DESIGN SIMULATION AND FABRICATION OF RF BAND PASS FILTER

PROJECT REPORT

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ABSTRACT

In this thesis five different filters are designed and triple-band filter is fabricated. Single-band bandpass filters for 4 GHz and 6 GHz are designed using microstrip coupled lines for 6/4 GHz Transverter applications. Transverters have a combined up converter and down converter that is used to vary the communication frequencies of a transceiver device. Simulations are done using Advanced Design System (ADS) simulator and RO4003 substrate with the thickness of 0.8 mm is used. The simulated design has low insertion loss and high return loss on the desired 6/4 GHz Transverter frequency bands. A 3rd order and 5th order dual-band chebyshev parallel coupled microstrip line bandpass filter is designed for Industrial, Scientific, and Medical (ISM) radio band and so this filter allows 2.4 GHz and 5 GHz frequency bands. ISM band is used in dual band routers and 2.4/5 GHz transverter. The designed filter is simulated using Advanced Design System (ADS) simulator and implemented on FR4 substrate with relative dielectric constant of 4.6. The simulated design has high return loss and low insertion loss on the desired ISM frequency bands. A Microstrip triple-band band pass filter 4GHz for 6/4 GHz transverter and 2.4 and 5 GHz for WLAN applications is designed and simulated using Agilent ADS software and implemented on FR4 substrate with relative dielectric constant of 4.6 and standard thickness of 1.6 mm.

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LIST OF ABBREVIATIONS

RF-Radio Frequency

EM-Electromagnetic

RC-Resistor Capacitor

BW-Bandwidth

WiFi-Wireless Fidelity

WiMAX- Worldwide Interoperability Microwave Access

QoS-Quality of Service

TEM- Transverse Electromagnetic

FBW-Frequency Bandwidth

LPF-Low Pass Filter

HPF- High Pass Filter

BPF- Band Pass Filter

BRF- Band Reject Filter

PCB-Printed Circuit Board

ADS- Advanced Design Software

FR4-Flame Retardant
RO4003-Roger 4003

CHAPTER 1

INTRODUCTION

In the previous years, wireless communication systems have developed tremendously, there was a prompt development in ultra-wideband systems, wireless internet like Wi-Fi and WiMAX, broadband personal communication systems and 3G (third generation), 4G (fourth generation) technologies. Due to this rapid development, there was a need for more rigid microwave components nowadays satellite systems changed their path from static telecommunications systems to mobile, remote sensing and navigation applications. Microwave components include microwave resonant components such as microwave filters, dielectric resonant antenna arrays, and duplexers. Because of the rapid growth in the wireless communication area, it created more challenging requirements that enforce challenges on various novel designs, optimization, and understanding of components. In microwave filters, the challenges are to be faced in miniaturization, bandwidth, phase linearity, and selectivity of the filters.

1.1 Microwave Communication

The electromagnetic waves are the waves whose frequency ranges from 300 MHz - 300 GHz, these range of frequencies are referred as microwaves. The wavelength of this waves in free space is about 1 m – 1 mm. The electromagnetic spectrum is shown in figure 1.1, it demonstrates schematically the electromagnetic spectrum. Further, some selected frequency spectrums are allocated into many frequency bands as betokened in Table 1.1. Frequency boundaries between RF and microwave are almost arbitrary. The boundary relies on the specific technologies established for the utilization of that particular frequency range.

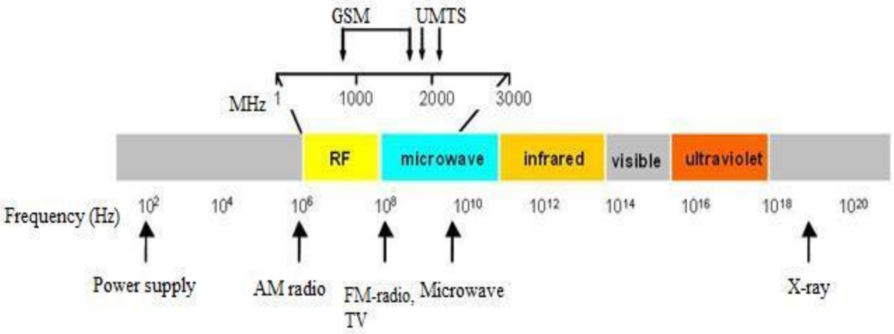


Figure 1. 1 Electromagnetic spectrum

Table 1.1 Frequency bands

Band	Frequency range
HF Band	3 to 30 MHz
VHF Band	30 to 300 MHz
UHF Band	300 to 1000 MHz
L-Band	1 to 2 GHZ
S-Band	2 to 4 GHZ
C-Band	4 to 8 GHZ
X-Band	8 to 12 GHZ
Ku-Band	12 to 18 GHZ
K-Band	18 to 27 GHZ
Ka-Band	27 to 40 GHZ
V-Band	40 to 75 GHZ
W-Band	75 to 110 GHZ
Mm-Band	110 to 300 GHz

1.2 Definition of a Filter

A filter is used to regulate the frequency response at a fixed point in the EM spectrum by providing low loss transmission at the preferred frequency band and high attenuation at remaining frequencies. Filters are extensively used in many applications like communications, remote sensing, radars etc. A filter is generally a two-port network.

1.3 Role of filters in microwave communication

Filters are essential for separating and sorting signals in communication systems. To cull or confine the RF/microwave signals within given spectral limits, filters are used. The role of filters in communication systems is to usually transmit and receive amplitude and/or phase modulated signals through a communication channel. To get rid of or suppress spurious frequencies from being transmitted or received in radio transmitters and receivers, filters are used. Evolving applications such as wireless communication remains to challenge RF/microwave filters with even more rigid requirements like smaller size, lighter weight and lower cost with better performance. Filters used in communication and radar applications are implemented in different kinds of transmission lines comprising stripline, rectangular waveguide, and microstrip. Filters are also the integral part of multiplexers which are of major demand in the broadband wireless access communication systems.

1.4 Applications of filters

Microwave filters play an important role in almost every RF/microwave communications system. A microwave filter is basically a device that is used to discriminate between wanted and unwanted signals within a specified frequency band. The term microwave refers to the frequency range between 300 MHz and 30 GHz. As the communication systems evolve, higher frequencies are explored and new standards are set. Also, the filter requirements in terms of selectivity become more stringent due to the limited available frequency spectrum. Other filter specifications are generally dictated by the intended application.

1.5 Satellite filters

Satellite filters cover a large frequency range depending on the specific service offered by the satellite payload [1]. For example, navigation mobile satellite systems are naturally activated in the L and S bands (1-2 GHz, 2-4 GHz, respectively) and remote sensing applications will work mainly in the C-band (4-8 GHz). For most viable communications, there is an outstanding high demand on the frequency spectrum, higher Ku-band (12-18 GHz) and other upper-frequency bands (20-30 GHz) are considered [2]. A communication satellite is basically a repeater that receives microwave signals, amplifies them and resends them to the receiving end. The bandwidth is divided into narrow band channels, since the practical considerations due to non-linarites and effect of noise in power amplifiers. The partition and recombination of channels are done by means of input and output multiplexers individually. The input and output multiplexers are poised of many narrow bandpass filters (typical fractional bandwidths between 0.2% and 2%). Satellite microwave bandpass filters have been typically executed using waveguide technology due to high-quality factors and high power handling capability. On the other hand, waveguide filters are bulky and heavy. There has been a significant amount of work done to reduce the size and weight of satellite filters. A fruitful solution involves using dual-mode cavities, i.e. cavities that support two degenerate resonances [3]. This reduces a number of physical cavities by an aspect of two. Also, the usage of dual-mode cavities permits the implementation of topologies that are capable of producing transmission zeros at finite frequencies and hence improving filter selectivity.

1.6 Microwave filters in cellular communication

Microwave filters are very important components in cellular systems where stringent filter specifications are required both on the mobile station and base station levels. All modern full duplex personal communications systems require transmit and receive filters for each transceiver unit at least at the base station level. Transmit filters must be very selective to prevent out of band inter-modulation interference to satisfy regulatory requirements as well as prevent adjacent channel interference. Acceptable levels of adjacent channel interference in TDMA second generation mobiles are specified in GSM ETSI standards as C/A > -9dB. In practice, a C/A of -6 dB is used in the network design. Also, the transmit filters must have low insertion loss to satisfy efficiency requirements. A typical transmit filter contains a return loss of 20dB and passband insertion loss of 0.8 dB It is obvious that the technology used in filter realization in base stations is significantly different from that used in handsets. Although the filter specifications in handsets are less stringent due to lower power handling (33dBm maximum transmit power), size requirements remain a challenging task. One of the main difficulties is parasitic or unwanted coupling that is caused by the close proximity of the resonators.

Another application of filters is in cellular systems microwave links to connect base stations to BSC (base station controller) and then to the MSC (Mobile Switching Center). These are high-speed links with directive dish antennas. There are few licensed bands for transmission such as 8, 11, 18, 23, 24 and 38 GHz. The choice of the frequency band depends on spectrum availability, the length of the hop and required link reliability. Filters for transmission systems are usually constructed using waveguide technology due to the high-quality factors requirements and high power handling capabilities.

CHAPTER 2

LITERATURE REVIEW

2.1 Band Pass Filters

The cut-off frequency or f_c point in a simple RC passive filter can be accurately controlled using just a single resistor in series with a non-polarized capacitor, and depending on which way around they are connected either a low-pass or a high-pass filter is obtained. One simple use for these types of Passive Filters is in audio amplifier applications or circuits such as in loudspeaker crossover filters or pre-amplifier tone controls. Sometimes it is necessary to only pass a certain range of frequencies that do not begin at 0Hz, (DC) or end at some high-frequency point but are within a certain frequency band, either narrow or wide.

By connecting or "cascading" together with a single **Low-pass Filter** circuit with a **High-pass Filter** circuit, we can produce another type of passive RC filter that passes a selected range or "band" of frequencies that can be either narrow or wide while attenuating all those outside of this range. This new type of passive filter arrangement produces a frequency selective filter known commonly as a **Band Pass Filter** or **BPF** for short. Using capacitors and inductors, a bandpass filter has a structure similar to the one shown in the diagram below.

Unlike a low-pass filter that only passes signals of a low-frequency range or a high-pass filter which pass signals of a higher frequency range, a Band Pass Filters passes signals within a certain "band" or "spread" of frequencies without distorting the input signal or introducing extra noise. This band of frequencies can be any width and is commonly known as the filters Bandwidth**.**

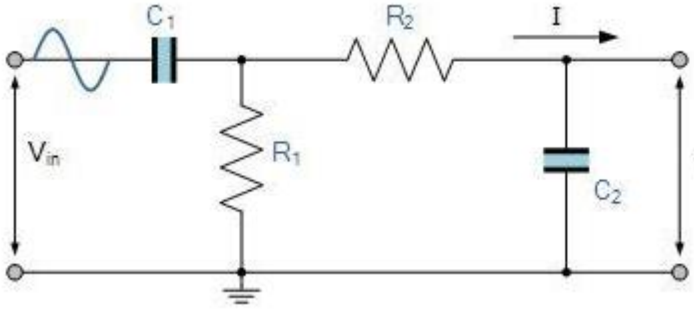


Figure 2.1 RC implementation of the bandpass Filter

Bandwidth is commonly defined as the frequency range that exists between two specified frequency cut-off points (f_c), that are 3dB below the maximum center or resonant peak while attenuating or weakening the others outside of these two points. Then for widely spread frequencies, we can simply define the term "bandwidth", BW as being the difference between the lower cut-off frequency (f_{cLOWER}) and the higher cut-off frequency ($f_{cHIGHER}$) points. In other words, $BW = f_H - f_L$. Clearly, for a pass band filter to function correctly, the cut-off frequency of the low-pass filter must be higher than the cut-off frequency for the high-pass filter. The "ideal" Band Pass Filter can also be used to isolate or filter out certain frequencies that lie within a particular band of frequencies, for example, noise cancellation.

Band pass filters are known generally as second-order filters, (two-pole) because they have "two" reactive component, the capacitors, within their circuit design. One capacitor in the low-pass circuit and another capacitor in the high-pass circuit.

The Bode Plot or frequency response curve above shows the characteristics of the band pass filter. Here the signal is attenuated at low frequencies with the output increasing at a slope of +20dB/Decade (6dB/Octave) until the frequency reaches the "lower cut-off" point f_L. At this frequency, the output voltage is again $1/\sqrt{2} = 70.7\%$ of the input signal value or -3dB (20 log (Vout/Vin)) of the input.

