MERITS OF PARALLEL COUPLED BANDPASS FILTER OVER END COUPLED BANDPASS FILTER IN X BAND

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Abstract- This paper represents the comparison between the end coupled BPF and Parallel coupled BPF with the same parameters. Parallel coupled BPF has merits over end coupled BPF. The occupied area of the parallel coupled BPF is less compared to end coupled BPF. Bandwidth of the parallel coupled BPF is large compared to end coupled. Return loss and insertion loss of parallel coupled BPF has less compared to end coupled. The only advantage of end coupled BPF is its simple design equations and less complex geometry and easy fabrication. These two filters are designed at high centre frequency 10.2 GHz and high dielectric constant 10.2 to achieve the wideband. Full wave IE3D electromagnetic simulation software is used to design and analysis of end coupled BPF and parallel coupled BPF.

Keywords- End Coupled BPF, Parallel Coupled BPF, IE3D, Return Loss, Insertion Loss, Even And Odd Modes

I. INTRODUCTION

The main advantage of microstrip filter is its compact size because in most of the application it is required and disadvantage is, a limitation to operate in the high frequency region due to its junction effect and resonance. Microstrip filter plays a important role for satellite and ground communication systems [1]. Microstrip filter is the essential component in the transmitter and receiver systems. Generally low pass filter is used in the transmitter and bandpass filter is used in the receiver system. WiMAX is the emerging technology which is vastly being used in the wireless broad band communication [2]. Some research organizations are looking forward to invent the better communication technology in terms error free signal with wide capacity to carry the large data. Microstrip filter shows the flexibility in using the electromagnetic spectrum intelligently by sharing a spectrum, since the electromagnetic spectrum is limited. For the broad band systems wide band bandpass filter plays an important role. It was believed that by using the miniaturization techniques the performance of the microstrip filter such as insertion loss and return loss would deteriorate. Even miniaturization techniques enhance the performance of the filter. Some filter designs are simple but we have to compromise with the performance of the filter on other side some filter design are complex and optimization is required but there performance is acceptable. In many books classical methods are given to design the bandpass filter [3]-[5]. In these books it is suggested to design microstrip filter with maximum number of resonators to achieve minimum insertion loss. The filter design has been carried out on the full wave electromagnetic simulator IE3D which works on the methods of moments. In this paper we have designed two types of microstrip bandpass filter and compared the compactness, losses and band size of these two filters. We kept all specification same only the design approach is different for the comparison of bandpass microstrip filter.

II. STRUCTURE OF END COUPLED HALF WAVE LENGTH RESONATOR MICROSTRIP BANDPASS FILTER

In Fig.1 general layout of end-coupled half wavelength resonator microstrip bandpass filter is shown whose each section is approximately half wavelength ($\lambda_g/2$) long at the mid-band frequency (f_0) where λ_g is the guided wavelength. The gap (S) between two resonators which is capacitive hence there is a capacitive coupling between the two open ended resonators. The gap between the resonators is known as J-inverters. The function of these J-inverters is revert back the large impedance level towards the ends of each half-wavelength resonator. Due to the revert back action of impedance this is shunt type of resonance. The filter acts as shunt type resonator [6]. If the gap between the resonators is very small then this capacitive coupling acts as a purely series capacitance but practically the gap is large enough so the gap is not entirely series capacitance but shunt capacitance also taken into account.

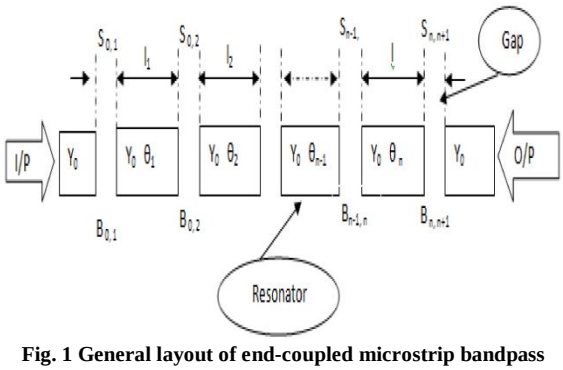

Fig. 1 General layout of end-coupled microstrip bandpass filter.

