UNIVERSITI TEKNOLOGI MARA

COMPACT MULTIBAND ANTENNAS ON LOW TEMPERATURE CO-FIRED CERAMIC (LTCC) TECHNOLOGY

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CONFIRMATION BY PANEL OF EXAMINERS

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ABSTRACT

In recent years, the developments of wireless system that can operate over multiband frequency with compact size have enormous growth. In this project, LTCC technology is benefited for miniaturization of multiband antennas for short range medical sensor application. Three antenna designs on LTCC multilayer substrate have been proposed. They are Aperture Coupled antenna (ACA), Dual Patch Microstrip Antenna (DPMA) and Triple Band Off-Center Fed Microstrip Antenna (TBOCFMA). In aperture coupled antenna structure, observation on the controlling parameters of the aperture coupled antenna on LTCC multilayer substrate package is conducted to investigate the effect of aperture slot at various layers with different height. The proposed concept of this idea is simulated on Ferro A6M microstrip ceramic substrate and compared with the simulated of aperture coupled antenna on Flame Retardent 4 (FR-4) substrate at operating frequency of 5.8 GHz. Thus, the best location of the ground plane that contains the aperture slot has been adopted in DPMA design. In DPMA, dual band frequency spectrum operating at 5.8 GHz and 6.3 GHz frequency band has been proposed. This design develops dual radiating patch at the top and bottom of the overall substrate with the aperture slot at the ground between patches. The second radiating patch is designed to place at the feedline that is innovated from the aperture coupled structure. This design then fabricated and a good agreement was achieved between the simulation and measurement results. Meanwhile, the third design TBOCFMA operating at 5.8 GHz, 6.3 GHz and 10 GHz frequency band is presented. This design adopted the dual radiating patch with the aperture slot at the ground between second radiation patch in DPMA. The feedline then was fed with an off-centred feedline technique to create another resonant frequency. Fabrication also has been done for this design for feasibility of study purpose. The complexity of the LTCC technology fabrication process is covered in this thesis.

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LIST OF SYMBOLS

Symbols

c	Speed of Light
f	Frequency
λ	Wavelength
ε_r	Dielectric Constant
$tan\ \delta$	Loss Tangent
BW	Bandwidth
Q	Quality Factor
η	Efficiency
G	Gain
D	Directivity
L_p	Length of Patch
W_p	Width of Patch
d	Distance of OCF Length
Z_o	Characteristic Impedance
L_{stub}	Length of Stub
C_p	Coupling Factor

LIST OF ABBREVIATIONS

Abbreviations	
RF	Radio Frequency
PIFA	Planar Inverted-F
DCS	Digital Communication System
SOP	System-On-Package
GCPW	Grounded Coplanar Waveguide
ISM	Industrial, Scientific and Medical
MICS	Medical Implantable Communication Service
WMTS	Wireless Medical Telemetry System
OCF	Off-Center-Fed
AUT	Antenna Under Test
EF	Expansion Factor
LTL	Layer Transfer Layout
UiTM	Universiti Teknologi MARA
MTC	Microwave Technology Center
SP	Stacked Patch
ARG	Antenna Research Group
UKM	Universiti Kebangsaan Malaysia
TMRND	Telekom Malaysia Research and Innovation Center
AC	Aperture Couple
LTCC	Low Temperature Co-Fired Ceramic
ACA	Aperture Coupled Antenna
DPMA	Dual Patch Microstrip Antenna
TBOCFMA	Triple Band Off-Center-Fed Microstrip Antenna
WLAN	Wireless Local Area Network
SMA	Sub Miniature version A
2D	Two-Dimensional
3D	Three-Dimensional

CHAPTER ONE
INTRODUCTION

1.1 RESEARCH BACKGROUND

In recent years, the development of wireless system operating over multi-frequency band and the integration of microwave circuit and antenna has an enormous growth. As a result, there has been a growing interest in antenna research for industry and academia. Previously, there are some popular techniques to create multiband by generating resonance at the operating frequency in antenna such as Planar Inverted-F Antenna (PIFA) [1], U-Slot antenna [2], inverted-L monopole antenna [3], single cell metamaterial loading [4], coupled V-Slot [5], inductive slot [6], shorting wall [7], split-ring monopole antenna [8] and defected ground slot [9] that have been carried out by many researchers. Those researches that have been done, due to the demands of communication industry for multiband devices application, can be embedded in laptops, smart-phones and other communication devices.

In reality, the development of wireless communication is demanding for smaller volume and lightweight antenna especially for a short range biomedical application. To implement the multiband antenna with the requirement above, a lot of conventional multiband internal antennas are in the form of monopoles or PIFAs (planar inverted-F antennas) [1], and which are usually narrow-banded and cannot cover the some communication bands. Thus, the straightforward design using more than one antenna to cover the whole communication bands is required. However, many problems come together with this multiple-antenna, such as interference between different antennas within the limited space. Therefore, the multiband antenna design evolved into a single-port antenna of a driven element and other parasitic element(s) with the feeding by the direct power coupling from the driven element. Types of parasitic are such as shorted strip type, slotted type and floating strip type which are usually designed for bandwidth enhancement.

