DESIGN AND IMPLEMENTATION OF HIGHER ORDER DIFFERENTIATOR USING MICROSTRIP LINES

A Thesis submitted towards the partial fulfilment of the requirement for the award of the degree of

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Submitted by

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CERTIFICATE

This is to certify that the thesis report entitled, "**Design and Implementation of higher order Differentiator using Microstrip lines"** being submitted by **Narendra Mohan Misra** to the *Department of Electronics and Communication Engineering and Applied Physics, Delhi Technological University* in the 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 him 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 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 result 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

The differentiator is a device that performs the mathematical operation of differentiation providing as an output signal the derivative of an arbitrary input signal in the time domain. The differentiation operation can be used directly in signal peak detection and in positive-going or negative-going slope recognition. Besides, differentiators have been used extensively in several areas such as signal processing or pulse generation. Particularly, they constitute an important element in the analysis of signals in radar and sonar systems, in the processing of biomedical or biomechanical data, and in the calculation of geometrical parameters in image processing. Moreover, they play a significant role in reconfigurable pulse shapers and in photonic-based microwave waveform generators.

Digital differentiators are, in general, limited by the operational frequency and bandwidth, which results from the maximum achievable sampling frequency. A wider bandwidth solution can be achieved by using optical devices. So far, the differentiator are mainly implemented in circuits for low-speed applications. Thus the implementation of these circuits for high frequency applications has been largely ignored.

In this project, simple and accurate formulations are employed to represent stable and optimized discrete-time infinite impulse response processes for first and higher order differentiator in the Z-domain. These formulations, in conjunction with the representations of transmission-line elements in the Z-domain, leads to transmission-line configuration that are eligible for wide-band microwave circuits. In particular, many Z domain formats of transfer functions have been obtained to represent the characteristics of a differentiator.

Design simulations for digital differentiator are performed in Agilent SystemVue. In order to translate these circuits for high frequency application, T-parameter (chain scattering parameter) is employed. ADS simulations were used to accurate determine the final design.

The designed models are implemented using non-uniform microstrip lines in Agilent ADS and Agilent EMPro. Simulation results shows proposed models as good candidate for wide band microwave application.

Finally the fabrication of microwave differentiators are done using non-uniform microstrip lines on a RT/duroid® 5880 substrate.

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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_o	:	Characteristic impedance of microstrip line

Chapter 1

Introduction

1.1 Overview

The differentiator is a device that performs the mathematical operation of differentiation providing as an output signal the derivative of an arbitrary input signal in the time domain. The differentiation operation can be used directly in signal peak detection and in positive-going or negative-going slope recognition. Besides, differentiators have been used extensively in several areas such as signal processing or pulse generation [1]–[20]. Particularly, they constitute an important element in the analysis of signals in radar and sonar systems [1], in the processing of biomedical or biomechanical data [2], and in the calculation of geometrical parameters in image processing [3]. Moreover, they play a significant role in reconfigurable pulse shapers [4] and in photonic-based microwave waveform generators [5].

Several strategies to perform the differentiation operation are summarized below, taking into consideration the frequency range and operational bandwidth. An elementary differentiator circuit proposed for analog electronics consists of an *RC* network in conjunction with an operational amplifier, where the current flowing through the capacitor is proportional to the derivative of the voltage across the capacitor [6]. The use of an operational amplifier in the design leads to the fact that this solution is restricted to low-frequency signals. Higher frequencies of operation have been achieved using digital techniques. For instance, a second-order recursive digital differentiator was obtained by inverting the transfer functions of integrators and stabilizing them [7]. Furthermore, a closed-form method for the design of higher order digital differentiators using an Eigen filter approach was proposed [8]. Although a good performance has been obtained, digital differentiators are, in general, limited by the operational frequency and bandwidth, which results from the maximum achievable sampling frequency.

A wider bandwidth solution can be achieved by using optical devices. A relevant number of studies have been presented to perform differentiation of signals in the optical domain, where integrated-optic transversal filter topologies [9], concatenated bulk-optics interferometers [10], and all-fiber approaches based on fiber gratings [11]–[13] must be remarked. An important body of recent work concerns the specific use of photonic technologies for differentiation of microwave waveforms [14]–[16]. Photonic components offer broadband operation; however, their integration with microwave devices remains troublesome.

Finally, all-microwave techniques to design differentiators will also be surveyed here. A basic first-order differentiator for a limited bandwidth has been proposed in simulation by Tsai and Jeng in [18] applying a transmission-line approach to approximate differentiation operation. An approximated solution in the -domain was also developed by Hsue *et al.* in [19] to implement first- and second-order differentiators, whose transfer functions are emulated using shunt stubs combined with serial lines. Recently, Nguyen and Caloz designed first- and second- order microwave differentiators using the time-derivative effect of directional coupled-line couplers, which is constrained by the trade-off between the duration of the input pulse and the target coupler central frequency [20].

A particularly interesting application for microwave differentiators is their use in signal processing and pulse generation for ultra-wideband (UWB) systems [21]–[24]. UWB is a radio technology approved by the Federal Communications Commission (FCC) for unlicensed operation in the frequency range from 3.1 to 10.6 GHz for signals with power spectral density below 41.2 dBm/MHz [25]. Numerous applications have been targeted for UWB technology, including high data-rate wireless communication [26], [27], homeland security [28], and specialized radar imaging [29], [30]. UWB pulse generators based on differentiation operation can be, in general, divided into static and dynamic devices. A static pulse generation aims at obtaining the fixed pulse shapes that optimally fit the FCC mask [31], [32], while dynamic systems offer real-time adaptation to different spectral specifications by overlapping successive derivatives of an input pulse [18].

The design procedure for differentiators as shown in flow chart figure 1.1 involves first obtaining a multivariable system function prototype and then optimizing its transfer function with reference to ideal, to obtain the wideband stable differentiators.

In this project, simple and accurate formulations are employed to represent stable and optimized discrete-time infinite impulse response processes for first and higher order differentiator in the Z-domain. These formulations, in conjunction with the representations of transmission-line elements in the Z-domain, leads to transmission-line configuration that are eligible for wide-band microwave circuits. In particular, many Z domain formats of transfer functions have been obtained to represent the characteristics of a differentiator.

The transmission line configuration can emulate the characteristics of the differentiator developed in a DSP study, meanwhile the operating frequency band of a differentiator is, thus, extended further into the microwave range. Both first and second order differentiators are implemented with microstrip transmission lines, of which the operating frequency is determined by the physical length of each line section. It is, therefore, plausible to design differentiators having operating frequencies around 10 GHz.

Computers are powerful tools for the microwave designers in performing arduous and error-prone calculations. Computers can be used as a tool to design many circuits and components faster and cheaper than conventional methods. The designed models are implemented using non-uniform microstrip lines in Agilent ADS[1] and Agilent EMPro. Simulation results shows proposed models as good candidate for wide band microwave application.

The theory required for the design and implementation of the Microwave differentiator has been gathered from IEEE journals, relevant books[2], and internet. This report describes the design simulation and implementation of 1st and 2nd order microwave differentiator using microstrip transmission line.

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 obtained their strategy and getting a good result as required. The figure 1.1 depicts the design flow strategies used for obtaining optimized microwave differentiator circuits from discrete-time system function prototype. And project writing will start when we meet all design specification as required after fabrication of all microwave differentiator.

[1]qthelp://ads.2011.10.app/doc/examples/S-Parameters_of_2-Port_Terminated_with_Other_Networks.html
[2]M. Radmanesh, Radio Frequency and Microwave Electronics, Prentice Hall, 2001
[2]Gupta, K. C., et al. (1981). Computer-Aided Design of Microwave Circuits, Artech.
[2]qthelp://ads.2011.10.app/doc/examples/S-Parameters_of_2-Port_Terminated_with_Other_Networks.html

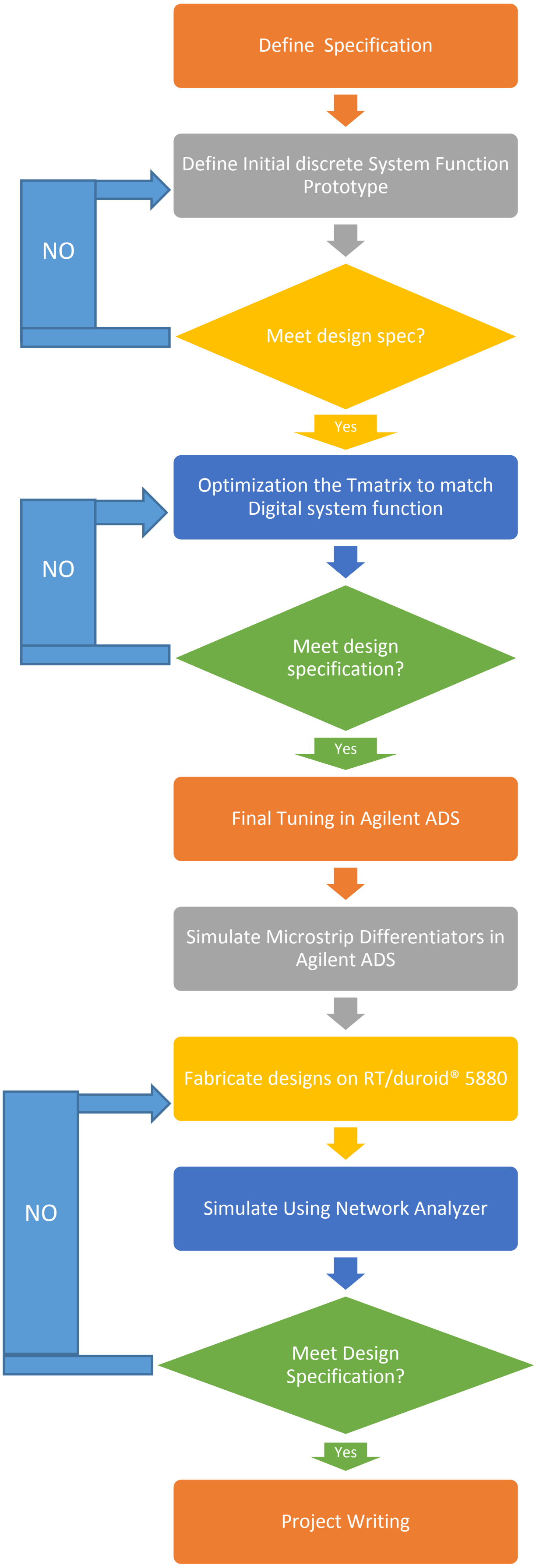

Figure.1.1: Flow chart of designing process for microwave differentiators

1.3 Motivation and Problem Statement

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

1.4 Goals/Scope of present work

The main goals of this project are to get acquainted with microwave circuit designing using tool like Agilent Advanced Design System and EMPro software and the basics of DSP techniques. The present work consists of designing of 1^{st} and higher order microwave differentiator using microstrip transmission line technology. The scope of this project lies on designing and implementation of other microwave device components like differentiator awith different time constant and microwave filters etc.

The next section describes the organization of chapters in the thesis.

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. Here detail formulation of transfer function in Z-domain has been given which will be used in the rest of the thesis. In particular, many Z domain formats of the stable and optimized transfer functions have been obtained to represent the characteristics of a differentiator. The chain scattering parameter or T-parameter for serial transmission line, short stub and open stub are derived.

Chapter 3: The detailed designing of stable and optimized digital differentiator system functions have been explained in this chapter. Here, the basic equations governing differentiators are derived. The designed system function is analysed in software tool like Agilent SystemVue. Implementation of direct form I and direct form II using MATLAB are realised.

Chapter 4: Illustrates the thorough designing of First order microwave differentiators. Upon using the system functions designed in Chapter 3 corresponding microstrip line configuration is obtained and optimized to derive the characteristic impedance of microstrip sections. Software Simulation performed in Agilent ADS followed by exporting the designed prototype model to Agilent EMPro. Finally, Plotting of magnitude response of final tuned differentiator are presented.

Chapter 5: Describes the designing methodology of second order microwave differentiators. Based on the second order digital differentiators obtained in Chapter 3 the designing of optimized microwave differentiators are presented. The designed integrator models are also analysed in Agilent EMPro. Lastly, magnitude response of designed integrators are presented.

Chapter 6: The detail fabrication process is illustrate here and fabrication of first and second order microwave differentiator with four design is done. All four design are fabricated on RT/duroid® 5880 substrate and final fabricated device meeting all specification is added into the report.

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

Chapter 2

Literature Review

2.1 Introduction

This chapter reviews several basic but important concepts that are necessary to comprehend the contents of this report. Here general formulation of transfer function in Z domain and at microwave frequency in terms of T-parameter (chain scattering) is discussed and equations are formed to link both techniques. The concept of time constant for differentiator and integrator is introduced.

2.2 Formulation of the Transfer Function in the Z domain

A DSP system (digital differentiator) can be defined with sets of recursive difference equations of the form (2.1)

$$y[n] = a_0 x[n] + a_1 x[n-1] + ... + a_{M-1} x[n-(M-1)] - b_1 y[n-1] + b_2 y[n-2] - ... - b_N y[n-N] \quad 2.1$$

Where, $x(n)$ is the digital input and $y(n)$ is the digital output of the filter. The parameters specify $H(z)$, the Z-transform of an impulse response $h(n)$. The output of IIR is the convolution of the input $x(n)$ with $h(n)$.

The system function for linear, time-invariant, causal digital filter can be expressed in the Z-domain in the form [9]:

$$H(z) = \frac{\mathrm{B(z)}}{A(z)} = \frac{\sum_{i=0}^{N} b_i z^{-i}}{1 + \sum_{j=1}^{N} a_j z^{-j}} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + \ldots + b_N z^{-N}}{1 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_M z^{-N}} = K \frac{\prod_{i=1}^{N} (z - z_i)}{\prod_{i=1}^{N} (z - p_i)} \quad 2.2$$

The coefficients of the polynomial are a_i and b_i. The zeros and poles of the factored form are z_i and p_i, respectively. The gain factor K is necessary for equivalence between the polynomial and factored forms. The order of H(z) is determined by N.

Not all filters defined by H(z) are feasible or implementable. Two properties of H(z) of concern to this thesis are

- A causal, linear, time invariant (LTI) system with system function $H(z)$ is bounded input bounded output (BIBO) stable if and only if all the poles of H(z) lie inside the unit circle.($|p_i| < 1$)

- A causal, stable, LTI system with system function $H(z)$ is real if and only if all complex poles and zeros of H(z) have complex conjugate pairs or exist singularly on the real axis.

These properties should be enforced during the design and optimization process of an IIR filter. For optimize digital IIR filters, a method for mapping a filter transfer function $H_n(z)$ to an element x_n is needed. Two straightforward methods for doing this include mapping either the coefficients of the polynomial form of $H_n(z)$ or the roots and gain of the factored form of $H_n(z)$ to the vectors of x_n. While both of these options are mathematically equivalent, polynomial coefficients b_i and a_i can have several orders of magnitude of dynamic range necessitating a very large search space S. However, this is not the case for the factored version, there by prompting its selection. Filter stability requires that all poles p_i of $H_n(z)$ are inside the unit circle, thus, limiting the search space S for p_i . Placement of the zeros z_i, although not dictated by stability, can be restricted to the same region by imposing a minimum-phase requirement. Minimum-phase is accomplished by having all poles and zeros of $H_n(z)$ inside the unit circle. This has the drawback of greatly restricting the possible phase response that can be achieved by the optimization algorithm, but this does not matter here since magnitude response is the only factor of optimization considered in this thesis.

Several design algorithms exist for finite-impulse-response (FIR) filters that enable relatively simple use of the filters in common practice. For example, the frequency weighted least squares (FWLS) technique enables an FIR filter of a given order to be designed according to a desired frequency response [10]. The resulting design equation has a closed form solution resulting in a very fast, accurate, and precise result. The design of infinite-impulse-response (IIR) filters, on the other hand, has shown to be more difficult. IIR filters are often preferred to FIR filters because of excellent magnitude response characteristics, especially when high attenuation or sharp transition bands are desired [11]. IIR filters typically meet a given set of specifications with a much lower filter order than a corresponding FIR filter and preserves impulse response and shape of frequency response, if there is no aliasing. The final digital filter design is independent of the sampling interval parameter T. The digital IIR filter design task can be approached like any other optimization problem.

2.2.1 Discrete-Time Differentiator

It is well known that the operation of a time derivative of a signal is represented by a complex-frequency variable *s*in the Laplace transform representation. Neglecting the loss factor, the complex-frequency variable s is equal to $j\omega$, i.e. $s = j\omega$, where is the signal angular frequency. As a result, a differentiator is a high-pass filter and the amplitude of its system function increases linearly as the signal frequency increases.

The frequency response of an ideal differentiator is given by

$$H_{\mathrm{Diff}}(\omega)=K_{\mathrm{d}}(j\omega) \qquad 2.3$$

Where,$j = \sqrt{-1}$, K_d is the proportional constant of differentiator and ω is the angular frequency in radians.

Various methods had been developed to design discrete finite impulsive response (FIR) and infinite impulsive response (IIR) differentiators [12]–[16]. Al-Alaoui [6] used Simpson's rule to develop a stable second-order recursive differentiator. Al-Alaoui [12] used interpolation method to develop a stable, minimum-phase digital differentiator. Pei and Shyu [15] used the Eigen approach to design high order digital differentiators. In order to obtain low relative error, Kumar and Ohba [16] employed optimal method to develop digital differentiators which are maximally accurate at low frequencies. In order to develop a wide-band differentiator, Khan and Ohba [8] employed the central difference approximations of the derivative of a function to obtain a maximally linear differentiator. An important aspect of the previous investigation is that the exploration focused on the improvement of linearity over a wide frequency band.

2.3 Formulation of the Transfer Function in terms of T-Parameter

The S matrix is a very convenient way to describe an n-port in terms of waves. It is very well adapted to measurements and simulations[3]. However, it is not well suited to for characterizing the response of a number of cascaded 2-ports. A very straightforward manner for the problem is possible with the T matrix (transfer matrix), which directly relates the waves on the input and on the output.