The design equations of end coupled BPF are as follows:

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

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

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

Where n = order of the filter, and $g_0, g_1, \ldots\ldots g_n$ are the elements of prototype lowpass filter with a normalized cut-off $\Omega c = 1$ and FBW = Fractional Bandwidth of bandpass filter. Jj,j+1 are the characteristic admittances of J-inverters and Y_0 is the characteristic admittance of the end lines.

Let us suppose that gap capacitance is a perfect series capacitance then the susceptance $B_{j,j+1}$ is as follows:

$$\frac{B_{j,j+1}}{Y_0} = \frac{\frac{J_{j,j+1}}{Y_0}}{1-\left(\frac{J_{j,j+1}}{Y_o}\right)^2} \quad (4)$$

and

$$\theta_j = \pi - \frac{1}{2}\left[\tan^{-1}\left(\frac{2B_{j-1,j}}{Y_0}\right) + \tan^{-1}\left(\frac{2B_{j+1,j}}{Y_0}\right)\right] \text{ radians} \quad (5)$$

Where θ_j is the electrical length and B_j is the susceptance of jth half-wavelength resonator. This is important that all electrical lengths and susceptances should be calculated at the mid-band frequency, f_0. In the above equation of electrical length the term in the bracket represents the calculation of negative electrical length of J - inverter.

A. Modelling of gap in microstrip

The gap (S) in the microstrips is equivalent to combination of series and shunt capacitances. The gap in the microstrips is modelled as π-network. In the Fig. 2 it is shown what is the effect of gap in microstrips so when we are realizing any microstrip structure, the effect should be taken into an account in order to get the good response. In microstrip structure theory there many closed form expressions are given to deal with this type of problem but it is only fruitful when we use the exact formula for the concern problem.

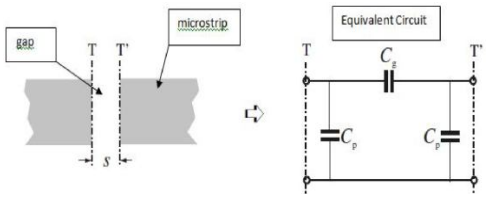

Fig. 2 Microstrip gap and its equivalent capacitive circuit modelled as π- network.

Coupling gap $S_{j,j+1}$ between the end coupled microstrip filter which causes the capacitance. This series capacitance is given as:

$$C_g^{j,j+1} = \frac{B_{j,j+1}}{\omega_0} \quad (6)$$

Where $\omega_0 = 2\pi f_0$ is the angular frequency at the mid-band. The physical lengths (l) of microstrip resonator is determined by

$$l_j = \frac{\lambda_{g0}}{2\pi}\theta_j - \Delta l_j^{e1} - \Delta l_j^{e2} \quad (7)$$

Where $\Delta l_j^{e1,e2}$ are the effective lengths of shunt capacitances which exist at the both ends of the microstrip jth resonator. It is shown in the fig.2 gap has a equivalent circuit which is a combination of series capacitance (C_g) and the shunt capacitance (C_p).

Effective lengths are given as:

$$\Delta l_j^{e1} = \frac{\omega_0 C_p^{j-1,j}}{Y_0}\cdot\frac{\lambda_{g0}}{2\pi} \quad (8)$$

$$\Delta l_j^{e2} = \frac{\omega_0 C_p^{j,j+1}}{Y_0}\cdot\frac{\lambda_{g0}}{2\pi} \quad (9)$$

III. DESIGN SPECIFICATIONS OF END COUPLED BANDPASS MICROSTRIP FILTER.

Centre frequency, f_0: 10 GHz
No. of poles, n: 5
FBW: 0.10 = 10%
Bandpass ripple: 0.1 dB
Prototype: Chebyshev
Height of the substrate, h: 0.635 mm
Dielectric Constant, ε_r : 10.2
Effective dielectric constant $\varepsilon_{r,eff}$ = 6.79
Characteristic impedance, Z_0: 50Ω
Width of microstrip, w: 0.55 mm

The design of end coupled half wavelength microstrip bandpass filter is given in the Fig.1.

