SCHOOL OF ELECTRONICS ENGINEERING

VIT - CHENNAI CAMPUS

BAND-PASS FILTER DESIGN FOR MICROWAVE FREQUENCIES USING HFSS

ECE402 – Microwave Engineering

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ABSTRACT

At the receiver side there is a requirement to filter out the noises and pass only the desired signal frequency for processing. Hence, a Band Pass Filter (BPF) is required for the same. In the present project the designing of a compact microwave parallel edge coupled line BPF has been discussed and implemented. The BPF consists of a 4-parallel coupled line pairs designed for a Chebyshev response at a center frequency of 2.48 GHz with a fractional bandwidth of 10%. The filter has been implemented using FR4 substrate of dielectric constant 4.2. The physical parameters of the parallel coupled line filter sections have been simulated using the HFSS software to provide the closest values of the band pass filter prototype values.

INTRODUCTION

Microwave filters are two port networks used in an electronic system capable of allowing transmission of signals over the pass-band and rejecting unwanted harmonics over the stop-band. Different kinds of approximations, like Butterworth, Chebyshev and Elliptic function have been proposed and widely used as models for microwave-filter synthesis .Strip-line filters play an important role in many RF applications. As technologies advances, more stringent requirements of filters are felt. One of the requirements is the compactness of filters. Edge-coupled strip-line is used instead of micro-strip line as strip-line does not suffer from dispersion and its propagation mode is pure TEM. Hence it is the preferred structure for coupled line filters. Therefore, a third order Chebyshev edge-coupled strip-line filter is designed in the present work.

A general structure of parallel edge coupled strip line band pass filter that uses half-wavelength line resonators shown in Fig 1.They are positioned in adjacent resonators 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 end couple structures.

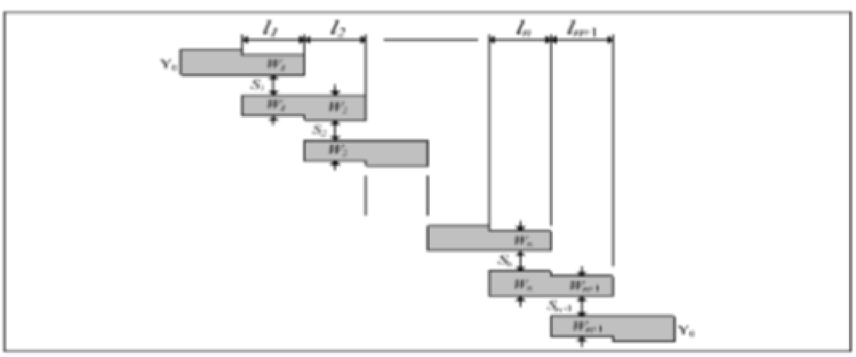

Fig. 1 General structure of parallel edge coupled strip line band pass filter

Design and Calculation

To design the band-pass filter with 3rd order Coupled Line configuration following specification are considered:-

- a center frequency of 2.48 GHz
- bandwidth of 10%
- equal ripple in the pass-band of 0.5dB

According to D.M Pozar, the coefficients for equal ripple in the pass-band of 0.5dB third order Chebyshev filter are g0= 1.0000, g1= 1.5963, g2 = 1.0967, g3= 1.5963, g4= 1.0000.

The design equations for this type of filter are given by

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_0 g_1}} \qquad (1)$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2}\frac{1}{\sqrt{g_j g_{j+1}}} \quad j = 1 \text{ to } n-1 \qquad (2)$$

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

Where n is a number of filter order, and $g_0, g_1, \ldots g_n$ are the element of a low pass prototype with a normalized cut off $\Omega c = 1$, and FBW is the fractional bandwidth of band pass 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. The even- and odd-mode characteristic impedances of the coupled strip line resonators are determined by

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

$$(Z_{0o})_{J,J+1} = \frac{1}{Y_0}\left[1 - \frac{J_{J,J+1}}{Y_0} + \left(\frac{J_{J,J+1}}{Y_0}\right)^2\right] \qquad (5)$$

To calculate the admittance inverter using equation (1) (2) & (3)