[3]www.microwaves101.com/encyclopedia/sparameters.cfm

The transfer function of a cascaded network can be found by multiplying the chain scattering matrices of the components composing the network. The chain scattering parameters T_{mn},*m*, *n* = 1,2 of a two-port network are defined by assuming the waves V_1^+ and V_2^-at port 1 in Fig. 2.1 are dependent variables, and the waves and at port 2 are independent variables. The T matrix (transfer matrix), which directly relates the waves on the input and on the output, is defined as:

$$\begin{bmatrix} V_1^+ \\ V_1^- \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} V_2^+ \\ V_2^- \end{bmatrix} \qquad 2.4$$

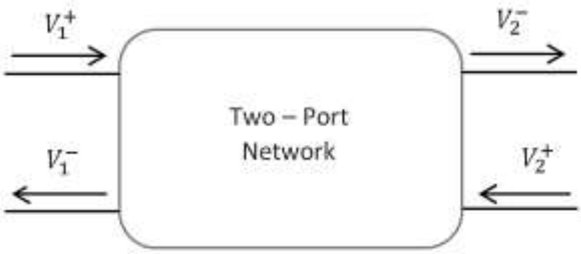

Figure.2.1. Two-port network

As the transmission matrix (T matrix) simply links the input and outgoing waves in a way different from the S matrix, one may convert the matrix elements mutually. The chain scattering matrix can be found from the scattering matrix in the following way:

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} \frac{1}{S_{21}} & -\frac{S_{22}}{S_{21}} \\ \frac{S_{11}}{S_{21}} & S_{21} - \frac{S_{11}S_{22}}{S_{21}} \end{bmatrix} \qquad 2.5$$

Let the length of all stubs and transmission-line sections be $l = \lambda_o/4$, where λo is the wavelength of the lines at the normalizing angular frequency ω_o. In other words, the electrical length of all components is 90^o at the normalizing frequency.

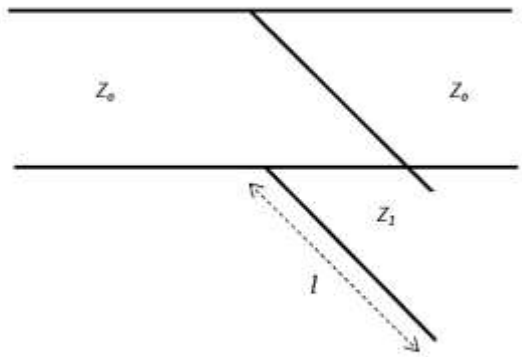

Figure.2.2 Open-circuited stub

Given the impedance of an open-circuited stub to be Z_1, shown in Fig. 2.2, we find that its chain scattering parameters are as follows:

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}_{O.C.} = \begin{bmatrix} 1+j\dfrac{Z_0}{2Z_1}\tan(\beta l) & j\dfrac{Z_0}{2Z_1}\tan(\beta l) \\ -j\dfrac{Z_0}{2Z_1}\tan(\beta l) & 1-j\dfrac{Z_0}{2Z_1}\tan(\beta l) \end{bmatrix} \quad 2.6$$

Where, Z_o is the reference characteristic impedance and is the propagation constant. The reference planes for both ports are at the intersection of the stub and the reference transmission line.

Let ω be the angular frequency and be the propagation delay caused by the length. All the terms $j\tan(\beta l) = j\tan(\omega\tau)$can be represented in a new form by using $D^{-1} = e^{-j\omega\tau}$, which can be considered as a unit of delay, i.e.

$$j\tan(\omega\tau) = \frac{e^{j\omega\tau} - e^{-j\omega\tau}}{e^{j\omega\tau} + e^{-j\omega\tau}} = \frac{D - D^{-1}}{D - D^{-1}} \quad 2.7$$

Consequently, we have

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}_{O.C.} = \frac{1}{1+D^{-2}}\begin{bmatrix} (1+a)+(1-a)D^{-2} & a-aD^{-2} \\ -a+aD^{-2} & (1-a)+(1+a)D^{-2} \end{bmatrix} \quad 2.8$$

Where, $a = Z_o/2Z_1$

If the stub is short circuited, its chain scattering parameters can be expressed as follows:

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}_{S.C.} = \frac{1}{1-D^{-2}}\begin{bmatrix} (1+a)-(1-a)D^{-2} & a+aD^{-2} \\ -a-aD^{-2} & (1-a)-(1+a)D^{-2} \end{bmatrix} \quad 2.9$$

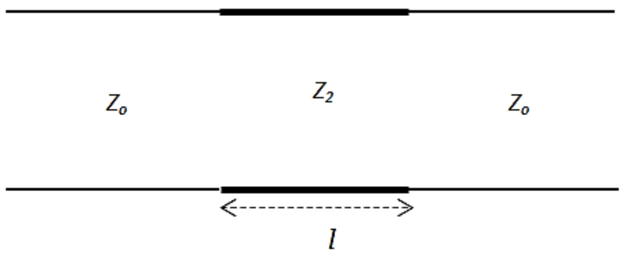

Figure.2.3. Transmission-line section

By the same token, the chain scattering parameters of a transmission line section with impedance Z_2, shown in Fig. 2.3, can be converted to functions in the Z domain as follows:

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}_{T.L.S.} = \frac{1}{D^{-1}(1-\Gamma^2)} \begin{bmatrix} 1-\Gamma^2 D^{-2} & -(\Gamma-\Gamma D^{-2}) \\ \Gamma-\Gamma D^{-2} & -\Gamma^2+D^{-2} \end{bmatrix} \qquad 2.10$$

where, $\Gamma_m = \dfrac{Z_2 - Z_1}{Z_2 + Z_1}$. The reference planes for both ports are at two connecting points between Z_2 and Z_0.

By cascading open-circuited/short-circuited stubs and transmission line sections to form a network, the overall chain scattering matrix of the network can be found by the multiplications of the chain scattering matrix of each component, i.e.,

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}_{Network} = \prod_{i=1}^{N} \begin{bmatrix} T_{11}^{i} & T_{12}^{i} \\ T_{21}^{i} & T_{22}^{i} \end{bmatrix} \qquad 2.11$$

Where, N is the number of the components, andT_{11}^{i},T_{12}^{i} ,T_{21}^{i}, $T_{22}^{i}$and are the matrix elements representing the i_{th} component.

Assume the network is composed of K open-circuited stubs, L short-circuited stubs, and M transmission-line sections. The fact that the numerators of all the matrix elements in (2.7) - (2.9) have the form of $\alpha_o + \alpha_1 D^{-2}$($\alpha_o$ and $\alpha_1$are real numbers) leads to the following:

$$T_{11}(D) = \frac{\sum_{i=0}^{N} \alpha_i D^{-2i}}{\prod_{k=1}^{K}(1+D^{-2}) \prod_{l=1}^{L}(1-D^{-2}) \prod_{m=1}^{M}(D^{-1}(1-\Gamma_m^2))} \qquad 2.12$$

Where all α_i's are real numbers and can be determined by the characteristic impedances of both stubs and transmission-line sections. In addition, the term ($1 + D^{-2}$) comes from each open circuited stub, the term ($1 - D^{-2}$) comes from each short-circuited stub, and $D^{-1}(1 + \Gamma_m^2)$ comes from the m_{th} transmission- line section.

When the output port of the network uses matched termination, we have $V_2^+ = 0$ in Fig. 1. The transfer function, denoted as $T(D)$, can then be obtained by the inverse of $T_{11}(D)$, i.e.,

$$T(D) = \left.\frac{V_2^-}{V_1^+}\right|_{V_2^+=0} = \frac{1}{T_{11}(D)} = \frac{\prod_{k=1}^{K}(1+D^{-2})\prod_{l=1}^{L}(1-D^{-2})\prod_{m=1}^{M}(D^{-1}(1-\Gamma_m^2))}{\sum_{i=0}^{N}\alpha_i D^{-2i}} \qquad 2.13$$

To make (2.13) in a form proper for the design purpose, we set $z = D^{-2}$, which corresponds a scaling by two on the frequency axis. The transfer function is then modified as follows:

$$T(z) = T(D)\big|_{z=D^2} = \frac{z^{-M/2}\prod_{k=1}^{K}(1+z^{-1})\prod_{l=1}^{L}(1-z^{-1})}{\sum_{i=0}^{N}A_i z^{-i}} \qquad 2.14$$

Where, $A_i = \dfrac{\alpha_i}{\prod_{m=1}^{M}(D^{-1}(1-\Gamma_m^2))}$ are functions of the characteristic impedances of both stubs and transmission-line sections. Equation (2.14) reveals that T(z) has zeros at z = -1 (or the normalizing frequency ω_o), which are contributed by the open-circuited stubs, and zeros at dc, which are contributed by the short-circuited stubs. If the zeros contributed from the stubs are removed from $T(z)$, the remaining part of the transfer function is recognized as an AR process multiplied by a term of $z^{-M/2}$ corresponding to some delay. We express the AR process with the function and we get

$$T_{AR}(z) = \frac{1}{\sum_{i=0}^{N}A_i z^{-i}} \qquad 2.15$$

Since the frequency response of the AR process is uniquely determined by the coefficients A_i and these coefficients are determined by the characteristic impedances of both stubs and transmission-line sections, we could adjust the impedances of these components so that $T_{AR}(z)$ approximates a proposed AR process.

Transmission line Configuration	T- parameter
Serial Transmission line	$\frac{1}{z^{-1/2}(1-\Gamma^2)}\begin{bmatrix} 1-\Gamma^2 z^{-1} & -(\Gamma-\Gamma z^{-1}) \\ \Gamma-\Gamma z^{-1} & -\Gamma^2+z^{-1} \end{bmatrix}$ where, $\Gamma_m = \frac{Z_2-Z_1}{Z_2+Z_1}$
Shunt-Short stub	$\frac{1}{1-z^{-1}}\begin{bmatrix} (1+a)-(1-a)z^{-1} & a+az^{-1}) \\ -a-az^{-1} & (1-a)-(1+a)z^{-1} \end{bmatrix}$ where, $a = \frac{Z_0}{2Z_1}$
Shunt-Open stub	$\frac{1}{1+z^{-1}}\begin{bmatrix} (1+a)+(1-a)z^{-1} & a-az^{-1}) \\ -a+az^{-1} & (1-a)+(1+a)z^{-1} \end{bmatrix}$ where, $a = \frac{Z_0}{2Z_1}$

Table I: Basic Transmission-Line Element's Chain Scattering-Parameter Matrices

Chapter 3

Designing of Discrete Time Differentiators

3.1 Introduction

The focus of this chapter is the designing of digital differentiator. Here, the basic equations governing differentiators. The designed system function is analysed in software tool like Agilent Advanced Design System. Implementation of direct form I and direct form II using MATLAB are realised.

A digital IIR filter can be defined with sets of recursive difference equations of the form

$$y[n] = a_0 x[n] + a_1 x[n-1] + ... + a_{M-1} x[n-(M-1)] - b_1 y[n-1] + b_2 y[n-2] - ... - b_N y[n-N] \quad 3.1$$

Where x[n] is the digital input and y[n] is the digital output of the filter. The parameters specify *H(z)*, the Z-transform of an impulse response *h(n)*. The output of IIR is the convolution of the input with *h(n)*.

The system function for linear, time-invariant, causal digital filter can be expressed in the Z-domain in the form:

$$H(z) = \frac{\mathrm{B}(z)}{A(z)} = \frac{\sum_{i=0}^{N} b_i z^{-i}}{1 + \sum_{j=1}^{N} a_j z^{-j}} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + \ldots + b_N z^{-N}}{1 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_M z^{-N}} = K \frac{\prod_{i=1}^{N} (z - z_i)}{\prod_{i=1}^{N} (z - p_i)}$$

3.2

The coefficients of the polynomial are a_i and b_i. The zeros and poles of the factored form are z_i and p_i, respectively.

For optimization of the discrete time system function prototype, an error function is defined as:

$$Err = Min \left[\int_0^{\pi} (H_{Ideal}(z) - H_{New}(z))^2 d\Omega \right] \quad 3.3$$

Error function is basically an objective function for optimization algorithm, which is calculated by integrating the error between ideal response and proposed system function response. Sampling period 'T' of the filter is normalised to unity (i.e. T = 1) for the frequency plots and Nyquist frequency is taken as π radians. The integration is performed over normalized frequency (frequency vector) Ω over the range of 0 to π.

3.2 Implementation Direct form realization of digital differentiator:

The filter (differentiator) obtained can be realised in either the direct form I or direct form II. We prefer to realize a circuit that would require a minimum number of unit delays that is equal to the order of the filter. A realization that contains the minimum number of delays is defined as canonical realization.

Filter Realizations

Once we have obtained the transfer function of an FIR or IIR filter that approximates the desired specifications in the frequency domain or the time domain, our next step is to investigate as many filter structures as possible, before we decide on the optimal or suboptimal algorithm for actual implementation or application. A given transfer function can be realized by several structures or what we will call “circuits,” and they are all equivalent in the sense that they realize the same transfer function under the assumption that the coefficients of the transfer function have infinite precision. But in reality, the algorithms for implementing the transfer function in hardware depend on the filter structure chosen to realize the transfer function. We must also remember that the real hardware has a finite number of bits representing the coefficients of the filter as well as the values of the input signal at the input. The internal signals at the input of multipliers and the signals at the output of the multipliers and adders also are represented by a finite number of bits. The effect of rounding or truncation in the addition and multiplications of signal values depends on, for example, the type of representation of binary numbers, whether they are in fixed form or floating form, or whether they are in sign magnitude or two-complementary form. The effects of all these finite values for the number of bits used in hardware implementation is commonly called “finite word length effects,”

It is true that a real hardware can be programmed to implement a large number of algorithms, by storing the data that represent the input signals and coefficients of the filter in a memory. But remember that it can implement an algorithm only in the time domain, whereas programming it to find the frequency response is only a simulation. Three algorithms in the time domain that are the recursive algorithm, convolution sum, and the

FFT algorithm. It is the difference equations describing these algorithms that have to be implemented by real digital hardware.[30]

But when the two algorithms have to be programmed and implemented by hardware devices, the results would be very different and the accuracy of the resulting output, the speed of the execution, and the throughput, and other factors would depend not only on the finite word length but also on so many other factors, including the architecture of the DSP chip, program instructions per cycle, and dynamic range of the input signal.

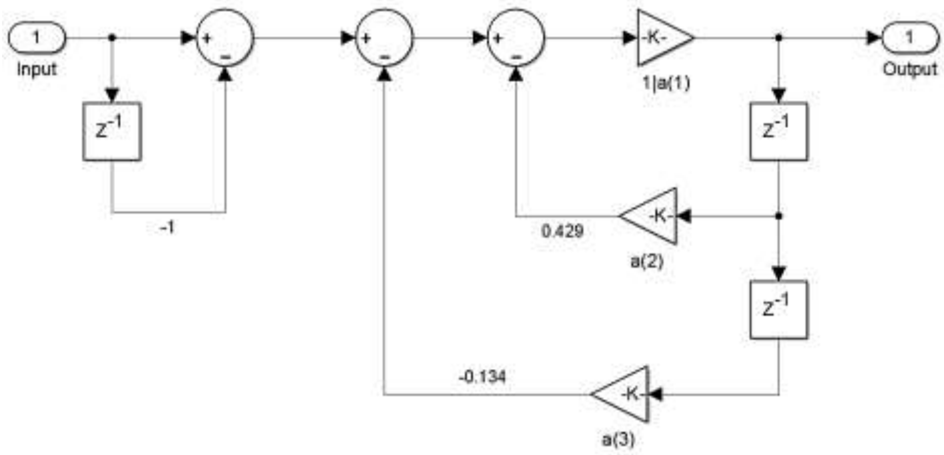

Figure.3.1 Direct form 1 realization of digital differentiator by MATLAB

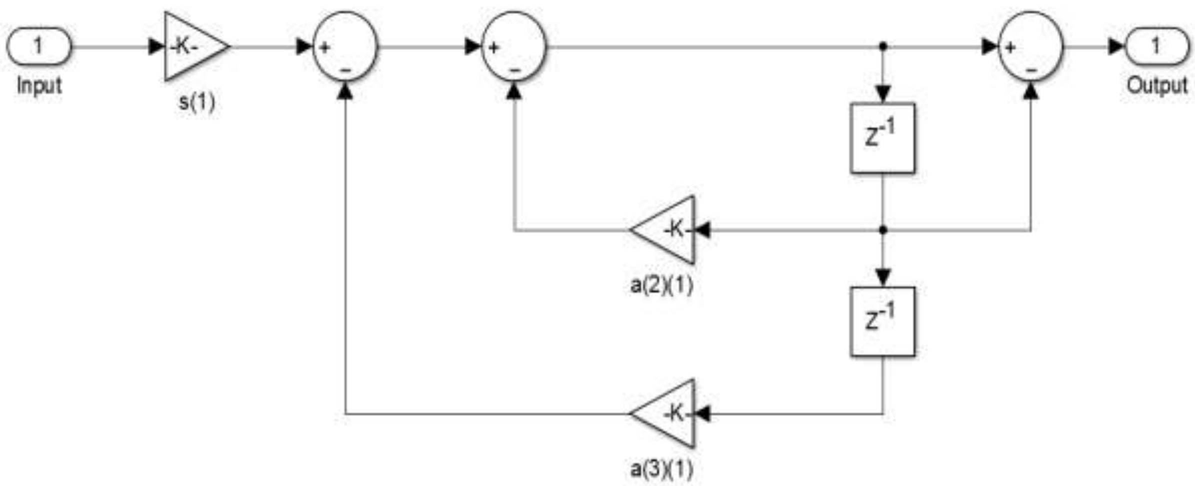

Figure.3.2 Direct form II realization of digital differentiator by MATLAB

The above differentiator can be implemented on hardware but there is practical limitation of these circuits. In order to make differentiator to work in microwave frequency.Microstrip is suitable candidate for these frequency applications.

