menyimpulkan bahawa teknik resonan satah mempunyai kelebihan kerana saiznya yang lebih kecil menyebabkan proses pembuatan kos rendah. Walau bagaimanapun, dengan membandingkan perspektif yang paling penting iaitu kepekaan dan faktor Q , teknik planar pastinya lebih rendah daripada yang lain dan dihadkan oleh julat resonan yang dihasilkannya. Oleh itu, tesis ini memperkenalkan pelaksanaan berbeza bagi teknik planar yang sama iaitu dua jalur metamaterial untuk mengatasi kelemahan sensitiviti. Penderia jalur dwi beroperasi dalam dua frekuensi berbeza dalam julat

1GHz hingga 5 GHz. Ia boleh digunakan dengan sama ada pepejal, cecair, gas atau serbuk, bergantung pada struktur penderia dan reka bentuk dengan Polydimethylsiloxane (PDMS) sebagai bekas untuk bahan dalam ujian (MUT). Reka bentuk akan disimulasikan dalam teknologi simulasi komputer (CST) dan hasilnya, menghasilkan resonans sempit dan faktor Q yang tinggi setanding dengan tesis penyelidik terdahulu. Bukti ini bahawa sensor yang dicadangkan boleh menjadi salah satu penyelesaian untuk mencirikan pemalar dielektrik bahan untuk menentukan sifat dan tahap kualitinya.



ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to everyone that has helped and encouraged me to complete this thesis. Every advice from my main supervisor, Professor Dr. Zahriladha Bin Zakaria, and co supervisor, Dr Ahmed Jamal Abdullah Al-Gburi, is very helpful and I am highly indebted to them in completing this final year project and thesis.

Not to mention, with a deep sense of reverence towards my precious parents, I am grateful to have them always supported me morally. If not for them, I would never complete through all my journey and my final year thesis. For that I am always deeply in appreciation.

Special thanks to my class representative who is my friend and all my colleagues for their support and help. Lastly, for those who involve indirectly to helped me complete my final year thesis, thank you to everyone.

TABLE OF CONTENTS

Declaration	
Approval	
Dedication	
Abstract	i
Abstrak	iii
Acknowledgements	v
Table of Contents	vi
List of Figures	x
List of Tables	xiii
List of Symbols and Abbreviations	xv
List of Appendices	xviii
CHAPTER 1 INTRODUCTION	1
1.1 Project Overview	1
1.2 Problem Statement	2
1.3 Objectives	2
1.4 Scope of Work	3

1.5	Significant of Project	4
1.6	Thesis Outline	4
CHAPTER 2 BACKGROUND STUDY		6
2.1	Introduction	6
2.2	Theory	7
2.2.1	Material Characterization Methods	7
2.2.1.1	Non-Resonant Methods	7
2.2.1.2	Resonant Methods	8
2.2.2	Perturbation Theory (Resonant Methods)	9
2.2.3	Comparison Material Characterization Methods	11
2.3	Previous Research (Planar Resonator)	13
2.3.1	Enhanced Coupled Ring Resonator	13
2.3.2	Complementary Split Ring Resonator (CSRR)	18
2.3.3	Dual Band Metamaterial	23
2.3.4	Comparison of Previous Research	28
CHAPTER 3 METHODOLOGY		30
3.1	Introduction	30
3.2	Flowchart	31
3.3	Gantt Chart	36
3.4	Mathematical Analysis	36

3.4.1	Feedline Calculation	36
3.4.2	Patch Calculation	37
3.4.3	Substrate Calculation	38
3.4.4	Q-factor Calculation	38
3.4.5	Sensitivity Calculation	39
3.5	Resonant Sensor Design (Calculation)	39
3.6	Simulation Process	41
3.6.1	Resonant Sensor Design (Parametric Studies / Optimizer)	42
3.6.2	Maximum Concentration Area	48
3.6.3	CorelDRAW software	49
3.7	Manufacturing Process	49
3.7.1	Specification of Material	49
3.7.2	Fabrication Process	51
3.7.3	Vector Network Analyzer (VNA)	52
3.7.4	Measurement Process	53
CHAPTER 4 RESULTS AND DISCUSSION		54
4.1	Result of Microwave Sensor	54
4.1.1	Resonant Frequency Analysis (Validation)	55
4.1.2	Resonant Frequency Analysis (Comparison)	59
4.1.3	Dielectric Properties Error Analysis	62

