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Design and Performance Analysis of 2.45 GHz Microwave Bandpass Filter with Reduced Harmonics

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Abstract:- Many technologies require installation of different filters with advanced features. Microwave bandpass filter is one of those filters that can be used for wireless LAN and Bluetooth .This paper describes how to design a interdigital microwave bandpass filter for 2.45GHz. So, this work focuses on the design of parallel coupled line bandpass filter, two sets of interdigital band-pass filter at 2.45 GHz on singlelayer structures, compare among these filters, proposed one suitable for users. Primarily coupled line filter, then asymmetrical and symmetrical interdigital band pass filter has been designed for single layer structure. To design these filters and to study simulation results, highly efficient, powerful application software Advanced Design System ® and Sonnet EM responses were used frequency transmission coefficient Forward |S21|, Forward reflection coefficient |S11| were represented and comparative studies among designed filters were performed. 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 centre frequency, very sharp roll off factor. In contrast, symmetrical interdigital band-pass filters have narrow bandwidth and minimized ripple.

Keywords:-Bandpass Filter, Chebyshev Filter, Interdigital, Coupled-line, SAI, and SSI

I. INTRODUCTION

A microwave filter is a two-port network which provides 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 with a predetermined frequency response in terms of amplitude and phase. The microwave filter is used to pass energy at a specified resonant frequency at microwave range. Filters play important roles in much RF/microwave applications. Now communication industry needs more stringent requirements—higher performance, smaller size, lighter weight, and lower cost. There are many recent developments in novel materials and fabrication technologies, such as high-temperature superconductors (HTS), low-temperature cofired ceramics (LTCC), monolithic microwave integrated circuits (MMIC), microelectromechanic system (MEMS), and micromachining technology. To fabricate more efficient device using these novel materials, more functional filters are needed which can be used in wireless LAN and Bluetooth application.

In recent electronic communication systems, like Wireless Local Area Network (LAN) and Bluetooth technology, 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 incompatible with the systems where size is an important consideration. The length of parallel coupled filter is too long and it further increases with the order of filter. To solve this, 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, asymmetrical and symmetrical interdigital filter configuration on single layer.

II. RELATED WORKS

The basic concept of filters was proposed in 1915 independently by Campbell and Wagner. Their results were obtained 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].

The image parameter method was developed in the 1920s by Campbell, Zobel, and some others. This method involves specification of the passband and stopband 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 [4]. 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 [5]. 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.

Nowadays, lowpass prototype network with angular cutoff frequency of 1 rad/s terminated by in 1-Ω impedances is normally used as a starting point in the design of microwave filters. The final design of lumped-element lowpass, bandpass, bandstop and highpass filters can be obtained from lowpass prototype using frequency and impedance transformation. Modern filter theory is expanded from lumped element (LC) resonators to distributed resonators, such as waveguide, coaxial and micro-strip/strip-line. In the design of many distributed resonator filters values of elements of lowpass prototype network are used to determine important transmission characteristic of filters using formula derived for each type of filters [6].

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 [7].

Interdigital filters consist of parallel coupled quarter-wavelength lines which are short-circuited at one end and open-circuited at another end [8]. Interdigital filters have the first spurious harmonic at $3f_0$. Coupling between interdigital lines is stronger than between comblines 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 [9]. Accurate design of interdigital filters in micro-strip also involves optimization techniques, for example aggressive space mapping optimization [10]or optimization that uses an accurate computer aided design method which is based on the identification of direct and parasitic coupling of each resonator [11].

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.

III. PARALLEL COUPLED-LINE BANDPASS FILTERS

Fig. 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.

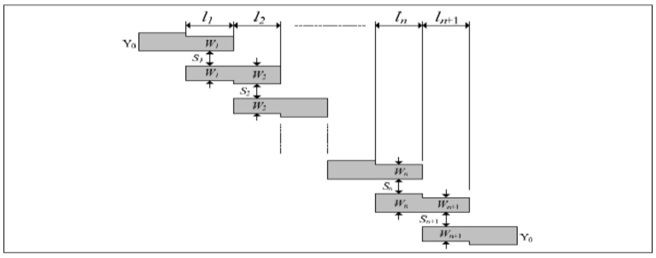


Fig. 3.1: General structure of parallel coupled-line microstrip bandpass filter

The design equations for this type of filter are given by[5]

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

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

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

Where, n is a number of filter order, and g_0, g_1, . . . g_n are the element of a ladder-type lowpass prototype with a normalized cutoff $\Omega_c = 1$, 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. This is because of the both types of filter can have the same lowpass 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

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

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

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

IV. 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 Fig.4.1 [11]. 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 90° 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 the 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 to 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.

