WEARABLE EMBROIDERED ANTENNA DESIGN FOR BODY WORN APPLICATION

NORHAYATI BINTI MUTALIB

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Electrical Engineering (Electronic and Telecommunication)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

DECEMBER 2015

My humble effort I dedicated to my dearest mother, my late father and siblings for the affection, love, encouragement and prays along with all hardworking and respected teachers, colleagues, friends and to all who's believe in the value of knowledge.

ACKNOWLEDGEMENT

In the name of Allah Most Gracious and Most Merciful

Firstly, special thanks to my supervisor, Prof. Dr. Mohamad Kamal bin A. Rahim for the opportunity, guidance, support, encouragement and motivation throughout the project. All the advised, knowledge and experience that has been shared were so valuable and important to me as a guidance to face the future.

Then, a huge appreciation also goes to my family, my beloved mother Pn. Romlah binti Ibrahim who pray for my success days and night, my late father who put a hope that her daughter will become an engineer. My brother and my sisters who always support me mentally and financially.

Other than that, a million thanks also to my friends who always stay by my side throughout the journey especially to Sis. Arrauzah Razak and Sis. Nur Syahirah for the support, motivation and positive words. Last but not least, to all who had contributed to this project in term of time, opinion and ideas directly and indirectly, may Allah bestow His Grace and favors upon all.

Thank You

ABSTRACT

Wearable textile antenna is a technology for future body worn applications as a part of effort to enhance the quality of daily life. As a body worn antenna, the antenna should own a characteristics such as flexible, lightweight, small size and easily integrated onto body of human or animal. In this project, wearable textile dipole antenna with UTM logo shape was designed for body worn application. The antenna was operated under 3 GHz resonant frequency. Substrate used for this antenna is fleece fabric and the radiating element is covered by copper thread. This antenna is fabricated by using embroidery technique where the radiating element is integrated into substrate rather than attached to the substrate by glue or handsewn. The objectives of this project are to design and simulate wearable dipole antenna for body worn application, to fabricate wearable dipole antenna using embroidery technique and to compare the performance of embroidered dipole antenna with ShieldIT fabric dipole antenna, The design and simulation of the antenna is done by using Computer Simulation Technology (CST) Microwave Studio software. Fabrication of the antenna is done by embroidered UTM shape dipole antenna on fleece substrate by using computerized embroidery machine.The result showed that ShieldIT fabric dipole antenna had better performance than embroidered antenna in term of return loss and bandwidth.

ABSTRAK

Antena tekstil adalah teknologi baru untuk aplikasi pada pakaian dan ia adalah salah satu usaha untuk meningkatkan kualiti kehidupan harian manusia. Sebagai antena yang diaplikasikan pada pakaian, antena tersebut perlu memiliki sifat-sifat seperti berikut iaitu fleksibel, ringan, bersaiz kecil dan mudah untuk digayakan pada badan manusia dan haiwan. Dalam projek ini, tekstil antena dipole berbentuk logo UTM direka untuk tujuan aplikasi pada pakaian. Antena tersebut beroperasi pada frekuensi 3 GHz. Substrat yang digunakan untuk antena ini ialah kain fleece manakala elemen radiasinya pula menggunakan benang kuprum. Proses pembuatan antenna ini menggunakan teknik sulaman iaitu elemen radiasinya disulam di atas subsrat berbanding antena-antena sebelum ini yang menggunakan teknik gam dan jahitan tangan. Antara objektif bagi projek ini adalah mereka dan simulasi antena dipole untuk aplikasi pada pakaian, menghasilkan antena dipole untuk aplikasi pada pakaian dengan menggunakan teknik sulaman dan membandingkan prestasi antena dipole yang disulam dan dengan antena yang antena dipole yang dihasilkan menggunakan kain ShieldIT. Rekaan dan simulasi antena ini dihasilkan menggunkan perisian Computer Simulation Technology (CST) Microwave Studio. Proses pembuatannya dilakukan dengan menyulam antena berbentuk logo UTM pada substrat fleece dengan menggunakan mesin sulaman berkomputer. Dari segi return loss dan jalur lebar, keputusan menunjukkan antena dipole daripada kain ShieldIT mempunyai prestasi yang lebih baik berbanding antenna dipole yang disulam.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

