DESIGN OF RF FILTER BASED ON RF COMPONENTS

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Thanks to Allah for all the blessing in accomplishing this thesis. I dedicate this work to my beloved mother and father for their infinite love, patience and encouragement that helped me to accomplish this course of work successfully.

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ABSTRACT

Inductors, L, and capacitors, C, are among the most important circuit elements, especially for the radio frequency, RF, applications. Such applications of these components include frequency-tuning circuits, filters, mixers, and matching networks. This thesis presents the design and modelling of RF filters that consist of on-chip RF components. Firstly, two on-chip RF components have been separately designed before they were formed into an RF filter. The chosen configurations are the interdigital capacitor and spiral inductor. The effects of parameter variations on quality factor and inductance or capacitance values were investigated using simulation software. Upon achieving the desired performances, the components were arranged into series and shunt, forming two corresponding filter configurations. Both configurations were then connected to form a single stage series-shunt LC filter using parallel connection. Simulation results showed that both components operate well at the desired 13 GHz RF frequency of operation. The series and shunt LC filters demonstrate characteristics of a bandpass filter. At -3 dB or half-power insertion and return losses, both exhibit operating bandwidths from 8 GHz to 11 GHz, i.e. 3.0 GHz or 32 %. In ratio form, this is 11/8 = 1.375 which is quite broad. The single stage series-shunt LC filter also demonstrates characteristics of a bandpass filter. It exhibits slightly less -3 dB operating bandwidth from 8.75 GHz to 10.25 GHz, i.e. 1.5 GHz or 16 %. In ratio form, this is 10.25/8.75 = 1.17 which is slightly broad. This is halved that of the series and shunt LC filters. Hence, the former exhibits a maximum Q factor of approximately 3.2, which is doubled that of the single stage series-shunt LC filter.

ABSTRAK

Induktor, L, dan kapasitor, C, merupakan antara elemen terpenting litar, terutamanya bagi aplikasi frekuensi radio, RF. Contoh applikasi termasuklah litar menala-frekuensi, penapis, pencampur, dan rangkaian padanan. Tesis ini membentangkan rekabentuk dan pemodelan penapis RF yang terdiri daripada komponen *on-chip* RF. Pertamanya, dua komponen RF direkabentuk secara berasingan terlebih dahulu sebelum digabung menjadi struktur penapis. Konfigurasi yang dipilih adalah kapasitor salingdigital dan induktor pilin. Pengaruh perubahan parameter terhadap faktor kualiti dan nilai aruhan atau muatan telah diselidik menggunakan perisian simulasi. Setelah prestasi yang dikehendaki diperoleh, komponen ini disambung secara siri dan selari untuk membentuk dua konfigurasi penapis sehubungan. Kedua-dua konfigurasi kemudiannya disambung membentuk penapis LC siri-selari peringkat tunggal. Keputusan simulasi menunjukkan bahawa kedua-dua komponen berkendali dengan baik pada frekuensi 13 GHz yang dikehendaki. Penapis LC siri dan selari telah berjaya mempamerkan ciri penapis lulus jalur. Pada paras -3 dB atau kehilangan sisipan dan kembali setengah-kuasa, kedua-duanya memiliki lebarjalur kendalian dari 8 GHz hingga 11 GHz, i.i. 3.0 GHz atau 32 %. Dalam bentuk nisbah, ini ialah 11/8 = 1.375 iaitu agak luas. Penapis LC siri-selari peringkat tunggal telah juga mempamerkan ciri penapis lulus jalur. Ia memiliki lebarjalur kendalian yang kurang sedikit, iaitu dari 8.75 GHz hingga 10.25 GHz, i.i. 1.5 GHz atau 16 %. Dalam bentuk nisbah, ini ialah 10.25/8.75 = 1.17 iaitu luas sedikit. Ini ialah separuh daripada keluasan lebarjalur litar LC siri dan selari. Oleh itu, litar pertama memiliki faktor Q maksimum bernilai hampir 3.2, iaitu dua kali ganda pada penapis LC siri-selari peringkat tunggal.

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LIST OF SYMBOLS

A	-	Plate area
A_1	-	Interior capacitance of the finger
A_2	-	Two exterior capacitance of the finger
C	-	Capacitance
D	-	Separation between the plates
F	-	Frequency
H	-	Substrate height
L	-	Inductance
L	-	Finger Length
Q	-	Quality factor
Q_c	-	Quality factor due to conductor losses
Q_d	-	Quality factor due to dielectric losses
$Q_{\max}$	-	Maximum quality factor
R_{DC}	-	DC resistance
R_s	-	Series resistance
s	-	Finger spacing
w	-	Conductor width
x	-	Finger width
Z_{11}	-	Impedance at 1 when port 2 is open
Z_{12}	-	Transition impedance when port 1 is short-circuited
Z_{21}	-	Transition impedance when port 2 is short-circuited
Z_{22}	-	Impedance at 2 when port 1 is open
∂	-	Metal skin depth
μ_0	-	Free space permeability

ε_r	-	Relative dielectric constant
μm	-	Micron meter
Ω	-	Unit of resistivity, Ohm
ω	-	Radian frequency, rad/s
σ	-	Bulk conductivity
π	-	22/7
λ	-	Unit of wavelength

LIST OF ABBREBRIATIONS

C	-	Capacitor
CMOS	-	Complementary Metal Oxide Silicon
dB	-	Decibel
EM	-	Electromagnetic simulation
GaAs	-	Gallium Arsenide
GHz	-	Giga-hertz
Hz	-	Hertz
IC	-	Integrated circuit
IDC	-	Interdigital capacitor
Im	-	Imaginary
L	-	Inductor
nH	-	nano Henry
MHz	-	Mega-hertz
MIC	-	Microwave integrated circuit
MIM	-	Metal insulator metal
MMIC	-	Monolithic microwave integrated circuit
pF	-	pico Farad
Re	-	Real
RF	-	Radio frequency
SI	-	Spiral Inductor
SRF	-	Self-resonant frequency
vs	-	versus
3-D	-	Three dimension

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CHAPTER 1

INTRODUCTION

The first chapter presents introductory part of thesis; project background, objective, scopes of project, and finally the organization of the thesis.

