COMPACT MICROSTRIP BANDPASS FILTER

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ABSTRACT

In microwave communication systems, the bandpass filter is an essential component, which is usually used in both transmitter and receiver. Parallel-coupled microstrip bandpass filter is one of the most popular filters in communication systems. However, this arrangement of parallel-coupled microstrip bandpass filter gives disadvantage in terms of size where the arrangement of this topology results in an electrically large in size of the filter. Therefore, this project focuses on designing a compact microstrip bandpass filter by using Sonnet Lite software at centre frequency of 3.2GHz with the bandwidth of 400MHz. Besides, the design of the compact microstrip bandpass filter has achieved the objective when it successfully reduced the overall size to about 70% as compared to the size of conventional filter, which is parallel-coupled microstrip bandpass filter. Both filters give the same performance based on their frequency responses. The design also has successfully fabricated and measured by using network analyzer software to verify the simulated results obtained earlier. Although there is slightly mismatch between the simulated and measured frequency response due to some fabrication errors and variation of material properties, the design of filter is not affected since the results obtained from the designing process by using Sonnet Lite software are still valid and can be used in future improvement of the design.
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CHAPTER 1

INTRODUCTION

This chapter introduces the idea and concept of the project. It consists of project background and the overview of the project.

1.1 Project Overview

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. Emerging applications such as wireless communications continue to challenge RF/microwave filters with ever more stringent requirement which are higher performance, smaller size, lighter weight, and lower cost. Depending on the requirements and specifications, RF/microwave filters may be designed as lumped element or distributed element circuits; they may be realized in various transmission line structures, such as waveguide, coaxial line, and microstrip.
A filter is an AC circuit that separates some frequencies from others within mixed-frequency signals [1]. A common need for filter circuits is in high-performance stereo systems, where certain ranges of audio frequencies need to be amplified or suppressed for best sound quality and power efficiency.

The design of filters’ circuit may be very simple, consisting of a single capacitor or inductor whose addition to given network leads to improved performance. They may also be fairly sophisticated, consisting of many resistors, capacitors, inductors and op amps in order to obtain the precise response curve required for a given application. Filters are used in modern electronics to obtain dc voltages in power supplies, eliminate noise in communication channels, separate radio and television channels from the multiplexed signal provided by antennas and boost the bass signal in a car stereo as for example.

Basically, the concept of filter is that it selects the frequencies that may pass through a network. There are several varieties, depending on the needs of a particular application.

A low-pass filter passes frequencies below a cutoff frequency, while significantly damping frequencies above the cutoff. A high-pass filter, on the other hand, does just the opposite. The chief figure of merit of a filter is the sharpness of the cutoff, or the steepness of the curve in the vicinity of the corner frequency.

Combining a low-pass and a high-pass filter can lead to a band pass filter. In this type of filter, the region between the two corner frequencies is referred to as the passband; the region outside the passband is referred to as the stopband. By swapping the cutoff frequencies of the two filters, a band stop filter can be created, which allows both high and low frequencies to pass but attenuates any signal with a frequency between the two corner frequencies.

Microstrip filters are always preferred over the lumped filters at higher frequencies. For designing of a bandpass filter with minimum ripples in the passband and with sharp rejections the most widely used filters are coupled line, hairpin, and end coupled and cascaded quadruplet (CQ) filters. For the requirements at around 1.243 GHz
the end coupled may be avoided because of size constrains and CQ filters have two attenuation poles which is difficult to design to have these poles at the desired frequencies. Coupled and hairpin filters can be used at this frequency to have the desired response in the passband, but the coupled line filter occupies large size where as in the hairpin second harmonics and the other harmonics were very prominent and not desirable for a filter required at the output of multiplier.

Parallel-coupled microstrip bandpass filter is one of the most popular bandpass filter and can be applied in many application of microwave communication systems. General layout of this bandpass filter is shown in figure 1.

