

Design and Performance Analysis of 2.45 GHz Microwave Multilayer Interdigital Band Pass Filter

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Abstract- Filters with advanced features have numerous applications in many modern technologies. Microwave bandpass filter is one of those filters that can be used for wireless communication .This paper emphasis how to design an interdigital microwave bandpass filter for 2.45GHz. So, this paper focuses on the design of parallel coupled line bandpass filter, two sets of interdigital band-pass filter at 2.45 GHz on single and multilayer structure, compare among these filters, proposed one suitable for users. Primarily coupled line filter, then asymmetrical and symmetrical interdigital band pass filters have been designed for single and multilayer structure. Simulated results are very close to the desired response. The results showed that each filter works well at operating frequency. Asymmetric filters have excellent return loss at center frequency, very sharp roll off factor. In contrast, symmetrical interdigital band-pass filters have narrow bandwidth and minimized ripple. Finally, the multilayer configuration with dielectric substrates showed that the bandwidth is broaden up, insertion loss and return loss are reduced than single layer configuration.

***Key words*— Interdigital Bandpass Filter, Microstripline, Coupled-line, ADS, Sonnet, SAI, SSI, MAI, and MSI.**

1. INTRODUCTION

A microwave filter is a two-port network to provide transmission at frequencies within the pass band of the filter and attenuation in the stop band of the filter for controlling the frequency response at a certain point in a microwave system. Generally speaking, a filter is any passive or active network which has a predetermined frequency response in terms of amplitude and phase. At microwave range, the microwave filter passes energy at a specified resonant frequency. There are many important roles of a filter in much RF/microwave applications. Now communication industry requires more stringent requirements—higher performance, smaller size, lighter weight, and lower cost. Modern technologies introduces novel materials and fabrication technologies, such as high-temperature superconductors (HTS), low-temperature co-fired ceramics (LTCC), monolithic microwave integrated circuits (MMIC), microelectromechanic system (MEMS), and micromachining technology. These novel materials and technologies can be used to fabricate more efficient and more functional filters which can be used in wireless LAN and Bluetooth application.

In modern communication systems, high performance and small size bandpass filters are essentially required to enhance the system performance and to reduce the fabrication cost. Existing Parallel coupled microstrip filters have been widely used in the RF front end of microwave and wireless communication systems for decades. But their large size is problematic with the systems where size is important consideration. To overcome this drawback, the compact filter structures are required in demand for space-limited operations. Interdigital filter is one of the available compact configurations. There are many advantages using this structure. This paper focuses on the performances of Coupled line microstrip Bandpass filter, symmetrical and symmetrical interdigital filter configuration on single layer and multilayer structures.

2. RELATED WORKS

The basic concept of filters was proposed independently by Campbell and Wagner. Their obtained results are from earlier work on loaded transmission lines and classical theory of vibrating systems. Afterwards, two different filter theories were developed, known as image parameter theory and insertion loss theory [1], [2].

Then, the image parameter method was developed by Campbell, Zobel, and some others. This method involves specification of the pass-band and stop-band characteristics for a cascade of 2-port networks. The image viewpoint, used in this method is similar to the wave viewpoint used in the analysis of transmission lines. Hence, this method provides a link between practical filters and infinite periodic structures [3]. Simple filters can be designed without requiring a computer.

However, sometimes impractical component values can be obtained using image parameter method [12]. This approximate technique was the only practical filter design method until computers become widespread. The insertion loss theory, also known as modern filter theory, is far more complex but accurate design technique. It owns its origin to the work of Cauer and Darlington who put forward a theory that involves a set of problems relating to modern network synthesis [13]. This design method consists of two basic steps: determination of a transfer function that approximates required filter specification and synthesis of electrical circuit using frequency response estimated by the previous transfer function. Although this method was very efficient, it had become widely used only since high speed computers, used to make all necessary complex calculations, became widely available. In the design of many distributed resonator filters values of elements of low-pass prototype network are used to determine important transmission characteristic of filters using formula derived for each type of filters [4].

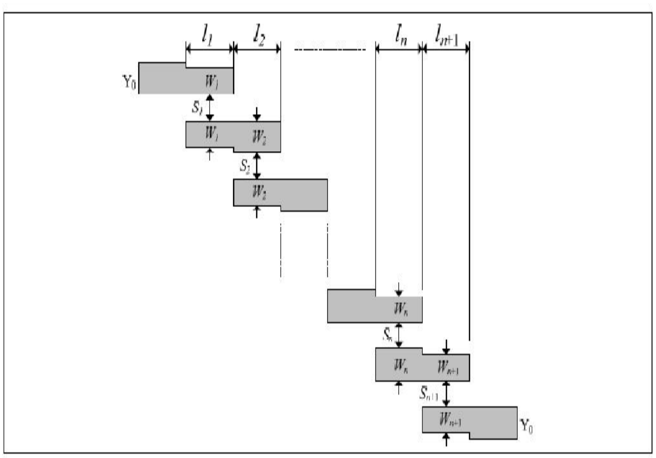
In wireless communications, bandpass filters are the most widely used filter. For the design of microstrip bandpass filters, several various techniques exist and most of proposed novel filters with advanced characteristics are based on these several structures [5].

Interdigital filters consist of parallel coupled quarter-wavelength lines which are short-circuited at one end and open-circuited at another end [6]. Interdigital filters have the first spurious harmonic at $3f_0$. Coupling between interdigital lines is stronger than between couple-lines and gap between resonators can be larger, making interdigital filters simpler to fabricate for high frequency and wide bandwidth applications, when dimensions of filters are quite small [7]. Accurate design of interdigital filters in micro-strip also involves optimization techniques, for example aggressive space mapping optimization [8] or optimization that uses an accurate computer aided design method which is based on the identification of direct and parasitic coupling of each resonator [9].

Due to the development of wireless communications and the appearance of new systems there is high demand in small size, low cost filters with high performance. Therefore, miniaturization of bandpass filters with improvement of their characteristics is a big challenge in modern filters design. This is achieved by improvement of conventional concepts and approaches, as well as by introduction of new topologies and designs like interdigital filter.

3. PARALLEL COUPLED-LINE BANDPASS FILTERS

Figure (3.1) illustrates a general structure of parallel coupled-line microstrip bandpass filter that uses half-wavelength line resonators. They are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators, and thus, this filter structure is particularly convenient for constructing filters having a wider bandwidth as compared to the other structures.