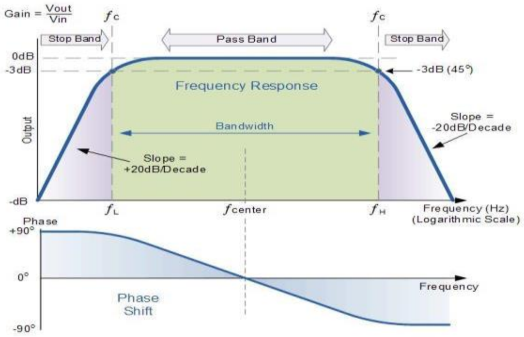


Figure 2.2 Amplitude and phase plot for a general bandpass filter

The output continues at maximum gain until it reaches the "upper cut-off" point f_H where the output decreases at a rate of -20dB/Decade (6dB/Octave) attenuating any high-frequency signals. The point of maximum output gain is generally the geometric mean of the two -3dB value between the lower and upper cut-off points and is called the "Center Frequency" or "Resonant Peak" value fr. This geometric mean value is calculated as being $fr^2 = f_{\text{(UPPER)}} \times f_{\text{(LOWER)}}$.

A band pass filter is regarded as a second-order (two-pole) type filter because it has "two" reactive components within its circuit structure, then the phase angle will be twice that of the previously seen first-order filters, i.e., **180°**. The phase angle of the output signal **LEADS** that of the input by **+90°** up to the center or resonant frequency, f_r point where it becomes "zero" degrees (0°) or "in-phase" and then changes to **LAG** the input by **-90°** as the output frequency increases. The upper and lower cut-off Frequency points for a band pass filter can be found using the same formula as that for both the low and high-pass filters, For example.

$$f_c = \frac{1}{2\pi RC}\ Hz$$

Then clearly, the width of the pass band of the filter can be controlled by the positioning of the two cut-off frequency points of the two filters. Bandpass filters play a significant role in wireless communication systems. Transmitted and received signals have to be filtered at a certain center frequency with a specific bandwidth. In designing of microstrip filters, the first step is to carry out an approximated calculation based on using of concentrated components like inductors and capacitors. After getting the specifications required, we realized the filter structure with the parallel-coupled technique. Experimental verification gives a comparison, how close the theoretical results and measurements look like.

The advances of telecommunication technology arising hand in hand with the market demands and governmental regulations push the invention and development of new applications in wireless communication. These new applications offer certain features in telecommunication services, which in turn offer three important items to the customers. The first is the coverage, meaning each customer must be supported with a minimal signal level of electromagnetic waves, the second is capacity that means the customer must have sufficient data rate for uploading and downloading of data, and the last is the quality of services (QoS) which guarantee the quality of the transmission of data from the transmitter to the receiver with no error. In order to provide additional transmission capacity, a strategy would be to open certain frequency regions for new applications or systems. WiMAX (Worldwide interoperability Microwave Access) and Wi-Fi which is believed as a key application for solving many actual problems today is an example.

In realization of such a system like WiMAX, we need a complete new transmitter and receiver. A bandpass filter is an important component must be found in the transmitter or receiver. The bandpass filter is a passive component which is able to select signals inside a specific bandwidth at a certain center frequency and reject signals in another frequency region, especially in frequency regions, which have the potential to interfere the information signals. In designing the bandpass filter, we are faced the questions, what is the maximal loss inside the pass region, and the minimal attenuation in the reject/stop regions, and how the filter characteristics must look like in transition regions. In the process to fulfill these requirements, there are several strategies taken in the realization of the filters, for example, the choice of waveguide technology for the filter is preferred with respect to the minimal transmission loss (insertion loss). This strategy is still actual in satellite applications. The effort to fabricate waveguide filters prevents its application in huge amounts. As an alternative, Microstrip filter based on printed circuit board (PCB) offers the advantages easy and cheap in mass production with the disadvantages higher insertion losses and wider transition region. In this work we would like to give a way to conceive, design and fabricate bandpass filter for the WiMAX application at the frequency 2.4 GHz with parallel coupled microstrips as opposed to the designed filter for wireless local area network at 5GHz, and which used the composite resonators and stepped impedance resonators for filter realization.

2.2 Basics of Filter

Transfer Function

In Radio Frequency (RF) applications, for defining transfer function we use the scattering parameter S21. In many applications, we use instead the magnitude of S21, the quadrate of S21 is preferred.

$$|S_{21}(j\Omega)|^2 = \frac{1}{1 + \mathcal{E}^2 F_n^2(\Omega)}$$

ε is the ripple constant, $Fn(\Omega)$ filter function and Ω is frequency variable. If the transfer function is given, the insertion loss response of the filter can calculate by

$$L_A(\Omega) = 10\, log \frac{1}{|S_{21}(j\Omega)|^2}\; dB$$

2.3 Butterworth Filters

Filters designed with Butterworth approach show the maximal flat characteristics in the pass region. The figure below shows the attenuation characteristics of lowpass Butterworth filter. In the pass band region, *f*<*fc*, the attenuation of ideal low-pass filter is 0 dB, a good approximation must have characteristics close to zero from the frequency zero Hertz to a certain so-called cut-off frequency *f*c. For *f*>*f*c, the ideal low-pass filter attenuates the signal completely or LA→∞. The quadrate of the magnitude of the transfer function

$$|S_{21}(j\Omega)|^2 = \frac{1}{1+\Omega^{2n}}$$

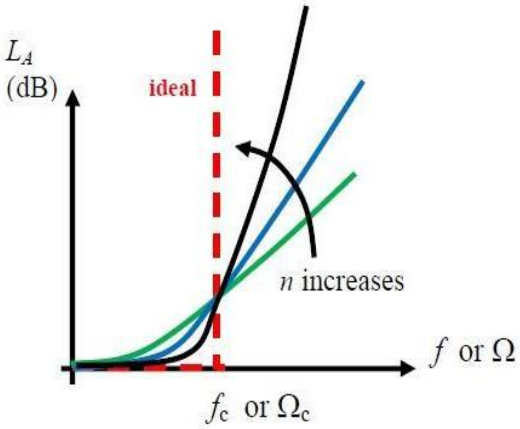


Figure 2.3 Graph showing the frequency response of a low-pass filter

The figure below gives the circuit implementation of the filter by means of concentrated components like inductors (L) and capacitors (C), for the even and odd filter degree (n). The Butterworth approach for designing filter uses the condition attenuation of 3 dB at the frequency Ω=Ωc=1 so that the following equations can be used for collecting the values of L and C for the circuits

$$|S_{21}(j\Omega)|^2 = \frac{1}{1+\mathcal{E}^2 T_n^2(\Omega)}$$

$\mathrm{T}_\mathrm{n}^2(\Omega)$ is Chebyshev function type 1 with order n.

$$g_0 = g_{n+1} = 1$$
$$g_i = 2\sin\left(\frac{(2i-1)\pi}{2n}\right)$$
$$for\ i = 1\ to\ n.$$

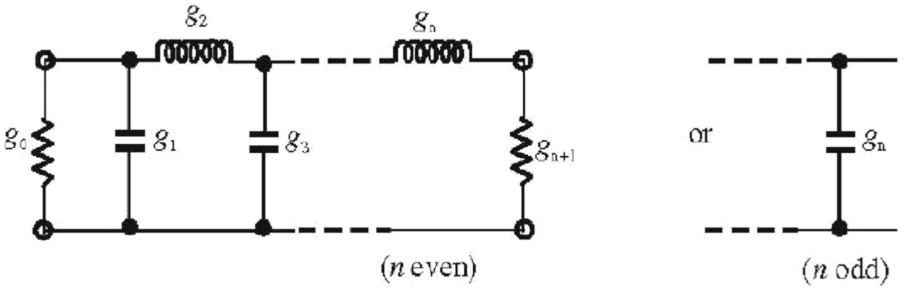


Figure 2.4 Parameter illustration for a band pass filter

The value of *n* can be determined if an additional constraint is given, for example, the filter must have minimal attenuation factor at a certain frequency.

2.4 Chebyshev Filter

In the practical implementation, the specification for losses in pass region can normally be higher than zero. Chebyshev approach exploits this not so strictly given specification values. It can be 0.01 dB, or 0.1 dB, or even higher values. The Chebyshev approach thereby shows certain ripples in the pass region, this can lead to better (higher) slope in the stop region. Figure 2.5 shows the attenuation characteristics for lowpass filter based on Chebyshev approach. The quadrate of the magnitude of the transfer function with Chebyshev approach is given by

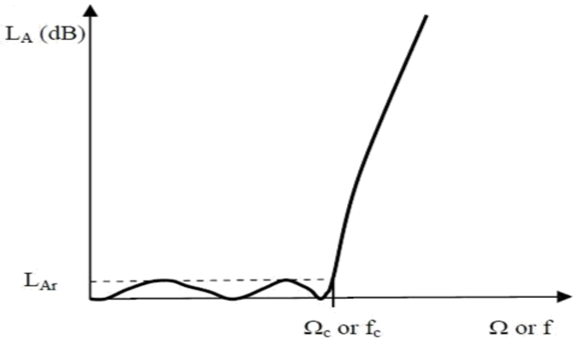


Figure 2.5 Ideal response of a Chebyshev low-pass filter

$$g_0 = 1$$

$$g_1 = \frac{2}{\gamma}\sin\left(\frac{\Pi}{2n}\right)$$

$$g_i = \frac{1}{g_{i-1}} \frac{4\sin\left(\frac{(2i-1)\Pi}{2n}\right)\sin\left(\frac{(2i-3)\Pi}{2n}\right)}{\gamma^2 + \sin^2\left(\frac{(i-1)\Pi}{n}\right)} \sin\left(\frac{(2i-1)\Pi}{2n}\right)$$

$$for\_i = 2ton$$

$$g_{n+1} = \begin{cases} 1 \, for odd n \\ \coth^2\left(\frac{\beta}{4}\right) for even n \end{cases}$$

where

$$\beta = \ln\left[\coth\left(\frac{L_{Ar}}{17.37}\right)\right]$$

$$\gamma = \sinh\left(\frac{\beta}{2n}\right)$$

2.5 Transformation to Bandpass Filter

The previous observation was done for low-pass implementation. A transformation to Band pass is needed for getting bandpass characteristics. In the transformation, the component L will be converted to serial combinations of Ls and Cs, whereas component C becomes a parallel combination of Lp and Cp. With the cut-off frequencies ω1 and ω2 as lower and upper boundary, we can calculate the center frequency and the relative frequency bandwidth as follows

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

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

The value for the new components are

For the serial combination.

$$L_s = \left(\frac{1}{FBW(\omega_0)}\right) Z_0(g)$$

$$C_s = \left(\frac{FBW}{\omega_0}\right) \frac{1}{Z_0 g}$$

For the parallel combination.

$$C_p = \left(\frac{1}{FBW(\omega_0)}\right) \frac{g}{Z_0}$$

$$L_p = \left(\frac{FBW}{\omega_0}\right) \frac{Z_0}{g}$$

Z_0 is the value of load impedance, normally $Z_0 = 50\Omega$

2.6 Microstrip Transmission Line

Microstrip transmission line is the most used planar transmission line in Radio frequency (RF) applications [4]. 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 lines in RF applications, microstrip can also be exploited for designing certain components, like a filter, coupler, transformer or power divider. If a microstrip transmission line, as depicted in Figure 2.6 is used for transport of wave with relatively 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.

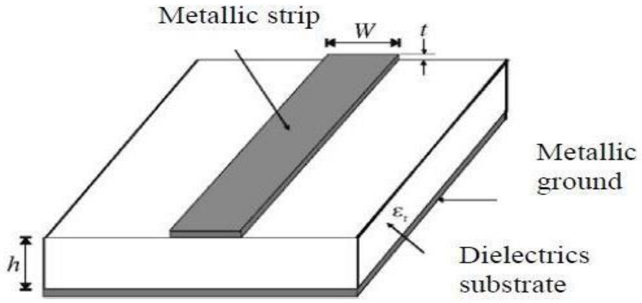


Figure 2.6 Structure of a microstrip Transmission line

The width of the strip *W* together with the dielectric constant and the thickness of the substrate determines the characteristic impedance *Z*o of the line.

