UNIVERSITI PUTRA MALAYSIA

FERRITES-BASED THICK FILM WITH LINSEED OIL AS ORGANIC VEHICLE FOR ENHANCED MICROSTRIP PATCH ANTENNA

INTAN HELINA HASAN

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FERRITES-BASED THICK FILM WITH LINSEED OIL AS ORGANIC VEHICLE FOR ENHANCED MICROSTRIP PATCH ANTENNA

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By

INTAN HELINA HASAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2018

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DEDICATIONS

In the name of Allah,
The most beneficent, the most merciful.

To my father and mother;
my idols, my mentors, my guardian angels.

My husband; my pillar of strength.

My children; my main reason to survive this journey.

My siblings; my confidantes.

Without you, I could never finish this journey alone.
This work is dedicated to all of you….

THANK YOU.

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

FERRITES-BASED THICK FILM WITH LINSEED OIL AS ORGANIC VEHICLE FOR ENHANCED MICROSTRIP PATCH ANTENNA

By

INTAN HELINA HASAN

May 2018

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Faculty: Institute of Advanced Technology

Research on microstrip patch antenna (MPA) has been growing in the past few decades due to its planar profile and easy fabrication. Its simplicity of structure which includes a conductive patch, a dielectric substrate, a ground plane and a microstrip feeder is making it more popular for integration in electronic and telecommunication devices focusing on flexibility. There is however few disadvantages of MPA, such as narrow bandwidth, low power and limited material selection if current printed circuit board (PCB) etching fabrication technique is used. Ferrite substrates are known to be able to help overcome this issue, but the dielectric and magnetic properties of bulk ferrites are difficult to control and manipulate.

This work aims to solve mentioned problems by using thick film technology which utilizes screen printing method to include ferrite thick film in the MPA structure as substrate overlay to help enhance the bandwidth performance of MPA. Yttrium iron garnet (YIG) and nickel zinc ferrite (NZF) were chosen as the starting ferrite nanopowders. Preparation of the paste by mixing nanopowders with linseed oil as organic vehicle and characterization of the ferrite thick film paste were carried out to investigate properties of the thick film. Results showed that the thick film exhibited moderate permittivity and permeability, which is suitable for MPA fabrication. The actual fabricated MPA with ferrite thick film inclusion on FR4 substrate showed that the thick film improved the performance of MPA with firing temperature of 200°C. MPA with YIG thick film on FR4 substrate exhibited improved return loss and -10dB bandwidth to -35.74 and 0.40 GHz respectively, while Q factor was reduced to 14.00, as compared to MPA with only silver patch which has return loss, -10 dB bandwidth and Q factor of -17.86 dB, 0.26 GHz and 21.54

respectively. As for MPA with NZF thick film, the return loss and bandwidth improved to -29.34 dB, 0.48 GHz respectively, while the Q factor reduced to 11.75. Meanwhile, the same firing temperature did not give same effect to the MPA with ferrite thick film on Kapton substrate. Compared with MPA with only silver patch which has return loss, -10 dB bandwidth and Q factor of -17.29 dB, 0.88 GHz, 6.41 respectively, the improvement of MPA measurement results occurred when the firing temperature is increased to 300°C. MPA with YIG thick film exhibited improved return loss of -23.67 dB but reduced -10dB bandwidth to 0.70 GHz, while Q factor was increased to 8.4. As for MPA with NZF thick film, the return loss and bandwidth improved to -28.73 dB and 1.16 GHz respectively, while the Q factor reduced to 5.10.

