

DESIGN & IMPLEMENTATION OF STEPPED IMPEDANCE MICROSTRIP LOW PASS FILTER USING ADS & MATLAB

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Submitted by

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CERTIFICATE

This is to certify that the thesis report entitled, "**Design & Implementation of Stepped Impedance Microstrip Low Pass Filter Using ADS & MATLAB**" being submitted by **Pramila** to the *Department of Electronics and Communication Engineering and Applied Physics, Delhi Technological University* in partial fulfilment of the requirement for award of Master of Technology degree in *Microwave and Optical Communication* is a record of bona fide work carried out by her under the supervision and guidance of Dr. Priyanka Jain. The matter embodied in this report has not been submitted for the award of any other degree.

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DECLARATION

I hereby declare that all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. This report is my own, unaided work. I have fully cited and referenced all material and results that are not original to this work. It is being submitted for the degree of Master of Technology in Engineering at the Delhi Technological University. It has not been submitted before for any degree or examination in any other university.

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ABSTRACT

In this report a design technique for a Stepped impedance Microstrip Low-pass filters is presented by using Agilent Advanced Design System (ADS) simulations in order to find the optimal design parameters required to arrive at an approximate solution. ADS simulations were used to accurately determine the final design. The experimental results are in good agreement with theoretical values. Most communication systems contain an RF front end which performs signal processing with RF filters. Microstrip filters are a low cost means of doing this. Filters play an important role in microwave applications. Microstrip filters play various roles in wireless or mobile communication systems. There is an increasing demand for newer microwave and millimeter-wave systems to meet the emerging telecommunication challenges with respect to size, performance and cost. This report describes the design of a low cost and low insertion loss S-band Low Pass Filter (LPF) by using a microstrip layout which works at 2.4 GHz for a dielectric constant of 4.05 with a substrate thickness of 1mm for order $N=6$. Microstrip technology is used for simplicity and ease of fabrication. The design and simulation are performed using a 3D full wave electromagnetic simulator IE3D. We have also developed program code in MATLAB to plot the insertion loss (S_{21} parameter) of the Low pass filter.

A stepped impedance low pass microstrip filter has been designed, simulated, fabricated and tested using a vector network analyser of operating range 5KHz to 20 GHz. The cutoff frequency achieved is lower than the design specification value (2.4GHz).

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LIST OF ABBREVIATIONS

ADS	:	Advanced Design System
c	:	Speed of light
DSP	:	Digital Signal Processing
ϵ_{reff}	:	Effective relative permittivity
EDA	:	Electronics Design Automation
EMPro:		Electromagnetic Professional
Err	:	Error
f	:	Frequency
f_s	:	Sampling frequency
FEM	:	Finite element method
FIR	:	Finite Impulse Response
h	:	Height of dielectric substrate
H(z)	:	Discrete time System function
IIR	:	Infinite Impulse Response
K	:	Gain
l	:	Length of microstrip
λ	:	Wavelength
OCS	:	Open circuit Stub
Ω	:	Normalized frequency
S	:	Scattering Parameter
SCS	:	Short circuit Stub
STL	:	Serial Transmission Line
$\tan\delta$:	Loss tangent of dielectric or dissipation factor
t	:	Thickness
τ	:	Time constant
T	:	Sampling Time interval
Γ	:	Reflection coefficient
TLS	:	Transmission line section
w	:	Width of microstrip
z^{-1}	:	unit sample delay
Z_N	:	Characteristic impedance of N_{th} Section of microstrip line
Z_0	:	Characteristic impedance of microstrip line 50 Ohms

Introduction

1.1 Overview

A Microstrip low-pass filter is a filter that passes low frequency signals but reduces the amplitude of signals with frequencies higher than the cutoff frequency. The real amount of attenuation for each frequency changes from filter to filter. Hence it is also known as treble cut filter or high-cut filter when applied in Sound applications. A low-pass filter is the reverse of a high-pass filter. Low-pass filters are applied in many different forms such as electronic circuits, audio applications, acoustic barriers, blurring of images etc. Low-Pass filters are largely used in many microwave and millimeter-wave systems to reject the higher frequencies and pass the desired low frequencies below cutoff. A Low-pass filter has many useful properties like easy fabrication, compact size, and very low insertion loss. Hence, it has increased applications in cellular mobile communication and microwave circuits.

Microwave communication systems are expanding rapidly to higher frequency such as S-band since they can provide many advantages over conventional wireless links, for example the larger bandwidth and smaller device size. These filters are realized with microstrip lines. Our goal is to achieve high accuracy in obtaining the required designed parameters (like the cutoff frequency and return loss) The filters are one of the primary and necessary components of a microwave 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 on a single board. Conventional filter structures like equal ripple and Butterworth low pass filters are requirement of special fabrication methods. Conventional low frequency techniques for fabrication does not fit at these frequencies due to the very high losses associated. The design and simulation are performed using 3D full wave method of moment based electromagnetic simulator IE3D. The response of the filter is also verified using a program code in MATLAB.

1.2 Design Flowchart

To be more systematic in designing process, the flow diagram must be obtained. The flow diagram can be used as a guide to the designer to obtain their strategy and getting a good result as required. The figure 1.1 depicts the design flow strategies used for obtaining microwave low pass filter circuits from stepped impedance method.

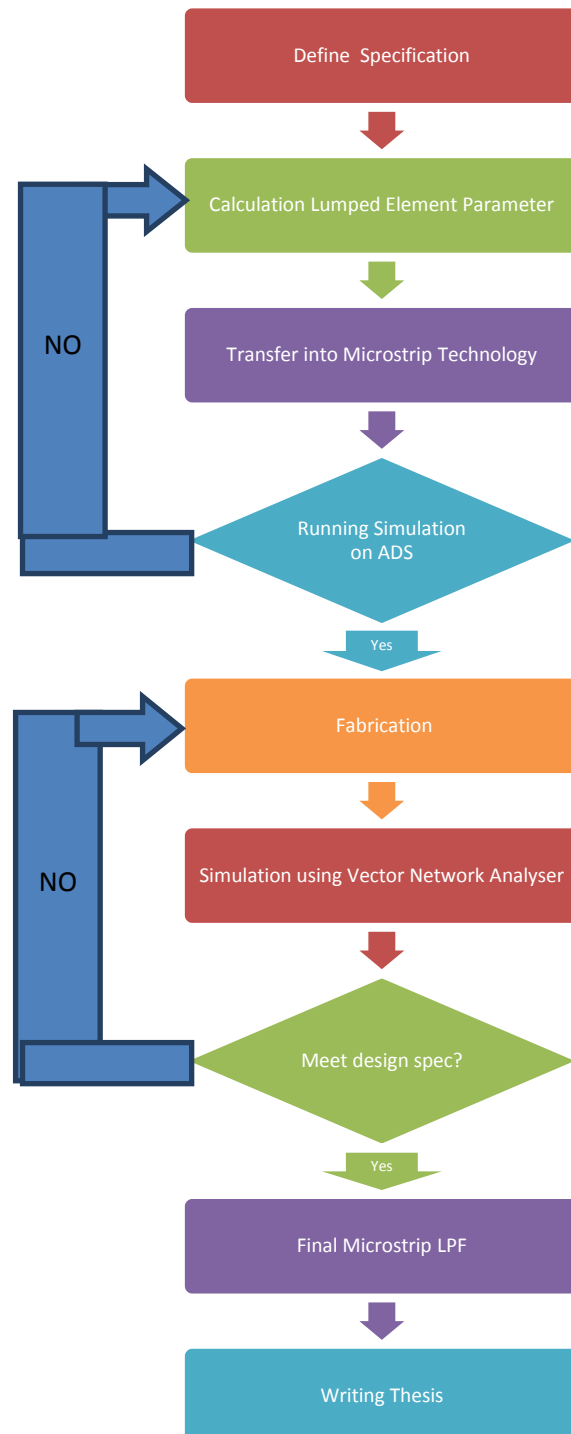


Figure 1.1 Flow chart of designing process for microwave low pass filter.

1.3 Motivation and Problem Statement.

The motivation for project came while under taking course on RF, Microwave and Millimeter Circuits. The circuit theory for filter is very well developed in Microwave. These devices are mainly implemented in circuits for low frequency application. Thus, so far the implementation of low pass filter for high frequency application has been largely ignored. So an idea came to relate the microwave techniques by representations of transmission-line elements using stepped impedance method for higher frequency circuit designing i.e. for microwave device implementation.

Several scopes of work have been determined are:-

1. Doing literature review by referring to related books and IEEE journal.
2. To calculate the stepped impedance lowpass filter, design and simulate the filter using Agilent ADS software to met WLAN specification.
3. To obtain the physically dimension filter values, dielectric material characteristic and obtain frequency response of the filter.
4. To fabricate filter on the microstrip board
5. Analysis will be carried out to compare the simulation and the measurement result.

1.4 Goals/Scope of present work

The main goals of this project are to get acquainted with microwave circuit designing using CAD tool like Agilent Advanced Design System, SystemVue4 and EMPro5 software. The present work consists of designing of stepped impedance low pass filter using microstrip transmission line technology. The scope of this project lies on designing and implementation of other microwave device components like stepped impedance low pass filter for different order etc.

1.5 Report Organization

The thesis report is divided into seven chapters, each having ample information for comprehending the concepts of this project.

Chapter 1: presents introduction to project, design flow chart, discusses the motivation and problem statement, goal and scope of present work.

Chapter 2: literature review and the theory involved in the research work of this project have been presented in this chapter. Doing research to know the detail about designing microstrip low pass filter. Gives an overview of basic filter theory (Butterworth filter response, Chebyshev filter response and Elliptical filter response) and network variables. Have meeting with supervisor and lecturers.

Chapter 3: describes the designing methodology of microwave low pass filter. The detail designing of low pass filter using the stepped impedance method have been explained in this chapter.

Chapter 4: illustrates the thorough designing of microwave low pass filter. Upon using the system functions designed in Chapter 3 corresponding microstrip line configuration is obtained and tuned to derive the characteristic impedance of microstrip sections. Software Simulation performed in Agilent ADS followed by exporting the designed prototype model to Agilent EMPro and program is performed in MATLAB environment. Finally, Plotting of magnitude response of final tuned low pass filter are presented.

Chapter 5: then proceed to design microstrip filter using etching technique and do the measurement using spectrum analyser. Finally, comparison between simulation and measurement data.

Chapter 6: summarizes detailed results of simulation analysis and measured result from vector network analyser is compared with simulation result of ADS software. Application of lowpass filter is discussed.

The Final chapter of the thesis (Chapter 7) presents the conclusions and problem encounter. The significance and contribution of this work is summarized.

Literature Review

2.1 Introduction

Microwave filter are two-port network, reciprocal, passive, linear device which attenuate heavily the unwanted signal frequencies while permitting transmission of wanted frequencies. The type of construction of this filter is a reflective filter which is consists of capacitive and inductive elements producing ideally zero reflection loss in the pass band region and very high attenuation in the stop band region. The practical filters have small non-zero attenuation in the pass band a small signal output in the attenuation or stop band due to the presence of resistive losses in reactive elements of propagating medium [1]. The proposed Microstrip Stepped-Impedance lowpass filter is designed for 2.4 GHz operating frequency which is suitable for ISM band (Industry, Scientific and Medical).

The stepped impedance distribution element filter is one of the most popular microstrip filter configurations used in the lower microwave frequencies. It is easy to manufacture because it has open-circuited ends and it is easy to design. Microstrip filters play an important role in many RF applications. As technologies advances, more stringent requirements for filters are required. One of the requirements is compactness of filters. In modern wireless telecommunication system, compact size and high performance filter are commonly required to reduce the cost and enhance system performance. The use of microwave filters can be found in many applications in microwave circuits and telecommunication systems, implemented in a number of topologies. One of the conventional filters is the stepped impedance filter mainly due to the ease of implementation in either microstrip or coplanar technology [8][13].

Earlier filter designs have mostly been focused on using a modified silicon substrate where the variation in substrate height and effective permittivity is accomplished by etching. Different concepts and materials have been suggested for achieving a high dielectric constant and also the advantage of being tunable by varying the composition. Several ideas of how to perform this with different technologies have been presented. Also commercially available low temperature co-fired ceramics (LTCC) tapes exist with dielectric values of about 4 to 10. These tapes, together with high dielectric constant

ceramics (bi-pyrochlore), could also be combined and used for achieving a variation in dielectric constant.

The stepped impedance filter is normally design by alternating low and high impedance regions where the change in impedance is controlled by the line width of the strip. For achieving a high degree of attenuation in the stop band, it is necessary to obtain a 'high to low impedance ratio' ($Z_h = Z_l$) or increase the order of the filter. If a dielectric homogeneous substrate is used the limitations are directly related to the achievable line widths. In addition, to arrive at narrow line widths could also be difficult due to process limitations (minimum possible feature size). By using a nonhomogeneous dielectric substrate instead where a change in dielectric constant, ϵ , is introduced, it would be possible to create stepped impedance filter with a continuous microstrip width. Other designs have also utilised the method of etching the ground plane to producing a variation in the effective permittivity. However, using etching ground plane will locally change the effective permittivity. The technology of etching the ground plane will also introduce unwanted radiation in microwave applications and therefore require necessary shielding. Therefore other designs utilising materials with different dielectric constants could offer a new possibility to produce filters and other devices.

