

UNIVERSITI TEKNOLOGI MARA

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



Thesis submitted in fulfillment
of the requirements for the degree of
Master of Science

Faculty of Electrical Engineering

April 2015

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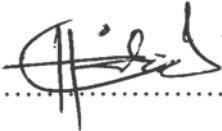
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I, hereby, acknowledge that I have been supplied with the Academic Rules and Regulations for Post Graduate, Universiti Teknologi MARA, regulating the conduct of my study and research.

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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 Retardant 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.

ACKNOWLEDGEMENT

With the name of ALLAH S.W.T Most Gracious Most Merciful

Alhamdulillah, deepest gratitude to Allah S.W.T for his blessing and finally allow me to complete this research for postgraduate degree of Master Science in Electrical Engineering. First of all, I would like to acknowledge my genuine gratitude to my supervisor, Associate Professor Dr. Mohd. Tarmizi Bin Ali, who has bent every effort to facilitate implementation of this project and has given invaluable support and useful advice throughout the course of the work regarding the project and preparation of this thesis.

I am deeply obliged to the Institute for Universiti Teknologi MARA (UiTM) for the generous financial support I have received for my Master program. I would also like to acknowledge all my great colleagues at Antenna Research Group (ARG). Special thanks to personnel, especially Mr. Khalim Bin Kamisan who's professionally give their cooperation in many aspect and made the whole project possible. Deepest gratitude are also goes to members of Microwave Technology Centre (MTC), Postgraduate Students at Telephony Laboratory for their assist through out this research.

Special thanks to my parents, my family who has supported me throughout the years because they are my motivation and spirit to complete this thesis successfully. Last but not least, Special thanks to all lecturers, researchers, academicians, friends and also to people around me who willing to give a hand during this project. Thank you for the kind helps which really made on each one of you a backbone of this project and this thesis. May Allah bless all of you.

TABLE OF CONTENT

| | Page |
|---|-------------|
| CONFIRMATION BY PANEL OF EXAMINERS | ii |
| AUTHOR'S DECLARATION | iii |
| ABSTRACT | iv |
| ACKNOWLEDGEMENT | v |
| TABLE OF CONTENT | vi |
| LIST OF TABLES | ix |
| LIST OF FIGURES | x |
| LIST OF SYMBOLS | xvii |
| LIST OF ABBREVIATIONS | xviii |
| | |
| CHAPTER ONE: INTRODUCTION | 1 |
| 1.1 Research Background | 1 |
| 1.2 Problem Statements | 4 |
| 1.3 Objectives Of The Research | 5 |
| 1.4 Scope Of Work | 5 |
| 1.5 Organization Of The Thesis | 6 |
| | |
| CHAPTER TWO: LITERATURE REVIEW | 8 |
| 2.1 Introduction | 8 |
| 2.2 Antenna in LTCC Technology | 8 |
| 2.2.1 Multiband Microstrip Antenna in LTCC | 9 |
| 2.2.2 LTCC In millimeter-Wave (mmW) Antenna | 12 |
| 2.3 Multiband Antennas | 17 |
| 2.3.1 Dual Band Antenna | 17 |
| 2.3.2 Tri-Band Antenna | 20 |
| 2.4 Off-Centre-Feeding antenna | 22 |
| 2.5 Summary | 24 |

