UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electronics and Computer Engineering

ISOLATION PERFORMANCE IMPROVEMENT USING DEFECTED GROUND STRUCTURE IN RF SWITCH

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Master of Science in Electronic Engineering

2016

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**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science of
Electronic Engineering**

Faculty of Electronics and Computer Engineering

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2016

DECLARATION

I declare that this thesis entitle "Isolation Performance Improvement using Defected Ground Structure in RF Switch" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Mohammad Hairi bin Abdul Hadi

Date : 10th August 2016

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature : ....

Supervisor Name : Assoc. Prof. Dr. Badrul Hisham Ahmad

Date : 30 Aug 2016

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DEDICATION

To my beloved mother and father, wife and little son

ABSTRACT

The potential application of Defected Ground Structure (DGS) for isolation improvement of RF switch was presented in this thesis. The discrete PIN diode was used as switching element in the RF switch design and the PIN diode relatively had a low isolation problem. Mathematical modeling was determined to model the equivalent circuit of the PIN diode with DGS. DGS can be modeled as a parallel connection of capacitor and inductor. Parameter study was applied to understand the relationship between inductance and capacitance of DGS and its dimension where the etched areas and the gap width under the DGS ground plane were strongly correlated with the inductance and capacitance of the DGS. Five pairs of inductance and capacitance values of DGS were varied to obtain resonant frequency at 4.0 GHz. Isolation formulas was derived in S21 parameter using transmission ABCD matrix. It can be seen that the resonant frequency of the discrete PIN diode with DGS was shifted to higher frequency during ON state and was shifted to lower frequency during OFF state. Isolation response of the equivalent circuit of PIN diode with DGS was analyzed at desired operating frequency of 1.5 GHz. The isolation improvement was achieved where PIN diode isolation was improved from -10.1 dB to -35 dB at 1.5 GHz when DGS was employed. Based on the mathematical modeling, Electromagnetic (EM) simulation was performed where commercialized NXP Semiconductor PIN diode model was applied to integrate with the square shaped DGS and circle shaped DGS. Both DGS types were designed at 4.0 GHz with different dimension layouts and the best attenuation of -22.5 dB and -27.5 dB were achieved for square shaped DGS and circle shape DGS. Three designs which were Design A, Design B and Design C were designed to select the best design for prototyping purpose. Design C offered the best PIN diode isolation performance where high isolation of -35.6 dB and -39.4 dB were achieved using square shaped DGS and circle shape DGS at 1.6 GHz. By fabricating the Design C using FR4 substrate in measurement activity, the measured results clearly showed that the isolation of the series discrete PIN diode was improved using the circle and square shaped DGSs for -27.7 dB and -32.2 dB at frequency of 1.4 GHz and 1.3 GHz. Thus, it was validated that the mathematical modeling had a strong agreement with simulation and measurement results which proved that DGS was capable of improving the isolation performance of discrete PIN diode.

ABSTRAK

Potensi aplikasi Struktur Bawah Terpunar (SBT) untuk penambahbaikan isolasi suis RF telah dibentangkan di dalam tesis ini. diod PIN diskret telah digunakan sebagai elemen suis dalam reka bentuk suis RF dan diod PIN mempunyai isolasi yang rendah. Model matematik telah ditentukan untuk memodelkan litar setara bagi diod PIN dengan SBT.SBT boleh dimodelkan sebagai sambungan selari kapasitor dan induktor.Kajian parametrik telah digunakan untuk memahami hubungan antara kearuhan dan kemuatan SBT dan dimensinya di mana kawasan berpunar dan lebar jurang di bawah SBT mempunyai kaitan rapat dengan kearuhan dan kemuatan SBT.Lima jenis nilai kearuhan dan kemuatan SBT telah diperbagaikan untuk mendapatkan frekuenci resonan pada 4.0 GHz. Formula isolasi diperolehi di dalam bentuk parameter S21 dengan menggunakan matriks ABCD transmisi.Ia boleh dilihat bahawa frekuensi resonan diod PIN diskret dengan SBT telah beralih kepada frekuensi yang lebih tinggi semasa keadaan BUKA dan telah beralih ke frekuensi yang lebih rendah dalam keadaan TUTUP. Respon isolasi litar setara bagi diod PIN dengan SBT dianalisis pada frekuensi operasi 1.5 GHz. Peningkatan isolasi telah dicapai di mana isolasi PIN diod telah meningkat daripada -10.1 dB ke -35 dB pada 1.5 GHz apabila SBT diaplikasikan. Berdasarkan model matematik, simulasi elektromagnet (SE) telah dilakukan di mana model diod PIN NXP Semiconductor komersil telah digunakan untuk diintegrasikan dengan SBT berbentuk persegi dan SBT berbentuk bulat. Kedua-dua jenis SBT telah direka pada 4.0 GHz dengan susun atur dimensi yang berbeza dan atenuasi terbaik iaitu -22.5 dB dan -27.5 dB telah dicapai untuk SBT berbentuk persegi dan SBT berbentuk bulat. Tiga jenis reka bentuk iaitu Jenis A, Jenis B and Jenis C telah direka untuk memilih reka bentuk yang terbaik untuk tujuan prototaip. Jenis C memberikan isolasi terbaik bagi diod PIN di mana isolasi tinggi iaitu -35.6 dB dan -39.4 dB telah dihasilkan menggunakan DGS berbentuk persegi dan DGS berbentuk bulat pada 1.6 GHz. Dengan fabrikasi Jenis C menggunakan substrat FR4 di dalam aktiviti pengukuran, hasil kajian dengan jelas menunjukkan bahawa isolasi diod PIN diskret telah dipertingkatkan dengan menggunakan SBT berbentuk persegi dan SBT berbentuk bulat untuk -27.7 dB dan -32.2 dB pada frekuensi 1.4 GHz dan 1.3 GHz. Oleh itu, ini menunjukkan bahawa model matematik mempunyai hubungkait yang kuat dengan keputusan simulasi dan pengukuran yang membuktikan bahawa SBT berupaya untuk meningkatkan isolasi diod PIN.

