



Designing of Half Wavelength Parallel- Edge Coupled Line Band Pass Filter Using HFSS

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Abstract—The Ultra-wideband systems use wireless technology capable of transmitting data over spectrum of frequency bands for short and long distances with very low power and high data rates. At the receiver side there is an 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 paper 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 centre frequency of 2.48 GHz with a fractional bandwidth of 10%. The filter has been implemented using FR4 substrate of dielectric constant 4.2 with thickness of 1.58mm and 3.38mm respectively. 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. The corresponding Insertion Loss S_{21} is less than -2.2db & return loss is -12.50db with centre frequency 2.48GHz

Keywords— Parallel Edge-Coupled line, Chebyshev, HFSS

I. INTRODUCTION

Since the Federal Communications Commission (FCC)'s decision to permit the unlicensed operation band from 3.1 to 10.6 GHz in 2002 [1], Ultra-Wideband (UWB) technology has been getting more attention for high-speed wireless connectivity applications. UWB systems are very promising, because they offer much higher transmission data rates than those of other wireless communication systems can be obtained with low power dissipation. 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 [2] have been proposed and widely used as models for microwave-filter synthesis [3]. Strip-line filters play an important role in many RF applications. As technologies advances, more stringent requirements of filters are felt [4]. 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 [5], [6], [7]. Therefore, a third order Chebyshev edge-coupled strip-line filter is designed in the present work.

A. Basic Theory

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.

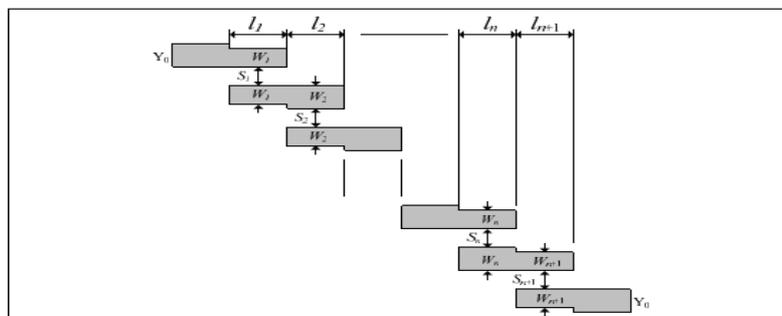


Fig.1: General structure of parallel edge coupled strip line band pass filter

The design equations for this type of filter are given by

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi \text{FBW}}{2 \epsilon_0 \epsilon_1}} \tag{1}$$

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

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

Where n is a number of filter order, and g_0, g_1, \dots, g_n are the element of a ladder-type 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. However, the implementation will be different. To realize the J-inverters obtained above, the even- and odd-mode characteristic impedances of the coupled strip line resonators are determined by

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

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

II. DESIGNING METHODOLOGY

A. Parallel-Coupled, Half-Wavelength Resonators Filters

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% and equal ripple in the pass-band of 0.5dB. FR4 substrate of dielectric constant 4.2 with thickness of 1.58 mm and 3.38 mm is used respectively. According to D.M Pozar [2] the coefficients for equal ripple in the pass-band of 0.5dB third order Chebyshev filter are $g_0 = 1.0000$, $g_1 = 1.5963$, $g_2 = 1.0967$, $g_3 = 1.5963$, $g_4 = 1.0000$. These values are for low-pass prototype design with source and load impedance equal to unity. A ladder circuit that begins with a series element is chosen, g_1 and g_3 are inductors and g_2 is a capacitor.

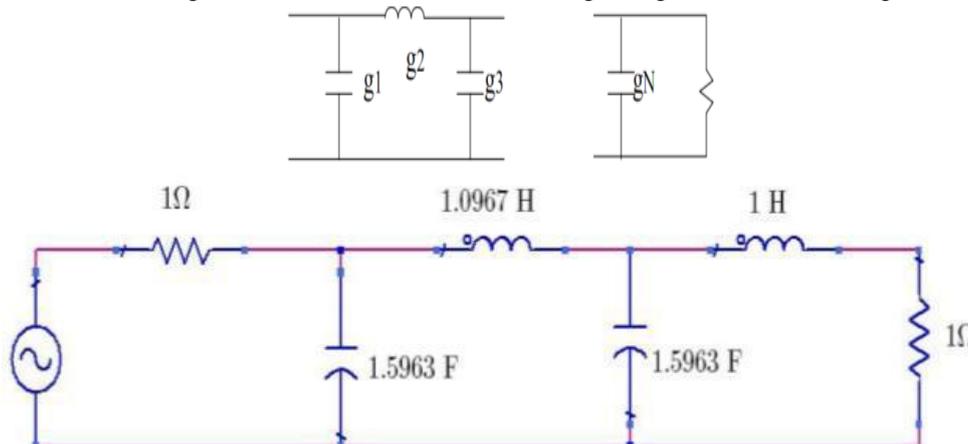


Fig. 2: A ladder network for a third order low pass Chebyshev filter prototype beginning with a shunt element.