1) Determining the admittance inverter constants for 1st line pair:

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_0 g_1}} = \sqrt{\frac{\pi}{2 \times 1.0000 \times 1.5963}} = 0.3137$$

2) Determining the admittance inverter constants for 2nd line pair:

$$\frac{J_{1,2}}{Y_0} = \frac{\pi FBW}{2}\frac{1}{\sqrt{g_1 g_2}} = \frac{\pi \times 0.1}{2}\frac{1}{\sqrt{1.5963 \times 1.0967}} = 0.1187$$

3) Determining the admittance inverter constants for 3rd line pair:

$$\frac{J_{2,3}}{Y_0} = \frac{\pi FBW}{2}\frac{1}{\sqrt{g_2 g_3}} = \frac{\pi \times 0.1}{2}\frac{1}{\sqrt{1.0967 \times 1.59637}} = 0.1187$$

4) Determining the admittance inverter constants for 4th pair:

$$\frac{J_{2,3}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_2 g_3}} = \sqrt{\frac{\pi}{2 \times 1.0000 \times 1.5963}} = 0.3137$$

The EVEN and ODD impedances of line pairs was determined by following equation (4) & (5)

1) *For 1[st] line pairs:*

$$(Z_{oe})_{0,1} = \frac{1}{1/50}\left[1 + 0.3137 + (0.3137)^2\right] = 70.6047$$

$$(Z_{oe})_{0,1} = \frac{1}{1/50}\left[1 - 0.3137 + (0.3137)^2\right] = 39.2355$$

2) *For 2[nd] line pairs:*

$$(Z_{oe})_{1,2} = \frac{1}{1/50}\left[1 + 0.1187 + (0.1187)^2\right] = 56.6407$$

$$(Z_{oo})_{1,2} = \frac{1}{1/50}\left[1 - 0.1187 + (0.1187)^2\right] = 44.7688$$

3) *For 3[rd] line pairs:*

$$(Z_{0e})_{2,3} = \frac{1}{1/50}\left[1 + 0.1187 + (0.1187)^2\right] = 56.6407$$

$$(Z_{oo})_{2,3} = \frac{1}{1/50}\left[1 - 0.1187 + (0.1187)^2\right] = 44.7688$$

4) *For 4[th] line pairs:*

$$(Z_{oe})_{3,4} = \frac{1}{1/50}\left[1 + 0.3137 + (0.3137)^2\right] = 70.6047$$

$$(Z_{oo})_{3,4} = \frac{1}{1/50}\left[1 - 0.3137 + (0.3137)^2\right] = 39.2355$$

Use single line equations to find and from and . With the given =4.2, find that for =50, w/h is approximately 1.95.

Therefore, W/h 2 has been chosen. Find out value W/h

$$\mathrm{W/h} = \frac{8\exp(A)}{exp(2\times A)-2}$$

$$A = \frac{Z_c}{60}\left\{\frac{\varepsilon_r + 1}{2}\right\}^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left\{0.23 + \frac{0.11}{4.2}\right\}$$

For $(\mathrm{w/h})_{se}$ 1^{st} line pairs & 4^{th} line pairs:

$$A = \frac{35.30235}{60}\left\{\frac{4.2 + 1}{2}\right\}^{0.5} + \frac{4.2 - 1}{4.2 + 1}\left\{0.23 + \frac{0.11}{4.2}\right\} = 1.10637$$

$$(\mathrm{w/h})_{se} = \frac{8\ \exp(1.10637)}{exp(2\times 1.10637) - 2} = 3.38717$$

For $(\mathrm{w/h})_{so}$ 1^{st} line pairs & 4^{th} line pairs:

$$A = \frac{19.61775}{60}\left\{\frac{4.2 + 1}{2}\right\}^{0.5} + \frac{4.2 - 1}{4.2 + 1}\left\{0.23 + \frac{0.11}{4.2}\right\} = 0.68486$$

$$\left(\frac{\mathrm{w}}{\mathrm{h}}\right)_{so} = \frac{8\ \exp(0.68486)}{exp(2\times 0.68486) - 2} = 8.20366$$

