OPTIMAL DESIGN OF DUAL BAND BAND PASS FILTER USING STEPPED IMPEDANCE RESONATORS

A thesis report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

in

Electronics and communication engineering

Submitted By

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SHRI VISHNU ENGINEERING COLLEGE FOR WOMEN,

(AUTONOMOUS)

Approved by AICTE & Permanently Affiliated to JNTUK, Kakinada

Vishnupur , Bhimavaram-534202,A.P.,INDIA

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CERTIFICATE

This is to certify that the thesis entitled, "**Optimal Design of Dual Band Band Pass Filter using Stepped Impedance Resonators** " is being submitted by **BH .V.L.S.D.N.Jyothi (17B01A0410), B.Sai Srilekha (17B01A0413), D.Satya Sree V L Prasanna (17B01A0427) and D.Lalitha Prasanna (17B01A0461)** in partial fulfillment of the requirement for the award of Bachelor of Technology in **Electronics and Communication Engineering**, to Shri Vishnu Engineering College for Women (Autonomous), Bhimavaram is a record of bonafied work done by them under our guidance and supervision.

Supervisor	Head of the Department
Mr.G. Challa Ram	Dr.K.Padma Vasavi, Ph D
Assistant Professor	Professor & Head
Department of ECE	Department of ECE

DECLARATION

We are the students of Shri Vishnu Engineering College for Women hereby declare that this project work entitled "Optimal Design of Dual Band Band Pass Filter using Stepped Impedance Resonators" being submitted to the Department of ECE, SVECW(A) affiliated to JNTU, Kakinada for the award of BACHELOR OF TECHNOLOGY in Electronics and Communication Engineering is a record of bonafide work done by us and it has not been submitted to any other Institute or University for the award of any other degree or prize.

Project Associates

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Project Associates

ABSTRACT

Firstly, quarter wavelength SIRs are designed to generate their first two resonant modes in the two specified passbands, and they are sequentially cascaded by alternative J and K inverters. In design, SIRs need to be chosen not only to satisfy the prescribed dual-band central frequencies, but also to compensate for the deficient values of k inverters at these two frequencies. Following that, a generalized synthesis method is extensively described for design and exploration of novel dual-band filters on the microstrip-line topology. A second-order dual-band Chebyshev bandpass filters with dual passbands are at 5.8 and 1.8 GHz is designed and investigated by full wave Electromagnetic simulation

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION:

As the tremendous demand for Multi-band bandpass filters (BPFs) with excellent performance characteristics and compact size is need of an hour. Due to the distinct properties of multiband BPFs, such as wide rejection band, deep transmission zeros, high selectivity, sharp roll-off rate, and tunable behavior, they have a specific place in the RF receivers. Therefore, this method demonstrates good dual-pass band performance with sharpened out-of-band rejection skirts and deepened mutual band isolation.

1.2 OBJECTIVE:

- The main objective of the project is to design a Dual-band band pass filter using Quarter wavelength SIR with pass bands at 5.8GHz and 1.8GHz.
- In order to improve the characteristics SIR's are sequentially cascaded by alternative J and K inverters.

1.3 BACKGROUND:

With the advance of modern wireless communication systems, a single transceiver operating at multiple frequency bands had become very popular. The development of wide-band communications has increased the application of wide-band microwave filters. Diverse design techniques and geometries have been proposed to design wide-band bandpass filters (BPFs) over the last few years. The dual-band bandpass filter is another essential microwave frontend component for integration of miniaturized dual-band systems.

Band pass filters (BPFs) have an essential role in different wireless communication systems especially in microwave systems that are constrained with a small occupied area for microwave components and circuits. This type of filters should satisfy the following specifications, such as size compactness, harmonics suppression, high selectivity, and insertion loss reduction in the achieved band to be compatible with the modern communication systems. Transmission zeros should also be taken into account in filter design to achieve the desired selectivity. The most intuitive method to implement a dual-band bandpass filter is to simply combine two bandpass filters with two distinctive central frequencies in parallel, at the cost of enlarged circuit size and complicated matching network. In a dual-band bandpass filter was constituted by embedding a band stop filter inside a wideband bandpass filter. Recently, a large number of dual-band bandpass filters have been designed based on the two different-order resonant modes of various transmission-line resonators namely, a dual-mode resonator.

1.4 LITERATURE SURVEY:

1.4.1 SYNTHESIS METHOD FOR EVEN-ORDER SYMMETRICAL CHEBYSHEV BANDPASS FILTERS WITH ALTERNATIVE J/K INVERTERS AND λ/4 RESONATORS SONGBAI ZHANG, STUDENT MEMBER, IEEE, AND LEI ZHU, FELLOW, IEEE

MICROWAVE bandpass filters based on λ/4 resonators possess several attractive features, such as compact size, relaxed inter-resonator coupling, and wide upper stopband. In a prominent λ/4 resonator interdigital bandpass filter was developed where each resonator had its own ground portrays the schematics of two conventional Chebyshev bandpass filter prototypes with third and fourth order, respectively. In these networks, three or four λ /4 resonators are cascaded in series by alternative J and K inverters. Since and inverters could both be easily implemented on the uniplanar coplanar waveguide (CPW) structure, there were plenty of examples of bandpass filters designed and fabricated on a CPW structure. In particular, this kind of filter was widely used for exploration of high-temperature superconductor (HTS) filters and the milli-meter-wave integrated filter. On the other hand, two second-order microstrip bandpass filters were proposed based on λ/4 resonators in the alternative J-K-J form and the K inverter was implemented with a shunt open-end stub with a length shorter or longer than the λ/4, whereas a via-hole was employed to function as a simple inverter. Following the work in few compact fourth-order microstrip bandpass filters were reportedly constituted with quasi-elliptic functionality and widened upper stopband.

Using the λ/4 stepped-impedance resonators (SIRs), compact filters with improved upper stopband performance were demonstrated and a dual-band bandpass filter was presented in with the use of the first two resonant modes in the λ/4 SIRs in the J-K-J form. However, only even-order Butterworth frequency responses were achieved although a few fourth-order filters on the specified quadruplet topology were designed on CPW and microstrip line topologies. Bandpass filters designed in fact heavily depends on the extensive tuning and optimization via the full-wave simulator rather than the expected synthesis method. No reported works really systematically addressed the synthesis design for the symmetrical bandpass filter based on the λ/4 resonators.

1.4.2 DUAL-BAND MICROSTRIP BANDPASS FILTER USING STEPPED-IMPEDANCE RESONATORS WITH NEW COUPLING SCHEMES YUE PING ZHANG AND MEI SUN

A DUAL-BAND filter is a key component of a radio transceiver in a dual-band wireless communication system. Intuitively, a dual-band filter can be realized with the combination of two single-band filters. However, this approach not only consumes twice the size of a single-band filter, but also requires additional external combining networks. Guo et al. have redesigned the two single-band filters so that one filter has a low-pass and the other a high-pass characteristic, thus one filter is open in the passband of the other, and as a result, there is no need of additional combining networks. Alternatively, the dual-band filter can be realized using resonators that consist of open or short stubs in parallel or in series to create two passbands with three transmission zeros. At first showed that three parallel open stubs are needed while Lee et al demonstrated that only two parallel open stubs are enough to behave as a resonator with dual-band properties. Tsai et al extended from parallel open to series open stubs and also found that filters with short stubs are duals of the ones with open stubs. The parameters of their duals can be easily obtained by using the duality transformations. Recently more, and more dual-band filters have been realized with stepped impedance resonators because of their dual-band behavior, simple structures, and well-established design methodology. In this paper, we also report on a dual-band filter using stepped-impedance resonators with the new coupling schemes. It is found that the new coupling schemes can improve both the layout compactness and performance of the dual-band filter. More importantly, the dual-band filter is further studied for a single-package solution of dual-band radio transceivers. The dual-band filter is, therefore, integrated into a ceramic ball grid array package. The integration is analyzed with an emphasis on the connection of the dual-band filter to the antenna and transceiver die.

1.5 PROBLEM IDENTIFICATION:

Dual band pass filters can be realised by connecting two different filter circuits.

The problem associated with Dual Band pass filters are large circuit size causes high insertion loss. To overcome that Dual band pass filter designed by using SIR has small circuit size there by reducing insertion loss. Dual-mode resonator are composed of open/short circuit stubs attached to a transmission line resonator.

Another problem while designing even dual-band filter was quite difficult in theory to mathematically evaluate and stepped impedance transmission line and coupling degrees can only found using cut-try methods. In SIR we can evaluate coupling degrees by using fractional bandwidth and resonator's reactance slope.

1.6 ORGANISATION OF THESIS:

CHAPTER - II

FILTERS

2.1 FILTERS

Prototype filters are electronic filter designs that are used as a template to produce a modified filter design for a particular application. They are an example of a nondimensionalised design from which the desired filter can be scaled or transformed. They are most often seen in regard to electronic filters and especially linear analogue passive filters. However, in principle, the method can be applied to any kind of linear filter or signal processing, including mechanical, acoustic and optical filters.

Filters are required to operate at many different frequencies, impedances and bandwidths. The utility of a prototype filter comes from the property that all these other filters can be derived from it by applying a scaling factor to the components of the prototype. The filter design need thus only be carried out once in full, with other filters being obtained by simply applying a scaling factor.