Recently, the new stepped impedance geometry with different working principle, design procedure, performance, and physical size, mediate, and high working frequency have been introduced. It is called electromagnetic bandgap structure (EBG structure) [8]. The comparison between these two techniques and analysis is explained on [11]. This EBG structure has the advantage working in higher frequency and high attenuated in the stopband. Less size that conventional stepped impedance geometry. However, the ripples level of in the passband of this EBG structure higher that conventional stepped impedance technique. In combination with progress in finding new high dielectric constant materials this could be an interesting technology for improving some of the filter performances. The size reduction of the filter could also become an important factor where large line widths could be replaced by smaller line widths by introducing a higher dielectric constant.

2.2 Network Parameter and Overview of Filters

Filter networks are essential building elements in many areas of RF/microwave engineering. Such networks are used to select/reject or separate/combine signals at

different frequencies in a host of RF/microwave systems and equipment. Although the physical realization of filters at RF/microwave frequencies may vary, the circuit network topology is common to all. At microwave frequencies, voltmeters and ammeters for the direct measurement of voltages and currents do not exist. For this reason, voltage and current, as a measure of the level of electrical excitation of a network, do not play a primary role at microwave frequencies. On the other hand, it is useful to be able to describe the operation of a microwave network such as a filter in terms of voltages, currents, and impedances in order to make optimum use of low-frequency network concepts. It is the purpose of this chapter to describe various network concepts and provide equations that are useful for the analysis of filter networks.

2.2.1 Network variables

Most RF/microwave filters and filter components can be represented by a two-port network, as shown in Figure 2.1 , where V_1 , V_2 and I_2 , I_1 are the voltage and current variables at the ports 1 and 2, respectively, Z_{01} and Z_{02} are the terminal impedances, and E_s is the source or generator voltage. Note that the voltage and current variables are complex amplitudes when we consider sinusoidal quantities. For example, a sinusoidal voltage at port 1 is given by

$$v_1 = |V_1| \cos(\omega t + \theta) \quad (2.1)$$

Because it is difficult to measure the voltage and current at microwave frequencies, the wave variables a_1 , b_1 and a_2 , b_2 are introduced, with a indicating the incident waves and b the reflected waves. The relationships between the wave variables and the voltage and

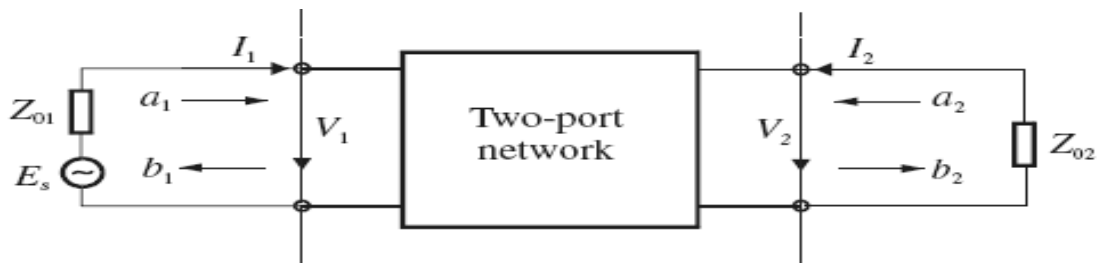


Figure 2.1-Two port network

current variables are defined as

$$V_n = \sqrt{Z_{0n}}(a_n + b_n)$$

$$I_n = \frac{1}{\sqrt{Z_{0n}}} (a_n - b_n)$$

2.2.2 Scattering Parameter

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

$$\begin{aligned} S_{11} &= \frac{b_1}{a_1} \text{ (When } a_2 = 0) & S_{12} &= \frac{b_1}{a_2} \text{ (When } a_1 = 0) \\ S_{21} &= \frac{b_2}{a_1} \text{ (When } a_2 = 0) & S_{22} &= \frac{b_2}{a_2} \text{ (When } a_1 = 0) \end{aligned}$$

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

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \quad (2.2)$$

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

The parameters S_{11} and S_{22} are also called the reflection coefficients, whereas S_{12} and S_{21} the transmission coefficients. These are the parameters directly measurable at microwave frequencies. The S parameters are in general complex, and it is convenient to express them in terms of amplitudes and phases. Often their amplitudes are given in decibels (dB), which are defined as $20 \log |S_{mn}|$ dB. ($m, n = 1, 2$) Where the logarithm operation is base 10. This will be assumed through this book unless otherwise stated. For filter characterization, we may define two parameters:

$$L_A = 20 \log |S_{mn}| \text{ dB} \quad m, n = 1, 2 (m \neq n)$$

$$L_R = 20 \log |S_{nn}| \text{ dB} \quad n = 1, 2$$

Where L_A denotes the insertion loss between ports n and m and L_R represents the return loss at port n . Instead of using the return loss, the voltage standing wave ratio VSWR may be used. The definition of VSWR is

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

In network analysis or synthesis, it may be desirable to express the reflection parameter S_{11} in terms of the terminal impedance Z_{01} and the so-called input impedance $Z_{in1} = \frac{V_1}{I_1}$, which is the impedance looking into port 1 of the network. Such an expression can be deduced by evaluating S_{11} in terms of the voltage and current variables using the relationships defined. This gives

$$S_{11} = \frac{b_1}{a_1} = \frac{\frac{V_1}{\sqrt{Z_{01}}} - \sqrt{Z_{01}}I_1}{\frac{V_1}{\sqrt{Z_{01}}} + \sqrt{Z_{01}}I_1}$$

$$S_{11} = \frac{Z_{in1} - Z_{01}}{Z_{in1} + Z_{01}}$$

Similarly, we can have

$$S_{22} = \frac{Z_{in2} - Z_{02}}{Z_{in2} + Z_{02}}$$

Where $Z_{in2} = \frac{V_2}{I_2}$ is the input impedance looking into port 2 of the network. Equations indicate the impedance matching of the network with respect to its terminal impedances.

The S parameters have several properties that are useful for network analysis. For a reciprocal network $S_{12} = S_{21}$. If the network is symmetrical, an additional property, $S_{11} = S_{22}$, holds. Hence, the symmetrical network is also reciprocal. For a lossless passive network the transmitting power and the reflected power must equal to the total incident power. The mathematical statements of this power conservation condition are

$$|S_{11}|^2 + |S_{21}|^2 = 1$$

$$|S_{22}|^2 + |S_{12}|^2 = 1$$

2.2.3 Short-Circuit Admittance Parameter

The short-circuit admittance or Y parameters of a two-port network are defined as

$$Y_{11} = \frac{I_1}{V_1} \text{ (When } V_2 = 0) \quad Y_{12} = \frac{I_1}{V_2} \text{ (When } V_1 = 0)$$

$$Y_{21} = \frac{I_2}{V_1} \text{ (When } V_2 = 0) \quad Y_{22} = \frac{I_2}{V_2} \text{ (When } V_1 = 0)$$

in which $v_n = 0$ implies a perfect short-circuit at port n . The definitions of the Y parameters may also be written as

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \quad (2.3)$$

Where the matrix containing the Y parameters is called the short-circuit admittance or simply Y matrix, and may be denoted by $[Y]$. For reciprocal networks $Y_{12} = Y_{21}$. In addition to this, if networks are symmetrical $Y_{11} = Y_{22}$. For a lossless network, the Y parameters are all purely imaginary.

2.2.4 Open-Circuit Impedance Parameter

The open-circuit impedance or Z parameters of a two-port network are defined as

$$Z_{11} = \frac{V_1}{I_1} \text{ (When } I_2 = 0) \quad Z_{12} = \frac{V_1}{I_2} \text{ (When } I_1 = 0)$$

$$Z_{21} = \frac{V_2}{I_1} \text{ (When } I_2 = 0) \quad Z_{22} = \frac{V_2}{I_2} \text{ (When } I_1 = 0)$$

Where $I_n = 0$ implies a perfect open-circuit at port n . These definitions can be written as

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad (2.4)$$

The matrix, which contains the Z parameters, is known as the open-circuit impedance or Z matrix and is denoted by $[Z]$. For reciprocal networks, $Z_{12} = Z_{21}$. If networks are symmetrical, $Z_{12} = Z_{21}$ and $Z_{11} = Z_{22}$. For a lossless network, the Z parameters are all purely imaginary.

2.2.5 ABCD Parameter

The *ABCD* parameters of a two-port network are given by

$$A = \frac{V_1}{V_2}(\text{When } I_2 = 0), \quad B = \frac{V_1}{-I_2}(\text{When } V_2 = 0)$$

$$C = \frac{I_1}{V_2}(\text{When } I_2 = 0), \quad D = \frac{I_1}{-I_2}(\text{When } V_2 = 0)$$

These parameters are actually defined in a set of linear equations in matrix notation

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix} \quad (2.5)$$

Where the matrix comprised of the *ABCD* parameters is called the *ABCD* matrix. Sometimes, it may also be referred to as the transfer or chain matrix. The *ABCD* parameters have the following properties:

$$AD - BC = 1, \quad \text{For a reciprocal network}$$

$$A = D, \quad \text{For a symmetrical network}$$

2.3 Classification of Filters

In general Filters are the electronics devices which are used to select interest of application or reject any particular frequency band.

There are four types of filters they are

- ❖ Low Pass Filters
- ❖ High Pass Filters
- ❖ Band Pass Filters
- ❖ Band Stop Filters

Low pass filter allows low frequency signals to be transmitted from the input to the output with little attenuation. However, as the frequency exceeds a certain cut off point, the attenuation increases significantly with the result of delivering an amplitude reduced signal to the output port.

The opposite behavior is true for a high pass filter, where the low frequency signal components are highly attenuated in amplitude, while beyond a cut-off frequency point the signal passes the filter with little attenuation. Band pass and band stop filters restrict the pass band between specific lower and upper frequency points where the attenuation is either low (band pass) or high for (band stop) compared to the remaining frequency band. Figure summarizes their gain v and normalized frequency f behavior:

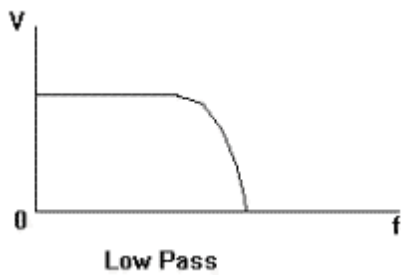


Figure 2.2: Low pass filter response

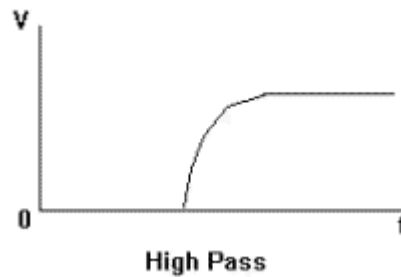


Figure 2.3: High pass filter response

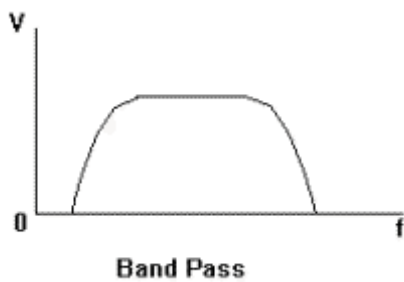


Figure 2.4: Band pass filter response

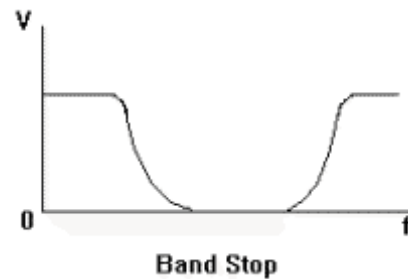


Figure 2.5: Band stop filter response

2.3.1 Butterworth Filter:

The transfer function of a two-port filter network is a mathematical description of network response characteristics, namely, a mathematical expression of S_{21} . On many occasions, an amplitude-squared transfer function for a lossless passive filter network is defined as

$$|S_{21}(j\Omega)|^2 = \frac{1}{1 + \varepsilon^2 F_n^2(\Omega)} \quad (2.6)$$

Where ϵ is a ripple constant, $F_n(\Omega)$ represents a filtering or characteristic function, and Ω is a frequency variable. For our discussion here, it is convenient to let Ω represent a radian frequency variable of a low pass prototype filter that has a cutoff frequency at $\Omega = \Omega_c$ for $\Omega_c = 1$ (rad/s). The amplitude-squared transfer function for Butterworth filters that have an insertion loss $L_{Ar} = 3.01$ dB at the cutoff frequency $\Omega_c = 1$ is given by

$$|S_{21}(j\Omega)|^2 = \frac{1}{1+\Omega^{2n}} \quad (2.7)$$

Where n is the degree or the order of filter, which corresponds to the number of reactive elements, required in the lowpass prototype filter. This type of response is also referred to as maximally flat because its amplitude-squared transfer function defined has the maximum number of $(2n - 1)$ zero derivatives at $\Omega = 0$. Therefore, the maximally flat approximation to the ideal lowpass filter in the pass band is best at $\Omega = 0$, but deteriorates as Ω approaches the cutoff frequency Ω_c . Figure 2.6 shows a typical maximally flat response