By taking the above specifications, 5 poles Chebyshev prototype filter is designed. Since it is Chebyshev prototype so prototype parameters are $g_0 = g_6 = 1$, $g_2 = g_4 = 1.3712$, $g_1 = g_5 = 1.1468$, $g_3 = 1.9750$. By using the above equations [1-9], we have to determine the dimensions of microstrip filter such as s and l. All the intermediate calculated values are given in the table- I.

TABLE I
Filter parameter values for end coupled microstrip bandpass filter.

Filter Parameter	Value	Filter Parameter	Value
$\frac{J_{0,1}}{Y_0} = \frac{J_{5,6}}{Y_0}$	0.2053	$S_{1,2} = S_{4,5}$	0.3 mm
$\frac{J_{1,2}}{Y_0} = \frac{J_{4,6}}{Y_0}$	0.1878	$S_{2,3} = S_{3,4}$	0.4 mm
$\frac{J_{2,3}}{Y_0} = \frac{J_{3,4}}{Y_0}$	0.1431	ϵ_{re}	6.79
$\frac{B_{0,1}}{Y_0} = \frac{B_{5,6}}{Y_0}$	0.2143	λ_{g0}	11.5 mm
$\frac{B_{1,2}}{Y_0} = \frac{B_{4,5}}{Y_0}$	0.1946	$\Delta l_1^{e1} = \Delta l_5^{e1}$	0.09188 mm
$\frac{B_{2,3}}{Y_0} = \frac{B_{3,4}}{Y_0}$	0.1460	$\Delta l_2^{e1} = \Delta l_4^{e1}$	0.1348 mm
$\theta_1 = \theta_5$	2.7535 rad.	Δl_3^{e1}	0.1726 mm
$\theta_2 = \theta_4$	2.8139 rad.	$\Delta l_1^{e2} = \Delta l_5^{e2}$	0.1348 mm
θ_3	2.8575 rad.	$\Delta l_2^{e2} = \Delta l_4^{e2}$	0.1726 mm
$C_g^{0,1} = C_g^{5,6}$	0.068213 pF	Δl_3^{e2}	0.1726 mm
$C_g^{1,2} = C_g^{4,5}$	0.061943 pF	$l_1 = l_5$	4.81mm
$C_g^{2,3} = C_g^{3,4}$	0.046473 pF	$l_2 = l_4$	4.84 mm
$S_{0,1} = S_{5,6}$	0.2 mm	l_3	4.88 mm

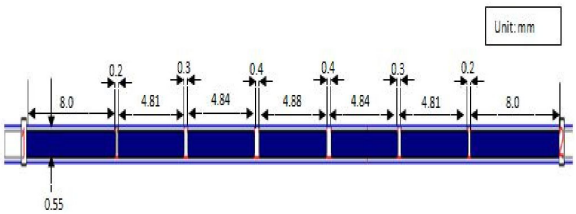

Fig. 3 End coupled half wavelength resonator bandpass microstrip filter.

In Fig.3 half wavelength resonator end coupled microstrip bandpass filter is shown. The design process is carried out by using EM simulator IE3D. The physical structure of this filter is very simple, less complex and it has very simple type of discontinuities, gap discontinuities between the coupled resonators. This is a simple strip line pattern. It is not suitable for wide band application. If this structure is realized on multilayer then it may work for wide band applications [7]. Strip line structure has a limitation that it doesn't allow the fractional band width more than 10% (Theoretical). To obtain wide band response, tight coupling is required between the capacitive gaps. For narrow gaps series capacitance is dominant. Characteristic impedance of each strip line is same (50 ohm). Due its simple structure of only strip lines or sections and capacitively coupled gaps between them it is easy to simulate and its fabrication is also simple. The spurious response of the filter can be easily controlled by making slight changes in the structure [8]. The gap between the resonators play very important role in evaluating the susceptances of the gap. Desired results can be achieved by optimization of these capacitive gaps through the em simulator IE3D. Using em simulator, optimization is time consuming and not very accurate so another way of optimizing is ANN modelling to save time and for better accuracy [9].