2.7 Designing Band pass Filter

The figure below shows the filter structure observed in this work. This filter type is known as a parallel-coupled filter. The strips are arranged parallel close to each other so that they are coupled with certain coupling factors. We use the following equations for designing the parallel-coupled filterg_0, g_1. g_n can be taken from Table, FBW is the relative bandwidth as explained before, J_j,j+1 is the characteristic admittance of J-inverter and Yo is the characteristic admittance of the connecting transmission line. With the data of characteristic admittance of the inverter, we can calculate the characteristic impedances of even-mode and odd-mode of the parallel-coupled microstrip transmission line, as follows

$$Z_o J_1 = \sqrt{\frac{\pi\Delta}{2g_1}}$$

$$Z_o J_N = \frac{\Delta\pi}{2\sqrt{g_{N-1} g_N}}$$

$$Z_o J_{N+1} = \sqrt{\frac{\pi\Delta}{2 g_N g_{N+1}}}$$

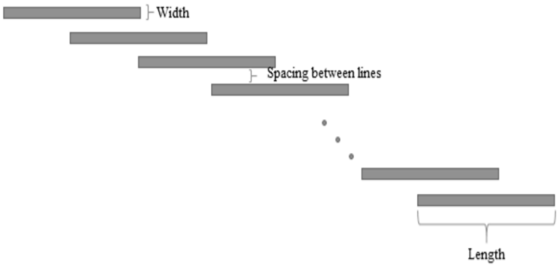


Figure 2.7 Diagram of parallel coupled microstrip lines

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right]$$

For j = 0 to n

$$(Z_{00})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right]$$

For j = 0 to n

2.8 The Microstrip

The microstrip belongs to the group of parallel-plate transmission lines and consists of a single ground plane and an open strip conductor separated by a dielectric substrate. Microstrip lines are the most commonly used form of transmission lines for microwave integrated circuits. Also, microstrips are used as circuit components for filters, phase shifters, couplers, resonators, and antennas.

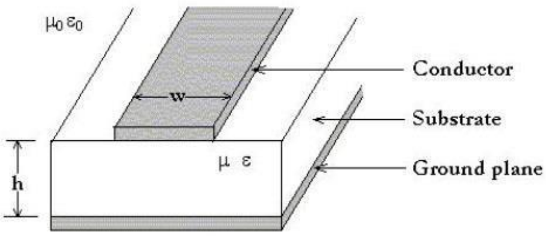


Figure 2.8 Diagram of a microstrip transmission line

The electromagnetic field in the microstrip line is not confined only to the dielectric and because of the fringing; the effective relative permittivity ε_{eff} is less than the relative permittivity ε_r of the substrate. The electromagnetic waves in microstrip propagate in TEM (transverse electric magnetic) mode, which is characterized by electric and magnetic fields that exist only in the plane perpendicular to the axis of the wave propagation.

2.9 Parallel Couple Microstrip Lines

As in the case of a single microstrip line, a parallel-coupled microstrip arrangement is also a TEM-mode system. The relative polarities of the voltages on the coupled microstrip lines at any specific plane along the structure and at any specific time will be the same or opposite. The two field distributions result in even mode and odd-mode characteristic impedances denoted by Z_{0e} and Z_{0o}. These characteristic impedances are major parameters in design procedures. In two different modes of field distribution, namely the even-mode and the odd mode. These modes are illustrated in the figures below.

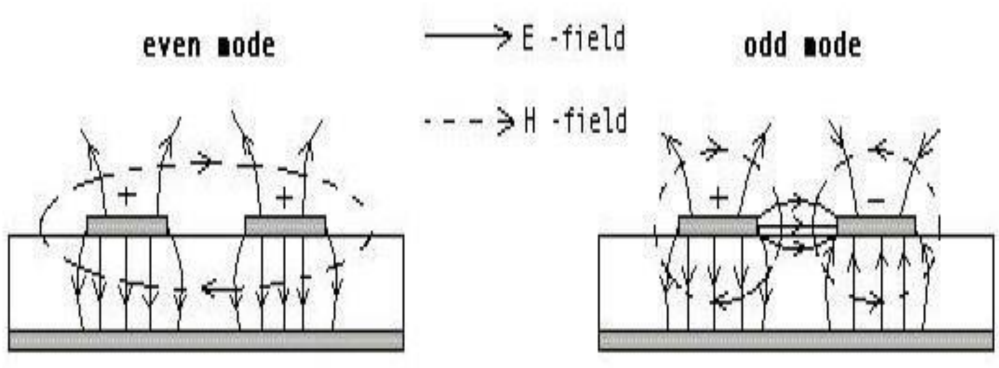


Figure 2.9 Even and Odd modes for the microstrip line

The complete behaviour of the parallel-coupled microstrip structure can be obtained by superposition of the effects due to these two modes.

2.10 The Filter

A filter is a device or substance that passes electric currents at certain frequencies or frequency ranges while preventing the passage of others. Based on the frequencies they pass, the filters are classified as low-pass filters (LPF), high-pass filters (HPF), band pass filters (BPF) and band reject filters (BRF) [5]. These filter types are best explained based on the characteristics of a normalized low-pass filter because characteristics of other filter types can be related to the low-pass filter characteristics. The ideal low-pass filter is characterized by zero loss and zero ripples in the pass band, an infinite attenuation slope at cut-off frequency and infinite attenuation in the stop band.

2.11 DUALBAND FILTER

Band pass filter is used to allow a range of frequency i.e., from the lower frequency to upper frequency but nowadays it is possible to design a dual-band filter which allows two range of frequencies in last phase 2.4 and 5 GHz with 100 MHz bandwidth is designed.

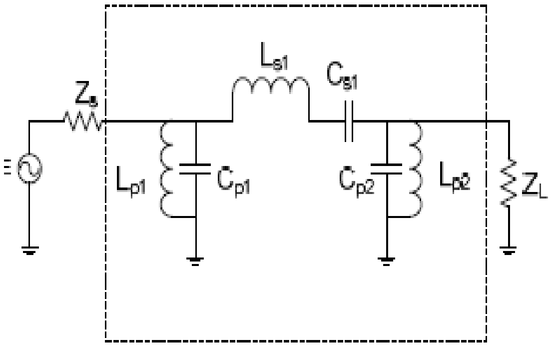


Figure 2.10 Single band filter

Figure 2.10 Shows the band pass prototype for single band filter for the lumped elements where this capacitors and inductors are converted into the microstrip lines for a better result.

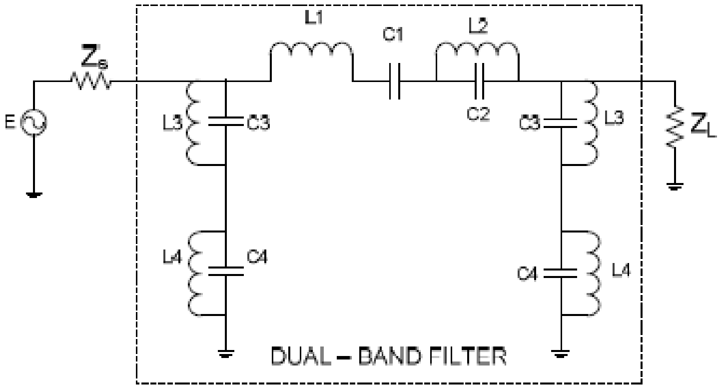
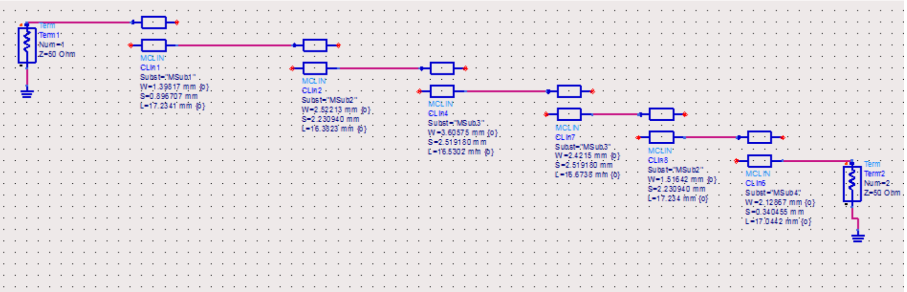


Figure 2.11 Dual band filter

Figure 2.11 Shows the Dual band filter for the lumped elements where this capacitors and inductors are converted into the microstrip lines for a better result.



Term
Term1
Num=1
Z=50 Ohm

MCLIN
CLin1
Subst="MSub1"
W=1.39817 mm {o}
S=0.896707 mm
L=17.2341 mm {o}

MCLIN
CLin2
Subst="MSub2"
W=2.52213 mm {o}
S=2.230940 mm
L=16.3823 mm {o}

MCLIN
CLin4
Subst="MSub3"
W=3.60575 mm {o}
S=2.519180 mm
L=16.5302 mm {o}

MCLIN
CLin7
Subst="MSub3"
W=2.4215 mm {o}
S=2.519180 mm
L=16.6738 mm {o}

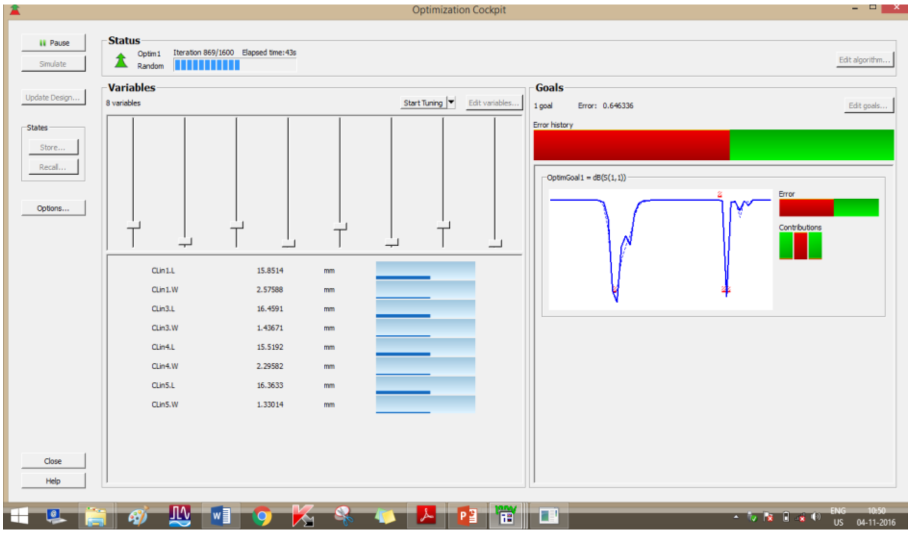
MCLIN
CLin8
Subst="MSub2"
W=1.51642 mm {o}
S=2.230940 mm
L=17.234 mm {o}

MCLIN
CLin6
Subst="MSub4"
W=2.12867 mm {o}
S=0.340455 mm
L=17.0442 mm {o}

Term
Term2
Num=2
Z=50 Ohm

Figure 2.12 Coupled line design using ADS

Figure 2.12 Shows the design for the coupled line filter where this is designed using the ADS software and then optimized for better results.



Optim1 Iteration 869/1600 Elapsed time:43s
Random

8 variables

CLin1.L	15.8514	mm
CLin1.W	2.57588	mm
CLin3.L	16.4591	mm
CLin3.W	1.43671	mm
CLin4.L	15.5192	mm
CLin4.W	2.29582	mm
CLin5.L	16.3633	mm
CLin5.W	1.33014	mm

1 goal Error: 0.646336

OptimGoal1 = dB(S(1,1))

Figure 2.13 Optimization tool in ADS

Figure 2.13 shows the optimization tool which is used to optimize the width, length, and spacing in coupled line design and optimization is done to achieve the result required for the applications. In this thesis a single band, double band, and triple band filters are designed and the triple band filter is explained with image.

