CONTENTS

APPROVAL ii

SELF DECLARATION AGAINST PLAGIARISM iii

ABSTRACT iv

DEDICATION v

ACKNOWLEDGMENTS vi

PREFACE vii

CONTENTS viii

LIST OF TABLES xi

LIST OF FIGURES xii

LIST OF ABBREVIATION xiv

1 INTRODUCTION 1
- 1.1 Background . . . 1
- 1.2 Problem Identification . . . 2
- 1.3 Objective . . . 3
- 1.4 Scope of Work . . . 4
- 1.5 Hypothesis . . . 4
- 1.6 Research Method . . . 5
- 1.7 Thesis Organization . . . 5

2 REVIEW OF LITERATURE AND STUDIES 7
- 2.1 Fifth Generation . . . 7
- 2.2 5G Mobile Antennas at mmWave . . . 8
- 2.3 Vivaldi Antenna . . . 10
- 2.4 Impedance Matching . . . 11
- 2.5 Microstrip Feedline . . . 12
- 2.6 Array Antenna . . . 13
- 2.7 4×4 Butler Matrix . . . 14
  - 2.7.1 90° Hybrid Coupler . . . 15
  - 2.7.2 Cross Over . . . 17
  - 2.7.3 Phased Shifter . . . 18
- 2.8 IEEE Std C95.1-2005 . . . 18

3 EXPERIMENTAL DESIGN AND SIMULATION 20
3.1 Research Flow . . . 20
3.2 Requirement and Parameter Design Study . . . 21
3.3 Material Selection . . . 22
3.4 Design of 4 × 4 Butler Matrix . . . 22
3.4.1 Flow Chart of 4 × 4 Butler Matrix . . . 24
3.4.2 Design and Simulation of 90°Hybrid . . . 25
3.4.3 Design and Simulation of Cross Over . . . 27
3.4.4 Design and Simulation of Phase Shifter . . . 29
3.4.5 Design of path connecting butler matrix to antennas . . . 30
3.5 Design of Single and Array Antennas . . . 31
3.5.1 Flow Chart of Antennas Design . . . 31
3.5.2 Single Element Antenna Configuration . . . 32
3.5.3 Simulation of Single Element Antenna . . . 33
3.5.4 Simulation of Array Antenna . . . 37
3.6 Mobile Phone Modelling . . . 39
3.7 Determine Position of Sub Array Antenna . . . 40
3.8 System Level Performance . . . 41

4 RESULT AND ANALYSIS 42
4.1 4×4 Butler Matrix . . . 42
4.1.1 VSWR and Bandwidth . . . 45
4.2 Integration of Butler Matrix and Array Antenna . . . 46
4.3 Mobile Phone Modeling . . . 50
4.4 Integration of Subarray-Butler Matrix on Mobile Phone . . . 51
4.5 System Level Performance . . . 54
4.5.1 Returnloss . . . 55
4.5.2 SAR Measurement . . . 55
4.5.3 Radiation Patern . . . 56
4.5.4 Gain . . . 58

5 CONCLUSION AND FUTURE WORK 60
5.1 Conclusions . . . 60
5.2 Future Work . . . 60

BIBLIOGRAPHY 61

Appendices 63

A Cartesian Radiation Pattern in Butler Matrix 65

B SAR MEASUREMENT 67

C GAIN MEASUREMENT 69

D CARTESIAN RADIATION PATTERN **71**