DESIGN AND DEVELOPMENT OF WIDEBAND 3dB/90º COUPLER USING MULTIPLE-ROWS VIAS SUBSTRATE INTEGRATED WAVEGUIDE (SIW) TECHNIQUE

by

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TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	**i**
ACKNOWLEDGMENT	**ii**
TABLE OF CONTENTS	**iii**
LIST OF TABLES	**vii**
LIST OF FIGURES	**ix**
LIST OF ABBREVIATIONS	**xiii**
LIST OF SYMBOLS	**xv**
ABSTRAK	**xvii**
ABSTRACT	**xviii**
CHAPTER 1 : INTRODUCTION	**1**
1.1 Research Background and Motivation	1
1.2 Problem Statement	2
1.3 Objectives	3
1.4 Scope of the Project	4
1.5 Lists of Contribution	4
1.6 Report Organization	5
CHAPTER 2 : LITERATURE REVIEW	**7**
2.1 Introduction	7
2.2 Theory of Coupler	7
2.3 Scattering Parameter of coupler	9
2.3.1 Coupling Factor (C)	9
2.3.2 Insertion Loss (IL)	9

2.3.3 Return Loss 10

2.3.4 Isolation (I) 10

2.3.5 Bandwidth (BW) 10

2.4 Analysis of Waveguide 11

2.4.1 Rectangular Waveguide 11

2.4.2 Waveguide Coupler 13

2.5 Substrate Integrated Waveguide (SIW) Coupler Theory 15

2.5.1 Substrate Integrated Waveguide (SIW) Structure and Theory 15

2.5.2 Substrate Integrated Waveguide (SIW) and Transition 17

2.6 Review Previous Research of Substrate Integrated Waveguide (SIW) Coupler 19

2.7 Summary of Chapter 26

CHAPTER 3 : METHODOLOGY 28

3.1 Introduction 28

3.2 Project Methodology 28

3.2.1 Overall System Flow Chart 29

3.3 Design Specification 29

3.3.1 Coupler Specification 30

3.3.2 Substrate Specification 31

3.4 Coupler Design Technique 32

3.4.1 Design Process of Coupler 33

3.4.2 Geometry of Coupler 33

3.4.3 The Dimension of Coupler 37

3.4.3.1 Equation of Substrate Integrated Waveguide (SIW) 39

3.4.3.2 Substrate Integrated Waveguide (SIW) to Microstrip Transition 41

3.5 Fabrication, Measurement Tools and Procedure 44

3.5.1 Fabrication Process 45

3.5.1.1 SIW Coupler Structure Realization 47

3.5.1.2 CNC Drilling (Phase I) 48

3.5.1.3 Etching Process (Phase II) 50

3.5.1.4 Soldering Prototype Process (Phase III) 51

3.5.2 Measurement Tools and Procedure 53

3.5.2.1 Vector Network Analyzer 53

3.5.2.2 Calibration Procedure of Network Analyzer 55

3.6 Chapter Summary 57

CHAPTER 4 : RESULT & DISCUSSION 59

4.1 Introduction 59

4.2 Parametric Study 59

4.2.1 Variable Pitch Between Holes 60

4.2.2 Variable Diameter of Metallic Via Holes 64

4.2.3 Parametric Study of Multi-rows Vias 68

4.3 Simulation Results 75

4.3.1 Simulated S-Parameter of the Proposed SIW Coupler with 3-rows Vias (Ku-Band) 75

4.3.2 S-Parameter of SIW Coupler with 3-rows Vias (K-Band) 77

4.4 Measurement Result and Discussion 78

4.4.1 Scattering Parameter Results at Ku-Band 78

4.4.2 Scattering Parameter Results at K-Band 79

4.5 Phase Difference Result 81

4.5.1 Simulated and Measured of Phase Difference (Ku-Band) 82

4.5.2 Simulated and Measured of Phase Difference (K-Band) 83

4.6 Chapter Summary 84

CHAPTER 5 : CONCLUSION **86**

5.1 Conclusion 86

5.2 Future Work 87

REFERENCES **89**

Appendices **93**

APPENDIX B SMA Connector Data Sheet **94**

APPENDIX C ROGERS RO4003C DATA SHEET **97**

LIST OF TABLES

NO.		PAGE
Table 2.1:	Previous research on development of SIW Coupler	24
Table 3.1:	Coupler Specification	31
Table 3.2:	Substrate Specification	32
Table 3.3:	Parameters of SIW Coupler	36