Interdigital band pass filters shown in Fig 4.1 have several features such as [12]

- 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 be enhanced by multiple order poles of attenuation at dc and even multiples of the center frequency of the first pass band.

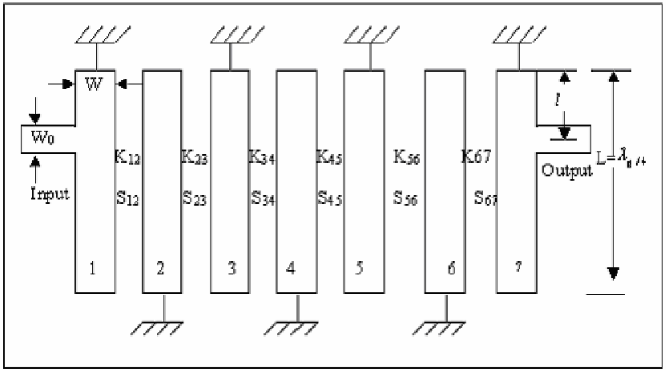


Fig. 4.1: Interdigital band pass filter structure

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.

A. INTERDIGITAL BAND PASS FILTER DESIGN

Original theory and design procedure for interdigital band pass filters with coupled-line input or output are described here. Explicit design equations for the type of band pass filter with tapped line are explained in this section [11].

The electrical length can be obtained from

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

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

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

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

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

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

$$C_n = \frac{Y_1 - Y_{n-1,n}}{v} \qquad \text{…………..(10)}$$

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

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

$$C_t = \frac{\cos\theta_t \sin^3\theta_t}{\omega_0 Y_t\left(\frac{1}{Y_0^2} + \frac{\cos^2\theta \sin^2\theta_t}{Y_t^2}\right)} \text{………………………..(12)}$$

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:

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

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

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

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

$$F = C_{a}C_{b} + C_{ab}(C_{a} + C_{b}) \text{ ……..………………. (14)}$$

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:

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

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

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

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

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 a asymmetrical coupled lines 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

$$K_{n,n+1} = \frac{f_{2} - f_{1}}{f_{0}\sqrt{\left(g_{g}g_{n+1}\right)}} \text{ ……….. (16)}$$

Where, $f_{0} = \left(f_{2} + f_{1}\right)/2$, 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

$$Q_{L} = \frac{f_{0}g_{1}}{\left(f_{2} - f_{1}\right)} = \frac{f_{0}g_{n+1}}{\left(f_{2} - f_{1}\right)} \text{ ………. (17)}$$

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

$$\frac{Q_{L}}{Z_{0}/Z_{01}} = \frac{\pi}{\left[4\sin^{2}\left(\pi/2L\right)\right]} \text{ ………. (18)}$$

B. 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 [11]. Fig. 4.2 shows an example of asymmetrical interdigital band pass filter.

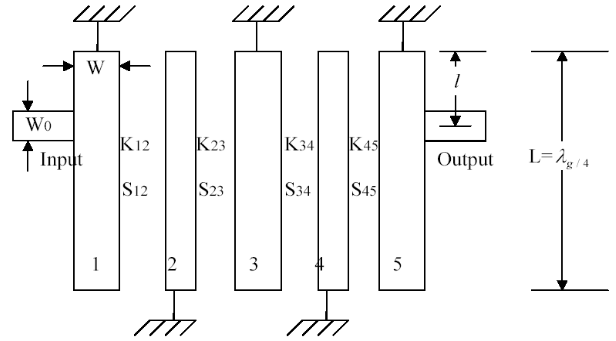


Fig. 4.2: Asymmetrical interdigital band pass filter

C. SYMMETRICAL INTERDIGITAL BAND PASS FILTER

In symmetrical interdigital band pass filter, all the resonators will have the same line width [11]. There are two advantages of this configuration. Firstly, the 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