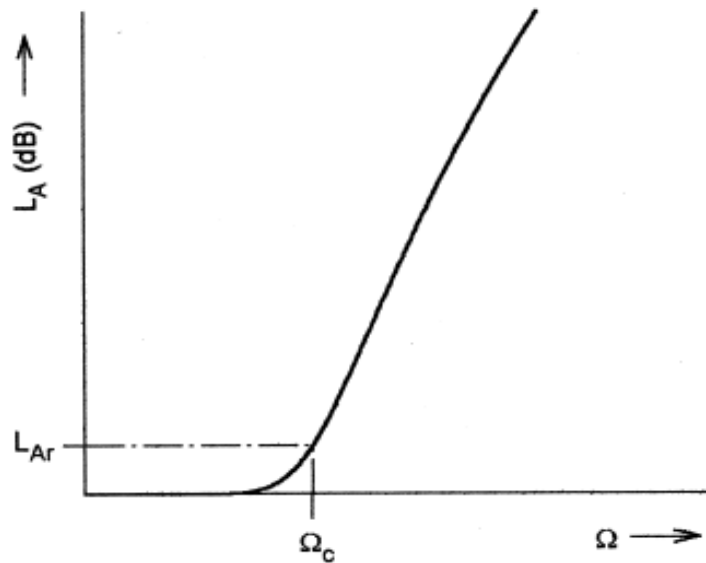


Figure 2.6 -Butterworth low pass filter response

2.3.2 Chebyshev Filter

The Chebyshev response that exhibits the equiripple pass band and maximally flat stop band is depicted in Figure 2.7. The amplitude-squared transfer function that describes this type of response is

$$|S_{21}(j\Omega)|^2 = \frac{1}{1+\varepsilon^2 T_n^2(\Omega)} \quad (2.8)$$

Where the ripple constant ε is related to a given pass band ripple L_{Ar} in dB by

$$\varepsilon = \sqrt{10^{L_{Ar}/10} - 1}$$

$T_n(\Omega)$ is a Chebyshev function of the first kind of order n , which is defined as

$$T_n(\Omega) = \begin{cases} \cos(\cos^{-1} \Omega) & |\Omega| \leq 1 \\ \cosh(n \cosh^{-1} \Omega) & |\Omega| \geq 1 \end{cases} \quad (2.9)$$

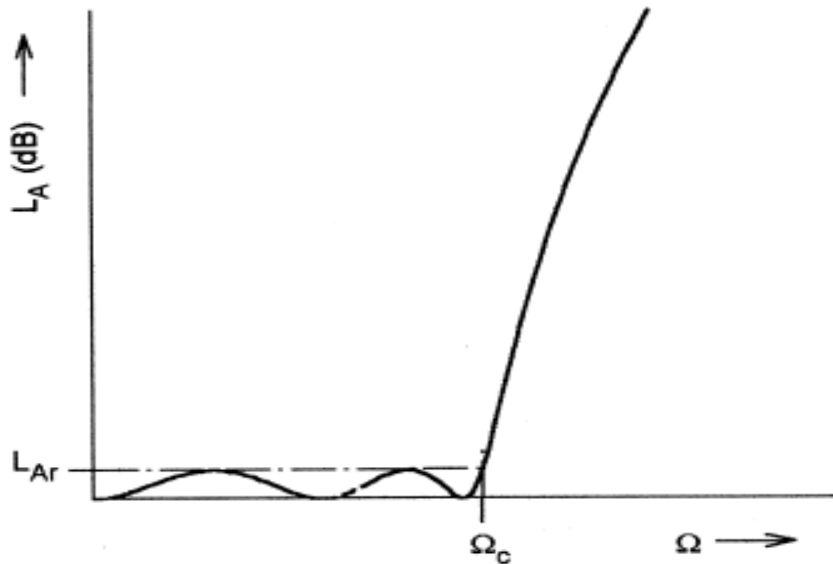


Figure 2.7-Chebyshev low pass filter response

2.3.3 Elliptic Filter:

The response that is equal-ripple in both the passband and stopband is the elliptic function response, as illustrated in Figure 2.8. The transfer function for this type of response is

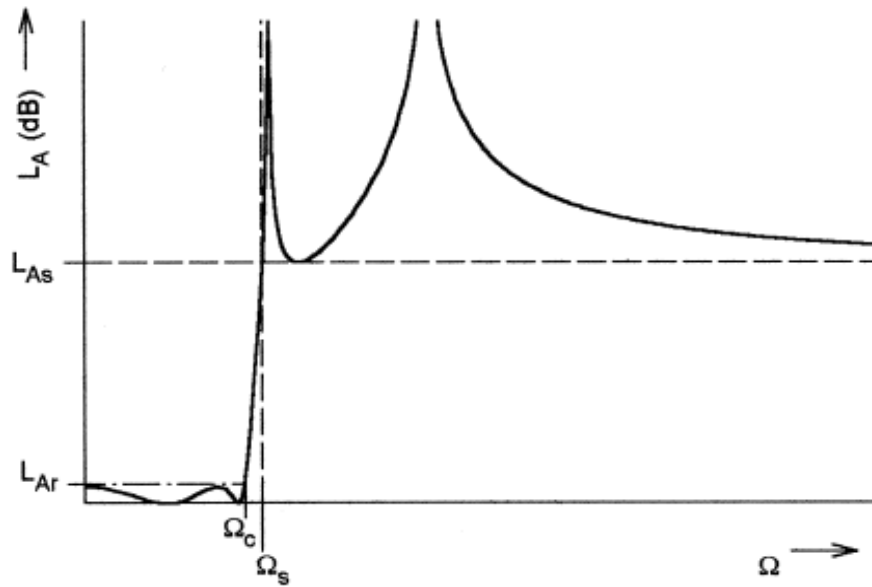


Figure 2.8- Elliptic low pass filter response

$$|S_{21}(j\Omega)|^2 = \frac{1}{1+\varepsilon^2 F_n^2(\Omega)} \quad (2.10)$$

With

$$F_n^2(\Omega) = \begin{cases} M \frac{\prod_{t=1}^{\frac{n}{2}} \Omega_t^2 - \Omega^2}{\prod_{t=1}^{\frac{n}{2}} \Omega_s^2 / \Omega_t^2 - \Omega^2} & \text{for } n \text{ even} \\ N \frac{\prod_{t=1}^{\frac{n-1}{2}} \Omega_t^2 - \Omega^2}{\prod_{t=1}^{\frac{n-1}{2}} \Omega_s^2 / \Omega_t^2 - \Omega^2} & \text{for } n \text{ odd} \end{cases}$$

Where $\Omega_t (0 < \Omega_t < 1)$ and $\Omega_s > 1$ represent some critical frequencies; M and N are constants to be defined [4–5]. This chapter describes the network variable (S-parameter, Y parameter) which are used in filter synthesis. Classical prototype filters are classified as ; maximally flat, chebyshev and elliptical function filters.

2.4 Microstrip Technology

Microstrip is a type of electrical transmission line which can be fabricated using printed circuit board [PCB] technology, and is used to convey microwave frequency signals and

it consists of a conducting strip separated from a ground plane by a dielectric layer known as the substrate [7]. Filter can be formed from microstrip. It is device that existing as the pattern of metallization on the substrate. Microstrip technology is far cheaper than waveguide technology, as well as being far lighter and more compact.

2.5 Overview of Microstrip Line

Figure 2.9 shows the dielectric layer of microstrip substrate. Microstrip transmission lines consist of a conductive strip of width (W) and thickness (t) and a wider ground plane, separated by a dielectric layer ("substrate") of thickness (h). Microstrip is by far the most popular microwave transmission line, especially for microwave integrated circuits and MMICs. The major advantage of microstrip over stripline is that all active components can be mounted on top of the board. The disadvantages are that when high isolation is required such as in a filter or switch, some external shielding may have to be considered. Given the chance, microstrip circuits can radiate, causing unintended circuit response. A minor issue with microstrip is that it is dispersive, meaning that signals of different frequencies travel at slightly different speeds. Variants of microstrip include embedded microstrip and coated microstrip, both of which add some dielectric above the microstrip conductor.

A transmission line can be considered as a distribution - parameter network, where voltage and current can vary in magnitude and phase over the length of the line [8]. Since the size of the microwave solid-state device is vary small [10], the technique of signal input on these devices and extracting output power from the uses microstrip lines on the surface on which they can be easily mounted. A conducting strip (microstrip line) with a width and a thickness is on the top of a dielectric substrate that has a relative dielectric constant and a thickness, and the bottom of the substrate is a ground (conducting) plane.

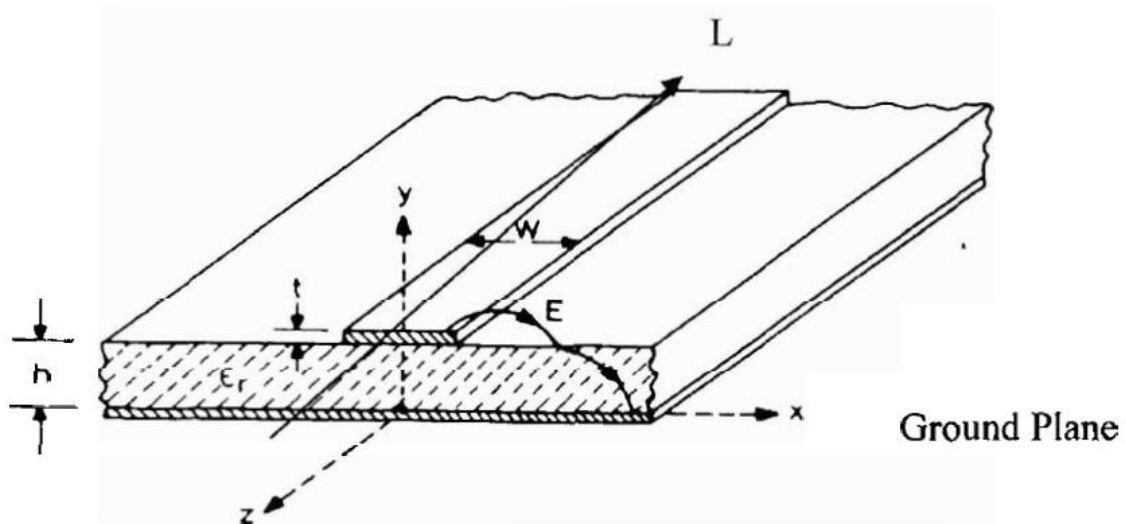


Figure.2.9 Microstrip Dielectric Layer.

Where:

l = element of length

W = element of width

ϵ_r = effective permeability of dielectric

h = height of dielectric

t = conductor thickness

E = electromagnetic plane

Due to the absence of a top ground plate and the dielectric substrate above strip, the electric field lines remain partially in air and partially in the lower dielectric substrate. Due to the presence of discontinuity and open structure, the Transverse ElectroMagnetic (TEM) mode is not pure propagate along the microstrip structure. This is what they called quasi-TEM [8]. We could say that the radiation loss is proportional to the square of the frequency. The use of thin and high dielectric materials reduces the radiation loss of the open structure where the fields are mostly limited inside the dielectric. In this project, we use the simplified formula to determine the width and height of the filter element. The full detailed on how to generate the equation is on [12].

2.5.1 Effect of dielectric constant

Since the propagation field lines in a microstrip lies partially in air and partially inside the - homogenous dielectric substrate, the propagation delay time for a quasi-TEM mode is

related to an effective dielectric constant can be generated by assuming the thickness of conductor, t . The accurate equation that is explain the microstrip line will be establish by using conformal mapping, but this equations are too complex and it has need the long manual equation. Hence, to get the better approximation in short term during compute to parameter line approximation, the easy formulas empirical are used [12]. That is to use the empirical formulas that are only depend to line dimension Width (W), height (h) and dielectric constant, ϵ_r . This formula is called Transmission Line Method (TLM). For the narrow strip line, $W/h < 1$, the electric constant of ϵ_{eff} the substrate material given by;

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + 12 \frac{h}{w}}} + 0.04 \left(1 - \frac{w}{h} \right)^2 \right]; \quad \frac{w}{h} \leq 1 \quad (2.11)$$

Where the ϵ_{eff} is the effective permeability of each filter element.

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + 12 \frac{h}{w}}} \right]; \quad \frac{w}{h} \gg 1 \quad (2.12)$$

2.5.2 Effect of Strip Thickness

The thickness t , is usually very small when the microstrip line is realized by conducting thin films. Therefore, its effect may quite often be ignored in calculation process. The thickness is only use in simulation process to determine the substrate parameters.

2.5.3 Effect of Enclosure

In microstrip applications, a conductor enclosure is normally required. The presence of conducting side walls will affect both the characteristic impedance and the effective dielectric constant. In [10], the comparison between shielded and unshielded gives the different parameter. To reduce the effect of enclosure, the height up to the top air space should be more than eight times and the distance to walls more than five times the substrate thickness.

Mathematical Study of Stepped Impedance LPF

3.1 Introduction

This chapter will discuss the step by step procedure for designing a basic stepped impedance low pass filter. Flowchart is one of the projects planning method to assist the project development by guiding us throughout the project so that no important step oblivious. It describes how the tasks are planned to achieve the objective of the project. This chapter describes the method in designing and in other chapters also will included illustrations, selection, simulation and fabrication of the filter.

This chapter is to do calculation to obtain the lumped element of low pass filter. Main component needed for the project was identified after taking several necessary considerations such as the value of capacitor and inductor in each sections of the filter.

Next, the lumped element of the filter was simulated using Advance Design System to ensure it performs the desired function properly. The observation of frequency response from the lumped element will be taken to ensure the desired distribution element low pass filter can be realized from it.

Fabrication is preceded after simulation is done. Then, testing troubleshooting repeated until satisfactory functioning of the circuitry is attained.

3.2 Design of Stepped impedance low pass filter

The step by step procedure for designing a basic lowpass filter by Different Method. The Focus of this project is to Explain and Implement the Low pass Filter using Stepped Impedance lowpass filter.

3.2.1 Designing a Low Pass Prototype (LPP) Filter

Select an Appropriate low pass Filter prototype. There are many prototype but in this project figure (3.1) is consider to design the low pass filter.