Especially useful is the ability to transform from one bandform to another. In this case, the transform is more than a simple scale factor. Bandform here is meant to indicate the category of passband that the filter possesses. The usual band forms are low pass, high pass, band pass and band stop, but others are possible. In particular, it is possible for a filter to have multiple pass bands. In fact, in some treatments, the band stop filter is considered to be a type of multiple passband filter having two pass bands. Most commonly, the prototype filter is expressed as a low pass filter, but other techniques are possible.

2.1.1 LC FILTERS

LC filters refer to circuits consisting of a combination of inductors (L) and capacitors (C) to cut or pass specific frequency bands of an electric signal. Capacitors block DC currents but pass AC more easily at higher frequencies. Conversely, inductors pass DC currents as they are, but pass AC less easily at higher frequencies. In other words, capacitors and inductors are passive components with completely opposite properties. By combining these components with opposite properties, noise can be cut and specific signals can be identified.

2.2 LOW PASS FILTER

Low-pass filters are filter circuits that pass DC and low-frequency signals and cut high-frequency signals. They are the most widely used filter circuits and are mainly used to cut high-frequency noise. In audio, they are also used to cut treble/mid-range sound components of bass speakers.

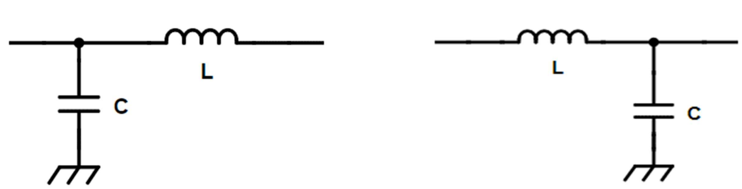
2.2.1 TYPES OF LOW-PASS FILTERS

Although capacitors and inductors each have noise removal capabilities on their own, combining these two components will achieve a significant level of noise removal. Inductors connected in series block high-frequency noises, whereas capacitors connected in parallel work to form high-frequency noises.

However, noise removal effects change depending on the magnitude of the external impedance on the input and output sides. For example, even if a low-impedance capacitor is used to bypass noise, the noise will flow to the load side if the output impedance is lower. Conversely, even if a high-impedance capacitor is used to block noise, the noise will flow to the load side if the output impedance is higher. Therefore, when the external impedance is high, capacitors should be placed nearby, and when it's low, inductors should be used. The four types of low-pass filters shown below are used by taking external impedances into consideration

1. L-TYPE-I FILTER

   When the input impedance ⇒ High
   and the output impedance ⇒ Low



(a) (b)

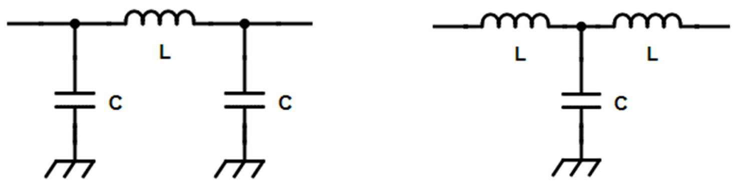
Fig. 2.2.1. (a) L-Type Filter-I (b) L-Type Filter-II

2. L-TYPE-II FILTER

   When the input impedance ⇒ Low
   and the output impedance ⇒ High

3. π-TYPE FILTER

   When the input impedance ⇒ High
   and the output impedance ⇒ High



(a) (b)

Fig. 2.2.2. (a) π-Type Filter (b) T-Type Filter

4. T-TYPE FILTER

   When the input impedance ⇒ Low
   and the output impedance ⇒ Low

2.3 BAND PASS FILTER

Band pass filters using LC components, i.e. inductors and capacitors are used in a number of radio frequency applications. These filters enable a band of frequencies to be passed through the filter, while those in the stop band of the band pass filter are rejected.

These filters are typically used where a small band of frequencies need to be passed through the filter and all others rejected by the filter.

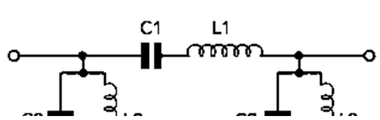


Fig 2.3.1. Basic Band Pass Filter

In electronics and signal processing, a filter is usually a two-port circuit or device which removes frequency components of a signal (an alternating voltage or current). A band-pass filter allows through components in a specified band of frequencies, called its passband but blocks components with frequencies above or below this band. This contrasts with a high-pass filter, which allows through components with frequencies above a specific frequency, and a low-pass filter, which allows through components with frequencies below a specific frequency. In digital signal processing, in which signals represented by digital numbers are processed by computer programs, a band-pass filter is a computer algorithm that performs the same function. The term band-pass filter is also used for optical filters, sheets of colored material which allow through a specific band of light frequencies, and acoustic filters which allow through sound waves of a specific band of frequencies.

An example of an analogue electronic band-pass filter is an RLC circuit (a resistor–inductor–capacitor circuit). These filters can also be created by combining a low-pass filter with a high-pass filter.

A band pass signal is a signal containing a band of frequencies not adjacent to zero frequency, such as a signal that comes out of a band pass filter.

An ideal band pass filter would have a completely flat passband: all frequencies within the passband would be passed to the output without amplification or attenuation, and would completely attenuate all frequencies outside the passband.

In practice, no band pass filter is ideal. The filter does not attenuate all frequencies outside the desired frequency range completely; in particular, there is a region just outside the intended passband where frequencies are attenuated, but not rejected. This is known as the filter roll-off, and it is usually expressed in dB of attenuation per octave or decade of frequency. Generally, the design of a filter seeks to make the roll-off as narrow as possible, thus allowing the filter to perform as close as possible to its intended design. Often, this is achieved at the expense of pass-band or stop-band ripple.

The bandwidth of the filter is simply the difference between the upper and lower cutoff frequencies. The shape factor is the ratio of bandwidths measured using two different attenuation values to determine the cut-off frequency, e.g., a shape factor of 2:1 at 30/3 dB means the bandwidth measured between frequencies at 30 dB attenuation is twice that measured between frequencies at 3 dB attenuation.

Optical band-pass filters are common in photography and theatre lighting work. These filters take the form of a transparent coloured film or sheet.

Band pass filters can also be used outside of engineering-related disciplines. A leading example is the use of band pass filters to extract the business cycle component in economic time series. This reveals more clearly the expansions and contractions in economic activity that dominate the lives of the public and the performance of diverse firms, and therefore is of interest to a wide audience of economists and policy-makers, among others.

Economic data usually has quite different statistical properties than data in say, electrical engineering. It is very common for a researcher to directly carry over traditional methods such as the "ideal" filter, which has a perfectly sharp gain function in the frequency domain. However in doing so, substantial problems can arise that can cause distortions and make the filter output extremely misleading. As a poignant and simple case, the use of an "ideal" filter on white noise (which could represent for example stock price changes) creates a false cycle. The use of the nomenclature "ideal" implicitly involves a greatly fallacious assumption except on scarce occasions. Nevertheless, the use of the "ideal" filter remains common despite the filter's serious limitations and likelihood of key deceptions.

Fortunately, band-pass filters are available that steer clear of such errors, adapt to the data series at hand, and yield more accurate assessments of the business cycle fluctuations in major economic series like Real GDP, Investment, and Consumption - as well as their sub-components. An early work, published in the Review of Economics and Statistics in 2003, more effectively handles the kind of data arising in macroeconomics. In this paper entitled "General Model-Based Filters for Extracting Trends and Cycles in Economic Time Series", Andrew Harvey and Thomas Trimbur develop a class of adaptive band pass filters. These have been successfully applied in copious situations involving business cycle movements in myriad nations in the international economy.

A band-pass filter can be characterized by its Q factor. The Q-factor is the reciprocal of the fractional bandwidth. A high-Q filter will have a narrow passband and a low-Q filter will have a wide passband. These are respectively referred to as narrow-band and wide-band filters.

One of the easiest and most straightforward forms of filter to design is the constant-k filter. Like the high pass filters and the low pass filters, there are two topologies that are used for these filters, namely the Pi and the T configurations. Rather than having a single element in each leg of the filter as in the case of the low pass and high pass filters, the band pass filter has a resonant circuit in each leg. These resonant circuits are either series or parallel tuned LC circuits.

(a) (b)

Fig 2.3.2. (a) T-Type Band pass LC Filter(b) п-Type Band Pass LC Filter

2.3.1 BAND PASS FILTER TYPES

There are many types of band pass filter circuits are designed. Let’s explain the major types of filter circuits in detail.

1. ACTIVE BAND PASS FILTER

The active band pass filter is a cascading connection of high pass and low pass filter with the amplifying component as shown in the below figure.

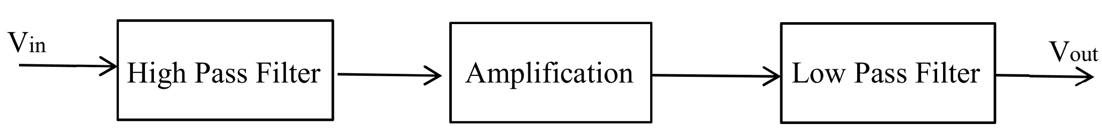


Fig 2.3.3. Block Diagram of Active Band Pass Filter

2. PASSIVE BAND PASS FILTER

The passive filter used only passive components like resistors, capacitors, and inductors. Therefore, the passive band pass filter is also used passive components and it does not use the op-amp for amplification. So, like an active band pass filter, the amplification part is not present in a passive band pass filter.