Table 3.4:	Optimized dimensions of proposed Ku-Band and K-Band SIW coupler	44
Table 4.1:	Reflection coefficient in various pitch (p) vias value at Ku-Band and K-Band	61
Table 4.2:	Transmission coefficient in various pitch (*p*) vias value at Ku-Band and K-Band	63
Table 4.3:	Reflection coefficient in different diameter (*d*) vias value at Ku-Band and K-Band	65
Table 4.4:	Transmission coefficient in various diameter (*d*) vias value at Ku-Band and K-Band	67
Table 4.5:	Reflection coefficient, S_{11} in multi rows vias at Ku-Band and K-Band	72
Table 4.6:	Isolation coefficient, S_{41} in multi rows vias at Ku-Band and K-Band	73
Table 4.7:	Transmission coefficient, S_{21} in multi rows vias at Ku-Band and K-Band	74
Table 4.8:	S-parameters simulated results at Ku-Band	77
Table 4.9:	SIW Coupler Magnitude	81

Table 4.10: SIW Coupler Phase at 14 GHz and 23 GHz 84

LIST OF FIGURES

NO. **PAGE**

Figure 2.1: Basic Operation symbols of Coupler (Pozar, 2005) 8

Figure 2.2: TE and TM operation (Pozar, 2005) 12

Figure 2.3: Wave Propagation (Alfonso et al., 2012) 13

Figure 2.4: Geometry of Parallel Waveguides (Pozar, 2005) 14

Figure 2.5: Geometry of Skewed Waveguides (Pozar, 2005) 14

Figure 2.6: The Riblet short-slot coupler (Pozar, 2005) 15

Figure 2.7: Air-filled Waveguide (Kim, Lee, Kim, Song, & Circular-posts, 2004) 16

Figure 2.8: Dielectric-filled Waveguide (Kim et al., 2004) 16

Figure 2.9: Substrate Integrated Waveguide (SIW) (Deslandes, Bozzi, Arcioni, & Wu, 2003) 17

Figure 2.10: A lossless network matching (Pozar, 2005) 17

Figure 2.11: Structure of SIW coupler and Transition 18

Figure 2.12: Structure of SIW coupler (Hao et al., 2006) 20

Figure 2.13: Structure of SIW Coupler at Ku-Band (Carrera & Navarro, 2010) 21

Figure 2.14: Structure of SIW Coupler at K-Band (Carrera & Navarro, 2010) 21

Figure 2.15: SIW coupler at X-Band (Sabri et al., 2013) 22

Figure 2.16: Compact 3D integrated circuit (Doghri et al., 2015) 22

Figure 2.17: Structure of SIW Coupler (Nasri et al., 2016) 23

Figure 3.1: Overall System Project Flow 29

Figure 3.2:	Specification and Parameters Flow Chart	34
Figure 3.3:	The conventional configuration of SIW coupler	35
Figure 3.4:	Evolution Structure of SIW coupler (a) Single rows (b) Dual rows	37
Figure 3.5:	The proposed configuration of SIW coupler	38
Figure 3.6:	Perspective view of proposed SIW coupler	38
Figure 3.7:	Structure of Substrate Integrated Waveguide (SIW)	39
Figure 3.8:	The Structure of Circular Metallic Via	40
Figure 3.9:	Microstrip taper and line model (H. Kumar et al., 2012)	42
Figure 3.10:	Fabrication Process Flow (Phase I-Phase III)	46
Figure 3.11:	Top view of ground plane	48
Figure 3.12:	Bungard Drill Holes	49
Figure 3.13:	Drilling metallic via by using CNC Machine	49
Figure 3.14:	Printed Circuit layout on Film	50
Figure 3.15:	Photoresist layer Process	51
Figure 3.16:	Developer and Etching Process	51
Figure 3.17:	(a) Copper wire 0.57 mm, (b) Soldering Prototype	52
Figure 3.18:	Photograph of prototype SIW coupler (Ku-Band)	52
Figure 3.19:	Photograph of prototype SIW coupler (K-Band)	53
Figure 3.20:	Agilent’s PNA-X 5245A PNA Network Analyzer	54
Figure 3.21:	Block diagram of the S-parameter measurements performed on coupler	54
Figure 3.22:	Measurement process using PNA Network Analyzer	55