ACKNOWLEDGMENT

In preparing this thesis, I was in contact with various individuals, researchers, academicians, and practitioners. They have contributed towards my understanding and thought. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Associate Professor Dr. Badrul Hisham Ahmad, andco-supervisor Dr. Wong Peng Weng, for the encouragement, guidance, critiques, and friendship. I am also very thankful to my research partner, Dr. Noor Azwan Shairi, whom I spent most of my research and learning time with, for his guidance, advice, and motivation and he had always assisted me in gaining better understanding of the technical aspects in/of the research work. Without their continued support and interest, this thesis would not have been similar to the one presented here.

I am truly indebted to the government of Malaysia for awarding me with the FRGS (Fundamental Research Grant Scheme). In addition, Universiti Teknikal Malaysia Melaka (UTeM) deserves a special thank you for their assistance in supplying the relevant literatures.

My fellow postgraduate students should also be recognized for their continuous support. My sincere appreciation also extends to all my colleagues and others who have provided assistance on various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this very limited space. Last but not least, I am grateful to all my family members for their undying support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BiCMOS	-	Bipolar & Complementary Metal-Oxide-Semiconductor
CPW	-	Coplanar Waveguide
DGS	-	Defected Ground Structure
DPDT	-	Double Pole Double Throw
EM	-	Electromagnetic
FET	-	Field Effect Transistor
GaAs	-	Gallium Arsenide
InP	-	Indium Phosphate
MEMS	-	Micro-Electrochemical Systems
MMIC	-	Monolithic Microwave Integrated Circuit
MOCVD	-	Metal Organic Chemical Vapor Deposition
PBG	-	Photonic Band Gap
PHEMT	-	Pseudomorphic High Electron Mobility Transistor
RF	-	Radio Frequency
SiGe	-	Silicon Germanium
SPST	-	Single Pole Single Throw
SPDT	-	Single Pole Double Throw
TDD	-	Time Division Duplex

LIST OF APPENDICES

LIST OF PUBLICATIONS

The research papers produced and published during the course of this research are as follows:

1. Hadi, M. H., Ahmad, B. H., Shairi, N. A., and Wen Wong, P., 2013. Effect of a Discrete PIN Diode on Defected Ground Structure. In *Wireless Technology and Applications (ISWTA), 2013 IEEE Symposium on* (pp. 333-337). IEEE.
2. Hadi, M. H., Ahmad, B. H., Wong, P. W., and Shairi, N. A., 2014. An Overview of Isolation Improvement Techniques in RF Switch.*Journal of Engineering & Applied Sciences*, *9*(3).
3. Hadi, M. H., Ahmad, B. H., Shairi, N. A., and Wen Wong, P., 2014. Isolation Improvement of Discrete PIN Diode Switch using Square Dumbbell Defected Ground Structure. In *Asia-Pacific Conference on Applied Electromagnetics (APACE), 2014 IEEE Symposium on* (pp. 333-337). IEEE.