3. RLC BAND PASS FILTER

As the name suggests RLC, this band pass filter contains only resistor, inductor and capacitor. This is also a passive band pass filter.

According to the connection of RLC, there are two circuit configurations of the RLC band pass filter. In the first configuration, the series LC circuit is connected in series with the load resistor. And the second configuration is parallel LC circuit is connected in parallel with a load resistor

4. WIDE BAND PASS FILTER

According to the size of bandwidth, it can divide into a wide band pass filter and a narrow band pass filter. If the Q-factor is less than 10, the filter is known as a wide pass filter. As the name suggests, the bandwidth is wide for the wide band pass filter.

In this type of filter, the high pass and low pass filter are different sections as we have seen in the passive band pass filter. Here, both filters are passive.

Another circuit arrangement can be done by using an active high pass and an active low pass filter.

5. NARROW BAND PASS FILTER

The band pass filter which has a quality factor greater than ten. The bandwidth of this filter is narrow. Therefore, it allows the signal with a small range of frequencies. It has multiple feedback. This band pass filter uses only one op-amp.

This band pass filter is also known as multiple feedback filter because there are two feedback paths. In this band pass filter, the op-amp is used in non-inverting mode.

2.4 CHEBYSHEV & BUTTERWORTH FILTER

2.4.1 CHEBYSHEV FILTER

Chebyshev filters are analog or digital filters having a steeper roll-off than Butterworth filters, and have passband ripple (type I) or stopband ripple (type II). Chebyshev filters have the property that they minimize the error between the idealized and the actual filter characteristic over the range of the filter but with ripples in the passband. This type of filter is named after Pafnuty Chebyshev because its mathematical characteristics are derived from Chebyshev polynomials. Type I Chebyshev filters are usually referred to as "Chebyshev filters", while type II filters are usually called "inverse Chebyshev filters".

Because of the passband ripple inherent in Chebyshev filters, filters with a smoother response in the passband but a more irregular response in the stopband are preferred for certain applications.

2.4.2 BUTTERWORTH FILTER

A Butterworth filter is a type of signal processing filter designed to have a frequency response as flat as possible in the passband. Hence the Butterworth filter is also known as “maximally flat magnitude filter”. It was invented in 1930 by the British engineer and physicist Stephen Butterworth in his paper titled “On the Theory of Filter Amplifiers”.

The frequency response of the Butterworth filter is flat in the passband (i.e. a band pass filter) and roll-offs towards zero in the stopband. The rate of roll-off response depends on the order of the filter. The number of reactive elements used in the filter circuit will decide the order of the filter.

The inductor and capacitor are reactive elements used in filters. But in the case of Butterworth filter only capacitors are used. So, the number of capacitors will decide the order of the filter.

2.4.3 BUTTERWORTH FILTER APPLICATIONS

The applications of a Butterworth filter are listed below:

- Because of the maximal flat frequency response in the passband, it is used as an anti-aliasing filter in data converter applications.
- The Butterworth filter is used in the audio processing application. An efficient audio noise reduction tool can be developed using a Butterworth filter.
- It is also used in various communication and control systems.
- It is used in radar to design the display of radar target tracking.
- It is used for motion analysis.

2.4.4 DIFFERENCE BETWEEN BUTTERWORTH AND CHEBYSHEV FILTER

- The order of the Butterworth filter is higher than the Chebyshev filter for the same desired specifications
- Butterworth filter requires more hardware whereas Chebyshev filter requires less hardware.
- In Butterworth filter there is no ripple in passband and stopband of frequency response but for Chebyshev filter there is either ripple in passband or stopband.
- Butterworth filter doesn’t have any types whereas Chebyshev filter has two types; type-1 and type-2.
- The Butterworth filter has a wider transition band compared to the Chebyshev filter.
- The cutoff frequency of butterworth filter is not equal to the passband frequency whereas the cutoff frequency of Chebyshev filter is equal to the passband frequency.

2.5 DUAL BAND BAND PASS FILTER

Dual-band bandpass filters (BPFs) provide the functionality of two separate filters, but in the size of a single filter. They have become an important part of many multiple-band communications systems, passing desired channels while rejecting unwanted interference and noise.

By using a pair of quarter-wave (λ/4) uniform-impedance resonators (UIRs) and a pair of λ/4 stepped-impedance resonators (SIRs), it was possible to construct a dual-band BPF. The filter, with tunable center frequencies, provides good selectivity and high out-of-band suppression, using folded resonators for extremely compact size.

A number of methods have been developed for the design of dual-band BPFs.They can be designed by using two dissimilar BPFs in parallel or cascade with common input/output (I/O) coupling structure. While this technique makes it possible to adjust the passband frequencies independently, it leads to a filter with relatively large size. In this two separate passbands were created from one initially wide passband by forming a stopband between the two bands. Dual-mode resonators are widely used in dual-band BPFs. This filter's passband frequencies are not independent and the filter circuit is relatively large.

Another popular way to design dual-band BPFs is by employing multimode resonators. This approach leads to a dual-band BPF with small size, but with limited independent tuning of the passband frequencies due to the internal structure of the filter.

In order to design a dual-band bandpass filter with prescribed dual-passband bandwidths, it is critical to individually synthe_size the expected dual-band inter-resonator coupling degrees. For a dual-band coupled-line inverter, a common synthesized method was to construct various design graphs for the dual_band capacitive coupling degrees with varied coupling lengths and gaps, and the realizable bandwidths were restricted to the common region of all design graphs. However, initial estimation on coupling lengths and gaps highly relies on time-consuming cut and try method. In contrast, the dual band K inverter has rarely been adopted in dual band filter applications. The K value of a metallic via monotonically increases with frequency, thus blocking it from the application in dual-band filters with adjustable dual pass bands.

2.6 TRANSFORMATIONS

2.6.1 FREQUENCY AND ELEMENT TRNSFORMATIONS

The frequency transformation, which is also referred to as frequency mapping, is required to map, for example, a Chebyshev response in the lowpass prototype frequency domain to that in the frequency domain ω in which a practical filter response such as lowpass, highpass, bandpass, and band stop are expressed. The frequency transformation will have an effect on all the reactive elements accordingly, but no effect on the resistive elements.

In addition to the frequency mapping, impedance scaling is also required to accomplish the element transformation. The impedance scaling will remove the $g_0 = 1$ normalization and adjusts the filter to work for any value of the source impedance denoted by Z_0. For our formulation, it is convenient to define an impedance scaling factor γ_0 as

$$\gamma_0 = \begin{cases} Z_0/g_0 & \text{for } g_0 \text{ being the resistance} \\ g_0/Y_0 & \text{for } g_0 \text{ being the conductance} \end{cases}$$

where $Y_0 = 1/Z_0$ is the source admittance. In principle, applying the impedance scaling upon a filter network in such a way that has no effect on the response shape.

$$\begin{aligned} L &\rightarrow \gamma_0 L \\ C &\rightarrow C/\gamma_0 \\ R &\rightarrow \gamma_0 R \\ G &\rightarrow G/\gamma_0 \end{aligned}$$

Let g be the generic term for the lowpass prototype elements in the element transformation to be discussed. Because it is independent of the frequency transformation, the following resistive-element transformation holds for any type of filter:

$$\begin{aligned} R &= \gamma_0 g \quad \text{for } g \text{ representing the resistance} \\ G &= \frac{g}{\gamma_0} \quad \text{for } g \text{ representing the conductance} \end{aligned}$$

2.6.2 BANDPASS TRANSFORMATION:

Assume that a lowpass prototype response is to be transformed to a bandpass response having a passband $\omega_2 - \omega_1$, where ω_1 and ω_2 indicate the passband-edge angular frequency. The required frequency transformation is

$$\Omega = \frac{\Omega_c}{FBW}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$$

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0}$$

$$\omega_0 = \sqrt{\omega_1 \omega_2}$$

where ω_0 denotes the center angular frequency and FBW is defined as the fractional bandwidth. If we apply this frequency transformation to a reactive element g of the lowpass prototype, we have

$$j\Omega g \rightarrow j\omega \frac{\Omega_c g}{FBW\omega_0} + \frac{1}{j\omega}\frac{\Omega_c \omega_0 g}{FBW}$$

which implies that an inductive/capacitive element g in the lowpass prototype will transform to a series/parallel LC resonant circuit in the bandpass filter. The elements for the series LC resonator in the bandpass filter are

$$L_s = \left(\frac{\Omega_c}{FBW\omega_0}\right)\gamma_0 g \qquad C_s = \left(\frac{FBW}{\omega_0 \Omega_c}\right)\frac{1}{\gamma_0 g} \qquad \text{for } g \text{ representing the inductance}$$

where the impedance scaling has been taken into account as well. Similarly, the elements for the parallel LC resonator in the bandpass filter are

$$C_p = \left(\frac{\Omega_c}{FBW\omega_0}\right)\frac{g}{\gamma_0} \quad \text{for } g \text{ representing the capacitance}$$
$$L_p = \left(\frac{FBW}{\omega_0\Omega_c}\right)\frac{\gamma_0}{g}$$