Fig(3.1): General structure of parallel coupled-line microstrip bandpass filter.

The design equations for this type of filter are given by[10]

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FWB}{g_0 g_1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FWB}{2}\frac{1}{\sqrt{g_j g_{j+1}}} \quad j = 1 to n-1 \ldots\ldots\ldots.. (2)$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FWB}{2 g_n g_{n+1}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, n is a number of filter order, and g_0, g_1 . . . g_n are the element of a ladder-type low-pass prototype with a normalized cutoff Ω_c = 1, and FBW is the fractional bandwidth of bandpass filter. $J_{j,j+1}$ are the characteristic admittances of J-inverters and Y_0 is the characteristic admittance of the terminating lines. The reason for this is because the both types of filter can have the same low-pass network representation. However, the implementation will be different.

To realize the J-inverters obtained above, the even- and odd-mode characteristic impedances of the coupled microstrip line resonators are determined by

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad j = 0 ton \cdots (4)$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad j = 0 ton \quad \cdots (5)$$

The use of the design equations and the implementation of microstrip filter of this type will be illustrated after few sections.

4. INTERDIGITAL BAND PASS FILTER

The Interdigital configuration is the most compact filter where the resonators are placed side by side with one end short circuited and other end open circuited alternatively as shown in figure(4.1) [9]. The filter configuration shown, consists of an array of n TEM- mode or quasi-TEM- mode transmission line resonators, each of which has an electrical length 90º at center frequency, f_0 . In general, the physical dimensions of the line elements or the resonators can be the same or different depending on the designs. Coupling is achieved by way of the fields fringing between adjacent resonators separated by spacing $S_{i,i+1}$ for i = 1 .. n-1. The filter input and output used tapped lines, each with a characteristic admittance, Y_t which may set to be equal the source or load characteristic admittance Y_0. An electrical length is $\theta_{t,}$ measured away from the short circuited end of the input or output resonator, indicates the tapping position, where $Y_{1=}$ Y_n denotes the single microstrip characteristic impedance of the input or output resonator.

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Interdigital band pass filters shown in Figure (4.1) have several features such as [11]

- Very compact structures.
- The tolerances required in manufacture are relatively relaxed because of the relatively large spacing between resonator elements.
- The second pass band is centered at three times the center frequency of the first pass band. Besides that, there are no possibility spurious responses in between.
- Filter can be fabricated in structural forms, which are self-supporting so that dielectric material need not be used. Thus, electric loss can be eliminated.
- Strength of the stop band and rates of cutoff can been enhanced by multiple order poles of attenuation at dc and even multiples of the center frequency of the first pass band.

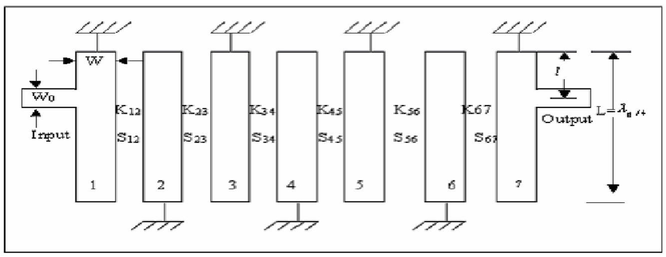

Figure (4.1): Interdigital band pass filter structure

W_0 = width of characteristic impedance
W = width of resonator
K = coupling efficiency
S = space between resonator
L= length of resonator

This type of microstrip band pass filter is compact, but requires use of grounding microstrip resonator, which is accomplished with via holes. However, because the resonators are quarter-wavelength long using the grounding, the second pass band filter is centered at about three times the center frequency of the desired first pass band, and there are no possibilities of any spurious response in between.

4.1. INTERDIGITAL BAND PASS FILTER DESIGN

Original theory and design procedure for interdigital band pass filters with coupled-line input or output are shown below. Explicit design equations for the type of band pass filter with tapped line are given by [9].

The electrical length can be obtained from

$$\theta = \frac{\pi}{2}\left(1 - \frac{FBW}{2}\right) \quad \text{............(6)}$$

Where, FBW is the fractional bandwidth and g_i represents the element values of a ladder type of low pass prototype filter with normalized cutoff frequency at Ω_c=1.

The admittance is,

$$Y = \frac{Y_1}{\tan\theta} \quad \text{.................. (7)}$$

Inverter admittance of each resonator is expressed by

$$J_{i,i+1} = \frac{Y}{\sqrt{g_i g_{i+1}}} \quad \text{for i=1 to n-1.........(8)}$$

$$Y_{i,i+1} = J_{i,i+1}\sin\theta \quad \text{for i=1 to n-1.........(9)}$$

Self Capacitance, C_i (i = 1 to n) per unit length for the each line elements can be obtained from

$$C_1 = \frac{Y_1 - Y_{1,2}}{v}$$

$$C_n = \frac{Y_1 - Y_{n-1,n}}{v}$$

$$C_i = \frac{Y_1 - Y_{i-1,i} - Y_{i,i+1}}{v} \quad \text{for } i = 2 \text{ to } n-1$$

.........................(10)

Mutual Capacitance, $C_{i,i+1}$ (i = 1 to n - 1) per unit length for the each line elements can be obtained from

$$C_{i,i+1} = \frac{Y_{i,i+1}}{v} \quad \text{for i=1 to n-1...............(11)}$$

C_t is the capacitance to be loaded to the input and output resonators in order to compensate for resonant frequency shift due to the effect of the tapped input and output.
It can be obtained from

$$C_t = \frac{\cos\theta_t \sin^3\theta_t}{\omega_0 Y_t\left(\frac{1}{Y_0^2} + \frac{\cos^2\theta \sin^2\theta_t}{Y_t^2}\right)}$$

...........................(12)

Where, $Y_t = Y_1 - \frac{Y_{1,2}^2}{Y_1}$ and $\theta_t = \frac{\sin^{-1}\left(\sqrt{\frac{Y \sin^2\theta}{Y_0 g_0 g_1}}\right)}{1 - \frac{FBW}{2}}$

.... (13)

