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Design of Interdigital Bandpass Filter

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Abstract: The purpose of this paper described about the design of microwave interdigital bandpass filter at different frequencies. A microwave filter is two port network used to control the frequency response. This paper presented the simulation of interdigital bandpass filter and chebyshev bandpass filter with lumped elements using ADS (Advanced Design System Software). In this filters RT-DUROID substrate is used with 0.5mm thickness.

Index terms: Interdigital, bandpass filter, lumped elements.

I. INTRODUCTION

Realization of filters using Lumped elements at Microwave frequencies become difficult, because the dimensions of the circuit elements becomes comparable with the wavelength of the microwaves because of this a distribution circuit approach is necessary. For realizing the lumped behavior of Capacitor, Inductor or Resistor, the component size must be much smaller than the wave length. If we want to use lumped elements at microwave frequencies it must satisfy the below condition [3].

$$L << \frac{\lambda}{10}$$

There are two filter synthesis techniques popularly used. They are the image parameter method and the insertion loss method. 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. This method consists of several steps as follows

(i) Design of prototype low pass filter with the desired pass band characteristic.
(ii) Transformation of this prototype network to the required band pass filter with the specified centre and band edge frequencies.
(iii) Realization of the network in the microwave form by using sections of microwave transmission lines, whose reactance corresponds to those of distributed circuit elements [3-4].

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.

In symmetrical interdigital band pass filter, all the resonators will have the same line width.

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 [9]. 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 $Z_{oei,i+1}$ and $Z_{ooi,i+1}$, the spacing are adjusted for matching the coupling coefficient $K_{i,i+1}$, which is given by

$$K_{i,i+1} = \frac{Z_{oei,i+1} - Z_{ooi,i+1}}{Z_{oei,i+1} + Z_{ooi,i+1}}$$

In this way, all spacing can be determined. Figure1 shows the symmetrical interdigital band pass filter.

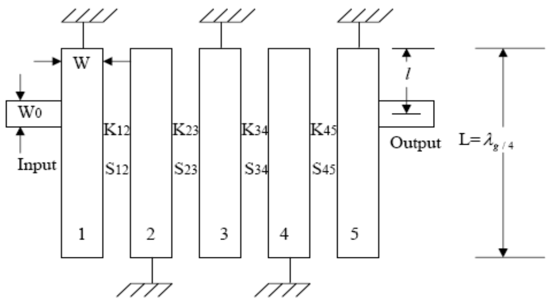

Figure1.Symmetrical interdigital band pass filter.

Where,
$W0$ = width of characteristic impedance, W = width of resonator, K = coupling efficiency, S = space between resonator, L= length of resonator

Interdigital band pass filters have several features such as [7]

1. They are very compact structures.
2. The tolerances required in manufacture are relatively relaxed because of the relatively large spacing between resonator elements.
3. The second pass band is centered at three times the center frequency of the first pass band. Besides that, there are no possibilities of spurious responses in between.
4. The Filter can be fabricated in structural forms, which are self-supporting so that dielectric material need not be used. Thus, dielectric loss can be eliminated.
5. 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.

Interdigital filters consist of an array of parallel lines between ground planes.

II. EVEN AND ODD MODE CAPACITANCE

The even and odd mode characteristic impedances and effective dielectric constant of the coupled microstrip lines

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may be obtained from even and odd mode capacitance. The even and odd mode capacitance may be obtained from [1]

$$C_0 = C_p + C_f + C_{gl} + C_{go}$$

$$C_e = C_p + C_f + C_f^{'}$$

Where, C_p *is* parallel plate capacitance between the strip and the ground plane and can be shown as

$$C_P = \frac{\epsilon_0 \epsilon_r \; w}{h}$$

C_f *is* the fringe capacitance and can be expressed as

$$2C_f = \sqrt{\frac{\epsilon_{re}}{cz_c - c_p}}$$

$C_f^{'}$ is the modified of fringe capacitance, C_f, in the single line due to the presence of another line. It can be express as

$$C_f^{'} = \frac{c_f}{1 + A(\frac{h}{s})\tan(\frac{8s}{h})}$$

Where $A = \exp\left[-0.1\exp\left(2.33 - 2.53\frac{W}{h}\right)\right]$

While, C_{ga} and C_{gd} are fringe capacitances for the air and dielectric regions across the coupling gap.