Figure 3.23: Calibration Kit 57

Figure 3.24: Calibration measurement process by using Through 57

Figure 3.25: SOLT calibration terminators (Short, Open, Load, Through) 57

Figure 4.1: The conventional configuration of SIW coupler 60

Figure 4.2: Reflection coefficient, S_{11} (dB) with different *p* (*d* is fixed at 0.6 mm) 61

Figure 4.3: Transmission coefficient, S_{21} (dB) with different *p* (*d* is fixed at 0.6 mm) 62

Figure 4.4: Reflection coefficient, S_{11} (dB) with different *d* (*p* is fixed at 0.92 mm) 64

Figure 4.5: Transmission coefficient, S_{21} (dB) with different *d* (*p* is fixed at 0.92 mm) (a) Ku-Band, (b) K-Band 66

Figure 4.6: Evolution Structure of SIW coupler (a) Single rows (b) Dual rows 69

Figure 4.7: E-Field Distribution (a) Single rows Via, (b) Dual rows Via, 70

Figure 4.8: Reflection coefficient, S_{11} (dB) with different rows of vias 71

Figure 4.9: Isolation coefficient, S_{41} (dB) with different rows of vias 72

Figure 4.10: Transmission coefficient, S_{21} (dB) with different rows of vias 74

Figure 4.11: Simulated Result of SIW coupler (Ku-Band) 76

Figure 4.12: Simulated Result of SIW coupler (K-Band) 78

Figure 4.13: Simulated and measured S-parameters of SIW coupler at Ku-Band 79

Figure 4.14: Simulated and measured S-parameters of SIW coupler at K-Band 80

Figure 4.16: Simulated and measured phase difference of SIW coupler at Ku-Band 82

Figure 4.17: Simulated and measured phase difference of SIW coupler at K-Band 83

Figure 5.1: Configuration of SIW structure with cross slot coupling design (Hafiz, Jamaluddin, & Selvaraju, 2018) 88

LIST OF ABBREVIATIONS

AutoCAD	Computer Aided Design Software
BW	Bandwidth
C	Coupling Factor
CST	Computer Simulation Technology
CNC	Computer Numerical Control
dB	Decibel
DFW	Dielectric Field Waveguide
EM	Electromagnetic
FBW	Fractional Bandwidth
GBR	Gerber
Hz	Hertz
IL	Insertion Loss
I	Isolation
OrCAD	Proprietary Software Tool Suite
PEC	Perfect Electric Conductor
PCB	Printed Circuit Board
PNA	Performance Network Analyzer
RL	Return Loss
SIW	Substrate Integrated Waveguide
SMA	Sub-Miniature version A
TE modes	Transverse Electric
TM modes	Transverse Magnetic

TL	Transmission Line
UV	Ultra-violet
VNA	Vector Network Analyzer

LIST OF SYMBOLS

c	Velocity of light
d	Diameter of via (mm)
ε_r	Relative Permittivity of Substrate
f_c	Centre Frequency (GHz)
f_h	High Frequency (GHz)
f_l	Lower Frequency (GHz)
h	Thickness of Substrate (mm)
L_{eff}	Effective Length (mm)
L	Length of Rectangular Coupler (mm)
L_t	Length of transition Taper (mm)
p	Distance between via (mm)
S_{11}	Reflection Coefficient
S_{41}	Isolation Coefficient
$\tan\delta$	Tangent Loss
t	Thickness of Copper (mm)
$W_{aperture}$	Width of aperture (mm)
W_{siw}	Width of Substrate Integrated Waveguide (mm)
W_m	Width of microstrip TL (mm)
W_t	Width of transition Taper (mm)
W_{eff}	Effective Width (mm)
W	Width of Rectangular Coupler (mm)
Z_o	Characteristic Impedance (ohm)

λ_g	Guided Wavelength

Reka Bentuk dan Pengenalpastian Jalur Lebar Pengganding 3dB/90 Darjah yang Menggunakan Teknik bilangan baris lubang Pandu Gelombang Substrat Bersepadu (SIW)