As conclusion, a novel ferrite thick film paste with linseed oil as organic vehicle has been successfully developed and characterized. Furthermore, ferrite thick film inclusion in MPA fabrication has proven to enhance the bandwidth of the antenna, leading to a success in fabrication of MPA on flexible substrate with enhanced performance. The flexibility of the antenna may have vast possibilities in various applications in the future, such as wearable antenna, and flexible telecommunication devices.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

FILEM TEBAL BERASASKAN FERIT DENGAN MINYAK LINSID SEBAGAI VEHIKEL ORGANIK UNTUK PENAMBAHBAIKAN ANTENA TAMPAL MIKROJALUR

Oleh

INTAN HELINA HASAN

Mei 2018

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Penyelidikan tentang antena tampalan mikrojalur (MPA) telah berkembang sejak beberapa dekad yang lalu disebabkan profil yang satah dan fabrikasi yang mudah. Kesederhanaan struktur yang merangkumi plat tampal berkonduktif, substrat dielektrik, satah bumi dan penghantar mikrojalur menjadikannya lebih popular untuk integrasi dalam peranti elektronik dan telekomunikasi yang menumpukan kepada kelenturan. Walau bagaimanapun terdapat beberapa kelemahan MPA, seperti lebar jalur yang sempit, kuasa yang rendah dan pilihan material yang terhad jika menggunakan teknik fabrikasi punaran untuk papan litar tercetak (PCB). Substrat ferit diketahui dapat membantu mengatasi masalah ini, tetapi sifat dielektrik dan magnetik ferit berbentuk pukal sukar untuk dikendalikan dan dimanipulasikan.

Kerja ini bertujuan untuk menyelesaikan masalah ini dengan menggunakan teknologi filem tebal yang menggunakan kaedah percetakan skrin untuk memasukkan filem tebal ferit dalam struktur MPA sebagai lapisan substrat untuk membantu meningkatkan prestasi MPA. garnet ferum yttrium (YIG) dan ferit zink nikel (NZF) dipilih sebagai ferit serbuk nano permulaan. Penyediaan pes dengan mencampurkan serbuk nano dengan minyak linsid sebagai vehikel organik dan pencirian pes pekat ferit telah dilakukan untuk menyiasat sifat filem tebal. Keputusan menunjukkan bahawa filem tebal mempamerkan ketelusan dan kebolehtelapan sederhana, yang sesuai untuk fabrikasi MPA. Fabrikasi MPA yang sebenar dengan rangkuman filem tebal ferit pada substrat FR4 menunjukkan bahawa filem tebal meningkatkan prestasi MPA dengan suhu pengapian 200°C. MPA dengan filem tebal YIG

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mempamerkan kehilangan daya yang lebih baik dan lebar jalur -10dB masing-masing -35.74 dB dan 0.40 GHz, manakala faktor Q berkurang kepada 14.00, jika dibandingkan dengan MPA dengan hanya tampalan perak yang mempunyai kehilangan daya, lebar jalur dan faktor Q masing-masing -17.86 dB, 0.26 GHz dan 21.54. Bagi MPA dengan filem tebal NZF, kehilangan daya dan lebar jalur meningkat masing-masing -29.34 dB dan 0.48 GHz, manakala faktor Q berkurang kepada 11.75. Sementara itu, suhu pengapian yang sama tidak memberikan kesan yang sama kepada MPA dengan filem tebal ferit pada substrat Kapton. Berbanding dengan MPA dengan hanya tampalan perak yang mempunyai kehilangan daya, lebar jalur -10 dB dan factor Q masing-masing -17.29 dB, 0.88 GHz dan 6.41, peningkatan bacaan pengukuran MPA berlaku apabila suhu pengapian ditingkatkan kepada 300°C. MPA dengan filem tebal YIG mempamerkan kehilangan daya yang lebih baik sebanyak -23.67 dB tetapi lebar jalur -10dB berkurang sebanyak 0.70 GHz, manakala faktor Q meningkat kepada 8.4. Bagi MPA dengan filem tebal NZF, kehilangan daya dan jalur lebar meningkat masing-masing sebanyak -28.73 dB dan 1.16 GHz, manakala faktor Q berkurang sebanyak 5.10.