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

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

$$\frac{J_{0,1}}{Y_0} = \sqrt{\frac{\pi FBW}{2g_0 g_1}} = \sqrt{\frac{\pi \times 0.1}{2 \times 1.0000 \times 1.5963}} = 0.3137$$

- 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:

$$\frac{J_{2,3}}{Y_0} = \frac{\pi FBW}{2} \frac{1}{\sqrt{g_2 g_3}} = \frac{\pi \times 0.1}{2} \frac{1}{\sqrt{1.0967 \times 1.5963}} = 0.1187$$

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

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

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

1) For 1st line pairs:

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

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

2) For 2nd line pairs:

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

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

3) For 3rd line pairs:

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

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

4) For 4th line pairs:

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

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

Using (4) and (5) design equations yield the design parameters, half of which listed in Table I because of symmetry of the filter, where the even- and odd-mode impedances are calculated for Y=1/Z and Z=50 ohms.

TABLE I: DESIGN PARAMETERS

J	J_{J+1}/Y_0	$(Z_{oe})_{jj+1}(\Omega)$	$(Z_{oo})_{jj+1}(\Omega)$
0	0.3137	70.6047	39.2355
1	0.1187	56.6407	44.7688
2	0.1187	56.6407	44.7688
3	0.3137	70.6047	39.2355

The next step of the filter design is to find the dimensions of coupled edge-strip lines that exhibit the desired even - and odd-mode impedances. Firstly, determine equivalent single edge-strip shape ratios (w/d) s. Then it can relate coupled line ratios to single line ratios.

For a single edge-strip line,

$$Z_{oss} = \frac{(Z_{oe})_{jj+1}}{2}$$

$$Z_{oso} = \frac{(Z_{oo})_{jj+1}}{2}$$

1) For 1st line pairs & 4th line pairs:

$$Z_{oss} = \frac{70.6047}{2} = 35.30235$$

$$Z_{oso} = \frac{39.2355}{2} = 19.61775$$

2) For 2nd line pairs & 3rd line pairs:

$$Z_{oss} = \frac{56.6407}{2} = 28.32035$$

$$Z_{oso} = \frac{44.7688}{2} = 22.3844$$

Use single line equations to find $(w/h)_{es}$ and $(w/h)_{so}$ from Z_{oss} and Z_{oso} . With the given $\epsilon_r=4.2$, find that for $z_0=50$, w/h is approximately 1.95.

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

$$W/h = \frac{8 \exp(A)}{\exp(2 \times A) - 2} \quad (6)$$

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

For $(w/h)_{ss}$ 1st line pairs & 4th line pairs:

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

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

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

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

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

For $(w/h)_{ss}$ 2nd line pairs & 3rd line pairs:

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

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

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

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

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

It is able to find $(w/h)_{ss}$ and $(w/h)_{so}$ by applying Z_{oss} and Z_{oso} (as Z_c) 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 [8]

$$\frac{s}{h} = \frac{2}{\pi} \cosh^{-1} \left[\frac{\cosh \left(\left(\frac{\pi}{2} \right) \left(\frac{w}{h} \right)_{ss} \right) + \cosh \left(\left(\frac{\pi}{2} \right) \left(\frac{w}{h} \right)_{so} \right) - 2}{\cosh \left(\left(\frac{\pi}{2} \right) \left(\frac{w}{h} \right)_{so} \right) - \cosh \left(\left(\frac{\pi}{2} \right) \left(\frac{w}{h} \right)_{ss} \right)} \right] \quad (7)$$

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 2nd line pairs & 3rd line 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 $\frac{w}{h}$

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

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 & 3rd line 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 ϵ_{eff} .

$$\epsilon_{rs} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}} \quad (9)$$

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

$$\epsilon_{rs} = \frac{4.2 + 1}{2} + \frac{4.2 - 1}{2} \frac{1}{\sqrt{1 + \frac{12}{1.6106}}} = 3.1504$$

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

$$\epsilon_{rs} = \frac{4.2 + 1}{2} + \frac{4.2 - 1}{2} \frac{1}{\sqrt{1 + \frac{12}{2.2368}}} = 3.2342$$

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,

$$l = \frac{\lambda_g}{4} = \frac{c}{4f\sqrt{\epsilon_{rs}}} \quad (10)$$

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

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{rs}}} = \frac{300}{2.48\sqrt{3.1504}} \text{ mm} = 0.068153$$

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:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{res}}} = \frac{300}{2.48\sqrt{3.2342}} \text{mm} = 0.067264$$

Thus the required resonator of 2nd line pairs & 3rd line pairs:

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

Using the design equations for coupled edge-strip lines given (7) and (8), the width and spacing for each pair of quarter wavelength coupled sections are found, and listed in Table II

TABLE II: WIDTH AND THE QUATER WAVELENGTH

J	W_j/h	S_j/h	ϵ_{res}	$\vartheta(\text{mm})$
1	1.6106	0.0288	3.1504	0.01704
2	2.2368	0.2728	3.2342	0.01682
3	2.2368	0.2728	3.2342	0.01682
4	1.6106	0.0288	3.1504	0.01704