![Diagram of parallel-coupled microstrip bandpass filter](image)

\[ Y_0 = 1/Z_0 \]

Figure 1.1: General structure of parallel-coupled microstrip bandpass filter [1]

The filter structure is of open circuited coupled microstrip lines. The components are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators, and making this filter structure particularly convenient for constructing filters having a wider bandwidth as compared to other type of bandpass filter.

This paper will concentrate on the design of a compact size microstrip bandpass filter. This filter will be developed and then will be compared with existing structures.
Two existing filters were designed which are the conventional parallel coupled microstrip bandpass filter, and the other one is the existing compact microstrip bandpass filter with multispurious suppression. The selected frequency used for the design is based on the current applications in communication systems. The design process is done by using the Sonnet Lite software and then followed by the fabrication of the designed filter. The analysis of the designed filter will be presented and discussed briefly in further chapters.

1.2 Problem Statement

In microwave communication systems, the bandpass filter is an essential component, which is usually used in both transmitter and receiver. Parallel-coupled microstrip bandpass filter is one of the most popular filters in communication systems due to its advantages of ease in manufacture, ease of synthesis method, low cost and high practicality.

The parallel-coupled microstrip bandpass filter structure is of open circuited coupled microstrip lines. The components are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators, and making this filter structure particularly convenient for constructing filters having a wider bandwidth as compared to other type of bandpass filter.

However, this arrangement of parallel-coupled microstrip bandpass filter gives disadvantage in terms of size. The arrangement of this topology results in an electrically large in size of the filter. Thus, this problem of size limit the application for this type of filter in certain communication systems and it became less favourable as compared to other filters.
A compact, low insertion loss and wide rejection band bandpass filter has come to be one of the recent trend in global system for mobile communication (GSM), wireless code-division multiple-access (WCDMA), and wireless local area network (WLANs).

It is clear that there is a need to design a compact filter to fulfil the recent need in microwave communication system. Microstrip line is a good candidate for filter design due to its advantages of low cost, compact size, light weight, planar structure and easy integration with other components in single board. Thus, a compact microstrip bandpass filter is proposed to be designed.

1.3 Objectives

The objectives of this project are:

i. To design a compact microstrip bandpass filter for a selected frequency using Sonnet Lite software

ii. To analyze the performance of the designed filter in terms of its S parameters, physical size of the filter and bandwidth.

iii. To compare the designed compact microstrip bandpass filter with the conventional bandpass filter.

iv. To fabricate and measure the frequency response of the designed filter for the frequency used.
1.4 Scope

i. This project is aimed to design a compact microstrip bandpass filter at centre frequency \( f_0 \) of 3.2Ghz. This centre frequency is selected as it is widely used in many microwave application such as Wi-fi, Bluetooth, WiMax etc.

ii. The designed filter also aimed to be smaller in overall size as compared to the conventional parallel-coupled microstrip bandpass filter.

iii. The designed filter also will be analysed in terms of its S-parameter such as the return loss \( (S11) \) and insertion loss \( (S21) \). Besides, the size of the designed filter will be observed and compared with the conventional microstrip parallel-coupled bandpass filter. In addition, the size of bandwidth of the designed filter also will be observed.

iv. Finally, the designed filter will be fabricated and tested for the selected frequency by using network analyzer.
CHAPTER 2

THEORETICAL BACKGROUND

2.1 Filter Definition

Basically, an electrical filter is a circuit that can be designed to modify, reshape or reject all unwanted frequencies of an electrical signal and accept or pass only those signals wanted by the circuits’ designer [2]. In other words they "filter-out” unwanted signals and an ideal filter will separate and pass sinusoidal input signals based upon their frequency.