| | |
|--|-----------|
| CHAPTER THREE: MICROSTRIP ANTENNA ON LTCC TECHNOLOGY | 25 |
| 3.1 Introduction | 25 |
| 3.2 Microstrip antenna | 29 |
| 3.2.1 Feeding methods | 31 |
| 3.2.2 Transmission-line model of rectangular patch | 33 |
| 3.3 Off-Center-Fed (OCF) technique | 46 |
| 3.3.1 Windom Antenna | 46 |
| 3.3.2 Method of Off-Centre-Fed Antenna. | 47 |
| 3.4 LTCC Technology | 50 |
| 3.4.1 Introduction to LTCC | 50 |
| 3.4.2 LTCC material | 50 |
| 3.5 The Fabrication of LTCC | 51 |
| 3.5.1 Screen Mesh | 52 |
| 3.5.2 Co firing and technological process | 59 |
| 3.6 Measurement Setup | 76 |
| 3.6.1 S-parameter Measurements Setup | 76 |
| 3.6.2 Radiation Pattern Measurements Setup | 77 |
| 3.7 Summary | 78 |
| | |
| CHAPTER FOUR: MULTIBAND ANTENNA ON LTCC TECHNOLOGY | 79 |
| 4.1 Introduction | 79 |
| 4.2 Development of Aperture Coupled Antenna on LTCC Technology | 81 |
| 4.2.1 Parametric Study on Aperture Coupled Antenna on LTCC | 84 |
| 4.2.2 Simulation Result of Aperture Coupled Antenna on LTCC | 89 |
| 4.2.3 Comparison of the LTCC and FR4 Simulation | 91 |
| 4.3 Dual Band with Dual Patch Microstrip Antenna (DPMA) on LTCC Technology | 94 |
| 4.3.1 Parametric Study on Dual Patch Microstrip Antenna on LTCC | 98 |
| 4.3.2 Simulation Result DPMA on LTCC technology | 102 |
| 4.3.3 Surface Current of DPMA | 106 |
| 4.4 Triple Band with off-center-fed microstrip antenna (TBOCFMA) on LTCC technology | 108 |

| | |
|--|-----|
| 4.4.1 Parametric Study of TBOCFMA on LTCC Technology | 112 |
| 4.4.2 Simulation Result of TBOCFMA on LTCC Technology | 115 |
| 4.4.3 Electric-field distribution of TBOCFMA on LTCC Technology. | 119 |
| 4.5 Summary | 121 |
| | |
| CHAPTER FIVE: THE MEASUREMENT OF COMPACT MULTIBAND ANTENNA ON LTCC TECHNOLOGY | 122 |
| 5.1 Introduction | 122 |
| 5.2 Experimental work of Dual Band Antenna on LTCC Technology | 123 |
| 5.2.1 Return loss measurement of DPMA on LTCC | 128 |
| 5.2.2 Radiation pattern measurement of DPMA on LTCC | 132 |
| 5.3 Experimental Work of TRIPLE BAND Antenna on LTCC Technology | 134 |
| 5.3.1 Return loss measurement of DPMA on LTCC | 138 |
| 5.3.2 Radiation pattern measurement of TBOCFMA on LTCC | 142 |
| 5.4 Summary | 144 |
| | |
| CHAPTER SIX: CONCLUSION AND RECOMMENDATION | 145 |
| 6.1 Conclusion | 145 |
| 6.2 Future Work | 147 |
| 6.2.1 Real application measurement | 147 |
| 6.2.2 Multi-frequency | 147 |
| 6.2.3 Millimeter-wave application | 148 |
| | |
| REFERENCES | 149 |
| APPENDICES | 158 |
| AUTHOR'S PROFILE | 168 |

LIST OF TABLES

| Table | Title | Page |
|--------------|---|-------------|
| Table 3.1 | Parameters and Specification of Screen Mesh and Frame | 54 |
| Table 3.2 | Punching Tools For Via Punching | 62 |
| Table 3.3 | Basic Technical Data for Via Punching Machine Keko Pam-4S | 62 |
| Table 3.4 | Printing Parameters | 64 |
| Table 3.5 | Laminating Parameters | 70 |
| Table 4.1 | Ferro A6M Parameter | 79 |
| Table 4.2 | Optimized Parameter Value of ACA | 84 |
| Table 4.3 | Optimized Parameter Value for Aperture Slot at Layer 3, 5 and 7 | 86 |
| Table 4.4 | Return Loss and Gain of Aperture Coupled on LTCC at Different Layers | 91 |
| Table 4.5 | Comparison Between Ferro A6M and FR4 | 93 |
| Table 4.6 | Optimized Parameter Value For DPMA | 97 |
| Table 4.7 | Optimized Parameter Value of TBOCFMA | 111 |
| Table 5.1 | Dimension of Fabricated DPMA on LTCC (F1-2) | 126 |
| Table 5.2 | Bandwidth Comparison of Simulation and Measurement | 131 |
| Table 5.3 | Main Lobe Level and Back Lobe Level of Fabricated DPMA | 133 |
| Table 5.4 | Dimension of Fabricated TBOCFMA on LTCC (F2-5) | 137 |
| Table 5.5 | Bandwidth Comparison of Simulation and Measurement | 142 |
| Table 5.6 | Main Lobe Level and Back Lobe Level for Fabricated TBOCFMA | 144 |