WBAN	-	Wireless Body Area Network
IEEE	-	Institute of Electrical and Electronics Engineers
UTM	-	Universiti Teknologi Malaysia
PCB	-	Printed Circuit Board
FR-4	-	Flame Retardant 4
CST	-	Computer Simulation Technology
BSN	-	Body Sensor Network
MICS	-	Medical Implant Communication System
ISM	-	Industrial Scientific Medical
UWB	-	Ultra Wide Band
AAL	-	Ambient Assisted Living
FTFE	-	Polytetrafluoroethylene
PET	-	Polyethylene
PIFA	-	Planar Inverted F Antenna
USB	-	Universal Serial Bus
SMA	-	Sub Miniature
VNA	-	Vector Network Analyzer

LIST OF SYMBOLS

h	-	Wireless Body Area Network
ε_r	-	Relative Permittivity
$\tan \delta$	-	Loss Tangent
λ	-	wavelength
c	-	velocity of light
f	-	frequency
ε_{eff}	-	effective dielectric constant of microstrip line
ε_r	-	permittivity of substrate
d	-	thickness of substrate
W	-	width of microstrip line
L_1 , L_2	-	length

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Recently, wearable technology has received a lot of attention from industry, media and researchers worldwide. This technology is a fast growing area which believe to have a lot of advantages such as improving human productivity in daily life, enhancement in tracking asset or workflow, improve healthcare monitoring, upgrade security in identification area and etc. Some examples of wearable technology devices available in the market nowadays are smart watch, fitness devices, healthcare monitoring, tailored technology and many more. The emerging of wearable electronic device lead to the development of Wireless Body Area Network (WBAN). WBAN is under IEEE 802.15.6 standard is the act of connecting various wearable electronic devices in and on the human body [1]. To connect the devices to each other or to the outside system, the antenna that can be worn on body is required so called wearable antenna.

Wearable antenna plays important role in WBAN. Wearable antenna special characteristics such as light weight, low cost, free maintenance, easily attached to garment and no installation required [2]. Frequently, this kind of antenna is textile or fabric based antenna since fabric is considered as the most suitable material for body worn application due to its flexibility and robustness [3]. In this project, a fabric-based antenna that operated under 3 GHz resonant frequency was designed with fleece fabric as a substrate and copper thread which act as radiating element was used to form UTM logo shape dipole antenna by using embroidery technique. Details of the design, design methodology and the benefits of this antenna will be discussed in the next chapter.

1.2 Problem Statement

The design process of wearable antenna must consider these two important things. Firstly is to make sure the antenna properly function and has good performance with minimum return loss. Secondly is to ensure the antenna design is suitable and comfortable for body worn application in term of flexibility, size, weight and structure. In this case, material selection to fabricate the antenna is one of the important factor. However, the conventional fabricated antenna commonly were manufactured by using rigid printed circuit board (PCB) material such as FR-4 board, Taconic and conventional Rogers. All the mentions material were not suitable for on body application since these materials are not flexible and unable to conform to the human body effectively especially around body curvature such as around human arm or leg. Therefore, in this project, fleece and copper thread was choose as substrate and radiating element respectively due to its flexibility, light weigh and ability to conform to the curvature of human body. Furthermore, the used of copper thread to form embroidery on substrate also able to provide strong attachment between the radiating element and the textile substrate.

1.3 Objectives

The objectives of the project are:

1. To design and simulate wearable dipole antenna for body worn application.
2. To fabricate wearable dipole antenna using embroidery technique.
3. To compare performance of embroidery dipole antenna with Shieldit dipole antenna.

1.4 Project's Scope

The objectives of this project can be achieved with several outlined scopes. In this project, the design and simulation of the antenna is done by using Computer Simulation Technology (CST) Microwave Studio software use planar antenna. The antenna operation frequency is under 3 GHz. All properties of the substrate and radiating element for software design are key in according to the properties of fleece and copper thread. The details properties of fleece and copper thread will be discussed further in Chapter two. Type of antenna choose for this project is UTM logo shape dipole antenna. The characteristics of the antenna and the reason of choosing this antenna also will be discussed in the next chapter.