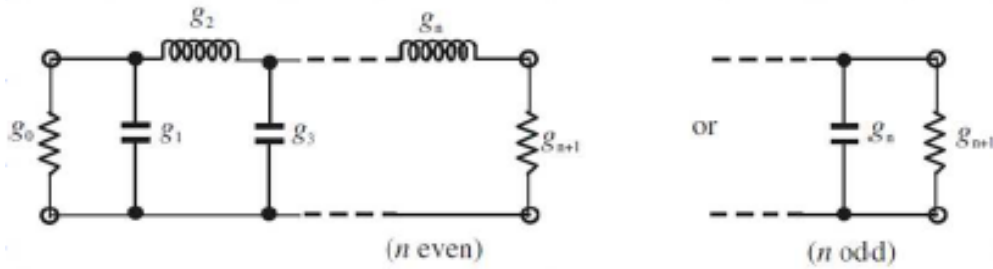


Figure.3.1 prototype of lowpass filter circuit.

3.2.2 The choice of filter

The choice of the type of response including pass band ripple and the number of reactive elements.

- Butterworth (Maximally flat) filter
- Chebyshev (Equal ripple) filter
- Elliptical filter

3.2.3 Find an appropriate Microstrip realization

To design the low pass filter there are many microstrip realization which are following. In this chapter the main focus on stepped impedance technique to design the lowpass filter.

- Stepped Impedance Lowpass Filter
- Low pass Filter using open circuited stubs

3.3 Design Considerations

$z_{oc} < z_0 < z_{0L}$, where z_{oc} and z_{0L} denote the characteristic impedances of the low and high impedance lines, respectively, and z_0 is the source impedance, which is usually 50 ohms.

Lower z_{oc} results in a better approximation of a lumped-element capacitor, but the resulting line width W_c must not allow any transverse resonance to occur at operating frequency

Higher z_{0L} leads to a better approximation of a lumped-element inductor, but z_{0L} must not be so high that its fabrication becomes difficult, or its current-carrying capability becomes a limitation.

3.4 Stepped Impedance Low Pass Filter

The stepped impedance distribution element filter is one of the most popular microstrip filter configurations used in the lower microwave frequencies. It is easy to manufacture because it has open-circuited ends and it is easy to design. General structure- Cascaded Structure of High- and Low Impedance TML.

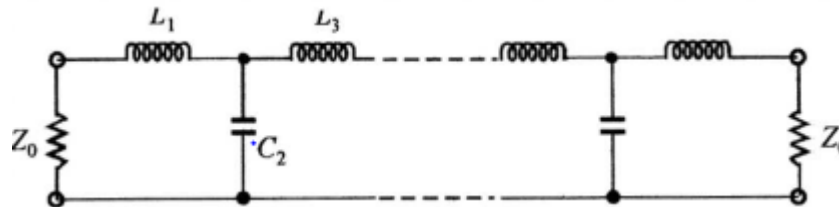


Figure.3.2 lowpass filter prototype circuit.

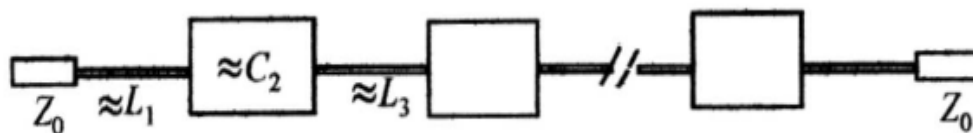


Figure.3.3 Microstrip layout of low pass filter.

3.4.1 Z - Parameter Analysis of Transmission Line

we know the impedance matrix of a symmetric two port device:

$$Z = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \quad (3.1)$$

Regardless of the construction of this two port device, we can model it as a simple “T-circuit”, consisting of these impedance:

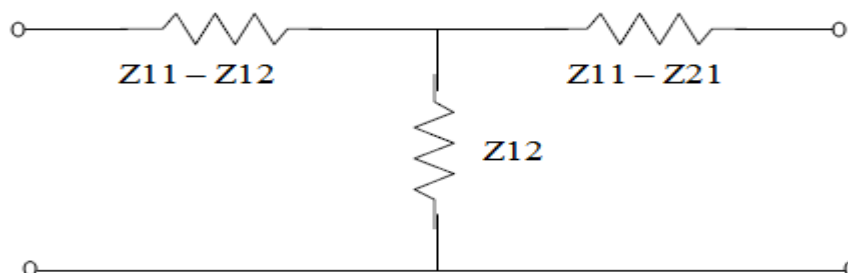


Figure.3.4 Two port network

If the two series impedances have an impedance value equal to $Z_{11} - Z_{21}$, and the shunt impedance has a value equal to Z_{21} , therefore any symmetric two-port network can be modelled by this “T-circuit”.

For example, consider a length L of transmission line (a symmetric two port network)

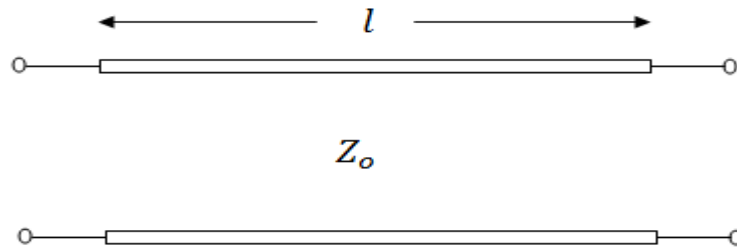


Figure.3.5 Transmission line

That the impedance parameters of this two port network are:

$$Z_{11} = Z_{22} = -jZ_0 \cot \beta l \quad (3.2)$$

$$Z_{12} = Z_{21} = -Z_0 \csc \beta l \quad (3.3)$$

With little trigonometry,

$$Z_{11} - Z_{12} = jZ_0 \tan \left(\frac{\beta l}{2} \right) \quad (3.4)$$

Further more, if βl is small

$$\sin \beta l \approx \beta l \quad \cos \beta l \approx 1 \quad \tan \beta l \approx \beta l$$

Where βl is expressed in radians.

$$Z_{11} - Z_{12} \approx jZ_0 \left(\frac{\beta l}{2} \right) \quad (3.5)$$

And also

$$Z_{12} = Z_{21} = -jZ_0 \csc \beta l \approx \frac{Z_0}{j\beta l} \quad (3.6)$$

Thus, an electrically short ($\beta l \ll 1$) transmission line can be approximately modelled with a “T-circuit” as

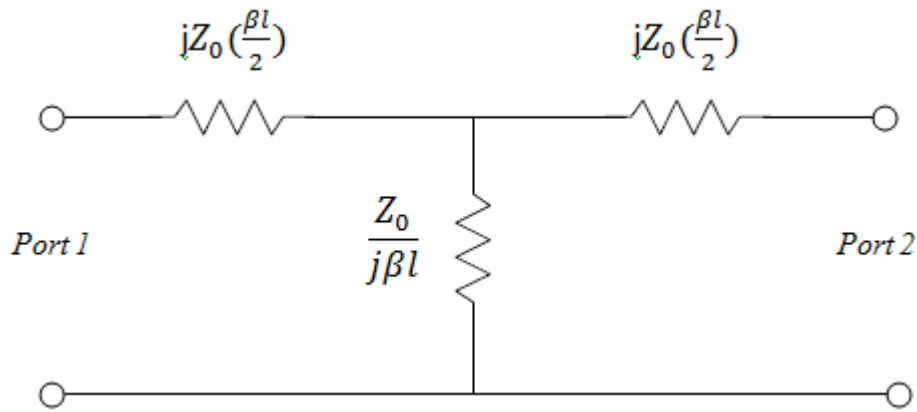


Figure.3.6 T-Equivalent circuit for transmission line section having $\beta l < \frac{\pi}{4}$

3.5 Transmission line approximation for filter design

Consider the characteristic impedance of the transmission line is relatively large. we will denote this large characteristic impedance as Z_0^h . Note the shunt impedance, value $\frac{Z_0^h}{j\beta l}$. Since the numerator (Z_0^h) is relatively large, and the denominator ($j\beta l$) is small, the impedance shunt device is very large. So large, in fact, that we can approximate it as an open circuit .

$$\frac{Z_0^h}{j\beta l} \approx \infty \quad \text{for } \beta l \ll 1 \text{ and } Z_0^h \gg Z_0$$

So now we have a further simplification of our model:

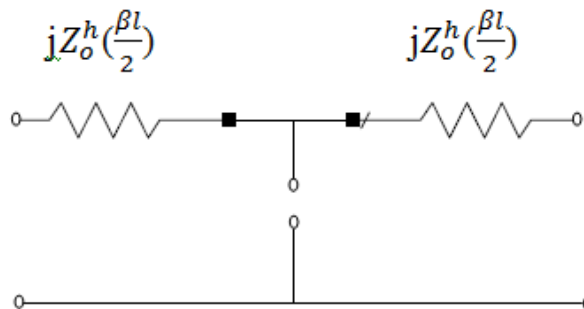


Figure.3.7(a)

The remaining impedances are now in series, so the circuit can be further simplified to:

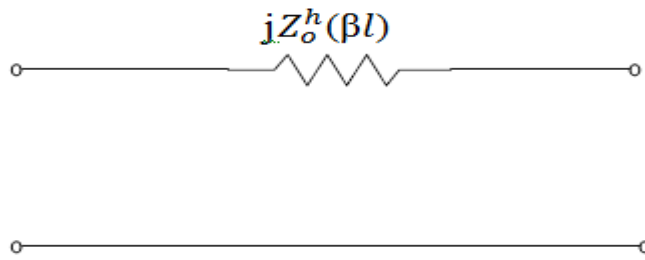


Figure.3.7(b)

Figure.3.7(a),3.7(b) The equivalent circuit for transmission line with short electrical length and large characteristic impedance Z_0^h .

consider the another case of characteristic impedance of the transmission line has a relatively low value, denoted as Z_0^l , where $Z_0^l \ll Z_0$. Note the series impedance, values $jZ_0 \left(\frac{\beta l}{2}\right)$. Since both Z_0^l and βl are small, the product of the two is very small. So small, in fact, that we can approximate it as a short circuit.

$$jZ_0 \left(\frac{\beta l}{2}\right) \approx 0 \quad \text{for } \beta l \ll 1 \text{ and } Z_0^l \ll Z_0$$

So further simplification of our model:

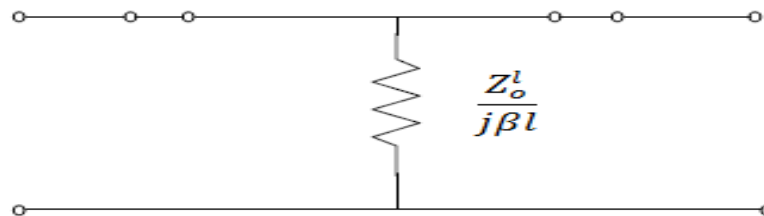


Figure.3.8(a)

Which of course further simplifies to:

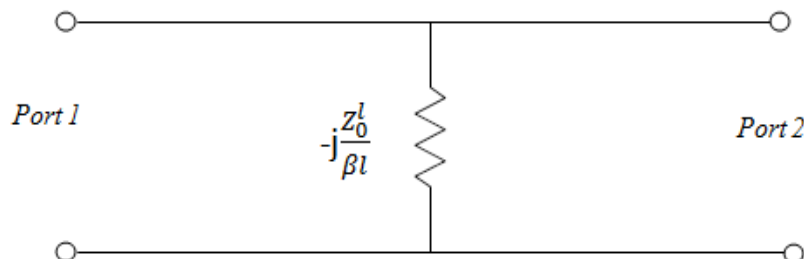


Figure.3.8(b)

Figure.3.8(a)3.8,(b) The equivalent circuit for transmission line with short electrical length and small characteristic impedance Z_0^l .

3.5.1 Design of Inductor using transmission line

The two equivalent circuits for an electrically short transmission line. The one with large characteristic impedance Z_0^h has the form of a series inductor, and the one with small characteristic impedance Z_0^l has the form of a shunt capacitor.

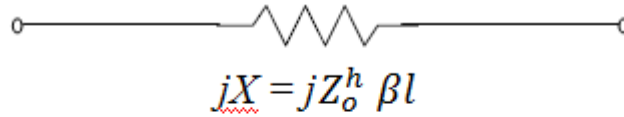


Figure.3.9 Electrically short transmission line circuit

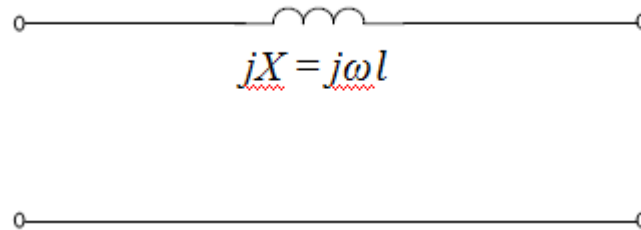


Figure.3.10 Inductive transmission line circuit

Are identical if :

$$jZ_0^h \beta l = j\omega L \Rightarrow Z_0^h \beta l = \omega L \quad (3.7)$$

Thus, the “series inductor” of our transmission line length is:

$$L = \frac{Z_0^h \beta l}{\omega} \quad (3.8)$$

Recall that $\beta = \omega/v_p$, so that:

$$L = \frac{Z_0^h \beta l}{\omega} = \frac{Z_0^h l}{v_p} \quad (3.9)$$

In other words, the series impedance resulting from our short transmission line is:

$$Z = j\omega \left(\frac{Z_0^h l}{v_p} \right) \quad (3.10)$$

Moreover, one of these approximations was that the electrical length of the transmission line small. This obviously cannot be true at all frequencies. As the signal frequency increases, so does the electrical length—our approximation solution no longer be valid.