The compactness in multiband frequency antenna is interesting to be investigated for further research. Furthermore there are some improvement in conventional multiband microstrip antenna is needed to provide a better performance and an efficient multiband antenna. It is also cost effective to have them in a single antenna [1–10]. Low Temperature Co-fired Ceramics (LTCC) is a multilayer substrate technology for device integration and miniaturization. This technology has been growing continuously since the appearance of the first commercial co-fired ceramic product for robust capacitors in the early 60's [11]. In the standard LTCC technology ceramic green tapes are processed by punching and screen printed to form vertical interconnect and planar conductor patterns, laminated and finally fired at 850 °C to form a highly integrated substrate [11]. The low sintering temperature provided by the LTCC technology is the key factor enabling its advantageous utilization for today's packaging concepts in microwave modules [2]. The motivation for the use of LTCC technology is the possibility of fabricating three dimensional circuits using multiple ceramic layers allowing more complex design circuits and device structures. In industrial and telecommunication area it is contrasted to the conventional ceramic technology due to the low investment and short process development. Moreover, the technology is flexible in obtaining interesting properties of the ceramic material by controlling processing methodology [11, 12]. Moreover, high fired density with repeatable shrinkage and frequency characteristics is necessary for high performance and low cost modules.

The research contributions in this thesis describe the uniqueness of the LTCC technology for the compact multiband antenna that operates at 5.8 GHz, 6.3 GHz and 10 GHz. There are three antenna structures were designed; aperture coupled antenna (ACA) on LTCC, dual patch microstrip antenna (DPMA) on LTCC and triple band off-center-fed microstrip antenna (TBOCFMA) on LTCC. The ACA is one of the popular structure in microstrip with the technique of feeding microstrip patch antenna that does not require a direct connection between the antenna and feedline and has been proposed by D.M Pozar in 1985 [13]. Indirect connection between the feedline and the patch has triggered some idea in this thesis for the innovation of the compact multiband antenna on LTCC by innovate the structure of the feedline that operates at 5.8 GHz. However, there are about 8 layers of Ferro A6M ceramic substrates are included in the multilayer package of the LTCC that must be synthesized before further innovation to have an optimum antenna performance. Thus, the performance of the ACA on LTCC has been covered in this thesis with some parametric studies to locate the best layer of the aperture slot. In addition, some of the antenna parameters of ACA on LTCC were compared with the ACA on FR-4 to show the feasibility of this substrate.

The second antenna structure was developed known as DPMA which is the main purpose of this structure is to generate the second resonant frequency at 6.3 GHz with the first resonant frequency is remained at 5.8 GHz. The structure of this dual patch is yielded from the innovation of the ACA antenna structure, which is the open stub of the feedline that is added with a radiating patch. It is interesting to say that the radiation mechanism of this DPMA structure is the aperture slot that allows the magnetic field from the radiation patch 2 to couple with the radiation patch 1 and radiates the electromagnetic wave to the same direction. This approach has obtain a compactness of the overall thickness by the advantage of LTCC as compared to the conventional substrates such as FR-4 with comparison of 0.768 mm of overall 8 layers substrate to 1.6 mm thickness of a single layer.

In the third design, TBOCFMA develops dual radiating patch with the aperture slot at the ground between second radiation patch (DPMA structure) that has been fed with off-centred feedline technique to create another resonant frequency at 10 GHz. The first off-centre fed dipole antenna, or known as "Windom Antenna" that was named after Loren Windom has been reported in a comprehensive article in 1928-29 to create multiband antenna [14]. The off centre feeding technique was used to create the third resonant to produce tri-band application while the dual-patch with centre-fed remains giving dual band operating frequency at 5.8 GHz and 6.3 GHz. This is due to the fact that when offsetting the feed position away, the resonant behaviour of the antenna has changed and gives the third resonant frequency to the antenna to operate in triple band frequency.

1.2 PROBLEM STATEMENTS

Recently, portable mobile communication devices become extremely miniaturized and so as multi-functional to support various user necessities, such as multi-band multi-standard especially in short range biomedical application , so that various antennas mounted in those devices need to be housed in a limited space without performance degradation. A multiband system is becoming necessary to provide more services for various users of personal wireless communications. It is also necessary for multiband antenna design to be available as a diversity antenna for wireless communication systems [15, 16]. It is well known that antenna gain and radiation efficiency in general proportional to the size of the antenna, and as a result the internal antenna designed to have multi-band properties in limited internal space that maintain the antenna performance is hard to construct. Hence, in order to overcome these problems, various research and development on novel structures and materials for antennas have been actively pursued, and various techniques to compensate performances of existing antenna structure have also been investigated [17, 18].