ABSTRAK

Teknik pandu gelombang substrat bersepadu (SIW) adalah pilihan yang baik apabila mereka bentuk pengganding 3dB / 90° pada frekuensi tinggi kerana teknik ini menunjukkan kehilangan yang rendah berbanding dengan microstrip tradisional. Dalam teknik microstrip, sesetengah medan magnet dan magnetik disebarkan ke udara (ketelusan rendah berbanding dengan substrat), yang menyumbang kepada kehilangan isyarat. Kehilangan dalam microstrip adalah lebih penting apabila beroperasi pada frekuensi tinggi. Sebaliknya, isyarat bergerak dalam substrat dengan teknik SIW, dipandu oleh lubang logam di kedua-dua sisi talian penghantaran. Penyebaran ini sama dengan penyebaran gelombang di mana tiada isyarat yang disebarkan ke udara. Kemungkinan kehilangan isyarat boleh berlaku melalui kebocoran antara lubang yang membawa kepada kemerosotan prestasi penyambung SIW. Teknik yang dibentangkan untuk meningkatkan prestasi penyampai SIW dalam kesusasteraan terbuka sama ada mempunyai jalur lebar terhad, dimensi yang lebih besar, atau terhad kepada prestasi simulasi sahaja. Oleh itu, satu pendekatan untuk meningkatkan jalur lebar operasi (> 20%) penyambung SIW untuk aplikasi frekuensi tinggi dibentangkan dalam tesis ini. Teknik pengganding SIW yang dicadangkan direka, dianalisis dan disahkan pada dua julat frekuensi berbeza, Ku-Band (11-17 GHz) dan K-Band (20-26 GHz). Kedua-dua reka bentuk ini dilaksanakan pada Roger RO4003c dengan ketebalan (h) 0.508 dan ketelusan relatif (ε_r) daripada 3.55. Pengoptimuman reka bentuk pengganding yang dicadangkan diselidik menggunakan alat simulasi CST Microwave Studio. Penyelidikan bermula dengan mengambil kira nilai yang berlainan d (diameter lubang) dan p (jarak antara lubang). Melalui analisis kajian parametrik, nilai optimum d dan p untuk mencapai kehilangan sisipan minimum (S_{21}, S_{31}) adalah d=0.6 mm dan p=0.92 mm. Nilai-nilai dimensi yang dioptimumkan kemudiannya digunakan dalam kajian parametrik berikutnya bagi pengganding SIW di mana pada tahap ini, baris tambahan dengan jumlah lubang logam yang berlainan digunakan di tengah kedua sisi tepi struktur pengganding. Adalah dijelaskan bahawa prestasi terbaik pengganding SIW dapat dicapai apabila 3 baris lubang logam dilaksanakan di pusat kedua-dua sisi tepi struktur pengganding. Dengan mempertimbangkan kehilangan pantulan dan pengasingan yang lebih baik daripada 10 dB, pekali gandingan 3 ± 1.5 dB dan perbezaan fasa antara port output 90 ° ± 5 °, hasil simulasi menunjukkan jalur lebar operasi yang lebih baik sebanyak 43.88% di Ku-Band dan 26.31% di K-Band. Hasil eksperimen penggambaran SIW yang dicadangkan dicapai menggunakan Penganalisis Rangkaian PNA-X 5245A PNA dimana hasil yang diukur sepadan dengan hasil simulasi. Secara keseluruhannya, kaedah yang dicadangkan untuk pengganding SIW mempunyai jalur lebar dengan sambutan gandingan rata dan kehilangan kembali dan pengasingan yang lebih baik. Oleh itu, ia mempunyai potensi yang baik untuk dilaksanakan dalam aplikasi frekuensi tinggi.

Design And Development wideband of 3dB/90 Degrees Coupler Using Multiple-rows Via Substrate Integrated Waveguide (SIW) Technique