CHAPTER 3

METHODOLOGY

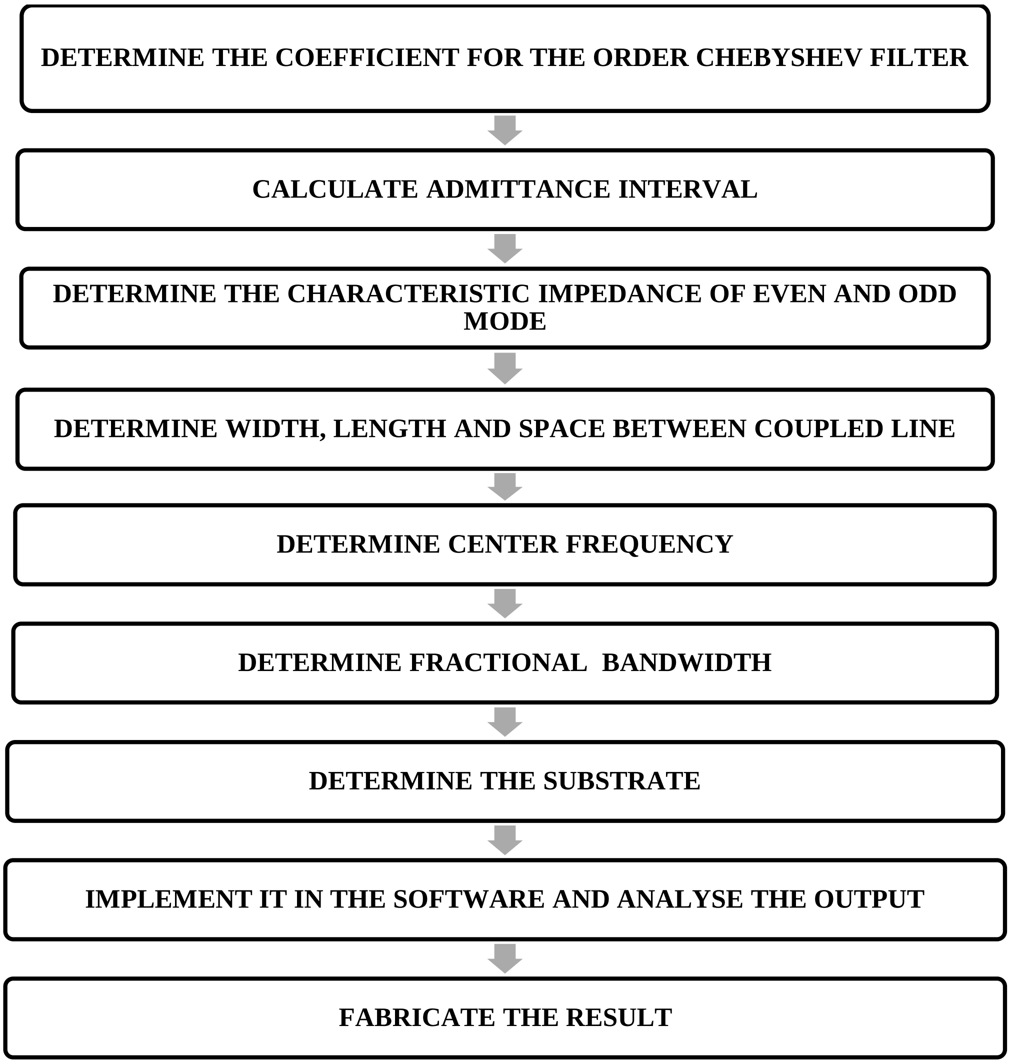


Figure 3.1 Flow chart for design implementation

3.1 Advanced Design System (ADS)

ADS provides an integrated design environment to designers of RF electronic products such as mobile phones, page, satellite communications, radar systems, and high-speed data links. Keysight ADS supports every step of the design process—schematic capture, layout, design rule checking, time circuit simulation, and electromagnetic field simulation—allowing the engineer to fully characterize and optimize an RF design without changing tools. It is an electronic design automation software system produced by Keysight EEsof EDA, a division of Keysight Technologies. Keysight EDA has donated copies of the ADS software to the electrical engineering departments at many universities, and a large percentage of new graduates are experienced in its use. As a result, the system has found wide acceptance in the industry.

Figure 3.2 ADS Software

3.2 DESIGN PROCEDURE FOR COUPLED LINE FILTER

The design procedure for the dual band chebyshev parallel coupled microstrip line bandpass filter is arranged as Step 1–9.

Step 1: Define Bandpass Filter Specifications.
Step 2: Select the order of the filter.
Step 3: Calculate the bandwidth for the desired frequencies.
Step 4: Calculate the admittance interval J_n.
Step 5: Determine even and odd mode impedances.
Step 6: Select the appropriate substrate for filter design.
Step 7: Using LineCalc tool in ADS, calculate the width, length, and spacing between lines of the filter.
Step 8: Use the width, length, and spacing between lines values to design the coupled line filter.
Step 9: Obtain the layout design and output of the filter.

A single band filters for 4GHz and 6GHz are designed for the application of 6/4 GHz transverter. A dual band chebyshev parallel coupled microstrip line bandpass filter is designed for 2.4 GHz and 5 GHz frequencies as these frequencies are commonly used in ISM band for worldwide operations.

3.3 SINGLE BAND FILTER DESIGN

3.3.1 DESIGN PROCEDURE

Advanced Design System (ADS) software is used for simulation [6]. Design procedure includes 3 steps.

Step 1: Choose the specification of the filters.

Filters are classified into Lowpass filter, High-pass filter, Bandpass filter, and Band stop filter. The filter used for this application is a bandpass filter. A bandpass filter allows the specific range of frequencies and block remaining frequencies. The substrate used for the bandpass filter design is RO4003 [7]. The Specification of the substrate is tabulated in Table 3.1.

Table 3.1. Specification of substrate

Specification	**Value**
Substrate Name	RO4003
Order of filter, N	3
Center Frequency for 4 GHz, f_c	4 GHz
Center Frequency for 6 GHz, f_c	6 GHz
Impedance, Z_0	50 Ω
Fractional Band Width, Δ	0.1

Step 2: Calculation of filter parameters.

Chebyshev prototype with the ripple factor of 0.5 dB and the order of 3 is selected for the filter design [8]. Microstrip line, coupled line, hairpin, comb line are some of the designs used for the manufacturing of filters and these designs are selected according to the requirement of the application. The filter in this paper is designed using Coupled lines approach. The theoretical values of the Coupled line chebyshev 3rd order filter are obtained using the following equations [9]. Fractional bandwidth of the filter is determined using the following equations and the obtained coefficients of the 3rd order filters are provided in the Table 3.2.

$$\omega_1 = 2\pi f_1$$

$$\omega_2 = 2\pi f_2$$

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

$$\Delta = \left(\frac{\omega_1 \omega_2}{\omega_o}\right)$$

Table 3.2. Ripple Factor 20log10 ε = 0.5 dB

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7
1	0.6986	1.0000					
2	1.4029	0.7071	1.9841				
3	1.5963	1.0967	1.5963	1.0000			
4	1.6703	1.1926	2.3661	0.8419	1.9841		
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000	
6	1.7254	1.2479	2.6064	1.3137	2.4578	0.8696	1.9841

The fractional bandwidth is used to identify the inverter impedance. The inverter admittance J_N is calculated using the following equations where N represent the order of the filter.

$$Z_o J_1 = \sqrt{\frac{\pi\Delta}{2g_1}}$$

$$Z_o J_N = \frac{\Delta\pi}{2\sqrt{g_{N-1}g_N}}$$

$$Z_o J_{N+1} = \sqrt{\frac{\pi\Delta}{2g_N g_{N+1}}}$$

Even mode (Z_{oe}) and Odd mode (Z_{oo}) impedances of the coupled line is calculated using the following equations. The Calculated inverter admittance, even mode and odd mode values of 4 GHz filter and 6 GHz filter are justified in the Table 3.3 and Table 3.4 respectively.

$$Z_{oe} = Z_o[1 + JZ_o + (JZ_o)^2]$$

$$Z_{oo} = Z_o[1 - JZ_o + (JZ_o)^2]$$

Table 3.3. Inverter admittance, even mode and odd mode impedance values of 4 GHz filter

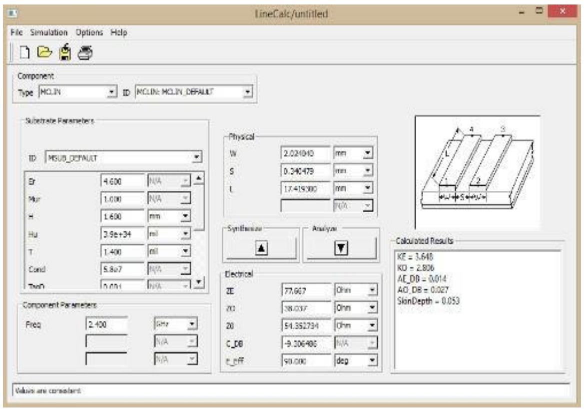
G_n	$Z_o J_n$	Z_{oe}	Z_{oo}
1.5963	0.2218	63.5497	41.3697
1.0967	0.0593	53.1408	47.2108
1.5963	0.0593	53.1408	47.2108
1.000	0.2218	63.5497	41.3697

Table 3.4. Inverter admittance, even mode and odd mode impedance values of 6 GHz filter

G_n	$Z_o J_n$	Z_{oe}	Z_{oo}
1.5963	0.2429	65.0950	40.8050
1.0967	0.0356	51.8433	48.2833
1.5963	0.0356	51.8433	48.2833
1.000	0.2429	65.0950	40.8050

Step 3: Implementation of bandpass filter in ADS

LineCalc tool in the ADS software is used for the application of converting the even and odd mode impedance values into the Width, Spacing, and Length of the coupled line. The LineCalc window in ADS is shown in Figure 3.3



Type: MCLIN
ID: MCLIN: MCLIN_DEFAULT

ID: MSUB_DEFAULT
Er: 4.600 N/A
Mur: 1.000 N/A
H: 1.600 mm
Hu: 3.9e+34 mil
T: 1.400 mil
Cond: 5.8e7 N/A
TanD: 0.001 N/A

Freq: 2.400 GHz

W: 2.024040 mm
S: 0.340479 mm
L: 17.419300 mm

ZE: 77.667 Ohm
ZO: 38.037 Ohm
Z0: 54.352734 Ohm
C_DB: -9.306486 N/A
E_Eff: 90.000 deg

KE = 3.648
KO = 2.806
AE_DB = 0.014
AO_DB = 0.027
SkinDepth = 0.053

Values are consistent

Figure 3.3 LineCalc window in ADS

Parallel-coupled lines is another popular topology for printed boards, for which open-circuit lines are the simplest to implement since the manufacturing consists of nothing more than the printed track. The design consists of a row of parallel λ/2 resonators, but coupling over only λ/4 to each of the neighbouring resonators, so forming a staggered line as shown in Figure 3.4. Wider fractional bandwidths are possible with this filter than with the capacitive gap filter [10-12].

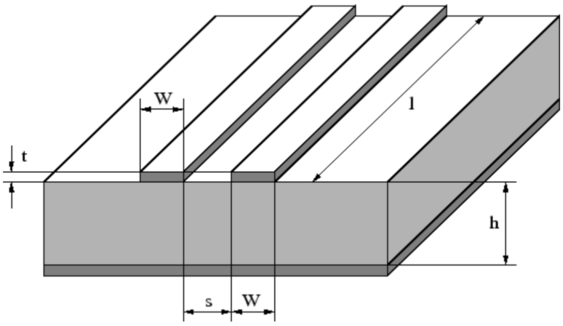


Figure 3.4 Structure of coupled line

Characteristic impedance, Z_o is the impedance between the conductors when there is no coupling to ground. Even mode impedance, Z_{oe} is the impedance between one conductor and the ground plane when both conductors are driven with same polarity signal against the ground. Odd mode impedance, Z_{oo} is the impedance between one conductor and the ground plane when the conductors are driven with opposite polarity signal against the ground. Theoretically calculated even mode impedance, odd mode impedance and characteristics impedance are substituted in LineCalc to calculate the width, space, and length of the coupled line.

3.3.2 RESULT AND DISCUSSION FOR SINGLE BAND 3RD ORDER CHEBYSHEV FILTER

Coupled lines are used to design a filter with the configuration of perfect conductor and the RO4003 substrate. The schematic and layout windows of the designed bandpass filters are shown in figure 3.3.2.