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

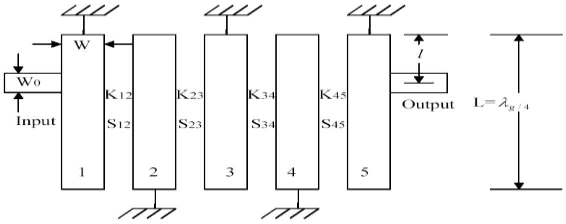


Fig. 4.3: Symmetrical interdigital band pass filter

V. 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 [13]. In this work, 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.

A. 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.
-

B. CHEBYSHAPE PROTOTYPE FILTER

For Chebyshape lowpass filter with an insertion loss L_{Ar}=0.2dB at the cutoff Ω_c=1, the element values computed by (2.50) .The values for n=3 are given below

Table 1: Element values for Chebyshape lowpass 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

C. SIMULATOR USED

In this work, Advanced Design Studio 2009(ADS) and Sonnet Lite 12.53 has been used. They could be integrated within themselves and provide a friendly interface for the user. Some features of them are discussed below.

D. 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	Chebyshev
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

1) Parallel Coupled Line Filter Design:

From Table (1), we got the element values for a 3rd 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

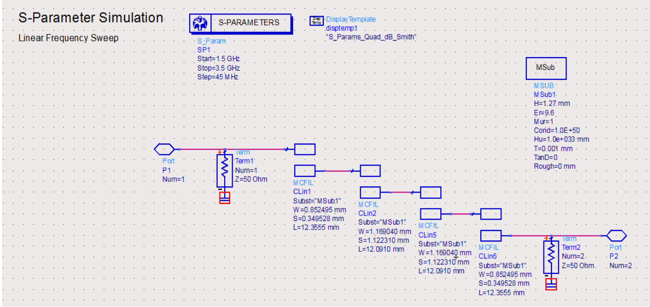
n	**g_n**	**Z_0J_n**	**$Z_{0e}J_n$**	**$Z_{0o}J_n$**
1	1.228	0.395752	77.6185285	38.0433886
2	1.153	0161633	59.3879113	43.2246113
3	1.228	0161633	59.3879113	43.2246113
4	1	0.395752	77.6185285	38.0433886

Using LineClac of Advanced Design System [14], 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 Fig. 5.1.



S_Param
SP1
Start=1.5 GHz
Stop=3.5 GHz
Step=45 MHz

disptemp1
"S_Params_Quad_dB_Smith"

MSUB
MSub1
H=1.27 mm
Er=9.6
Mur=1
Cond=1.0E+50
Hu=1.0e+033 mm
T=0.001 mm
TanD=0
Rough=0 mm

P1
Num=1

Term1
Num=1
Z=50 Ohm

CLin1
Subst="MSub1"
W=0.852495 mm
S=0.349528 mm
L=12.3555 mm

CLin2
Subst="MSub1"
W=1.169040 mm
S=1.122310 mm
L=12.0910 mm

CLin5
Subst="MSub1"
W=1.169040 mm
S=1.122310 mm
L=12.0910 mm

CLin6
Subst="MSub1"
W=0.852495 mm
S=0.349528 mm
L=12.3555 mm

Term2
Num=2
Z=50 Ohm

P2
Num=2

Fig. 5.1: Schematic View of 3rd order Coupled Line Filter

2) *Single Layer Interdigital Filter Design*

2.1. Single Layer Asymmetrical Interdigital Filters (SAI): Using the values of table 1 for a 3rd 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

n	**$Z_{0ei,i+1}$**	**$Z_{0oi,i+1}$**
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_2 mm**	**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	11.76	1.4	1.3	7.1	5.6	1.2	3