1.5 Report Outline

This report is systematized in five chapters. Chapter one gives an overview and the introduction of the project.

Chapter two discussed the literature review on the introduction and the concept of wearable antenna mostly which operates under 2.4 GHz to 5.8 GHz frequency band The introduction to Dipole Antenna and its characteristic also is going to be discussed in this chapter. Moreover, this chapter also gives some explanation and comparison about embroidered antenna that has been done by some researchers previously. Other than that, the benefit of wearable embroidered antenna also is discussed in term of sizing and operation.

Next is Chapter three. This chapter contains the design methodology of the project. The design overview and all the tools and modules used in this project are discussed in this chapter including antenna design parameter and calculation involved.

After that, the next chapter which is Chapter four is on result and analysis of the project. This chapter will discussed on the result obtained from simulation and measurement based on the comparison done by embroidered dipole antenna and Shieldit dipole antenna.

Then, Chapter 5 is discussed on conclusion of the project and also some recommendation for better result and improvement as well as future work of the project. Lastly, this report is ended by Chapter 6 which is references.

1.6 Summary of Work

The project flow is outlined as illustrated in Figure 1.1. The project is begun with literature review followed by design and simulation of dipole antenna using CST Microwave Studio. The simulation result will show functionality or performance of the antenna in term of return loss and radiation pattern. Simulation result of return loss and radiation pattern will be analyzed so that it meet the requirement for return loss and radiation pattern of dipole antenna. If requirement is fulfilled, the next step of the project can be proceed which is to fabricate wearable embroidered antenna. However, if the simulation result is not optimized, the step has to turn back to design and simulation step in order to identified if there any problem or mistake that has been done during designing the antenna.

After finish with antenna fabrication, the completed fabricated antenna will undergo a testing to identified weather the antenna can function properly. The testing is done by using antenna testing equipment such as network analyzer for testing antenna return loss. The measured result then will be compared to the simulated result for both embroidered and Shieldit antenna. The varies from the result will be analyzed and discussed further in the last step of this project which is in final report writing.

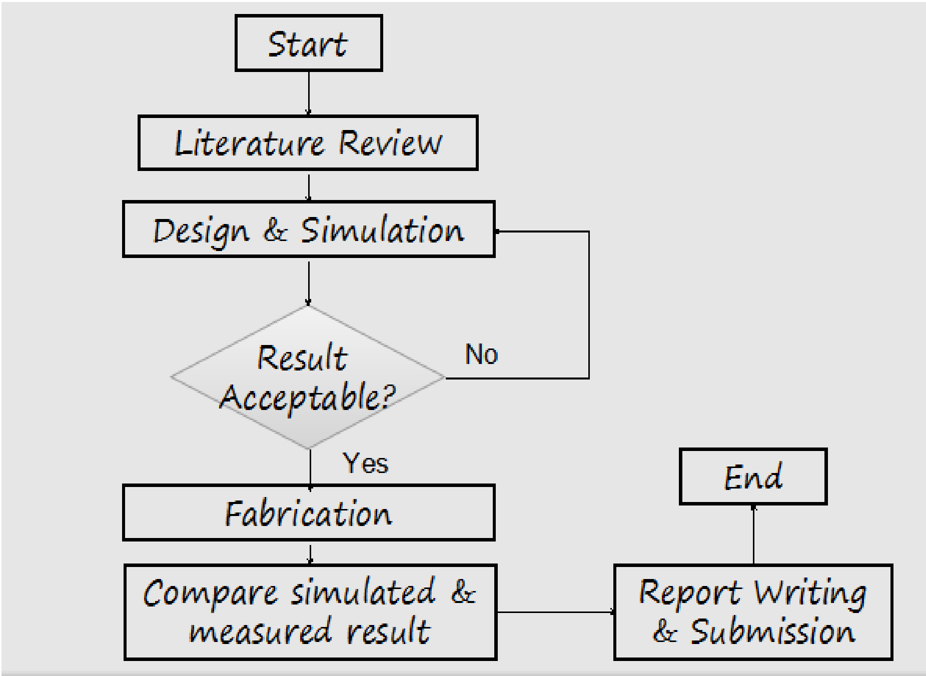

Figure 1.1 Project flow

Table 1.1 and Table 1.2 shows the Gantt chart of the project schedules for phase one and phase two respectively. The implementation of phase one was in semester one which covers studying and understanding of literature review and also the determination of project specification. Previous research that is related on this project and various types of wearable embroidered antenna and fabrication techniques are studied. Other than that, this phase include designs and simulate of prototype embroidered antenna using CST Microwave Studio software.