2.6.3 RICHARDS' TRANSFORMATION:

Distributed transmission-line elements are of importance for designing practical microwave filters. A commonly used approach to the design of a practical distributed filter is to seek some approximate equivalence between lumped and distributed elements. Such equivalence can be established by applying Richards' transformation. Richards showed that distributed networks, comprised of commensurate-length (equal electrical length) transmission lines and lumped resistors, could be treated in analysis or synthesis as lumped-element LCR networks under the transformation

$$t = \tanh\frac{lp}{v_p}$$

where p = σ + jω is the usual complex frequency variable, and l/vp is the ratio of the length of the basic commensurate transmission-line element to the phase velocity of the wave in such a line element. t is a new complex frequency variable, also known as Richards' variable. The new complex plane, where t is defined, is called the t-plane. For lossless passive networks p = jω and the Richards' variable is simply expressed by

$$t = j\tan\theta$$

Where

$$\theta = \frac{\omega}{v_p} l = \text{the electrical length}$$

Assuming that the phase velocity vp is independent of frequency, which is true for TEM transmission lines, the electrical length is then proportional to frequency and may be expressed as

$$\theta = \theta_0 \omega / \omega_0$$

where θ0 is the electrical length at a reference frequency ω0. It is convenient for discussion to let ω0 be the radian frequency at which all line lengths are quarter-wave long with θ0 = π/2 and to let = tan θ, so that

$$\Omega = \tan\left(\frac{\pi}{2}\frac{\omega}{\omega_0}\right)$$

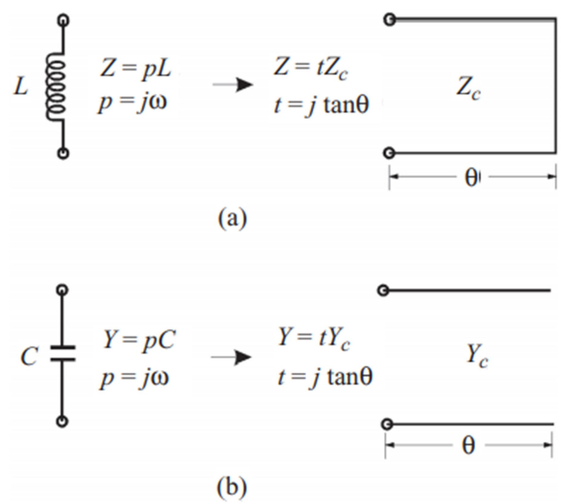


Fig. 2.6.1 Lumped- and distributed-element correspondence under Richards' transformation.

2.6.4 KURODA IDENTITIES

In designing transmission line filters, various network identities may be desirable to obtain filter networks that are electrically equivalent, but that differ in form or in element values.

Such transformations not only provide designers with flexibility, but also are essential, in many cases, to obtain networks that are physically realizable with physical dimensions. The Kuroda identities, form a basis to achieve such transformations, where the commensurate line elements with the same electrical length θ are assumed for each identity. The first two Kuroda identities interchange a unit element with a shunt open- or a series short-circuited stub, and a unit element with a series short- or a shunt open-circuited stub. The other two Kuroda identities, involving the ideal transformers, interchange stubs of the same kind. The Kuroda identities may be deduced by comparing the ABCD matrices of the corresponding networks.

2.7 APPLICATIONS

Bandpass filters are widely used in wireless transmitters and receivers. The main function of such a filter in a transmitter is to limit the bandwidth of the output signal to the band allocated for the transmission. This prevents the transmitter from interfering with other stations. In a receiver, a bandpass filter allows signals within a selected range of frequencies to be heard or decoded, while preventing signals at unwanted frequencies from getting through. Signals at frequencies outside the band which the receiver is tuned at, can either saturate or damage the receiver. Additionally they can create unwanted mixing products that fall in band and interfere with the signal of interest. Wideband receivers are particularly susceptible to such interference. A bandpass filter also optimizes the signal-to-noise ratio and sensitivity of a receiver.

In both transmitting and receiving applications, well-designed bandpass filters, having the optimum bandwidth for the mode and speed of communication being used, maximize the number of signal transmitters that can exist in a system, while minimizing the interference or competition among signals. Outside of electronics and signal processing, one example of the use of band-pass filters is in the atmospheric sciences. It is common to band-pass filter recent meteorological data with period range of, for example, 3 to 10 days, so that only cyclones remain as fluctuations in the data fields.

CHAPTER - III

RESONATOR

A resonator is a device or system that exhibits resonance or resonant behaviour. That is, it naturally oscillates with greater amplitude at some frequencies, called resonant frequencies, than at other frequencies. The oscillations in a resonator can be either electromagnetic or mechanical. Resonators are used to either generate waves of specific frequencies or to select specific frequencies from a signal. Musical instruments use acoustic resonators that produce sound waves of specific tones. Another example is quartz crystals used in electronic devices such as radio transmitters and quartz watches to produce oscillations of very precise frequency.

3.1.STEPPED IMPEDANCE RESONATOR:

Stepped Impedance Resonator (SIR) can be considered as two transmission lines of different lengths and characteristic impedance. Its design parameters are controlled by both length and impedance ratio. The current density along the transmission line can be controlled by the alternating segments of high and low characteristics impedance lines. Due to its high Q-factor and compactness, it has been employed in filters, oscillators and mixers.

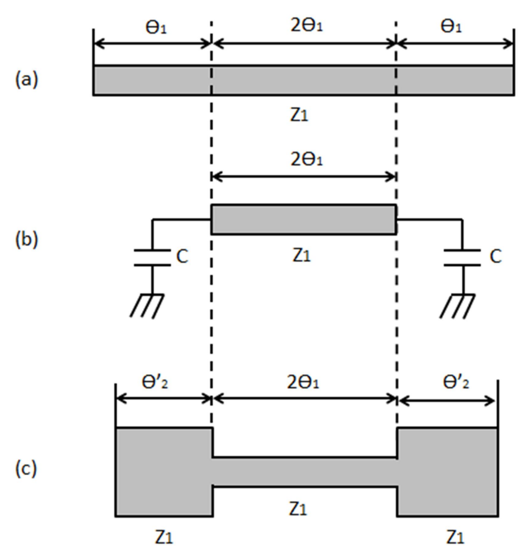


Fig.3.1.1. Structural variations of (a)Uniform Impedance Resonator(UIR) (b)Capacitor loaded UIR (c)Stepped- Impedance Resonator (SIR).

The aim of development of SIR was to overcome the limitations like limited design parameter and spurious responses etc. of Uniform Impedance Resonator (UIR) and Capacitor loaded UIR. Fig.3.1.1 depicts the structural variations of (a) UIR, (b) Capacitor loaded UIR and (c) SIR. The condition of resonance for SIR signal is given by

$$\frac{Z_2}{Z_1} = \tan\beta_1 l_1 * \tan\beta_2 l_2 = K \qquad \text{--------(1)}$$

Where Z_1 is the impedance of narrow section, Z_2 is the impedance of wider section and θ_1 and θ_2 are the electric lengths of narrow and wider sections having characteristic impedance Z_1 and is given by

$$\theta_1 = \beta_1 l_1 \qquad \text{------(2)}$$

From equation (1), is given by

$$K = \frac{\tan\theta_1 * (\tan\theta_T - \tan\theta_1)}{(1+\text{ta}\ \ \theta_T * \tan\theta_1)} \qquad \text{------(3)}$$

And θ_T is the total electrical length of the transmission line and is given by

$$\theta_T = \theta_1 + \theta_2 \qquad \text{------(4)}$$

θ_T is minimum when

$$\theta_1 = \theta_2 = \tan^{-1}\sqrt{K} \qquad \text{------(5)}$$

Using equations (2) and (5)we get

$$\theta_{T(min)} = \tan^{-1}\left(\frac{2\sqrt{K}}{1-K}\right) \qquad \text{------(6)}$$

For $0 < K < 1$, we get the minimum line length of the resonator.

3.2.TYPES OF STEPPED IMPEDANCE RESONATOR:

SIR has three main types that can be employed in the composite transmission line as fundamental structure of transmission line namely: half wave, quarter wave and one wave.

1. λg/4 or QUARTER-WAVE SIR:

For application-oriented viewpoint, the λg /4 type SIR is the most attractive among various types of SIR. When quarter is compared with the half wave structure in the same frequency response then the dimension of quarter wave is small, which can be used in the design of band pass filter. It is also noteworthy that reducing a size and conceal of harmonic response. By using practical design examples using air-cavity type and dielectric-type coaxial SIR are introduced.The fundamental structure of Quarter-Wave SIR is displayed in Fig.3.2.1.

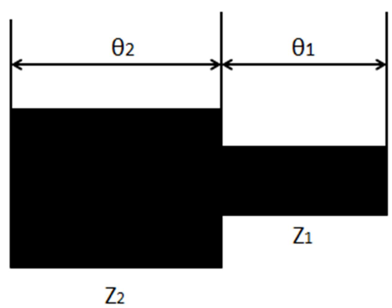


Fig.3.2.1. Basic Structure of λg/4-Type SIR.

2. λg/2 or HALF-WAVE SIR:

In half-wave SIR, SIR is composed of a strip line configuration, working in millimetre-wave band which may be beneficial for reducing the insertion loss. Fig.3.2.2 shows the basic structure of Half-Wave SIR.

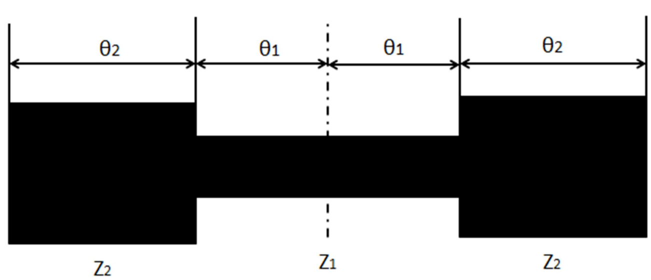


Fig.3.2.2. Basic Structure of λg/2-Type SIR.