Thus, this realization is accurate only for low frequencies. Well, for this filter to provide a response that accurately follows the lumped element design, our approximation should be valid for frequencies up to the filter cutoff frequency.

A general rule of thumb is that a small electrical length is defined as being less than $\pi/4$ radians. Thus, to maintain this small electrical length at cutoff frequency, our realization must satisfy the relationship:

$$\beta_c l = \frac{\omega_c L}{Z_0^h} < \frac{\pi}{4} \quad (3.11)$$

Note that this criterion is difficult to satisfy if the filter cutoff frequency and/or the inductor value L that we are trying to realize is large. Our only recourse for these challenging condition is to increase the value of characteristic impedance Z_0^h . But there is always a practical limit to how large (small) can make the characteristic impedance of a transmission line. Assuming that we can satisfy the above constraint, we can approximately realize a lumped inductor or inductance value L by selecting the correct characteristic impedance Z_0^h and line length l of our short transmission line:

$$L = \frac{Z_0^h l}{v_p} \quad (3.12)$$

3.5.2 Design of Capacitor using transmission line

The low impedance transmission line provided a shunt impedance that matched a shunt capacitor:

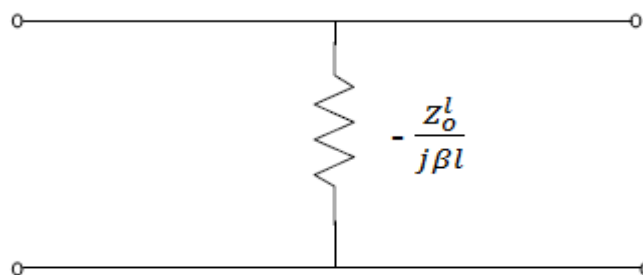


Figure.3.11 Electrically shunt transmission line circuit

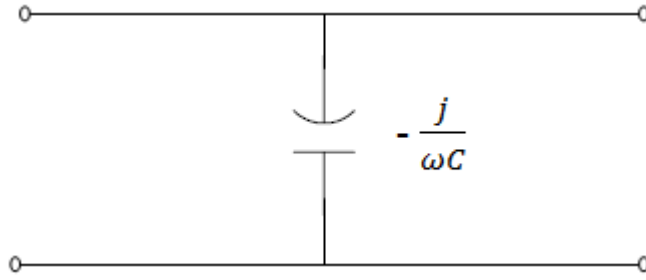


Figure. 3.12 capacitive transmission line circuit

Are identical if:

$$-j \frac{Z_0^l}{\beta l} = -j \frac{1}{\omega C} \Rightarrow \frac{\beta l}{Z_0^l} = \omega C \quad (3.13)$$

Thus, the shunt capacitor of transmission line length is:

$$C = \frac{\beta l}{\omega Z_0^l} \quad (3.14)$$

But again using the fact that $\beta = \omega/v_p$:

$$C = \frac{l}{v_p Z_0^l} \quad (3.15)$$

And thus the shunt reactance of our transmission line realization is:

$$Z = \frac{-j}{\omega} \left(\frac{v_p Z_0^l}{l} \right) \quad (3.16)$$

Although this again appears to provide exactly the same behaviour as a capacitor (as a function of frequency), it is likewise accurate only for low frequencies, where $\beta l < \frac{\pi}{4}$.

Thus from our realization equality:

$$\frac{\beta l}{Z_0^l} = \omega C \quad (3.17)$$

We can conclude that for our approximations to be valid at all frequencies up to the filter cutoff frequency, the following inequality must be valid:

$$\beta_c l = \omega_c C Z_0^l < \frac{\pi}{4} \quad (3.18)$$

Note that for difficult design cases where ω_c and/or C is very large, the line characteristic impedance Z_0^l must be made very small. Now approximately realize a lumped capacitor

of inductance value C by selecting the correct characteristic impedance Z_0^l and line length l of our short transmission line :

$$C = \frac{l}{v_p Z_0^l} \quad (3.19)$$

Design Of Microstrip Low Pass Filter

4.1 Introduction

The following chapter describes briefly the requirements and consideration taken related to the development of a conventional stepped impedance lowpass filter. This includes all the mathematical formulae related and the calculation of the responses.

A filter is a network that provides perfect transmission for signal with frequencies in certain passband region and infinite attenuation in the stopband regions. Such ideal characteristics cannot be attained, and the goal of filter design is to approximate the ideal requirements to within an acceptable tolerance. Lowpass filter (LPF) that transmit all signals between DC and some upper limit ω_c , and attenuate all signals with frequencies above ω_c . Filter can be further divided into active and passive type. The output power of passive filter will always be less than the input power while active filter allows power gain. In this project we will only discuss passive filter. The characteristic of a passive filter can be described using the transfer function approach or the attenuation function approach. At microwave frequency the attenuation function description is preferred. Figure 4.1 show the characteristic of passive lowpass filter.

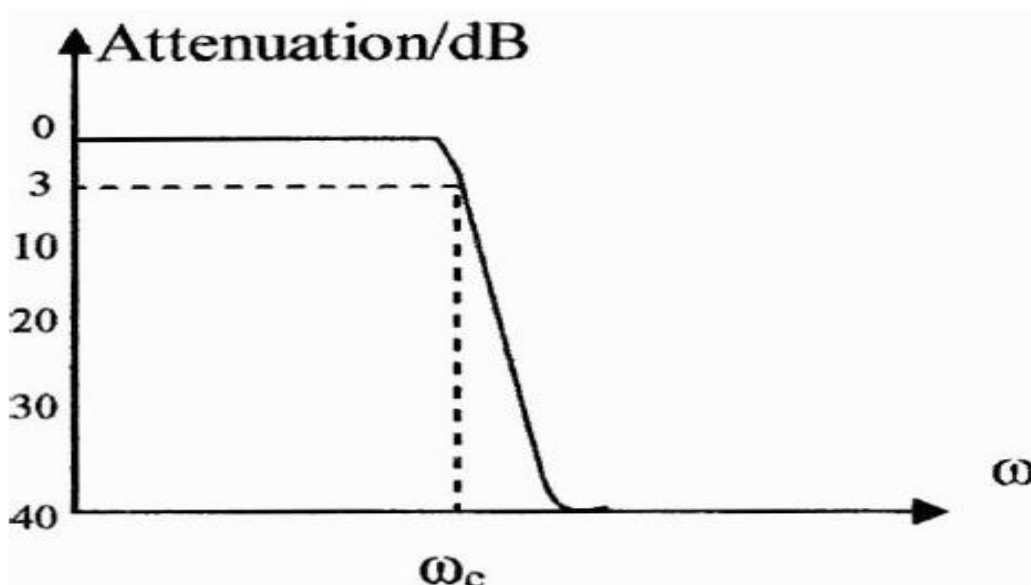


Figure 4.1 A lowpass filter frequency response.

4.2 Design of Stepped Impedance Microstrip Low- Pass Filters

In general, the design of microstrip low-pass filters consists of two main steps. The first step is to select an appropriate low-pass prototype. The choice of the type of response, including passband ripple and the number of reactive elements, will lie on the required specifications [1]. The element values of the lowpass prototype filter, which are usually normalized to make a source impedance $g_0 = 1$ and a cutoff frequency $\Omega_c = 1.0$, are then transformed to the L-C elements for the desired cutoff frequency and the desired source impedance, which is normally 50 ohms for microstrip filters. Having obtained a suitable lumped element filter design, the next main step in the design of microstrip lowpass filters is to obtain an appropriate microstrip realization that approximates the lumped element filter. The element values for the low pass prototype with maximally flat response it is necessary to have more than 20dB insertion loss at 4GHz, characteristic impedance (source or load) $Z_0 = 50$ ohms, are taken from normalized values g_i i.e. $g_1, g_2, g_3, \dots, g_n$. The filter is supposed to be fabricated on a substrate with dielectric constant and of thickness t mm. for Angular (normalized) cutoff frequency Ω_c , using the element transformation. Microstrip line short sections and stubs, whose physical lengths are smaller than a quarter of guided wavelength ($\lambda_g/4$) at which they operate, are the most common components for approximate microwave realization of lumped elements in microstrip filter structures.

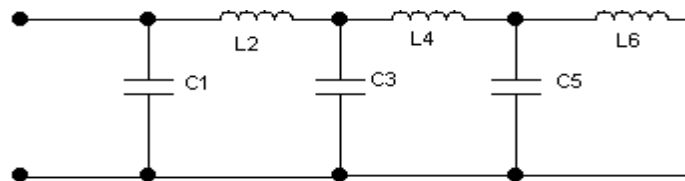


Figure 4.2 : Lowpass filter prototype circuit.

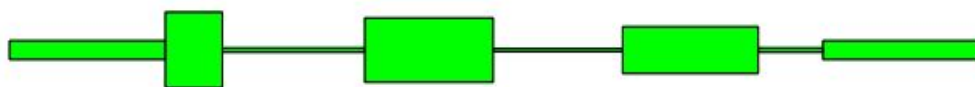


Figure 4.3 : Microstrip layout of stepped impedance low pass filter

4.2.1 Electrical length for Inductor and Capacitor

Electrical Length for Inductor Section as

$$\beta l = \frac{LR_0}{Z_h} \quad (4.1)$$

Electrical Length for Capacitor Section as

$$\beta l = \frac{CZ_l}{R_0} \quad (4.2)$$

with minimum 20 dB attenuation at 4GHz , the elements value (n) was founded, there is six-elements ($n=6$) lumped circuit microwave filter and Butterworth prototyped was created for the following normalized values

$$g_1 = 0.517; g_2 = 1.414; g_3 = 1.932; g_4 = 1.932; g_5 = 1.414; g_6 = 0.517; g_7 = 1.000$$

by using these values calculate the values of βl for inductor and capacitor after this use the lincalc of ADS to calculate the width and length of lowpass filter which is describe in next step.

4.2.2 Dimension of the Filter

Use LineCalc to determine the physical parameters of the MLINs with the help of Low Impedance ,High Impedance and Electrical Length.

4.2.3 Agilent Line Calc:

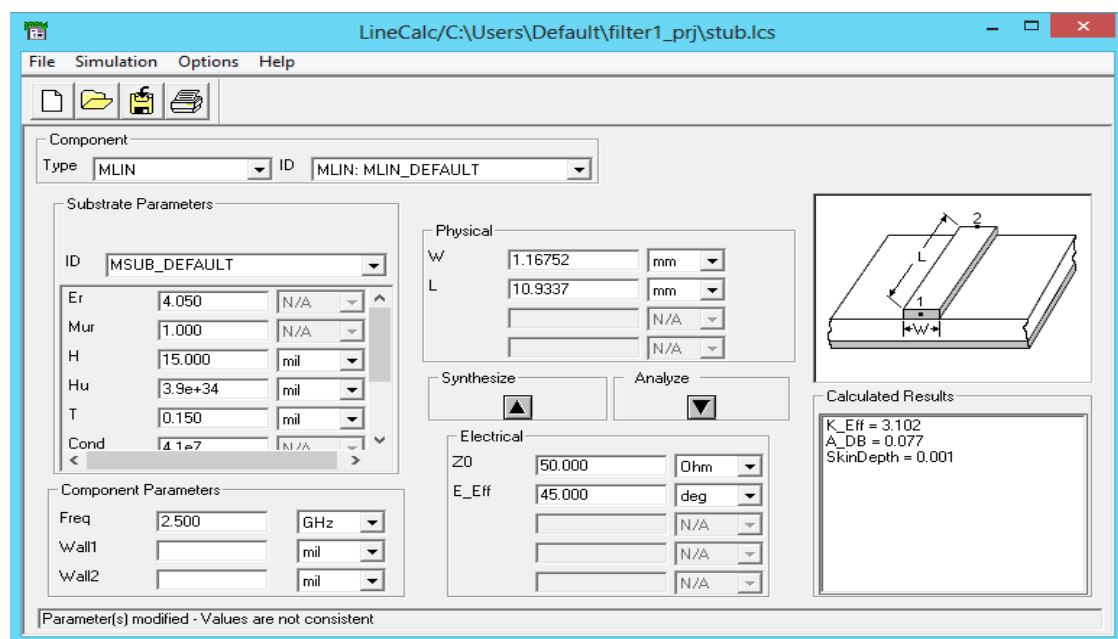


Figure.4.4 Agilent ADS Line Calc

Corresponding to the value of characteristic impedance of each sections of transmission line is consider low impedance and high impedance (20 and 120 respectively) and the values of width and length of each section of microstrip is obtained from Agilent Line calc tool as shown in figure 4.4. The dielectric substrate is used having a thickness of 1mm and relative dielectric constant of $\epsilon = 4.05$. Table 4.1 tabulates the dimensions of each transmission line section.

4.2.4 Table for the parameters of transmission line

In the following table 4.1 describe the transmission line parameter like width and length for the transmission line. These width and length for transmission line is calculated with the help of line calculation in Agilent Advance design system software. For using the Lincal of Agilent ADS first calculate the electrical length by using the equation 4.1 and equation 4.2 .

Components	Z_l or Z_h (Low and High Impedance)	Electrical Length(βl) In degree	Width (mm)	Length (mm)
MLIN1	20	11.8	5.042193	4.153494
MLIN2	120	33.8	0.2817	10.386624
MLIN3	20	44.3	4.266471	9.35586
MLIN4	120	46.1	0.20658	9.35586
MLIN5	20	32.4	3.10288	9.883887
MLIN6	120	12.3	0.2817045	4.724985
MLIN7	50	45	1.2399	11.3641
MLIN8	50	45	1.2399	11.3641

Table.4.1: Serial Transmission Line parameter from Line Calc width and length for each transmission line.