For $(\mathrm{w/h})_{se}$ 2^{nd} line pairs & 3^{rd}line pairs:

$$A = \frac{28.32035}{60}\left\{\frac{4.2 + 1}{2}\right\}^{0.5} + \frac{4.2 - 1}{4.2 + 1}\left\{0.23 + \frac{0.11}{4.2}\right\} = 0.91874$$

$$(\mathrm{w/h})_{se} = \frac{8\ \exp(0.91874)}{exp(2\times 0.91874) - 2} = 4.68361$$

For $(\mathrm{w/h})_{so}$ 2^{nd} line pairs &3^{rd} line pairs:

$$A = \frac{22.3844}{60}\left\{\frac{4.2 + 1}{2}\right\}^{0.5} + \frac{4.2 - 1}{4.2 + 1}\left\{0.23 + \frac{0.11}{4.2}\right\} = 0.75921$$

$$\left(\frac{\mathrm{w}}{\mathrm{h}}\right)_{so} = \frac{8\ \exp(0.75921)}{exp(2\times 0.75921) - 2} = 6.66380$$

It is able to find and by applying and (as Zc) to the single line strip equations. Now it comes to a point where it reach the w/h and s/h for the desired coupled edge-strip line using a family of approximate equations as following

$$\frac{s}{h} = \frac{2}{\pi} cosh^{-1}\left[\frac{cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{\mathrm{w}}{\mathrm{h}}\right)_{se}\right) + cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{\mathrm{w}}{\mathrm{h}}\right)_{so}\right) - 2}{cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{\mathrm{w}}{\mathrm{h}}\right)_{so}\right) - cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{\mathrm{w}}{\mathrm{h}}\right)_{se}\right)}\right]$$

For find out value $\frac{s}{h}$ of 1st line pairs & 4th line pairs:

$$\frac{s}{h} = \frac{2}{\pi} cosh^{-1}\left[\frac{cosh\left(\left(\frac{\pi}{2}\right)3.38717\right) + cosh\left(\left(\frac{\pi}{2}\right)8.20366\right) - 2}{cosh\left(\left(\frac{\pi}{2}\right)8.20366\right) - cosh\left(\left(\frac{\pi}{2}\right)3.38717\right)}\right] = 0.0288$$

For find out value $\frac{s}{h}$ of 2ndline pairs & 3rdline pairs:

$$\frac{s}{h} = \frac{2}{\pi} cosh^{-1}\left[\frac{cosh\left(\left(\frac{\pi}{2}\right)4.68361\right) + cosh\left(\left(\frac{\pi}{2}\right)6.66380\right) - 2}{cosh\left(\left(\frac{\pi}{2}\right)6.66380\right) - cosh\left(\left(\frac{\pi}{2}\right)4.68361\right)}\right] = 0.2728$$

For find out value $\frac{w}{h}$

$$\frac{w}{h} = \frac{1}{\pi}\left[cosh^{-1}\frac{1}{2}\left(\left(cosh\left(\frac{\pi s}{2h}\right) - 1\right) + \left(cosh\left(\frac{\pi s}{2h}\right) + 1\right) cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{\mathrm{w}}{\mathrm{h}}\right)_{se}\right)\right) - \left(\frac{\pi s}{2h}\right)\right] \quad (8)$$

For find out value $\frac{w}{h}$ of 1st line pairs & 4th line pairs:

$$\frac{w}{h} = \frac{1}{\pi}\left[cosh^{-1}\frac{1}{2}\left(\left(cosh\left(\frac{\pi \times 0.288}{2 \times 1.58}\right) - 1\right) + \left(cosh\left(\frac{\pi \times 0.288}{2 \times 1.58}\right) + 1\right) cosh\left(\left(\frac{\pi}{2}\right)3.38717\right)\right) - \left(\frac{\pi \times 0.288}{2 \times 1.58}\right)\right]$$

$$\frac{w}{h} = 1.6106$$

For find out value $\frac{w}{h}$ of 2nd line pairs & 3rdline pairs:

$$\frac{w}{h} = \frac{1}{\pi}\left[cosh^{-1}\frac{1}{2}\left(\left(cosh\left(\frac{\pi \times 0.2728}{2 \times 1.58}\right) - 1\right) + \left(cosh\left(\frac{\pi \times 0.2728}{2 \times 1.58}\right) + 1\right) cosh\left(\left(\frac{\pi}{2}\right)4.68361\right)\right) - \left(\frac{\pi \times 0.2728}{2 \times 1.58}\right)\right]$$

$$\frac{w}{h} = 2.2368$$

The edge-strip transmission line by overall dielectric constant in order to is TEM Propagation. There are a number of formulas, listed for the calculation of $\epsilon_{eff.}$:-

