METAMATERIAL FILTENNA AT 2.4GHZ FOR BLUETOOTH APPLICATION

MOHD NUR AMIN BIN HASHIM

A project report submitted in partial fulfilment of the requirements for the award of the degree of Master of Engineering (Electronics and Telecommunication)

> Faculty of Electrical Engineering Universiti Teknologi Malaysia

> > JANUARY 2018

ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to my supervisor, Dr. Mohd Fairus Bin Mohd Yusoff for the continuous support throughout my master study and research, for his assistance, patience, motivation, and enthusiasm. His guidance helped me in all the time of research and writing of this thesis. I could not imagine having a better supervisor and mentor for my master study.

Besides, of my supervisor, I would like to thank my family especially my wife, kids and my parents for the greatest support and motivation throughout my study. My appreciation also goes to all lecturers for all of their assistance and helped me along the way. Without their assistance and support, I would not have finished this project report.

Lastly, I would like to thank all my friends especially Dai,Dib, and Chan, for the assistance they provided for the research project.

ABSTRACT

Nowadays, modern technologies such as aerospace, medical electronics and communication systems requires reliability and accuracy to support a very large number of standards such as Bluetooth. Thus, there is a huge demand to have a bluetooth antenna that are both capable to have precise measurement and high reliability. Combination of filter and antenna or filtenna is an alternative solution in the RF frontend circuit to reduce the transmission losses. In addition, Metamaterials are materials typically engineered with novel or artificial structures to produce electromagnetic properties that are impossible to retrieve in nature. Metamaterials offer many advantages in electromagnetic applications from microwave to optical range, especially for the radiated-wave devices. Thus, in this project, a metamaterial filtenna at 2.4GHz for bluetooth application has been proposed and designed. It combines SRR band pass filter with MELC resonator antenna. All of the simulations are done using Computer Simulation Technology full wave simulator software. Then, we compared the proposed filtenna performances with conventional filtenna. From the simulation results, it can be seen that metamaterial filtenna has better performances in terms of higher antenna gain (5.44dBi) and low return loss (22.2dB).

ABSTRAK

Pada masa kini, teknologi moden seperti sistem aeroangkasa, elektronik perubatan dan komunikasi memerlukan kebolehpercayaan dan ketepatan untuk menyokong sejumlah standard yang sangat besar seperti Bluetooth. Oleh itu, terdapat permintaan besar untuk mempunyai antena bluetooth yang kedua-duanya mampu menghasilkan pengukuran yang tepat dan kebolehpercayaan yang tinggi. Gabungan penapis dan antena atau filtenna adalah penyelesaian alternatif dalam litar RF depan akhir untuk mengurangkan kerugian transmisi. Di samping itu, Bahan Metamaterial adalah bahan yang biasanya direkayasa dengan struktur novel atau buatan untuk menghasilkan sifat elektromagnet yang tidak mungkin diperoleh semula. Bahan metamaterial menawarkan banyak kelebihan dalam aplikasi elektromagnetik dari gelombang mikro ke julat optik, terutama bagi peranti gelombang radiasi. Oleh itu, dalam projek ini, satu metamaterial filtenna pada 2.4GHz untuk aplikasi bluetooth telah dicadangkan dan direka. Ia menggabungkan penapis pas band SRR dengan antena resonator MELC. Semua simulasi dilakukan menggunakan perisian simulasi gelombang penuh Teknologi Simulasi Komputer. Kemudian, kami membandingkan persembahan filtenna yang dicadangkan dengan filtenna konvensional. Dari hasil simulasi, dapat dilihat bahawa metamaterial filtenna mempunyai prestasi yang lebih baik dari segi keuntungan antena yang lebih tinggi (5.44dBi) dan kehilangan pulangan yang rendah (22.2dB).