It may also be desirable to use the even and odd mode impedances for filter designs. The self and mutual capacitances per unit length of a pair of parallel – coupled lines denoted by a and b may be related to the line characteristic admittances and impedances by:

$$Y_{oe}^a = vC_a \qquad Y_{oo}^a = v(C_a + 2C_{ab})$$

$$Y_{oe}^b = vC_b \qquad Y_{oo}^b = v(C_a + 2C_{ab})$$

$$Z_{oe}^a = \frac{C_a}{vF} \qquad Z_{oe}^a = \frac{C_b + 2C_{ab}}{vF}$$

$$Z_{oo}^b = \frac{C_b}{vF} \qquad Z_{oe}^b = \frac{C_a + 2C_{ab}}{vF}$$

$$F = C_a C_b + C_{ab}(C_a + C_b)$$

.... (14)

In order to obtain the desired even and odd mode impedances, the coupled lines in association with adjacent coupled resonators will generally have different line widths, resulting in pairs of symmetric coupled lines. The two modes, which are also termed "c" and "π " modes correspond to the even and odd modes in the symmetric case, have different characteristic impedances, This may cause some difficulty for filter design. To overcome it, an approximate design approach is used.
The designs equations are:

$$Z_{oo1,2} = Y\frac{1}{Y_1 - Y_{1,2}} \;,\; Z_{oo1,2} = Y\frac{1}{Y_1 + Y_{1,2}}$$

$$Z_{oei,i+1} = Y\frac{1}{2Y_1 - 1/Z_{oei-1,i} - Y_{i.i+1} - Y_{i-1,i}} \quad \text{for i=2 to n-2}$$

$$Z_{ooi,i+1} = \frac{1}{2Y_{i,i+1} + 1/Z_{oei-1,i}} \quad \text{for i=2 to n-2}$$

$$Z_{oen-1,n} = \frac{1}{Y_1 - Y_{n-1,n}}, Z_{oon-1,n} = \frac{1}{Y_1 + Y_{n-1,n}}$$
………………(15)

Where, $Z_{oei,i+1}$ and $Z_{ooi,i+1}$ are the even and odd mode impedances of coupled lines associated with resonator i and i + 1. For asymmetrical coupled lines for a filter design, each of the even and odd mode impedances may be seen as an average of the two c mode impedances for adjacent coupled lines. Similarly, each of the odd mode impedances may be seen as an average of the two associated modes impedances The normalized coupling coefficient of a pair of resonators is given by

$$K_{n,n+1} = \frac{f_2 - f_1}{f_0\sqrt{(g_g g_{n+1})}} \quad \text{……….. (16)}$$

where $f_0 = (f_2 + f_1)/2$, the center frequency, are the low pass prototype element values normalized to $\omega_c = 1$ and r=1.
The single loaded Q for the filter is given by

$$Q_L = \frac{f_0 g_1}{(f_2 - f_1)} = \frac{f_0 g_{n+1}}{(f_2 - f_1)} \quad \text{………. (17)}$$

The position of the input and output line point's l can be calculated from

$$\frac{Q_L}{Z_0 / Z_{01}} = \frac{\pi}{\left[4\sin^2(\pi / 2L)\right]} \quad \text{………. (18)}$$

4.2. ASYMMETRICAL INTERDIGITAL BAND PASS FILTER

Asymmetrical interdigital band pass filter is interdigital band pass filter with asymmetrical coupled lines. This means that the resonator will not have same line widths [9]. Figure (4.2) shows an example of asymmetrical interdigital band pass filter.

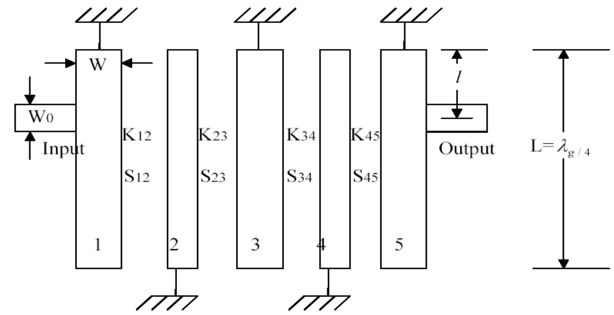

Figure (4.2): Asymmetrical interdigital band pass filter

4.3. SYMMETRICAL INTERDIGITAL BAND PASS FILTER

In symmetrical interdigital band pass filter, all the resonators will have the same line width [9]. There are two advantages of this configuration. Firstly, is that more design equations and data on symmetric coupled lines are available for the filter design. Secondly, the unloaded quality factor of each resonator will be much the same. However, a difficulty arises because it is generally not possible to realize arbitrary even and odd mode impedances with a fixed line width.
Therefore, instead of matching to the desired $Z_{0ei,i+1}$ and $Z_{0oi,i+1}$, the spacing $S_{i,i+1}$ are adjusted for matching to

$$K_{i,i+1} = \frac{Z_{0ei,i+1} - Z_{0oi,i+1}}{Z_{0ei,i+1} + Z_{0oi,i+1}} \quad \text{………. …. (19)}$$

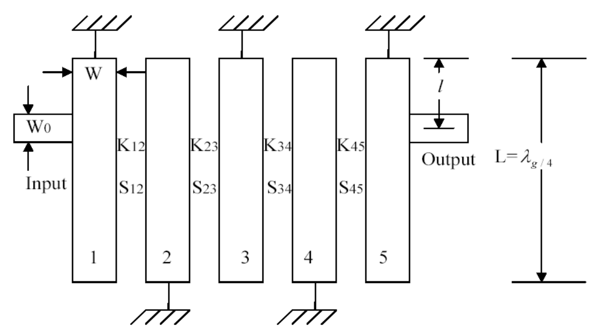

Figure (4.3): Symmetrical interdigital band pass filter.

4.4. MULTILAYER INTERDIGITAL BAND PASS FILTER

Although multilayer circuit configuration have been widely used for digital and low frequency system, Radio Frequency, RF and microwave circuits are usually fabricated using single layer configuration. The use of multilayer configurations makes microwave circuits more compact and the design more flexible. For multilayer band pass filter design, various conductors may be located at different layers as shown in Figures 4.4 and 4.5[16].

The overall procedure can be broken up into three steps:

- Evaluation of normal mode parameters for various coupled line sections.
- Determine physical dimensions to obtain the required normal mode parameters as computed in step one.
- Simulation of physical structure obtained in step two to verify the design.