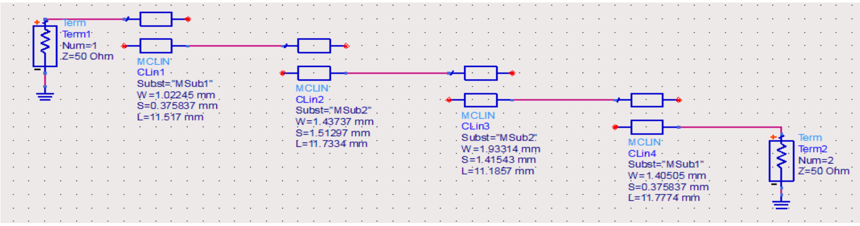


Figure 3.5 Schematic of 4 GHz bandpass filter

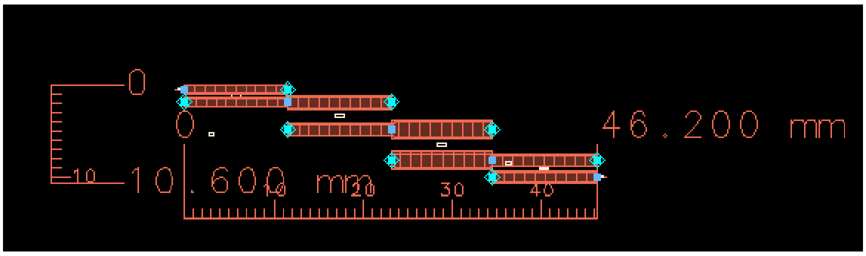


Figure 3.6 Layout of 4 GHz bandpass filter

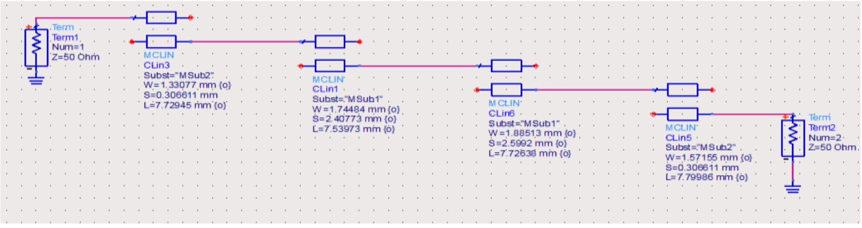


Figure 3.6 Schematic of 6 GHz bandpass filter

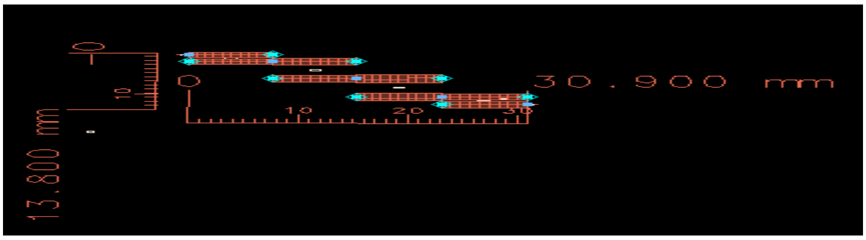


Figure 3.8 Layout of 6 GHz bandpass filter

The Simulated S parameters of 4 GHz and 6 GHz bandpass filters are highlighted using marker in the Figure 3.8 and Figure 3.10

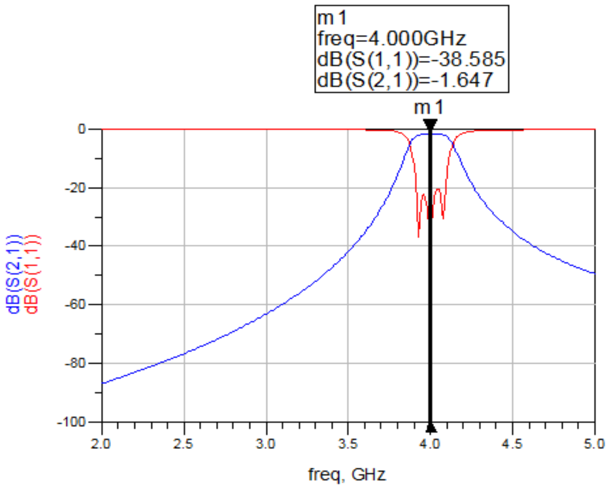


Figure 3.9 Simulated S parameters of 4 GHz bandpass filters

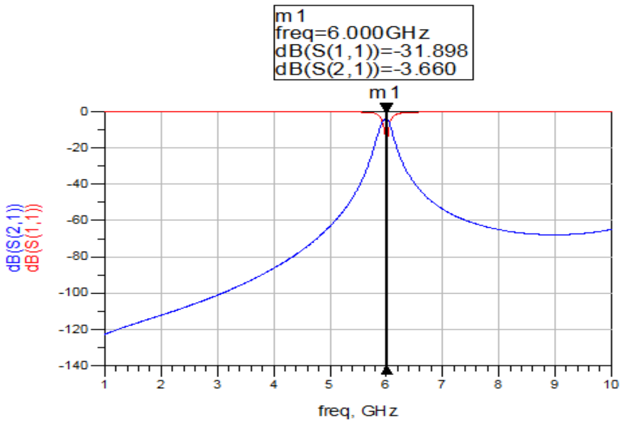


Figure 3.10 Simulated S parameters of 6 GHz bandpass filters

The 4 GHz and 6 GHz simulation outputs provide the return loss and insertion loss values. The simulation output of filter has low insertion loss and high return loss at the desired frequencies. For 4 GHz band pass filter, S_{11}= -38.585 dB and S_{21}= -1.647 dB and for 6 GHz bandpass filter, S_{11}= -31.898dB and S_{21}= -3.660 dB. The size of the designed 4 GHz filter is length = 46.2 mm and width = 10.6 mm (46.2 mm x 10.6 mm) and the size of the designed 6 GHz filter is length = 30.9 mm and width = 13.8 mm (30.9 mm x 13.8 mm).

3.4 DUALBAND FILTER DESIGN

3.4.1 3rd ORDER CHEBYSHEV BANDPASS FILTER DESIGN

Step 1. Determine the coefficient for the 3rd order Chebyshev Filter

Table.3.5 Ripple factor $20\log_{10}\varepsilon = 3.0$ dB

N	**g_1**	**g_2**	**g_3**	**g_4**	**g_5**	**g_6**	**g_7**
1	1.9953	1.0000					
2	3.1013	0.5339	5.8095				
3	3.3487	0.7117	3.3487	1.0000			
4	3.4389	0.7483	4.3471	0.5920	5.8095		
5	3.4817	0.7618	4.5381	0.7618	3.4817	1.0000	
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095

Step 2. Calculate the admittance interval

$$J_1 = \frac{1}{Z_o}\sqrt{\frac{\pi\Delta}{2g_1}} = 0.00433$$
$$J_2 = \frac{1}{2Z_o}\frac{\pi\Delta}{\sqrt{g_1 g_2}} = 0.00203$$
$$J_3 = \frac{1}{2Z_o}\frac{\pi\Delta}{\sqrt{g_2 g_3}} = 0.00203$$
$$J_4 = \frac{1}{Z_o}\sqrt{\frac{\pi\Delta}{2g_3 g_4}} = 0.00792$$

Step 3. Determine the characteristic impedance of even and odd mode

$$Z_{oe1} = Z_o\left(1 + J_1 Z_o + (J_1 Z_o)^2\right) = 63.1686$$
$$Z_{oo1} = Z_o\left(1 - J_1 Z_o + (J_1 Z_o)^2\right) = 41.5186$$

$$Z_{oe2} = Z_o\left(1 + J_2 Z_o + (J_2 Z_o)^2\right) = 55.6021$$
$$Z_{oo2} = Z_o\left(1 - J_2 Z_o + (J_2 Z_o)^2\right) = 45.4321$$

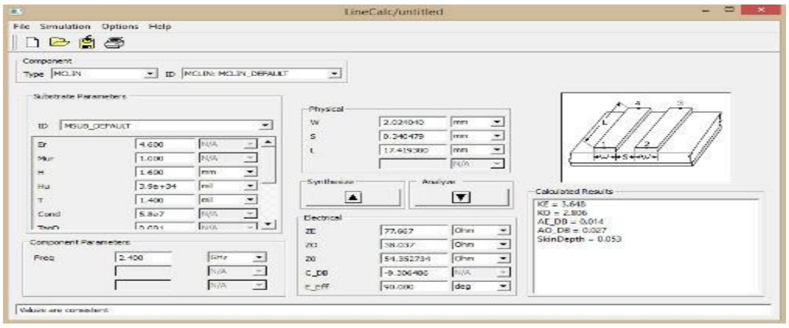
$$Z_{oe3} = Z_o\left(1 + J_3 Z_o + (J_3 Z_o)^2\right) = 55.6021$$
$$Z_{oo3} = Z_o\left(1 - J_3 Z_o + (J_3 Z_o)^2\right) = 45.4321$$

$$Z_{oe4} = Z_o\left(1 + J_4 Z_o + (J_4 Z_o)^2\right) = 77.6676$$
$$Z_{oo4} = Z_o\left(1 - J_4 Z_o + (J_4 Z_o)^2\right) = 38.0376$$

Table.3.6 even and odd mode impedance values

G_n	J_n	Z_{oe}	Z_{oo}
3.3437	0.00433	63.1686	41.5186
0.7117	0.00203	55.6021	45.4321
3.3487	0.00203	55.6021	45.4321
1.0000	0.007926	77.6676	38.0376

Step 4. Determine width, length, and space between coupled line using ADS software



Component
Type MCLIN
ID MCLIN: MCLIN_DEFAULT

Substrate Parameters
ID MSUB_DEFAULT
Er 4.600 N/A
Mur 1.000 N/A
H 1.600 mm
Hu 3.9e+34 mil
T 1.400 mil
Cond 5.8e7 N/A
TanD 0.001 N/A

Component Parameters
Freq 2.400 GHz

Physical
W 2.024040 mm
S 0.340479 mm
L 17.419300 mm

Electrical
ZE 77.667 Ohm
ZO 38.037 Ohm
Z0 54.352734 Ohm
C_DB -9.306486 N/A
E_Eff 90.000 deg

Calculated Results
KE = 3.648
KO = 2.806
AE_DB = 0.014
AO_DB = 0.027
SkinDepth = 0.053

Values are consistent

Figure 3.11 LineCalc window

Table.3.7 width, length, and space between coupled line

Line	**W(mm)**	**S(mm)**	**L(mm)**
1	1.83456	0.340495	15.8474
2	2.931	2.121000	17.2487
3	1.6457	2.121000	16.1427
4	1.24677	0.340495	18.4394

Step 5. Determine the substrate

Table.3.8 the Substrate

Specification	**Value**
Name	FR4
Substrate Thickness, H	1.6 mm
Dielectric Constant, ε_r	4.600
Metal Thickness	1.4 mil
TanD	0.001

Step 6. Simulation

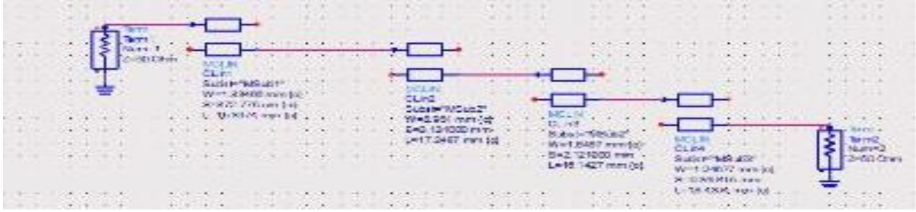


Figure 3.12 Design of 3rd order Chebyshev Filter

Figure 3.12 shows the Design of dual band coupled line chebyshev 3rd order filter. Chebyshev Filter has ripples at the pass band and stop band but the roll-off factor is higher for chebyshev filter. In this design, the Width, Length, and Space values are used to design layout.

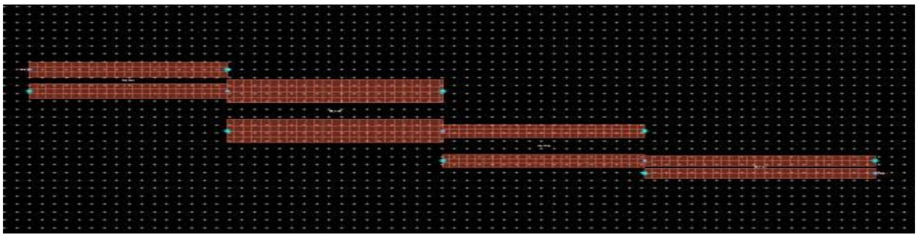


Figure 3.13 Layout of 3rd order Chebyshev Filter

Figure 3.13 shows the simulation Design of dual band coupled line chebyshev 3rd order filter. The design obtained from the layout should be same as that of design on the PCB board after fabrication parameters should be precisely fabricated on the board.

3.4.2 RESULT AND DISCUSSION FOR 3RD ORDER CHEBYSHEV FILTER

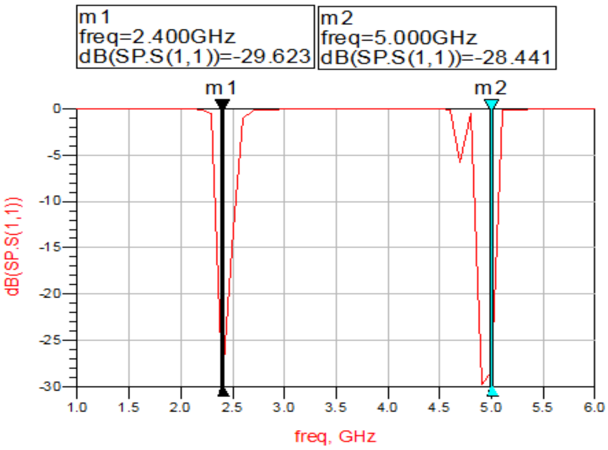


Figure 3.14 Layout Design Output

Figure 3.14 shows the simulation design output of dual band coupled line chebyshev 3rd order filter. The result obtained from the layout should be same as that of the result obtained after fabrication. The dual band coupled line chebyshev 3rd order filter 2.4 GHz and 5GHz is designed and the layout design for the FR4 substrate is shown the return loss is reduced to -29dB and -28 dB respectively with low insertion loss.

