DESIGN AND PERFORMANCE OF MULTIBAND SPLIT RING RESONATOR ARRAY

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by

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TABLE OF CONTENTS

Page

CHAPTER THREE – PARAMETRIC EVALUATION ON SPLIT RING RESONATOR ARRAY DESIGN

CHAPTER FOUR – NEW MULTIBAND DESIGN OF SPLIT RING RESONATOR

CHAPTER FIVE – CONCLUSION AND FUTURE WORK

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BSF	Band Stop Filter
BW	Bandwidth
C	Capacitor
CF	Compression Factor
CSRR	Complementary Split Ring Resonator
CST	Computer Simulation Technology
dB	Decibel
DGS	Defective Ground Structure
DMS	Defective Microstrip Structure
DoE	Design of Experiments
DXF	Document Exchange Format
E	Electric Field
ECAL	Electronic Calibration Module
EM	Electromagnetic
FSS	Frequency Selective Surface
GHz	Gigahertz
H	Magnetic Field
HCCSRR	Hexagonal Cascaded Complementary Split Ring Resonator
HQ	High Quality
HSRR	Hexagonal Split Ring Resonator
IL	Insertion Loss
ISM	Industrial Scientific and Medical
J	Admittance Inverter
L	Inductor
LHM	Left Handed Material
M	Measured results
MSSRR	Micro-Split Split Ring Resonator

MW	Microwave
MWS	Microwave Studio
PCB	Printed Circuit Board
RF	Radio Frequency
RL	Return loss
RSM	Response Surface Methodology
S	Simulated result
SIR	Stepped Impedance Resonator
SMA	Sub Miniature version A
SRR	Split Ring Resonator
SSRR	Square Split Ring Resonator
SWR	Standing Wave Ratio
WCS	Working Coordinate System
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
3D	3 Dimensional

LIST OF SYMBOLS

a	Gap between inner and outer ring of SRR
a_{ext}	External ring dimension
a_{avg}	Average ring dimension
c	Width of metallic strip
c_o	Velocity of light in free space
$\mathrm{C_o}$	Series capacitance
$\mathrm{C_g}$	Capacitance gap
C_{eq}	Total equivalent capacitance of SRR
C_{pul}	Capacitance per unit length
d	Side length of SRR
ε	Permittivity
ε_o	Free space permittivity
ε_r	Dielectric constant of substrate
f_r	Resonance frequency
f_{os}	Expansion of resonant frequency formula
g	Split gap of SRR
h	Thickness of substrate
l	Wire length
L_T	Total inductance of SRR
μ	Permeability
r_{ext}	External radius dimension
s	Distance separation of SRR
t	Thickness of SRR strip
w	Distance separation between transmission line and SRR
w_o	Basic resonant frequency
z_o	Characteristic impedance
π	Pi

γ	Wire loop of square qeometry
λ	Wavelength
Γ	Reflection Coefficient
⬇	Number of runs

REKA BENTUK DAN PRESTASI TATASUSUNAN KEPELBAGAIAN JALUR PENYALUN GELANG BELAH

ABSTRAK

Dalam system komunikasi berteknologi canggih, penuras jalur batas tunggal boleh direka untuk berkelakuan seperti kepelbagaian jalur penuras jalur batas. Untuk menghasilkan keluaran frekuensi penolakan kepelbagaian jalur, beberapa teknik yang berbeza telah diperkenalkan. Sebahagian daripada teknik tersebut menunjukkan bahawa bilangan frekuensi yang terbentuk bergantung kepada bilangan nombor tatasusunan yang digunakan. Penambahan lebihan tatasusunan dalam reka bentuk penuras bole menyebabkan pembentukan penuras yang besar di mana ia tidak praktikal dalam aplikasi teknologi moden. Oleh itu, penggunaan penyalun gelang belah diperkenalkan untuk tujuan pengecilan sempurna. Kerja ini bertumpu pada ciri-ciri penyalun gelang belah dan penilaian prestasi penuras jalur batas. Kaedah pertama yang digunakan adalah Reka Bentuk Eksperimen di mana ia adalah kaedah awal analisis dan diikuti oleh proses pengoptimuman untuk mendapatkan parameter paling ketara di dalam penyalun gelang belah. Kemudian, pendekatan kepelbagaian jalur yang mengandungi kepelbagaian tatasusunan dan kepelbagaian saiz penyalun gelang belah diperkenalkan. Keputusan daripada pelaksanaan penyalun gelang belah untuk penjanaan kepelbagaian jalur menunjukkan bahawa, reka bentuk penuras jalur batas tunggal berjaya beroperasi pada 5.8 GHz. Kepelbagaian saiz penuras jalur batas yang dicadangkan mempamerkan dua, tiga dan empat bilangan penolakan frekuensi diantara 1 dan 10 GHz dengan pengurangan saiz 71.7% berbanding kepelbagaian tatasusunan penuras konvensional.