While, for phase two, the task of the project involved the fabrication of embroidered antenna and Sheildit antenna. After finished with fabrication, the antennas will undergo testing for measured return loss and radiation pattern. Then, result from measurement for both antenna was compared to the simulation and the result are analyzed based on the performance.

Table 1.1: Project schedule phase 1

MONTH	FEB			MARCH					APRIL				MAY			JUNE	
WEEK			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Research on related topic			■	■	■												
Literature review				■	■	■	■	■	■	■	■	■	■	■	■	■	■
Study for methodology						■	■	■	■	■	■	■	■	■	■	■	■
Submit proposal										■							
Presentation													■				
Report writing														■	■	■	■

Table 1.1: Project schedule phase 2

MONTH	SEPT				OCTOBER				NOVEMBER				DECEMBER				
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Design & Simulation	■	■	■	■	■	■	■	■	■								
Fabrication										■	■	■	■				
Testing										■	■	■	■				
Submit Presentation Material													■				
Presentation														■			
Report writing															■	■	■

REFERENCES

1. E. G. Lim, Z. Wang, J. C. Wang, M. Leach, R. Zhou, C.U. Lei and K. L.Man, "Wearable Textile Substrate Patch Antennas," *Engineering Letters*, vol.22, no. 2, May 2014.

2. N. H. M. Rais, P. J. Soh, F. Malek, S. Ahmad, N. B. M. Hashim and P. S. Hall, "A Review of Wearable Antenna," *Loughborough Antennas and Propagation Conference, United Kingdom,* 2009, pp. 225 - 228.

3. N. J. Ramly, M. K. A. Rahim, N. A. Samsuri, M. E. Jalil, M. A. A. Majid, N. A. Elias and R. Dewan, "Leaf-Shaped Dual Band Antenna Textile Performance for On-Body Application," *IEEE Asia-Pacific Conference on Applied Electromagnetic (APACE), Johor Bahru, Malaysia*, 2014, pp. 257 - 260.

4. Marian Wnuk, Marek Bugaj, Rafal Przesmycki, Leszek Nowosielski, and Kazimierz Piwowarczyk, "Weareble Antenna Constructed in Microstrip Technology," *Progress In Electromagnetics Research Symposium Proceedings, Kuala Lumpur, Malaysia,* March 27 - 30, 2012, pp. 67 - 71.

5. M. E. Jalil, M. K. A. Rahim, N. A. Samsuri, N. A. Murad, H. A. Majid, K. Kamardin and M. A. Abdullah, "Fractal Koch Multiband Textile Antenna Performance with Bending, Wet Condition and On the Human Body," *Progress in Electromagnetic Research*, vol. 140, 2013, pp. 633-652.

6. A. Tsolis, W. G. Whittow, A. A. Alexandridis and J. C. Vardaxoglou, “Embroidery and Related Manufacturing Technique for Wearable Antennas: Challenges and Opportunuties,” *Electronic Journal*, 2014, pp. 314 - 338.

7. S. Bashir, “Design and Synthesis of Non Uniform High Impedance Surface Based Wearable Antennas,” *A Doctoral Thesis, Loughborough University,* 2010, pp. 2-18.

8. R. Saba, T. Deleruyelle, J, Alarcon, M. Alkhoury and P. Pannier, "A novel textile antenna for passive UHF RFID tag,” A*ntennas and Propagation (ISAP), 2012 International Symposium*, 2012, pp. 882-885.