$$C_{gd} = \frac{\epsilon_0 \epsilon_r}{\pi}\ln[\coth(\frac{\pi s}{4h})] + 0.65 C_f (\frac{0.02\sqrt{\epsilon_r}}{s/h} + 1 - \frac{1}{\epsilon_r^{\;2}})$$

$$C_{ga} = \varepsilon_0 \frac{K(k^{'})}{K(k)}$$

$$k = \frac{s/h}{s/h + 2w/h^{'}}$$

$$k^{'} = \sqrt{1 - k^2}$$

The even and odd mode characteristic impedances Z_{ce} and Z_{co} can be obtained from capacitance value, that is

$$Z_{ce} = (c\sqrt{C_e^a C_e})^{-1}$$

$$Z_{co} = (c\sqrt{C_o^a C_o})^{-1}$$

Where C_e^a and C_o^a are the even and odd mode capacitances for the coupled microstrip line configuration with air as dielectric. Dielectric constant $\in_{re}^{e}$ can be obtained by

$$\in_{re}^{e} = \frac{C_e}{C_e^a}$$

$$\in_{re}^{o} = \frac{C_o}{C_o^a}$$

III. INTERDIGITAL BAND PASS FILTER DESIGN

The Explicit design equations for the type of band pass filter with tapped line are given by the electrical length can be obtained from [9]

$$\theta = \frac{\pi}{2}(1 - \frac{FBW}{2})$$

Where, FBW is the fractional bandwidth and g_1 represents the element values of a ladder type of low pass prototype filter with normalized cutoff frequency at $\Omega_c = 1$

The admittance is

$$Y = \frac{Y_1}{\tan\theta}$$

Inverter admittance of each resonator is expressed by

$$\frac{J_{i,i+1}}{Y} = \frac{1}{\sqrt{g_i g_{i+1}}} \quad \text{For i = 1 to n – 1}$$

$$\frac{J_{n,n+1}}{Y} = \frac{1}{\sqrt{g_n g_{n+1}\omega^{'}}}$$

$$N_{k,k+1} = \sqrt{\left(\frac{J_{k,k+1}}{Y_A}\right)^2 + \frac{\tan^2\theta_1}{4}} \quad \text{k= 1 to n-1}$$

$$M_1 = Y_A(\frac{J_{01}}{Y_A}\sqrt{h+1})$$

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

$$\frac{C_0}{\varepsilon} = \frac{376.7}{\sqrt{\varepsilon_r}}[2Y_A - M_1]$$

$$\frac{C_1}{\varepsilon} = \frac{376.7}{\sqrt{\varepsilon_r}}\left[Y_A - M_1 + hY_A\left[\frac{\tan\theta_1}{2} + (\frac{J_{01}}{Y_A})^2 + N_{12} - \frac{J_{12}}{Y_A}\right]\right]$$

$$\frac{C_k}{\varepsilon} = \frac{376.7}{\sqrt{\varepsilon_r}} hY_A\left(N_{k-1,k} + N_{k,k+1} - \frac{J_{k-1,k}}{Y_A} - \frac{J_{k,k+1}}{Y_A}\right) \quad \text{for k =2 to n–1}$$

$$\frac{C_n}{\varepsilon} = \frac{376.7}{\sqrt{\varepsilon_r}}\left[Y_A - M_n + hY_A\left[\frac{\tan\theta_1}{2} + (\frac{J_{n,n+1}}{Y_A})^2 + N_{n-1,n} - \frac{J_{n-1,n}}{Y_A}\right]\right]$$