Typical the structural variations of λg /2 type SIR are Straight type, Hairpin type, Ring type, Hairpin type with internal coupling and Ring type with internal coupling and are shown in Fig.3.2.3.

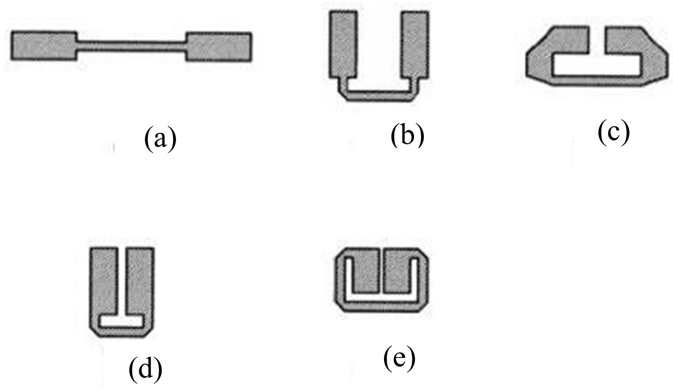


Fig. 3.2.3. Structural variations of half wave SIR (a) Straight type, (b)Hairpin type, (c) Ring type, (d) Hairpin type coupling, (e) Ring type coupling.

3. ONE-WAVE SIR:

In one-wave SIR, SIR is formed by use of micro-stripline, slot line or stripline structure. It has slow radiation loss characteristics and also has an ability to eliminate the parasitic components. In short-circuit and open-circuit, these components can be easily induced with quarter wave and half wave. The elementary structure of one-wave SIR is presented in Fig.3.2.4.

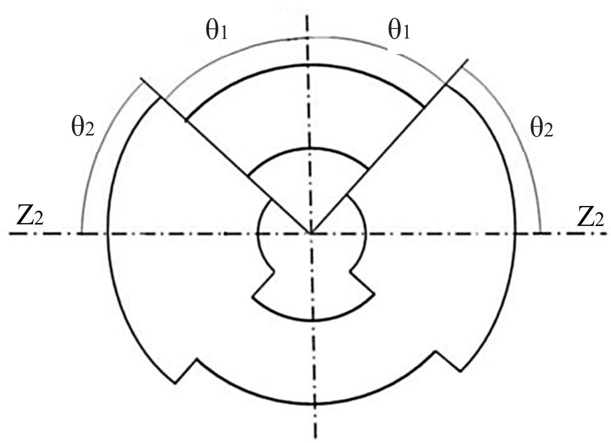


Fig.3.2.4. Basic Structure of λg- Type SIR.

There are two orthogonal resonance modes within a 1-λ ring resonator. They have been applied to filtering devices using these two modes. The practical application of this dual-mode ring resonator can be divided into two approaches; the first approach is by independently operating the two orthogonal modes in 4-port devices, the second approach is to utilize an internal coupling between the two degenerate modes for 2-port devices.

4. TRI- SECTION SIR:

Tri- Section SIR consists of three different characteristics impedances sections Z1, Z2 and Z3 as depicted in Fig.3.2.5. There are a number of ways to design multi-band filters, for example filters cascade, filters paralleled that have been exhibited including SIR, dual mode resonators, meandered open loop resonators, and photonic bandgap structures.

In 2005, tri- section SIR with short and low impedance section installed in usual two section SIR structure. Further, in 2008, three arbitrarily specified resonant frequencies, the impedance ratios of an equal electric length tri band transceiver (TR-SIR) can be calculated using a simple set of formulas, without help of any designed graph.

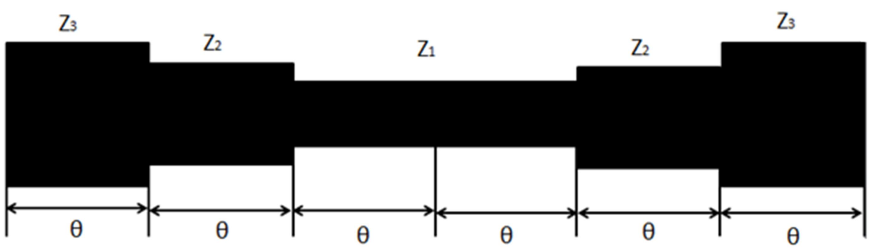


Fig.3.2.5. Tri-Section SIR.

5. COUPLED SIR:

The coupled SIR is used to replace two dual-band baluns combining with a single ended dual-band filter, or two single band balanced band pass filter in balanced RF front- end. With eight quarter wavelength type coupled SIRs in the balanced dual band filter provides the required differential mode dual band response. Further in 2007, SIR was designed for a new fourth-order balanced BPF to get the desired differential mode performance.

6. PSEUDO- INTERDIGITAL SIR:

The cascaded open-stub structure is employed to achieve the dual band BPF and result in large size and circuit complexity. A pseudo-interdigital SIRs (PI- SIRs) was introduced in 2007 to attain tuned impedance ratio and good transmission performance.

7. KA- BAND SIR:

A new coupling structure is proposed to increase the coupling coefficient which overcomes the limitation of fabricating craft in millimeter-wave band having Ka-band filter. Planar filters are normally used in frequency band below the Ka-band. The problem of pool coupling from the feed port to SIR structure is solved by applying Ka- band.

3.3 FILTER SYNTHESIS

3.3.1 QUARTER-WAVELENGTH SIR:

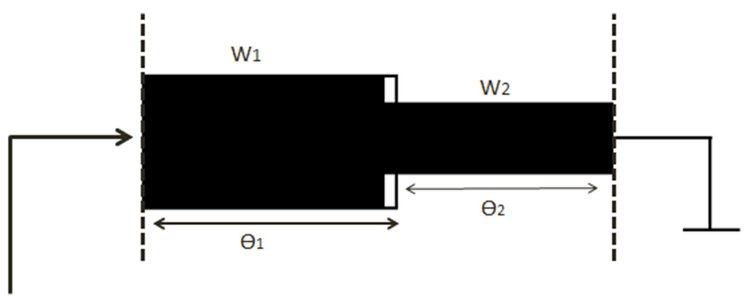


Fig. 3.3.1. Schematic of a λ/4 SIR

Fig. 3.3.1 shows the schematic of a λ/4 SIR, which consists of two impedance sections as Z_1 and Z_2 with electrical lengths of θ_1 and θ_2, respectively. The left-end of Z_1 section is short circuited, hence, $Z_L=0$, the impedance Zin, as indicated in Fig.3.3.1, is formulated as :

$$Z_{\text{in}} = jZ_1 \frac{R\tan\theta_1 \tan\theta_2 - 1}{R\tan\theta_2 + \tan\theta_1}$$

------(1)

where the impedance ratio R is defined as:

Z_1/Z_2

According to the resonant condition:

$Z_L + Z_{in} = 0$

the numerator in (1) becomes zero, i.e.,

$$R \tan \theta_1 * \tan \theta_2 - 1 = 0 \qquad \text{------(2)}$$

By labeling the frequency ratio of the second and first resonant modes as

$$k = f^{II}_0 / f^{I}_0$$

the second resonant mode excluding the dispersion effect is restricted as

$$R \tan k\theta_1 * \tan k\theta_2 - 1 = 0 \text{ ------(3)}$$

For both resonant modes, the reactance slope of this λ/4 SIR is defined and derived as

$$\begin{aligned} x_{\text{in}} &= \frac{f}{2}\frac{dX_{\text{in}}}{df}\bigg|_{f=f_0^{\mathrm{I}},f_0^{\mathrm{II}}} \\ &= \frac{Z_1}{2}\frac{\theta_1 \sec^2\theta_1 + R\theta_2 \sec^2\theta_1 \sec^2\theta_2 + R^2\theta_1 \sec^2\theta_1 \tan^2\theta_2}{(R\tan\theta_2 + \tan\theta_1)^2} \end{aligned} \qquad \text{------ (4)}$$

where θ_1 and θ_2 are the two distinctive electrical lengths of the λ/4 SIR at the first resonant mode with the frequency . In synthesis, (4) is then numerically analyzed and solved with resorting to a varied impedance ratio R ranging from 0.3 to 1.6 and varied length ratio α ranging from 0.2 to 0.7,

$$\alpha = \frac{\theta 1}{\theta 1 + \theta 2} \qquad \text{------(5)}$$

3.3.2. FILTER SYNTHESIS:

Besides the formulation of the dual-mode resonators for a dual-band filter in Fig.3.3.1, the inductive K inverter needs to be introduced between two adjacent resonators and its coupling degree near the designated dual pass bands must be analyzed and investigated. In this paper, a shunt short-circuited stub is formed to serve as the K inverter and its physical. This stub could be characterized using the lump model and distributed model, but the resultant K is only valid for the narrowband case since these models have not included any junction effect or frequency dispersion. As a result, we need to carry out accurate characterization on this shunt stub with a metallic via in a wide frequency range that must cover the desired dual pass bands. In this paper, the broad

Band K value is extracted or de- embedded from the full-wave simulated S -parameters.