Sebagai kesimpulan, pes filem tebal ferit baru dengan minyak linsid sebagai vehikel organik berjaya dihasilkan dan dicirikan. Tambahan lagi, rangkuman filem tebal ferit dalam fabrikasi MPA terbukti dapat meningkatkan jalur lebar antena, seterusnya berjaya menghasilkan fabrikasi MPA pada substrat yang mudah lentur dengan prestasi yang dipertingkatkan. Kelenturan antena mungkin mempunyai kemungkinan besar dalam pelbagai aplikasi pada masa akan datang, seperti antena boleh pakai dan juga peranti telekomunikasi mudah lentur.

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LIST OF ABBREVIATIONS

MPA	Microstrip patch antenna
YIG	Yttirum iron garnet
NZF	Nickel zinc ferrite
GPS	Global positioning system
PCB	Printed circuit board
PFC	Printed film circuit
FR4	Flame retardant 4
ISM	Industrial, scientific and medical
XRD	X-ray diffraction
VSWR	Voltage standing wave ratio
RL	Return loss
FBW	Fractional bandwidth
LTCC	Low temperature co-fired ceramic
PTFE	Polytetrafluoroethylene
UHF	Ultra high frequency
GGG	Gadolinium gallium garnet
EMC	Electromagnetically coupled
SOC	Silver organic complex
EBG	Electromagnetic band-gap
AEMT	Anisotropic effective medium theory
FDTD	Finite-difference time-domain

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LDPE	Low dispersed polyethylene
CNT	Carbon nanotube
PVB	Polyvinyl butyral
SPEs	Screen printed electrodes
DSSC	Dye sensitized solar cells
FTO	Fluorine-doped tin oxide
BST	Barium-strontium-titanate
PMC	Perfect magnetic conductor
FESEM	Field Emission Scanning Electron Microscope
TGA	Thermal gravimetric analysis
EDX	Energy dispersive x-ray
VSM	Vibrating Sample Magnetometer
CST	Computer simulation technology
SMA	SubMiniature version A
VNA	Vector Network Analyzer
FMR	Ferromagnetic resonance

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CHAPTER 1

INTRODUCTION

1.1 Overview

Antenna plays a very important role in telecommunication technology; without antenna integrated in a communication device, the device cannot send or receive information in the form of signals. There are several types of antennas including dipole antenna, horn antenna, wire antenna and others. In 1950s, microstrip patch antenna (MPA) was first introduced [1], and since then has gained a lot of interests from telecommunication industry players due to its flat or planar profile, easy to fabricate, small size and low manufacturing cost. This type of antenna is widely applied in wireless communication systems, including cellular devices, Global Positioning System (GPS) devices, and wireless internet routers [2], [3]. Patch antenna is typically constructed by fabricating a conductive patch onto a dielectric substrate. The permittivity and thickness of the substrate give influences to the parameters of the antenna, including the resonant frequency, bandwidth and return loss of the antenna. There are few types of materials that are being studied and used as the substrate, such as ceramic, semiconductor, ferrimagnetic, synthetic and composite materials.

Ferrimagnetic materials or ferrites are one type of magnetic materials, having a certain degree of susceptibility to magnetization. However if compared to ferromagnetic materials, they have different magnetic ordering, thus they are weaker in terms of magnetization, and have incomplete or non-zero net magnetization. Based on these properties, ferrites are divided to two categories, which are hard and soft ferrites. Hard ferrites have high coercivity and high remanence after being magnetized, which makes them perfect as permanent magnets. Soft ferrites on the other hand, have low coercivity that makes the magnetic direction can be easily reversed to normal state with low loss energy. These types of ferrites also have high electrical resistivity and low magnetic losses at higher frequency range, which makes them suitable for microwave applications [4]. Ferrites are also being studied as substrates for patch antennas, which can be tuned when external magnetic field is applied [5].