LIST OF FIGURES

| Figure | Title | Page |
|-------------|---|------|
| Figure 2.1 | Geometry And Dimensions of the Compact LTCC Dual-Band Perturbed Hexagonal Microstrip Antenna (a) Lower Patch, (b) Upper Patch, (c) Top View and (d) Side View | 9 |
| Figure 2.2 | Compact Dual-Band GPS Microstrip Antenna Using Multilayer LTCC Substrate Design. [33] | 10 |
| Figure 2.3 | Design of Triple-Band Ltcc Antenna Using Meander Line Structure For Mobile Handsets [36] | 11 |
| Figure 2.4 | A Compact Dual-Band Meander-Line Antenna For Biomedical Applications [33] | 12 |
| Figure 2.5 | Microstrip Array Antenna With Parasitic Elements Alternately Arranged Over Two Layers Of LTCC Substrate For Millimeter Wave Applications [45] | 13 |
| Figure 2.6 | Wideband LTCC 60 GHz Antenna Array With A Dual-Resonant Slot and Patch Structure [46] | 14 |
| Figure 2.7 | Wideband High-Gain 60 GHz LTCC L-Probe Patch Antenna Array With A Soft Surface [49] | 15 |
| Figure 2.8 | Ltcc Microstrip Parasitic Patch Antenna For 77 GHz Automotive Applications [53] | 16 |
| Figure 2.9 | Dual-Band Wearable Cuff Button Antenna [55] | 18 |
| Figure 2.10 | Dual Band Low Profile Antenna For Body Centric Communications [56] | 19 |
| Figure 2.11 | Design Of A Triple-Band On-Body Antenna For a Biomedical Repeater Application [57] | 20 |
| Figure 2.12 | Novel Triple-Band Biotelemetry System With Miniaturized Antenna For Implantable Sensing Applications [10] | 21 |
| Figure 2.13 | A Design Of Off-Centered-Feed Array Antenna For ISM Band [58] | 22 |
| Figure 2.14 | Design of a Circular Polarized Nearly Square Microstrip Patch Antenna With Offset Feed [59] | 23 |

| | | |
|-------------|--|----|
| Figure 2.15 | Geometry of Compact Planar Antenna For UWB Application [60] | 24 |
| Figure 3.1 | Flow Chart of The Research (a) ACA, (b) DPMA and (c) TBOCFMA | 28 |
| Figure 3.2 | Microstrip Antenna [61] | 30 |
| Figure 3.3 | The Four Popular Types of Feeding In Microstrip Antenna [25] | 32 |
| Figure 3.4 | Slot Dimension and Parameters For Matching Optimization [62] | 33 |
| Figure 3.5 | Field Configuration of A Microstrip Patch Antenna (a) Geometry View, (b) Side View And (c) Top View [64]. | 34 |
| Figure 3.6 | Microstrip Insert-Fed Patch Antenna | 36 |
| Figure 3.7 | Analytical Line Impedance Calculation In Cst Microwave Studio | 38 |
| Figure 3.8 | Geometry View of Aperture Coupled Antenna [66] | 40 |
| Figure 3.9 | Smith Chart Plot Of The Impedance Locus Versus Frequency For An Aperture Coupled Microstrip Antenna [66] | 40 |
| Figure 3.10 | Side View Of (a) Stacked Patches Configurations For Wideband and Multiband Operation and (b) The Two Layers Stacked Rectangular Microstrip Antenna[68] | 41 |
| Figure 3.11 | Aperture Coupled Stacked Patch Antenna For Broadband Application [67] | 42 |
| Figure 3.12 | Windom Antenna | 47 |
| Figure 3.13 | Off-Center-Fed For (a) Half-Wave Dipole and (b) Currents Distribution On A Full Wave Dipole | 48 |
| Figure 3.14 | Radiation Pattern Of Dipole For (a) Center-Fed and (b) Off-Center-Fed | 49 |
| Figure 3.15 | Microstrip Rectangular Patch OCF Technique | 49 |
| Figure 3.16 | Commercial Ltcc Material Data | 51 |
| Figure 3.17 | Ltcc Multilayer Fabrication Process Flow | 52 |
| Figure 3.18 | Screen Mesh Process Flow | 53 |
| Figure 3.19 | Variation Size Of Screen Mesh By Different Size of Wire Diameter [73] | 54 |
| Figure 3.20 | (a) Printed Ltcc Template Layout (LTL) For Confirmation Before Screen Mesh is Framed And (b) Screen Mesh Final Product With Stainless Steel Frame | 55 |
| Figure 3.21 | The Actual Design Dimensions Be Scaled Up To 1.17 | 56 |