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE	
	TITLE PAGE	i	
	DECLARATION	ii	
	ACKNOWLEDGEMENT	iii	
	ABSTRACT ABSTRAK		
	TABLE OF CONTENTS	vi	
	LIST OF TABLES	viii	
	LIST OF FIGURES	ix	
	LIST OF ABBREVIATION	xii	
	LIST OF SYMBOLS	xiii	
1	INTRODUCTION	1	
	1.1 Project Background	1	
	1.2 Problem Statement	2	
	1.3 Objectives	3	
	1.4 Scope of the project	3	
	1.5 Report Outline	4	
2	LITERATURE REVIEW	5	
	2.1 Introduction	5	
	2.2 Introduction to Metamaterial	5	
	2.3 Engineering negative ε and negative μ	6	

	2.4	Resonant Structures of MTM	9
	2.5	Previous research on Metamaterial and Filtenna	10
	2.6	Summary	30
3	ME	THODOLOGY	31
	3.1	Introduction	32
	3.2	Project Overview	33
	3.3	Design Specification	33
	3.4	Square Split Ring Resonator Band Pass Filter	34
		Design	
	3.5	Electric Field Coupled Resonator Design	35
	3.6	Microstrip Patch Antenna Design	38
	3.7	Band Pass Filter Design Using Stepped Impedance	39
		Resonator	
	3.8	Project Gantt Chart	40
	3.9	Summary	41
4	RES	SULT AND DISCUSSION	42
	4.1	Introduction	42
	4.2	Square Split Ring Resonator	43
	4.3	Metamaterial Antenna	44
	4.4	Metamaterial Filtenna	47
	4.5	Conventional Filtenna	49
	4.6	Performance Comparison of MTM and	51
		Conventional Filtenna	
5	CON	NCLUSION AND FUTURE WORKS	54
	5.1	Conclusion	54
	5.2	Future Works	55

REFERENCES

56

LIST OF TABLE

TABLE NO.

TITLE

PAGE

2.1	Summary of current resonance structures	10
3.1	Project Design Specification	34
4.1	Overall dimension for Square SRR	43
4.2	Square SRR scattering parameter	44
4.3	The overall dimension of MTM antenna	45
4.4	Return loss and bandwidth of MTM antenna	46
4.5	The overall dimension of MTM filtenna	48
4.6	Dimension of conventional filtenna	50
4.7	S parameters MTM vs Conventional Filtenna	51
4.8	Radiation pattern MTM vs Conventional Filtenna	52
4.9	Performance comparison MTM vs Conventional Filtenna	53

LIST OF FIGURE

FIGURE NO.

TITLE

PAGE

1.1	Frontend Circuitry 2	
2.1	The design of filtering antenna [13]	11
2.2	Return loss of the antenna [13]	12
2.3	Radiation pattern of design [13]	12
2.4	Design of [3]	13
2.5	Scattering parameters for design [3]	13
2.6	Overall design structure of [14]	14
2.7	The return loss of design [14]	15
2.8	Radiation pattern of design [14]	15
2.9	Overall design of [15]	16
2.10	The scattering parameters [17]	17
2.11	The overall design of [13]	18
2.12	The overall scattering parameters of [13]	18
2.13	The overall structure of design [4]	19
2.14	Overall scattering parameters for design [4]	20
2.15	Front design [17]	21
2.16	Rear design [17]	21
2.17	Return Loss for normal patch antenna [17]	22
2.18	Return Loss normal patch antenna loaded	22
	with MTM [17]	
2.19	Overall structure[18]	23
2.20	The scattering parameters at 2.66 GHz [18]	24
2.21	The radiation pattern at xz plane [18]	24