$$\frac{C_{n+1}}{\varepsilon} = \frac{376.7}{\sqrt{\varepsilon_r}}[2Y_A - M_n]$$

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

$$\frac{C_{01}}{\varepsilon} = \frac{376.7}{\sqrt{\varepsilon_r}}[M_1 - Y_A] \quad \text{for i = 1 to n – 1}$$

$$\frac{C_{k,k+1}}{\varepsilon} = \frac{376.7}{\sqrt{\varepsilon_r}} hY_A\left(\frac{J_{k,k+1}}{Y_A}\right)$$

$$\frac{C_{n,n+1}}{\varepsilon} = \frac{376.7}{\sqrt{\varepsilon_r}}[M_N - Y_A]$$

h$\rightarrow$ admittance scale factor.

$$\frac{2C_{k+1,k}}{\varepsilon} + \frac{C_k}{\varepsilon} + \frac{2C_{k,k+1}}{\varepsilon}$$

IV. SIMULATION RESULTS

For this simulation, first the theoretical calculations are calculated i.e., length and width for interdigital filters and simulated in ADS. This paper presented the simulation of interdigital band pass filter and chebyshev band pass filter with lumped elements using advanced design system software. In this filters RT DUROID substrate is used with 0.5mm thickness.

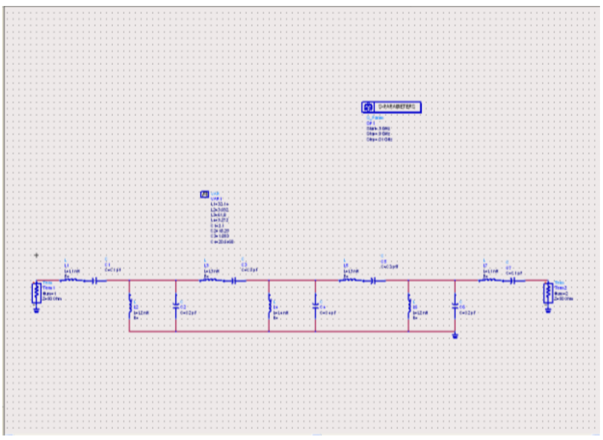

Figure2: Schematic for 0.5 to 0.75 GHz bandpasss filter

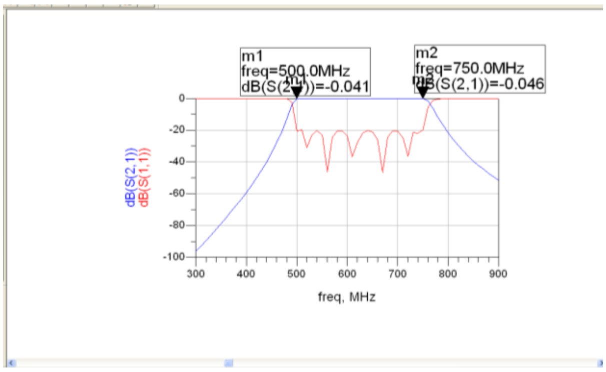

Figure3: Response of 0.5 to .75 GHz filter

Figure2.is the design of 0.5 to 0.75 GHz bandpass filter. For this filter calculated the order. This is 7th order filter. And this is symmetric. For this filter insertion loss is 0.041dB and return loss is 20 dB and the negative peak is 45 dB, rejection is at0.4 GHz 60 dB, 0.85 GHz 40 dB is obtained.

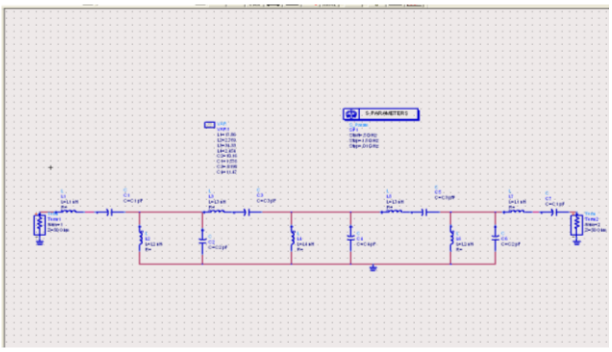

Figure4: Schematic for 0.75 to 1.2 GHz bandpasss filter.