3.4.3 5th ORDER CHEBYSHEV BANDPASS FILTER DESIGN

Step 1. Specification

Table 3.9. Design Specifications of bandpass filter

Specification	**Value**
Order of filter, N	5
Center Frequency, f_c	2.4 GHz and 5 GHz
Impedance, Z_0	50 Ω
Fractional Band Width, Δ	0.1

Increasing the order of the filter will increase the selectivity. A 5th order chebyshev bandpass filter is selected to satisfy the requirements of the ISM band applications [13]. Element values for the normalized chebyshev prototype are determined and the standard values for the 3 dB ripple factor for a chebyshev filter are represented in Table 3.10[14].

Table 3.10. Ripple Factor $20\log_{10}\varepsilon = 3.0$ dB

N	g_1	g_2	g_3	g_4	g_5	g_6
1	1.995	1.000				
2	3.101	0.533	5.809			
3	3.348	0.711	3.348	1.000		
4	3.438	0.748	4.347	0.592	5.809	
5	3.481	0.761	4.538	0.761	3.481	1.000

The bandwidth for the desired frequencies is calculated using the equations [15].

$$\omega_1 = 2\pi f_1$$

$$\omega_2 = 2\pi f_2$$

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

$$\Delta = \left(\frac{\omega_1\omega_2}{\omega_o}\right)$$

The admittance interval Jn is calculated using the equations.

$$Z_oJ_1 = \sqrt{\frac{\pi\Delta}{2g_1}}$$

$$Z_oJ_N = \frac{\Delta\pi}{2\sqrt{g_{N-1}g_N}}$$

$$Z_oJ_{N+1} = \sqrt{\frac{\pi\Delta}{2g_Ng_{N+1}}}$$

The even and odd mode impedances, Zoe and Zoo for the 5th order chebyshev filter are calculated using the equations [16].

$$Z_{oe} = Z_o[1 + JZ_o + (JZ_o)^2]$$

$$Z_{oo} = Z_o[1 - JZ_o + (JZ_o)^2]$$

The calculated even and odd mode impedance values for 5th order chebyshev filter are tabulated in Table 3.11

Table 3.11. Even and Odd mode impedance values for 5th order chebyshev filter

G_n	J_n	Z_{oe}	Z_{oo}
3.481	0.003874	61.5609	42.1909
0.761	0.000802	52.0854	48.0754
4.538	0.000702	51.8166	48.3066
0.761	0.000702	51.8166	48.3066
3.481	0.000802	52.0854	48.0754
1.000	0.003874	61.5609	42.1909

The bandpass filter is designed using FR4 substrate as it was more cost effective. The specification of the FR4 substrate used for bandpass filter design is shown in Table 3.12.

Table 3.12. FR4 Substrate specification

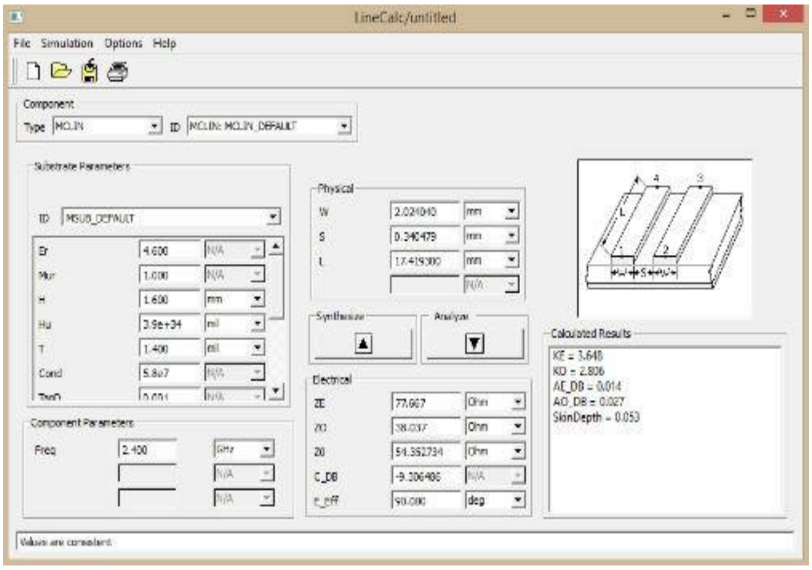
Specification	**Value**
Substrate Thickness, H	1.6 mm
Dielectric Constant, ε_r	4.600
Metal Thickness	1.4 mil
TanD	0.001

The 5th order chebyshev bandpass filter is designed based on the obtained theoretical values and optimized using Optim tool in ADS to improve the efficiency of the filter in the desired frequency bands. Application of this filter includes Wi–Fi, Bluetooth, Car alarm, Zigbee, Radar and IEEE 802.11n radios [17-18]. 2.4 GHz and 5 GHz bands are free bands and are used in Industrial, Science and Medical fields.

Step 2. Optimization using ADS

Advanced Design System (ADS) simulator is used to generate schematic circuit of dual band chebyshev parallel coupled microstrip line bandpass filter. It provides the simulation tools to design and evaluate radio frequency (RF) filter. The evaluation parameters for the designed filter are return loss and insertion loss. Using the LineCalc tool the length, width, and spacing between lines of a coupled line are calculated directly from Z_{oe} and Z_{oo} values. The manipulation of width, length, and Spacing between lines using LineCalc tool in ADS is shown in Figure 3.15.

The parameters required for using LineCalc tool are
H: Substrate thickness (1.6 mm).
ε_r: Substrate relative dielectric constant (4.6).
Cond: Metal conductivity (5.8e7).
Hu: Upper ground plane to substrate spacing (3.9e+34 mil).
T: Thickness of metal layer (1.4 mils).
TanD: Dielectric loss tangent (0.001).
Rough: RMS surface roughness (0).



Component
Type MCLIN
ID MCLIN: MCLIN_DEFAULT

Substrate Parameters
ID MSUB_DEFAULT
Er 4.600 N/A
Mur 1.000 N/A
H 1.600 mm
Hu 3.9e+34 mil
T 1.400 mil
Cond 5.8e7 N/A
TanD 0.001 N/A

Component Parameters
Freq 2.400 GHz

Physical
W 2.024040 mm
S 0.340479 mm
L 17.419300 mm

Electrical
ZE 77.667 Ohm
ZO 38.037 Ohm
Z0 54.352734 Ohm
C_DB -9.306486 N/A
E_Eff 90.000 deg

Calculated Results
KE = 3.648
KO = 2.806
AE_DB = 0.014
AO_DB = 0.027
SkinDepth = 0.053

Values are consistent

Figure 3.15. Manipulation of width, length, and Spacing between lines using LineCalc Tool in ADS

The values of width (W), length (L), and spacing between lines (S) of a coupled line are obtained from LineCalc tool and are tabulated in Table V. Based on these values, a 5th order dual band chebyshev parallel coupled microstrip line bandpass filter is generated using ADS.

Table 3.13. Width, Length, and Spacing between lines of a coupled line

Line	**W (mm)**	**L (mm)**	**S (mm)**
1	1.39817	17.2341	0.896707
2	2.52213	16.3823	2.230940
3	3.60575	16.5302	2.519180
4	2.4215	16.6738	2.519180
5	1.51642	17.234	2.230940
6	2.12867	17.0442	0.340455

3.4.4 RESULT AND DISCUSSION for 5th ORDER CHEBYSHEV FILTER

The 5th order chebyshev parallel coupled microstrip line bandpass filter is designed using ADS with characteristic impedance, Zo as 50Ω and its schematic is shown in Figure 3.16.

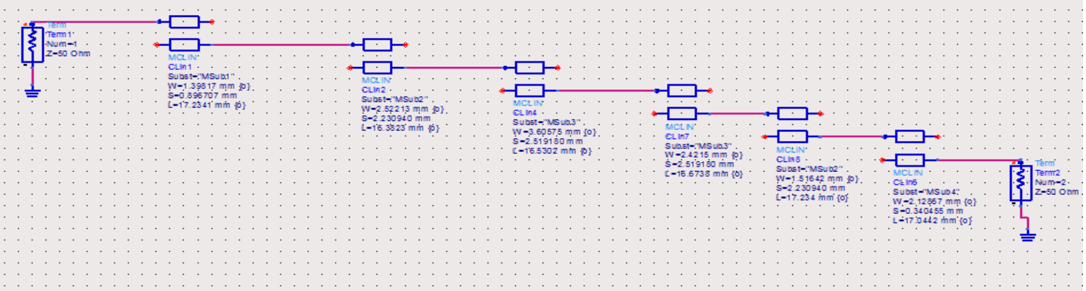


Figure 3.16 Schematic of 5th order chebyshev parallel coupled microstrip line bandpass filter

The schematic design is converted into Layout design by using the values of length, width, and space between the coupled lines. Layout design is the software version of the fabricated result. Layout design of 5th order chebyshev parallel coupled microstrip line bandpass filter is represented in Figure 3.17.

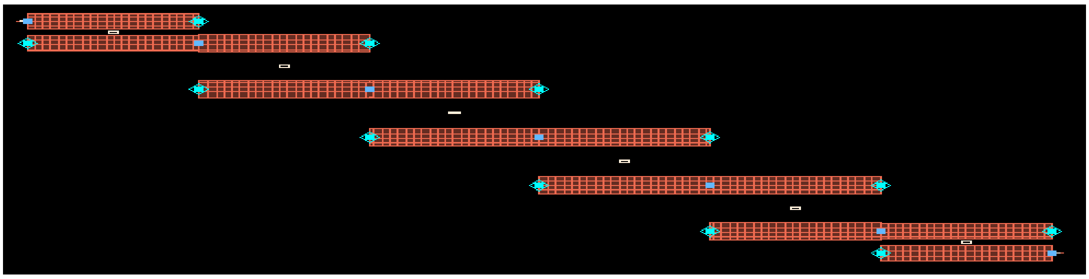


Figure 3.17 Layout of 5th order chebyshev parallel coupled microstrip line bandpass filter

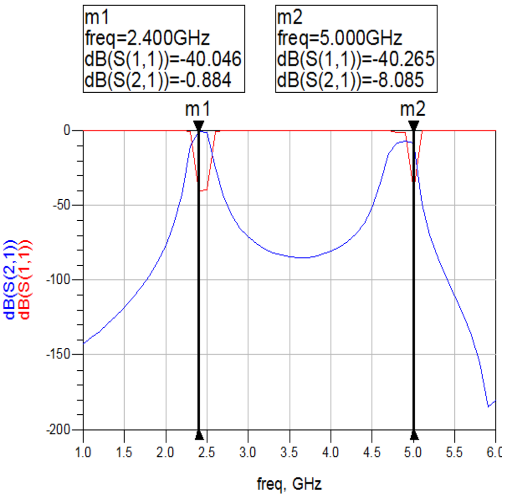


Figure 3.18 Simulated S_{11} and S_{21} parameters of 5th order chebyshev parallel coupled microstrip line bandpass filter

The Simulated S_{11} and S_{21} parameters of the 5th order chebyshev parallel coupled microstrip line bandpass filter is shown in Figure 3.18 From the Simulated S_{11} and S_{21} graph, S_{11} values for both 2.4 GHz and 5 GHz frequencies are over –40dB i.e. the designed bandpass filter allows the frequency bands from 2.30 GHz to 2.60 GHz as one band and 4.90 GHz to 5.15 GHz as another band. The return loss and insertion loss values for 2.4 GHz are –40.046 dB and –0.884 dB whereas the return loss and insertion loss values for 5 GHz are –40.265 dB and –8.085 dB. The obtained return loss is high and insertion loss is low for the ISM band applications.

3.5 TRIPLE BAND FILTER DESIGN USING MICROSTRIP LINE

3.5.1 Design Procedure for triple band

The basic and modified open stub filter sections are shown in Figure 3.5.1 (a) and (b) respectively. As indicated in Figure 3.5.1a, Z1 & Z2 are the characteristic impedances and θ1 & θ2 are the electrical lengths of the transmission line segments. The two lines are joined at both ends at the pass band center frequency fo. The input signal is divided into two components at one end and made to interfere at the other end of different phase and magnitudes, which is the concept of signal interference technique [19]. This technique is best suited for designing low insertion loss, sharp rejection and wide band pass filters.