2.22		
	The radiation pattern at yz plane [18]	25
2.23	The overall structure of [19]	26
2.24	The S11 parameters for [19]	26
2.25	E plan radiation pattern [19]	27
2.26	H plane radiation pattern [19]	27
2.27	The overall design of [20]	28
2.28	Overall Scattering parameters for [20]	28
2.29	One element with its S parameter	29
2.30	Two element with its S parameter [21]	30
2.31	Three element with its S parameter [21]	30
3.1	Research flow chart 1	32
3.2	Figure 3.2: Research Flow chart 2	33
3.3	As depicted in design [21]	35
3.4	Unit cell structure of ELC resonator as	37
	designed in[23]	
3.5	The equivalent circuit of [23]	38
3.6	Common design of microstrip patch	39
	Antenna	
3.7	Basic design of SIR[25]	40
3.8	Gantt chart of the research	41
3.8 4.1	Gantt chart of the research The designation of square SRR	41 43
4.1	The designation of square SRR	43
4.1 4.2	The designation of square SRR The scattering parameters for square SRR	43 44
4.1 4.2 4.3	The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna	43 44 45
4.1 4.2 4.3 4.4	The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna The rear view of MTM antenna	43 44 45 45
 4.1 4.2 4.3 4.4 4.5 	The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna The rear view of MTM antenna The scattering parameter of MTM antenna	43 44 45 45 46
 4.1 4.2 4.3 4.4 4.5 	The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna The rear view of MTM antenna The scattering parameter of MTM antenna The radiation pattern at 2.4 GHz for	43 44 45 45 46
 4.1 4.2 4.3 4.4 4.5 4.6 	The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna The rear view of MTM antenna The scattering parameter of MTM antenna The radiation pattern at 2.4 GHz for MTM antenna	43 44 45 45 46 47
 4.1 4.2 4.3 4.4 4.5 4.6 4.7 	The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna The rear view of MTM antenna The scattering parameter of MTM antenna The radiation pattern at 2.4 GHz for MTM antenna The front view of MTM filtenna	 43 44 45 45 46 47 48
 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 	The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna The rear view of MTM antenna The scattering parameter of MTM antenna The radiation pattern at 2.4 GHz for MTM antenna The front view of MTM filtenna The rearview of MTM filtenna	 43 44 45 45 46 47 48 48
 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 	 The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna The rear view of MTM antenna The scattering parameter of MTM antenna The radiation pattern at 2.4 GHz for MTM antenna The front view of MTM filtenna The rearview of MTM filtenna Front view of Conventional Filtenna 	 43 44 45 45 46 47 48 48 49
 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 4.10 	 The designation of square SRR The scattering parameters for square SRR The front view of MTM antenna The rear view of MTM antenna The scattering parameter of MTM antenna The radiation pattern at 2.4 GHz for MTM antenna The front view of MTM filtenna The rearview of MTM filtenna Front view of Conventional Filtenna The rear view of conventional filtenna 	 43 44 45 45 46 47 48 48 49 50

4.13

52

LIST OF ABBREVIATIONS

GPS	-	Global Positioning System
Hz	-	Hertz
Ghz	-	Gigahertz
MHz	-	Megahertz
LHM	-	Left Handed Materials
RHM	-	Right Handed Materials
DNG	-	Double Negative Materials
SRR	-	Split Ring Resonator
CRLH-TL	-	Composite Right Left Handed Transmission Line
RH TL	-	Right Handed Transmission Line
LH TL	-	Left Handed Transmission Line
dB	-	Decibel
dBi	-	Decibel with reference to isotropic
ZOR	-	Zero Order Resonance
BW	-	Bandwidth
MTM	-	Metamaterials
SIR	-	Stepped Impedance Resonator

LIST OF SYMBOLS

E	-	Electric Field
Н	-	Magnetic Field
c	-	Speed of light
f	-	Frequency
n	-	Refractive index
Z	-	Impedance
Х	-	Reactance
Y	-	Admittance
3	-	Permittivity
μ	-	Permeability
ω	-	Resonance frequency
λ	-	Wavelength
γ	-	Complex propagation constant

CHAPTER 1

INTRODUCTION

1.1 Project Background

The Wireless communication system has encountered a revolutionary improvement throughout the decade due to inventions that related to wireless products. Among major wireless products today are Global Positioning System, mobile phone, and consumer electronics product etc. All of these products have bluetooth connection either for extended connection with other electronics appliances or data transfer .Since bluetooth connection is very important, it will be great if overall performance of bluetooth connection is improved especially on its hardware. In bluetooth frontend circuitry, filter and antenna are the most important components. Moreover, these two components usually are designed separately. This will increase the overall size of frontend circuitry and introduce a transmission loss.