In low frequency applications (up to 100kHz), passive filters are generally constructed using simple RC (Resistor-Capacitor) networks, while higher frequency filters (above 100kHz) are usually made from RLC (Resistor-Inductor-Capacitor) components. Passive filters are made up of passive components such as resistors, capacitors and inductors and have no amplifying elements, so have no signal gain, therefore their output level is always less than the input.
Filters are so named according to the frequency range of signals that they allow to pass through them, while blocking or "attenuating" the rest. The most commonly used filter designs are the:

i. The Low Pass Filter – the low pass filter only allows low frequency signals from 0Hz to its cut-off frequency, $f_c$ point to pass while blocking those any higher.

ii. The High Pass Filter – the high pass filter only allows high frequency signals from its cut-off frequency, $f_c$ point and higher to infinity to pass through while blocking those any lower.

iii. The Band Pass Filter – the band pass filter allows signals falling within a certain frequency band setup between two points to pass through while blocking both the lower and higher frequencies either side of this frequency band.

A low-pass filter passes frequencies below a cutoff frequency, while significantly damping frequencies above the cutoff. A high-pass filter, on the other hand, does just the opposite. The chief figure of merit of a filter is the sharpness of the cutoff, or the steepness of the curve in the vicinity of the corner frequency.

Combining a low-pass and a high-pass filter can lead to a band pass filter. In this type of filter, the region between the two corner frequencies is referred to as the passband; the region outside the passband is referred to as the stopband. By swapping the cutoff frequencies of the two filters, a band stop filter can be created, which allows both high and low frequencies to pass but attenuates any signal with a frequency between the two corner frequencies.
2.2 Different Types of Filter

Filter can be classified into two types which are passive and active filters [1].

A passive filter can be constructed by simply using a single capacitor and a single resistor as shown in figure 2.1

![Figure 2.1: A simple low-pass filter constructed from a resistor-capacitor combination](image)

The transfer function for this low-pass filter circuit is

\[
H(s) = \frac{V_{out}}{V_{in}} = \frac{1}{1 + RCs} \quad (1)
\]

H(s) has a single corner frequency, which occurs at \( \omega = 1/RC \), and a zero at \( s \) equal infinity, leading to its “low-pass” filtering behavior. Low frequencies (\( s \) approaching zero) result in \( |H(s)| \) near its maximum value (unity, or 0dB), and high frequencies (\( s \) approaching zero) result in \( |H(s)| \) approaching zero. This behavior can be understood qualitatively by considering the impedance of the capacitor: as the frequency increases, the capacitor begins to act like a short-circuit to ac signals, leading to a reduction in the output voltage. The sharpness of the response curve in the vicinity of the cutoff frequency can be improved by moving to a circuit containing additional reactive (i.e. capacitive and/or inductive) elements.
The use of an active element such as the op amp in filter design can overcome many of the shortcomings of passive filters. The op amp circuits can be designed to provide gain. Op amp circuit can also exhibit inductor-like behavior through the strategic location of capacitors.

The internal circuitry of an op amp contains very small capacitance (typically on the order of 100pF), and these limit the maximum frequency at which the op amp will function properly. Thus, any op amp circuit will behave as low-pass filter with a cutoff frequency usually on the order of 10-100 kHz. If a smaller frequency is desired, an external filter can be added at the input or output of the op amp.

Active filters contain amplifying devices to increase signal strength while passive do not contain amplifying devices to strengthen the signal. As there are two passive components within a passive filter design the output signal has smaller amplitude than its corresponding input signal, therefore passive RC filters attenuate the signal and have a gain of less than one, (unity).

2.3 Microstrip Filter

Microstrip transmission line is the most used planar transmission line in Radio frequency (RF) applications [2]. The planar configuration can be achieved by several ways, for example with the photolithography process or thin-film and thick film technology. As other transmission line in RF applications, microstrip can also be exploited for designing certain components, like filter, coupler, transformer or power divider.