The common fabrication processes for MPA are by printed circuit board (PCB) etching technology, or thick film technology which utilizes screen printing method. The latter is preferred however due to its ease of fabrication,

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with less chemical handling. Thick film technology has been widely used in semiconductor production, either in surface mounted devices (SMT) fabrication or in printed film circuit (PFC) production. Another main advantage of this technique is that the material used for screen printing can be printed in any planar surfaces, from rigid to flexible substrates. This makes the thick film technology still relevant to the electronics industry nowadays, even though the technology has been around for decades.

1.2 Problem Statement

PCB etching method is commonly used to produce MPAs since it is the easiest method using commercially available flame-retardant 4 (FR4) coated with copper on both sides, and etching one side of FR4 with specific patch design for antenna. However there are limitations of using this method, such as the performance of the antenna depends solely on the design of MPA, since the materials for fabrication are fixed. Therefore there are disadvantages that cannot be ignored such as narrow bandwidth (3%), low power and low gain (6dBi) [6]. Thick film technology is the next best solution for MPA fabrication, with ability to use various substrates and thick film pastes with different dielectric and electrical properties which can be tailored to suit the performance required. Nevertheless, it is difficult to control the parameters of the MPA if using conventional conductive thick film pastes alone such as silver paste or copper paste. Furthermore, the use of copper paste is not preferable due to its oxidization in air at room temperature.

Based on past researches, ferrite substrates have helped to improve the performance of MPA due to its moderately high permittivity and permeability, and also the anisotropic behaviour of the materials. Ferrite bulks have been considered for this purpose, however it is difficult to control the permittivity and permeability of the magnetic materials in bulk form, and the fabricated ferrite substrates tend to be brittle, therefore these limitations become the reason of the bottleneck in research ferrites application in antenna fabrication.

1.3 Research Objectives

To tackle the problems discussed above, this project aims to study the use of nanosized yttrium iron garnet (YIG) and nickel zinc ferrite (NZF) powder as

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active element in thick film paste to enhance performances of microstrip patch antenna.

Research objectives of this project are:

1. To develop a ferrite paste using YIG and NZF powder with linseed oil based organic vehicle that is suitable for thick film printing.
2. To investigate the ferrite paste characteristics at different thick film fabrication processes.
3. To fabricate the microstrip patch antennas using the prepared thick film on FR4 and Kapton film.
4. To measure and analyze the performance of the fabricated microstrip antennas.

YIG and NZF are both soft ferrites which have low losses at microwave frequencies; therefore, the use of the chosen ferrites is hypothesized to help enhance the performance of MPA with their excellent properties.

1.4 Scope of the Project

This project is focused on the fabrication of the MPA and the study of ferrite film inclusion in enhancing the performance of the MPA. The scope of the project includes comparison of the substrate used in fabrication, and materials used for the thick film. The design of the antenna is not in scope of the project, therefore a basic rectangular patch antenna which resonates at selected frequency is used throughout the project. The selected resonant frequency is fixed at 5.8GHz during simulation to match the industrial, scientific and medical (ISM) radio band for wireless communication (WiFi), as depicted in Table 1.1 [7].

The effect of thickness of the thick film is also not in scope of the project, since the minimum thickness is based on the emulsion thickness of the stencil screen prepared by the screen supplier, which is fixed at 10µm, while since the semi automatic screen printing is used during this project of which the screen printing part was done manually, the actual thickness of the thick film is difficult to control. The thickness of the thick film is estimated to be around 10 to 20 µm range, and based on simulation with thickness variation of 10, 15 and 20 µm, there is almost no variation or deviation in terms of bandwidth and return loss of the antenna, as shown in Figure 1.1. Therefore for

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simulation for fabrication purpose, the thickness is fixed to 20 μm to take into account the maximum thickness of the printed thick film.