9. Mai. A. R. Osman, M. K. A. Rahim, N. A. Samsuri and M. E. Ali “Compact and Embroidered Textile Wearable Antenna”, *IEEE International RF and Microwave Conference, Seremban, Malaysia,* 2011, pp. 311-314.

10. K. Koski, L. Ukkonen, L. Sydanheimo, and Y. Rahmat Samii, “Embroidered Ground Plane Implementation for Wearable UHF RFID Patch tag Antennas,” *URSI,* 2014. pp. 274.

11. P. Salonen, Y. Rahmat-Samii, M. Schaffrath, M. Kivikoski, “Effect of Textile Materials on Wearable Antenna Performance: A Case Study of GPS Antenna,” *International Symposium Antennas Propagation,* Vol 1, 2004. pp. 459-462.

12. A. Tronquo, H. Rogier, C. Hertleer, L. Van Langenhove, “Robust Planar Textile Antenna for Wireless Body LANs Operating in 2.45 GHz ISM band”, in *Electron. Lett.* 2006, 42, pp. 5-6.

13. Sweety Purohit and Falguni Raval, “Wearable Textile Patch Antenna Using Jeans as Substrate at 2.45 GHz,” *International Journal of Engineering Research & Technology (IJERT),* vol.3, 2014, pp. 2456 - 2460.

14. M.K Elbasheer, Mai. A. R. Osman, Abuelnuor A., M. K. A. Rahim and M. E. Ali *“* Conducting Materials Effect on UWB Wearable Textile Antenna,’ *Proceeding of the World Congress on Engineering,* Vol. 1, London, U.K., 2014.

15. R. M. Rius, G. Talavera and J. Carrabina, “Developing and Study of Wearable and Flexible Antenna for Body Area Networks Working Under Extreme Condition,” *IEEE Journal*, 2012, pp. 1-5.

16. Tess Acti, A. Chauraya, S. Zhang, W. G. Whittow, R. Seager, J. C. Vardaxoglou and T. Dias, “ Embroidered Wire Dipole Antennas Using Novel Copper Yarns,” *Antenna and Wireless Propagation Letter,* vol.14, 2015. pp. 638-641.

17. S. Ahmad, N. S. Saidin and C. M. Che Isa, “ Development of Embroidered Sierpinski Carpet Antenna,” *Proceeding of the IEEE Asia-Pacific Conference on Applied Electromagnetic (APACE 2012), Melaka*, Malaysia, 2012, pp. 123 - 127.

18. J.C Matthews and G. Pettitt, “Development of Flexible, Wearable Antenna,” *Proceedings of the 3rd European Conference on Antennas and Propagation (EuCAP), Berlin*, Germany, March, 2009, pp. 273-277.

19. S. Zhang, A. Chauraya, W. Whittow, R. Seager, T. Acti, T. Dias, and Y. Vardaxoglou, “Embroidered Wearable Antenna Using Conductive Thread with Different Stitch and Spacings,” *Proceeding of the Loughborough Antenna and Propagation Conference (LAPC), Loughborough*, UK, 2013.

20. K. Koski, E. Moradi, A. A. Bahar, T. Bjorninen, L, Sydanheimo, and L. Ukkonen, “Durability of Embroidered Antennas in Wireless Body-Centric Healthcare Applications,” *Proceeding of the 7th European Conference on Antennas and Propagation (EuCAP), Gothenburg, Sweeden,* April, 2013, pp. 565-569.

21. J. G Santas, and A. Alomainy, " Textile antennas for on-body communications: Techniques and Properties," *Proceeding of the European Conference on Antennas and Propagation (EuCAP), Edinburgh,* Scotland, November, 2007.

22. S. Zhang, A. Chauraya, W. Whittow, R. Seager, T. Acti, T. Dias, and Y. Vardaxoglou, " Reapeatability of Embroidered Patch Antenna," *Proceeding of the Loughborough Antenna and Propagation Conference (LAPC), Loughborough,* UK, 2013.

23. J. Lilja, P. Solonen, T. Kaija, and P. de Maagt, "Design and Manufacturing of Robust Textile Antenna for Harsh Environment," *IEEE Trans. Antenna Propagation,* 2012, pp. 4130 - 4140.