If a microstrip transmission line is used for transport of wave with relative low frequency, the wave type propagating in this transmission line is a quasi-TEM wave. This is the fundamental mode in the microstrip transmission line.
Microstrip filters are always preferred over the lumped filters at higher frequencies. For designing of a bandpass filter with minimum ripples in the passband and with sharp rejections the most widely used filters are coupled line, hairpin, and end coupled and cascaded quadruplet (CQ) filters. For the requirements at around 1.243 GHz the end coupled may be avoided because of size constrains and CQ filters have two attenuation poles which is difficult to design to have these poles at the desired frequencies. Coupled and hairpin filters can be used at this frequency to have the desired response in the passband, but the coupled line filter occupies large size where as in the hairpin second harmonics and the other harmonics were very prominent and not desirable for a filter required at the output of multiplier.
2.4 Parallel - Coupled Microstrip Filter (Conventional filter)

Parallel-coupled microstrip bandpass filter is one of the most popular bandpass filter and can be applied in many application of microwave communication systems [2].

The filter structure is of open circuited coupled microstrip lines. The components are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators, and making this filter structure particularly convenient for constructing filters having a wider bandwidth as compared to other type of bandpass filter. General layout of this bandpass filter is shown in figure 2.3

![Figure 2.4: General structure of Parallel-Coupled Microstrip Bandpass Filter [2]](image)

The design equations involved in this type of filter are:

\[
\begin{align*}
J_{01} / Y_0 &= (\text{FBW}_\pi / 2g_0g_1)^{1/2} \\
J_{j,j+1} / Y_0 &= (\pi\text{FBW}) / 2(g_jg_{j+1})^{1/2} \quad j=1 \text{ to } n-1 \\
J_{n,n+1} / Y_0 &= (\pi\text{FBW} / 2g_ng_{n+1})^{1/2}
\end{align*}
\]

Where \(g_0, g_1 \ldots g_n\) are the element of a ladder-type lowpass prototype with a normalized cutoff \(\Omega_c=1\), and \(\text{FBW}\) is the fractional bandwidth of bandpass filter. \(J_{j,j+1}\) are the characteristics admittances of \(J\)-inverters and \(Y_0\) is the characteristics admittance of the terminating lines.

To obtain the \(J\)-inverters, the even- and odd-mode characteristic impedance of the coupled microstrip line resonators are determined by
(Z_{0e})_{j,j+1} = \left[ 1 + (J_{j,j+1} / Y_0) + (J_{j,j+1} / Y_0)^2 \right] / Y_0 \quad j=0 \text{ to } n \quad (4)

(Z_{0o})_{j,j+1} = \left[ 1 + (J_{j,j+1} / Y_0) + (J_{j,j+1} / Y_0)^2 \right] / Y_0 \quad j=0 \text{ to } n \quad (5)

The next step of the filter design is to find the dimensions of coupled microstrip lines that exhibit the desired even- and odd-mode impedances. For instance, referring to figure 3.1, \( w_1 \) and \( s_1 \) are determined such that the resultant even- and odd-mode impedances match to \((Z_{0e})_{0.1}\) and \((Z_{0o})_{0.1}\).

The actual lengths of each coupled line section are then determined by

\[ l_j = \left\{ \frac{\lambda_0}{4[\varepsilon_{re}]_j \times (\varepsilon_{ro})_j} \right\} - \Delta l_j \quad (6) \]

The software Sonnet lite used is the in the design process, therefore no need to calculate them manually because this software will automatically do it. Using this software, the value for the frequency and order should be inserted, and then it will display the values for width, length and separation for every substrate’s value. This report will focus on the design at the center frequencies of 3.2 GHz.

This type of filter is designed in order to be compared with the compact microstrip bandpass filter. The new designed of compact filter should give the same frequency response, with a smaller size filter.

2.5 S-Parameters

The network representation of a two-port network at high RF/microwave frequencies is called “scattering parameters” (or “S-parameters” for short) [2]. The high frequency S-parameters are used to characterize high RF/Microwave two-port networks. These parameters are based on the concept of travelling waves and provide a complete characterization of any two-port network under analysis or test at RF/Microwave frequencies. In view of the linearity of the electromagnetic field equations and the linearity displayed by most microwave components and networks, the “scattered waves”
(i.e. the reflected and transmitted wave amplitudes) are linearly related to the incident wave amplitude. The matrix describing this linear relationship is called the “scattering matrix” or $[S]$ [1].