IV. SIMULATION AND ANALYSIS

Fig. 4 shows the performance of the end coupled bandpass microstrip filter. The centre frequency is 9.3 GHz which is slightly shifted from 10 GHz. Return loss is -6 dB which is also higher. Insertion loss is -7 dB. Pass band ripples are higher than the predefined value of 0.1 dB. Fraction band width (FBW) is observed 5%. Simulated response is not in good agreement with the proposed response.

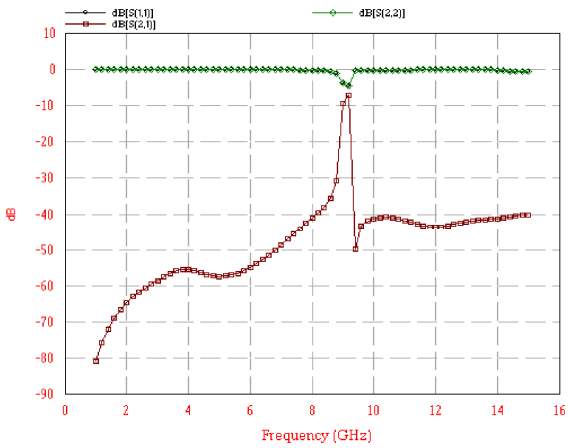

Fig. 4 S-parameter simulated at centre frequency 10 GHz of half wavelength end coupled bandpass microstrip filter.

Few reasons are accounted that expressions used are not explicit closed form expression for designing a filter. Dielectric losses and conductor losses are also responsible for conflict between the simulated and theoretical response. Gap spacing can be adjusted for better performance. Fig. 5 shows S-parameters of end coupled BPF which is designed at lower frequency 6 GHz and other parameters of design are same as for Fig. 4. Simulation result of Fig. 5 shows return loss – 19 dB. Insertion loss is -2 dB. Fractional Band Width is 6%. This shows end coupled BPF at lower frequencies gives better performance rather than at

higher frequencies. No spurious bands seen in Fig. 4 and Fig. 5.

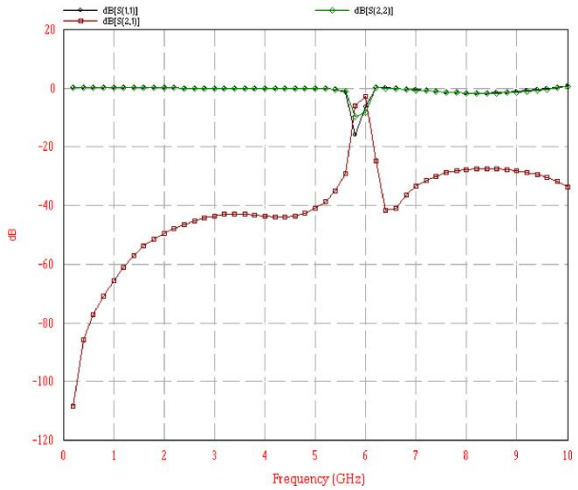

Fig. 5 S-parameter simulated at centre frequency 6 GHz of half wavelength end coupled bandpass microstrip filter

V. STRUCTURE OF PARALLEL COUPLED-LINE (OR EDGE COUPLED) HALF WAVELENGTH BANDPASS FILTERS

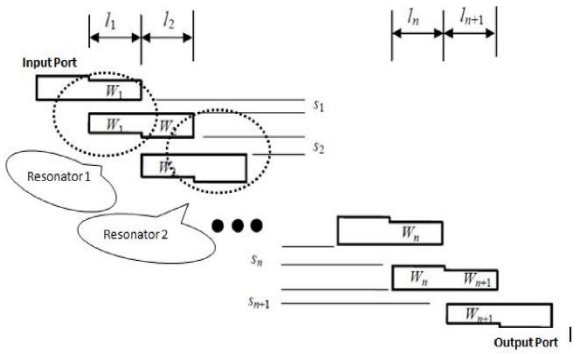

Fig. 6 General layout of parallel coupled half wavelength microstrip bandpass filter.