3.3 First Order Microwave Differentiator

For designing a differentiator that have the operating frequencies up to 10GHz using microstrip configuration, a network consist of a short stub and a serial transmission lines is used. It has been shown (Table 1) that zero occurring on the unit circle $|z| = 1$ can be implemented by using shunted transmission-line elements. It is well known that the operation of a time derivative of a signal is represented by a complex-frequency variable in the Laplace transform representation. Neglecting the loss factor, the complex-frequency variable is equal to $j\omega$, i.e. $s = j\omega$ where is the signal angular frequency. As a result, a differentiator is a high-pass filter and the amplitude of its system function increases linearly as the signal frequency increases. We consider a transformation relating the complex-frequency variable s and the discrete-time variable z in the z-domain as follows

$$s = \frac{2(1-z^{-1})}{T(1+dz^{-1})} \qquad 3.4$$

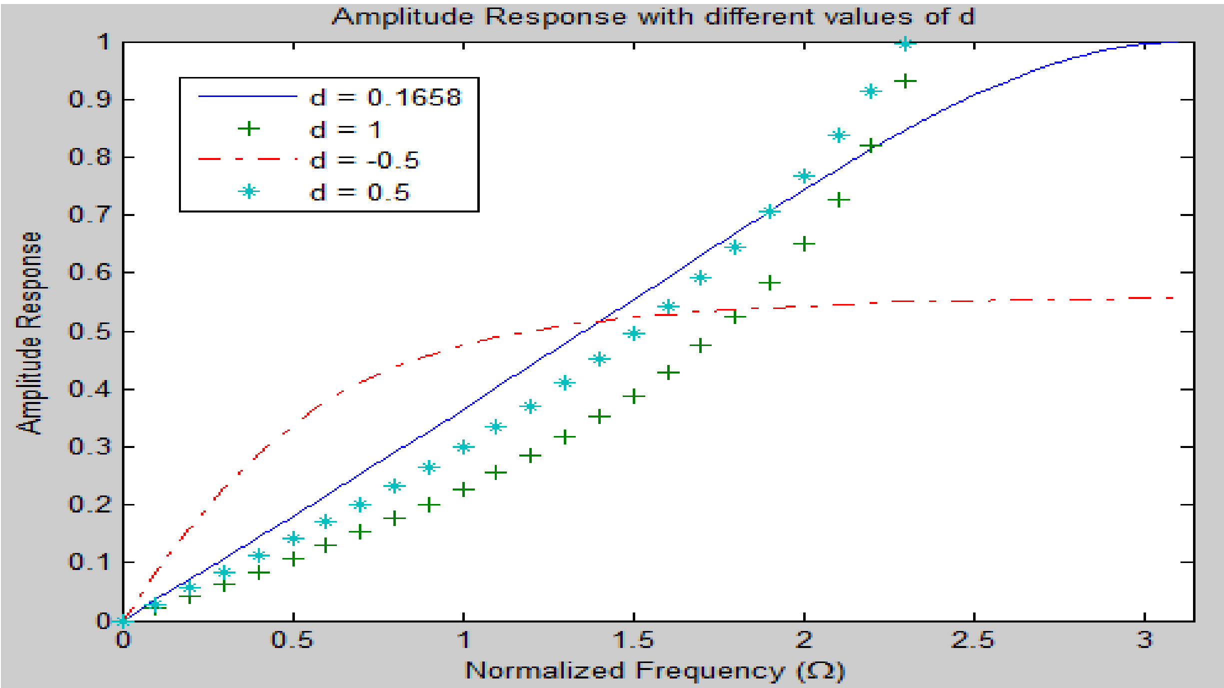

Figure.3.3: MATLAB amplitude response for different value to d

Where T is a normalization constant, d is a real constant, and z^{-1} represents a unit of time delay. Physically, T is the sampling time interval in the DSP study. If d is set equal to one, the transformation in (1) is called a bilinear transformation, which is widely used in converting analog prototypes to discrete-time prototypes [10]. When the frequency response of the differentiator is concerned, the parameter z in (3.4) is replaced with the following relation:

$$z = e^{j\Omega} \qquad 3.5$$

Where Ω is the frequency angle. The value of d strongly affects the linearity of the transformation. Apparently, the transformation in (3.4) has a good linearity in amplitude response when is d set equal to 0.1658. The value of 0.417 is selected to assume that the maximum value of s in (3.4) is unity for the entire frequencies when d=.1658. The bilinear transformation is improper to be adopted as the system function of a wide-band differentiator. We therefore, adopt (3.4) as the system function of the differentiator in a discrete-time IIR format and the selected system function of the first-order differentiator is

$$G(z) = \frac{0.417(1-z^{-1})}{(1+.1658z^{-1})} \qquad 3.6$$

If we implement a circuit with the system function shown in (3.6), the differentiator is accurate for the operating frequency up to 0.8 of the normalizing frequency. With a finite error tolerance, such a differentiator has a wider operating frequency bandwidth than those previously reported [7]. In particular, the concise mathematical expression will lead to a simple circuit configuration of the differentiator.

For a two-port network shown in Fig. 2.1, the chain-scattering parameters (or T-parameters) T_{mn} (*m*,*n* =1,2) of a two-port network are defined as follows

$$\begin{bmatrix} V_1^+ \\ V_1^- \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} V_2^+ \\ V_2^- \end{bmatrix} \qquad 3.7$$

Where V_1^+ and $V_1^-$are, respectively, the incident and reflected waves at port 1, and $V_2^+$and $V_2^-$are, respectively, the incident wave and the reflected wave at port 2. In Fig. 3, $V_1^+$and $V_1^-$are dependent variables, while $V_2^+$and $V_2^+$are independent variables. Table I shows the matrices for two transmission-line configurations [8], [9], namely, the serial transmission line and shunt-short stub in the Z -domain, where β_i (*i*=*a*,*b*), l_i ,and Z_i are the propagation constant, physical length, and characteristic impedance, respectively. Note that is the reference characteristic impedance, which is assumed to be 50 Ω, unless otherwise mentioned.

It is assumed that all finite lines have the same electrical length, i.e., , $\beta_a l_a = \beta_b l_b = \omega\tau$ where τ is the propagation delay time of finite lines. To obtain the *T* matrices in the *Z*-domain, we set

$$z^{-1} = e^{-2j\beta_i l_i} \quad 3.8$$

From above, If the output port of a shunt-short stub is loaded with a matched termination (i.e., $V_2^- = 0$), the transfer function T(z) of the shunt-short stub is given by $1/T_{11}$ (z), denoted as $S_{21}(z)$. From Table I, we obtain

$$T_{11}(D) = \frac{\sum_{i=0}^{N} \alpha_i D^{-2i}}{\prod_{k=1}^{K}(1+D^{-2})\prod_{l=1}^{L}(1-D^{-2})\prod_{m=1}^{M}(D^{-1}(1-\Gamma_m^2))} \quad 3.9$$

We can write it as,

$$S_{21}(\mathrm{z}) = T(D) = \left.\frac{V_2^-}{V_1^+}\right|_{V_2^+=0} = \frac{1}{T_{11}(D)} = \frac{\prod_{k=1}^{K}(1+D^{-2})\prod_{l=1}^{L}(1-D^{-2})\prod_{m=1}^{M}(D^{-1}(1-\Gamma_m^2))}{\sum_{i=0}^{N} \alpha_i D^{-2i}} \quad 3.10$$

To make (3.10) in a proper form for the design purpose, we set $z = D^{-2}$, which corresponds a scaling by two on the frequency axis. The transfer function is then modified as follows:

$$S_{21}(\mathrm{z}) = T(z) = \left.T(D)\right|_{z=D^2} = \frac{z^{-M/2}\prod_{k=1}^{K}(1+z^{-1})\prod_{l=1}^{L}(1-z^{-1})}{\sum_{i=0}^{N} A_i z^{-i}} \quad 3.11$$

Where, $A_i = \frac{\alpha_i}{\prod_{m=1}^{M}(D^{-1}(1-\Gamma_m^2))}$ are functions of the characteristic impedances of both stubs

and transmission-line section. If we set$S_{21}(z)$ to approximate the system function $G(z)$in (3.6) and neglect the propagation delay factor, we obtain

$$\frac{0.417(1-\mathrm{z}^{-1})}{(1+.1658\,\mathrm{z}^{-1})} \approx \frac{\prod_{l=1}^{L}(1-\mathrm{z}^{-1})}{\sum_{i=0}^{N} A_i z^{-i}} \quad 3.12$$

If we divide with $(1 - z^{-1})^L$, we get

$$\frac{0.417(1-z^{-1})}{(1+.1658z^{-1})(1-z^{-1})^{L-1}} \approx \frac{1}{\sum_{i=0}^{N} A_i z^{-i}} \qquad 3.13$$

Now the remaining task is to calculate the coefficient of the question and it is used to microstrip line characteristics impedance and dimension of microstrip line.

3.4 Second Order Microwave Differentiator

For a second-order differentiator, the system function $H(z)$ is obtained by squaring $G(z)$ and it is given by,

$$H(z) = \left[\frac{0.417(1-z^{-1})}{(1+.1658z^{-1})}\right]^2 \qquad 3.14$$

After defining the discrete-time system functions, the remaining task is to implement second-order differentiators with equal electric-length transmission lines. In other words, we synthesize the transmission-line circuits.

As,

$$S_{21}(z) = T(z) = T(D)\big|_{z=D^2} = \frac{z^{-M/2}\prod_{k=1}^{K}(1+z^{-1})\prod_{l=1}^{L}(1-z^{-1})}{\sum_{i=0}^{N} A_i z^{-i}} \qquad 3.15$$

Where, $A_i = \dfrac{\alpha_i}{\prod_{m=1}^{M}(D^{-1}(1-\Gamma_m^2))}$ are functions of the characteristic impedances of both stubs and transmission-line sections. If we set $S_{21}(z)$ to approximate the system function $H(z)$ in (3.14) and neglect the propagation delay factor, we obtain

$$\left[\frac{0.417(1-z^{-1})}{(1+.1658z^{-1})}\right]^2 \approx \frac{\prod_{l=1}^{L}\left(1-z^{-1}\right)}{\sum_{i=0}^{N} A_i z^{-i}} \qquad 3.16$$

If we divide with $(1 - z^{-1})^L$, we get

$$\left[\frac{0.417}{(1+.1658z^{-1})(1-z^{-1})^{L-2}}\right]^2 \approx \frac{1}{\sum_{i=0}^{N} A_i z^{-i}} \qquad 3.17$$

The next step is to compare the coefficients of denominators on both sides of (3.17) so that is as close to as possible. Notice that in (3.17) is determined by the characteristic impedances of all transmission lines. Upon comparing and tuning using ADS Tool, the coefficients of the denominators in (3.17), we obtain the characteristic impedances of transmission lines.

To implement a differentiator with transmission lines, the electrical length of each transmission-line section is set equal to 90 at the normalizing frequency.We have $l = \lambda_0/4$,where l represents the physical length of each transmission-line section and λ_0 is the wavelength at the normalizing frequency.

Chapter 4

Design of First order Microwave Differentiators

4.1 Introduction

In this chapter design methodology of microwave differentiator is discussed. Based on the digital differentiator transfer functions obtained in Chapter 3 the designing of optimized microwave differentiators are presented. Here, two different differentiator models with different time constant have been designed. In particular, the time constant is proposed to characterize the performance of the differentiator and it serves as an important factor that determines the magnitude response of a differentiator. The designed differentiator models are also analysed in Agilent EMPro software tool. Lastly, performance characteristic such as magnitude response of designed differentiator are presented.

4.2First Order Microwave Differentiator

For designing a differentiator that have the operating frequencies up to 10GHz using microstrip configuration, a network consist of a short stub and a serial transmission lines is used. It has been shown (Table 1) that zero occurring on the unit circle $|z| = 1$ can be implemented by using shunted transmission-line elements. The number of sections and configuration of microstrip is determined by the optimization process that involves the curve fitting of transfer function of transmission line to the amplitude response of the digital differentiator which represents a good approximation of an ideal differentiator in Z-domain. As, Transfer function for a network with L short circuit stub and M series transmission line is given by,

$$S_{21} = \frac{(1-z^{-1})^{L}\prod_{m=1}^{M}(1-\Gamma_m^2)}{\prod_{l=1}^{L}\left[(1+a)-(1-a)z^{-1}\right]\left[\prod_{m=1}^{M}1-\Gamma_m^2 z^{-1}\right]} \qquad 4.1$$

For single short circuit transmission line,

$$S_{21} = \frac{(1-\Gamma^2)(1-z^{-1})}{((1+a)-(1-a)z^{-1})(1-\Gamma^2 z^{-1})} \qquad 4.2$$

$$S_{21} = \frac{(1-\Gamma^2)(1-z^{-1})}{(1+a)-[(1+a)\Gamma^2+(1-a)]z^{-1}+(1-a)\Gamma^2 z^{-2}} \qquad 4.3$$

Where $\Gamma = \frac{Z_a - Z_0}{Z_a + Z_0}$ and $a = \frac{Z_0}{2Z_b}$ 4.4

Where, a and Γ are constant and reflection coefficient respectively, are the design variables to be obtained..

S. No.	Design variables	Value
1	a	1.049
2	Γ	0.043

Table 4.1 Optimized value of design variables obtained

The system function (4.3) obtained for transmission line network is equate with respect to digital differentiator system function obtained in (3.6). The comparison and tuning on ADS schematic window gives the value of optimized a and Γ coefficients.

4.2.1 Agilent Line Calc:

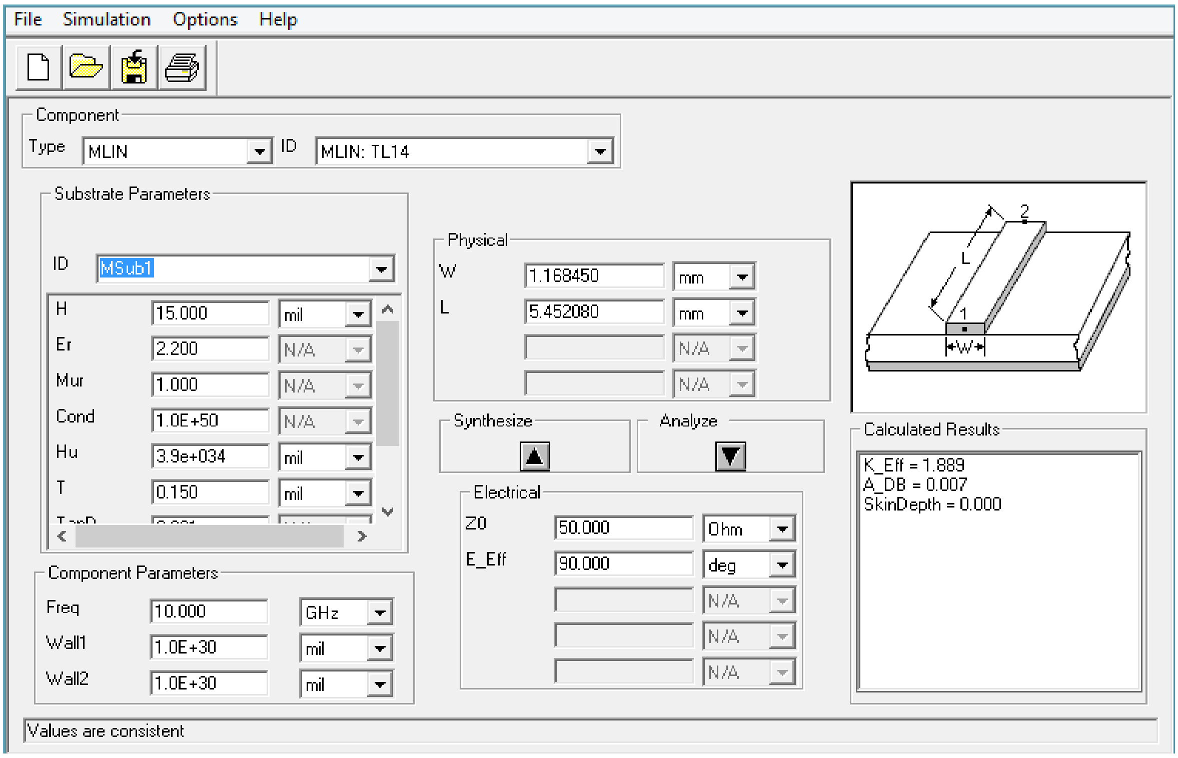

Figure.4.1 Agilent ADS LineCalc

Corresponding to designing variables a and Γ values as mentioned in table 4.1, the value of characteristic impedance of each sections of transmission line is calculated using (4.4) and the values of width and length of each section of microstrip is obtained from Agilent Line calc tool as shown in figure 4.1. The RT/duroid® 5880 is used as dielectric substrate having a thickness of 15 mil (0..381mm) and relative dielectric constant of ε = 2.2. Table 4.2 tabulates the dimensions of each transmission line section. Impedance of both the transmission lines are Z_1=47.62Ω, Z_2= 54.54Ω and device is terminated with Z_o = 50 Ω transmission line in order to impedance matching at input and output port.

Physical Dimensions of strip line:

S.No.	Configuration	Width (mm)	Length (mm)
1	TL	1.168450	5.452080
2	STL	1.347225	2.632192
3	SCL	1.3211	4.105296
4	SCL	1.3211	4.105496

Mcross	W1(mm)	W2(mm)	W3(mm)	W4(mm)
	1.168450	1.3211	1.347225	1.3211

Table.4.2: Transmission Line parameter from Line Calc Optimized coefficient value of first order differentiator

4.2.2 Schematic of microwave differentiator using Agilent ADS:

Figure 4.2 represents the schematic for microwave differentiator using Agilent ADS. To implement the shunt transmission-line stub having a characteristic impedance of 23.81 Ω, a parallel configuration i.e., the equivalent microstrips are placed symmetrically as shown in figure 4.2 is used. The transmission line TL4 and TL5 represents short stub and TL2 represents serial transmission line. The microstrip line named as TL1 and TL3 represents the 50Ω characteristic impedance transmission line. S Parameter palette is used for S parameter analysis of proposed differentiator. The simulation is performed with linear sweep of frequency from 1 to 10GHz.

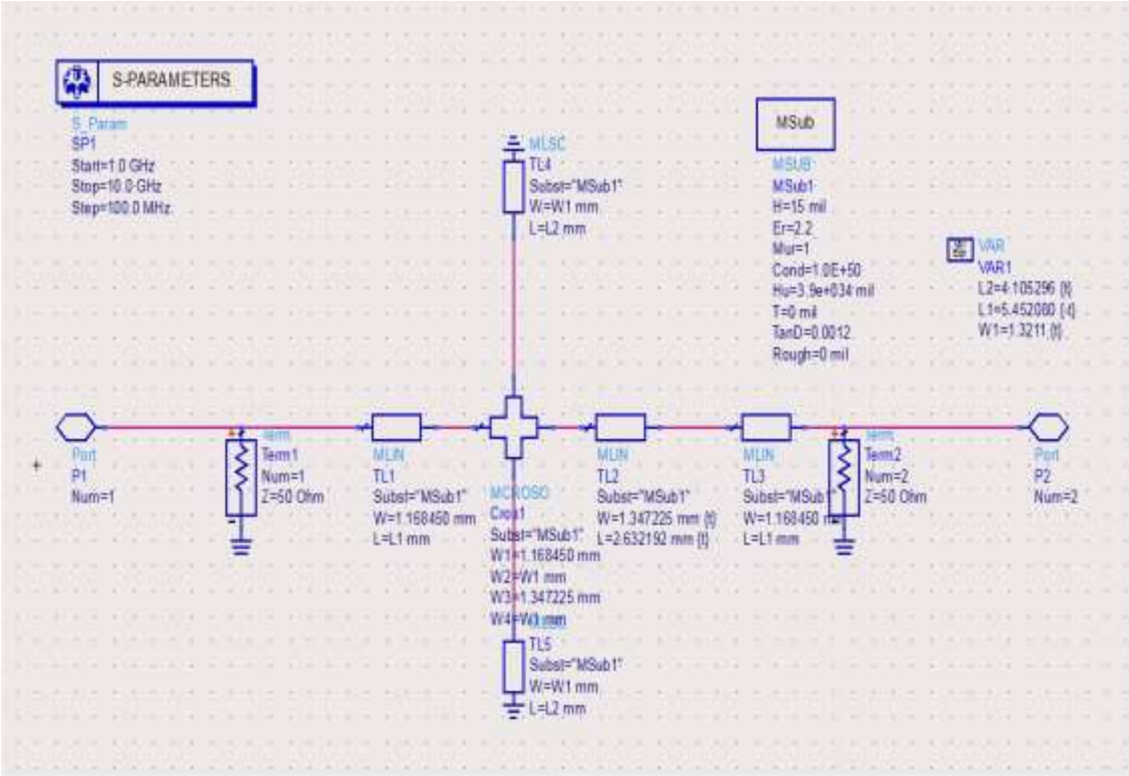

Figure.4.2:Agilent ADS Schematic of 1st Order Differentiator

4.2.3 Substrate definition of microstrip

A substrate in EM simulation describes the media where a circuit exists. To demonstrate the proposed design methodology, the microwave differentiator is simulated using microstrip line build on a RT/duroid® 5880 substrate with a thickness of 15mil (0.381mm) and relative dielectric constant of ε = 2.2.

