DESIGN OF QUASI-LUMPED ELEMENT BANDPASS FILTER

By

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REKABENTUK PENAPIS LULUS JALUR KUASI ELEMEN TERGUMPAL

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ABSTRACT

This dissertation demonstrates the design of quasi-lumped element bandpass filters operating at 2 GHz. The design was simulated before being implemented, because it was easy to make a mistake in the calculations and waste a lot of time. *Agilent Advance Design System software* (ADS) a computer-aided design CAD tool is used for the simulation purpose. In implementation, substrate Duroid is selected. The first part of this dissertation, the quasi-lumped element resonator consisting of the interdigital capacitor parallel with a straight line or meander line inductor is designed. The frequency response of the resonator depends on the length, width, number of interdigital fingers and gap is used in the quasi-lumped element resonator design. The advantage of using microstrip quasi-lumped element resonator is low loss because it reduces the connection between devices and PCB. Beside that, this resonator design is more low-cost, compact and simple to realize by comparing to the other resonators structure. The second part of this dissertation, a quasi-lumped element bandpass filter is built using three quasi-lumped element resonators. The final design is fabricated on Duroid-type printed circuit board after simulation. Measurement will be carried out using the vector network analyzer (VNA) after the fabrication. The network analyzer instrument is used to measure the scattering parameters (magnitude and phase) of two-port microwave network. The simulation and measurement result will be discussed in this dissertation. A meander line inductor achieves further filter miniaturization. Low-insertion loss, high return loss and high Q factor are simultaneously required for filters. In addition, these filters should be compact, low-cost, and high performance. This project includes literature review, simulation, fabrication and measurement.

ABSTRAK

Disertasi ini menunjukkan rekabentuk penapis lulus jalur kuasi-tergumpal yang beroperasi pada frequency 2 GHz. Sebelum proses fabrikasi, rekabentuk tersebut perlu disimulasi terlebih dahulu. Jika proses simulasi tidak dilakukan sebelum proses fabrikasi, ia akan menyebabkan mudah berlaku kesalahan dalam pengiraan dan membazirkan masa untuk merekabentuk. Perisian ADS '*Agilent Advance Design System'* adalah digunakan untuk tujuan simulasi tersebut. Substratum Duroid dipilih digunakan dalam proses implimentasi.Bahagian pertama dalam disertasi ini, penyalun jenis kuasi-tergumpal yang mengandungi pemuat antara digit selari dengan pengaruh jalur mikro direkabentuk. Sambutan frekuensi penyalun adalah bergantung kepada panjang, lebar, bilangan nombor jejari dan ruang yang digunakan dalam rekabentuk penyalun kuasi-tergumpal. Kebaikan bagi penyalun kuasi-tergumpal jenis jalurmikro ialah kehilangan akan berkurangan disebabkan pengurangan sambungan dengan peranti kepada litar PCB. Selain daripada itu, rekabentuk penyalun ini adalah kos yang rendah, lebih ringkas dan mudah direalisasikan jika berbanding dengan penyalun yang lain. Bahagian kedua dalam disertasi ini, penapis lulus jalur kuasi elemen tergumpal direkabentuk dengan menggunakan tiga penyalun kuasi-tergumpal. Rekabentuk yang terakhir akan difabrikasi dalam PCB jenis Duroid selepas proses simulasi. Setelah proses fabrikasi, penyukatan akan dijalankan dengan menggunakan *'vector network analyzer'* (VNA) untuk menguji spesifikasi bagi penapis. '*Network analyzer'* digunakan untuk menyukat parameter S bagi rangkaian mikrogelombang dua liang.. Keputusan bagi simulasi dan penyukatan akan dibincangkan dalam disertasi tersebut. Induktor jenis mikrojalur akan mencapai penapis yang lebih minimize. Kehilangan sisipan yang rendah, isyarat balikan yang tinggi, dan factor Q yang tinggi adalah diperlukan untuk sebuah penapis. Selain itu, penapis yang direkabentukkan hendaklah bentuk yang padat, kos rendah dan pencapaian yang tinggi. Projek ini merangkumi kajian ilmiah, simulasi, fabrikasi dan penyukatan.

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TABLE OF CONTENTS

LIST OF FIGURES

Pages

LIST OF TABLES

Pages

CHAPTER 1

INTRODUCTION

1.1 Motivation

Microwave is important component for channel selection and signal separation in many communication systems. The term of microwave may be used to describe electromagnetic (EM) waves with frequencies ranging from 300MHz to 300GHz (Figure 1.1), which correspond to wavelengths (in free space) from 1m to 1mm.