To have high radiation efficiency antennas, the antenna structure must be designed on a thick substrate layer. This requirement is in conflict with the demands for wireless transceiver miniaturization. A critical factor that limits any further antenna substrate thickness reduction in [19, 20], is the spacing between the antenna element and the conducting ground plane which has to be kept at one quarter of the propagation wavelength in the substrate material. This thickness influences the radiation efficiency [19]. The antenna with thickness less than quarter wavelength, the radiated fields of the reverse image of the currents in the conducting ground plane interfere destructively with those of the antenna currents and hence there is poor radiation efficiency.

However, high dielectric constant substrates along with a quarter wavelength layer can be used to solve this problem [21]. Meanwhile, LTCC is being pursuit and successfully developed to meet the requirements as to date telecommunication industry demands for high speed and high frequency operation of electronic devices with miniaturization advantageous such as in mm-wave application [22]. LTCC technology is an advance approach for high speed and high frequency devices packaging. LTCC is a ceramics substrate and it is a compact multilayer platform technology that can be used in fabricating components, modules and packages for the millimeter-wave frequencies. Main benefits of the LTCC are compactness, high packaging density, high thermal conductivity, reliability and stability [23, 24].

1.3 OBJECTIVES OF THE RESEARCH

In order to attain the completion of this project, the work is concentrated on the following objectives:

a. To investigate and analyze the performance and behavior between antenna on LTCC and Conventional Antenna board.
b. To design, simulate, fabricate and measure dual patch microstrip antenna on LTCC technology.
c. To compose a novel structure of a triple band off-centre-fed microstrip antenna on LTCC.

1.4 SCOPE OF WORK

The purpose of this project is to design, simulate, fabricate and measure the multiband antenna which involves three designs. They are ACA, DPMA and TBOCFMA. Towards achievement of the objectives of this project, this project was been constructed into three parts to make sure this project is on track. They are simulation, fabrication and measurement scopes. The first part is simulation which is a CST microwave studio suite software was used to design and optimize the proposed antenna. Furthermore, three techniques was adopted in creating multiband antenna such as aperture coupled antenna to create, dual stack patch antenna coupled through aperture slot and the off-center-feeding line. Second part is the fabrication process which is involving two manufacturer. In screen mesh process the process was done by TN Dynamic Sdn. Bhd. in Pulau pinang, Malaysia and the LTCC fabrication process was done by Telekom Malaysia Research and Development Center (TMRND) in Cyberjaya, Malaysia. The third part is the measurement part. In this work, the reflection coefficient of the prototype was measured by using Vector Network Analyzer by using the Antenna research group (ARG) facilities and the radiation pattern of the prototype was measured by anechoic chamber which it was held in ARG (UiTM) and Universiti Kebangsaan Malaysia (UKM).

1.5 ORGANIZATION OF THE THESIS

This present thesis has 6 chapters which consist of the theoretical background, methodology, literature review, design, fabrication and measurement of compact multiband antenna on LTCC technology. Chapter 1 briefly contains the introduction of the project, the research objectives and the scope of work done in the thesis. It also includes the organization of the thesis. While in chapter 2 contain literature review that discusses the theory and fundamental involves in relation to the multiband and LTCC antenna on previous work by researchers. Also included is the basic antenna parameters, several types of antenna feeding techniques and types of antenna geometry that form the concept of multiband antenna are also discussed.

Chapter 3 illustrates the methods used in designing compact multiband antenna on LTCC technology and explanation of method and tools used during simulation, fabrication and measurement. The LTCC terms, advantage and material selection is explained in this chapter. Furthermore, the method of LTCC fabrication process which consists of screen mesh process and co-firing technology; blanking, via punching, screen printing, drying, stacking, laminating, cutting and co-fired are also explained in detail. Moreover, the concept of printed microstrip antenna that is used in the integration of microstrip antenna structure and LTCC technology such as aperture coupled technique, stacked patch technique and off-center fed antenna are also covered. This method is adopted in the next chapter.

Chapter 4 describes the antenna design structures with details dimension involving aperture coupled antenna (ACA) on LTCC, dual patch microstrip antenna (DPMA) on LTCC and triple band off-center-fed microstrip antenna (TBOCFMA) on LTCC. This chapter also demonstrates the results obtained in the simulation of the multiband antennas. Some parametric studies in optimizing the antenna design structure is done in this chapter along the analysis of the variations.

Meanwhile, Chapter 5 exhibits the 6 prototypes samples of fabricated DPMA and TBOCFMA along with the challenges faces after the fabrication process. The tolerance from the shrinkage factor after fired is also determined in terms of the antenna patch dimensions. The measurement procedure adopted in this thesis is illustrated and the measurement results such as the S-parameters and the radiation pattern of the fabricated antennas is also analyzed. The comparison of the simulated and the measured graph is analyzed in this chapter to prove the simulated design and