4.2.4 Layout diagram of differentiator in ADS

Based on the schematic diagram (section 4.2.2) the layout for differentiator is generated in Agilent ADS. For characterization of designed differentiator meshing is performed and analysis is done in FEM solver. To generate an electromagnetic field solution from which S-parameters can be computed, FEM Simulator employs the finite element method. In general, the finite element method divides the full problem space into thousands of smaller regions and represents the field in each sub-region (element) with a local function. In FEM Simulator, the geometric model is automatically divided into a large number of tetrahedral, where a single tetrahedron is formed by four equilateral triangles. Figure 4.3 shows the layout structure of microstrip differentiator after meshing operation.

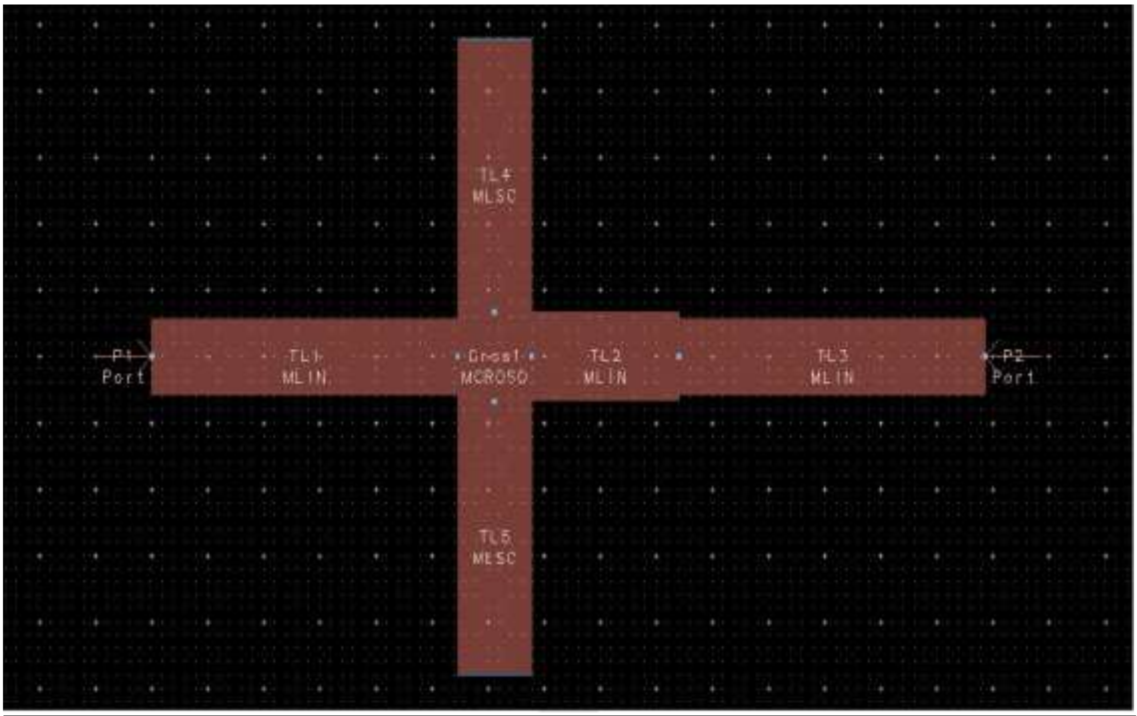

Figure.4.3: Layout diagram of 1st order differentiator

4.2.5 3D EMPro layout

Figure 4.4 represents the final two section microstrip differentiator prototype build in Agilent EMPro software

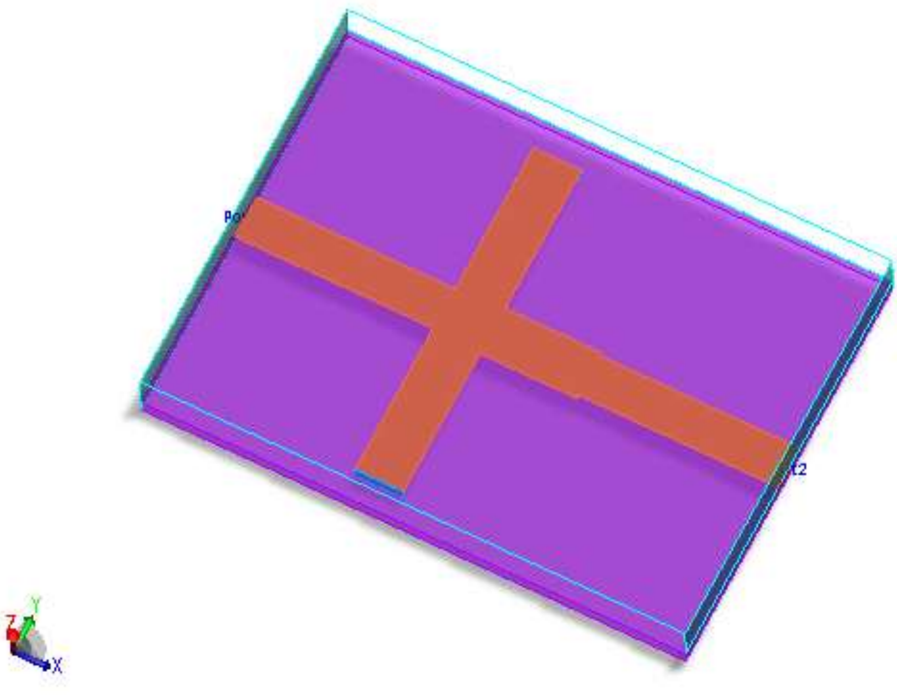

Figure.4.4: Agilent EMPro Layout diagram of first order differentiator

4.2.6 Magnitude Response of Ideal and Proposed Differentiator

For characterization of designed differentiator, transmission coefficient S_{21} parameters have been plotted together with ideal differentiator response to show to good degree of agreement between proposed and ideal differentiator. In can be seen that the designed microwave differentiator follow well the ideal differentiator characteristic between the frequency range 1 to 9GHz.

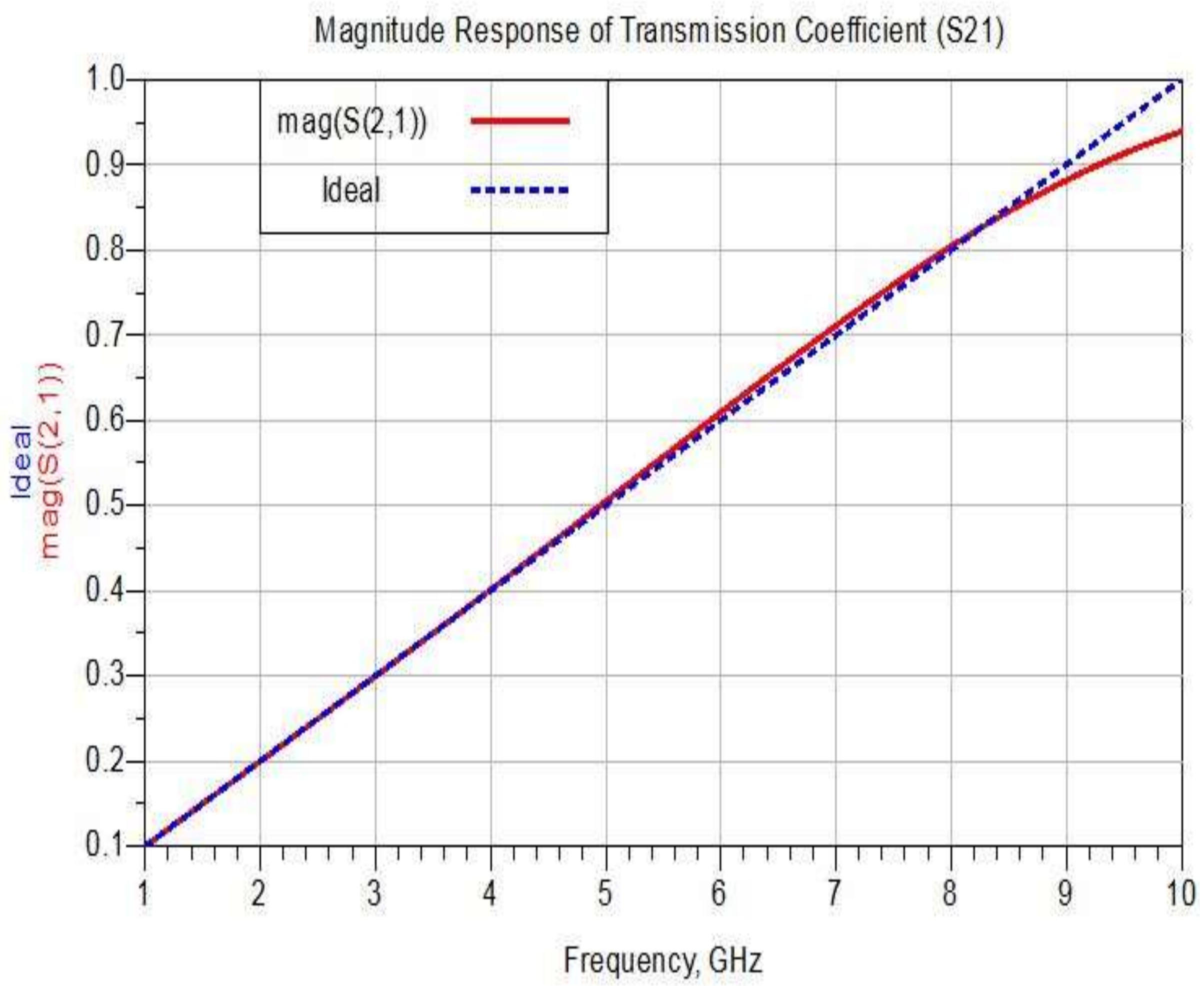

Figure.4.5: Frequency Response of 1st order differentiator and ideal differentiator by momentum simulation

4.3 First order Differentiator with different time constant

For designing a differentiator that have the operating frequencies up to 10GHz using microstrip configuration, a network consist of a short stub and a serial transmission lines is used. It has been shown (Table 1) that zero occurring on the unit circle $|z| = 1$ can be implemented by using shunted transmission-line elements. The number of sections of differentiator is determined by the optimization process that involves the curve fitting of transfer function of transmission line to the amplitude response of the digital differentiator (3.6) which represents a good approximation of an ideal differentiator.

As, Transfer function for a n

etwork with L short circuit stub and M series transmission line is given and considering single shunt short stub and three series section line,

$$S_{21} = \frac{(1-z^{-1})^{L}\prod_{m=1}^{M}(1-\Gamma_{m}^{2})}{\prod_{l=1}^{L}\left[(1+a)-(1-a)z^{-1}\right]\left[\prod_{m=1}^{M}1-\Gamma_{m}^{2}z^{-1}\right]} \qquad 4.5$$

The system function (4.5) obtained for transmission line network is equate with respect to digital differentiator system function obtained in (3.6). The comparison and tuning on ADS schematic window gives the value of optimized a and Γ coefficients.

S.No.	Design variables	Value
1	a_1	1.450
2	Γ_2	0.164
3	Γ_3	-0.062
4	Γ_4	0.015

Table 4.3 Optimized value of reflection coefficients obtained

Corresponding to reflection coefficients values as mentioned in table 4.3, the values of characteristic impedance of each section of transmission line can be calculated using (4.4).For implementation of microstrip differentiator , RT/duroid® 5880 is used as dielectric substrate having a thickness of 15mil (0.381mm) and relative dielectric constant of $\varepsilon = 2.2$. The characterisitics impedance of each section of transmission line are 34.323 Ω, 69.716 Ω, 44.135 Ω, 51.534 Ω and device is terminated by 50 Ω transmission line in order to impednce matching with SMA connector of 50 Ω impededance. The resultant value of the value of width and length of each section of microstrip is tabulated in table 4.4

Physical Dimensions of strip line:

S.N.	Configuration	Width (mm)	Length (mm)
1	TL	1.168450	5.452080
2	STL	0.9552452	4.9861234
3	STL	1.403350	4.5529512
4	STL	1.116290	5.459980
5	SCL	1.9266722	5.359880
6	SCL	1.9266722	5.359880

Table.4.4:Transmission Line parameter from Line Calc Optimized coefficient value of first order differentiator

4.3.1 Schematic of microwave differentiator using Agilent ADS

Figure 4.12 represents the schematic for microwave differentiator using Agilent ADS. To implement the shunt transmission-line stub having a characteristic impedance of 17.16 **Ω**, a parallel configuration i.e., the equivalent microstrips are placed symmetrically. The transmission line TL6 and TL7 represents short stub and TL2, TL3 and TL4 represents serial transmission line. The microstrip line named as TL1 and TL5 represents the 50**Ω** characteristic impedance transmission line. S_Parameter palette is used for S parameter analysis of proposed differentiator. The simulation is performed with linear sweep of frequency from 1 to 10GHz.

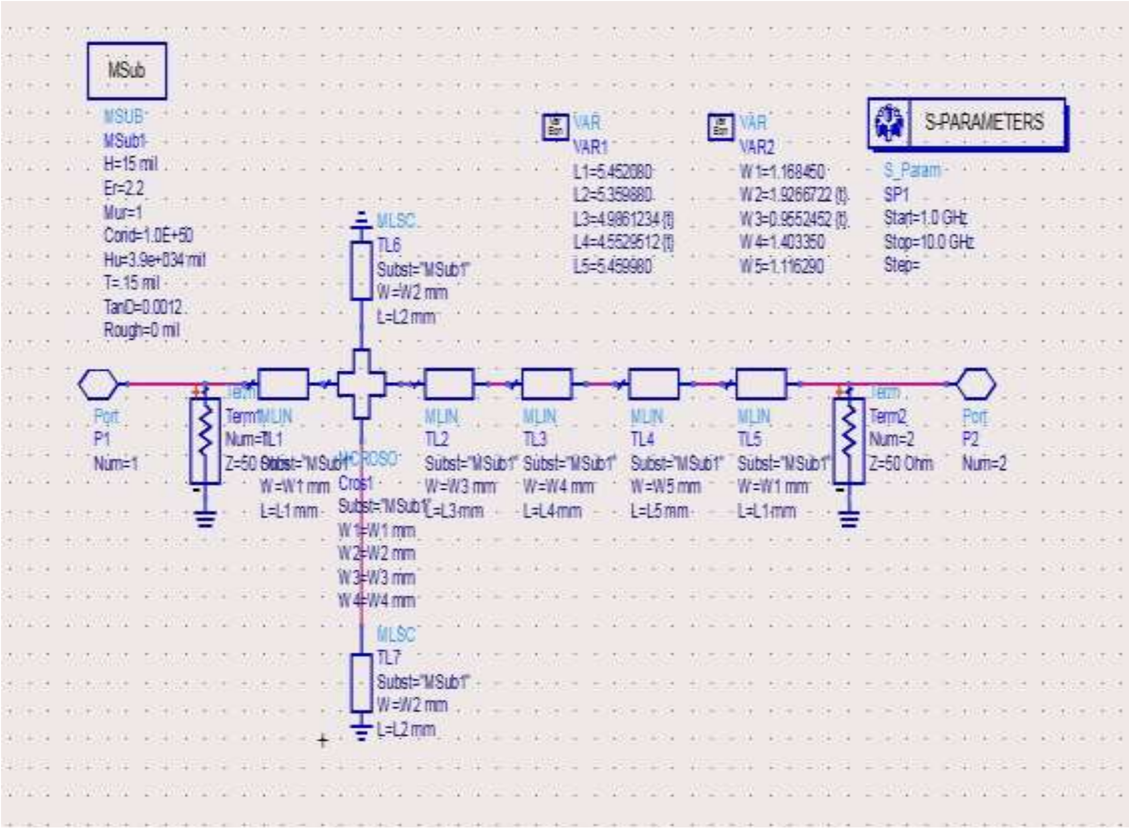

Figure.4.6: Agilent ADS Schematic of 1st Order Differentiator

4.3.2 Substrate definition of microstrip

A substrate in EM simulation describes the media where a circuit exists. To demonstrate the proposed design methodology, the microwave integrator is simulated using microstripe line is build on a RT/duroid® 5880 substrate with a thickness of 15mil (0.381mm) and relative dielectric constant of ε = 2.2.

4.3.3 Layout diagram of differentiator in ADS

Based on the schematic diagram (section 4.2.1) the layout of differentiator is generated as shown in figure 4.7. For characterization of designed differentiator meshing is performed and analysis is done in FEM solver. To generate an electromagnetic field solution from which S-parameters can be computed, FEM Simulator employs the finite element method. In general, the finite element method divides the full problem space into thousands of smaller regions and represents the field in each sub-region (element) with a local function.