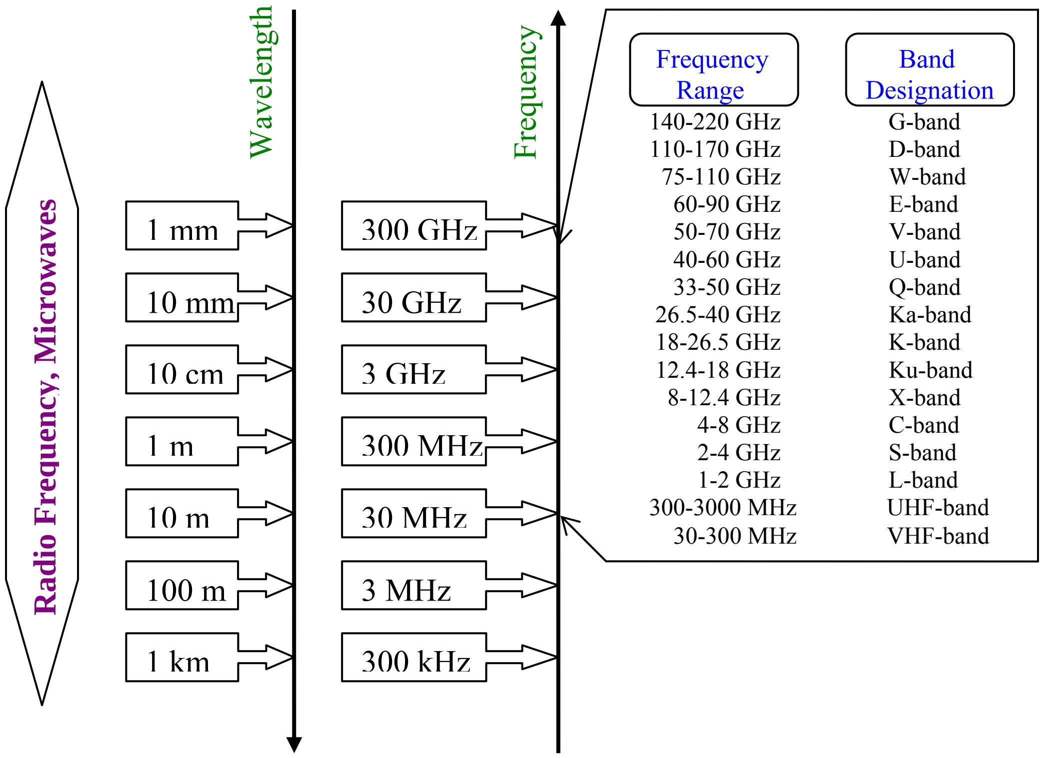


Figure 1.1: RF/ microwave spectrums.

Filters play important roles in many RF/ microwave applications. They are used to separate or combine different frequencies. The electromagnetic spectrum is limited and has to be shared; filters are used to select or confine the RF/ microwave signals within assigned spectral limits. The main filter functions are to reject undesirable signal frequencies outside the filter passband. If a system is noisy, recovery of the wanted signal may be impossible. If unwanted signals (including noise) are not removed sufficiently by filtering, the same problem can occur.

A microwave filter is a two-port network used to control the frequency response at a certain point in a microwave system by providing transmission at frequencies within the passband of the filter and attenuation in the stopband of the filter. Two-port filters considered are always symmetrical in network structure. The basic requirements for a microwave filter design are insertion loss and return loss because they decide the matching of port 1 and port 2. When classifying filters according to general frequency response, they are divided into four basic types: lowpass filter (LPF), highpass filter (HPF), bandpass filter (BPF) and bandstop filter (BSF).

Emerging applications such as wireless and mobile communications systems continue to challenge RF/ microwave signals with ever more stringent requirements-higher performance, smaller size, lighter weight, compact microwave components and low-cost. In most applications the common types of bandpass filter are required. Bandpass filter that passes all frequencies in a range ω_1 to ω_2 (a band of frequencies) and reject frequencies outside this range.

Depending on the requirements and specifications, RF/microwave filters may be designed as lumped element, quasi-lumped element or distributed element circuits. Subsequently, RF/microwave filters are realized in various forms of transmission line such as waveguide, coaxial line, stripline or microstrip line. Recently, especially in microwave circuits, microstrip line is used due to low-cost, easy fabrication, radiation losses and low dispersion. Therefore, in this dissertation, the microstrip line quasi-lumped element bandpass filter operating at 2 GHz is designed that is a lower microwave frequency. Microstrip quasi-lumped element resonator is the important part in the quasi-lumped element bandpass filter design. The advantage of using microstrip quasi-lumped element resonator is low loss because it reduces the connection between devices and PCB. Beside that, this resonator design is more low-cost, compact and simple to realize by comparing to the other resonators structure. Quasi-lumped element bandpass filter for operation in the low microwave region and above, tend to have small structures. The filter miniaturization is achieved by using more interdigital fingers and a meander line inductor.

1.2 The Applications of Bandpass Filter

One of the applications of bandpass filter is at the downlink satellite communication system. Downlink model is an earth station receiver includes bandpass filter (BPF), low noise amplifier (LNA), and RF to IF down converter. Referring to Figure 1.2, the bandpass filter limit the noise input to the low noise amplifier and the mixer would down convert the RF to IF frequency before demodulated to produce the baseband signal. The purpose of the bandpass filter is used to control the frequency response at low noise amplifier by providing transmission at frequencies within the passband of the filter and attenuation in the stopband of the filter. Thus, smaller size and lighter weight bandpass filter is requires. Beside that, bandpass filter is used at the output of an oscillator to pass the required frequency band only. At the input of a receiver and the amplifier, bandpass filter is utilized to pass the required frequency band only.

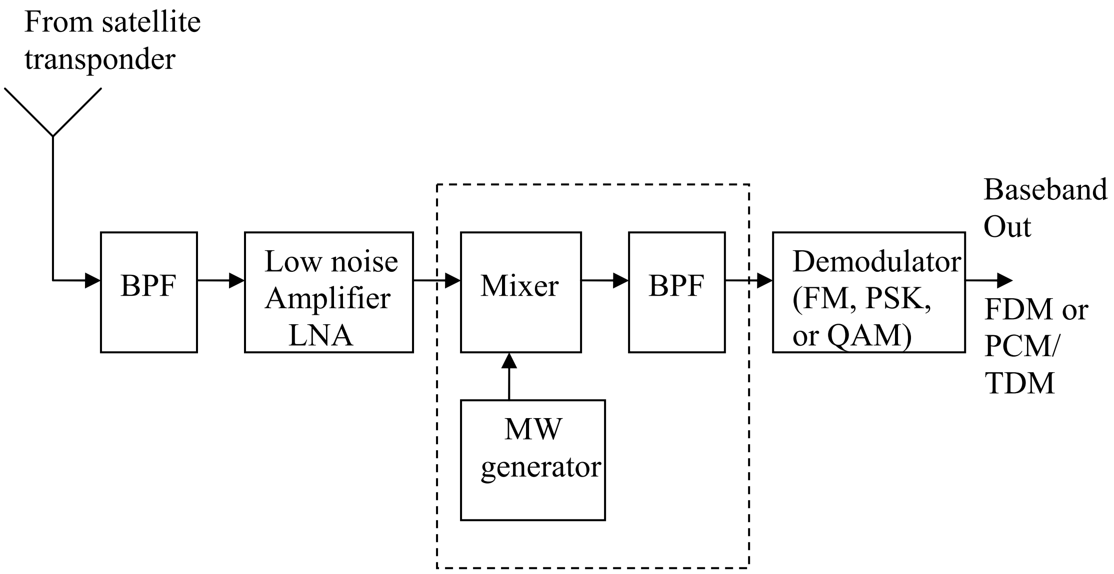


Figure 1.2: satellite downlink model.