4.1.4 Q-Factor Analysis	72
4.2 Comparison Commercialized, Prior and Existing Research Sensor	73
CHAPTER 5 CONCLUSION AND FUTURE WORKS	76
5.1 Conclusion	76
5.2 Suggestion for Future Work	77
REFERENCES	79
APPENDIX A ROGER 5880	83
APPENDIX B FR4	86



LIST OF FIGURES

Figure 2.1: Classification of EM material characterization method [1].	7
Figure 2.2: Schematic diagram of reflective method in coaxial line [2].	8
Figure 2.3: Schematic diagram of electrical field (EM) affected by resonance frequencies of coaxial probe [3].	9
Figure 2.4 Different coupling schemes (a) loose coupling (b) matched-stub coupling (c) quasi-linear coupling (d) enhanced coupling periphery [4].	13
Figure 2.5: Fabricated one-port microstrip ring-resonator with different coupling gaps [4].	14
Figure 2.6: Fabricated enhanced coupled one-port microstrip ring-resonator (a) without sample (b) with overlaid meat sample [4].	15
Figure 2.7: Simulation results unloaded resonator for the effect of coupling gap on resonant frequency (S_{11}) [4].	16
Figure 2.8: Amount of shift attained over the range of coupling gap [4].	17
Figure 2.9: Simulation result for different coupling schemes [4].	17
Figure 2.10: Experimental result for enhanced coupled ring-resonator [4].	18
Figure 2.11: Design of (a) circular and (b) rectangular CSRRs [5].	19
Figure 2.12: CSRR planar (a) Top View, (b) Perspective view, (c) Side view [5].	19
Figure 2.13: Resonant frequency versus dielectric constant [5].	20
Figure 2.14: Insertion loss versus tangent loss [5].	21
Figure 2.15: Measured for various dielectric sample S_{21} (dB) [5].	22

Figure 2.16: Measured value of complex permittivity [5].	23
Figure 2.17: Designation on CST (a) Design A, (b) Design B [6].	23
Figure 2.18: Parameter value of the dual band metamaterial design [6].	24
Figure 2.19: Location of MUT at maximum concentration of E-field [6].	24
Figure 2.20: Comparison result simulation and measurement of (a) Design A, (b) Design B [6].	26
Figure 2.21: Q-factor used in calculation for the design [6].	26
Figure 2.22: Comparison between simulation and measurement of the design A and design B [6].	27
Figure 2.23: Comparison permittivity value between simulation and measurement [6].	28
Figure 2.24: Comparison tangent value between simulation and measurement [6].	28
Figure 3.1: Flowchart on sensor part 1.	32
Figure 3.2: Flowchart of sensor part 2.	33
Figure 3.3: Measurement setup for the measurements of MUTs [7].	35
Figure 3.4: Project planning in Gantt chart.	36
Figure 3.5: Designation on CST [6].	42
Figure 3.6: Optimizer iteration setting for L_s , W_s , L_x .	43
Figure 3.7: Scattering parameter S_{21} (Linear) with peak amplitude near 0.01 with 3.2GHz achieved.	44
Figure 3.8: Optimizer iteration goals for S_{21} (linear) with target < 0.01 and range 3.18 to 3.22 GHz.	44
Figure 3.9: Optimizer iteration result for S_{21} (linear) with target < 0.01 and range 3.18 to 3.22 GHz.	45
Figure 3.10: Design A (Optimizer) with dimension and location of E-field.	47
Figure 3.11: Design B (Optimizer) with dimension and location of E-field.	48