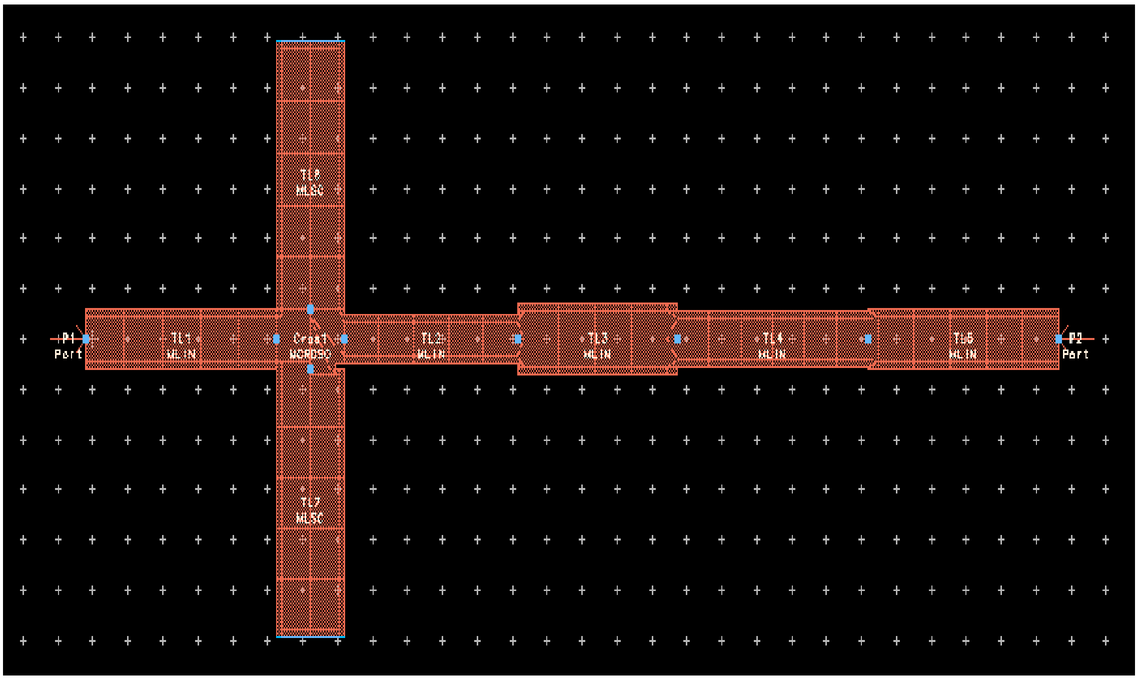

Figure.4.7: Layout diagram of 1st order differentiator

4.3.4 Agilent EMPro layout

Figure 4.8 represents the final microstrip differentiator prototype build in Agilent EMPro software.

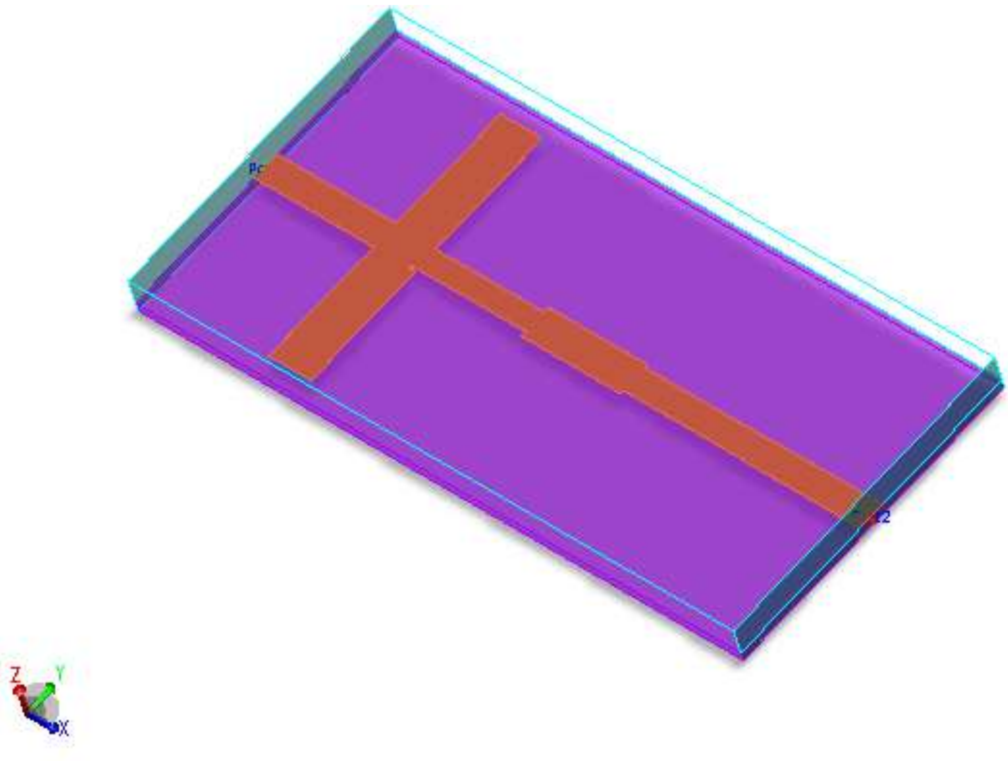

Figure.4.8: Agilent EMPro Layout diagram of first order differentiator

4.3.5 Magnitude Response of Ideal and Proposed Differentiator

For characterization of designed differentiator, S_{21} parameters have been plotted together with ideal differentiator response to show to good degree of agreement between proposed and ideal differentiator. In can be seen that the designed microwave differentiator follow well the ideal differentiator characteristic between the frequency range 1to 10 GHz.

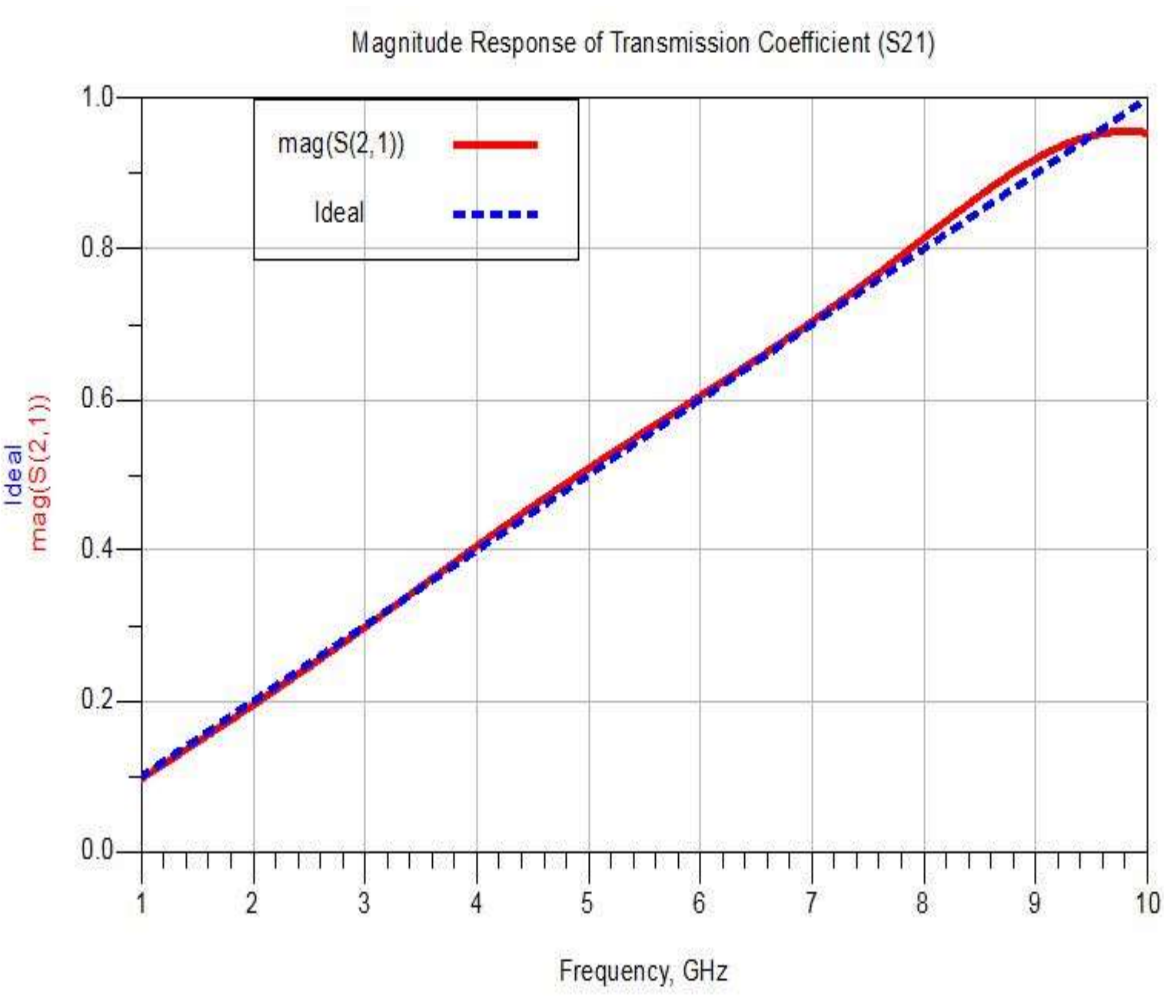

Figure.4.9: Frequency Response of 1st order differentiator and ideal differentiator by momentum simulation

Chapter 5

Design of Second order Microwave Differentiators

5.1 Introduction

This chapter illustrates the synthesis methodology of second order microwave differentiators. Based on the digital differentiators system functions obtained in Chapter 3 the designing of optimized microwave differentiators are presented. Here, two different differentiator models with different time constant have been designed. In particular, the time constant characterize the performance of the differentiators and it serves as an important factor that determines the amplitude response of a differentiators. The designed differentiator models are also analysed in Agilent EMPro software tool. Lastly, performance characteristic magnitude response of designed differentiators are presented.

5.2 Second Order Microwave Differentiator

For designing a differentiator that have the operating frequencies up to 10GHz using microstrip configuration, a network consist of a short stub and a serial transmission lines is used. It has been shown (Table 1) that zero occurring on the unit circle $|z| = 1$ can be implemented by using shunted transmission-line elements. The number of sections or device length of microstrip network determines the time constant and frequency response of differentiator. The number of sections and configuration of microstrip is determined by the optimization process that involves the curve fitting of transfer function of transmission line to the amplitude response of the digital differentiator (3.6) which represents a good approximation of an ideal differentiator in Z-domain.

Consider $T_{11}(\mathrm{z})$ for L short shunt stub and M series line section,

$$T_{11}(\mathrm{z}) = \frac{\sum_{i=0}^{N} A_i z^{-1}}{(1-\mathrm{z}^{-1})^{L} \prod_{m=1}^{M} (\mathrm{z}^{-1/2}(1-\Gamma^2{}_m))} \qquad 5.1$$

After neglecting the delay term we can write the general transfer function of cascade connection of transmission line consist of short shunt and series transmission line section,

$$S_{21} = \frac{(1-z^{-1})^L \prod_{m=1}^{M}(1-\Gamma_m^2)}{\prod_{l=1}^{L}\left[(1+a)-(1-a)z^{-1}\right]\left[\prod_{m=1}^{M} 1-\Gamma_m^2 z^{-1}\right]} \qquad 5.2$$

For three shunt section transmission line S_{21} as,

$$S_{21} = \frac{(1-z^{-1})^3(1-\Gamma_1^2)(1-\Gamma_2^2)(1-\Gamma_3^2)(1-\Gamma_4^2)}{\left[(1+a_1)-(1-a_1)z^{-1}\right]\left[(1+a_2)-(1-a_2)z^{-1}\right]\left[(1+a_3)-(1-a_3)z^{-1}\right](1-\Gamma_1^2 z^{-1})(1-\Gamma_2^2 z^{-1})(1-\Gamma_3^2 z^{-1})(1-\Gamma_4^2 z^{-1})} \qquad 5.5$$

system function (5.2) obtained for transmission line network is equate with respect to digital differentiator system function obtained in (3.14).

$$\left[\frac{0.417\left(1-z^{-1}\right)}{\left(1+.1658z^{-1}\right)}\right]^2 = \frac{(1-z^{-1})^L \prod_{m=1}^{M}(1-\Gamma_m^2)}{\prod_{l=1}^{L}\left[(1+a)-(1-a)z^{-1}\right]\left[\prod_{m=1}^{M} 1-\Gamma_m^2 z^{-1}\right]} \qquad 5.3$$

Where $\Gamma = \frac{Z_a - Z_0}{Z_a + Z_0}$ and $a = \frac{Z_0}{2Z_b}$ 5.4

Where, a_1, a_2, a_3 are constant and Γ_1 Γ_2, Γ_3 and Γ_4 reflection coefficient defined in table(1) respectively, are the design variables to be optimized. Corresponding to reflection coefficients values as mentioned above, the values of characteristic impedance of each section of transmission line can be calculated using (5.4).For implementation of microstrip integrator, RT/duroid® 5880 is used as dielectric substrate having ε = 2.2. The characterisitics impedance of each section of transmission line are 31.58 Ω, 36.567 Ω, and device is terminated by 50 Ω transmission line in order to impednce matching with SMA connector of 50 Ω impededance. The resultant value of the value of width and length of each section of microstrip is tabulated in table 5.1.

S.No.	Transmission line	Width (mm)	Length (mm)
1	SCL	0.5180715	5.033062
2	STL	1.4738658	1.218599
3	TL	1.168450	5.452080

Table.5.1: Transmission Line parameter from Line Calc Optimized coefficient value of second order differentiator

5.2.1 Schematic of microwave differentiator using Agilent ADS

Figure 5.1 represents the schematic for microwave differentiator using Agilent ADS. To implement the shunt transmission-line stub having a characteristic impedance of 15.79 Ω, a parallel configuration i.e., the equivalent microstrips are placed symmetrically. The transmission line TL1, TL2, TL3, TL4, TL5 and TL6 represents short stub and TL7, TL8 TL9 and TL10 represents serial transmission line. The microstrip line named as TL11 and TL12 represents the 50Ω characteristic impedance transmission line. S_Parameter palette is used for S parameter analysis of proposed differentiator. The simulation is performed with linear sweep of frequency from 1 to 10GHz.

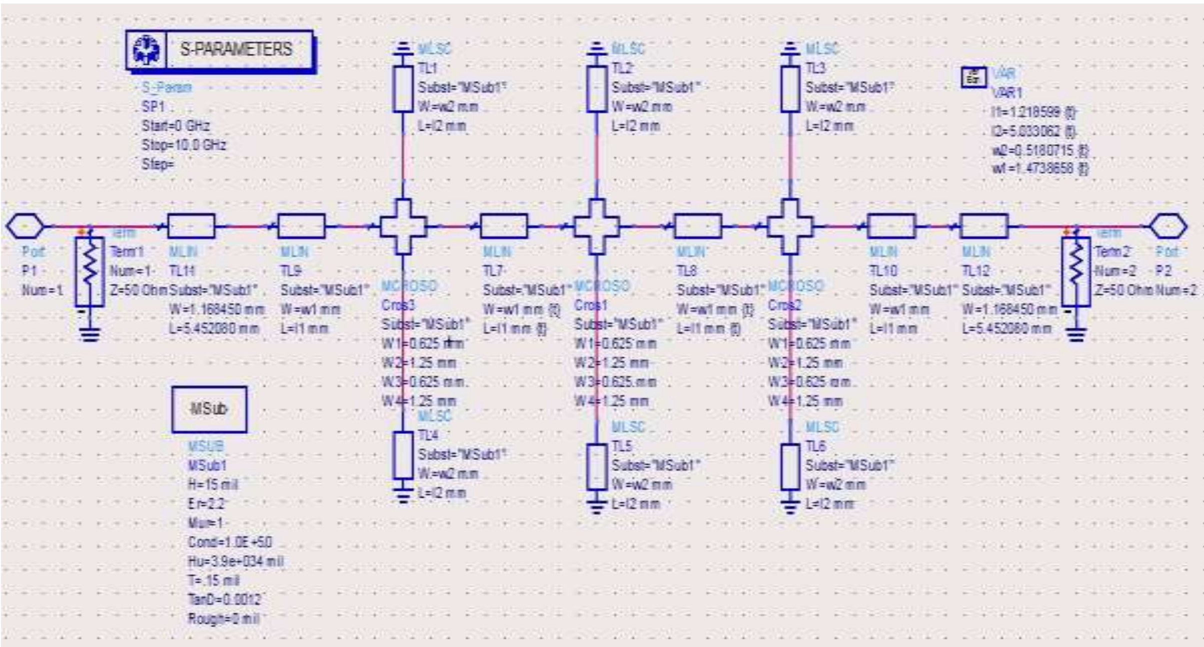

Figure.5.1. Agilent ADS Schematic of 2st Order Differentiator

5.2.2 Substrate definition of microstrip

A substrate in EM simulation describes the media where a circuit exists. To demonstrate the proposed design methodology, the microwave differentiator is simulated using microstripe line is build on a RT/duroid® 5880 substrate with a thickness of 15mil (0.381mm) and relative dielectric constant of ε = 2.2.

5.2.3 Layout diagram of differentiator in ADS

Based on the schematic diagram (section 5.2.1) the layout of differentiator is generated as shown in figure 5.2. For characterization of designed differentiator meshing is performed and analysis is done in FEM solver. To generate an electromagnetic field solution from which S-parameters can be computed, FEM Simulator employs the finite element method.