1.3 Tools

The required tools for software and hardware parts in this dissertation are listed below:

- HP Advance Design System software, ADS 2004A from Agilent
- CorelDraw Graphic Suite 12
- Duroid type PCB and copper conductor
- SMA connectors
- Solder weed
- Solder and solder lead
- Sucker
- Hewlett-Packard HP8753E network analyzer

1.4 Organization of the Dissertation

Chapter 2 gives the introduction and theory of microstrip line and scattering parameters for two-port network. The microstrip component such as lumped-element and quasi-lumped element is used to design of resonator and filter will be discussed briefly.

Chapter 3 concentrates on the fundamental of resonator. The characteristics of resonator are given. The advantages of using microstrip quasi-lumped element resonator are discussed. The fundamental of interdigital capacitor also presented in this chapter.

Chapter 4 gives the introduction of bandpass filter including the specification of bandpass filter and the classification of bandpass filter based on the configuration and characteristic of the filter. Microstrip filter is discussed in this chapter including the theory of the lumped-element filter. Some general filter implementation will be discussed briefly. Beside that, the several types of connectors are used to connect the bandpass filter and the network analyzer is considered.

Chapter 5 presents the procedure of design quasi-lumped element resonator and bandpass filter. The optimization and the measurement set-up are discussed briefly.

Optimization is required when the performance is not acceptable. The measurement set-up is important to minimize the effects of the sources of the errors inherent in the system.

Chapter 6 delineates all the simulation and measurement results. Analysis and discussion will be given in this chapter.

In chapter 7, conclusion and suggestions for future work are presented.

CHAPTER 2

LITERATURE REVIEW

In this chapter, introduce basic theory and characteristic of microstrip line is first given. Then, some useful formulas and properties of microstrip line are presented. Third, the microstrip component such as lumped-element and quasi-lumped element is used to design of resonator and filter will be discussed briefly. Finally, the theory of scattering parameters for two-port network is presented. S-parameter is important parameter in simulation and measurement.

2.1 Microstrip Fundamental

Microstrip line is one of the most popular types of planar transmission lines. It has many advantages such as low cost, small size, absence of critical matching and cutoff frequency, use of photolithographic processes for fabrication, is easily integrated with other passive and active microwave devices, good repeatability and reproducibility, ease of mass production, and compatibility with monolithic circuits.

2.1.1 Characteristic of Microstrip Line

The geometry of a microstrip line is illustrated in Figure 2.1 and 2.2. A conducting strip (microstrip line) with a length, L, a width, W and a thickness, t is printed on the top of a dielectric substrate that has a relative dielectric constant, ε_r and a thickness, h and the bottom of the substrate is a ground (conducting) plane [1].

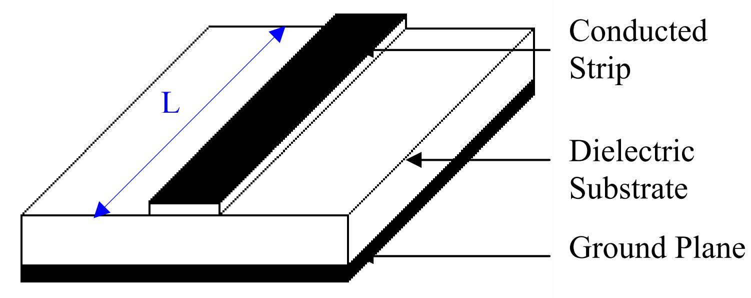


Figure 2.1: The geometry of a microstrip line (from top view).

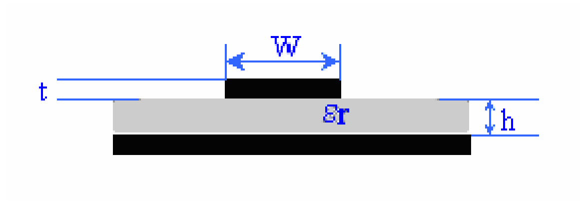


Figure 2.2: The geometry of a microstrip line (from side view).

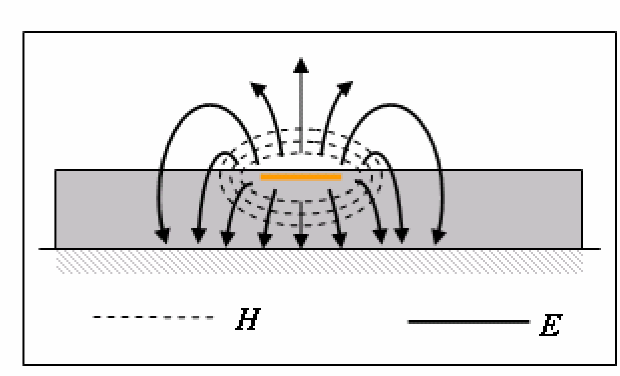


Figure 2.3: The Electric and magnetic field lines of a microstrip line.

Figure 2.3 shows the sketch of the electric and magnetic field lines for microstrip transmission line. From Figure 2.2 and 2.3, we can find that microstrip has some of its field lines in the dielectric region, concentrated between the strip conductor and the ground plane, and some fraction in pure TEM wave, since the phase velocity of TEM field in the dielectric region would be $c/\sqrt{\varepsilon_r}$, but the phase velocity of TEM fields in the air region would be c. Thus, a phase match at the dielectric-air interface would be impossible to attain for a TEM-type wave [2, 10].