If θ_1 and θ_2 are taken as θ_{10} and θ_{20} at fo, then at any arbitrary frequency f,

$$\theta_i = \frac{f\theta_{i0}}{f_0}\ , i = 1{,}2$$

For the basic filter section, the proposed electrical lengths are $\theta_{10} = 90^\circ$ and $\theta_{20} = 270^\circ$ and the corresponding Z1 & Z2 values are 25Ω and 50Ω respectively. The advantage of using low impedance values are decreased pass band insertion loss, increased selectivity, increased bandwidth, and ease of fabrication. Also, filter 3-dB center frequency depends on the chosen Z1 & Z2 values.

Figure 3.19 Configuration of (a) Basic filter section (b) Modified open stub filter section

Based on the lossless transmission line model, the ABCD matrix of the basic configuration of Figure 3.5.1a can be arrived as

$$\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} = \begin{bmatrix} \begin{array}{c} Z_1\cot\theta_2 + \ Z_2\cot\theta_2 \\ Z_1\csc\theta_2 + \ Z_2\csc\theta_2 \\ Z_1^2 + Z_2^2 + 2Z_1Z_2 \end{array} & \dfrac{jZ_1Z_2}{Z_1csc\theta_2 + Z_2csc\theta_2} \\ \dfrac{j(csc\theta_1csc\theta_2 - cot\theta_1cot\theta_2)}{Z_1Z_2(Z_1csc\theta_2 + \ Z_2csc\theta_2)} & \dfrac{Z_1cot\theta_2 + Z_2cot\theta_2}{Z_1csc\theta_2 + Z_2csc\theta_2} \end{bmatrix}$$

The corresponding S parameters are [20].

$$S_{11} = \frac{A_1 + {}^{B_1}/_{Z_0} - \ C_1Z_0 - D_1}{A_1 + {}^{B_1}/_{Z_0} + \ C_1Z_0 + D_1}$$

$$S_{21} = \frac{2}{A_1 + {}^{B_1}\!/_{Z_0} + C_1 Z_0 + D_1}$$

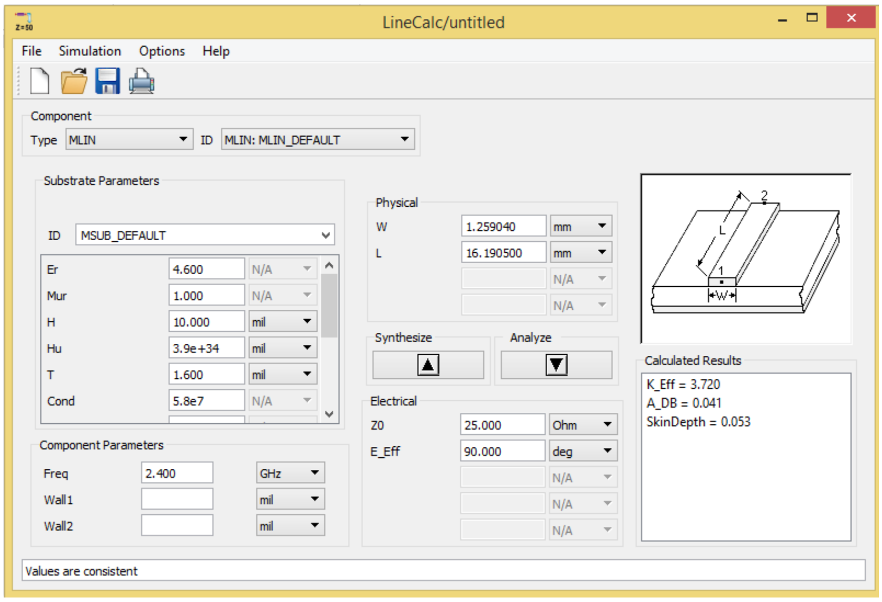
Where Zo is the port impedance.

To enhance the filter rejection characteristics, two shunt open stubs having equal characteristic impedance Z_S and electrical length θ_S are connected at both output and input sides. The open stubs are used to improve rejection. Then overall ABCD parameter of the modified section is given by [20].

$$\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} = \begin{bmatrix} 1 & -JZ_S cot\theta_s \\ 0 & 1 \end{bmatrix} \begin{bmatrix} cos\theta_L & jZ_L sin\theta_L \\ jsin\theta_L/Z_L & cos\theta_L \end{bmatrix}$$
$$X \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} cos\theta_L & jZ_L sin\theta_L \\ jsin\theta_L/Z_L & cos\theta_L \end{bmatrix} X \begin{bmatrix} 1 & -jcot\theta_S \\ 0 & 1 \end{bmatrix}$$

$$S_{11} = \frac{A_2 + {}^{B_2}\!/_{Z_0} - C_2 Z_0 - D_2}{A_2 + {}^{B_2}\!/_{Z_0} + C_2 Z_0 + D_2}$$
$$S_{21} = \frac{2}{A_2 + {}^{B_2}\!/_{Z_0} + C_2 Z_0 + D_2}$$

The modified open stub filter configuration discussed in the previous section is implemented in ADS tool. The value of Z1 & θ1, Z2 & θ2 are fixed as 25Ω & 90º, 50Ω & 270º respectively for the design.



Type MLIN
ID MLIN: MLIN_DEFAULT
ID MSUB_DEFAULT
Er 4.600 N/A
Mur 1.000 N/A
H 10.000 mil
Hu 3.9e+34 mil
T 1.600 mil
Cond 5.8e7 N/A
W 1.259040 mm
L 16.190500 mm
Z0 25.000 Ohm
E_Eff 90.000 deg
Freq 2.400 GHz
Wall1 mil
Wall2 mil
K_Eff = 3.720
A_DB = 0.041
SkinDepth = 0.053
Values are consistent

Figure 3.20 Manipulation of width, length, and Spacing between lines using LineCalc Tool in ADS

The operating frequency, the substrate details, impedances and electrical lengths are provided as input to ADS LineCalc tool, which provides the required length & width of the transmission line segment. The complete filter structure with dimension details & 50Ω transmission lines for both input and output coupling are shown in Figure 3.21. The corresponding layout generated for the filter is shown in Figure 3.22.

Table 3.14 Width and Length of Microstrip line

Line	**W (mm)**	**L (mm)**
TL 1	1.41	10
TL 2	1.71577	4.12649
TL 3	1.41	19.34
TL 4	2.89636	19.34
TL 5	1.28146	19.34
TL 6	2.67278	19.34
TL 7	1.00904	19.34
TL 8	1.41	19.34
TL 9	1.82464	3.96978
TL 10	1.41	10

3.5.2 Simulation and Results

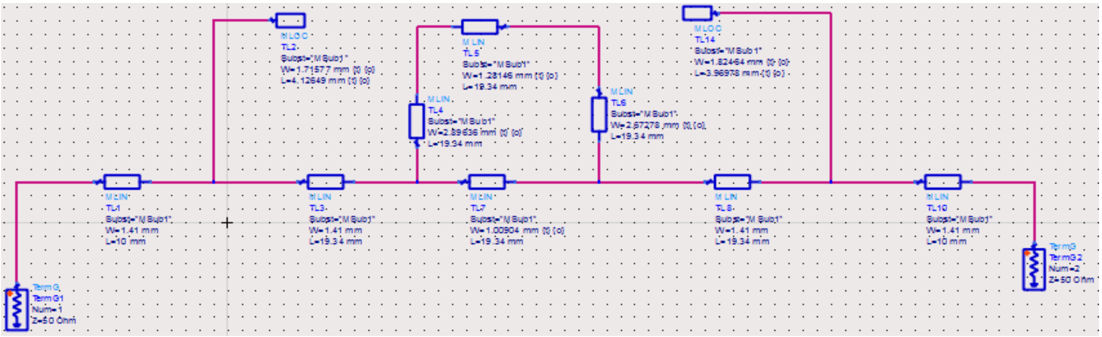


Figure 3.21 Schematic of modified open stub filter

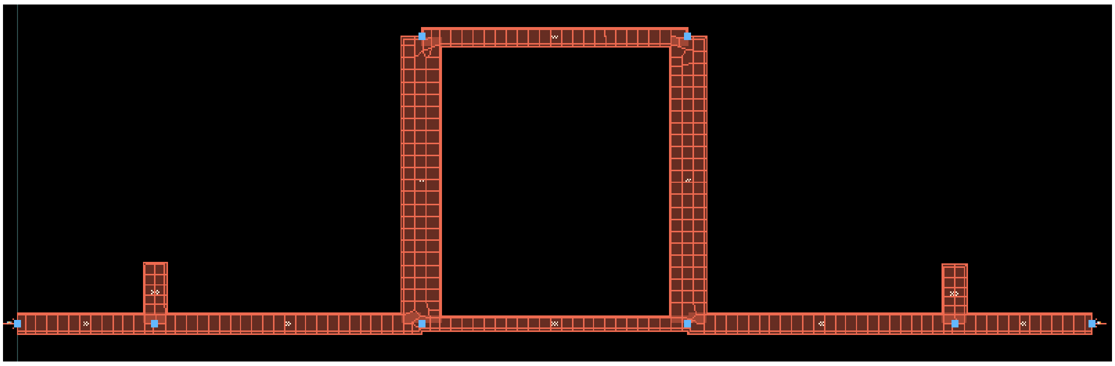


Figure 3.22 Layout of modified open stub filter

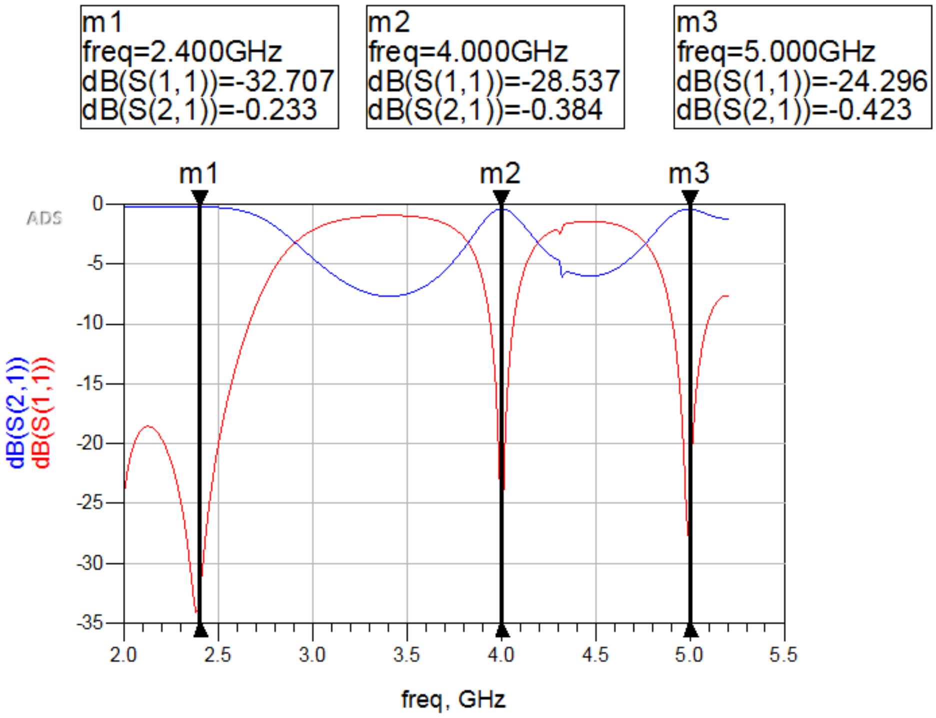


Figure 3.23 S parameter characteristics

From the S-parameter plot, it is observed that the filter design gives a rejection level of approximately -32 dB at 2.4 GHz, a rejection level of -28 dB at 4 GHz, and a rejection level of -24 dB at 5 GHz. Measured pass band insertion loss is -0.2 dB at 2.4 GHz, insertion loss is -0.3 dB at 4 GHz, and insertion loss is -0.4 dB at 5 GHz.

3.5.3 Filter Testing Procedure

ENA Series Network Analyser E5062A ranges from 300KHz-3GHz is used for testing the fabricated filters and antennas. In this thesis the bandpass filter is designed and fabricated and the fabricated filter is designed for the frequancy bands if 2.4 GHz, 4 GHz and 5 GHz but the maximum range of this network analyser is 3GHz so, only the 2.4GHz band is measured by following steps.

Step 1 : Connect the two port band pass filter in port 1 and port 2 using the cables.
Step 2 : Agilent window opens with E5062 menu from the menu select calibration
Step 3 : In the calibration window select calibrate -> 1 Port cal in 1 port cal window enable open, short, and load then click done and return.
Step 4 : In calibrate window select 2 port cal -> Reflection -> enable port 1 open, port 1 short, port 1 load, port2 open, port 2 short, and port 2 load click return.
Step 5 : In 2 Port cal window select Isolation enable port 1-2 Isol click return.
Step 6 : LED in por 1 and port 2 indicates that both the ports are enabled.
Step 7 : Click meas button to measure the S – parameter.
Step 8 : Click marker button to enable the marker 1 to measure Return loss.