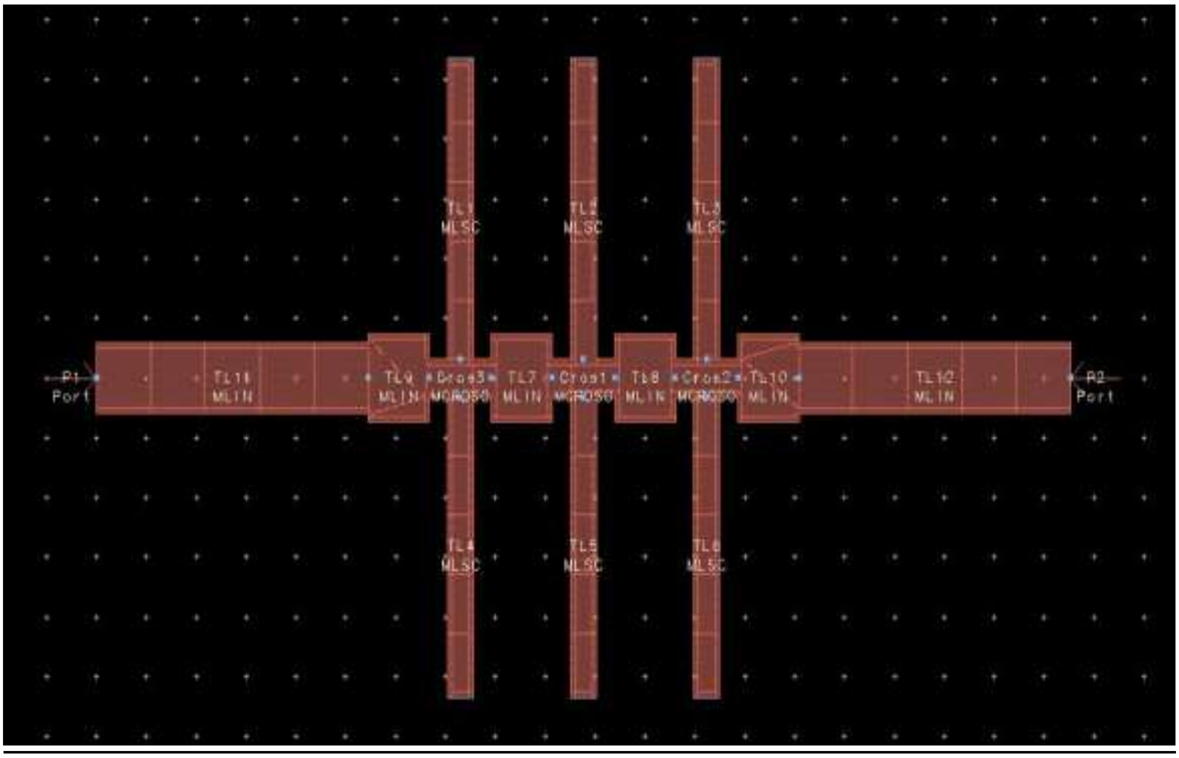

Figure.5.2: Layout diagram of 2st order differentiator

5.2.4 Agilent EMPro layout

Figure 5.3 represents the final microstrip differentiator prototype build in Agilent EMPro software

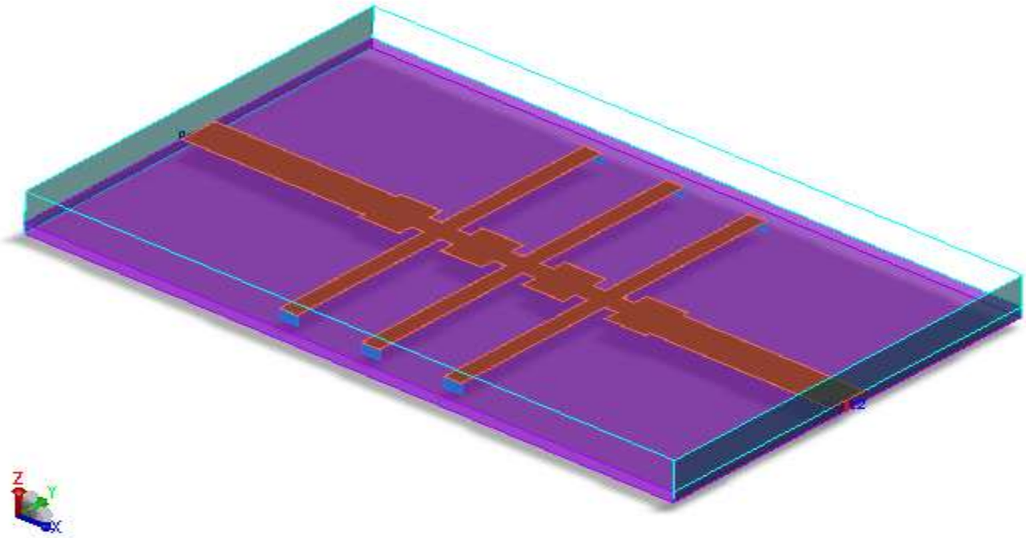

Figure.5.3: Agilent EMPro Layout diagram of second order differentiator

5.2.5 Magnitude Response of Ideal and Proposed Differentiator

For characterization of designed differentiator, transmission coefficient S_{21} parameters have been plotted together with ideal differentiator response to show to good degree of agreement between proposed and ideal differentiator. In can be seen that the designed microwave differentiator follow well the ideal differentiator characteristic between the frequency range 1 to 10GHz

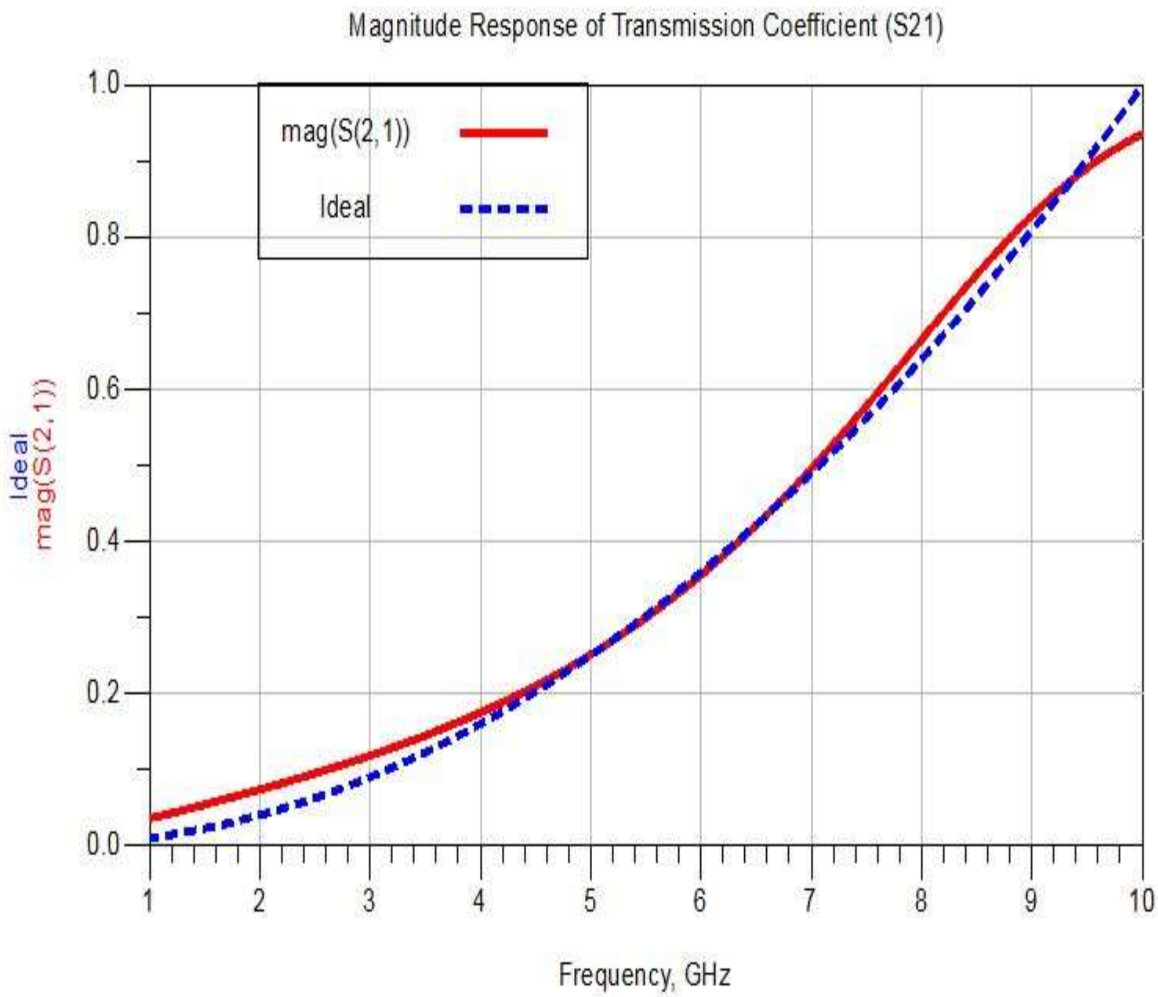

Figure.5.4: Frequency Response of 2^{st} order differentiator and ideal differentiator by momentum simulation

5.3 Second order Differentiator with different time constant

For designing a differentiator that have the operating frequencies up to 10GHz using microstrip configuration, a network consist of a short stub and a serial transmission lines is used. It has been shown (Table 1) that zero occurring on the unit circle $|z| = 1$ can be implemented by using shunted transmission-line elements. The number of sections of differentiator is determined by the optimization process that involves the curve fitting of transfer function of transmission line to the amplitude response of the digital differentiator (3.14) which represents a good approximation of an ideal differentiator. By again using the (5.3) and consider the three short shut stub and six series section line, the values of characteristic impedance of each section of transmission line can be calculated using (5.3)-(5.4).

For implementation of microstrip differentiator, RT/duroid® 5880 is used as dielectric substrate having a thickness of 15mil (0.381mm) and relative dielectric constant of $\varepsilon = 2.2$. The characterisitics impedance of each section of transmission line are 49.91 Ω, 54.19 Ω, 92.0 Ω, 75.54 Ω, 40 Ω, 40 Ω, 54.82 Ω, 61.34 Ω respectively and device is terminated by 50 Ω transmission line in order to impednce matching with SMA connector of 50 Ω impededance. The resultant value of the value of width and length of each section of microstrip is tabulated in table 5.2.

S.No.	Transmission line	W(mm)	L(mm)
1	STL	1.483548	2.626200
2	STL	0.5540086	2.706980
3	STL	1.165261	2.676480
4	STL	1.971056	2.538930
5	STL	2.7893808	2.627890
6	SCL	0.631691	5.439180
7	SCL	0.631691	5.439180
8	SCL	0.629089	5.439180
9	SCL	1.004640	0.629089
10	TL	1.168450	5.452080

Table.5.2: Transmission Line parameter from Line Calc Optimized coefficient value of 2^{nd} order differentiator

5.3.1 Schematic of microwave differentiator using Agilent ADS

Figure 5.5 represents the schematic for microwave differentiator using Agilent ADS. To implement the shunt transmission-line stub having a characteristic impedance of 24.955Ω, 25Ω, 20Ω, a parallel configuration i.e., the equivalent microstrips are placed symmetrically. The transmission line TL8, TL9, TL10, TL11, TL12 and TL5 represents short stub and TL1, TL2, TL3, TL4, TL5 and TL6 represents serial transmission line. The microstrip line named as TL7 and TL14 represents the 50Ω characteristic impedance transmission line. S_Parameter palette is used for S parameter analysis of proposed differentiator.The simulation is performed with linear sweep of frequency from 1 to 10GHz.

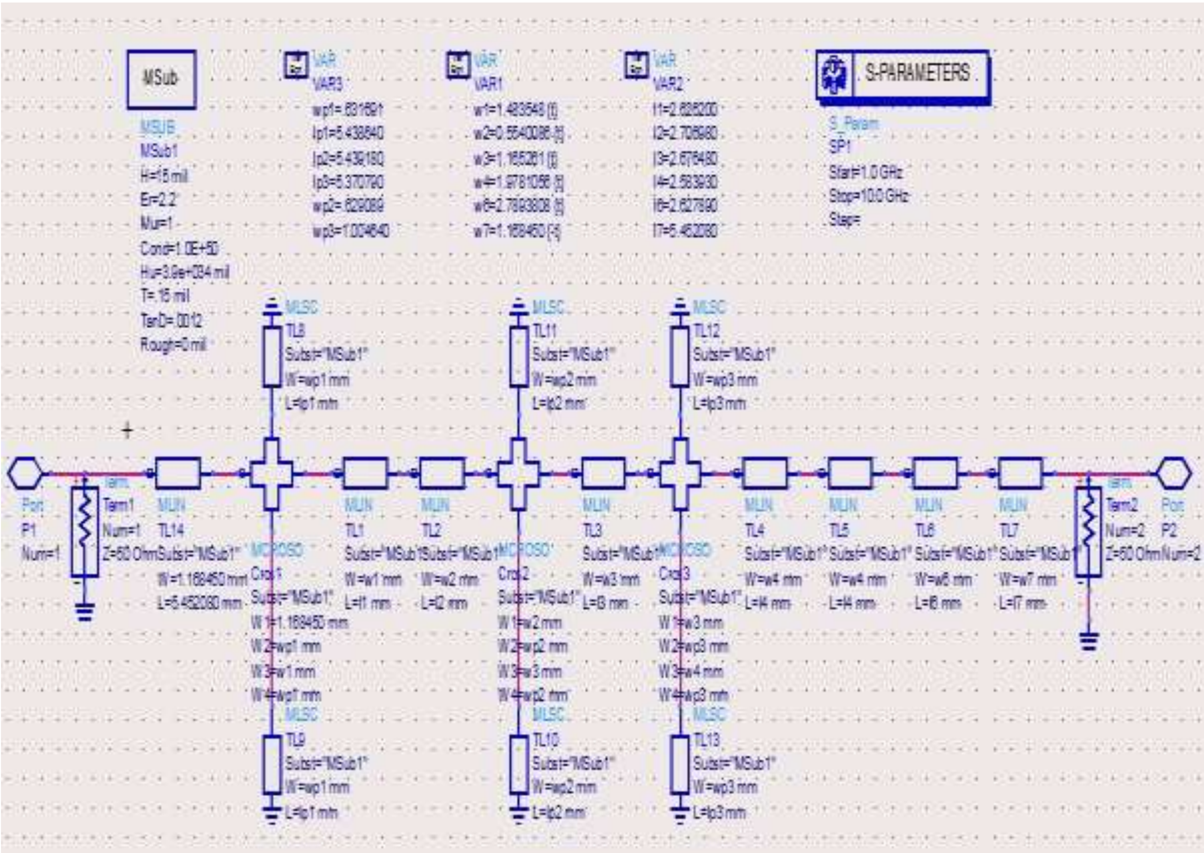

Figure.5.5. Agilent ADS Schematic of 2^{st} Order Differentiator

5.3.2 Substrate definition of microstrip

A substrate in EM simulation describes the media where a circuit exists. To demonstrate the proposed design methodology, the microwave differentiator is simulated using microstripe line is build on a RT/duroid® 5880 substrate with a thickness of 15mil (0.381mm) and relative dielectric constant of ε = 2.2

5.3.3 Layout diagram of differentiator in ADS

Based on the schematic diagram (section 5.3.1) the layout of differentiator is generated as shown in figure 5.6. For characterization of designed differentiator meshing is performed and analysis is done in FEM solver. To generate an electromagnetic field solution from which S-parameters can be computed, FEM Simulator employs the finite element method.

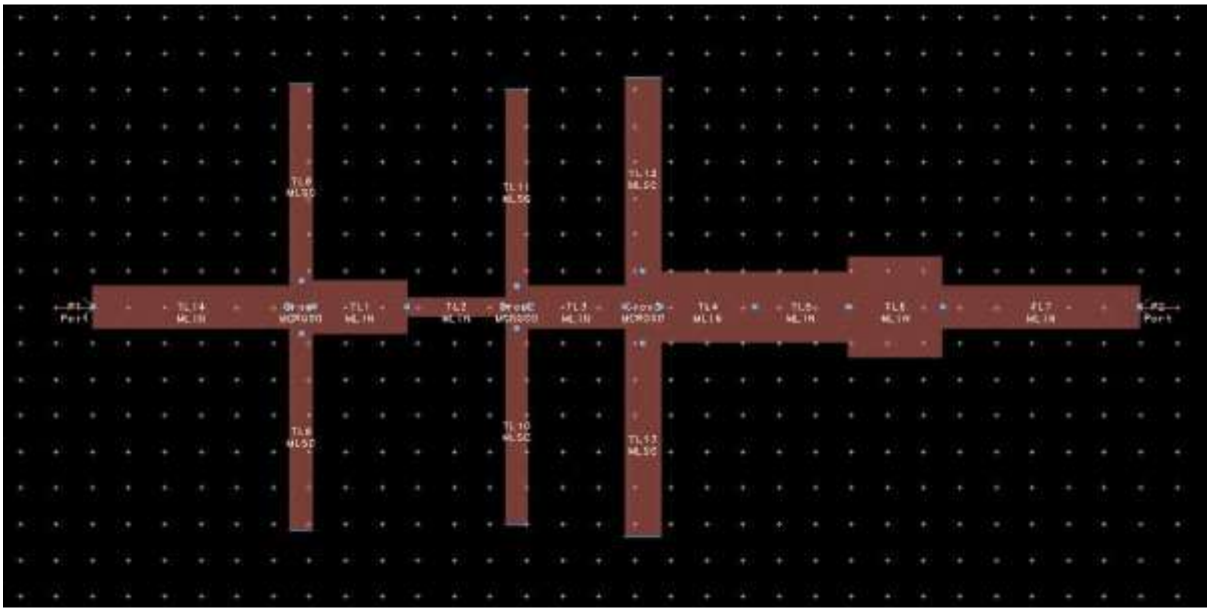

Figure.5.6: Layout diagram of 2st order differentiator

5.3.4 Agilent EMPro layout

Figure 5.7 represents the final microstrip differentiator prototype build in Agilent EMPro software.

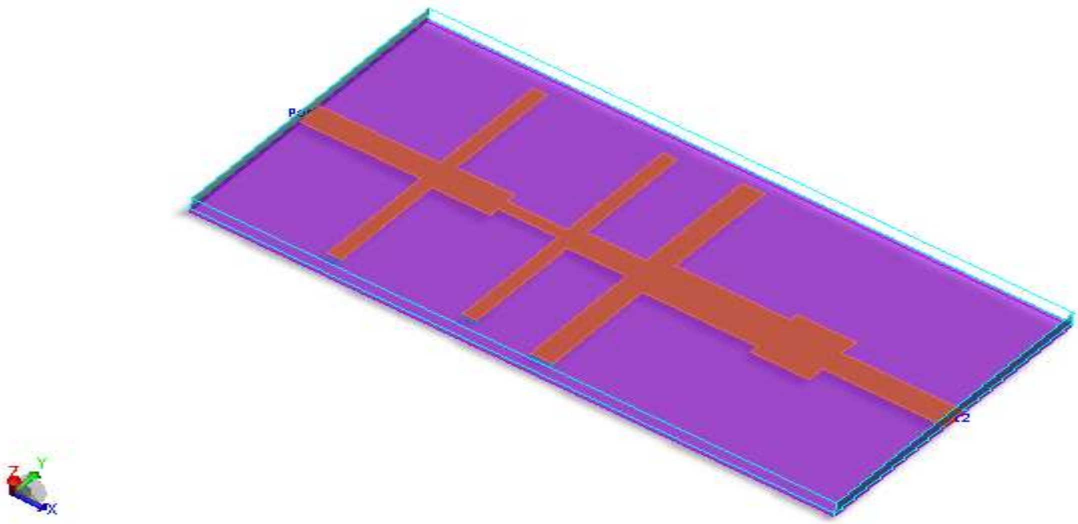

Figure.5.7: Agilent EMPro Layout diagram of second order differentiator

5.3.5 Magnitude Response of Ideal and Proposed Differentiator

For characterization of designed differentiator, S_{21} parameters have been plotted together with ideal differentiator response to show to good degree of agreement between proposed and ideal differentiator. In can be seen that the designed microwave differentiator follow well the ideal differentiator characteristic between the frequency range 1 to 10 GHz.