In actuality, the exact fields of a microstrip line constitute a hybrid TM-TE wave. The dielectric substrate is electrically very thin, ($d \ll \lambda$), and so the fields are quasi-TEM. In other words, the fields are essentially the same as those of the static case. Thus, good approximations for the phase velocity, propagation constant and characteristic impedance can be obtained from static or quasi-static solutions. Then the phase velocity and propagation constant can be expressed as [2, 10]

$$v_p = \frac{c}{\sqrt{\varepsilon_{eff}}} \tag{2.1}$$

$$\lambda = \frac{v_p}{f} = \frac{c}{f\sqrt{\varepsilon_{eff}}} = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{2.2}$$

$$Z_0 = \frac{1}{v_p c} \tag{2.3}$$

where ε_{eff} is the effective dielectric constant of the microstrip line. Since some of the field lines are in the dielectric region and some are in air, the effective dielectric constant satisfies the relation [2, 10],

$$1 < \varepsilon_{eff} < \varepsilon_r$$

and is dependent on the substrate thickness, d, and conductor width, W.

2.1.2 Some Useful Formulas and Properties of Microstrip Line

Characteristic impedance is the important characteristic of the microstrip line. The characteristic impedance and the effective constant of a microstrip line can be calculated as below [1, 2, 10]:

For W/h ≤1:

$$Z_O = \frac{60}{\sqrt{\varepsilon_{eff}}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right) \tag{2.4}$$

where

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[(1 + \frac{12h}{W})^{-0.5} + 0.04(1 - \frac{W}{h})^2] \tag{2.5}$$

For W/h ≥1:

$$Z_O = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{h} + 1.393 + 0.667\ln\left(\frac{W}{h} + 1.444\right)\right]} \qquad (2.6)$$

where

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[(1 + \frac{12h}{W})^{-0.5}] \qquad (2.7)$$

where ε_{eff} is the effective dielectric constant, ε_r is relative dielectric constant, W is conductor width and h is physical length of transmission line.

The characteristic impedance, Z_o and the width, *W* of the microstrip can be calculated in approximation formula as below [3]:

$$Z_o = \frac{377}{\sqrt{\varepsilon_r}\left(\frac{w}{h} + 2\right)}\Omega \qquad (2.8)$$

$$W = \left[\frac{377}{\sqrt{\varepsilon_0} Z_0} - 2\right]H \qquad (2.9)$$

2.2 Microstrip Components

Microstrip components, which are often encountered in microstrip filter designs, may include lumped inductors and capacitors, quasi-lumped elements (i.e., short line sections and stubs), and resonators. In most cases, the resonators are the distributed elements such as quarter-wavelength and half-wavelength line resonators. The choice of individual components may depend mainly on the types of filters, the fabrication techniques, the acceptable losses or Q factors, the power handling, and the operating frequency. These components are briefly described follows [1].

2.2.1 Lumped Inductors and Capacitors

Some typical configurations of planar microwave lumped inductors and capacitors are shown in Figure 2.4 and 2.5. These components may be categorized as the elements whose physical dimensions are much smaller than the free space wavelength λ_o of highest operating frequency, say smaller than 0.1 λ_o. Thus, they have the advantage of small size, low cost, and wide- band characteristics, but have lower Q and power handling than distributed elements. Owing to a considerable size reduction, lumped elements are normally attractive for the realization of monolithic microwave integrated circuits (MMICs). The applications of lumped elements can be extended to millimeter-wave with the emerging fabrication techniques such as the micromachining technique [1].

As illustrated in Figure 2.4, the high-impedance, straight-line section and meander line is the simplest form of inductor, used for low inductance values (typically up to 3nH), where as the spiral inductor (circular or rectangular) can provide higher inductance values, (typically up to 10nH) [1].

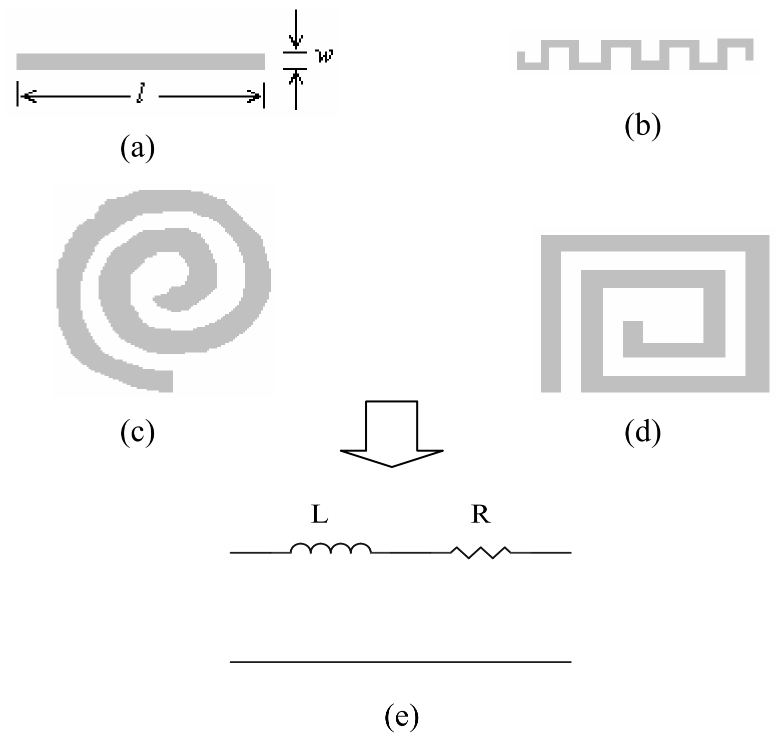


Figure 2.4: Lumped-element inductors [1]; (a) high-impedance line; (b) meander line; (c) Circular spiral; (d) square spiral; (e) their ideal circuit representation.

In Figure 2.5, the interdigital capacitor is more suitable for applications where low values of capacitance (less than 1.0pF) are required. The metal-insulator-metal (MIM) capacitor, constructed by using a thin layer of a low-loss dielectric (typically 0.5 μm thick) between two metal plates, is used to achieve higher values, say as high as 30pF in small areas. The metal plates should be thicker than three skin depths to minimize conductor losses [1].