Find out value of all dimensions

For section 1 and 4,

$S/h = 0.0288 \rightarrow s = 0.046 \text{ mm}$ and $w/h = 1.6106 \rightarrow w = 2.54 \text{ mm}$

For section 2 and 3,

$S/h = 0.2728 \rightarrow s = 0.431 \text{ mm}$ and $w/h = 2.2368 \rightarrow w = 3.53 \text{ mm}$

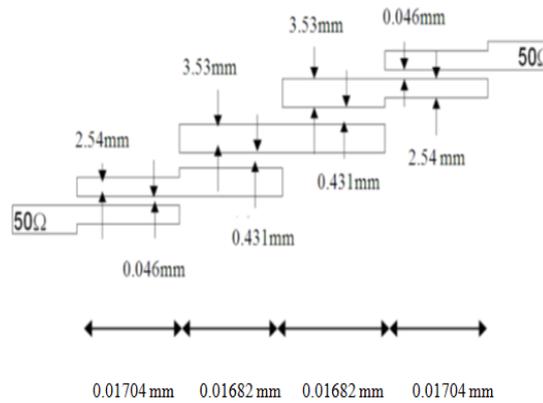


Figure 3: Layout of a three-pole micro strip edge-coupled band-pass filter

III. GEOMETRY ON HFSS

In this proposed design the width of the substrate is 3.38 mm and relative permittivity 4.2 and the conductor thickness 1.58 mm, Fig. 4 shows the 3-dimensional view of proposed band pass filter. Proposed design is simulated using HFSS.

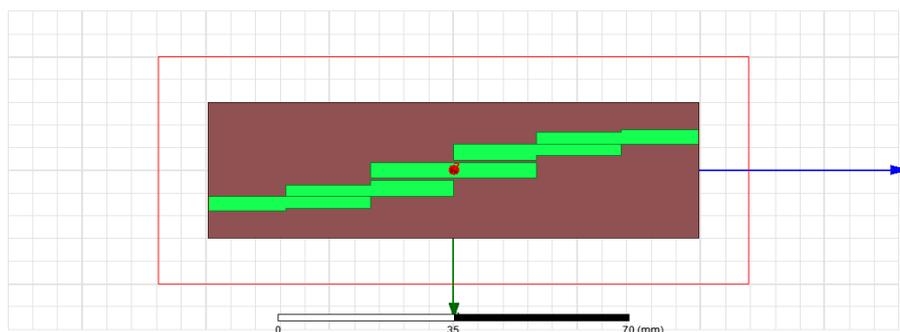


Fig. 4: Layout filter of 3rd order Edge couple Strip line band pass filter on HFSS.

Fig.4. indicates that the width, distance & length for section 1 & 4 are $w_1 = w_4 = 2.54$ mm, $s_1=s_4=0.046$ mm & $l_1=l_4=0.01704$ mm. And section two and three are $w_2=w_3= 3.53$ mm, $s_2=s_3=0.431$ mm & $l_2=l_3=0.01682$ mm.

IV. RESULT

A design of wideband band pass filter is designed which is based on a conventional 3rd order parallel Edge coupled-line. The filter is designed and simulated on the HFSS software. The simulation of the final layout provides a response between scattering parameters and the frequency of filter which is shown below.

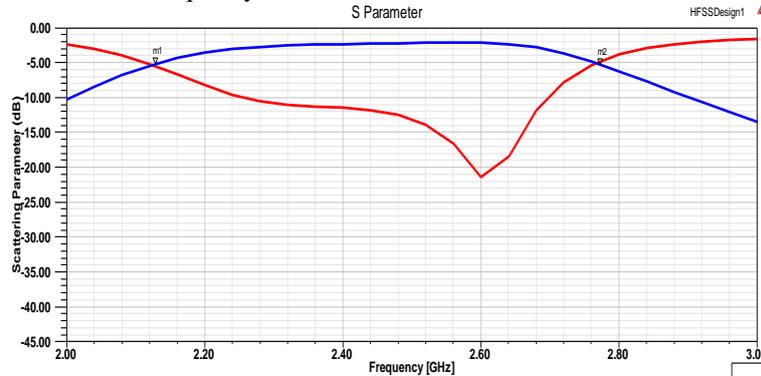


Fig. 5: HFSS plot of S₁₁ and S₂₁ versus frequency with the code giving the centre frequency as 2.48 GHz for FR4 substrate for 0.5 dB ripple.

This filter is capable to pass a frequency of 2.19GHz to 2.77GHz. The response of filter to be linear with centre frequency 2.48GHz. This filter has S₁₁ response has value of -12.50 dB and the Insertion Loss is S₂₁ less than -2.2dB at centre frequency 2.48GHz.

V. CONCLUSIONS

The design of BPF will definitely help the new researchers to understand the methodology and various steps in the process. The half wavelength parallel edge coupled BPF designed with centre frequency 2.48GHz using HFSS software has been presented in this paper. This filter has S₁₁ response at the centre frequency 2.48GHz with a value of -12.50dB and the corresponding Insertion Loss is S₂₁ less than -2.2dB. This filter has 0.58GHz bandwidth at the centre frequency 2.48GHz.

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