According to the classical synthesis method as summarized in, the required theoretical inter-resonator K coupling degree can be expressed as

$$K_{n,n+1} = \frac{\mathrm{FBW} x_n}{\sqrt{g_n g_{n+1}}}$$

------(6)

where FBW is the fractional bandwidth, X_n is the resonator's reactance slope of the synchronously tuned resonator, and g_s are the normalized elements in the low-pass filter prototype. Therefore, the ratio of inter-resonator at two dual-band frequencies can be calculated based on

$$\frac{K^{\mathrm{I}}_{n,n+1}}{K^{\mathrm{II}}_{n,n+1}} = \frac{\mathrm{FBW}^{\mathrm{I}} x^{\mathrm{I}}_n}{\sqrt{g_n g_{n+1}}} \bigg/ \frac{\mathrm{FBW}^{\mathrm{II}} x^{\mathrm{II}}_n}{\sqrt{g_n g_{n+1}}} = \frac{\mathrm{FBW}^{\mathrm{I}} x^{\mathrm{I}}_n}{\mathrm{FBW}^{\mathrm{II}} x^{\mathrm{II}}_n}.$$

------(7)

Alternatively, for the dual-band external coupling

$$\frac{K_{01}^{\mathrm{I}}}{K_{01}^{\mathrm{II}}} = \sqrt{\frac{Z_0 \mathrm{FBW}^{\mathrm{I}} x_1^{\mathrm{I}}}{g_0 g_1}} \Big/ \sqrt{\frac{Z_0 \mathrm{FBW}^{\mathrm{II}} x_1^{\mathrm{II}}}{g_0 g_1}} = \sqrt{\frac{\mathrm{FBW}^{\mathrm{I}} x_1^{\mathrm{I}}}{\mathrm{FBW}^{\mathrm{II}} x_1^{\mathrm{II}}}} \quad \text{------(8)}$$

where Z_0 is the I/O port impedance and superscripts I and II denote the first and second passbands, respectively. As the ratio of two fractional bandwidths is predetermined, k values of the shunt stubs short circuited with a metallic via at different frequencies are also fixed. The required $\lambda/4$ SIR reactance ratio among different stages can be calculated from (7) or (8). Hence, the $\lambda/4$ SIR can be preliminarily decided. Furthermore, based on, a set of design graphs for each J coupling between the constructed $\lambda/4$ SIRs can be formulated so as to derive the corresponding coupling structures of dual band inverters.

CHAPTER – IV

INVERTERS

Inverters are two-port networks used in many RF and microwave filters. The input impedance of an inverter terminated in an impedance Z_L is $1/Z_L$. Impedance and admittance inverters are the same network, with the distinction being whether Siemens or ohms are used to define them. An inverter is sometimes called a unit element (UE). At frequencies of a few hundred megahertz and below an inverter can be realized using operational and trans-conductance amplifiers. At microwave frequencies the simplest inverter is a one-quarter wavelength long line. In RF and microwave filter design they are used to convert a series element into a shunt element. It is much easier to realize shunt elements in distributed circuits than series elements. Similar circuit transformations enable an inductor to be replaced by a capacitor.

So the inverter both inverts the load impedance and scales it. Similarly, if Port 1 is terminated in Z_L the input impedance at Port 2 is Zin as defined above.

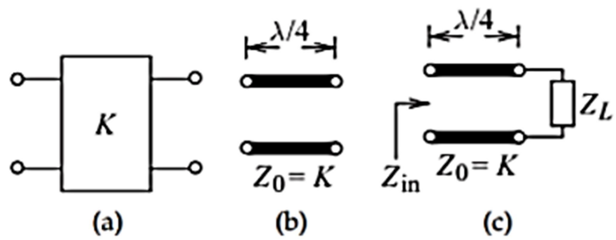


Figure 4.0.1: Inverter equivalence: (a) two-port impedance inverter (of impedance K); (b) a quarter-wave transmission line of characteristic impedance Z0=K; and (c) a terminated one-quarter wavelength long line.

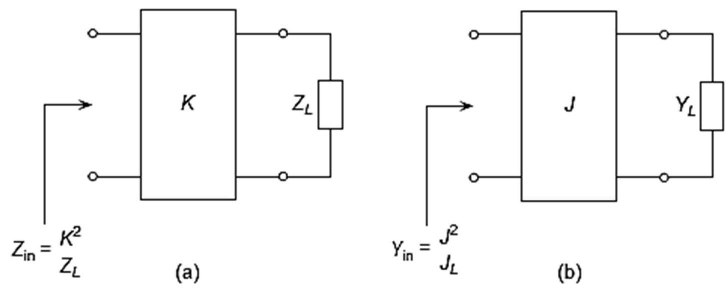


Fig 4.0.2. Impedance inverter (a) and Admittance inverter (b).

As we have seen, it is often desirable to use only series, or only shunt, elements when implementing a filter with a particular type of transmission line. The Kuroda identities can k used for conversions of this form, but another possibility is 10 use impedance {K} or admittance {J} inverters. Such inverters me especially useful fix band pass or band stop filters with narrow (< 10%) band widths.

An impedance inverter has the value K (in ohms), and sometimes K is called the characteristic impedance of the inverter. Sometimes K is just called the impedance of the inverter. For an admittance inverter J is used and is called the characteristic admittance of the inverter, and sometimes just the admittance of the inverter. They are related as J=1/K. A λ/4 long line with a load has an input impedance that is the inverse of the load, normalized by the square of the characteristic impedance of the line. So an inverter can be realized at microwave frequencies using a one-quarter wavelength long transmission line (see Figure 4.1(b)). For the configuration shown in Figure 4.1(c),

$$Z_{in} = \frac{K_2}{Z_L} \quad \text{----- (1)}$$

4.1. PROPERTIES OF AN IMPEDANCE INVERTER

An impedance inverter has the ABCD matrix

$$\mathbf{T} = \begin{bmatrix} 0 & \jmath K \\ \jmath/K & 0 \end{bmatrix} \qquad \text{------------- (2)}$$

where K is called the characteristic impedance of the inverter. With a load impedance, Z_L (at Port 2), the input impedance (at Port 1) is (as expected)

$$Z_{\text{in}}(s) = \frac{AZ_L + B}{CZ_L + D} = \frac{jK}{(j/K)Z_L} = \frac{K^2}{Z_L} \qquad \text{------------- (3)}$$

$$\begin{bmatrix} \cos\theta & jZ_0 \sin\theta \\ (j/Z_0)\sin\theta & \cos\theta \end{bmatrix} \qquad \text{------------- (4)}$$

Now the ABCD matrix of the transmission line of Figure 4.1(b) is which is identical to Equation (2) when the electrical length is $\theta=\pi/2$ (i.e., when the line is $\lambda/4$ long. The bandwidth over which the line realizes an impedance inverter is limited, however, as it is an ideal inverter only at the frequency at which it is $\lambda/4$ long.

4.2. REPLACEMENT OF A SERIES INDUCTOR BY A SHUNT CAPACITOR

A series inductor can be replaced by a shunt capacitor surrounded by a pair of inverters followed by a negative unity transformer (i.e., an inverter with K=1). This equivalence is shown in Figure 4.2.1 and this will now be shown mathematically.

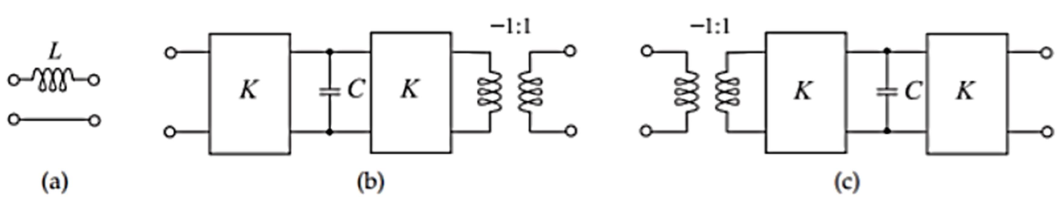


Figure 4.2.1: Equivalent realizations of a series inductor: (a) as a two-port;(b) its realization using a capacitor, inverters of characteristic impedance K, and a negative unity transformer; and (c) an alternative realization. $C=L/K^2$.

The ABCD matrix of the series inductor shown in Figure 4.2.1 (a) (which has an impedance of sL) is

$$\mathbf{T}_L = \begin{bmatrix} 1 & sL \\ 0 & 1 \end{bmatrix} \qquad \text{------------- (5)}$$

and the ABCD matrix of the shunt capacitor (which has an admittance of sC) is,

$$\mathbf{T}_1 = \begin{bmatrix} 1 & 0 \\ sC & 1 \end{bmatrix} \qquad \text{------------- (6)}$$

The ABCD matrix of an inverter with K in ohms (generally the unit is dropped and ohms is assumed) is

$$\mathbf{T}_2 = \begin{bmatrix} 0 & \jmath K \\ \jmath/K & 0 \end{bmatrix} \qquad \text{------------- (7)}$$

and finally, the ABCD matrix of a negative unity transformer is,

$$\mathbf{T}_3 = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \qquad \text{------------- (8)}$$

Then the ABCD matrix of the cascade shown in Figure 4.2.1(b) is

$$\begin{aligned} \mathbf{T}_C &= \mathbf{T}_2\mathbf{T}_1\mathbf{T}_2\mathbf{T}_3 \\ &= \begin{bmatrix} 0 & \jmath K \\ \jmath/K & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ sC & 1 \end{bmatrix} \begin{bmatrix} 0 & \jmath K \\ \jmath/K & 0 \end{bmatrix} \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \\ &= \begin{bmatrix} 0 & \jmath K \\ \jmath/K & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ sC & 1 \end{bmatrix} \begin{bmatrix} 0 & -\jmath K \\ -\jmath/K & 0 \end{bmatrix} \\ &= \begin{bmatrix} \jmath sCK & \jmath K \\ \jmath/K & 0 \end{bmatrix} \begin{bmatrix} 0 & -\jmath K \\ -\jmath/K & 0 \end{bmatrix} \\ &= \begin{bmatrix} 1 & sCK^2 \\ 0 & 1 \end{bmatrix} \qquad \text{------------- (9)} \end{aligned}$$

Thus $T_C=T_L$ if $L=CK^2$ (compare Equations (5) and (9)). Thus a series inductor can be replaced by a shunt capacitor with an inverter before and after it and with a negative unity transformer. The unity transformer may also be placed at the first port, as in Figure 4.2.1(c). Thus the two-ports shown in Figure 4.2.1 are all electrically identical, with the limitation being the frequency range over which the inverter can be realized. An interesting and important observation is that as a result of the characteristic impedance of the inverter (e.g., 50Ω), a small shunt capacitor can be used to realize a large series inductance value.