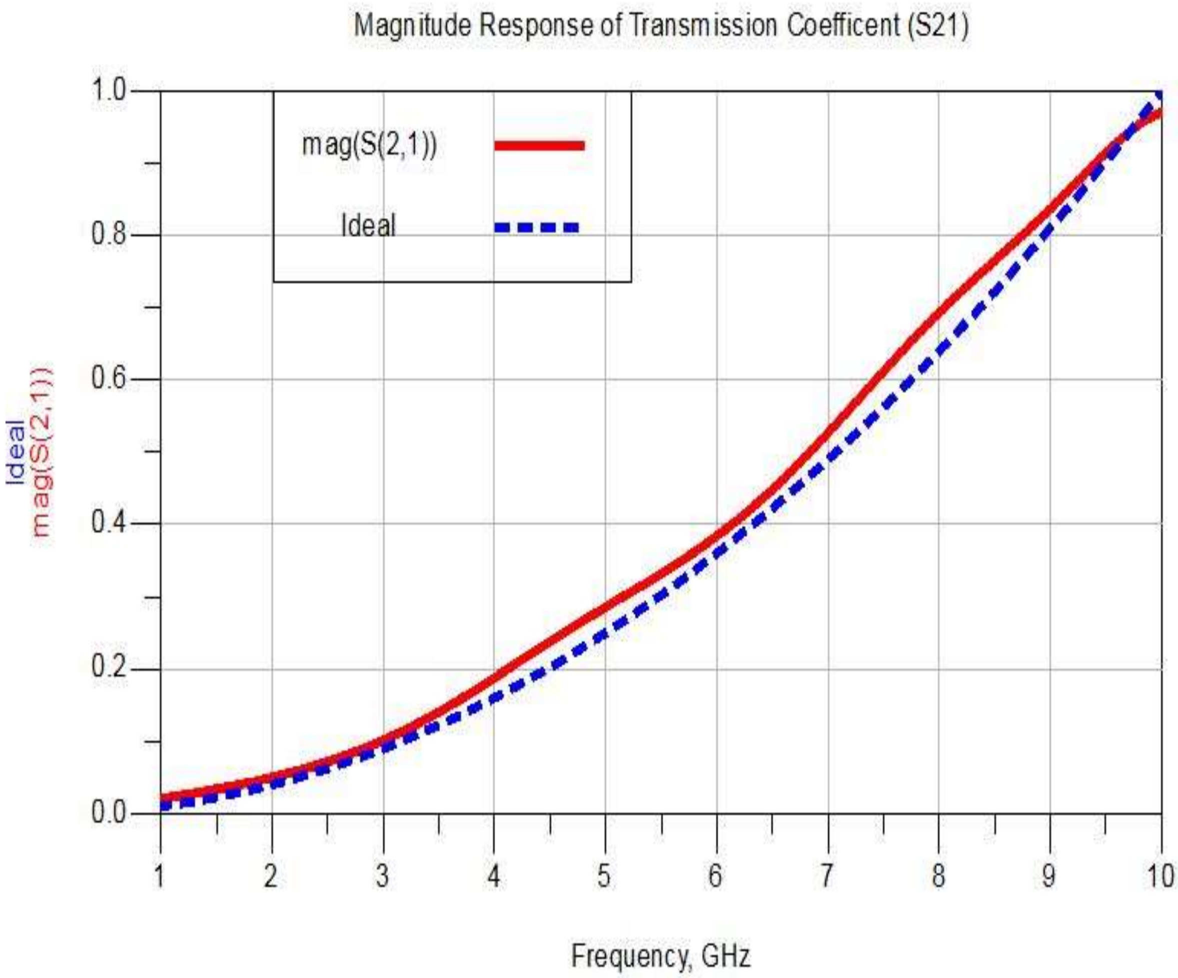

Figure.5.8: Frequency Response of the proposed 2^st order differentiator and ideal differentiator by momentum simulation

Chapter 6

Fabrication of Microwave Differentiators

6.1 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.

6.2 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.

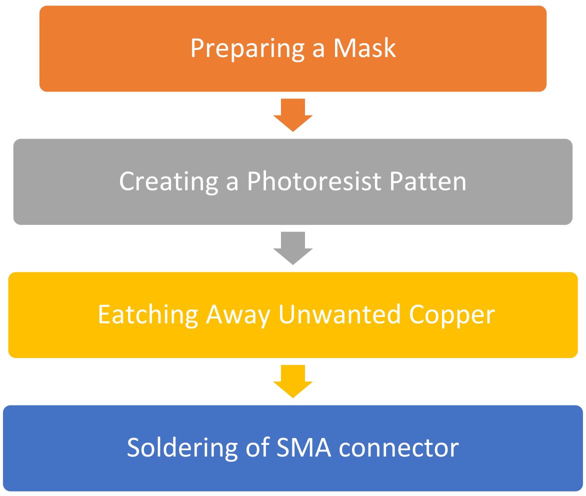

Figure 6.1: Flowchart of fabrication processes

6.3 Preparing a mask

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. DIFF.DXF). This file can be read out by iCad software.

6.3.1 *.DXF formats of Differentiators

ADS layout can be directly used to export design into *.DXF format or *.garber format. *.DXF format is produced in order to fabrication of both first and second order microsrip differentiator.

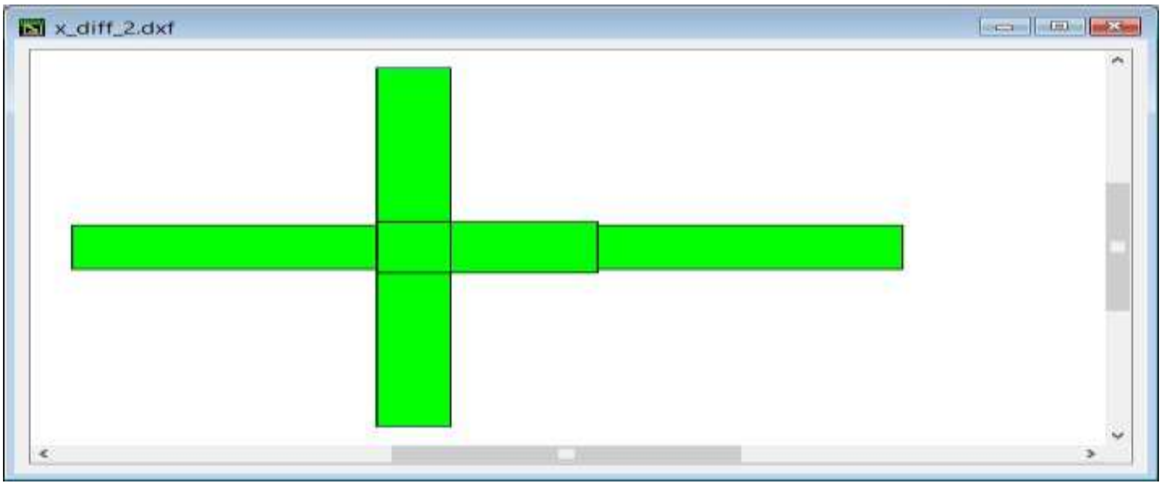

*Figure.6.2: *.DXG format for 1st order differentiator-I*

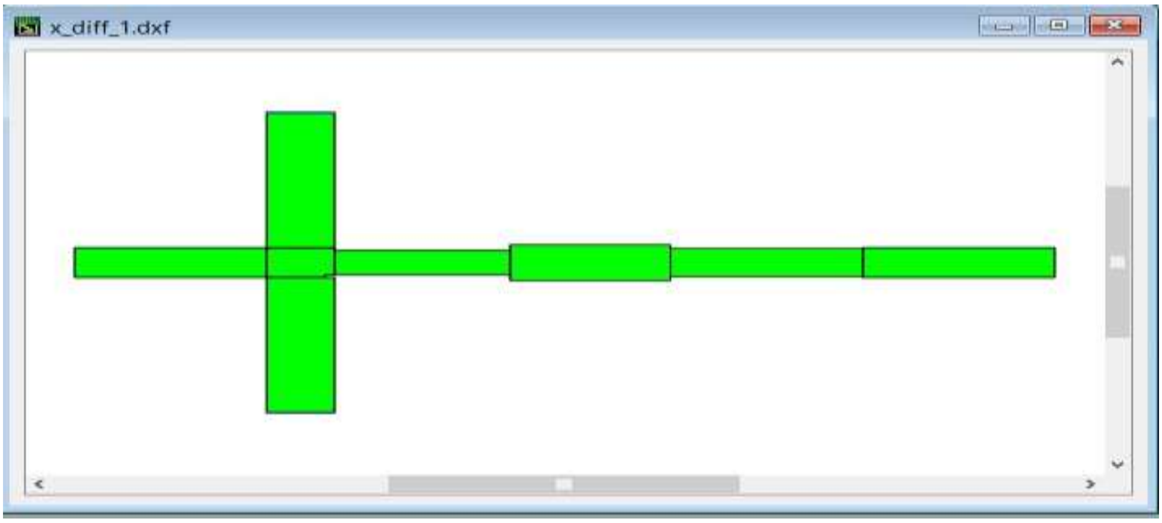

*Figure.6.3: *.DXG format for 1st order differentiator-II*

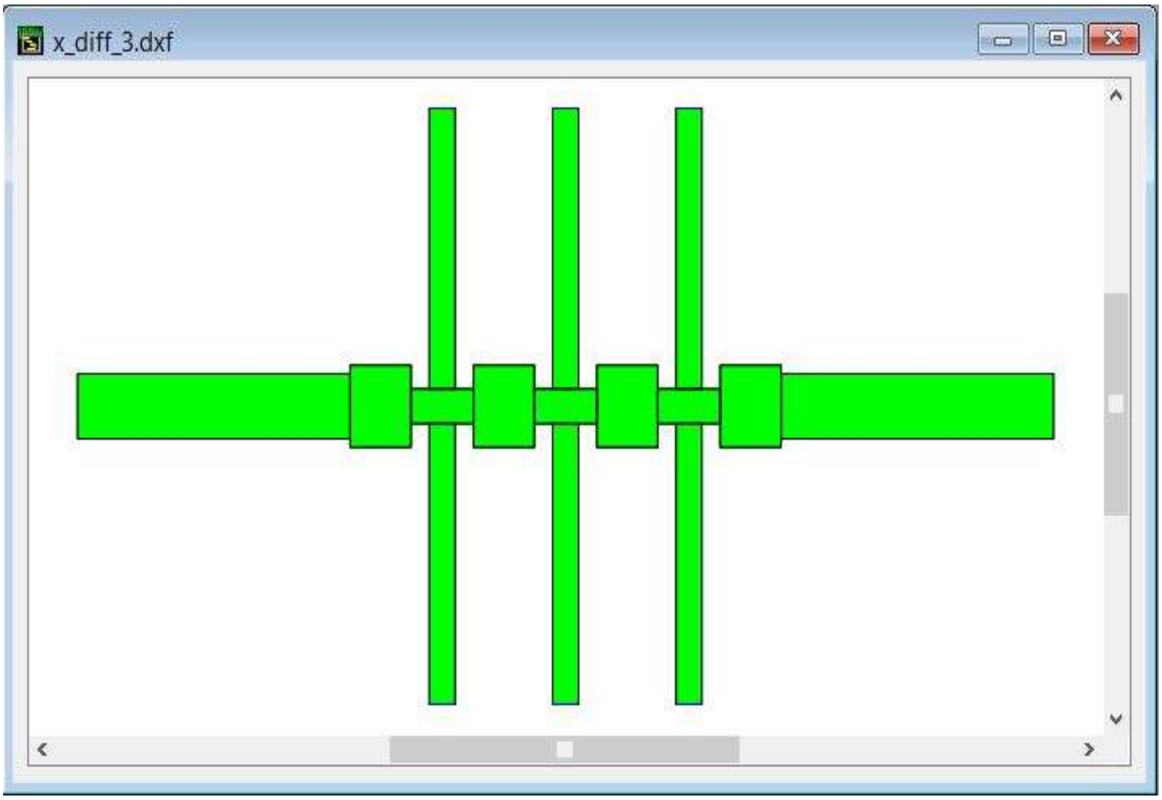

*Figure.6.4: *.DXG format for 2^{nd} order differentiator-I*

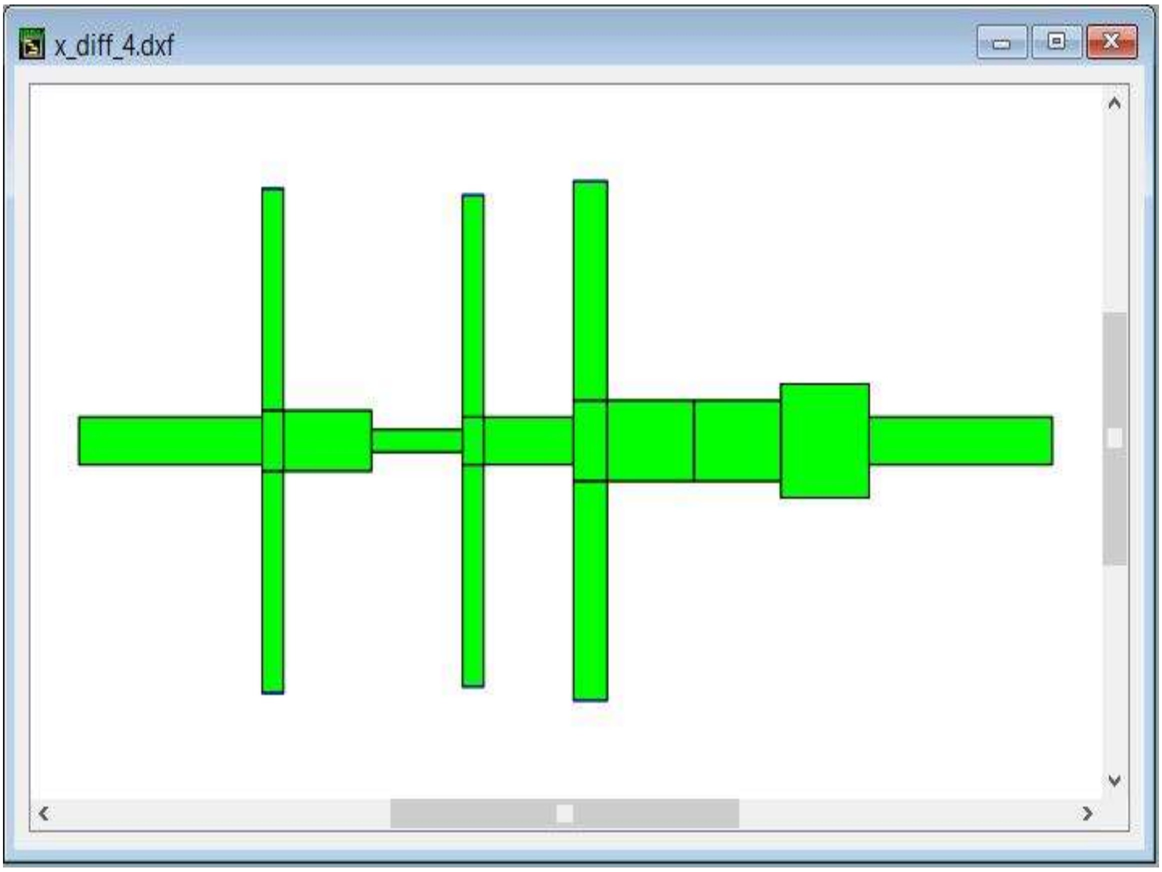

*Figure.6.5: *.DXG format for 2^{nd} order differentiator-II*

6.4 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 use and proceeds for photolithography.

6.5 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)

6.5.1 Photolithography Equipment

i. Ultraviolet Light Compartment.

ii. Hot Plate with temperature controlled.

6.5.2 Steps of the photolithography processes

The following are shows the steps of photoresist process.

6.5.2.1 Preparation of Developer

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

Figure: 6.6: Positive and Developer Photoresist

6.5.2.2 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).

Figure: 6.7: Ultraviolet exposure

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 min

6.5.3 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.

6.5.3.1 The concentration of solution

The inside temperature with filled container is kept constant at $50^\circ \sim 55^\circ$ 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.

6.6 Microstrip circuit of Differentiators

Finally, all first and second order microsrip differentiator circuit are fabricated and are shown,

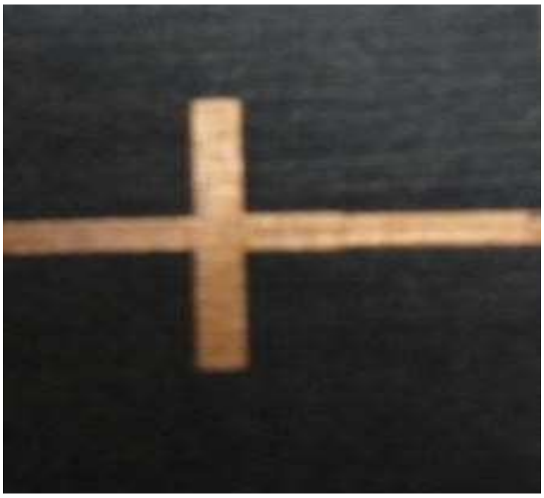

Figure 6.8: 1st order microstrip differentiator-I

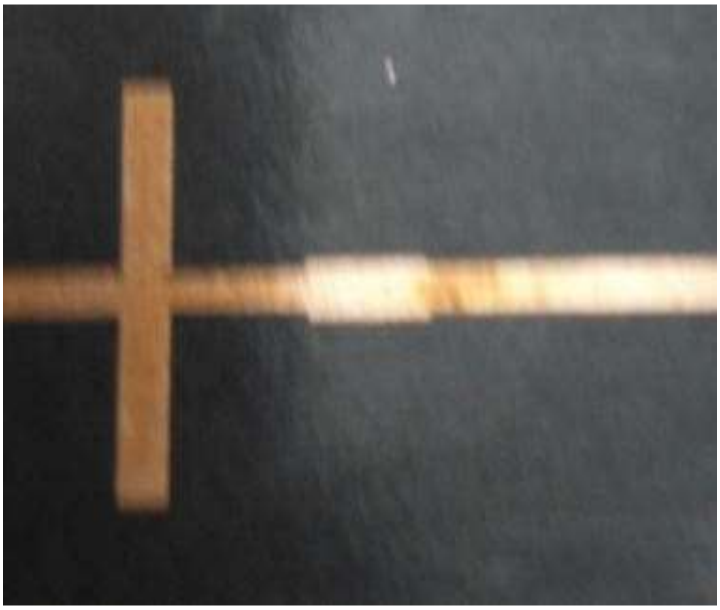

Figure 6.9:1st order microstrip differentiator-II.