And the tuned parameter values are

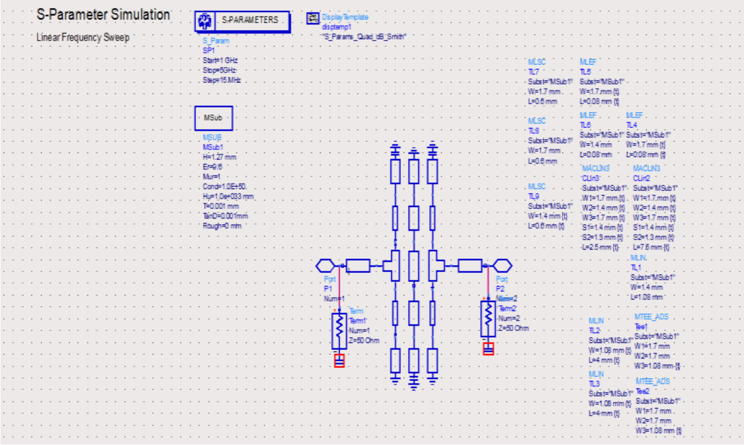
Table 7: Tuned parameter values for SAI filter design

W_1 mm	**W_2 mm**	**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 Fig 5.2.



S_Param
SP1
Start=1 GHz
Stop=5GHz
Step=15.MHz

disptemp1
"S_Params_Quad_dB_Smith"

MSUB
MSub1
H=1.27 mm
Er=9.6
Mur=1
Cond=1.0E+50
Hu=1.0e+033 mm
T=0.001 mm
TanD=0.001mm
Rough=0 mm

P1
Num=1

Term1
Num=1
Z=50 Ohm

P2
Num=2

Term2
Num=2
Z=50 Ohm

TL7
Subst="MSub1"
W=1.7 mm
L=0.6 mm

TL5
Subst="MSub1"
W=1.7 mm {t}
L=0.08 mm {t}

TL8
Subst="MSub1"
W=1.7 mm
L=0.6 mm

TL6
Subst="MSub1"
W=1.4 mm
L=0.08 mm

TL4
Subst="MSub1"
W=1.7 mm {t}
L=0.08 mm {t}

CLin3
Subst="MSub1"
W1=1.7 mm {t}
W2=1.4 mm {t}
W3=1.7 mm {t}
S1=1.4 mm {t}
S2=1.3 mm {t}
L=2.5 mm {t}

CLin2
Subst="MSub1"
W1=1.7 mm {t}
W2=1.4 mm {t}
W3=1.7 mm {t}
S1=1.4 mm {t}
S2=1.3 mm {t}
L=7.6 mm {t}

TL9
Subst="MSub1"
W=1.4 mm {t}
L=0.6 mm {t}

TL1
Subst="MSub1"
W=1.4 mm
L=1.08 mm

TL2
Subst="MSub1"
W=1.08 mm {t}
L=4 mm {t}

Tee1
Subst="MSub1"
W1=1.7 mm
W2=1.7 mm
W3=1.08 mm {t}

TL3
Subst="MSub1"
W=1.08 mm {t}
L=4 mm {t}

Tee2
Subst="MSub1"
W1=1.7 mm
W2=1.7 mm
W3=1.08 mm {t}

Fig.5.2: Schematic view of SAI Filter circuit

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 (J. S. Wong [28]), 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 3.9.

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 is shown in Fig 5.3.

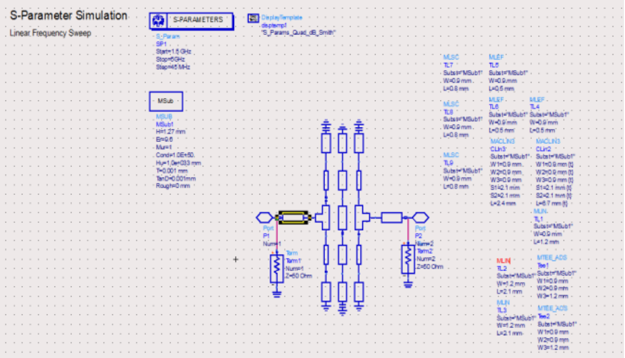


Fig. 5.3: Schematic view of SSI Filter circuit

VI. RESULT & DISSCUSION

Once the designing process has been completed, the this work 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 and single layer symmetric interdigital filter.