4.3. REPLACEMENT OF A SERIES CAPACITOR BY A SHUNT INDUCTOR

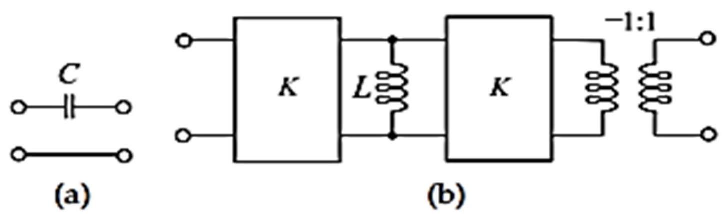


Figure 4.3.1: A series capacitor: (a) as a two port; (b) its realization using a shunt inductor, inverters and negative unity transformer' L=CK^2

A series capacitor can be replaced by a shunt inductor plus inverters and a negative transformer (see Figure 4.3.1). The ABCD parameters of the series capacitor in Figure 4.3.1 (a) are

$$\mathbf{T} = \begin{bmatrix} 1 & 1/sC \\ 0 & 1 \end{bmatrix} \qquad \text{------------- (10)}$$

and here it is shown that the cascade in Figure 4.3.1 (b) has the same ABCD parameters. The cascade in Figure 4.3.1 (b) has the ABCD parameters

$$\begin{aligned}\mathbf{T} &= \begin{bmatrix} 0 & \jmath K \\ \jmath/K & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/sL & 1 \end{bmatrix} \begin{bmatrix} 0 & \jmath K \\ \jmath/K & 0 \end{bmatrix} \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \\ &= \begin{bmatrix} 0 & \jmath K \\ \jmath/K & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/sL & 1 \end{bmatrix} \begin{bmatrix} 0 & -\jmath K \\ -\jmath/K & 0 \end{bmatrix} \\ &= \begin{bmatrix} \jmath K/sL & \jmath K \\ \jmath/K & 0 \end{bmatrix} \begin{bmatrix} 0 & -\jmath K \\ -\jmath/K & 0 \end{bmatrix} \\ &= \begin{bmatrix} 1 & K^2/sL \\ 0 & 1 \end{bmatrix} \qquad \text{-------------} \ (11)\end{aligned}$$

So the series capacitor, C, can be realized using a shunt inductor, L, inverters, and a negative unity transformer, and $C=L/K^2$. It is unlikely that this transformation would be exploited, as much better lower-loss capacitors can be realized at RF than inductors.

4.4 PRACTICAL IMPEDANCE AND ADMITTANCE INVERTERS

The impedance and admittance inverters used in the analysis are assumed to be ideal, exhibiting frequency independent characteristics. Such inverters do not exist. The simplest inverter is a quarter wavelength of transmission line. Needless to say, its inverting properties are suitable over very narrow bandwidths, and, in addition, using quarter-wave lines would make the filter structure very large. Such inverters serve the dual function of impedance inversion over wider bandwidths while providing a structure for realizing resonators, resulting in compact implementation of practical microwave filters.

CHAPTER – V

METHADOLOGY

5.1 DESIGN

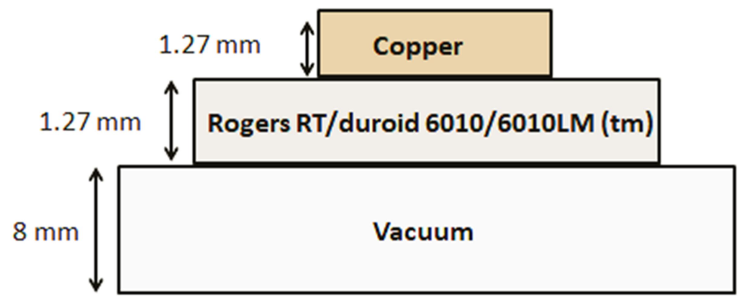


Fig 5.1.1. Side view of Three Dimensional model of Dual Band Band Pass Filter

5.1.1 SOLIDS

- Box Substrate : It is in the form of cube using material Rogers RT/duroid 56010/6010LM (tm) of permittivity 10.8 of lengths 20 mm, 40 mm, 1.27 mm.
- Box Vacuum: It is in the form of cube using material Vacuum of lengths 40 mm, 60 mm, 8 mm.
- Cylinder : It is in the form of cylinder using material copper of radius 0.2 mm, height -1.27 mm.

5.1.2 SHEETS

- Lumped Ports : Here we use two lumped ports in the form of rectangles of lengths 2.15 mm, -1.27 mm. In this the two lumped ports will have same lengths.
- The physical dimensions of Type-I are l1 = 2.15mm , w1 = 8.35mm; l2 = 0.5mm, w2 = 7.825mm; l3 = 7.85mm, w3 = 0.45mm; l4 = 2mm, w4 = 9mm; l5 = 1.1mm, w5 = 6.4mm; l6 = 2mm, w6 = 9mm; l7 = 7.85mm, w7 = 0.45mm; l8 = 0.5mm , w8 = 7.85mm; l9 = 2.15mm, w9 = 8.35mm; l10 = 1mm, w10 = 0.6mm

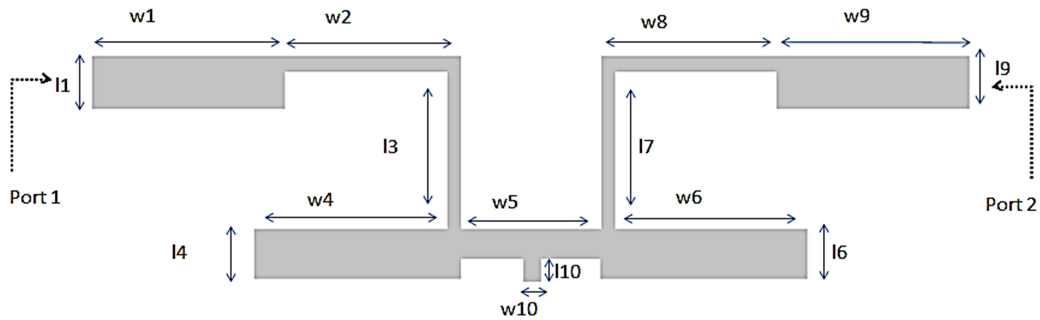


Fig 5.1.2. Second-order Dual-Band Band-Pass Filter (Type – I) at 1.8 and 5.8 GHz

- The physical dimensions of Type-II are l1 = 11.75mm, w1 = 2.15 mm; l2 = 0.5 mm, w2 = 7.825 mm; l3 = 2.775 mm, w3 = 0.45 mm; l4 = 0.45 mm, w4 = 3.65 mm; l5 = 2.525 mm, w5 = 0.45 mm; l6 = 2 mm, w6 = 9.2 mm; l7 = 1.1 mm, w7 = 6 mm; l8 = 2 mm, w8 = 9.2 mm; l9 = 2.525 mm, w9 = 0.45 mm; l10 = 0.45 mm, w10 = 3.65 mm; l11 = 2.775 mm, w11 = 0.45 mm; l12 = 0.5 mm, w12 = 7.825 mm; l13 = 11.75 mm, w13 = 2.15 mm; l14 = 1 mm, w14 = 0.6 mm.