S-parameters as defined above, have many advantages at high RF/Microwave frequencies which can be briefly stated as:

1) S-parameters provide a complete characterization of a network, as seen at its ports.

2) S-parameters make the use of short or open (as prescribed at lower frequencies) completely unnecessary at higher frequencies. It is a known fact that the impedance of a short or an open varies with frequency which is one reason why they are not useful for device characterization at high RF/Microwave frequencies. Furthermore, the presence of a short or open in a circuit in a circuit can cause strong reflections which usually lead to oscillations or damages to the transistor circuitry.

3) S-parameters require the use of matched loads for termination and since the loads absorb all the incident energy, the possibility of serious reflections back to the device or source is eliminated.

The scattering or $S$ parameters of a two-port network are defined in terms of the wave variables as:

$$
S_{11} = \frac{b_1}{a_1} \bigg|_{a_2=0} \quad S_{12} = \frac{b_1}{a_2} \bigg|_{a_1=0} \\
S_{21} = \frac{b_2}{a_1} \bigg|_{a_2=0} \quad S_{22} = \frac{b_2}{a_2} \bigg|_{a_1=0}
$$

where $a_n = 0$ implies a perfect impedance match (no reflection from terminal impedance) at port $n$. These definitions may be written as

$$
\begin{bmatrix}
    b_1 \\
    b_2
\end{bmatrix} = \begin{bmatrix}
    S_{11} & S_{12} \\
    S_{21} & S_{22}
\end{bmatrix} \begin{bmatrix}
    a_1 \\
    a_2
\end{bmatrix}
$$
S11 and S21 are the parameters to be considered in designing a filter. The response of the filter will be measured based on these two parameters.

S21 is representing the insertion loss of the filter. Insertion loss is defined as the ratio of power available from the source to the power delivered to the load.

On the other hand, S11 is representing the return loss of the filter. Return loss is defined as the ratio of power available from the source to the power reflected from the filter. Return loss is an important concept, particularly when dealing with the telephone network. Maximum power transfer in an electronic circuit can be achieved when the output impedance of a device (network) is exactly equal to the impedance of the device or transmission line connected to the output port. Return loss will show how well these impedances match, how close they are to being equal in value (ohms) to each other.
CHAPTER 3

LITERATURE REVIEW

At the starting point of searching the types of filter to be designed, some method has been used to find the information that suite the requirement in designing the compact microstrip bandpass filter. To help in more understanding and exposing to various types of filter design, the articles found in the IEEE website and some other websites are really useful. Different writer elaborate the different types of filter. Focusing on this report are some related articles that could be used in choosing which type of compact filter will be designed.

The article “Compact Microstrip bandpass Filter with Multispurious Suppression” written by H.W. Wu, S. K. Liu, M. H. Weng and C. H Hung (2010)[3]. This article presented a compact microstrip bandpass filter with multispurious suppression. The filter consists of two coupled half-wavelength stepped impedance resonators (SIRs) and tapped input/output (I/O) lines. With tuning the impedance ratio ($K$) and length ratio ($\alpha$) of SIRs, a very wide stopband can be easily achieved. The filter
is designed at 2.4GHz ($f_0$) with a wide stopband to 20 GHz (8.16$f_0$) and an average rejection level better than 25dB.

Figure 3.1: Fabricated filter [3]

Figure 3.1 shows the fabricated filter. The filter consists of two bended half-wavelength SIRs and tapped I/O lines. Size of the filter by adopting bended SIRs can be easily miniaturized. In addition, the arrangement of the tapped I/O lines can be further miniaturized the circuit size.