ABSTRACT

Substrate Integrated Waveguide (SIW) technique is a good candidate when designing a 3dB/90° coupler at high frequency as this technique exhibits low loss compared to traditional microstrip. In microstrip technique, some of the electric and magnetic field is propagating in the air (lower permittivity compared to substrate), which contributes to the loss of the signal. The loss in microstrip is more significant when operating at high frequency. In contrast, a signal is travelling inside a substrate in SIW technique, guided by metallic vias at both side of the transmission lines. This propagation is similar to the waveguide propagation where no signal is propagating in the air. The possibility of signal loss can be happened through leakage between vias which lead to the performance degradation of the SIW coupler. The presented techniques to enhance the performance of SIW coupler in open literature either has limited bandwidth, larger dimension, or limited to simulated performance only. Therefore, the multiple-rows vias to enhance the operational bandwidth (>20%) of SIW coupler for high frequency applications is presented in this thesis. The proposed SIW coupler technique are designed, analysed and validated at two different frequency ranges, Ku-Band (11-17 GHz) and K-Band (20-26 GHz). Both designs are implemented on Roger RO4003c with thickness (*h*) of 0.508 and relative permittivity (ε_r) of 3.55. The proposed SIW coupler design optimization is investigated using CST Microwave Studio simulation tool. The investigation is started by sweeping different values of *d* (diameter of vias) and *p* (pitch between vias). Through the parametric study analysis, the optimum value of *d* and *p* to achieve the minimum insertion loss (S_{21}, S_{31}) is *d*=0.6 mm and *p*=0.92 mm, respectively. These optimized dimensions values are then applied in the next parametric study of the SIW couplers where at this stage, additional rows with different number of metallic vias are applied at the centre of both edge side of the coupler structure. It is revealed that the best performance of the SIW coupler can be achieved when 3 rows of metallic vias implemented at the centre of both edge side of the coupler structure. By considering return loss and isolation better than 10 dB, coupling coefficient of 3±1.5 dB and phase difference between output port of 90°±5°, the simulated results show an improved operational bandwidth of 43.88% at Ku-Band and 26.31% at K-Band. The experimental results of the proposed SIW coupler are accomplished using Agilent PNA-X 5245A PNA Network Analyzer where the measured results agree well with the simulated results. In overall, the proposed method for the SIW coupler features wide bandwidth with flat coupling response and better return loss and isolation. Accordingly, it has good potential to be implemented in high frequency application.

CHAPTER 1 : INTRODUCTION

1.1 Research Background and Motivation

Recent years, there is a huge interest in microwave fields. The telecommunication services are currently on demand in term of the size, bandwidth and operating frequency. Couplers are vital and critical components in communication systems, which function to power division or power combining (Pozar, 2005).

The designing of microwave components passive devices such as filters, antennas and couplers can be implemented using Substrate Integrated Waveguide (SIW) technique. Substrate Integrated Waveguide (SIW) theory was first developed in 2003s and other researchers have emerged new technologies and attractive techniques for this sort of applications (Maurizio Bozzi, 2012; V.A. Labay & Bornemann, 2011). SIW is a method which involves the conductive via holes filled with conductive materials to connect both metal plate surfaces of dielectric substrate (H. Kumar, Jadhav, & Ranade, 2012). Common conductive materials being used are gold, copper, aluminium and silver. SIW technique shared enormous advantages with printed circuit. This includes size compaction, fast prototyping, high insertion loss and precise manufacturing.

The conventional rectangular waveguide is developed in 1952 by D.D.Grieg and H.F.Engelmann with outcomes of different techniques of coupler introduced for designing microwave circuits and components such as strip-line, microstrip and waveguide (Rosu, 1952). For the early research the conventional rectangular waveguide structure is bulky, does not support integration, low insertion loss and narrow bandwidth because of the characteristic of cut-off frequency (Rosu, 1952). Therefore, it is impossible to develop microwave circuits with this platform. Microstrip, strip line and co-planar waveguides have advantages of low cost, simple fabrication and low profile (Iizuka, Watanabe, Sato, & Nishikawa, 2002). Unfortunately, these printed circuits suffer packaging problems and significant losses. Meanwhile, the microstrip is miniaturize but they possess low Q-factor due to losses of substrate and high conductivity. Substrate Integrated Waveguide (SIW) is introduced by Ke Wu which preserves most benefits which is low loss (high Q-factor) and miniaturize (small size) (Tarek & Ke, 2013). Normally, problem occurs at high frequency is the trapping of surface waves which will decrease the efficiency of coupler. SIW takes this problem under control by placing conducting layer on both surfaces substrate, so that they exhibits low radiation or leakage loss (negligible), low insertion loss and insensitive to outer interference (Tarek & Ke, 2013).