DESIGN AND PERFORMANCE OF MULTIBAND SPLIT RING RESONATOR ARRAY

ABSTRACT

In advanced technology communication system, single band stop filter (BSF) can be designed to behave as multiband band stop filter. In order to produce multiband output frequency rejection, several different techniques were introduced. Some of the techniques show that the number of frequency formed depends on the number of array used. The addition of more arrays in filter design can cause the formation of large filter which is not practical in modern technology application. Therefore, the utilization of Split Ring Resonator (SRR) is introduced for the perfect miniaturization purposes. This work is focused on the characteristics in SRR and the evaluation on the most significant parameter that exists in SRR toward the performance of BSF. The first method used is the Design of Experiments (DoE) which is preliminary analysis method and followed by optimization process in order to obtain the significant parameter in SRR. Then, the multiband design approach consists of multi-array and multi-size SRR is introduced. The result from the implementation of SRR for multiband generation shows that, the design of single band array filter is successfully operated at 5.8 GHz. The proposed multi-size SRR bandstop filter exhibits two, three and four number of frequency rejections between 1 and 10 GHz with the size reduction of 71.7% compared to conventional multi-array filter.

CHAPTER ONE

INTRODUCTION

1.1 Background Study

In modern wireless communication system, the rapid growth of miniaturization size application with enhanced performance has caught an attention of various researchers around the world. They proposed varieties of miniaturization techniques for multiband output which some of them involves Split Ring Resonator (SRR) and some of them without SRR. SRR is one example that exhibits metamaterial capabilities with a characteristic of having negative permeability behaviour. Metamaterial were firstly known as Left-Handed Material (LHM) exhibiting a unique properties which are made up from artificial elements that are very hard to be discovered naturally. Unlike other naturally occurring material, the characteristics of metamaterial structures such as electrical permittivity, magnetic permeability and index of refraction are found to be negative. It is widely used in planar microwave technology especially in constructing a resonator based filter.

Another additional feature that increases the demand of SRR application is the structure of SRR that is compatible with the standard Printed Circuit Board (PCB) fabrication process. Thus, it decreases the difficulty of manufacturing process and cost substantially. While performing an application as a filter, the implementation of SRR will produce a narrowband band stop filtering properties. In this works, the single SRR can be related to the generation of multiband frequency output. SRR itself when coupled with the microstrip transmission line can exhibit stop band properties. Depending on the number of array that was implemented, the

SRR can produce a single band output and can be further expand into the generation of multiband output. The range of multiband frequency is from 1 – 10 GHz.

The advantage of SRR is not only limited on the production of narrowband filtering properties, it was also used in generation of multiband applications. One example for the application of multiband filter is in the field of high-speed imaging process. In order to capture a high quality (HD) images, such samples need to be taken multiple time while at the same time switching the whole single band filter cubes between photograph intervals. Later, these photos will be combined electronically and it involves such a complicated process and give rises to another limitations. Therefore, by implementing multiband filtering properties in this work area, it may overcome several limitations that emerged by this image processing area.

1.2 Problem Statement

From previous work, when combining SRR array with the microstrip transmission line, the design combination will exhibit a band stop characteristic. Since it is properly designed to reject any signal that passes through certain selected frequency, the normal problem occurs when more than one signal get in and interrupt the filtering mechanism and thus affects the performance of the filter. Due to this, an SRR array with microstrip transmission line is implemented as it is capable to produce a narrowband filtering ability.

Additionally, apart from producing single band rejection, the multiband output rejection model exhibit good feature in filter application such as the ability to produce multiple rejections at the same time. Several multiband techniques have been explored such us using stubs and FSS method. However, the common things showed by most of these techniques are that the number of frequency band is dependent on the number of array used. This also implies on the performance as they improved with the number of array that is being used. Some of the techniques include the implementation of SRR for multiband proposes. For the generation of multiband output that emphasize the usage of SRR, multiple array is needed which means more area needs to be accommodated for this techniques to be realised. This condition will cause a formation of large filter by the unnecessary number of SRR array used.

However, hypothetically the implementation of SRR exhibits a degree of freedom where its structure can be manipulated and without it affecting the resonant frequency. This means miniaturization of SRR array filter can be realized without any constraint from frequency related parameters. Therefore, by adjusting the physical properties of SRR, the multiband output result can be achieved without having multiple number of SRR array.