| | | |
|-------------|--|----|
| Figure 3.22 | LTL Design For Screen Mesh Process (Expend To 1.17 Scale) In ADS Simulation Tools With Blanking Dimension Coupon Size (204 X 204 mm) | 57 |
| Figure 3.23 | Alignment Line and Cavity | 58 |
| Figure 3.24 | Printing Pattern For The Line Width Evaluation | 58 |
| Figure 3.25 | TMRND LTCC Laboratory | 59 |
| Figure 3.26 | LTCC Multilayer Fabrication Process Flow | 60 |
| Figure 3.27 | Slitting From The Roll To 204 X 204 mm Pieces Process and (b) Molding of 204 X 204 mm Square. | 61 |
| Figure 3.28 | Blanking Process | 61 |
| Figure 3.29 | KEKO PAM-4S Machine | 63 |
| Figure 3.30 | (a) Before and (c) After Via Hole Process | 63 |
| Figure 3.31 | Screen Printing Process | 65 |
| Figure 3.32 | Experimental Work On Screen Printing Process | 65 |
| Figure 3.33 | (a) Before and (b) After Screen-Printing Process | 66 |
| Figure 3.34 | Pre-Conditioning Process | 66 |
| Figure 3.35 | Collating Process | 67 |
| Figure 3.36 | (a) Manual Stacker Plate Concept, (b) Aluminum Manual Block Stackers and (c) Stacked Collated Substrate | 68 |
| Figure 3.37 | Multilayer Substrate Stacked By A Pin System With Aluminum Manual Block Stackers Inserted In Oven For Pre-Conditioning Before Go Through Laminating Process. | 68 |
| Figure 3.38 | (a) The Process Of Wrapping The Stacked Substrate In To The Aluminum Moisture Bag, (b) Before and (c) After Vacuumed Condition | 69 |
| Figure 3.39 | (a) KEKO ILS-6A Isostatic Laminating System Machine and (b) Wrapped Stack Substrate In The Machine. | 70 |
| Figure 3.40 | Laminated Stacked Substrate (a) With Aluminium Moisture Barrier Bag, (b) Opened From The Aluminium Moisture Barrier Bag and (c) Ready To Cut. | 71 |
| Figure 3.41 | (a) KEKO Cutting Machine and (b) Machine Control Parameter | 72 |
| Figure 3.42 | (a) Template Squares Dimension and (b) Designs Dimension | 72 |
| Figure 3.43 | Ready For Sintering Process | 72 |
| Figure 3.44 | Heating Profile For The Multilayer LTCC | 73 |

| | | |
|-------------|---|----|
| Figure 3.45 | Carbolite Horizontal Tube Furnace For Co-Firing (a) Outside View and (b) Inside View. | 74 |
| Figure 3.46 | End Product After The Co-Firing Process | 74 |
| Figure 3.47 | Fault After Fired Antenna That Is Under Final Inspection Process (a) Imperfect Ground and Peel-Off, (b) Peel-Off and (c) Side Dimension Slanting. | 75 |
| Figure 3.48 | (a) Hole Is Monitored By Using Eyepiece-Less Microscope and (b) Fault Samples Fixed By Using Sliver Loaded Epoxy Adhesive | 75 |
| Figure 3.49 | Radiation Pattern Polar Plot Set Up | 77 |
| Figure 3.50 | The Actual Radiation Pattern Polar Plot Set Up (a) In Anechoic Chamber and (b) In Control Room. | 78 |
| Figure 4.1 | (a) General View, (b) Side View and (c) Geometry View Of Aperture Coupled Antenna On LTCC | 83 |
| Figure 4.2 | (a) Aperture Slot On Layer 3, (b) Aperture Slot On Layer 5 and (c) Aperture Slot On Layer 7 | 85 |
| Figure 4.3 | The Variations Of Simulated Reflection Coefficient, S_{11} For Different Layer Of Aperture Slot. | 86 |
| Figure 4.4 | Radiation Pattern Of Different Layer Of Aperture Slot | 87 |
| Figure 4.5 | The Simulated Result Of Reflection Coefficient, S_{11} Of Aperture Slot At Layer 6 | 89 |
| Figure 4.6 | Radiation Pattern Of Proposed Antenna In 3D | 90 |
| Figure 4.7 | The Simulated Result Of The Radiation Pattern For Aperture Coupled Antenna On LTCC At (a) E-Phi and (b) E-Theta | 90 |
| Figure 4.8 | Physical Thickness Comparison Of Aperture Coupled Antenna Using LTCC Technology And FR4 Substrate | 91 |
| Figure 4.9 | The S_{11} Of Aperture Coupled Antenna On FR4 Substrate and The Return Loss, S_{11} Of Aperture Coupled Antenna On LTCC Technology. | 92 |
| Figure 4.10 | Radiation Pattern Of Aperture Coupled Antenna On Different Substrate FR4 and LTCC | 93 |
| Figure 4.11 | (a) General View, (b) Geometry View Of DPMA On LTCC Technology | 95 |