1.2 Problem Statement

SIW coupler has an advantage of operating at high frequency compared to traditional microstrip. SIW exhibits low radiation loss, low insertion loss, complete shielding and compact size due to the metallic waveguides. In the past few years, there are a few different approaches that have demonstrated in the open literature to widen the operational bandwidth of the SIW coupler. For examples, the reported work of SIW coupler (Sabri, Ahmad, & Othman, 2013) operating at a low frequency, its design was simulated, and the prototype was fabricated for the validation. However, the operational bandwidth of the proposed SIW coupler is limited. Then, the others SIW coupler method is introduce a few vias with different diameter that achieve operating bandwidth 24% and better performance of reflection coefficient but reported result show limited simulation and operating frequency below than 12 GHz (Nasri, Zairi, & Gharsallah, 2016). Also, the SIW coupler demonstrated in (Srivastava, Mukherjee, & Biswas, 2015) introduced additional vias at centre of coupler and it shows a good performance in terms of magnitude. However, it increases phase imbalance about ± 10^{o} that lead to bandwidth reduction. Moreover, an analysis in (Carrera & Navarro, 2010) is uses multi-section (hybrid) that invented at Ku-Band and K-Band. Nevertheless, the size not compact because of use many vias and the bandwidth 14.33% (Ku-Band) and 11.41% (K-Band). At higher frequency (28-38 GHz), SIW coupler demonstrate very good performance in (Doghri, Djerafi, Ghiotto, & Wu, 2015) using three-dimensional (3-D) circuit but challenges occur when integrate with planar circuit. Therefore by reviewing these techniques, a new technique of SIW coupler is demanded to achieve wideband performance for all the related parameter (magnitude and phase) but also has a small size and easy integration with the planar circuit.

1.3 Objectives

There is two (2) primary purposes of this research project:

- To design and realize the wideband SIW 3dB/90^{o} coupler using multiple rows of vias technique for high-frequency applications at Ku-Band and K-band.
- To fabricate and validate the performance of the proposed SIW coupler in terms of magnitude and phase of the scattering parameters.

1.4 Scope of the Project

The scope of this project is to design and develop coupler with 3dB/90^{o} Substrate Integrated Waveguide (SIW) techniques for microwave applications. To validate the proposed SIW techniques on coupler designs. The design is investigated and implemented at two different high frequency range which is at Ku-Band and K-Band. In this research thesis, all designed couplers are implemented on Roger 4003C dielectric substrate. An analytical SIW calculation is done to verify the initial and optimized dimension of the coupler. In order to match between the SIW transitions to microstrip transition, tapered transition is applied. The simulation and optimization are carried out using Computer Simulation Tools (CST) Software. The simulated results of S-parameters such as return loss, insertion loss, transmission coefficients and phase difference between outputs are obtained. All the prototypes of coupler are implemented using Printed Circuit Board (PCB), CNC machine and Bungard drill holes. The measured couplers (experimental) is validated using Vector Network Analyzer (VNA).

1.5 Lists of Contribution

1. A new design of SIW Coupler with an enhanced bandwidth by introducing multiple-rows vias technique.
2. The proposed technique was demonstrated at two (2) different frequency range of, Ku-Band with bandwidth improvement of 43.88% and K-Band with bandwidth improvement of 26.31%.

1.6 Report Organization

The research thesis is divided into five chapters as follows. In **chapter 1**, the research background, problem statement, objective of project, scope of research, list of contribution and report organization are presented.

Chapter 2 explains the basic theoretical of technique and applications related to SIW Coupler are discussed in this section. The review of previous work is also presented

Chapter 3 contains the research project overview and methodology. This chapter discussed overall system flow chart and fabrication flow diagram that have been carried out. Besides that, the project tools and design specifications of SIW 3 dB/90^o coupler are also determined. Moreover, the coupler design technique applied in this project as well as fabrication and measurement process are also presented.

Chapter 4 contains detail information of coupler performance in terms of S-parameters such as reflected coefficient, isolation coefficient, bandwidth, and the phase difference between S_{21} and S_{31} of the coupler. Also, this chapter elaborates the simulated and measured (experimental) results of SIW 3 dB/90^o coupler. This includes designs for both frequencies which are K-Band and Ku-Band which simulation takes place by using Computer Simulation Technology (CST) Software.

Chapter 5 presents the summary and future project recommendation on overall research are presented. This conclusion is based on the performance (S-parameter) of