1.3 Objectives of Thesis

In order to develop a perfect design prototype that incorporates SRR into it, a suitable simulation process followed by a hardware implementation is essential before the model can be commercialized. A good design model consists of two main objectives that need to be fulfilled throughout the rest of research progress. The main objectives in this thesis are as follows;

- To model a single and multiple array of SRR band stop filter using CST microwave studio

- To develop a new model of multiband SRR filter incorporating multi-size SRR design

1.4 Scope of Thesis

This research focus on the development of Band Stop Filter (BSF) for the generation of single band at 5.8 GHz and multiple band of frequency at range of 1 – 10 GHz using Split Ring Resonator (SRR) array implementation. The generation of single band at 5.8 GHz is due to the ISM (Industrial Scientific and Medical) radio band application. 5.8 GHz band was chosen since the band is less congested as compared with channel at frequency 2.4 GHz or 900 MHz. The design evolves the characteristics of SRR that exhibit the most significant effects toward the performance of BSF. This whole project covers the design of SRR filter model, the simulation, fabrication and lastly the measurement assembly process. The instrumentation used for the purpose of designing and simulating the model is CST Studio Suite 14. For the Design of Experiment (DOE) section, the analysis is performed using Minitab 16 software. As for the measurement setup, PNA-X Network Analyzer is used to acquire the measured results. This work consists of more than one type of analysis. The performance of the proposed multiband SRR filter with the conventional multiband SRR filter is evaluated. However, due to the time limitation and budget constraint, the PCB fabrication process covers certain important and significant analysis only.

1.5 Thesis Organization

This dissertation is organized into five chapter altogether. It focuses on the implementation of square SRR into the realization of band stop filter and undergo different variation method of analysis for the improved performance of system.

In Chapter 2, a vast previous related works is presented on the usage of SRR that includes the basic concept and the formula derivations. A wide literature review about the interaction of SRR array with microstrip transmission line which exhibits the stop band characteristic is discussed. Moreover, this chapter also discussed the preliminary work on the SRR behavioural analysis. In addition, the generation of multiband using an array of SRR in previous research works also is included. However, it found that, multiband output can be generated by using the typical square of SRR but with a slight modification on geometrical structure.

Subsequently, in Chapter 3, the design methodology started with the evaluation analysis on single SRR array parameters. This chapter consist of mainly two analyse which represented by DoE process where it utilizes a Response Surface Methodology (RSM) type of analysis, followed by optimization process where it is a continuation from the DoE result analysis. In this section, several proposed model were chosen to be fabricated for testing purposes. All the design procedures including the results were compiled altogether for easy understanding. From the result of both analyse, it will be able to deduce which parameter is the most significant among others.

In Chapter 4, the new design approach for multiband production is introduced. It consists of two design approaches that exhibit similar objectives in generating multiple rejections. Both approaches go through CST MWS simulation and PCB fabrication process for measurement setup. The simulated and measured result are analysed in order to come up with the comparison between each approaches. Therefore, from comparison result, a better design approach can be constructed. This chapter includes the result for each multiband model that is inserted at the end of each design procedures.

Lastly, in Chapter 5, it discusses the conclusion for the whole thesis design. This chapter is important where it shows verification for all the objectives that have been mentioned earlier in Section 1.3 whether it is successfully achieved or not. Other than that, it briefly conclude all the analyses involve for each design of single array in Chapter 3, and multiple of array together with the multi-size analysis in Chapter 4. Future works is included in this last chapter as it provides several suggestions that can be used in order to improve any drawbacks that can be found in this research work. Thus, it will provide a better model for future research.

CHAPTER TWO

LITERATURE REVIEW

This section is mainly concentrated on the general overview for the whole research of the split ring resonator (SRR) development starting from the basic individual SRR structure. This section is divided into several topics that are important to be included and discussed in order to obtain the behavioural characteristics of SRR. The content of literature review focus on the SRR structure, SRR in single array, the optimization process of SRR, and the development of model that capable to generate multiband resonance frequency based on the implementation of SRR. The design objectives from this research can be achieved due to the supportive details of literature review which accomplished the research on the behavioural analysis of multiband SRR array design.

2.1 Split Ring Resonator (SRR) Theory

Metamaterial are artificial structures where they exhibit properties that hardly to be found in nature. These properties relied on the inter-atomic particles inside the structure and not on the constitution of atoms itself. The composition of the particles inside metamaterial is in periodically order unit cell. Here, the unit cell represents a small metallic resonator molecule. The interaction between small metallic metamaterial particles will produce an unusual pattern. This pattern consider the existence of electric permittivity and magnetic permeability which both of them become simultaneously negative. This is one of the most fundamental characteristics in metamaterial (Marek S. Wartak et al, 2011).