Figure 3.12: Location of MUT at maximum concentration of E-field [6].	48
Figure 3.13: Roger RT/duroid 5880 (Appendix A).	50
Figure 3.14: SMA-Connector.	51
Figure 3.15: Process of fabricating design on PCB.	52
Figure 3.16: Vector Network Analysis (VNA).	52
Figure 4.1: Comparison result simulation and experimental of (a) Design A (b) Design B.	56
Figure 4.2: Comparison result Design A for (a) simulation (b) experimental known permittivity (c) experimental unknown permittivity.	60
Figure 4.3: Comparison result Design B for (a) simulation (b) experimental known permittivity (c) experimental unknown permittivity.	61
Figure 4.4: Simulation graph of polynomial analysis based on permittivity range from 0.1 to 10 for (a) Design A (b) Design B.	63
Figure 4.5: Polynomial graph and formula of normal polynomial method for (a)(b) Design A and (c)(d) Design B.	65
Figure 4.6: Polynomial graph and formula of first method for (a)(b) Design A and (c)(d) Design B.	68
Figure 4.7: Comparison with previous sensor[6].	74
Figure 4.8: Comparison of price with commercialized sensor in market[6].	75

LIST OF TABLES

Table 2.1: Comparison of material characterization methods to measure dielectric properties [11], [12].	12
Table 2.2: Comparison of previous research.	29
Table 3.1: Parameter Designation (Design A).	40
Table 3.2: Parameter Designation (Design B).	41
Table 3.3: Parameter Designation Optimizer (Design A).	46
Table 3.4: Parameter Designation Optimizer (Design B).	46
Table 4.1: Comparison MUT simulation vs measurement of low frequency for Design A	57
Table 4.2: Comparison MUT simulation vs measurement of high frequency for Design A	57
Table 4.3: Comparison MUT simulation vs measurement of low frequency for Design B	58
Table 4.4: Comparison MUT simulation vs measurement of high frequency for Design B	58
Table 4.5: Simulation data of polynomial analysis based on permittivity range from 0.1 to 10	64
Table 4.6: Simulation data with offset of polynomial analysis based on permittivity range from 0.1 to 10	67
Table 4.7: Comparison of permittivity error for simulation and measurement of first method.	70

Table 4.8: Comparison of frequency error for simulation and measurement of second method.

72



LIST OF SYMBOLS AND ABBREVIATIONS

PDMS	:	Polydimethylsiloxane
DUT	:	Device Under Test
MUT	:	Material Under Test
FR-4	:	Flame Retardant 4 (UL94V-0 Standard) (Glass Name)
CST	:	Computer Simulation Technology
VNA	:	Vector Network Analyzer
PCB	:	Printed Circuit Board
PM	:	Perturbation Method
TM	:	Transverse Magnetic
TE	:	Transverse Electric
VC	:	Empty Cavity
GHz	:	Giga Hertz
MHz	:	Mega Hertz
Hz	:	Hertz
CSSR	:	Complementary Split Ring Resonator
SMA	:	Sub Miniature Version A
EM	:	Electromagnetic
S ₂₁ (dB)	:	Insertion Loss
S ₁₁ (dB)	:	Return Loss

μ_0	:	Permeability
BW	:	Bandwidth
f_c	:	Resonant Frequency Without Sample
f_s	:	Resonant Frequency With Sample
Q	:	Quality Factor
f_r	:	Resonance Frequency
Δf_r	:	Resonance Frequency Shifting
$\Delta \mu$:	Permeability Changes
$\Delta \varepsilon$:	Permittivity Changes
V	:	Perturbed Volume
E_0, H_0	:	Field Distribution Without Perturbation
E_1, H_1	:	Field Distribution With Perturbation
ε_r	:	Dielectric Constant
ε'_r	:	Actual Permittivity
ε''_r	:	Imaginary Part of Permittivity
μm	:	Micrometer
Z_0	:	Input Impedance
ε_{eff}	:	Effective Dielectric Constant
h	:	Height of Substrate
L _f	:	Microstrip Line
L _{feed}	:	½ Microstrip Line
f ₀	:	Resonant Frequency
W _p	:	Width of Patch
L _p	:	Length of Patch

Lstub : Length of Patch (stub)

Ls : Length of Substrate

Ws : Width of Substrate



LIST OF APPENDICES

Appendix A: ROGER 5880	83
Appendix B: FR4	86