For characterization purpose, alumina substrate was used during characterization of the ferrite thick film due to the ability of the substrate to withstand high temperature. For x-ray diffraction (XRD) analysis however, glass substrate was used to prevent unnecessary peaks that may come from alumina or polymer substrates. For fabrication purpose, two types of substrates were chosen, which are FR4 and Kapton film. FR4 is chosen since it is widely used in antenna fabrication, especially using PCB etching method, while Kapton film is chosen to demonstrate the flexibility of the fabricated ferrite thick film patch antenna.

1.5 Contribution

The idea of this project was conceived with the purpose to incorporate nanotechnology with thick film and communication technology with hopes to find an improved method to produce material for antenna fabrication with enhanced performance related to bandwidth and return loss. This project proposed a novel ferrite thick film paste using nanosized ferrite powder and linseed oil based organic vehicle which have never been reported before. YIG and NZF were chosen as the active powder due to their excellent dielectric and magnetic properties at higher frequency range, which can be utilized for the targeted frequency in this work. Meanwhile, linseed oil is a fast drying oil which can be a good candidate as organic vehicle for low temperature firing thick film paste.

By utilizing thick film technology, a novel flexible microstrip patch antenna on Kapton substrate has been able to fabricate with improved bandwidth performance. Thick film technology also contributes in terms of ease of fabrication, with ability to screen print prepared thick film paste on any desired substrate with suitable temperatures. With these new findings, it is hoped that flexible antennas can be integrated with other communication devices and further improve telecommunication technology in near future.

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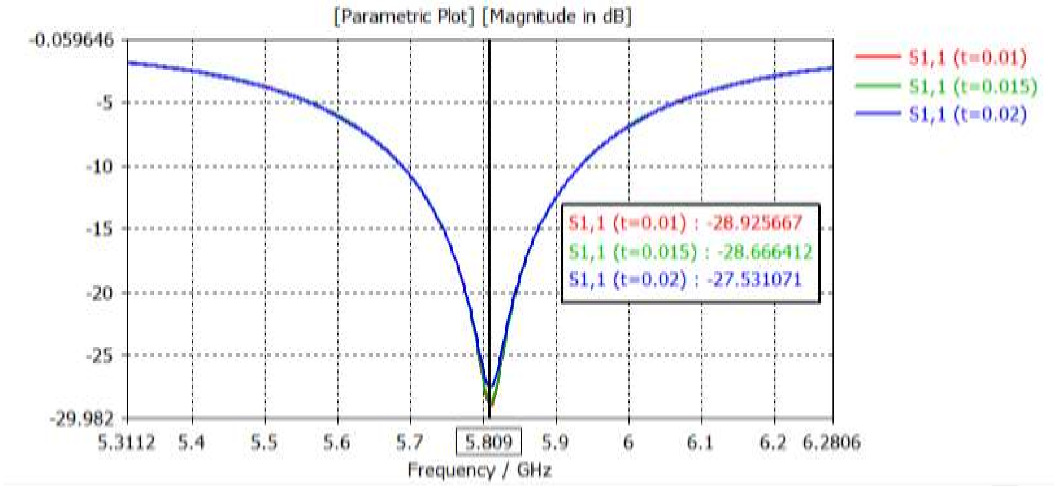
Table 1.1: ISM band frequency allocation by International Telecommunication Union (ITU) [7]