It will be a remarkable achievement to have a compact module consist of both filtering and radiating characteristics. Combination of these two main components will influence both performance and size of frontend circuitry

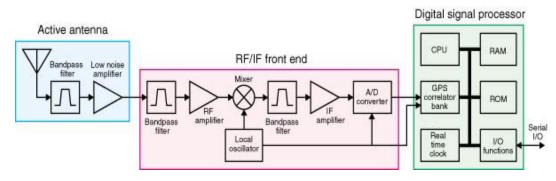


Figure 1.1 Frontend Circuitry

Metamaterials are artificial electromagnetic structures with unusual property not readily available in nature [1]. They are made from multiple elements arranged in repeating patterns at size that are smaller than the wavelengths of the phenomena they influence. As this arrangement, introduce a new structure, so does their properties. With a precise geometry, shape, size, orientation and arrangement give the newly arranged structure capability to manipulate electromagnetic waves. Among the highlighted capabilities are, blocking, absorbing, enhancing, or bending waves which ultimately has gone beyond what is possible with conventional materials. The history of metamaterials started in 1968 with the visionary speculation on the existence of substances with simultaneously negative values of ε and μ by the Russian physicist Viktor Veselago [2]. He pointed out no natural materials exhibit both negative electric permittivity and magnetic permeability. This project proposes a design of compact metamaterial filtenna to improve the overall performances.

1.2 Problem Statements

Separate design of filter and antenna at bluetooth frontend circuitry will make the circuit bigger and introduce transmission loss. By combination of filter and antenna at frontend circuitry, the overall size and transmission loses will be reduced. In addition, the filtenna model will use a metamaterial structure since metamaterial has proven to reduce overall size of microwave structure [3], [4]. In, addition, it also can improve the filter and antenna performances [1].Hence, the outcome for this project is to produce a compact and high performance filtenna at bluetooth frequency, 2.4 GHz.

1.3 Objectives

The objectives of this project are:

- a) To design metamaterial filtenna at 2.4GHz
- b) To compare the performance of metamaterial filtenna with conventional filtenna at 2.4GHz

1.4 Scopes of the project

In order to achieve the objectives of this project, there are guidelines need to be followed. Firstly, all the metamaterial characteristics will be studied. Next, using Computer Simulation Technology (CST) to design and simulate metamaterial bandpass filter and antenna that both operate at 2.4 GHz. After optimizations, next is to combine the metamaterial bandpass filter and antenna into one structure. This newly metamaterial filtenna will be compared with the conventional antenna to determine its overall performance.

1.5 Report Outline

This report is organized in five chapters. Chapter 1 gives an overview and the introduction of the project. Chapter 2 discusses the literature review on the definition, basic principle of metamaterial, metamaterial bandpass and metamaterial antenna. Chapter 3 covers the design methodology of the project. In this chapter the overview of the design and all the tools and modules used in the project are discussed. The outcomes of the project are then explained. Chapter 4 explains and analyzes the simulation results. Finally, chapter 5 covers the conclusion and potential future works that available for this particular research.

REFERENCES

- [1] T. Caloz, C. and Itoh, *Electromagnetic Metamaterials : Transmision Line Theory and Microwave Applications*. John Wiley & Sons, 2006.
- [2] V. Veselago, "The electrodynamics of substances with simultaneously negative values of ε and μ ," *Sov. Phys. Uspekhi*, vol. 10, no. 4, pp. 509–514, 1968.
- [3] S. Chatterjee *et al.*, "Radio Astronomy Application Based on Metamaterial ZOR Techniques," no. March, pp. 22–29, 2015.
- [4] G. Jang and S. Kahng, "Compact metamaterial zeroth-order resonator bandpass filter for a UHF band and its stopband improvement by transmission zeros," *IET Microwaves, Antennas Propag.*, vol. 5, no. 10, p. 1175, 2011.
- [5] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Trans. Microw. Theory Tech.*, vol. 47, no. 11, pp. 2075–2084, 1999.
- [6] D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, "Composite Medium with Simultaneously Negative Permeability and Permittivity," *Phys. Rev. Lett.*, vol. 84, no. 18, pp. 4184–4187, 2000.
- [7] J. Pendry *et al.*, "Extremely low frequency plasmons in metallic mesostructures.," *Phys. Rev. Lett.*, vol. 76, no. 25, pp. 4773–4776, 1996.
- [8] M. Brooks, "Review: Physics of the Impossible by Michio Kaku," New Scientist, vol. 197, no. 2645. p. 52, 2008.
- [9] R. W. Ziolkowski, "Design, fabrication, and testing of double negative metamaterials," *IEEE Trans. Antennas Propag.*, vol. 51, no. 7, pp. 1516–1529, 2003.
- [10] D. K. Ntaikos, N. K. Bourgis, and T. V. Yioultsis, "Metamaterial-based electrically small multiband planar monopole antennas," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 963–966, 2011.
- [11] C. Sabah, "Multi-resonant metamaterial design based on concentric V-shaped magnetic resonators," *J. Electromagn. Waves Appl.*, vol. 26, no. 8–9, pp. 1105–1115, 2012.
- [12] Y. X. Zhang, S. Qiao, W. Huang, W. Ling, L. Li, and S. G. Liu, "Asymmetric single-particle triple-resonant metamaterial in terahertz band," *Appl. Phys. Lett.*,