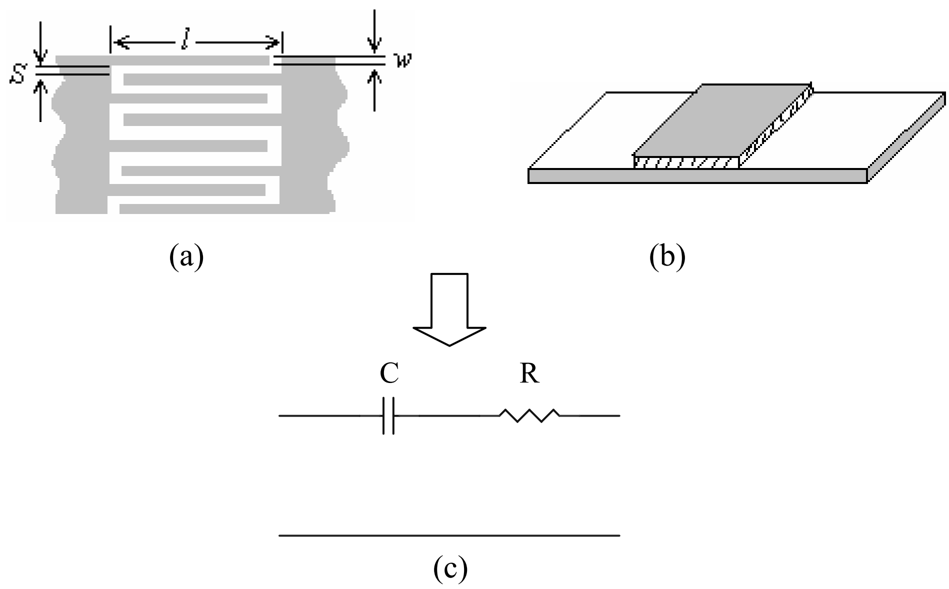


Figure 2.5: Lumped-element capacitors [1]; (a) interdigital capacitor; (b) MIM capacitor; (c) Their ideal circuit representation.

2.2.2 Quasi-lumped Elements

Microstrip line short sections and stubs, whose physical lengths are smaller than a quarter of guided wavelength λ_g at which they operate, are the most common components for approximate microwave realization of lumped elements in microstrip filter structures, and are termed quasi-lumped elements. They may also be regarded as lumped elements if their dimensions are even smaller, say smaller than $\lambda_g/8$. Some microstrip quasi-lumped elements are explain in [1] such as high-impedance and low-impedance short line section and open-circuited and short-circuited stubs.

2.3 Scattering Parameters

The scattering or S-parameters is used in many RF/ microwave applications for modeling component, component specify and circuit design. These S-parameters (magnitude and phase) of a one-port or two-port microwave network can be measured with modern measurement equipment such as vector network analyzer. These are the parameters directly measurable at microwave frequencies. S-parameters are important of the microwave design because this is easily to use and measure at high microwave frequency compare with other parameters. The diagram as depicted in Figure 2.6 is a diagram showing the S-parameters for a two-port network.

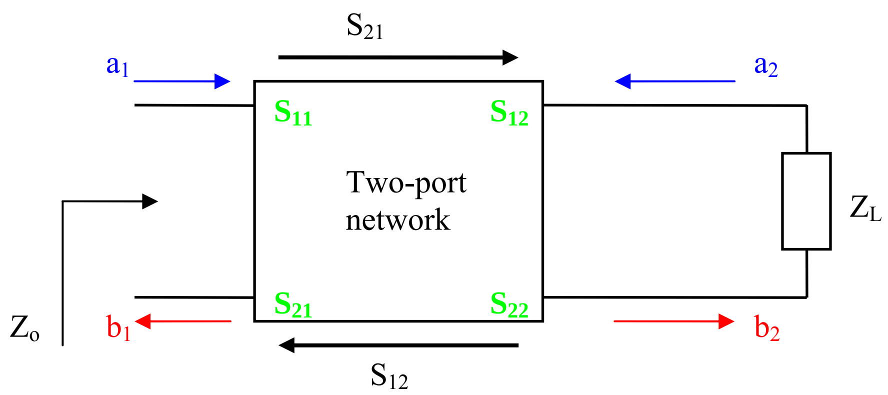


Figure 2.6: S-parameters for two-port network.

The S-parameters of a two- port network are defined in terms of the wave variables as [1]

$$S_{11} = \frac{b_1}{a_1}\Big|_{a_2=0} \quad : \text{ reflection coefficient at port 1} \qquad (2.10)$$

$$S_{12} = \frac{b_1}{a_2}\Big|_{a_1=0} \quad : \text{ transmission coefficient from port 2 to port 1} \qquad (2.11)$$

$$S_{21} = \frac{b_2}{a_1}\Big|_{a_2=0} \quad : \text{ transmission coefficient from port 1 to port 2} \qquad (2.12)$$

$$S_{22} = \frac{b_2}{a_2}\Big|_{a_1=0} \quad : \text{ reflection coefficient at port 2} \tag{2.13}$$

where $a_n = 0$ implies a perfect impedance match (no reflection from terminal impedance) at port n.

These definitions may be written as [1]

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{2.14}$$

where the matrix containing the S-parameters is referred to as the scattering matrix or S matrix, which may simply be denoted by [S].

The S-parameters are in general complex, and it is convenient to express in term of amplitudes and phases, $S_{mn} = |S_{mn}|e^{j\phi_{mn}}$ for m, n = 1, 2. Amplitudes are given in decibels (dB), which are defined as [1]

$$|S_{mn}| = 20\log_{10}|S_{mn}| \text{ dB} \quad \text{for m, n = 1, 2} \tag{2.15}$$

For filter characterization, there is two parameters define as [1]:

$$L_A = -20\log_{10}|S_{mn}| \text{ dB} \quad \text{for m, n = 1, 2 (m} \neq \text{n)} \tag{2.16}$$

$$L_R = 20\log_{10}|S_{nn}| \text{ dB} \quad \text{for n = 1, 2} \tag{2.17}$$

where L_A denotes the insertion loss between ports n and m and L_R represents the return loss at port n.