CHAPTER 1

INTRODUCTION

1.0 Research Background

Over the years, the Defected Ground Structure (DGS) provides significant advantage by extending its applicability such as in amplifiers (Kang *et. al.,* 2005, Lim *et. al.*, 2001), filters (Zakaria *et.. al.*, 2012, Banciu *et. al.*, 2007), power dividers (Lim et. al., 2001), couplers (Weng *et. al.*, 2008, Ahn *et. al.*, 2001), and switches (Kang et. al., 2000, Kim *et. al.*, 2006, Shairi *et. al.*, 2011).The DGS offers simple structure, compactness, low insertion loss characteristic, slow-wave effect, high characteristic impedance, and stop band effect. Hence, the DGS is found in many applications in modern day technology. The DGS is implemented by modifying guided wave characteristics where it changes the propagation constant and realized by etching only a few areas on the ground plane under a microstrip line (Kim *et. al.*, 2000). It has been reported in (Ahn *et. al.*, 2000, Kim *et. al.*, 2006) where the lumped components such as resistor, capacitor, and inductor are integrated with the DGS. Moreover, there are other active components which are employed with the DGS such as transistors (Park *et. al.*, 2004) and varactor diodes (Park*et. al.*, 2000).Apart from that, RF switches are also reported to be designed with the DGS embedded (Kang *et. al.*, 2000).

One of the significant specifications in RF switch is isolation. Isolation of the RF switch is a key feature in order to get excellent performance of the circuit design. RF switches can be categorized into two essential groups which are electromechanical switches (such as MEMS switch) and solid state switches (such as PIN diode and

FET).One of the RF switch application is in the RF transceiver system (Chang *et. al.*, 2003)of modern wireless data communication to perform time division duplex (TDD) switching for transmit and receive operations. Some of the RF switches encounter a limitation in terms of low isolation. For instance, the FET provides good isolation at low frequency. But, at higher frequency, the isolation of the FET degrades due to an effect of the drain-to-source capacitance (Agilent, 2006). Similarly, PIN diode performance is limited by the parasitic capacitance at high frequency in the form of isolation roll-off (Agilent, 2006) due to the junction capacitance becoming constant and dependent only on the geometry of the intrinsic layer at higher frequency (Avago, 2006). Hence, an isolation improvement of the RF switch has been a major issue in the microwave circuit design.

At present, there are several techniques of isolation performance improvement of the RF switch that have been reported as shown in Figure 1.1. One of them is by using materials with fabrication process design. In this technique, the PIN diode that is designed for high frequency operation is usually fabricated to have low capacitance because the reactance of the diode during the OFF state must be large compared to the line impedance in order to get high isolation (Doherty *et. al.*, 1999). Another technique is by employing resonator, transmission lines, circuit configuration, and resonant circuit. These techniques will be elaborately explained in the Chapter 2.

Due to the advantages provided by the DGS and the isolation issue of RF switch circuit design, this research work will focus on the potential of a new technique of isolation improvement in RF switch design by using DGS. The DGS has a potential for reducing parasitic capacitance in a PIN diode which is used for the switching element.