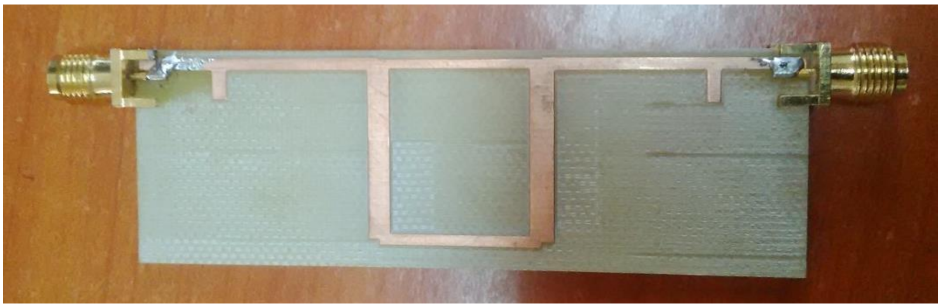


Figure 3.24 Fabricated triple band filter

Figure 3.25 ENA Series Network Analyser E5062A conected with Triple band filter

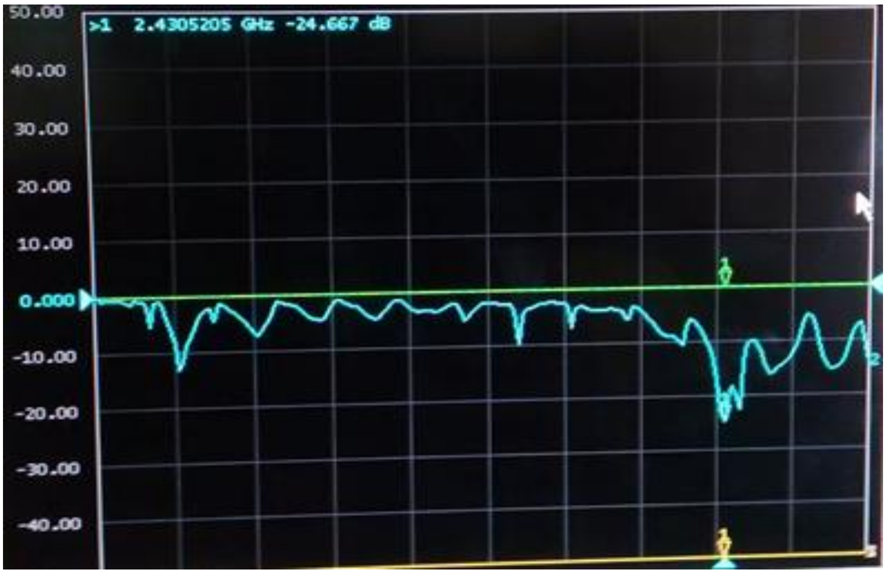


Figure 3.26 Fabricated result for return loss

CHAPTER 4

RESULT AND DISCUSSION

Single Band Filter

From Figure 3.10 Simulated S parameters of 6 GHz bandpass filters. The 4 GHz and 6 GHz simulation outputs provide the return loss and insertion loss values. The simulation output of filter has low insertion loss and high return loss at the desired frequencies. For 4 GHz band pass filter, S_{11}= -38.585 dB and S_{21}= -1.647 dB and for 6 GHz bandpass filter, S_{11}= -31.898dB and S_{21}= -3.660 dB. The size of the designed 4 GHz filter is length = 46.2 mm and width = 10.6 mm (46.2 mm x 10.6 mm) and the size of the designed 6 GHz filter is length = 30.9 mm and width = 13.8 mm (30.9 mm x 13.8 mm).

Dual Band Filter

Figure 3.14 shows the simulation design output of dual band coupled line chebyshev 3rd order filter. The result obtained from the layout should be same as that of the result obtained after fabrication. The dual band coupled line chebyshev 3rd order filter 2.4 GHz and 5GHz is designed and the layout design for the FR4 substrate is shown the return loss is reduced to -29dB and -28 dB respectively with low insertion loss.

Figure 3.18 represents the simulated S_{11} and S_{21} parameters of 5th order chebyshev parallel coupled microstrip line bandpass filter, From the Simulated S_{11} and S_{21} graph, S_{11} values for both 2.4 GHz and 5 GHz frequencies are over –40dB i.e. the designed bandpass filter allows the frequency bands from 2.30 GHz to 2.60 GHz as one band and 4.90 GHz to 5.15 GHz as another band. The return loss and insertion loss values for 2.4 GHz are –40.046 dB and –0.884 dB whereas the return loss and insertion loss values for 5 GHz are –40.265 dB and –8.085 dB. The obtained return loss is high and insertion loss is low for the ISM band applications.

Triple Band Filter

Figure 3.23 provides the S parameter characteristics, it is observed that the filter design gives a rejection level of approximately -32 dB at 2.4 GHz, a rejection level of -28 dB at 4 GHz, and a rejection level of -24 dB at 5 GHz. Measured pass band insertion loss is -0.2 dB at 2.4 GHz, insertion loss is -0.3 dB at 4 GHz, and insertion loss is -0.4 dB at 5 GHz. Figure 3.26 provides the fabricated filter return loss at 2.4 GHz is -24 dB.

CHAPTER 5

CONCLUSION

Microstrip Coupled line bandpass filter approach is designed using the configuration of perfect conductor and a RO4003 substrate. 4 GHz and 6 GHz filters are designed separately for the application of 6/4 GHz transverter. The filter has high return loss and low insertion loss for perfect performance in the desired frequency band. The evaluation of the performance measure of dual band 3rd order and 5th order parallel coupled microstrip line RF bandpass filter using chebyshev filter and 3 dB equal ripple responses that suit for ISM band applications is implemented in ADS. The filter was designed using a FR4 substrate with the thickness of 1.6 mm and dielectric constant of 4.6. It operates at 2.4 GHz and 5 GHz frequency bands. The designed filter values are optimized using Optim to provide better performance in the required ISM frequency bands. Designing dual band filter instated of two single band filter will reduce the cost by 50%. A more practical configuration using two transmission-line sections and shunt open stubs is presented for designing high-performance triple band pass filter. The main advantage is low insertion loss, simple structure, and easy realization. The designed filter structure is simulated using Agilent ADS tool and the results are in good agreement with the measurement.

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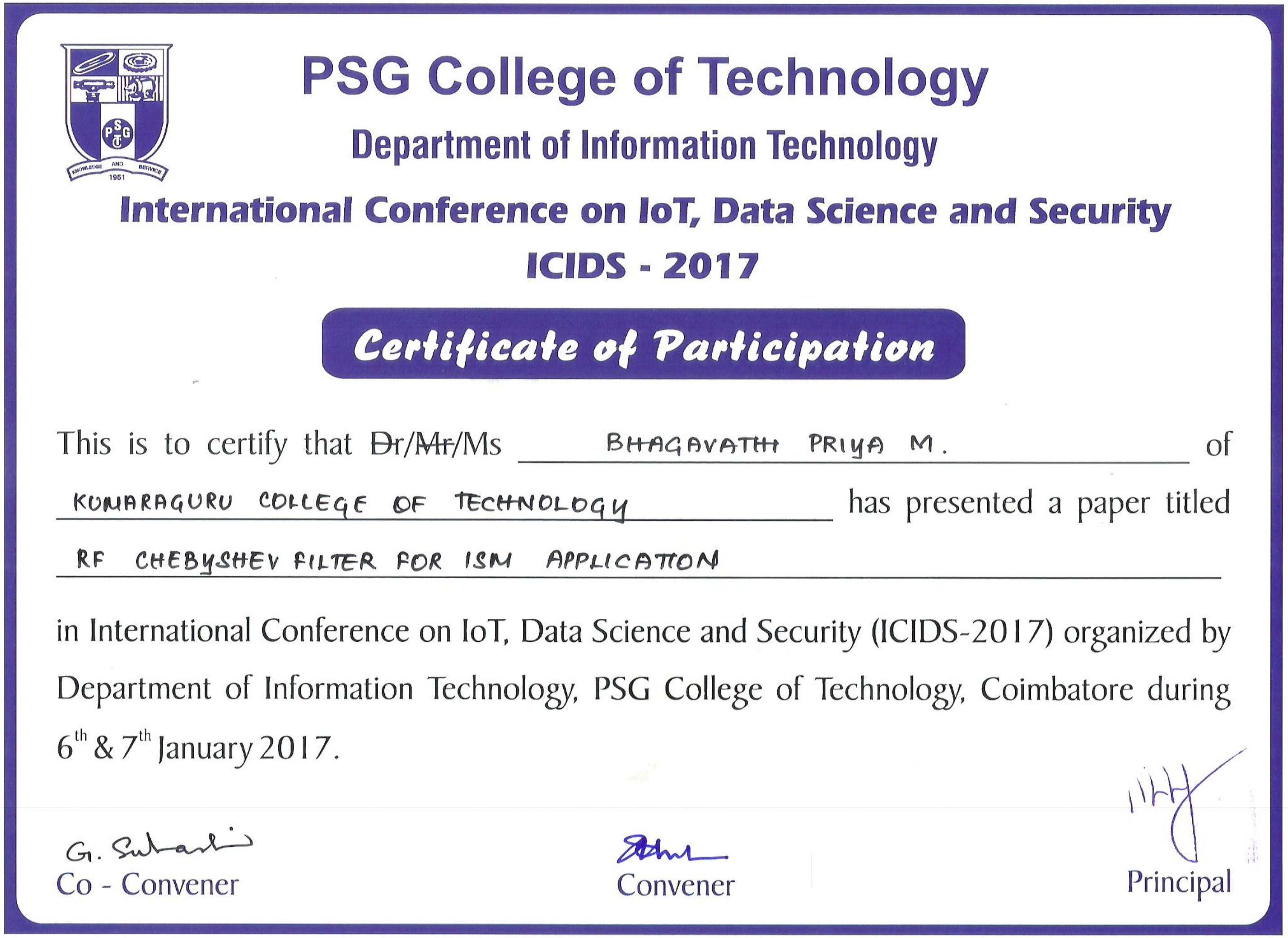
LIST OF PUBLICATIONS

CONFERENCE

- Presented a paper titled, “**RF Chebyshev Filter for ISM Application**” in IEEE International Conference on IoT, Data Science and Security (ICIDS) at PSG, Coimbatore.

- Presented a paper titled, “**A Microstrip Coupled Line Bandpass Filter For 6/4 GHz Transverter**” in IETE National Conference on Information Communication, VLSI and Embedded systems (ICVE) at Adhiyamaan College of Engineering, Hosur.

- Presented a paper titled, “**A cost effective dual band Chebyshev Parallel Coupled Microstrip Line Bandpass Filter for ISM band Applications**” in IEEE International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET) at SSN College, Chennai.



PSG College of Technology

Department of Information Technology

International Conference on IoT, Data Science and Security

ICIDS - 2017

Certificate of Participation

This is to certify that ~~Dr~~/~~Mr~~/Ms BHAGAVATHI PRIYA M. of KUMARAGURU COLLEGE OF TECHNOLOGY has presented a paper titled RF CHEBYSHEV FILTER FOR ISM APPLICATION in International Conference on IoT, Data Science and Security (ICIDS-2017) organized by Department of Information Technology, PSG College of Technology, Coimbatore during 6th & 7th January 2017.

Co - Convener

Convener

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CERTIFICATE OF PARTICIPATION

This is to certify that Mr./Ms. ....M. BHAGAVATHIPRIYA..........................
of........KUMARAGURU.........COLLEGE.......OF.........TECHNOLOGY..
has presented a paper entitled .....A......MICROSTRIP.......COUPLED......LINE..................
..BANDPASS.......FILTER....FOR....6/4 GHZ........TRANSVERTER..
in a Two Day National Conference "ICVE 2k17" held on 9th & 10th MARCH 2017.

Dr T MENAKADEVI
Co-ordinator, ISF

Dr G RANGANATH
Principal

Certificate

IEEE International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)

22–24 March 2017, Chennai, India

This is to certify that

M. BHAGAVATHI PRIYA

from

KUMARAGURU COLLEGE OF TECHNOLOGY

participated and presented a paper titled

A COST EFFECTIVE DUAL BAND CHEBYSHEV PARALLEL COUPLED MICROSTRIP LINE BAND PASS FILTER FOR ISM BAND APPLICATION

in the IEEE International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET) held at SSN College of Engineering, Chennai, India during 22–24 March 2017.

S. Salivahanan General Chair	S. Radha General Chair	Kishore R Organizing Chair	Prabagarane N Organizing Chair