The voltage standing wave ratio, VSWR is defined as [1]

$$VSWR = \frac{1+|S_{nn}|}{1-|S_{nn}|} \tag{2.18}$$

CHAPTER 3

RESONATOR

This chapter concentrates on resonator fundamental. First, the characteristics of resonator are discussed. Then, the microstrip resonator and the advantages of quasi-lumped element resonator are proposed. Finally, fundamental of interdigital capacitor is presented.

3.1 Introduction

Microwave resonator is used in a variety of applications, including filters, oscillators, frequency meters, and tuned amplifiers. Resonator is an important component in the filter structure. Resonator is used in the filter design that is utilized to pass the required frequency band only. Many types of resonator can be used in the design of a filter. There are microstrip resonator, distributed resonator, lumped element resonator and quasi-lumped element resonator. The operation of microwave resonator is very similar to the RLC lumped-element resonant circuit.

3.2 Characteristic of Resonator

The quasi-lumped element resonator typically been used in filter design. Resonator is the combination of inductance, L and capacitance, C. The impedance at resonance is equal to zero (Z=0). The resonant frequency of resonator is given as below [3]:

$$f_o = \frac{1}{2\pi\sqrt{LC}} \tag{3.1}$$

In the practical circuit, resistance, R and conductance, G elements can affect resonator has power losses. Quality factor, Q is an important parameter to determine the frequency selectivity and energy losses of the resonator.

For series RLC resonant circuit as illustrated in Figure 3.1, the input impedance, Z_{in} is [2]

$$R + jwL + \frac{1}{jwC} \approx R + j2\delta wL \approx R + j\frac{2RQ\delta w}{w_o} \tag{3.2}$$

where w_o is the resonant frequency, which is defined as [2]

$$w_o = \frac{1}{\sqrt{LC}} \tag{3.3}$$

and unloaded Q factor is given as below [3]

$$Q_0 = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 CR} \tag{3.4}$$

then the external Q, Q_{Ext} can be expressed as [2]

$$Q_{Ext} = \frac{w_o L}{R_L} \tag{3.5}$$

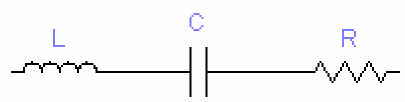


Figure 3.1: Series RLC resonator.

For parallel RLC resonant circuit as illustrated in Figure 3.2, the input impedance, Z_{in} is [2]

$$\left(\frac{1}{R} + jwC + \frac{1}{jwL}\right)^{-1} \approx \left(\frac{1}{R} + j2\delta wC\right)^{-1} \approx \left(\frac{1}{R} + j\frac{2Q\delta w}{Rw_o}\right)^{-1} \tag{3.6}$$

where w_o is the resonant frequency, which is defined as [2]

$$w_o = \frac{1}{\sqrt{LC}} \tag{3.7}$$

and the unloaded Q factor is given as below [3]

$$Q_0 = \frac{\omega_0 C}{G} = \frac{R}{\omega_0 L} \tag{3.8}$$

then the external Q, Q_{Ext} can be expressed as [2]

$$Q_{Ext} = \frac{R_L}{w_o L} \tag{3.9}$$

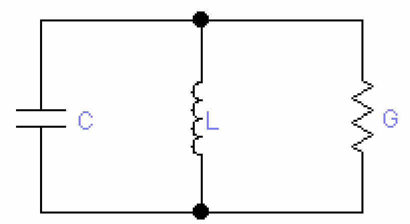


Figure 3.2: Parallel RLC resonator.

The loaded Q factor, Q_L is defined as below [3]

$$\frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_{Ext}} \tag{3.10}$$

Q_{Ext} is external Q factor that effect caused by external load resistor, R_L. From the resonator theory, the loaded quality factor (Q_L) can be expressed as [3]

$$Q_L = \frac{f_o}{f_1 - f_2} \tag{3.11}$$

The unloaded Q factor, Q_0 is defined as [3]

$$Q_0 = \frac{Q_L}{1 - 10^{-\frac{IL}{20}}} \tag{3.12}$$

Q_o (unloaded Q) is used to determine the quality of a resonant circuit. The unloaded Q is infinite, since no losses are included in the resonant circuit. Thus, there is no insertion loss in this case. Q_{Ext} (external load Q) is a measurement for a resonant circuit coupled to external circuit. Q_L (loaded Q) is a function for degree of coupling between the resonant circuit and external circuit.

Referring to the equation (3.11), f_1 is the upper cut-off frequency to determine the maximum frequency passed (with minimal loss) and f_2 is the lower cut-off frequency to decide the minimum frequency to be passed. f_o is the resonant frequency of resonator. IL is the insertion loss. Frequency response of resonator is shown in Figure 3.3.

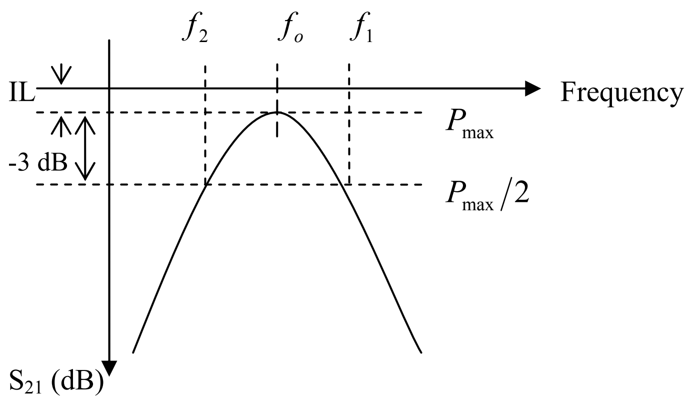


Figure 3.3: Frequency response of resonator.