Figure 3.2: Simulated frequency response of the designed filter [3]
Figure 3.2 shows the simulated frequency response of the filter under different coupling spacing $S_1$ and $S_4$ between the two SIRs. The coupled spacing ($S_1$ and $S_4$) is tuned to effectively yield the good inter-coupling degree and improve the return loss ($jS_{11}$) in the passband. From Fig. 3.2(a), $jS_{11}$ increases when increasing $S_1$ from 0.2 to 1mm (all the other dimensions are held constant), meanwhile, the insertion loss ($jS_{21}$) decreased due to the reduced inter-coupling degree. When increasing the $S_4$ from 0.2 to 1.8mm (the same with $S_2$ from 2 to 3.6 mm), the $jS_{11}$ becomes poor, as shown in Fig. 5(b). It implies that $S_1$ and $S_4$ dominate the inter-coupling degree in the passband.

In the other article, entitled “Compact Third-Order Microstrip Bandpass Filter Using Hybrid Resonators” written by F. Xiao and M.Norgren (2011) [4]. In this paper, a novel microwave bandpass filter structure is proposed. By introducing a metallic via hole, the filter structure operates as one $\lambda/2$ and two $\lambda/4$ uniform impedance resonators and consequently form a triplet coupling scheme. The equivalent circuit model is analyzed in detail, which shows that there is a transmission zero in the low stopband. Based on that concept, three microstrip filters are designed, fabricated and measured, respectively. The first filter has no source/load coupling and only one transmission zero is created. By introducing source/load coupling, the second filter can create three transmission zeros. The third filter can create a controllable transmission zero in upper stopband.

![Figure 3.3](Image)

Figure 3.3: The proposed third-order filter without the source/load coupling [4]
Figure 3.4: Fabricated filter and the simulated and measured frequency response of the filter [4]

The size of the filter is only $0.243\lambda_g \times 0.248\lambda_g$, where $\lambda_g$ is the microstrip guide wavelength at 1.94 GHz. The electromagnetic simulation is done by HFSS and the frequency response of the filter is measured by Angilent network analyzer. The simulated and measured frequency responses of the filter are presented on right of figure 5. The measured center frequency is 1.97 GHz and the measured fractional bandwidth 6.5%. The frequency shift might be unexpected tolerance in fabrication and material parameters. The insertion loss including the SMA connector loss is about 1.9 dB. The return loss in the passband is less than -9.5 dB. The return loss might be reduced further, if the rectangular bends in the filter structure are smoothed to reduce reflection.

In the other article, a straight split dual-mode microstrip resonator is proposed [5]. The frequencies of the two first oscillation modes in the resonator may be brought closer together by adjusting a split parameter whereas the frequency of the third mode remains approximately equal to the doubled average frequency of the first and the second modes. It is shown that formulas derived within 1D model give qualitatively true relations between the resonant frequencies and the structure parameters of the resonator. Examples of narrowband bandpass filters of the fourth and the sixth order are described. Transmission zeros below and above the passband substantially improve the filter's
performance. The simulated frequency response of the three-resonator dual-mode filter is compared with the measured response of the fabricated filter.

![Filter Layout and Fabrication](image)

**Figure 3.5:** The layout and the fabricated of the designed three-resonator filter [5]

The filter has an interdigital configuration. The dimensions of the internal resonator differ from the dimensions of the external resonators. That is caused by their different interaction with the entourage. Besides three dual-mode resonators, the filter has an additional short conductor that weakly couples input and output ports. It generates a transmission zero near the spurious passband to improve the filter performance.

![Frequency Response](image)

**Figure 3.6:** The frequency response of the three-resonator filter [5]
The frequency response of the three-resonator filter is presented in Figure 3.6. The dotted curve shows the computed transmission function when the additional conductor between the ports is absent. In this case, there is only one transmission zero in the upper stopband and the rejection function considerably decreases above the transmission zero. The dash curve shows the computed transmission function when the additional conductor is present. It is seen that the additional conductor generates one more transmission zero at its resonant frequency near the spurious passband but does not disturb the frequency response in the main passband. That improves the filter performance in the upper stopband.