| | | |
|-------------|---|-----|
| Figure 4.12 | “Window” That Has Been Created By Via Cavities At Substrate Layer 7 and Substrate Layer 8 For DPMA Design In CST Simulation Tools | 96 |
| Figure 4.13 | Different Length Of The Coupling Slots, L_a | 98 |
| Figure 4.14 | Simulated Reflection Coefficient, S_{11} Variation Size Of The Aperture Slot On The DPMA On LTCC Technology. | 99 |
| Figure 4.15 | Different Length Of The Radiating Patch 1, L_{p1} | 100 |
| Figure 4.16 | Simulated Reflection Coefficient, S_{11} Length Variation Of Patch 1 Of DPMA On LTCC Technology. | 100 |
| Figure 4.17 | Different Length Of The Radiating Patch 2, L_{p2} | 101 |
| Figure 4.18 | Simulated Reflection Coefficient, S_{11} Variation Size Of Radiation Patch 2 Of DPMA On LTCC Technology. | 102 |
| Figure 4.19 | Simulated Reflection Coefficient, S_{11} For DPMA On LTCC Technology and Without Second Radiation Patch. | 103 |
| Figure 4.20 | Simulated 3D Radiation Pattern At (a) 5.8 GHz DPMA On LTCC Technology and (b) 6.3 Ghz Of DPMA With The Antenna Positioned On The XY-Plane. | 104 |
| Figure 4.21 | The Simulated Result Of The Radiation Pattern In Polar Plot At 5.8 Ghz For (a) E-Phi,(b) E-Theta and At 6.3 Ghz For (c) E-Phi, (d) E-Theta. | 105 |
| Figure 4.22 | Combination Of Radiation Patterns In Polar Plot At Y-Z Plane For DPMA Design At 5.8 GHz and 6.3 GHz. | 106 |
| Figure 4.23 | The Simulated Results Of Current Distribution At Frequency (a) 5.8 GHz and (b) 6.3 GHz. | 107 |
| Figure 4.24 | (a) General View and (b) Geometry View Of TBOCFMA On LTCC Technology | 109 |
| Figure 4.25 | “Window” Created By Via Cavities At Substrate Layer 7 and Substrate Layer 8 For TBOCFMA Design In CST Simulation Tools | 110 |
| Figure 4.26 | Simulated Reflection Coefficient, S_{11} Variation Location Of Feeding From Centre To The Left Side Of Second Radiation Patch For TBOCFMA On LTCC Technology. | 112 |