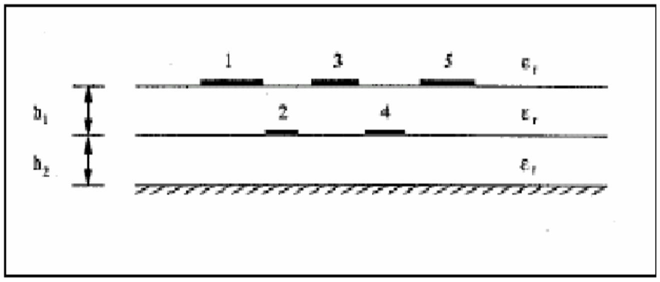

Figure (4.4): Cross sectional view of two-layer filter configuration [4]

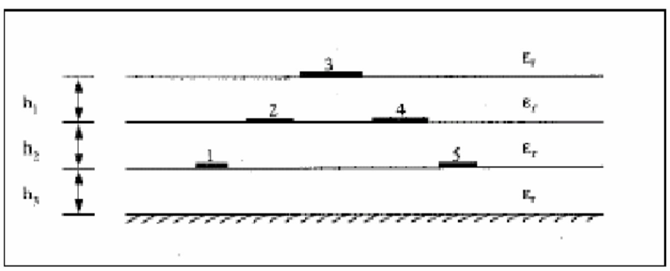

Figure (4.5): Cross sectional view of three-layer filter configuration [12].

5. DESIGN & SIMULATION

In general there are two types of filter, one is composed of lumped elements and another is of distributed elements. But, at high frequency (e.g. Microwave frequency) the distributed effect will be dominant, and this is the cause of the degradation of performance of lumped element filter. Due to this reason, most of the microwave bandpass filters are based on distributed elements (e. g. waveguides, microstrip lines, coplanar waveguide lines).The easy integration technique and low cost make them the main candidates for microwave filter designs.

To design an efficient filter, use of filter synthesizer technique is very important. There are two main filter synthesizer techniques: parameter method and insertion loss method [12]. In this paper, insertion loss method is used because it gives complete specification of physically realizable frequency characteristics over the entire pass and the stop bands from which the microwave filters are synthesized or designed preferable.

5.1. INSERTION LOSS METHOD

Basic design microwave filters are made from a prototype low pass design. In this method, a physically realizable network is synthesized that will give the desired insertion loss versus frequency characteristic. This method consists of the steps below:

- Design a prototype low pass filter with the desired pass band characteristic.
- Transformation of this prototype network to the required band pass filter with the specified centre and band edge frequencies.
- Realization of the network in the microwave form by using sections of microwave transmission lines, whose reactance corresponds to those of distributed circuit elements.

5.2. CHEBYSHAPE PROTOTYPE FILTER

For Chebyshape low-pass filter with an insertion loss L_{Ar}=0.2dB at the cutoff Ω_c=1, the element values computed by appropriate equations for Chebyshape filter .The values for n=3 are given below:

Table (1): Element values for Chebyshape low-pass prototype filters (n=3, Ω_c=1, L_{Ar}=0.2dB)

g_0	g_1	g_2	g_3	g_4
1.0	1.228	1.153	1.228	0.1

5.3. SIMULATOR USED

In this work, Advanced Design Studio 2009(ADS) and Sonnet Lite 12.53 have been used. They could be integrated within themselves and provide a friendly interface for the user.

5.4. DESIGN SPECIFICATION

For the first step of designing bandpass filter principle, the number of sections from the specified attenuation characteristics has to determine. Table (2) shows the chosen of design specification to use for design bandpass filter response.

Table (2): The Design Specification

Filter type	Chebyshape
Number of order ,n	3
Center frequency ,f_0	2.45GHz
Fractional Bandwidth ,Δf	0.122 or 12.24%

The board parameters are as follows:

- Name = Rogers TMM10
- Dielectric constant = 9.6
- Substrates thickness = 1.27 mm
- Metal thickness = 0.035 mm

5.4.1. PARALLEL COUPLED LINE FILTER DESIGN

From Table (1), we have got the element values for a 3^{rd} order Chebyshape Bandpass filter. Using those values, design specification and equation (1) to (5), we get the following table:

Table (3): The values of even and odd characteristic impedance for 3rd order coupled line filter

N	g_n	Z_0J_n	$Z_{0e}J_n$	$Z_{0o}J_n$
1	1.228	0.395752	77.6185285	38.0433886
2	1.153	0161633	59.3879113	43.2246113
3	1.228	0161633	59.3879113	43.2246113
4	1	0.395752	77.6185285	38.0433886

Using LineClac of Advanced Design System [13], the values for the resonator spacing s, the length and the width of the traces can be obtained. We get the following table:

Table (4): The values of Width, Length and Sapcing for 3rd order coupled line filter

N	Width,w(mm)	Spacing,s(mm)	Length,l(mm) (90°)
1	0.852495	0.349528	12.3555
2	1.169040	1.122310	12.0910
3	1.169040	1.122310	12.0910
4	0.852495	0.349528	12.3555

The calculated values are then implemented using Advanced Design Studio 2009. “MCFIL” blocks are used as coupled lines. The corresponding tuned values are then put on their respective fields of the blocks. Input and output are terminated with 50. line as “MLIN” blocks.The circuit schematic view is shown in Figure (5.1).

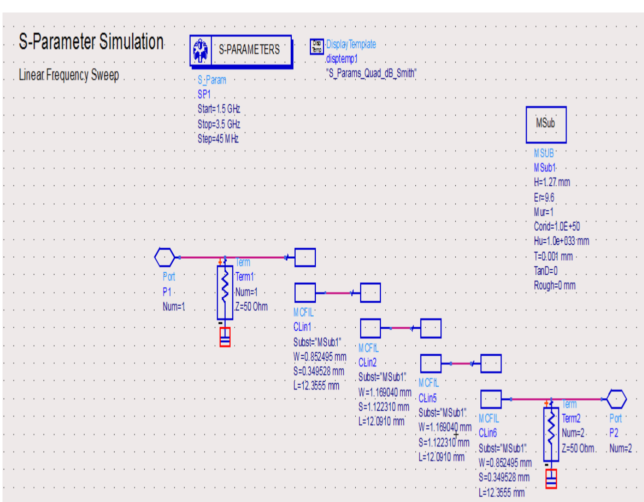

Figure (5.1): Schematic View of 3rd order Coupled Line Filter

5.4.2. SINGLE LAYER INTERDIGITAL FILTER DESIGN

5.4.2.1. SINGLE LAYER ASYMMETRICAL INTERDIGITAL FILTERS (SAI).

Using the values of table (1) for a 3^{rd} order Chebyshape filter, design specification and equation (6) to (15), we get the following Table of even and odd mode impedances

Table (5): The values of Even and Odd mode characteristics impedance

I	$Z_{0ei,i+1}$	$Z_{0oi,i+1}$
1	49.442	40.062

Filter dimension of the SAI filter is calculated from graph of even and odd mode characteristic impedances for coupled microstrip lines[14].From this graph, we get the width of two coupled lines (W) and spacing between them (s) are shown in Table (6).