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + \frac{12h}{W}}} \tag{9}$$

For find out value ε_{re} of 1st line pairs & 4th line pairs:

$$\varepsilon_{re} = \frac{4.2 + 1}{2} + \frac{4.2 - 1}{2}\frac{1}{\sqrt{1 + \frac{12}{1.6106}}} = 3.1504$$

For find out value ε_{re} of 2nd line pairs & 3rd line pairs:

$$\varepsilon_{re} = \frac{4.2 + 1}{2} + \frac{4.2 - 1}{2}\frac{1}{\sqrt{1 + \frac{12}{2.2368}}} = 3.2342$$

The effective dielectric constant of edge-strip is determined & the guided wavelength of the quasi-TEM mode of edge-strip is given by equation (10)
Thus the required resonator,

$$l = \frac{\lambda_g}{4} = \frac{c}{4f\sqrt{\varepsilon_{re}}} \tag{10}$$

For find out value λ_g of 1st line pairs & 4th line pairs:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} = \frac{300}{2.48\sqrt{3.1504}} mm = 0.068153$$

Thus the required resonator of 1st line pairs & 4th line pairs:

$$l = \frac{0.068153}{4} = 0.01704$$

For find out value λ_g of 2ndline pairs & 3rdline pairs:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} = \frac{300}{2.48\sqrt{3.2342}} m \quad = 0.067264m$$

Thus the required resonator of2nd line pairs & 3rd line pairs:

$$l = \frac{0.067264}{4} = 0.01682$$

Find out value of all dimensions For section 1 and 4, S/h= 0.0288 s=0.046 mm and w/h=1.6106 w=2.54mm For section 2 and 3, S/h=0.2728 s=0.431 mm and w/h=2.2368 w=3.53mm .