4.3 Schematic of stepped impedance LPF using Agilent ADS

Figure 4.5 represents the schematic for stepped impedance microwave low pass filter for N=6 elements using Agilent ADS. There are six transmission line for low and high impedances with the value of width and length of transmission line which is calculated with the help of LinCal using Agilent ADS. S-Parameter palette is used for S-parameter analysis of proposed wideband microwave low pass filter. The simulation is performed with linear sweep of frequency from DC to 5GHz.

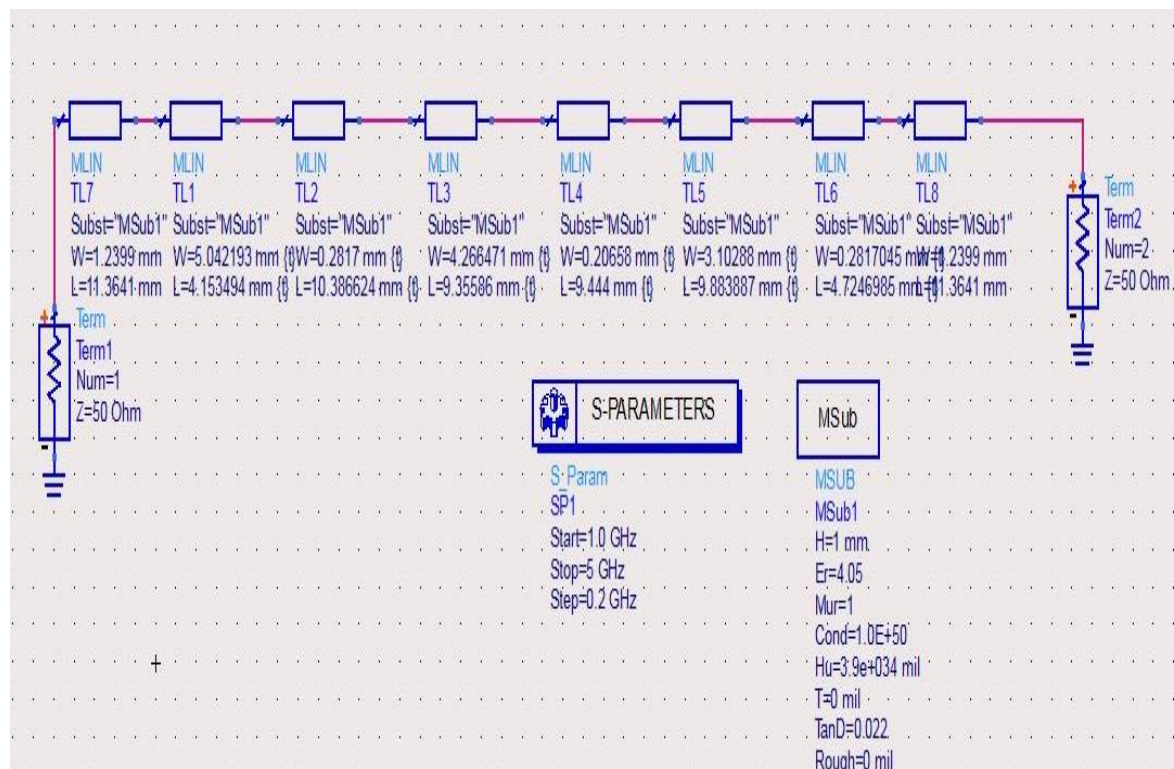


Figure 4.5: Agilent ADS Schematic of Stepped Impedance Low Pass Filter

4.3.1 Substrate definition of microstrip

A substrate in EM simulation describes the media where a circuit exists. To demonstrate the proposed design methodology, the microwave lowpass filter is simulated using microstrip line build on a substrate FR4 with a thickness of 1mm, loss tangent of 0.022 and relative dielectric constant of $\epsilon = 4.05$.

4.3.2 Layout diagram of six element low pass filter in ADS

Based on the schematic diagram (section 4.5) the layout for six element low pass filter is generated in Agilent ADS. For characterization of designed low pass filter meshing is

performed and analysis is done in FEM simulation. An FEM simulation mesh is a part of the entire 3D problem domain, which is divided into a set of tetrahedra (or cells). The pattern of cells is based on the geometry of a layout so each layout has a unique mesh calculated for it. The mesh is then applied to the geometry to compute the electric fields within each cell. It also helps to identify any coupling effects in the layout during simulation. From these calculations, S-parameters are then calculated for the layout.

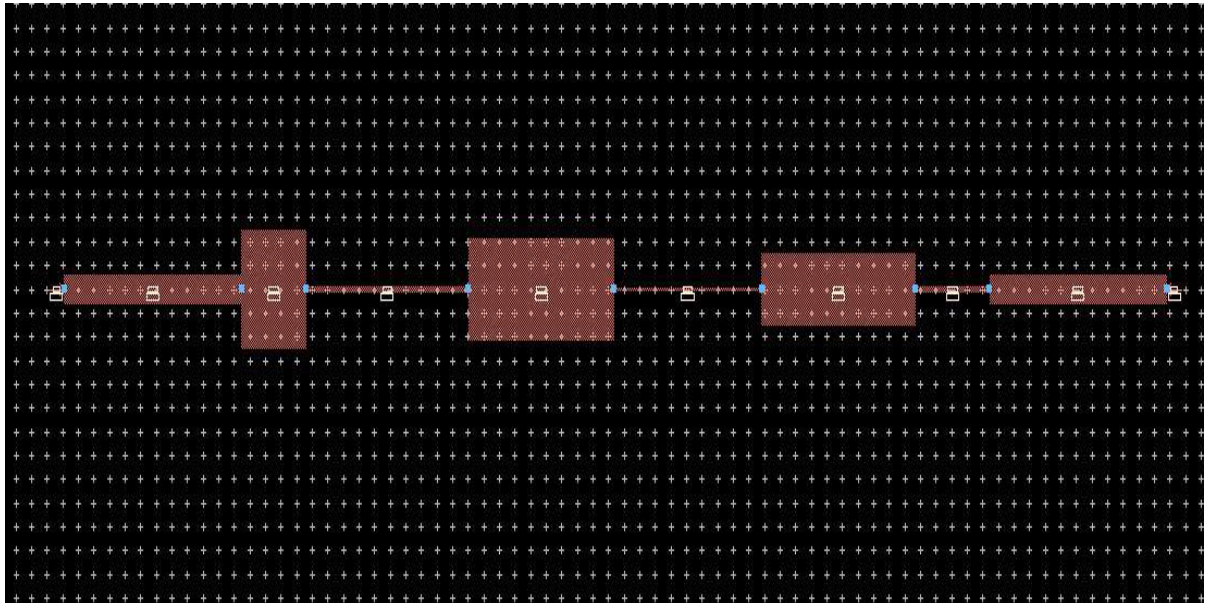


Figure.4.6: Layout diagram of stepped impedance lowpass filter with six sections

4.3.3 Agilent EMPro layout

Figure 4.7 represents the final microstrip low pass filter prototype build in Agilent EMPro software.

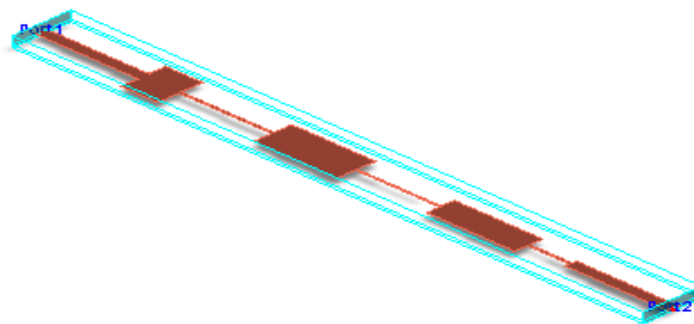


Figure 4.7: 3D Agilent EMPro Preview

4.3.4 Magnitude Response

For characterization of designed low pass filter , reflection coefficient S_{11} and transmission coefficient S_{21} parameters have been plotted. It can be seen that the designed microwave stepped impedance low pass filter follows well the ideal low pass filter characteristic between the frequency range 0 GHz to 5 GHz.

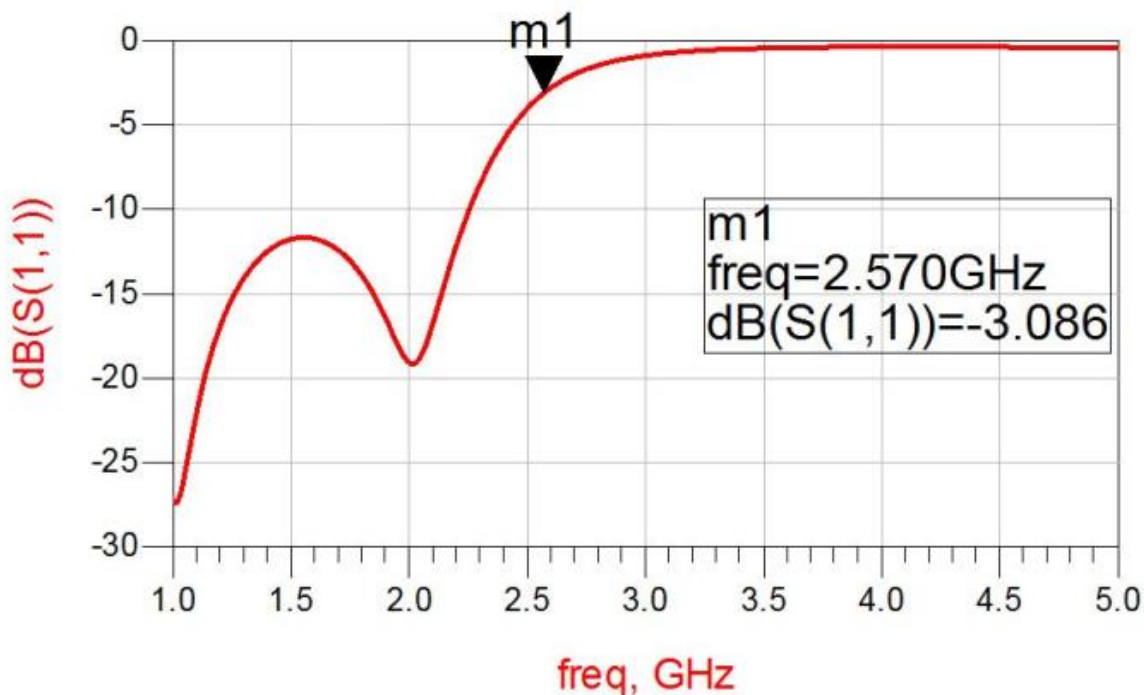


Figure.4.8: Frequency response of the S_{11} parameter.

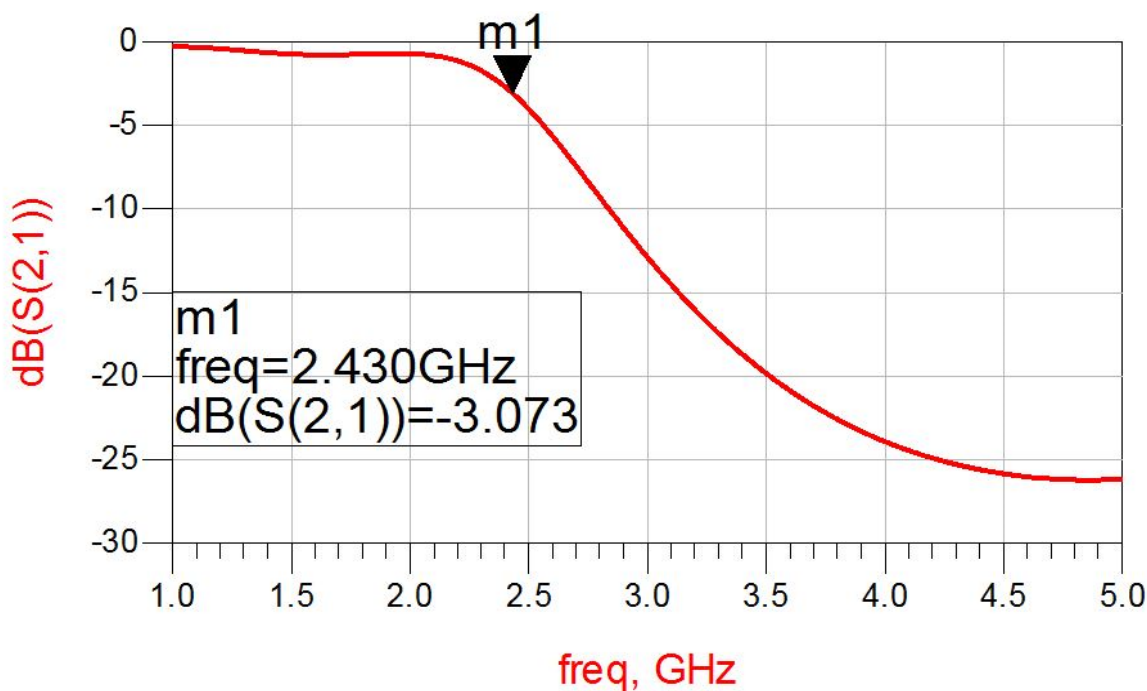


Figure.4.9: Frequency response of reflection coefficient (S_{21}) for a proposed design.

4.4 Magnitude Response for MATLAB Code

Magnitude response for stepped impedance lowpass filter using the ABCD parameters with the help of MATLAB software in system vue. This magnitude plot shows the same results appears in the Agilent ADS software. The 3dB frequency is obtained using MATLAB code at 2.4 GHz .