In an article entitled “Compact Microstrip UWB Bandpass Filter with Triple-Notched Bands”, the circuit topology and its corresponding electrical parameters of the initial microstrip UWB BPF are desired by a variation of genetic algorithm (VGA) [6]. Then, triple-notched bands inside the UWB passband are implemented by coupling a square ring short stub loaded resonator (SRSSLR) to the main transmission line of the initial microstrip UWB Bandpass filter. The triple-notched bands can be easily generated and set at any desired frequencies by varying the designed parameters of SRSSLR. For verification, a microstrip UWB BPF with triple-notched bands respectively centered at frequencies of 4.3 GHz, 5.8 GHz, and 8.1 GHz is designed and fabricated.

![Figure 3.7: Simulated and measured S-parameters of the UWB BPF [6]](image-url)
Figure 3.7 shows the comparison between the simulated and measured result. It can be seen that the fabricated UWB BPF has a pass-band from 3.1-10.9 GHz as we expected. Three notched bands with respective 3 dB FBWs of 7.1%, 6.8%, and 4.9% are achieved, which ensure a high selectivity for the designed UWB filter. Inside each notched band, the attenuation is better than -15 dB at the center frequencies of 4.3, 5.8, and 8.1 GHz. The minor discrepancy between simulation and measurement results are mainly due to the reflections from the SMA connectors and the finite substrate. Figure 3.8 shows the photograph of the fabricated UWB BPF.

In an article of “Compact Microstrip Dual-Mode Dual-Band Bandpass Filter Using Stubs Loaded Coupled Line”, the authors present two novel dual-mode dual-band bandpass filters (BPFs) by using stubs loaded coupled line [7]. The analytical equations of their transmission poles and transmission zeros are given by the classical even-/odd-mode method. Design rules for two dual-band BPFs are also given, which show the easily tuned passband frequency locations and in-band performance. As examples, two dual-mode dual-band BPFs, dual-band filter A with central frequencies (CFs) at 3.5/6.8 GHz and -3 dB fractional bandwidth (FBW) of 14%/10%, while dual-band filter B with CFs at 2.4/6.8 GHz and -3 dB FBW of 43%/16% are designed, fabricated and measured. Good agreement can be observed between the simulations and measurements. These two
filters exhibit simple design procedures, simple physical topology, low insertion losses, good return losses, high isolation and compact sizes.

The designing parameters for dual-band filter A at $f_{a0} = 5:15$ GHz are optimized as $Z_{1a} = 34 -$,$Z_{ca} = 148 -$,$kca = 0.34$ and $Z_{2a} = 126 -$,$ which corresponds to fractional bandwidth (FBWs) of 16%/8.2% and CFs at 3.5/6.8 for the WiMAX and RFID applications. The layout of fabricated dual-band filter B is given in Figure 3.9(a).

![Figure 3.9: (a) Layout (b) Fabricated dual-band filter A [7]](image)

ADS LineCalc tool are used to calculate the initial physical dimensions. The whole structure is optimized by full-wave EM-simulator HFSS, and the optimized physical dimensions are also labeled in Figure 3.9(a). The filter fabrication is done by using standard PCB etching process (0.08mm minimum gap or width). The photograph of fabricated dual-band filter B is shown in Figure 3.9(b). Its overall circuit size is 15:96mm×14:5mm (not including the feeding lines).
Figure 3.10 plots the simulated and measured results of fabricated dual-band filter A. Good agreement can be observed, and some slight discrepancies are due to the fabrication error as well as SMA connectors. In addition, the analysis discussed in the above section is appropriate for microstrip line due to the unequal even-/odd-mode phase velocities, which will also cause the difference between the ideal analysis and the HFSS simulation. The measured CFs and FBWs of two passbands are 3.6/6.7 GHz and 14.4%/10.4%, respectively. The measured insertion losses (ILs) at 3.5/6.8 GHz are 0.75/0.85 dB, and the return losses are better than 20/26 dB around these two frequencies, respectively. The fabricated dual-band filter A has a 20 dB band-to-band isolation from 4.77 GHz to 5.55 GHz, 15 dB rejection lower stopband from DC to 3.27 GHz and 10 dB rejection upper stopband from 7.1 GHz to 10.34 GHz.
REFERENCES