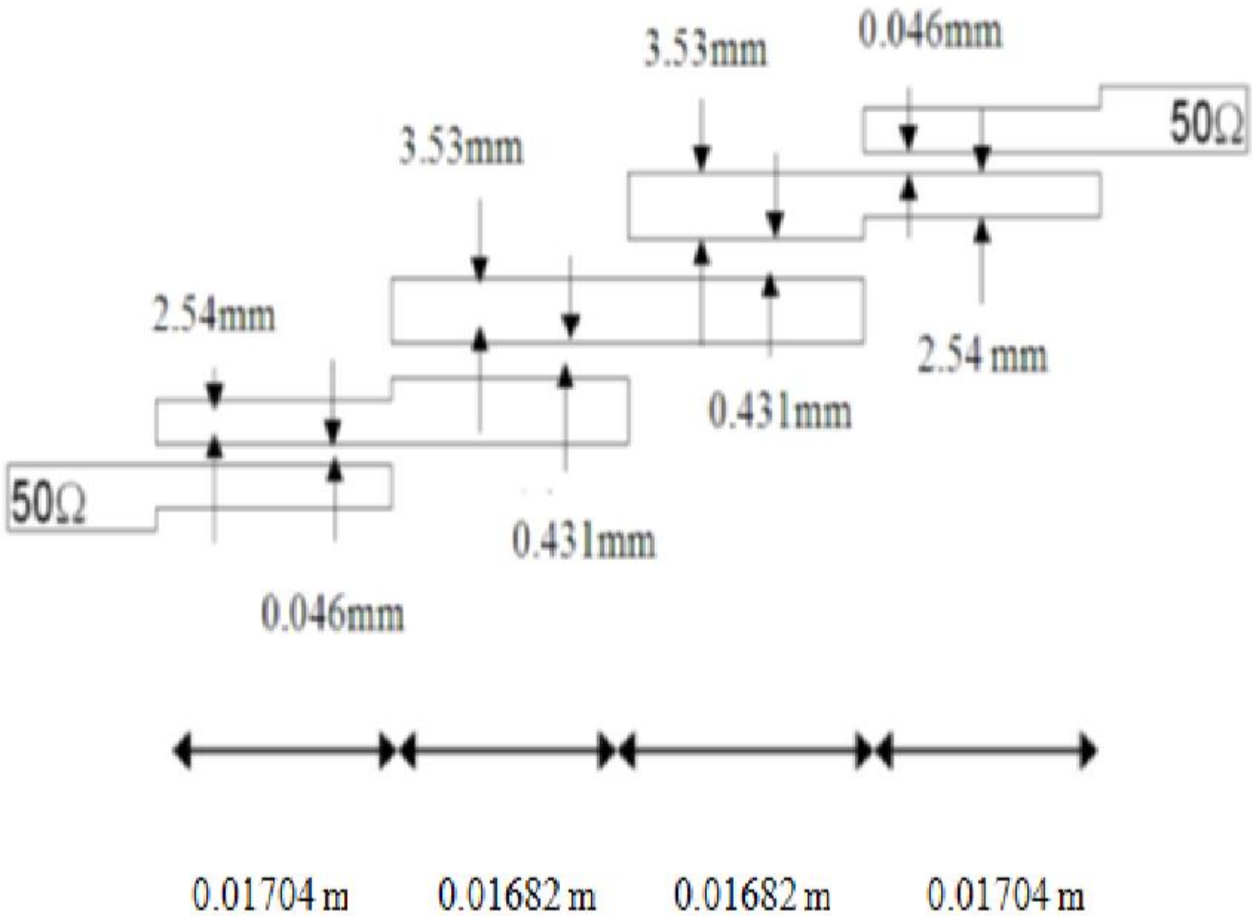

Fig. 2 Design of filter as per above calculations

RESULTS

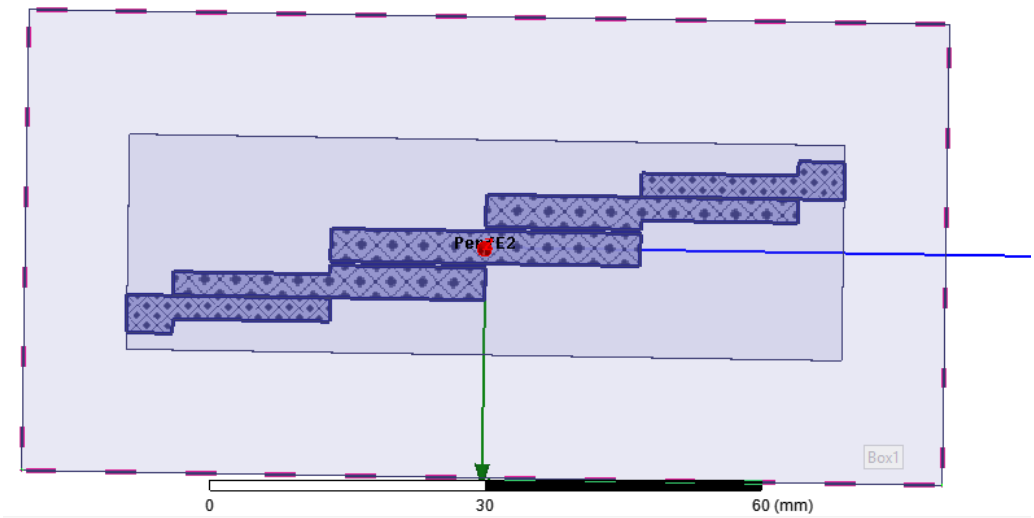

Fig. 3 coupled lines for filter

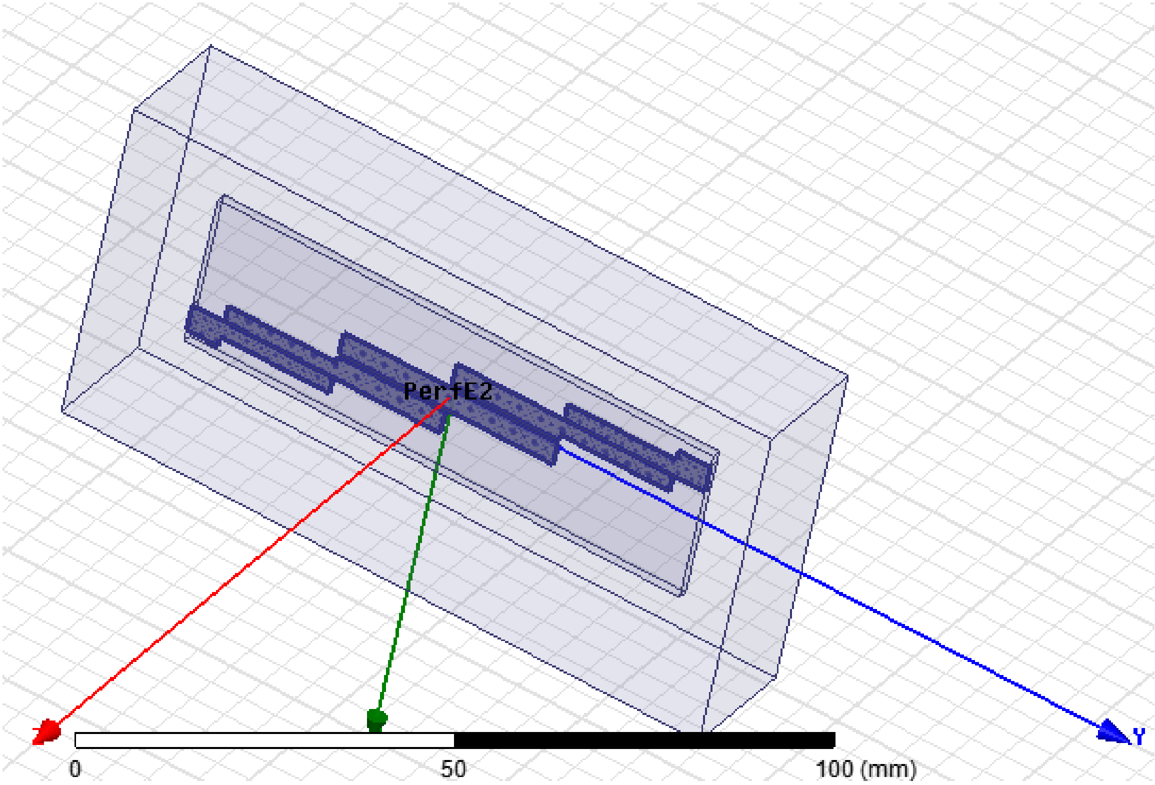

Fig. 4 Final HFSS design