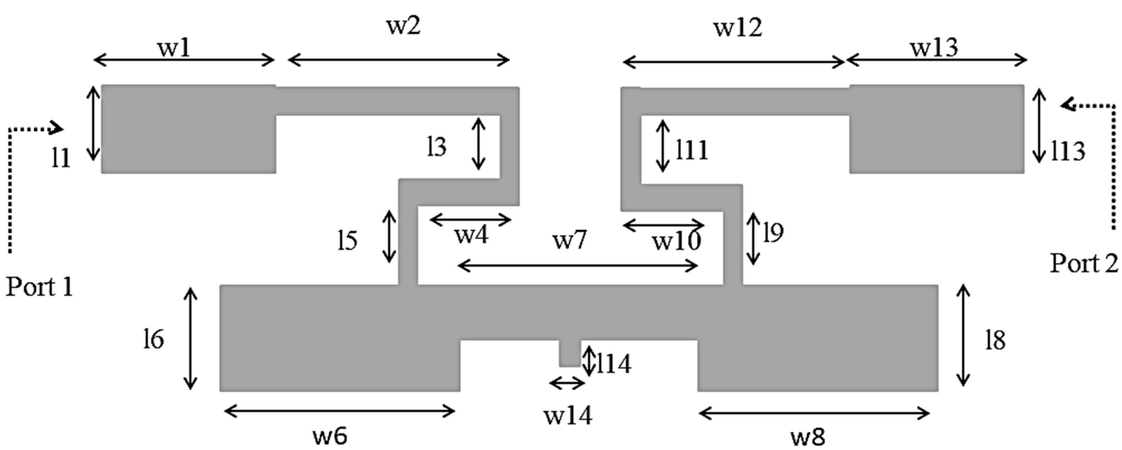


Fig 5.1.3. Second-order Dual-Band Band-Pass Filter (Type – II) at 1.8 and 5.8 GHz

CHAPTER - VI

SIMULATION RESULTS:

6.1 DUAL-BAND BANDPASS FILTER AT 1.8/5.8 GHz (Type-I):

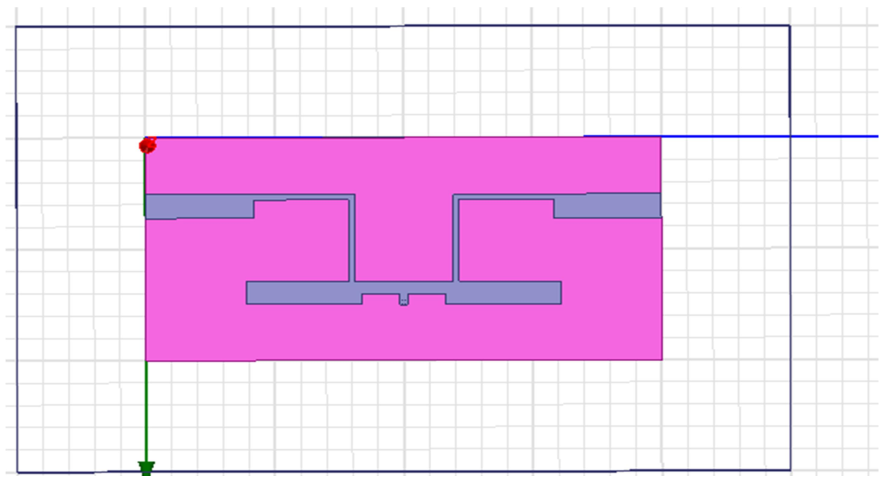


Fig 6.1.1: Proposed layout of second order Type-I Dual Band Band Pass Filter at 1.8 and 5.8 GHz.

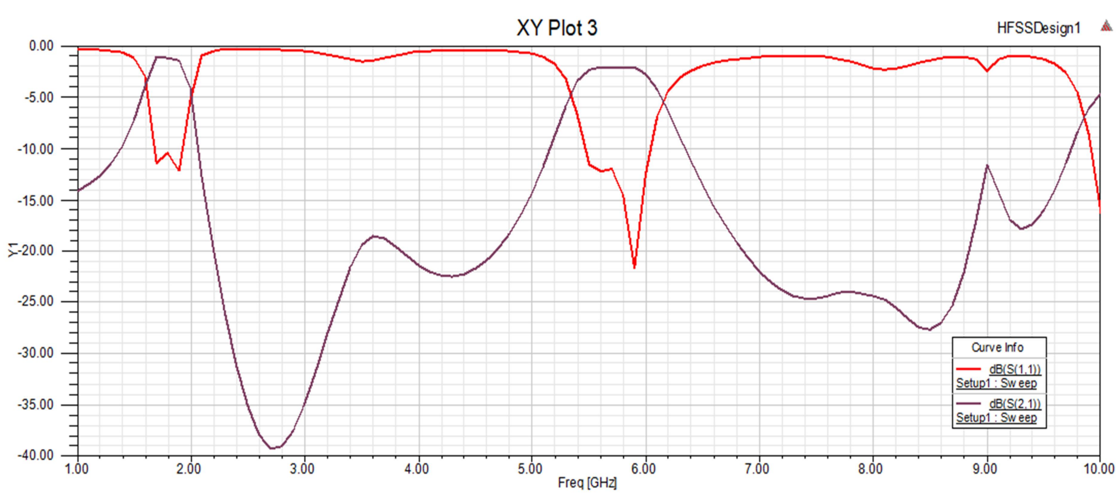


Fig 6.1.2: Simulated and measured results of Type-I band pass filter at both S(1,1) & S(2,1) parameters

A second-order Chebyshev dual-band bandpass filter with central frequencies,f^{I}_{0} = 1.8GHz and f^{II}_{0} = 5.8GHz. With the prescribed central frequencies ratio of (5.8/1.8) and reactance slope ratio of 4.6, the impedance ratio and length ratio of the SIR can be determined in a straightforward manner with reference to the design graph in Fig 6.1.2.

To further improve the dual-passband performance, the I/O coupling path is introduced by properly moving two dual-band impedance transformers closely to each other, resulting to form up an improved dual-band bandpass filter, namely, the Type II filter

6.2 DUAL-BAND BANDPASS FILTER AT 1.8/5.8 GHz (Type-II):

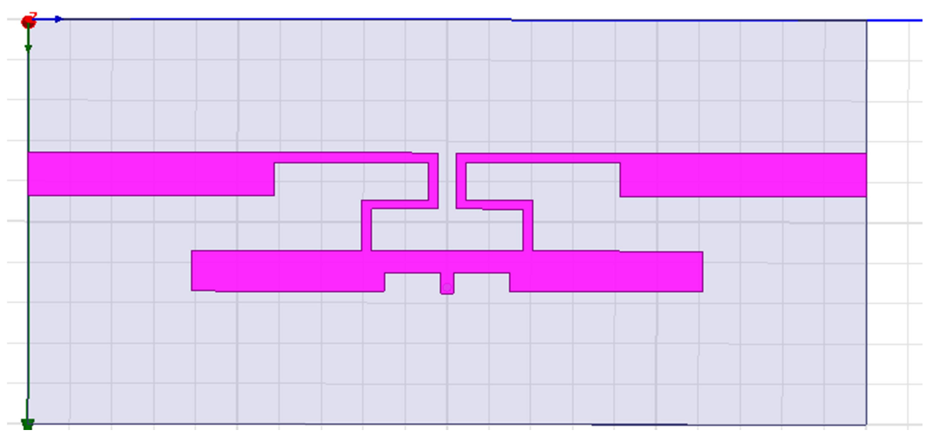


Fig 6.2.1: Proposed layout of second order Type-II Dual Band Band Pass Filter at 1.8 and 5.8 GHz

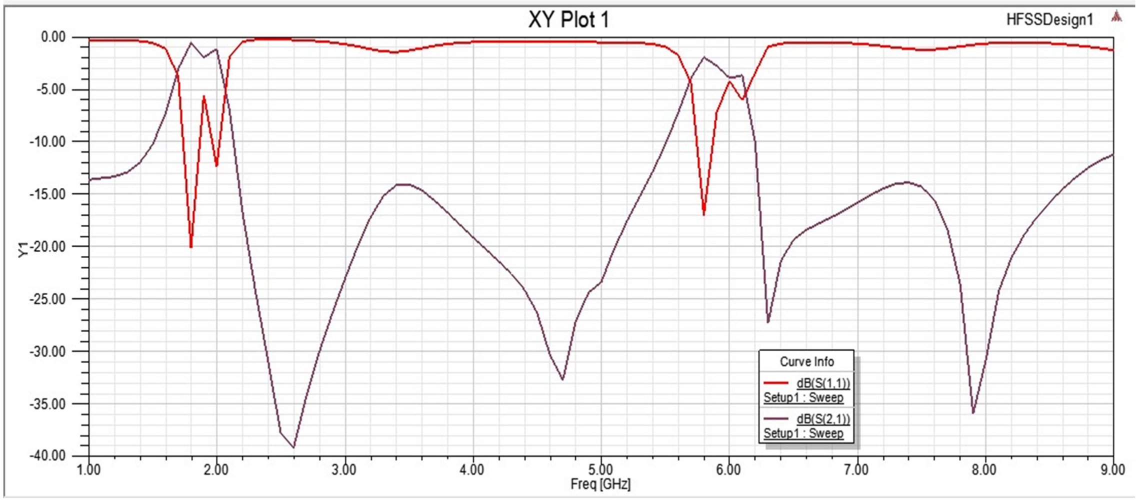


Fig 6.2.2: Simulated and measured results of Type-II Band Pass Filter at both S(1,1) & S(2,1) parameters

Due to the existence of a weak cross coupling path between the I/O ports, the two transmission zeros are created at 4.7 and 6.3 GHz when the coupled-line length of 2.3 mm and gap of 0.85 mm are selected.

CHAPTER - IX

CONCLUSION

A rigorous synthesis method for a class of dual band micro-strip band pass filter based on $\lambda/4$ SIRs has been presented and demonstrated in detail. In synthesis, the impedance or strip widths and the length of these $\lambda/4$ SIRs can be progressively synthesized from the prescribed dual band frequency ratios and full wave extracted K value ratios. The two compact dual band filters with the central frequencies at 1.8/5.8 GHz have been designed and tested. The simulated and measured results not only successfully validate the presented synthesis method, but also demonstrate good dual-pass band performance with sharpened out-of-band rejection skirts and deepened mutual band isolation as highly desired in filter design.

CHAPTER - X

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