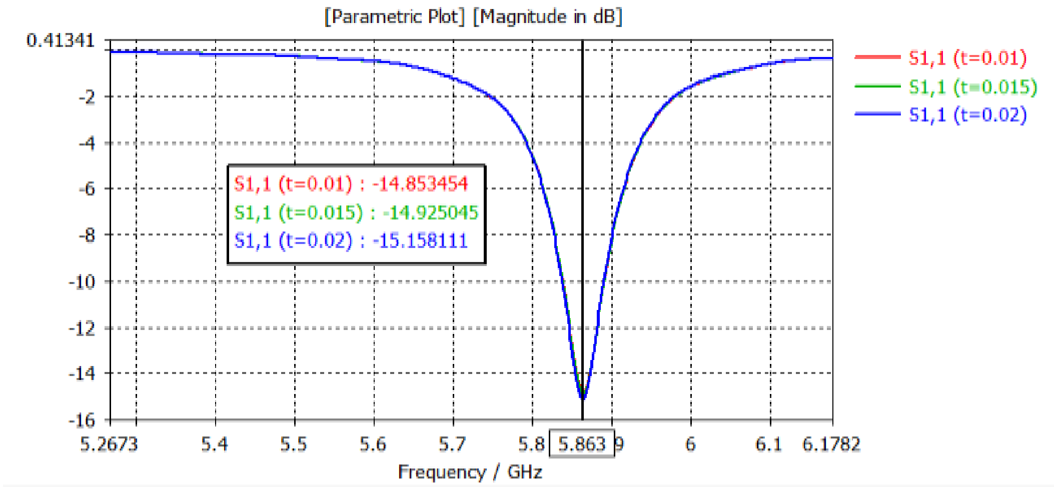
Frequency range		Type	Center frequency	Availability	Licensed users
6.765 MHz	6.795 MHz	A	6.78 MHz	Subject to local acceptance	FIXED SERVICE & Mobile service
13.553 MHz	13.567 MHz	B	13.56 MHz	Worldwide	FIXED & Mobile services except Aeronautical mobile (R) service
26.957 MHz	27.283 MHz	B	27.12 MHz	Worldwide	FIXED & MOBILE SERVICE except Aeronautical mobile service
40.66 MHz	40.7 MHz	B	40.68 MHz	Worldwide	Fixed, Mobile services & Earth exploration-satellite service
433.05 MHz	434.79 MHz	A	433.92 MHz	only in Region 1, subject to local acceptance	AMATEUR SERVICE & RADIOLOCATION SERVICE, additional apply the provisions of footnote 5.280
902 MHz	928 MHz	B	915 MHz	Region 2 only (with some exceptions)	FIXED, Mobile except aeronautical mobile & Radiolocation service; in Region 2 additional Amateur service
2.4 GHz	2.5 GHz	B	2.45 GHz	Worldwide	FIXED, MOBILE, RADIOLOCATION, Amateur & Amateur-satellite service
5.725 GHz	5.875 GHz	B	5.8 GHz	Worldwide	FIXED-SATELLITE, RADIOLOCATION, MOBILE, Amateur & Amateur-satellite service
24 GHz	24.25 GHz	B	24.125 GHz	Worldwide	AMATEUR, AMATEUR-SATELLITE, RADIOLOCATION & Earth exploration-satellite service (active)
61 GHz	61.5 GHz	A	61.25 GHz	Subject to local acceptance	FIXED, INTER-SATELLITE, MOBILE & RADIOLOCATION SERVICE
122 GHz	123 GHz	A	122.5 GHz	Subject to local acceptance	EARTH EXPLORATION-SATELLITE (passive), FIXED, INTER-SATELLITE, MOBILE, SPACE RESEARCH (passive) & Amateur service
244 GHz	246 GHz	A	245 GHz	Subject to local acceptance	RADIOLOCATION, RADIO ASTRONOMY, Amateur & Amateur-satellite service

1.6 Thesis Organization

The body of this thesis is divided into several chapters. Chapter 1 includes the introduction, problem statement, research objectives to solve the problem stated, scope of the project and contribution to the society. Chapter 2 consists of the literature review of the project, where past related researches are analyzed and discussed to relate to the problem stated in the introduction chapter. Chapter 3 describes the materials and equipments used in the project, and also the methods used to achieve the objectives of the thesis. Chapter 4 includes the results obtained during the project, and discussion to analyze and interpret the results. Finally, Chapter 5 contains the summary and conclusions from the results and discussion, and some recommendations for future research that can help other researchers in the same field.



(a)



(b)

Figure 1.1: Thick film thickness variation simulation for (a) MPA on FR4 substrate, (b) MPA on Kapton substrate.

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