A. 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)**	**|S21| at 2.45GHz (dB)**	**Bandwidth at 3dB (GHz)**
Parallel Coupled line Bandpass filter	3	-13.915	-0.180	0.36

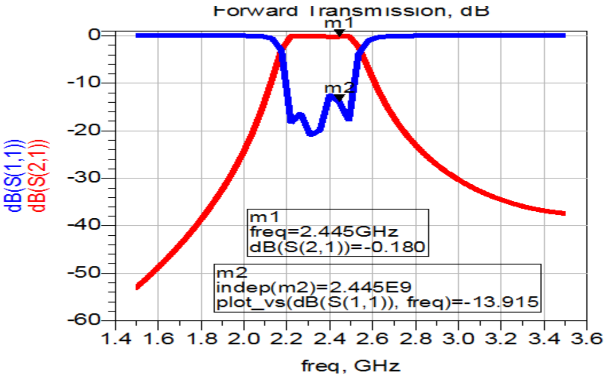


Fig. 6.1: Return Loss and Insertion Loss for Parallel Coupled line filter

In the Fig 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.

B. SIMULATION RESULT OF SAI & SSI FILTERS

Analysis has been made from the simulation results. Table (11) summarized the performances of the SAI and SSI filters. And Fig. 6.2 and Fig. 6.3 depicts the graphs of the performances.

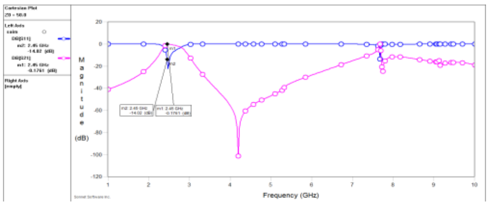


Fig. 6.2: Return Loss and Insertion Loss for SAI filter

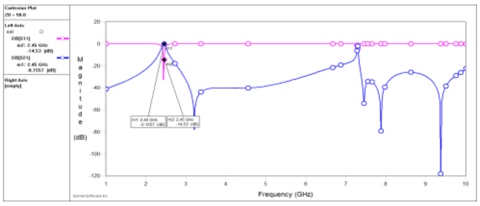


Fig. 6.3: Return Loss and Insertion Loss for SSI filter

Table 11: SAI & SSI filter simulation responses

Filter	n	|S11| at 2.45GHz (dB)	|S21| 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

Here, from Fig 6.1, 6.2 and 6.3, it is evident that the insertion loss in SAI and SSI filter is lower than the microstrip coupled line bandpass filter, and SSI has lower than the SAI filter of -0.02 dB. The bandwidth at -3dB is at 0.4GHz for SAI filter and 0.25GHz for SSI filter. Here SAI has a bandwidth higher than the desired bandwidth (0.3GHz) of 0.1GHz and SSI has a lower bandwidth than desired bandwidth of 0.05GHz.
SSI has a sharper slope than SAI filter, but the ripple in SSI is larger compared to SAI filters.

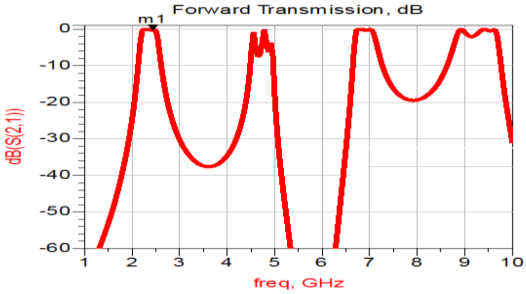


Fig. 6.4:|S21| response of Coupled line BPF

Another problem is that, in case of coupled line BPF, the passband ripple in first harmonic. The passband ripple is at 4.3GHz to 5.3GHz. Fig 6.4 shows passband ripples of coupled line BPF from 1 GHz to 10

GHz range. For SAI and SSI, insertion loss and return loss are good enough compared to coupled line filter. So the harmonics that produced in the coupled line filter are significantly reduced by using interdigital filter.

VII. 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.

However, the simulated results were close to the desired specification but not exactly matched with the desired specification. One main reason for this scenario is the software limitations. This could be due to the personal computer inability to handle large memory simulation files. There were some software limitations to complete the simulation in a satisfactory time frame with accurate results. Although the designed filter did not meet the specification perfectly therefore there are rooms for further improvement.

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