Figure5: Response for 0.75 to 1.2 GHz bandpass filter

Figure4 is the design of 0.75 to 1.2 GHz bandpass filter. For this filter calculated the order. This is 7th order filter. And this is symmetric. For this filter insertion loss is 0.041dB and return loss is 20 dB negative peaks is 46 dB, rejection is at 0.65 GHz 55 dB, and 1.3 GHz 30 dB is obtained.

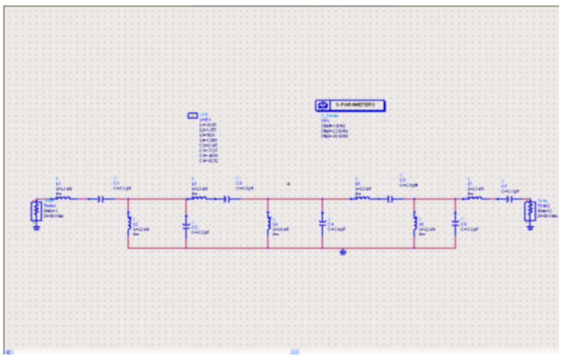

Figure6: Schematic for 1.2 to 1.7 GHz bandpasss filter.

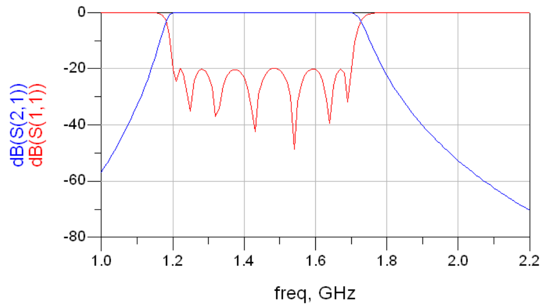

Figure7: Response for 1.2 to 1.7 GHz bandpass filter.

Figure6 is the design of 1.2 to 1.7 GHz bandpass filter. For this filter calculated the order. This is 7th order filter. And this is symmetric. For this filter insertion loss is 0.041dB and return loss is 20 dB, ejection is at 1.1 GHz 40 dB, 2 GHz 50 dB is obtained.

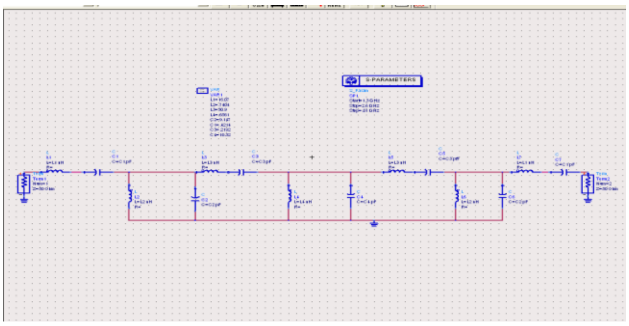

Figure8: Schematic for 1.7 to 2.2 GHz bandpasss filter.

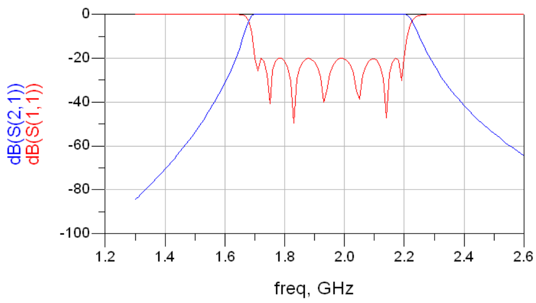

Figure9: Response for 1.7 to 2.2 GHz bandpass filter.

Figure8 is the design of 1.7 to 2.2 GHz bandpass filter. For this filter calculated the order. This is 7th order filter. And this is symmetric. For this filter insertion loss is 0.041dB and return loss is 20 dB, rejection is at 1.4 GHz 70 dB, 2.5 GHz 60 dB is obtained.