Insertion loss, IL is the attenuation of signal received at the receiver port. Quality factor is an important parameter to determine the frequency selectivity and energy losses of the resonator. A high quality factor results in narrow frequency response, less losses and narrow bandwidth. Therefore, the higher the selectivity of a resonator, the more accuracy of the resonant frequency which is allowed to pass through the filter. Insertion loss is inversely proportional to the quality factor of resonator.

The magnitude and phase characteristics for S_{11} at different quality factor are shown below:

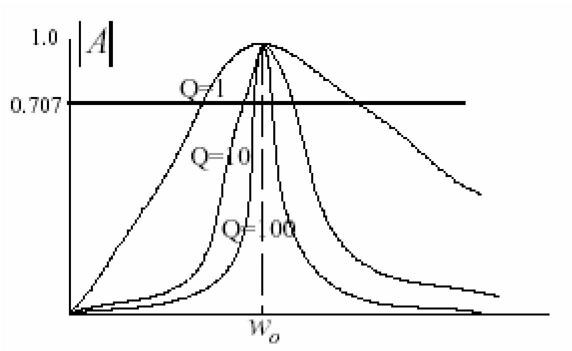


Figure 3.4: Magnitude graph of resonator.

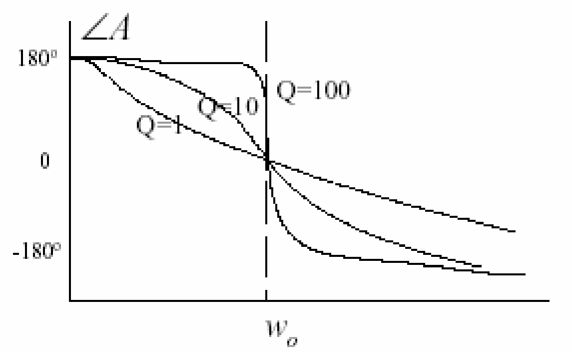


Figure 3.5: Phase graph of resonator.

A high value of Q results in narrow resonance response while a low value of Q results in wide resonance responce. Theoretically, resonator in the microstrip structure has low Q. However, microstrip resonator is low-cost and easy to fabricate. Therefore, in this filter design the microstrip quasi-lumped element resonator is designed.

3.3 Microstrip Resonator

A microstrip resonator is any structure that is able to contain at least one oscillating electromagnetic field. There are numerous forms of microstrip resonators. In general, mircostrip resonator for filter design may be described as a lumped-element or a quasi-lumped element resonator and distributed line or patch resonator [1]. In other words, the part of the resonator where the magnetic energy is stored is separated from the parts where the electric energy is stored. One advantage of this approach is a possible direct transformation of an equivalent circuit consisting of capacitors and inductors into a microstrip structure. This is however limited by the planar technology itself as well as fabrication restriction.

Lumped element or quasi-lumped element resonators are configured to form either a low, high or band pass filter, and the given number of elements is directly related to the Q and loss of the resonator. The simplest lumped-element or quasi-lumped element resonators formed by the lumped or quasi-lumped inductors and capacitors will obviously resonate at $w_0 = \frac{1}{\sqrt{LC}}$. However, they may resonate at some higher frequencies at which their sizes are no longer much smaller than a wavelength, and thus, by definition, they are no longer lumped or quasi-lumped elements [1].

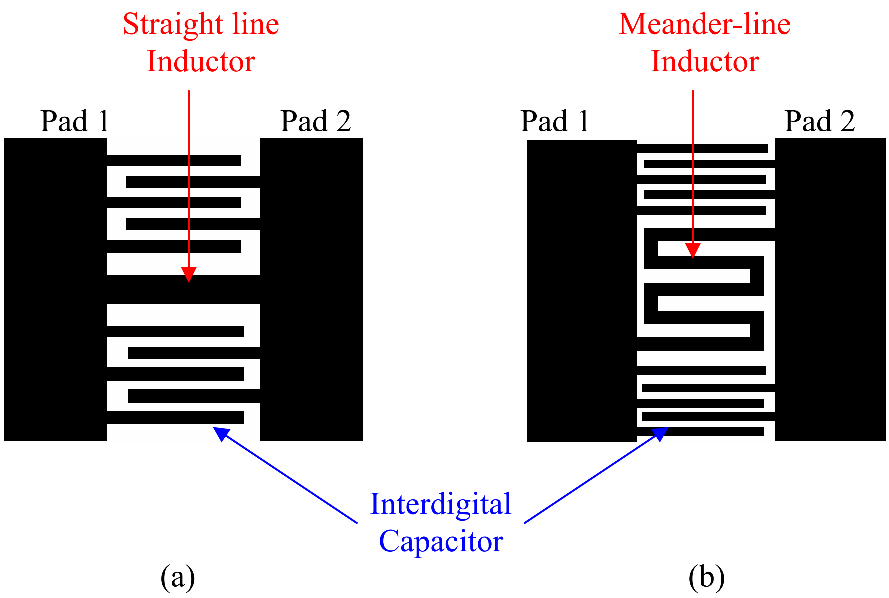
The distributed line resonator may be termed quarter-wavelength resonators, since they are $\lambda_{g0}/4$ long, where λ_{g0} is the guided wavelength at the fundamental resonant frequency, f_0. They can also resonant at other higher frequencies when $f \approx (2n-1)f_0$ for n= 2, 3, ···. Another typical distributed line resonator is the half-wavelength resonator, which is $\lambda_{g0}/2$ long at its fundamental resonant frequency, and can also resonate at $f \approx nf_0$ for n= 2, 3,··· [1].

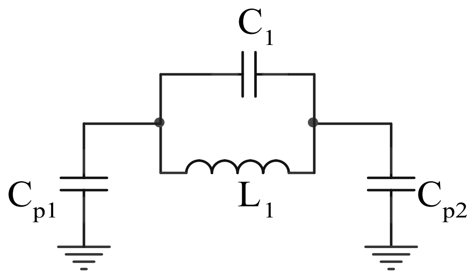
Generally, Lumped element or quasi-lumped element resonator lead to a significant size reduction and are therefore interesting for filter at lower frequencies. On the other hand, the unload quality factor of lumped element or quasi-lumped element resonator is significantly lower when compared with distributed resonator as metallization and dielectric losses have much higher influence. A realized structure is therefore always a compromise between miniaturization and tolerable losses [4].