Table (6): SAI filter design parameter

W_1 mm	W_2m m	W_3m m	L mm	S_{12} mm	S_{23} mm	ε_{re}^{e}	ε_{re}^{o}	W_t Mm	L_t mm
1.7	1.4	1.7	11.76	1.4	1.3	7.1	5.6	1.2	3

Table (7): Tuned parameter values for SAI filter design

W_1 Mm	W_2m m	W_3 mm	L mm	S_{12} mm	S_{23} mm	ε_{re}^{e}	ε_{re}^{o}	W_t mm	L_t mm
1.7	1.4	1.7	10.3	1.4	1.3	7.1	5.6	1.2	2.5

Those values are than implemented using ADS-2009. Here we use the following T-line Microstrip,

- MACLIN3 used as a coupled section
- MLSC used as short circuited end
- MLEF used as open circuited end
- MTEE-ADS used as tapped line connector
- MLIN used as tapped line

Circuit schematic view is shown in Figure (5.2).

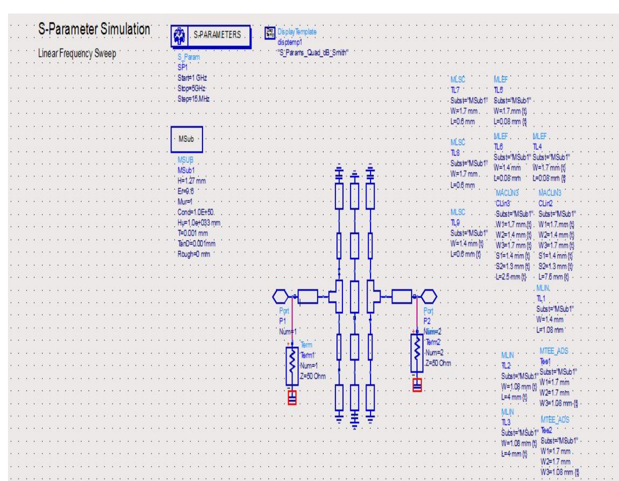

Figure (5.2): Schematic view of SAI Filter circuit

Using Sonnet "Translate only" tool, the schematic view can be translated into a Sonnet file. Which is then can be analyzed by Sonnet software to get the desired frequency response. This translation will then help us to design a multilayer filter. The Sonnet structure for SAI filter is shown in figure (5.3).

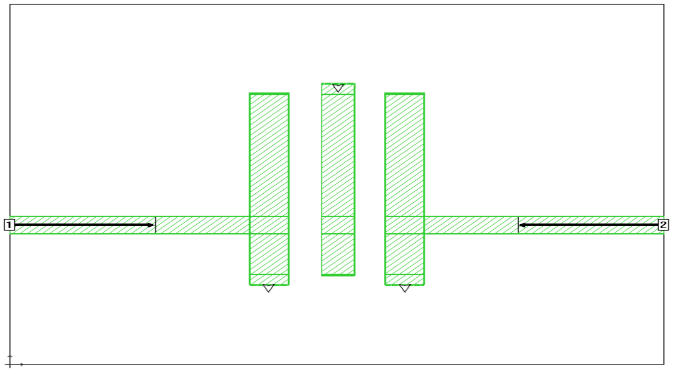

Figure (5.3): Sonnet structure for SAI-3 filter.

5.4.2.2. SINGLE LAYER SYMMETRICAL INTERDIGITAL FILTERS (SSI).

Using the values of table (1) for a 3rd order Chebyshape filter, design specification and equation (19) , we get the following Table of coupling coefficient of SSI filter.

Table (8): the values of Coupling Coefficient

I	$K_{i,i+1}$
1	0.101

Taking w/h=0.7, we can calculate the Width. From coupling coefficient and Q of interdigital filter[17], we get spacing between the resonators as summarized below. From the same graph, we get the Physical length measured from the input or output resonator to tap point. The values are shown in Table 9.

Table (9): SSI filter design parameter

W(mm)	L(mm)	S_{12}(mm)	S_{23}(mm)	W_t(mm)	L_t(mm)
0.9	11.1	2.1	2.1	1.2	2.1

The values are than tuned, to get the desired frequency response.

Table(10): Tuned parameter values for SSI filter design

W(mm)	L(mm)	S_{12}(mm)	S_{23}(mm)	W_t(mm)	L_t(mm)
0.9	11.6	2.1	2.1	1	3

Those values are than implemented using ADS-2009. Here we use the following Tline- Microstrip,

- MACLIN3 used as a coupled section
- MLSC used as short circuited end
- MLEF used as open circuited end
- MTEE-ADS used as tapped line connector
- MLIN used as tapped line

Circuit schematic view is shown in Figure (5.4).

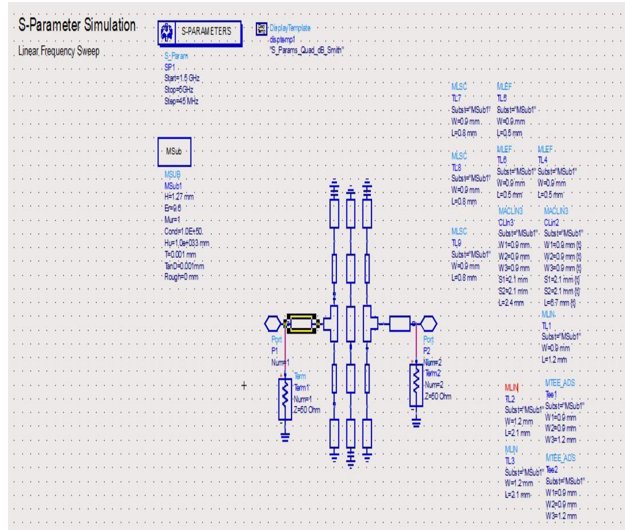

Figure (5.4): Schematic view of SSI Filter circuit

Using Sonnet "Translate only" tool, the schematic view can be translated into a Sonnet file. Which is then can be analyzed by Sonnet software to get the desired frequency response. This translation will then help us to design a multilayer filter. The Sonnet structure for SSI filter is shown in figure (5.5).