1.1 Project Background

Two most important circuit elements for radio frequency, RF, applications are RF inductors and capacitors. These form the basis of many RF circuits such as frequency-tuners, filters, mixers and matching networks [1]-[8]. A number of researches on the design of the on-chip components have been reported [9]-[24]. Several design configurations have been proposed. The feasibility of these elements to function as filters has been demonstrated [25]-[27]. Such feasibility is a challenging and interesting research on the lumped RF components.

1.2 Objective of Project

The objective of the project is to design an RF filter made of on-chip RF inductor and capacitor lumped elements. The chosen configurations are the interdigital capacitor and spiral inductor as depicted in Figures 1.1 and 1.2.

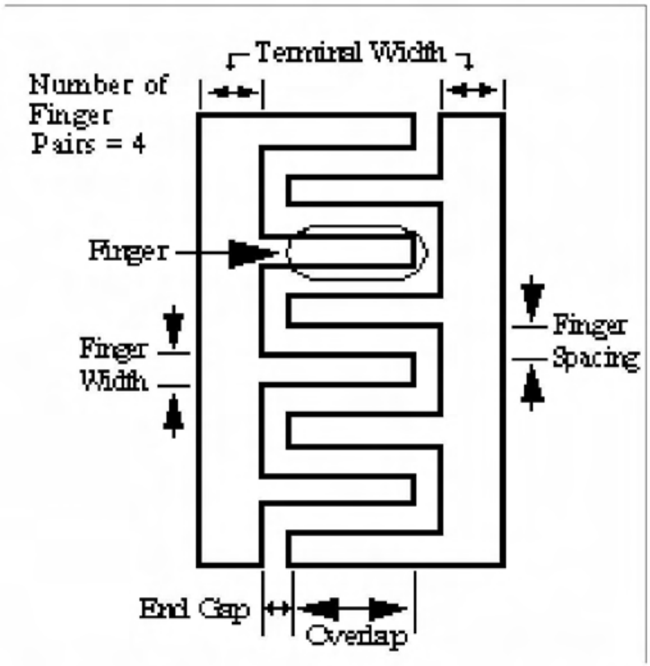

Figure 1.1: An interdigital capacitor configuration.

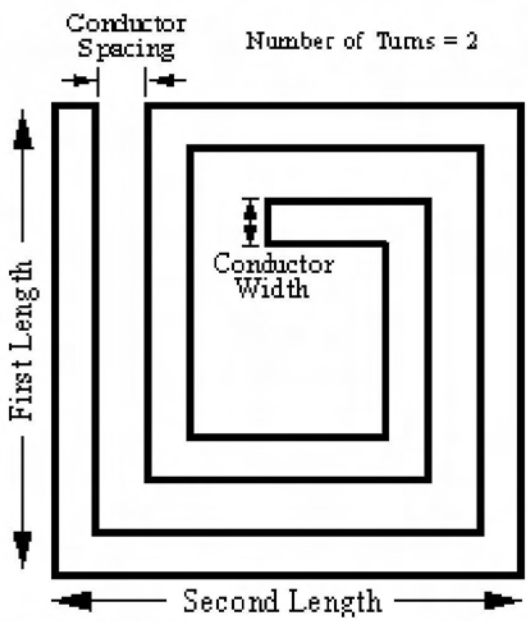

Figure 1.2: A spiral planar inductor configuration.

1.3 Scopes of Project

The scopes of the project are as follows:

(a) Optimization of the RF capacitor, C, with the highest quality factor, Q.
(b) Optimization of the RF inductor, L, with the highest quality factor, Q.
(c) Design of three LC filter configurations; namely, series LC filter, shunt LC filter and single-stage series-shunt LC filter.

MathCAD software [28] is used for mathematical computations while Microwave Office software [29] and SonnetLite software are used for the simulations. The computation RF lumped element components are desired to operate at 13 GHz with good return loss of below -10 dB, transmission coefficient of better than -10 dB and Q-factor of at least 65.

1.4 Organization of Thesis

This thesis consists of five chapters and described as follows:

Chapter 1 presents a brief background of the project, followed by the objective, and scopes of project. The organisation of the chapters in the thesis is then briefly described.

Chapter 2 briefly described the relevant theory, along with review of related research. Formulations used in passive microwave lumped elements, i.e. capacitors and inductors, are described. It also covers the principles of RF LC filters.

In Chapter 3, the design methodology of designing the filters formed from using these two RF elements is described. It also presents the flow of the project and a brief explanation on the software used.

The results obtained are presented and analysed in Chapter 4. A summary is provided.

The final chapter concludes the thesis. Suggestions for future work are then presented

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