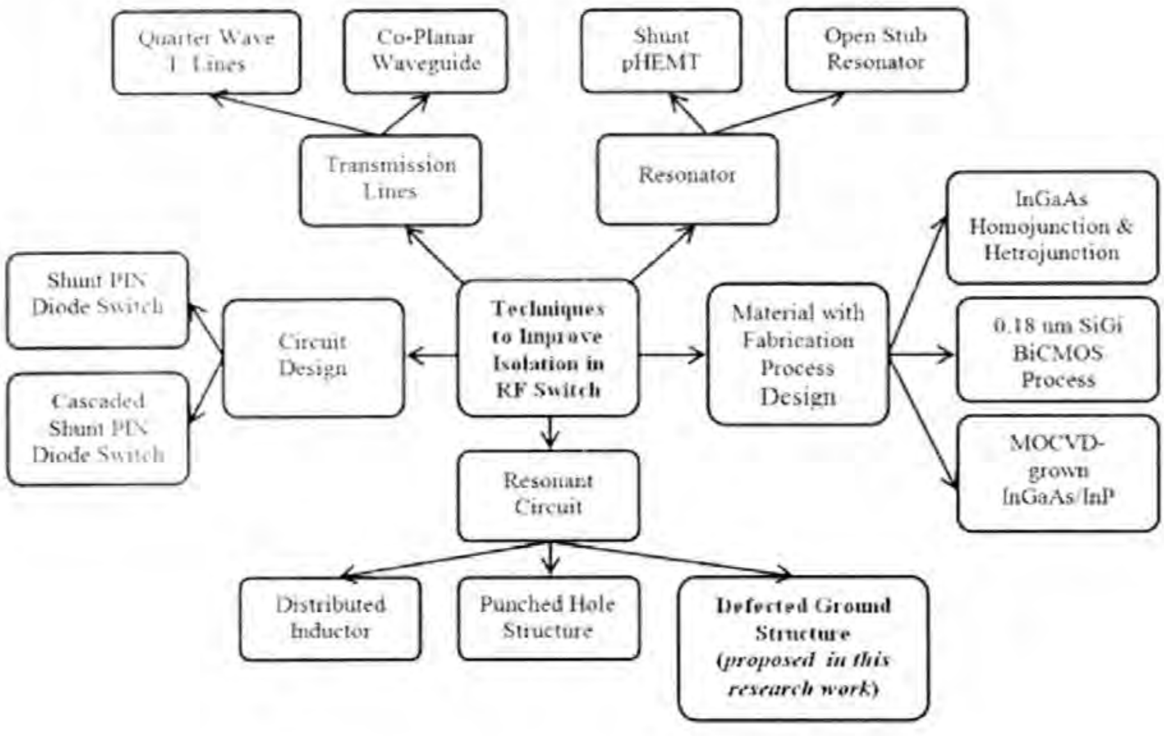

Figure 1.1 Techniques to improve isolation in RF switch

1.1 Problem Statement

Isolation in RF switch is defined as the ratio of the power delivered to the load for an ideal switch in the ON state to the power delivered to the load when the switch is in the OFF state. Isolation is one of the key performance parameter in RF switch design. In RF transceiver design, low isolation can cause RF power in the transmit part leaks into the receiver part and thus the RF power will not be fully transmitted to the antenna during the transmit mode as shown in Figure 1.2. Furthermore, this RF power leakage will distort active components in the RF receiver (for example Low Noise Amplifier). Based on the previous findings, there were few methods which capable of improving the isolation of RF switch such as material with fabrication process design, resonator, transmission line, circuit design and resonant circuit. However, there were few limitation and disadvantage of those techniques which will be discussed later in Chapter Two. Thus, the DGS was selected since it offered circuit simplicity, low cost and circuit size reduction. Therefore, this research will focus on the investigation of the potential of isolation improvement in RF switch design by using the DGS. The PIN diode was used for switching element. It can reduce the parasitic capacitance in the PIN diode and this contributed to the isolation improvement of PIN diode.

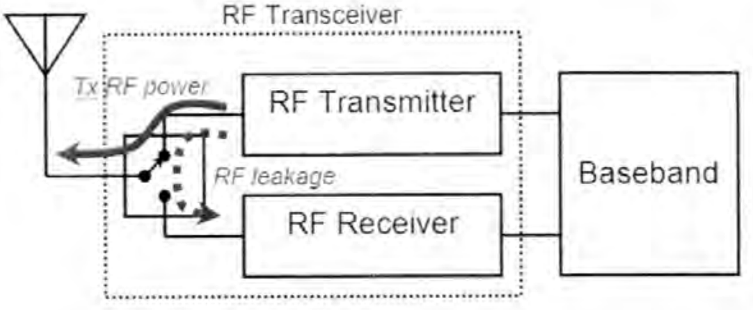

Figure 1.2 RF power leakage in RF Transceiver

1.2 Objectives

This thesis has three main objectives which are:

1. To model the RF switch with DGS design based on the equivalent circuit and mathematical modeling.
2. To investigate the isolation performance of the RF switch with DGS based on the EM circuit simulation.
3. To fabricate and measure the RF switch with DGS for the actual performance of isolation and validated with simulation result.

1.3 Scope of Research

This project scope was limited to the certain criteria following the project's objectives. There are many RF switch design parameters such as switching speed, return loss, voltage standing wave ratio (VSWR) and phase tracking. A key performance parameter in RF switch design which was investigated in this research is the isolation where DGS was the chosen technique to improve the isolation performance. For the switching element purpose, a discrete PIN diode was applied in the RF circuit design. Meanwhile, single pole single throw (SPST) design was chosen for the PIN diode design configuration.

Isolation in the RF switch was defined as the ratio of the power delivered to the load for an ideal switch during the ON state to the power delivered to the load when the switch is in the OFF state. The isolation of PIN Diode was measured in S_{21} (dB) during OFF state. Frequency of interest of PIN diode isolation using DGS was at 1.5 GHz. Apart from that, the insertion loss which was represented by the S_{21} measurement during ON state was slightly explained.

The discrete PIN diode with DGS design was modeled by the equivalent circuit which consisted of common lump elements. From the equivalent circuit of discrete PIN diode with DGS, a mathematical modeling was generated using the Maple software. A transmission (ABCD) matrix was applied to model and analyze the isolation response of the equivalent circuit of PIN diode with DGS. S-parameter of the equivalent circuit was derived based on the transmission (ABCD) matrix.

The simulation activities in this research work were performed in the Advanced Design System (ADS). The discrete PIN diode model was based on the commercialized PIN diode from NXP Semiconductors (part number: BAP64-02). Meanwhile, two types of DGS were studied and investigated in this research work which was square shaped DGS and circle shaped DGS. Fabrication procedures of the RF switch with DGS designs were manually implemented including photo resist development, laminating, etching, drilling, and shearing. FR4 was used as a PCB material in this research. The prototypes were then tested and measured using a network analyzer.