In this filter design the microstrip quasi-lumped element resonator is designed. Quasi-lumped element resonator is the important part in the quasi-lumped element bandpass filter design. The advantage of using microstrip quasi-lumped element resonator is reducing the number of component is used or is solder on the PCB. Quasi-lumped element resonator is not allow any component solder on the resonant circuit. Beside that, quasi-lumped element resonator structure is more low-cost and compact as compared to other resonators structure. In addition, the design theory is also more consice and simpler so the resonator is easy to design based on the spesification of the resonator. The resonator design is discussed in Chapter 5.

The quasi-lumped element resonator consists of an interdigital capacitor in parallel with a straight strip inductor. The inductor is the centre finger shorted across the capacitor. The pads connected at both ends of the structure act as capacitors to ground, which can be adjusted to tune the resonant frequency of the resonator. The layout of the quasi-lumped element resonator and an equivalent circuit of the structure are shown in Figure 3.6. The capacitor C_1 is an interdigital capacitor, an inductor L_1 is the microstrip inductor while capacitor C_{p1} and C_{p2} are the pad capacitors [5].

Beside that, the new resonator structure consists of an interdigital capacitor in parallel with a meander-line inductor, with a shunt capacitor to earth at the both ends. This is shown in Figure 3.6(b). This structure is more compact than the resonator structure in Figure 3.6(a).





(c)

Figure 3.6: Quasi-lumped element resonator structure (a) a straight line inductor (b) a meander-line inductor (c) Equivalent circuit of the structure.

In this dissertation, the quasi-lumped element resonator used in the filter design consists of an interdigital capacitor in parallel with a straight-line inductor or a meander line inductor is designed. Thus, the interdigital capacitor is one of the main element is used in this project. Therefore, the fundamental of the interdigital capacitor design will be discussed. Beside that, a microstrip inductor is the centre finger shorted across the capacitor. Microstrip inductor is designed base on the value of length, I_L and width, w_I in the square shape or meander line shape.

3.4 Interdigital Capacitor

The interdigital (or interdigitated) capacitor is an element for producing a capacitor such as high pass characteristic using microstrip lines. The shape of conductors is defined by the parameters shown in Figure 3.7. Notice that the long conductors or "fingers" provide coupling between the input and output ports across the gaps [6].

Typically, the gaps between fingers, G and the gap at the end of the fingers, GE are the same. The length, L and width, W of the fingers are also specified. Since the conductors are mounted on a substrate so the characteristics will also affect performance [6]. The important parameters in the microstrip line will affect performance are the height of the substrate, h and dielectric constant, ε_r. In addition, the thickness of the conductor, t and resistivity, ρ will also impact the electrical characteristics [6]. The fundamentals of microstrip line have been demonstrated in Chapter 2. Please refer to Figure 2.1 and 2.2 shows the geometry of a microstrip line.

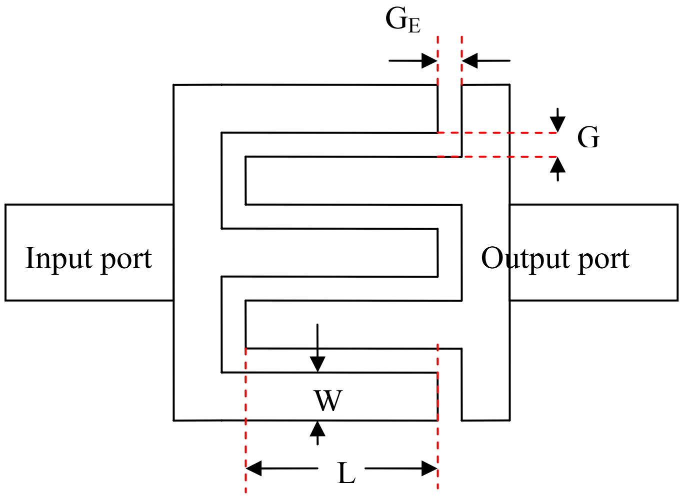


Figure 3.7: Microstrip interdigital capacitor geometry.

The design objectives are generally to provide the desired capacitance at the design frequency in a reasonable area. The dielectric constant is often given, since the printed circuit board may have other uses. The capacitance increases while the gaps are decreased. Manufacturing tolerances may dictate the smallest repeatable gap. Reducing the width of the fingers reduces the required board area, but increases the characteristic impedance of the line and in general lowers the effective capacitance. In addition, increasing the length of the fingers increases the capacitance, but increases the required board area [6].

The amount of capacitance is very small in the interdigital capacitor design. To obtain the larger values of capacitance, there are a few examples of design options. In general, these cause increases in the number of fingers, increases in the required board area and increasing the length of fingers increase the width and length of the capacitor, respectively [6]. Figure 3.8 depicts the interdigital capacitor after fabrication.

Figure 3.8: Interdigital capacitor.

According to J. P Silver [7], normally, a resonators need to be lightly coupled in order to maintain a high Q, this can be done by using a filter arrangement or by using very small value capacitors. Normal chip capacitors can go as low as 0.1pF, but for smaller capacitance it is convenient to use transmission line interdigital capacitors.

Literature review on the interdigital capacitor is very scarce so a basic design formula was used to get the initial dimensions and the final dimensions were optimized during RF simulations. The basic formula for the interdigital capacitor is given by

$$C = 0.83(N_F - 1) \bullet L \tag{3.13}$$

where N_F is the number of fingers, L is the length of fingers in cm and C is the capacitance in pF.

The resonators can be end coupled or parallel coupled using the gaps between them as the low value coupling capacitors. It is also possible to use interdigital capacitors to generate coupling capacitors less than 1pF. The interdigital capacitor performs coupling to blocking of DC.