| | | |
|-------------|--|-----|
| Figure 4.27 | Simulated Reflection Coefficient, S_{11} Variation Location Of Feeding From Centre To The Right Side Of Second Radiation Patch For TBOCFMA On LTCC Technology. | 113 |
| Figure 4.28 | Simulated Reflection Coefficient, S_{11} Variation Size Of W_{p2} Of TBOCFMA On LTCC Technology. | 114 |
| Figure 4.29 | Simulated Reflection Coefficient, S_{11} For TBOCFMA On LTCC Technology and Centre Feeding Technique | 115 |
| Figure 4.30 | (a) Simulated 3D Radiation Pattern At 5.8 GHz TBOCFMA On LTCC Technology, (b) Simulated 3D Radiation Pattern At 6.3 GHz Of TBOCFMA, (C) Simulated 3D Radiation Pattern At 10 GHz Of TBOCFMA With All Condition For The Antenna Located In The XY-Plane | 117 |
| Figure 4.31 | Exhibits The Radiation Pattern In Polar Plot At Y-Z Plane For Frequency Of 5.8 GHz, 6.3 GHz And 10 GHz | 118 |
| Figure 4.32 | Combination Of Radiation Patterns In Polar Plot At Y-Z Plane For TBOCFMA Design At 5.8 GHz, 6.3 GHz and 10 GHz | 119 |
| Figure 4.33 | The Simulated Result Of Electric Field Distribution (a) Top Patch and (b) Bottom Patch At Frequency 5.8 GHz | 120 |
| Figure 4.34 | The Simulated Result Of Electric Field Distribution (b) Top Patch And (c) Bottom Patch At Frequency 6.3 GHz | 120 |
| Figure 4.35 | The Simulated Result Of Electric Field Distribution (e) Top Patch and (f) Bottom Patch At Frequency 10 GHz | 120 |
| Figure 5.1 | The Fabricated Dual-Band Dpma With Overall Dimension Of 21.06 X 31.39 mm ² Not Attached The SMA Connector From (a) Top View, (b) Bottom View. | 124 |
| Figure 5.2 | The Fabricated Dual-Band DPMA Attached To SMA Connector From (a) Top View, (b) Bottom View | 124 |
| Figure 5.3 | 6 Samples Of Fabricated DPMA On LTCC | 125 |
| Figure 5.4 | (a) Fabricated DPMA Return Loss, S_{11} Measurement Set Up And (b) Fabricated DPMA Placed To The Aritsu Wiltron 3680-20 DC To 20 GHz. | 128 |
| Figure 5.5 | Measured And Simulated S_{11} For Sample (a) F1-1, (b) F1-2, (c) F1-3, (d) F1-4, (E) F1-5, (F) F1-6. | 129 |

| | | |
|-------------|---|-----|
| Figure 5.6 | Samples Of Fabrication Error (Silver Peel Off) After The Firing Process | 130 |
| Figure 5.7 | Comparison Of Measured and Simulated S_{11} Of Selected Fabricated DPMA On LTCC | 131 |
| Figure 5.8 | The Radiation Pattern Measurement Setup In The Anechoic Chamber (a) The Experimental Setup and (b) DPMA On Testing | 132 |
| Figure 5.9 | The DPMA E-Plane Normalized Radiation Pattern Measurement Results For Operating Frequency (a) At 5.8 GHz and (b) At 6.3 GHz | 133 |
| Figure 5.10 | The Fabricated TBOCFMA With Overall Dimension Of 22.34 X 29.25 mm ² Not Attached The SMA Connector From (a) Top View, (b) Bottom View. | 134 |
| Figure 5.11 | The Fabricated TBOCFMA Attached To SMA Connector From (a) Top View, (b) Bottom View | 135 |
| Figure 5.12 | 6 Samples Of Fabricated TBOCFMA On LTCC From (a) Top View and (b) Bottom View | 136 |
| Figure 5.13 | (a) Fabricated TBOCFMA Return Loss, S_{11} Measurement Set Up and (b) Fabricated TBOCFMA Placed To The Aritsu Wiltron 3680-20 DC To 20 GHz. | 138 |
| Figure 5.14 | Measured and Simulated S_{11} For Sample (a) F2-1, (b) F2-2, (c) F2-3, (d) F2-4,(e) F2-5, (f) F2-6. | 139 |
| Figure 5.15 | Samples Of Fabrication Fault (Silver Peel Off) After The Firing Process | 140 |
| Figure 5.16 | Measured Reflection Coefficient, S_{11} Of Fabricated TBOCFMA On LTCC | 141 |
| Figure 5.17 | The Radiation Pattern Measurement Setup In The Anechoic Chamber (a) The Experimental Setup and (b) TBOCFMA On Testing | 142 |
| Figure 5.18 | Measured Reflection Coefficient, S_{11} Of Fabricated TBOCFMA On LTCC At (a) 5.8 GHz, (b) 6.3 GHz And (C) 10 GHz. | 143 |

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