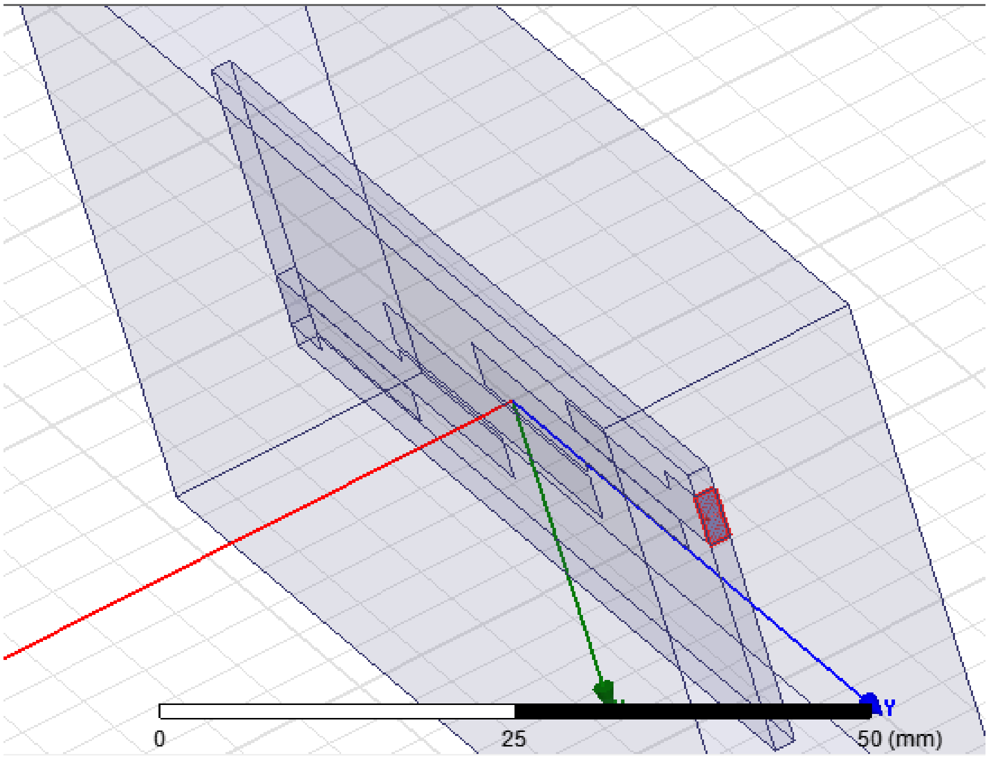

Fig. 5 Lumped port assignment for filter

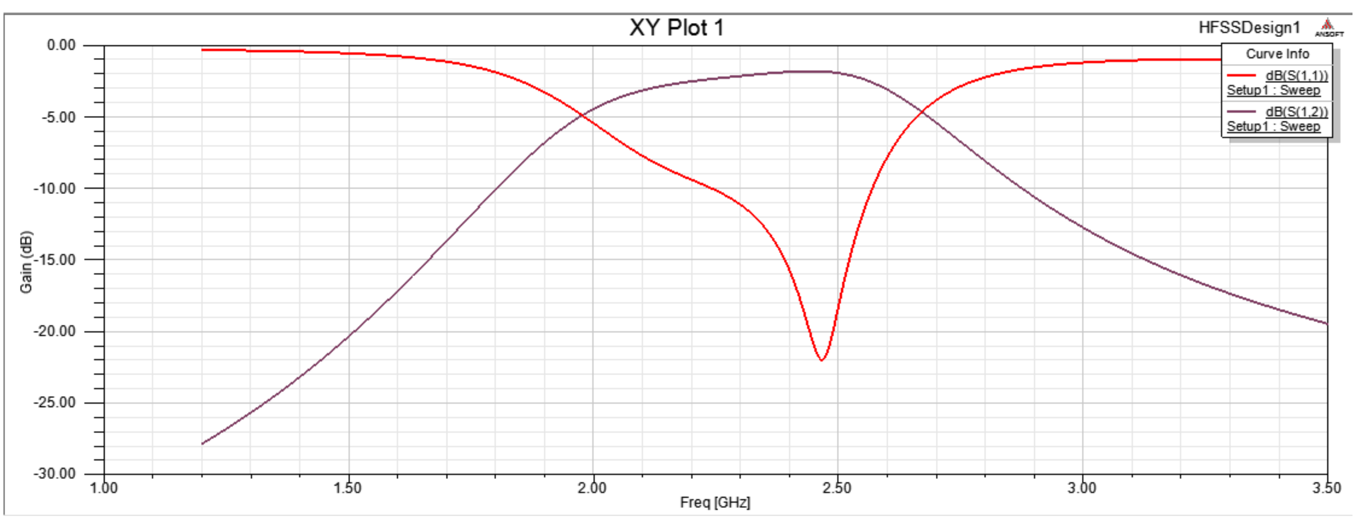

Fig. 6 Result of filter simulation in HFSS

CONCLUSION

The filter designed met all the desired specifications. The required calculations were done and there was no need for any optimization in the design. This third order Chebyshev filter is capable to pass a frequency of 2.19GHz to 2.77GHz. The response of filter has center frequency at 2.48GHz. This filter has the Insertion Loss of -1.9dB at center frequency of 2.48GHz.