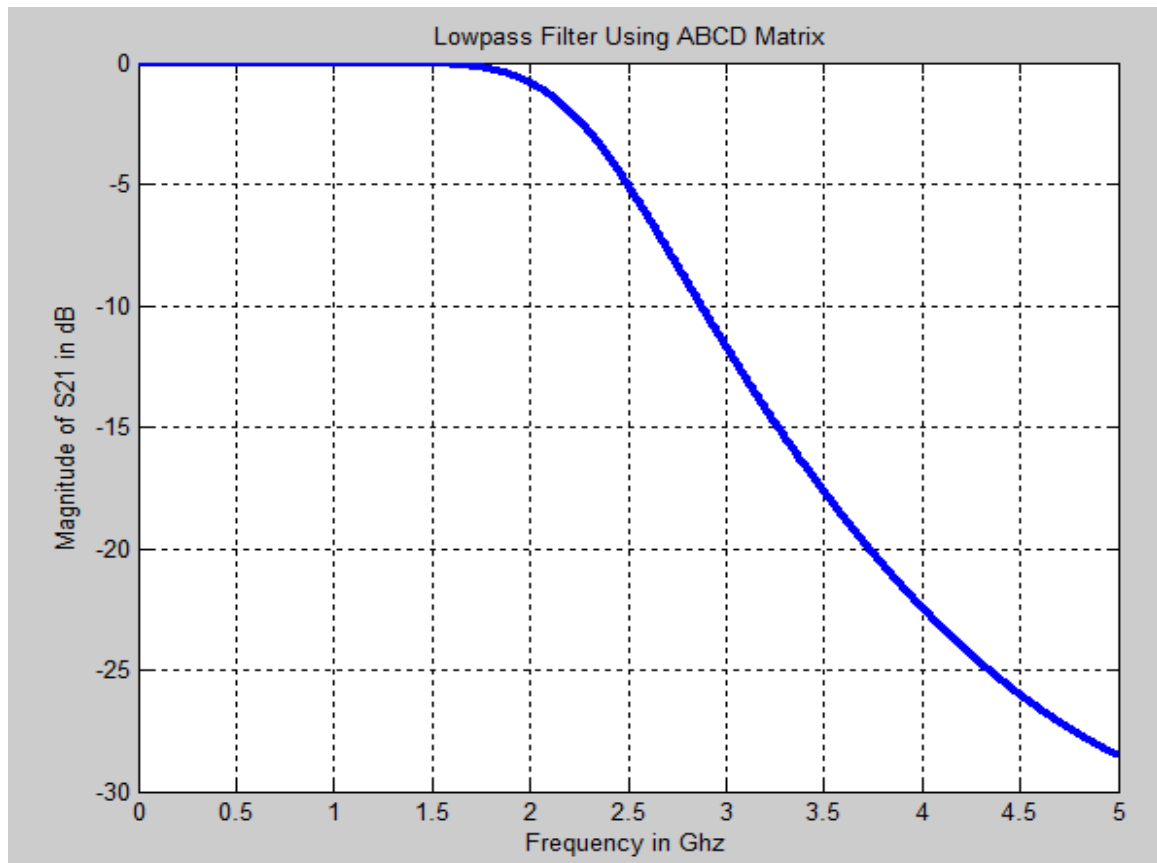


Figure.4.10 lowpass filter using ABCD parameters using system vue.

Fabrication of Microstrip Stepped Impedance LPF

5.1 Introduction

In modern day most super semiconductors are been processes in mass production, by using high technology machines. Machines are supported by computerise programming to get high precision, high quality and satisfied guarantee of consumers. Designing which is created by computer software becoming a priority among engineer or designer. ADS is using for microstrip circuit design. The circuit created on schematic window and layout of design is then created using layout window of ADS Momentum. After momentum simulation export that program of ADS files into *.DXF or *.garber extension file and then converted into iCAD module. Afterward That ADS file than exported into VISIO Technical software from which the layout was printed on a transparency to form the mask art work. The result of VISIO Technical artwork master is almost always a 1:1 scaled conductor pattern. Most iCAD software is capable of producing ‘phototools’ directly. All software can produce a high quality 1:1 scaled positive print (black conductor pattern on white paper) with high-resolution laser printer.

5.2 Design Flowchart

To be more systematic in designing process, the flow diagram must be obtained. The flow diagram can be used as a guide to the designer to obtained their strategy and getting a good result as required.



Figure 5.1: Flowchart of fabrication processes

5.3 Preparing a masking

Mask or transparency is the layout of artwork master that resulted from ADS software in a scaled conductor pattern. ADS is powerful software, has a capability to create exactly pattern with aids from iCAD filed called .DXF (i.e. LPF.DXF). This file can be read out by iCad software.

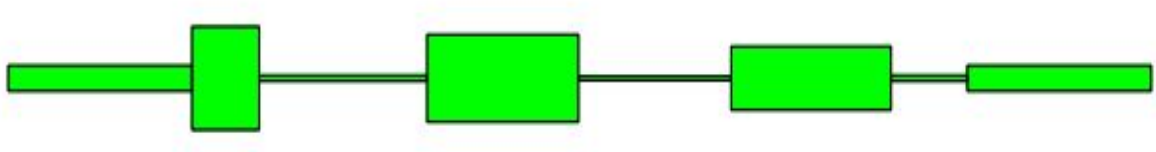


Figure 5.2: The MicrostripLPF .DXF file format

5.4 VISIO Technical

The main reason is to use the VISIO is that a 1:1 scaled layout can be produced and can be printed out. Since the microstrip is miniature in structure, the viewing can be enlarged above 100% and this factor can really help designers to check it out the accuracy of the microstrip layout.

The .DXF file produced by the iCAD program is not in scaled after transferred into .VSD (VISIO Technical file) and then adjust to filling with the black shading. Using high-resolution Laser jet printer then prints the scaled-layout. Masking is ready on transparency type as output from LaserJet printer. Now, the mask is ready to used and proceeds for photolithography.

5.4.1 Photolithography Process.

The filter was realised using normal Printed Circuit Boards (PCB) procedure.

The following are required to create layout circuit on the photoresist:

- i. Plastic tray
- ii. Photoresist Solution
 - Photoresist Positive (Spray type)
 - Photoresist Developer (Liquid)

5.4.2 Photolithography Equipment

- i. Ultraviolet Light Compartment.
- ii. Hot Plate with temperature controlled.

5.4.3 Steps of the photolithography processes.

The following are shows the steps of photoresist process.

5.4.3.1 Preparation of Developer

Firstly, ready the Photoresist Developer and Lid water with 1:4 in the plastic tray. Prepare for only one microstrip.



Figure5.3 Positive and Developer Photoresist



Figure.5.4 Ultraviolet exposure

5.4.3.2 Photolithography procedures

Step 1.

Peel off the thin film covered on main surface. (A Microstrip material has a double-sided surface). Cleanliness is most important to ensure the piece of microstrip no dust or no oily surface or contaminated surface. The microstrip material was cleaned by 'acetone' about 2~3 minutes. This is to clean dirt or oily contamination on the substrate surface. Almost solution are used such as Trichloroethylene, acetone and Methanol.

Step 2.

Using a hot plate to warming up the microstrip material. Adjust the hot plate about 100° C. Keep microstrip material on the hot plate about 10 minutes.

Step 3.

Using Positive Photoresist, spray it on the microstrip material constantly. Under 'red safelight', microstrip material is sprayed by Positive Photoresist while it was laid flat on the table. Ensure the sprayed angle about 30° to the work piece. Gives about 10cm away from the microstrip material. To making a good results of spraying, a photoresist spinner is preferable to eliminates bubbling and ensure the thickness uniformity.

Step 4.

Again keep on the hot plate about 5~7 minutes. (Prepare the Ultraviolet light compartment, turn-on the main switch and set-up the exposure time about 3 minutes).

Step 5.

Place the mask (transparency) on the compartment glasses; place the main surface into the mask. The mask was placed on the glasses in the ultraviolet light source compartment. The microstrip material was put on the mask with sensitised surface facing towards glasses.

Position it carefully, to get a good image. Close the compartment by clip-on. Push on the light and wait until the light off, (light off mean the exposure time are finished) 3 minutes is the optimum time for the exposure processing. If microstrip substrate is over exposed, diffraction of light will give the poor edges resolution of the image.

Step 6.

Remain under red safelight, take out from the compartment and solve with Photoresist Developer solution. To remove the unwanted areas which is no ultraviolet exposed and bring out the latent images of the filter.

The developer photoresist is to be used in diluted with lid water (recommended) at the ratio of 1:4. Keep on about 5~6 minutes; actually the black images will appears within 2~4 minutes.

5.4.4 Etching process

The etching was realised using a normal Printed Circuit Board (PCB) etching procedures. Etching is the process of removing unprotected copper from the microstrip to yield the wanted copper as conductor pattern. The common solution are used by industries are Ammonium Persulfate, Chromic Acid, Cupric Chloride and Ferric Chloride. The better solution used since it is relatively safe are Ferric Chloride, it is readily available at costs moderate hence produces excellent results.

This etching procedure is probably the easiest method. The etching container is filled with acid to a depth that will cover the submerged microstrip. The concentration of Ferric Chloride is not environment friendly, be careful when under processing.

5.4.4.1 The concentration of solution

The inside temperature with filled container is kept constant at 50° ~ 55° C by keep on the heater. The concentrations are constantly agitating with the built in air pump at the container.

There are three factors identified affected to the strength of concentration during etching process:

- i. The solution aged
- ii. Agitated concentration
- iii. Temperature of the concentration

Ferric Chloride should be used over and over again, but each time a microstrip circuit is etched, copper is removed and acid will be less strengthen or diluted. Less strengthens of concentration gives a more times to solve it. For the better result for microstrip processing, the new concentrations were used. It takes approximately one hour to etch a small piece of microstrip. The agitating and temperature also take place to speed up the etching process. More agitating and with suggested temperature would cut more time to finish it. Every time to time microstrip circuit has been checked. Satisfied microstrip, when unwanted copper is removed. The microstrip circuit was thoroughly rinsed under running water to avoid the chemical reaction. And the board will be handle with bare hands and should be proceed to further processing

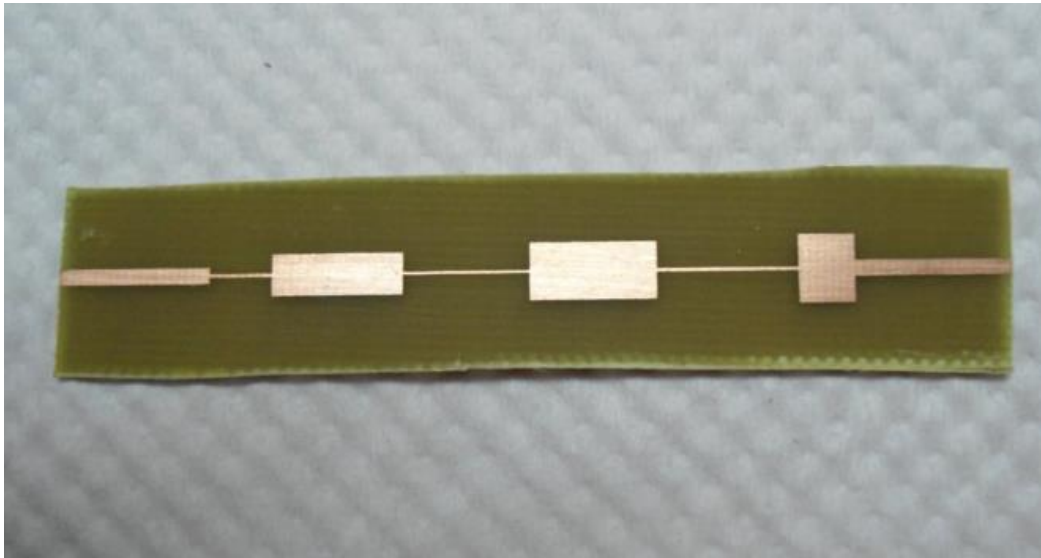


Figure 5.5 The Microstrip Circuit.

5.5 Soldering the Terminal Connector

Once the microstrip circuit is prepared, SMA connectors are soldered into the microstrip circuit. Ensure that the soldering process is neatly done to avoid the effect of resonance on the circuit. The continuity testing using a multi-meter to ensure the connection between the SMA connector and the microstrip is properly done. After all the above are completely satisfied, the Low-Pass filter is ready to be measured and characterized.