vol. 99, no. 7, 2011.

- T. L. I. Wu, Y. M. E. I. Pan, P. F. E. I. Hu, and S. Y. Zheng, "Design of a Low Profile and Compact Omnidirectional Filtering Patch Antenna," pp. 1083–1089, 2017.
- P.-C. Wu, Y.-L. Luo, and L. Chen, "Miniaturised wideband filtering antenna by employing CRLH-TL and simplified feeding structure," *Electron. Lett.*, vol. 51, no. 7, pp. 548–550, 2015.
- [15] Y.-L. Luo and L. Chen, "Compact filtering antenna using CRLH resonator and defected ground structure," *Electron. Lett.*, vol. 50, no. 21, pp. 1496–1498, 2014.
- [16] W. J. Wu, Y. Z. Yin, S. L. Zuo, Z. Y. Zhang, and J. J. Xie, "A new compact filter-antenna for modern wireless communication systems," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 1131–1134, 2011.
- [17] B. Garg, A. Sabharwal, G. Shukla, and M. Gautam, "Microstrip patch antenna incorporated with left handed Metamaterial at 2.4 GHz," in *Proceedings - 2011 International Conference on Communication Systems and Network Technologies, CSNT 2011*, 2011, pp. 208–210.
- [18] M. S. Majedi and A. R. Attari, "A compact and broadband metamaterialinspired antenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 12, pp. 345–348, 2013.
- [19] B. D. Bala, N. A. Murad, and M. K. A. Rahim, "Small electrical metamaterial antenna based on coupled electric field resonator with enhanced bandwidth," *Electron. Lett.*, vol. 50, no. 3, pp. 138–139, 2014.
- [20] Z. Aripin, Kusnandar, A. Najmurrokhman, and A. Munir, "Compact SRR-based microstrip BPF for wireless communication," in ICITACEE 2015 - 2nd International Conference on Information Technology, Computer, and Electrical Engineering: Green Technology Strengthening in Information Technology, Electrical and Computer Engineering Implementation, Proceedings, 2016, pp. 474–477.
- [21] M. Syahral and A. Munir, "Effect of elements number of SRR-based BPF to its characteristics," in *Proceedings - 2016 3rd International Conference on Information Technology, Computer, and Electrical Engineering, ICITACEE* 2016, 2017, pp. 1–4.

- [22] C. E. Balanis, "Antenna Theory: Analysis and Design, 3rd Edition Constantine A. Balanis," *Book.* p. 1136, 2005.
- [23] P. Pushkar and V. R. Gupta, "A design rule for an ELC resonator," in ICIIECS 2015 - 2015 IEEE International Conference on Innovations in Information, Embedded and Communication Systems, 2015.
- [24] I. Bahl, Lumped Elements for RF and Microwave Circuits, vol. 53, no. 9. 2013.
- [25] A. K. Tiwary, "Dual Bandpass Filter using SIR for WLAN," pp. 15–16, 2015.
- [26] M. Makimoto and S. Yamashita, "Microwave Resonators and Filters For Wireless Communication: Theory, Design and Application." p. 162, 2001.