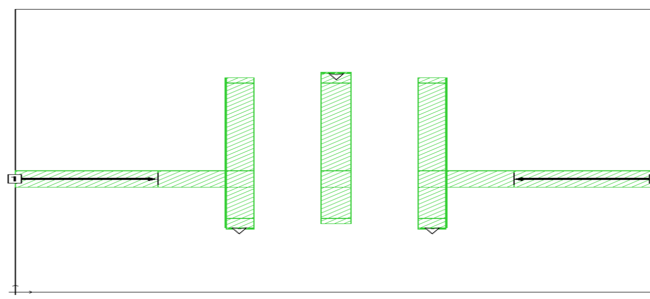

Figure (5.5): Sonnet structure for SSI filter

5.4.3. MULTILAYER INTERDIGITAL FILTER DESIGN

SAI and SSI filters were transformed into two layer configurations.

5.4.3.1. MULILAYER ASYMMETRICAL INTERDIGITAL FILTERS (MAI)

The Sonnet structure for Multilayer Asymmetrical Interdigital Band Pass (MAI) Filters is shown in Figure (5.6) and (5.7).

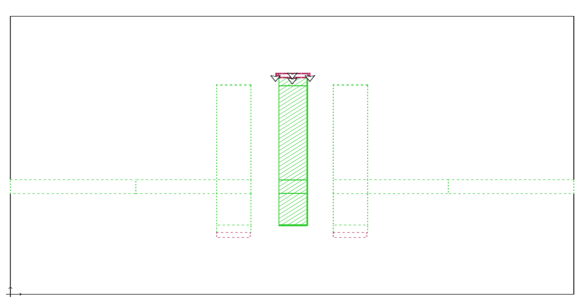

Figure (5.6): Sonnet structure two layer MAI filter (1st layer).

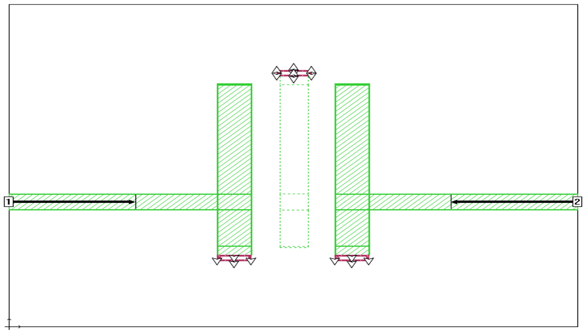

Figure (5.7): Sonnet structure two layer MAI filter (2nd layer).

5.4.3.2. MULILAYER SYMMETRICAL INTERDIGITAL FILTERS (MSI)

The Sonnet structure for Multilayer Symmetrical Interdigital Band Pass (MSI) Filters is shown in Figure (5.8) and (5.9).

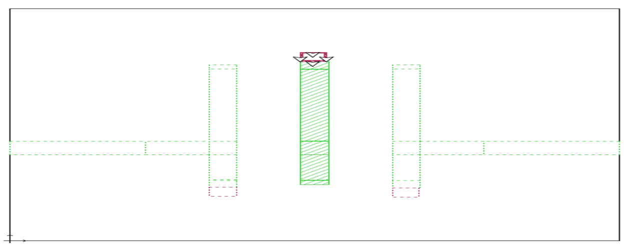

Figure (5.8): Sonnet structure two layer MSI filter (1st layer).

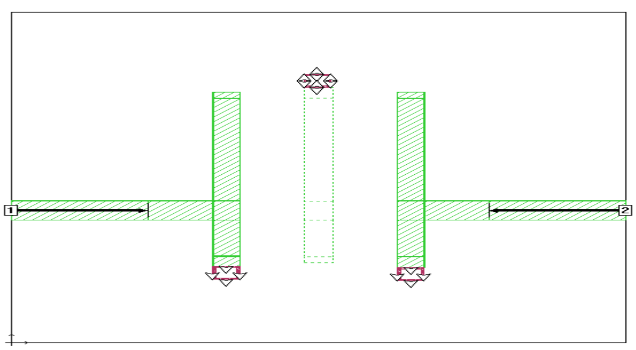

Figure (5.9): Sonnet structure two layer MSI filter (2nd layer).

6. RESULT & DISSCUSION

Once the designing process has been completed, the thesis moves onto the next step, where the simulations are being done to see the result of this project and to analyze whether the project had attained the objective, target and concept. The simulation process covers the entire coupled line filter, single layer asymmetric interdigital filter, and single layer symmetric interdigital filter, and multi layer asymmetric interdigital, multi layer symmetric interdigital filter. Finally, comparison among MSI, SSI, MAI and SAI are shown.

6.1. SIMULATION RESULT OF PARALLEL COUPLED LINE BANDPASS FILTER

Analysis of the parallel coupled line Bandpass filter has been made from the simulation results. The performance of the Parallel Coupled line Bandpass filter is summarized in Table (11).

Table (11): Coupled line filter simulation responses.

Filter	n	|S11| at 2.45 GHz (dB)	|S12| at 2.45GHz (dB)	Bandwidth at 3dB (GHz)
Parallel Coupled line Bandpass filter	3	-13.915	-0.180	0.36

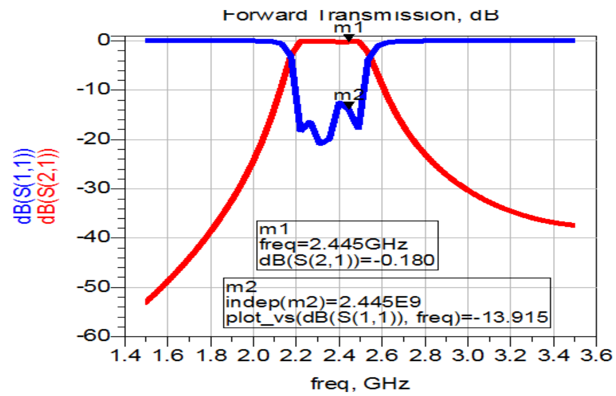

Figure (6.1): Return Loss and Insertion Loss for Parallel Coupled line filter.