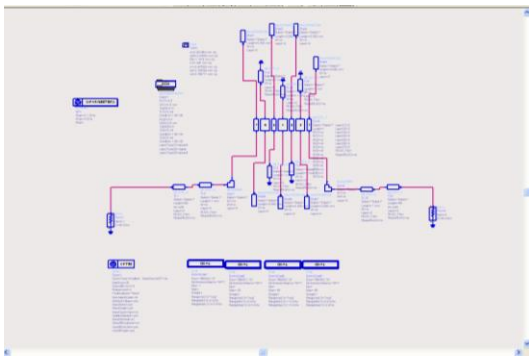

Figure10: Schematic for 2 to 2.5 GHz bandpasss filter.

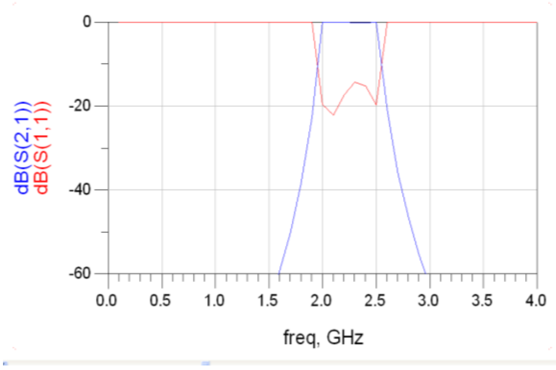

Figure11: Response for 2 to 2.5 GHz bandpass filter.

Figure10 gives the design of 2 to 2.5 GHz bandpass filter. In this 50 ohm microstrip lines are used. Substrate is 0.5 mm thickness RT DUROID substrate is used. Insertion loss is <0.1dB, return loss is20 dB, rejection at 1.5 and 3 GHz is >60 dB

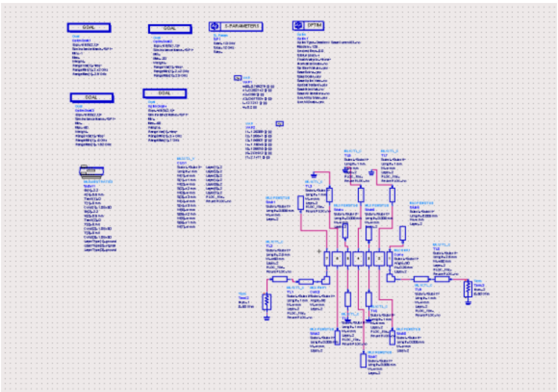

Figure12: Schematic for 2.5 to 3 GHz bandpass filter

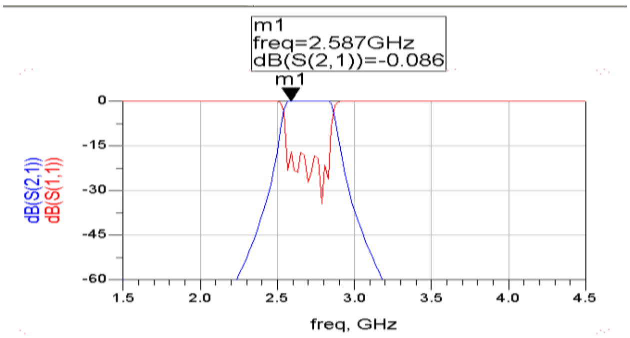

Figure13: Response for 2.5 to 3 GHz bandpass filter

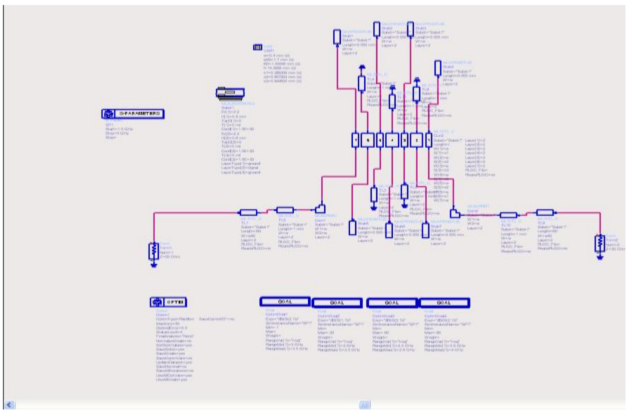

Figure14: Schematic for 3 to 3.5GHz bandpasss filter.