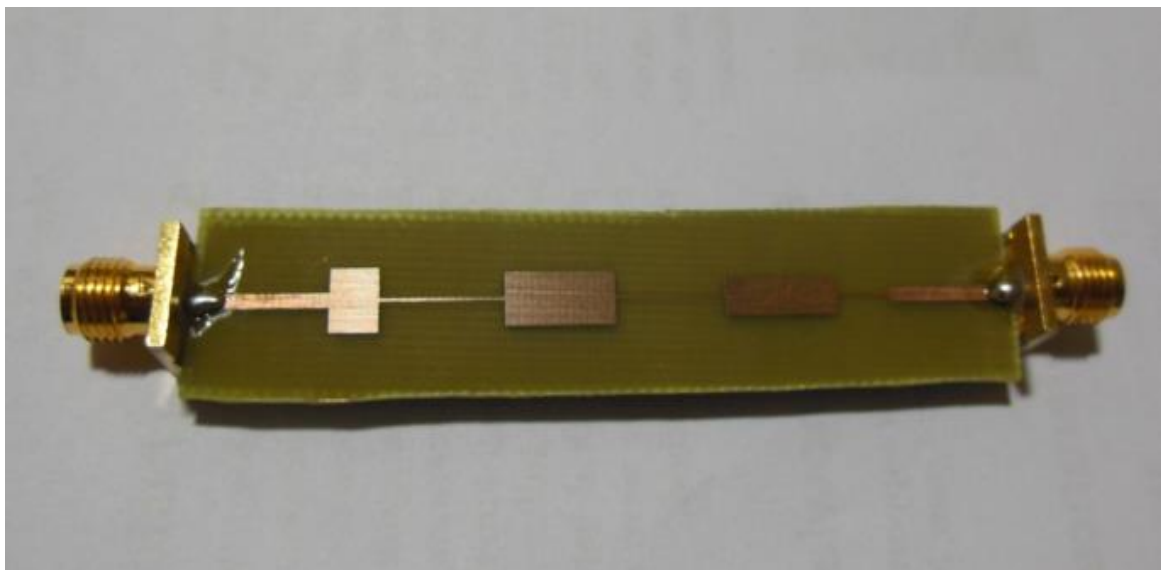


Figure.5.6 Low-Pass Filter

5.6 Testing of Microwave Lowpass Filter

Testing of any circuit fabricated using micstrip line based technology is done by using Vector Network Analyzer (VNA). It is basically used to measure all design specification like S-parameter of any two port network.

5.6.1 Vector Network Analyzer (VNA)

This instrument measure the scattering parameter (Magnitude and Phase) of one or two port active and passive microwave network form 5 KHz to 20 GHz. It is two port channel microwave receiver design to process the magnitude and phase of transmitted and reflected wave from the network.

In operation, there are two oscillator at two ports and two receiver ports is available so the we can test device from both side by providing then input signal without interchange of ports. In the very first step it is required to provide the reference to the VNA for all possible load like short circuit, open circuit, 50Ω impedance. Then it is required to connect to connect to test device and measure all the parameter to two port network includes S_{21} , S_{12} , S_{11} and S_{22} .



Figure.5.7 Vector Network Analyzer

5.6.2 Test Result of Microwave Lowpass Filter using VNA

Stepped Impedance lowpass filter for six element is tested on Vector network Analyzer and transmission coefficient S_{21} and reflection coefficient S_{11} of circuit is obtained and it shown in figure 5.8 and figure 5.9 respectively. Magnitude plot of microwave filter is obtained in frequency range of 1 to 5 GHz in dB and the frequency at 3.4 dB is 2.33GHz.

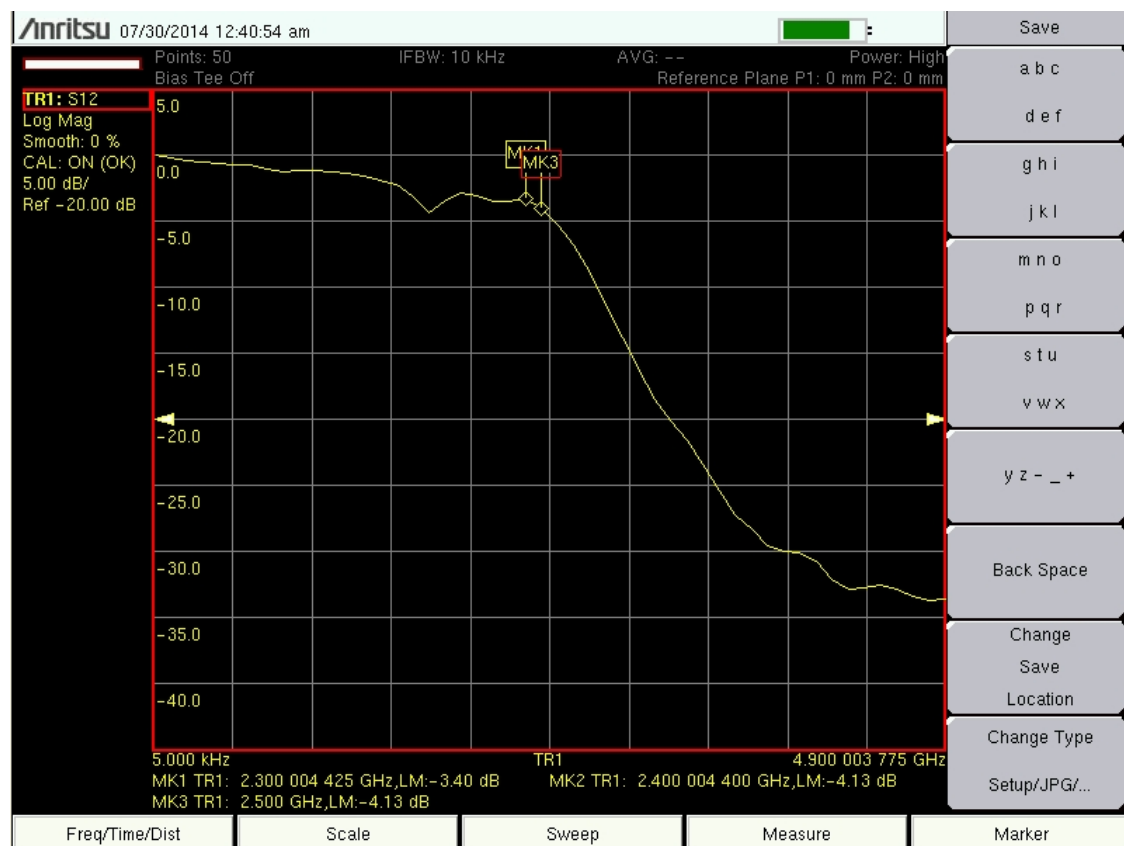


Figure.5.8 Frequency response of reflection coefficient (S_{21}) for a proposed design using vector network analyzer.

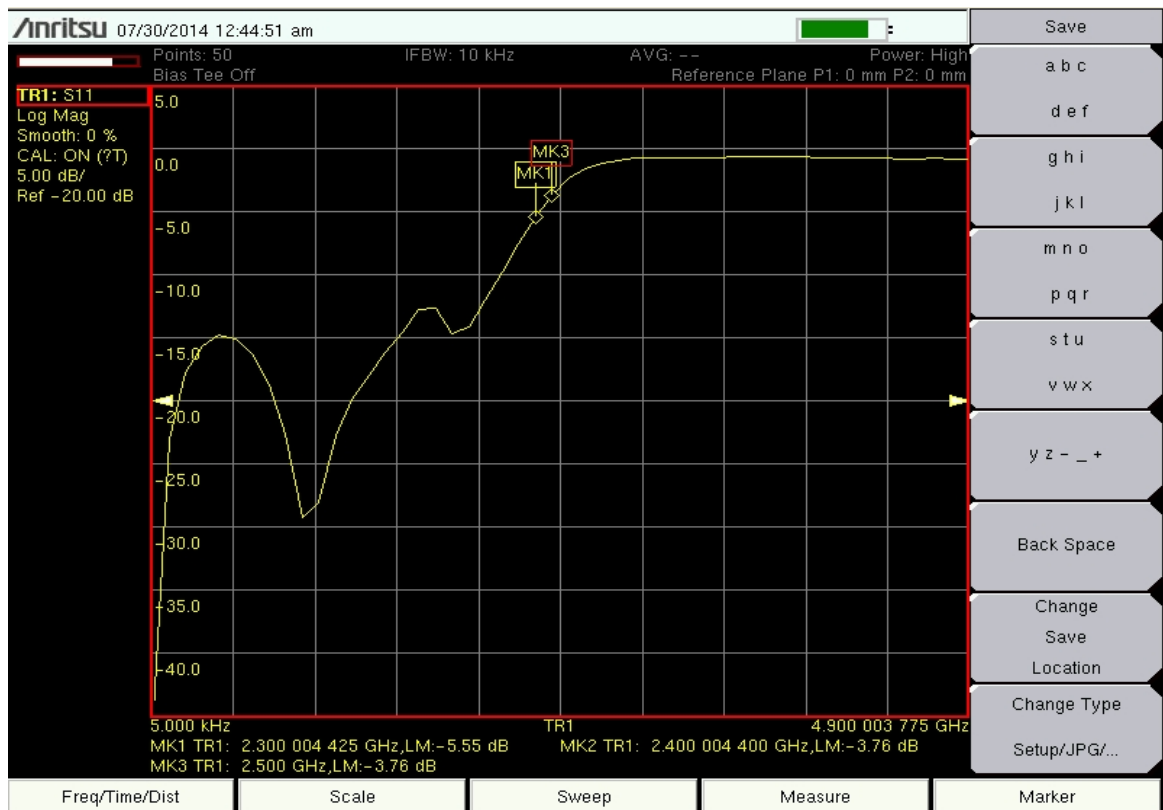


Figure.5.9 Frequency response of the S_{11} parameter using vector network analyzer.

6.1 Results and Discussion

- A stepped impedance low pass filter is design on ADS schematic window at cutoff frequency of 2.4 GHz and desired simulation result in figure 4.6 and figure 4.9 is obtained using ADS momentum tool.
- Desired stepped impedance low pass filter is produced in MATLAB environment meet all required specification shown in figure 4.10 .
- Designed stepped impedance low pass filter on ADS software is fabricated using FR4 substrate with dielectric constant 4.05 using photolithography technique shown in figure (5.6) and tested it on vector network analyzer (VNA) shown in figure (5.8) provide very good agreement between simulated and measured result.

6.2 Applications

The filters are one of the primary and important components of a microwave system. They are very essential part of the microwave system and any communication system. Any communication system cannot designed without filters. Low pass filter must be included at the transmitting end and the receiving side of the system to get desired spectrum. We have designed stepped impedance low pass filter because it takes less space than a similar low pass filter using stubs. Its compact nature minimizes required space for realization and is suitable for integration within Wireless system.

7.1 Conclusion

A stepped impedance low pass microstrip filter has been simulated, designed, fabricated and tested by measurement with a vector network analyzer. The cutoff frequency achieved is lower than the design specification value (2.4GHz). The discrepancy may be due to imperfect fabrication and connection of SMA connector. This filter is widely used today in radar, satellite and terrestrial communications, and electronic counter measure applications, both militarily and commercially.

7.2 Problems Encounter

While working on the project, there were some obstacles that we faced. These problems were the limitation of materials, the lack of equipment, and the inaccuracy during the assembling process. The lowpass filter will have a better performance if it has the larger ratio of the low and high impedance; however, due to the availability of material in store, we had to limit its ratio. Therefore, the filter could not reach the designed frequency range perfectly. The result of the filter was also effect due to the lack of equipment. When the SMA connectors connected to both end of the filter, there was a fault distance that unintended created since we do not have the right equipment to install them. It also limited us from adjusting the component position to be at the centre in order to have a high performance. Another problem that we had during the assembling process was the extra wire was added to each end of the transmission line when we soldered them together. That can also affect the result of the filter. Although there were problems that encountered while building the project, we tried our best to solve and eliminate them. The result of our produce was closely meet the project requirement, and that was a major accomplishment that we proudly had.

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APPENDIX

MATLAB Code for stepped impedance LPF

A.1 MATLAB Code

```
%Low Pass Filter Design Project
%Using the ABCD matrix with low and high impedance line
clc
clear all
close all
Z1=20; Z2=120; Z0=50;
fc=2.4;
j=sqrt(-1);
g1=0.517; g2=1.414; g3=1.932; g4=1.932; g5=1.414; g6=0.517;
BL1=g1*Z1/Z0; BL2=g2*Z0/Z2; BL3=g3*Z1/Z0; BL4=g4*Z0/Z2; BL5=g5*Z1/Z0;
BL6=g6*Z0/Z2;
k=0;
for f=[0:0.001:5]
A1=cos(BL1*f/fc); B1=j*Z1*sin(BL1*f/fc);
C1=(j/Z1)*sin(BL1*f/fc); D1=cos(BL1*f/fc);
A2=cos(BL2*f/fc); B2=j*Z2*sin(BL2*f/fc);
C2=(j/Z2)*sin(BL2*f/fc); D2=cos(BL2*f/fc);
A3=cos(BL3*f/fc); B3=j*Z1*sin(BL3*f/fc);
C3=(j/Z1)*sin(BL3*f/fc); D3=cos(BL3*f/fc);
A4=cos(BL4*f/fc); B4=j*Z2*sin(BL4*f/fc);
C4=(j/Z2)*sin(BL4*f/fc); D4=cos(BL4*f/fc);
A5=cos(BL5*f/fc); B5=j*Z1*sin(BL5*f/fc);
C5=(j/Z1)*sin(BL5*f/fc); D5=cos(BL5*f/fc);
A6=cos(BL6*f/fc); B6=j*Z2*sin(BL6*f/fc);
C6=(j/Z2)*sin(BL6*f/fc); D6=cos(BL6*f/fc);
M1=[A1 B1; C1 D1]; M2=[A2 B2; C2 D2];
M3=[A3 B3; C3 D3]; M4=[A4 B4; C4 D4];
M5=[A5 B5; C5 D5]; M6=[A6 B6; C6 D6];
T=M1*M2*M3*M4*M5*M6;
A=T(1,1); B=T(1,2); C=T(2,1); D=T(2,2);
S21=2/(A+B/Z0+C*Z0+D);
k=k+1;
Y1(k)=S21;
end;
plot([0:0.001:5], 20*log10(abs(Y1)), 'LineWidth',3); grid
```

```
xlabel('Frequency in Ghz');  
ylabel('Magnitude of S21 in dB');  
title(' Lowpass Filter Using ABCD Matrix');
```