In the Figure (6.1), blue and red colored line shows the |S(11)| and |S(21)| response of a microstrip coupled line bandpass filter. At Y-axis, gain in dB has plotted and in X-axis, frequency in GHz has been plotted.

Here, we have seen that the insertion loss is higher, but the bandwidth at -3dB is at 0.36GHz.It is a little bit higher than the desired bandwidth (0.3GHz) of 0.06GHz.

6.2. SIMULATION RESULT OF SAI & SSI FILTERS

Analysis has been made from the simulation results. Table (12) summarized the performances of the SAI and SSI filters. And Figure (6.2) and Figure (6.3) depicts the graphs of the performances.

Table (12): SAI & SSI filter simulation responses.

Filter	n	|S11| at 2.45GHz (dB)	|S12| at 2.45GHz (dB)	Bandwidth at 3dB (GHz)
SAI filter	3	-14.02	-0.176	0.4
SSI filter	3	-14.53	-0.156	0.25

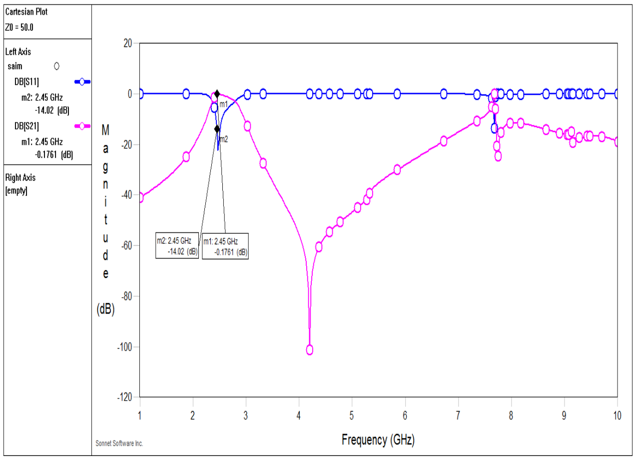

Figure (6.2): Return Loss and Insertion Loss for SAI filter.

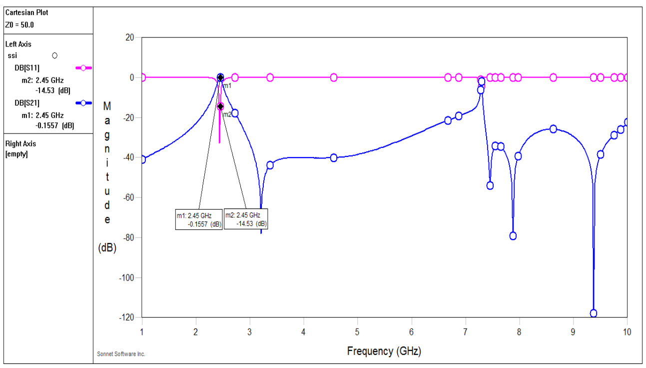

Figure (6.3): Return Loss and Insertion Loss for SSI filter.

From the above discussion, we have seen, in parallel coupled line bandpass filter, insertion loss and return loss is large enough than interdigital configuration.

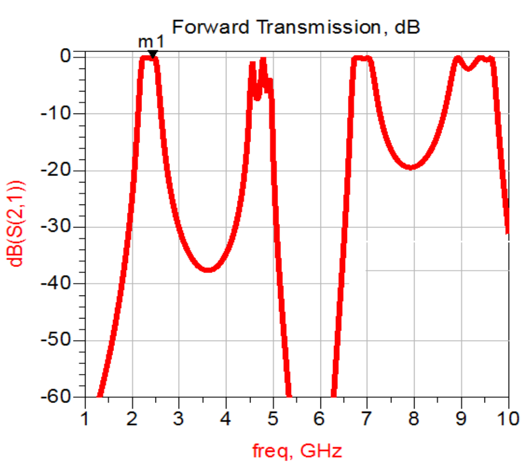

Figure (6.4):|S21| response of Coupled line BPF.

Another problem is that, the passband ripple in first harmonic. In case of coupled line BPF, the passband ripple is at 4.3GHz to 5.3GHz. Figure (6.4) shows passband ripple of coupled line BPF. In interdigital configuration, there are four different types of structure. For SAI insertion loss and return loss are good enough compared to coupled line filter. SSI has also the same advantage. But SSI has smaller bandwidth than desired bandwidth, which is 0.3GHz. SAI has larger bandwidth than the desired one.

6.3. SIMULATION RESULT OF MAI & MSI FILTERS

Analysis of the MAI and MSI filters has been made from the simulation results. The performance of the MAI and MSI filters is summarized in Table (13). And Figure (6.5) and Figure (6.6) depicts the graphs of the performances.

Table (13): MAI & MSI filter simulation responses.

Filter	n	|S11| at 2.45GHz (dB)	|S12| at 2.45GHz (dB)	Bandwidth at 3dB (GHz)
MAI filter	3	-18.82	-0.141	0.6
MSI filter	3	-24.47	-0.139	0.45