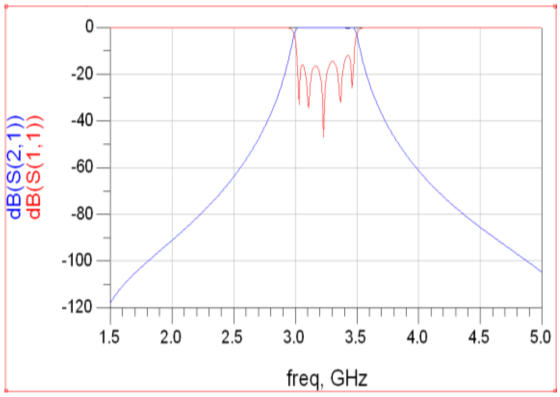

Figure15: Response for 3 to 3.5 GHz bandpass filter

Figure14 gives the design of 3 to 3.5 GHz bandpass filter. In this 50 ohm microstrip lines are used. Substrate is 0.5 mm thickness RT DUROID substrate is used. Insertion loss is <0.1dB, return loss is 20 dB, rejection at 2.5 and 4 GHz is >60 dB.

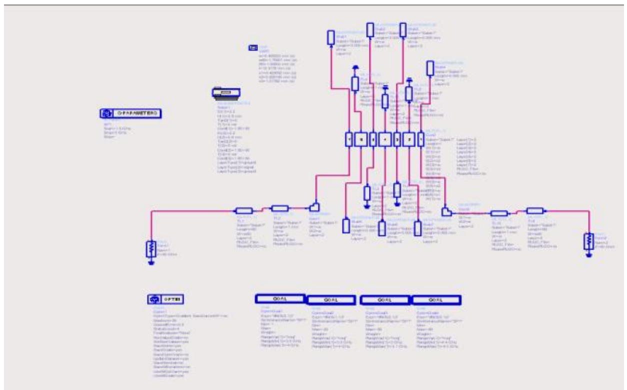

Figure16: Schematic for 3.5 to 4 GHz bandpasss filter.

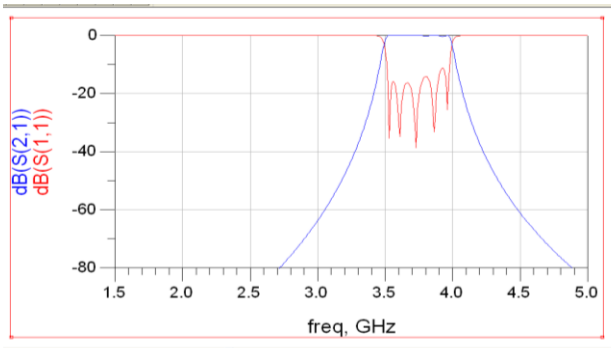

Figure17: Response for 3.5 to 4 GHz bandpass filter

Figure16 gives the design of 3.5 to 4 GHz bandpass filter. In this 50 ohm microstrip lines are used. Substrate is 0.5 mm thickness RT DUROID substrate is used. Insertion loss is <0.1dB, return loss is 20 dB, rejection at 3 and 4.5 GHz is >60 dB.

V. CONCLUSION

In this paper first designed the interdigital filters, it is given the response. But it is having less spacing. In this filter designs the main difficult is tuning. To get the exact or required output tune the filter. In simulation by changing the component values L, C for lumped bandpass filters and length, width and spacing for interdigital bandpass filters.

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