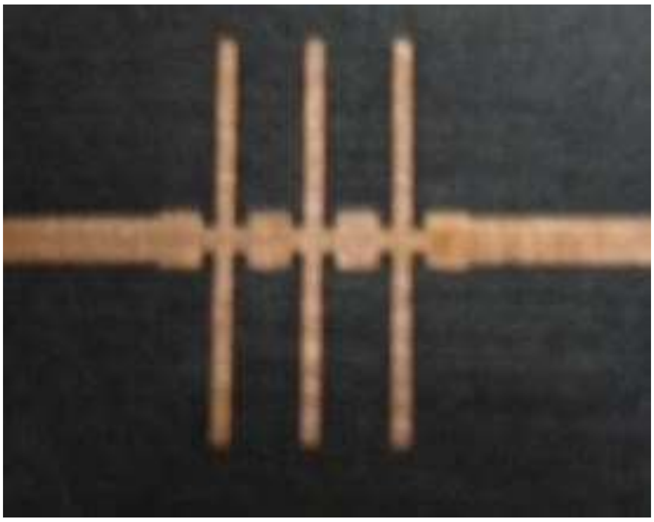

Figure 6.10: 2nd order microstrip differentiator-I

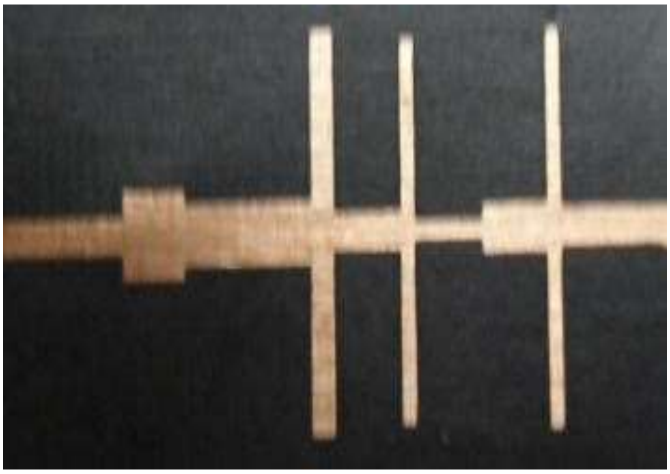

Figure 6.11:2nd order microstrip differentiator-II

6.7 Soldering the Terminal Connector

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

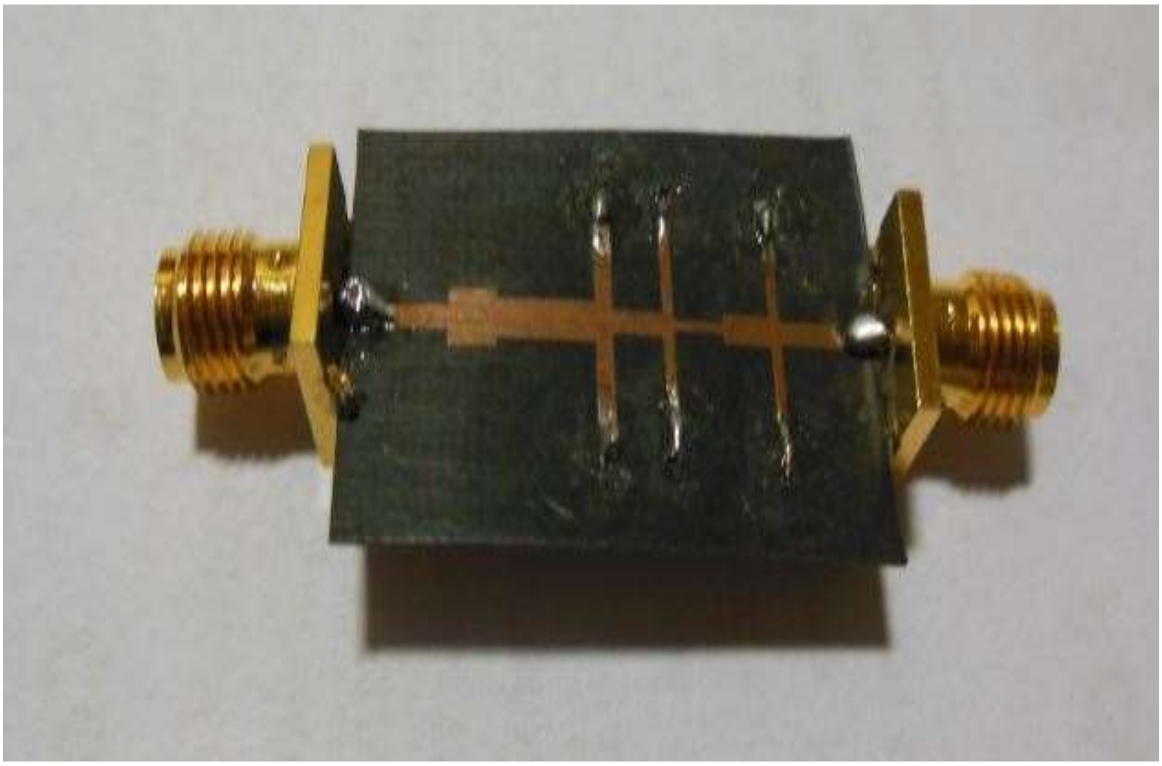

Figure 6.12: 2st order microstrip line based microwave differentiator

6.8 Testing of Microwave Differentiator

Testing of any circuit fabricated using micrstrip 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.

6.8.1 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, 50 Ω 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 6.13: Vector Network Analyzer

6.8.2 Test Result of Microwave Differentiator

Microwave differentiator of 2nd order is tested on Vector network Analyzer and transmission coefficient S_{21} of circuit is obtained and it shown in figure 4.14.Magnitude plot of microwave differentiator is obtained in frequency range of 1to 10 GHz in dB

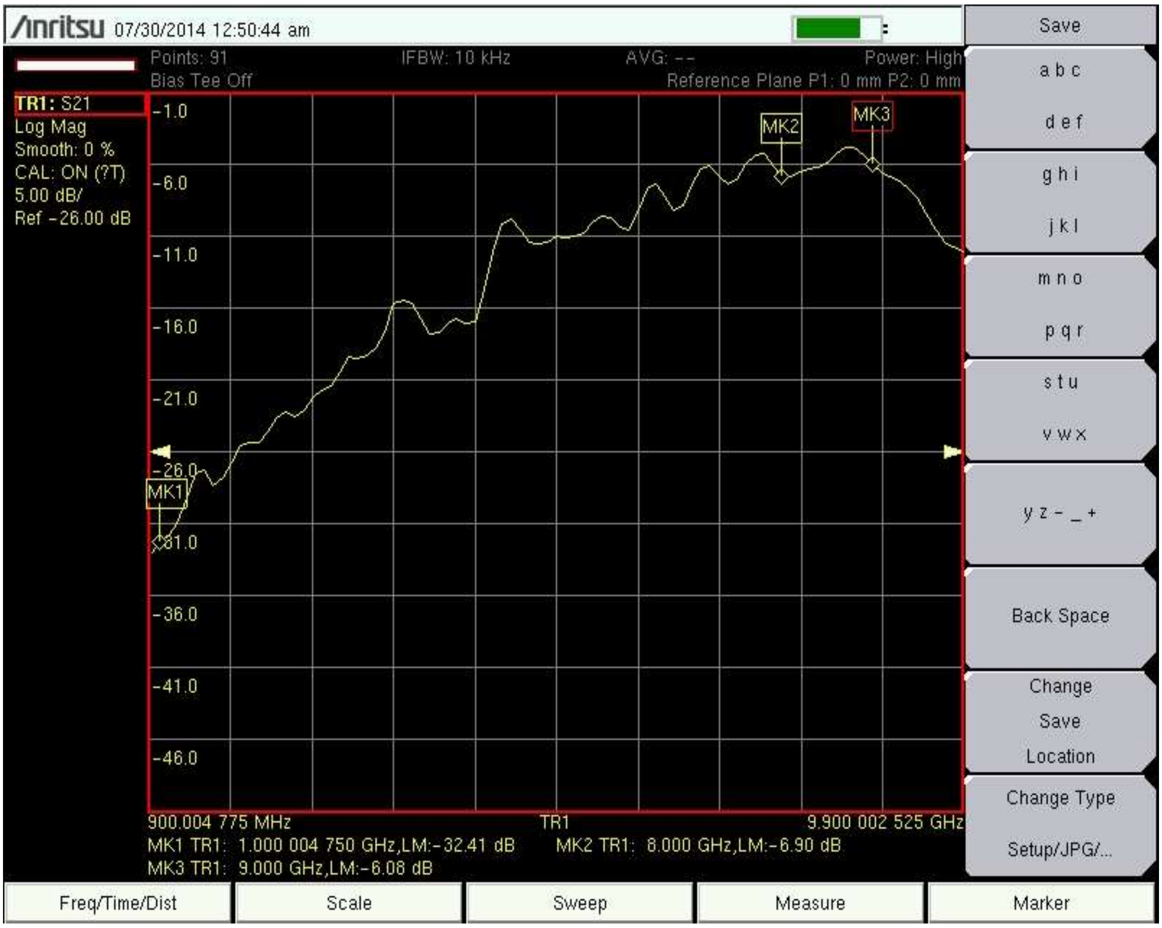

Figure 6.14: Transmission coefficient S_{21} *of 2nd order microwave differentiator using VNA*

Chapter 7

Results and Discussion

7.1 Results

The design of accurate digital differentiator has been presented. Thus the designed First and Second order differentiator are of high accuracy. The low order of the differentiator makes it suitable for real-time applications. It approximates an ideal differentiator in the pass band region with accuracy comparable to that obtained by higher order filters. The proposed method is fast and eases the design complexity of wideband digital First and and higher differentiators.

- It has been shown that zeros occurring on the unit circle $|z| = 1$ can be implemented by using shunted transmission-line elements.
- From figure 3.3, we came across conclusion that better linearity in amplitude response comes when d = 0.166. The relative error is less than 1% (or -40dB) when $0 \leq \Omega \leq 0.8\,\pi$. The bilinear transformation, when is one, has a good linearity when the normalized frequency is less than 0.3π. So, bilinear transformation is improper to be adopted as the system function of a wide-band differentiator.
- The magnitude response of simulated differentiators extends good linearity agreement of full band normalised frequency, which corresponds1 to 10GHz.
- Fabrication of all four design of both first and second order microstrip differentiator are build on a RT/duroid® 5880 substrate with a thickness of 15mil (0.381mm) and relative dielectric constant of ε = 2.2.
- Finally, Vector Network Analyzer is used to test the all specificetion of 2^{nd} order microwave differentiatior and compare it with simulated result obtained from ADS software.

7.2 Conclusions

The objective of this work has been to

- Simple and accurate formulations have been employed to represent both first and second-order differentiators in the Z-domain.

- In particular, the Z-domain representations of scattering characteristics of equal length non-uniform transmission lines facilitate the implementation of discrete domain differentiators in the microwave frequency range. These differentiators have been implemented by using microstrip transmission lines.
- Layout design of differentiators are fabricated using microstrip lines. Tested result of device shows small deviation from simulated result due practical limitations of fabrication process involve.
- It is possible that many other circuits developed in DSP studies can also be implemented by using transmission lines for microwave applications.

7.3 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. Therefore, the microwave differentiators could not reach the designed frequency range perfectly. After fabrication of all four differentiator, unavailability of SMA connector is result into testing of only one design is possible. Due to this, it is not possible to test other three designs and these are remain incomplete. When the SMA connectors connected to both end of the differentiators, 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 fabrication process was short circuit each of the microstrip transmission lines by creating the hole and extra wire was added to ground each end of the transmission line. Process result into change the effective length of device and contamination of conductor at each end. That can also affect the result of the differentiator. 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.

7.4 Future Scope of present work

By using different configuration of serial, short, and open stub Transmission line we can implement many other circuits developed in DSP studies. The future extension of this project shall be:

- Implementation of higher order integrators and differentiator, variable time constant differentiators, variable time constant integrators and
- Different types of filters such as Low pass, high pass, bandpass and bandstop filter for high frequency application.
- Design and fabrication of microwave differentiator using different substrate and compare the performance of all higher order differentiators.

REFERENCES

[1] M. I. Skolnik, *Introduction to Radar Systems*. NewYork:McGraw- Hill, 1980, pp. 399–408.

[2] S. Usui and I. Amidror, “Digital-low pass differentiation for biological signal processing,” *IEEE Trans. Biomed. Eng.*, vol. BME 29, no. 10, pp. 686–692, Oct. 1982.

[3] B. V. K. V. Kumar and C. A. Rahenkamp, “Calculation of geometric moments using Fourier plane intensities,” *Appl. Opt.*, vol. 25, no. 6, pp. 997–1007, Mar. 1986.

[4] M. H. Asghari and J. Azaña, “Proposal and analysis of a reconfigurable pulse shaping technique based on multi-arm optical differentiators,” *Opt. Commun.*, vol. 281, no. 18, pp. 4581–4588, Sep. 2008.

[5] J. P. Yao, “Photonics for Ultrawideband communications,” *IEEE Microw. Mag.*, vol. 10, no. 4, pp. 82–95, Jun. 2009.

[6] P. Horowitz andW. Hill, *The Art of Electronics*, 2nd ed. Cambridge, U.K.: Cambridge Univ. Press, 1989.

[7] M. A. Al-Alaoui, “Novel approach to designing digital differentiators,” *Electron. Lett.*, vol. 28, no. 15, pp. 1376–1378, Jul. 1992.

[8] S.-C. Pei and J.-J. Shyu, “Analytic closed-form matrix for designing higher order digital differentiators using eigen-approach,” *IEEE Trans. Signal Process.*, vol. 44, no. 3, pp. 698–701, Mar. 1996.

[9] N. Q. Ngo, S. F. Yu, S. C. Tjin, and C. H. Kam, “A new theoretical basis of higher-derivative optical differentiators,” *Opt. Commun.*, vol. 230, no. 1–3, pp. 115–129, Jan. 2004.

[10] Y. Park, J. Azaña, and R. Slavík, “Ultrafast all-optical first- and higher order differentiators based on interferometers,” *Opt. Lett.*, vol. 32, no. 6, pp. 710–712, Mar. 2007.

[11]R. Mersereau& M. Smith, *Digital Filtering: A Computer Laboratory Textbook*.John Wiley & Sons, Inc, 1994.

[12] N. K. Berger, B. Levit, B. Fischer, M. Kulishov, D. V. Plant, and J. Azaña, “Temporal differentiation of optical signals using a phase-shifted fiber Bragg grating,” *Opt. Exp.*, vol. 15, no. 2, pp. 371–381, Jan. 2007.

[13] M. A. Preciado, V. Garcia-Muñoz, and M. A. Muriel, “Ultrafast alloptical th-order differentiator based on chirped fiber Bragg gratings,” *Opt. Exp.*, vol. 15, no. 12, pp. 7196–7201, May 2007.

[14] B.Kumar and S. C. Dutta-Roy, “Design of digital differentiators for low-frequencies,” *Proc. IEEE*, vol. 76, pp. 287–289, Mar. 1988.

[15] S. C. Pei and J. J. Shyu, “Analytic closed-form matrix for designing higher order digital differentiators using eigen-approach,” *IEEE Trans. Signal Processing*, vol. 44, pp. 698–701, Mar. 1996.

[16] Y. Park, M. H. Asghari, R. Helsten, and J. Azaña, “Implementation of broadband microwave arbitrary-order time differential operators using a reconfigurable incoherent photonic processor,” *IEEE Photon. J.*, vol. 2, pp. 1040–1050, Dec. 2010.

[17] A. Filin, M. Stowe, and R. Kersting, “Time-domain differentiation of terahertz pulses,” *Opt. Lett.*, vol. 26, no. 24, pp. 2008–2010, Dec. 2001.

[18] C. Y. Tsai and S. K. Jeng, “Design of an ultra-wideband waveform shaping network using an analog microwave differentiator array fed by a Gaussian pulse signal,” in *IEEE AP-S Int. Symp. and USNC/URSI Nat. Sci. Meeting*, Albuquerque, NM, 2006, pp. 1307–1310.

[19] C.-W. Hsue,L.-C. Tsai, andK.-L.Chen, “Implementation of first-order and second-order microwave differentiators,” *IEEE Trans. Microw. Theory Techn.*, vol. 52, no. 5, pp. 1143–1147, May 2004.

[20] H. V. Nguyen and C. Caloz, “First- and second-order differentiators based on coupled-line directional couplers,” *IEEE Microw. Wireless Compon. Lett.*, vol. 18, no. 12, pp. 791–793, Dec. 2008.

[21] I. Arnedo, J. D. Schwartz, M. A. G. Laso, T. Lopetegi, D. V. Plant, and J. Azaña, “Passive microwave planar circuits for arbitrary UWB pulse shaping,” *IEEE Microw. Wireless Compon. Lett.*, vol. 18, no. 7, pp. 452–454, Jul. 2008.

[22] P. Rulikowski and J. Barrett, “Adaptive arbitrary pulse shaper,” *IEEE Microw. Wireless Compon. Lett.*, vol. 18, no. 5, pp. 356–358, May 2008.

[23] P. Rulikowski and J. Barrett, “Application of nonuniform transmission lines to ultra wideband pulse shaping,” *IEEE Microw. Wireless Compon. Lett.*, vol. 19, no. 12, pp. 795–797, Dec. 2009.

[24] J. Han and C. Nguyen, “A new ultra-wideband, ultra-short monocycle pulse generator with reduced ringing,” *IEEE Microw. Wireless Compon. Lett.*, vol. 12, no. 6, pp. 206–208, Jun. 2002.

[25] “Part 15 rules for unlicensed RF devices,” FCC,Washington, DC, Aug. 2006. [Online]. Available: http://www.fcc.gov/oet/info/rules

[26] R. J. Fontana, “Recent system applications of short-pulse ultra-wideband (UWB) technology,” *IEEE Trans. Microw. Theory Techn.*, vol. 52, no. 9, pp. 2087–2104, Sep. 2004.
[27] G. R. Aiello and G. D. Rogerson, “Ultra-wideband wireless systems,” *IEEE Microw. Mag.*, vol. 4, no. 2, pp. 36–47, Jun. 2003.
[28] P. Withington, H. Fluhler, and S. Nag, “Enhancing homeland security with advanced UWB sensors,” *IEEE Microw. Mag.*, vol. 4, no. 3, pp. 51–58, Sep. 2003.
[29] I. Gresham, A. Jenkins, R. Egri, C. Eswarappa, N. Kinayman, N. Jain, R. Anderson, F. Kolak, R. Wohlert, S. P. Bawell, J. Bennett, and J.-P. Lanteri, “Ultra-wideband radar sensors for short-range vehicular applications,” *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 9, pp. 2105–2122, Sep. 2004.
[30] A. G. Yarovoy, L. P. Ligthart, J. Matuzas, and B. Levitas, “UWB radar for human being detection,” *IEEE Aerosp. Electron. Syst. Mag.*, vol. 21, no. 3, pp. 10–14, Mar. 2006.
[31] T.-Y. Tzou and F.-C. Chen, “New 0.18- m CMOS pulse generator for impulse radio ultra-wideband communication systems,” *Microw. Opt. Technol. Lett.*, vol. 49, no. 2, pp. 342–345, Feb. 2007.
[32] H. Sheng, P. Orlik, A. M. Haimovich, L. J. Cimini Jr., and J. Zhang, “On the spectral and power requirements for ultra-wideband transmission,” in *Proc. IEEE Int. Commun. Conf.*, Anchorage, AK,May 2003, vol. 1, pp. 738–742.