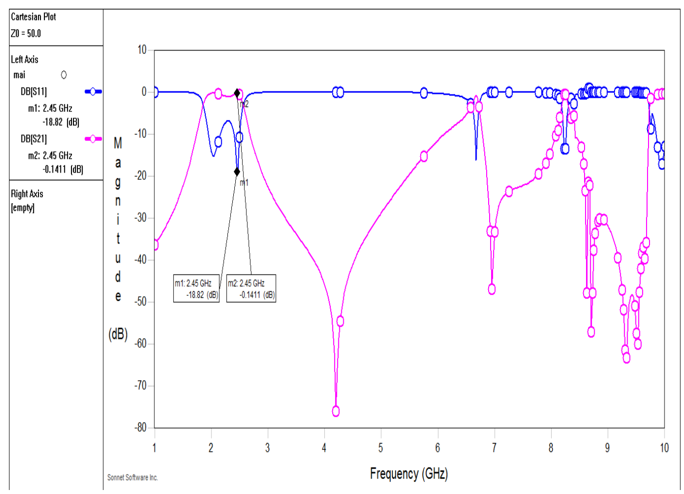

Figure (6.5): Return Loss and Insertion Loss for MAI filter

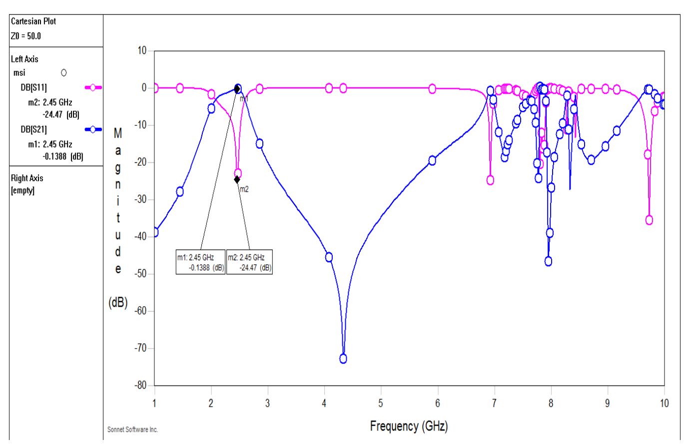

Figure (6.6): Return Loss and Insertion Loss for MSI filter

In the figure (6.4) blue and red colored line shows the |S(11)| and |S(21)| response of a MAI filter. In the figure (6.5) blue and red colored line shows the |S(21)| and |S(11)| response of a MSI filter. At Y-axis, gain in dB has been plotted and in X-axis, frequency in GHz has been plotted.

Here, we have seen that the insertion loss is lower than the single layer interdigital filter and the return loss is much improved from coupled line filter and single layer interdigital filter. MSI has lower than the MAI filter. The bandwidth at -3dB is at 0.6GHz for MAI filter and 0.5GHz for MSI filter. Again MSI has a sharper slope than MAI filter, but the ripple in MSI is larger compared to MAI filters.

In Figure (6.7), blue line shows response of MSI, pink line shows response of SSI, orange line shows response of MAI, green line shows response of SAI. It depicts the comparison among MSI, SSI, MAI and SAI.

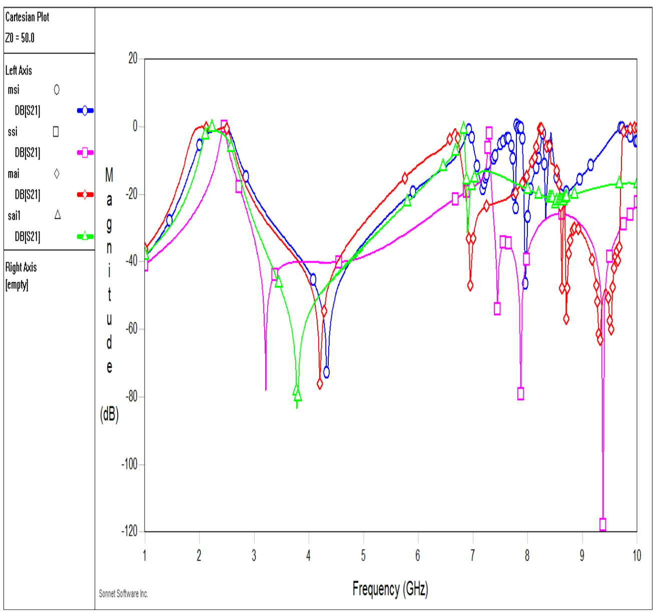

Figure (6.7): |S(21)| response of Single layer, Multilayer asymmetric, Single layer and Multilayer symmetric Interdigital filter

In SAI filter response the first harmonic appears 6.8GHz around. In SAI filter the first harmonic appears around 7.3GHz.

In MAI first harmonics appears around 6.7GHz and around 6.9GHz for MSI. This data shows that single layer configuration has an advantage than multilayer in case of passband ripple and appearing of first harmonics. But multilayer configuration has better insertion loss and return loss.

After above discussion, MSI has better insertion and return loss than MAI and bandwidth 0.45GHz is close enough to the desired bandwidth compared to the MAI filter. First passband harmonic is at 6.9GHz and number of ripple is reduced than MAI.

In MSI filter, the tap point distance is at 3 mm. The effect frequency variation on |S21| for different tap point distance is shown in the Figure (6.8).The optimal tap point for MSI filter has been selected from the figure bellow, simulated using sonnet EM software.

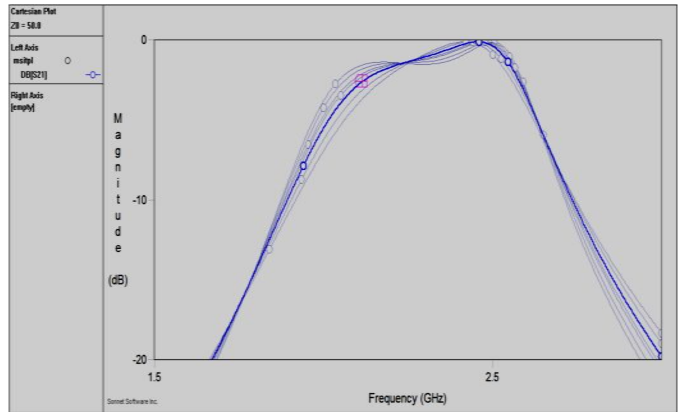

Figure (6.8): Effect of tap point variation of MSI filter

From the Figure (6.8), it is found that the insertion loss increases as the tap point height increases. The bandwidth also decreases with increasing height. Analyzing the Figure (6.8), the optimal tap point has been found about 3 mm, at which the insertion loss is considerable and the bandwidth is quite close to the desired value. Thus considering both the insertion loss and the bandwidth the optimal tap point height is 3mm.

From the above discussion, considering all the aspects, size, bandwidth and losses, it has come up that the Multilayer Symmetric Interdigital structure; with tapping point of 3 mm is the optimal structure for the desired response of MSI filter.

7. CONCLUSION

The goal of this work is to design a microstrip line microwave single layer interdigital Chebyshev band pass filter of centre frequency 2.45GHz and fractional bandwidth 0.122 has been nearly achieved using ADS 2009 and sonnet *EM* software. In this work, 3rd order Chebyshev microstrip line filter of coupled line and interdigital filter structures have been compared using Rogers TMM10 material as substrate. The optimum structure of the filter has found to be 3rd order interdigital structure. The designed filters were simulated for its input return loss $|S_{11}|$ and insertion loss $|S_{21}|$ responses. A comparison also has been made between filter performances.

From the analysis, MSI filter is proposed as the optimal one for 2.45GHz with optimal tapping point of 3mm.

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