Parallel coupled or edge coupled BPF is shown in the Fig. 6. The parallel coupled microstrips act as a resonator. To get the resonance, resonator length should be equal to $\lambda_g / 2$ and it's multiple. Maximum resonance is achieved in case of tight coupling. These resonators are tightly coupled along the half wavelength and hence give the wide band response. The length of the parallel coupled microstrip, $l_1, l_2, l_3, \ldots\ldots l_n, l_{n+1}$, are of first, second and n^{th} resonator respectively.

When two microstrips are arranged parallel as given in the Fig. 6 this gives a tight coupling and should be $\lambda_g / 2$ or odd multiple of $\lambda_g / 2$. $W_1, W_2, W_3, \ldots\ldots\ldots W_n, W_{n+1}$ are the width of the resonators. $s_1, s_2, s_3, \ldots\ldots\ldots s_n, s_{n+1}$ are gap between the two microstrips of the resonator, where n is the order of resonator. All resonators are cascaded together and this layout gives a wide band microstrip bandpass filter.

The design equations for parallel coupled resonator line microstrip BPF are as follows.

Realize the J-inverters obtained above (equ. 1-3), the even-mode and odd-mode characteristic impedances of the parallel coupled microstrip line resonators are given by Even- Mode characteristic impedance, Z_{0e}:

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad j = 0 \text{ to } n \tag{10}$$

Odd- Mode characteristic impedance, Z_{0o}:

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad j = 0 \text{ to } n \tag{11}$$

The length of the each resonator is given by

$$l_j = \frac{\lambda_0}{4\left[\sqrt{(\varepsilon_{re})_j \, X (\varepsilon_{ro})_j}\right]^{\frac{1}{2}}} - \Delta l_j \tag{12}$$

Where Δl the correction length of open end of microstrip. λ_0 is the midband wavelength. ε_{re} is the even mode dielectric constant. ε_{ro} is the odd mode dielectric constant.

VI. DESIGN SPECIFICATIONS OF PARALLEL COUPLED BANDPASS MICROSTRIP FILTER

Centre frequency, f_0: 10 GHz
No. of poles, n: 5
FBW: 0.15 = 15%
Bandpass ripple: 0.1 dB
Prototype: Chebyshev
Height of substrate, h: 0.635 mm
Dielectric Constant, ε_r: 10.2
Effective dielectric constant $\varepsilon_{r,eff}$ = 6.79
Characteristic impedance, Z_0: 50Ω
Midband wavelength, λ_0 = 6.79 mm

TABLE II
Filter parameter values for parallel coupled microstrip bandpass filter.

Filter Parameter	Value	Filter Parameter	Value
$\frac{J_{0,1}}{Y_0} = \frac{J_{5,6}}{Y_0}$	0.4534	$s_1 = s_6$	0.162 mm
$\frac{J_{1,2}}{Y_0} = \frac{J_{4,6}}{Y_0}$	0.1878	$s_2 = s_5$	0.541 mm
$\frac{J_{2,3}}{Y_0} = \frac{J_{3,4}}{Y_0}$	0.1431	$s_3 = s_4$	0.731 mm
$(Z_{0e})_{0,1} = (Z_{0e})_{5,6}$	82.8989 ohm	$(\varepsilon_{re})_1 = (\varepsilon_{re})_6$	6.5471
$(Z_{0e})_{1,2} = (Z_{0e})_{4,6}$	61.2100 ohm	$(\varepsilon_{re})_2 = (\varepsilon_{re})_5$	6.7611

$(Z_{0e})_{2,3} = (Z_{0e})_{3,4}$	58. 2123 ohm	$(\varepsilon_{re})_3 = (\varepsilon_{re})_4$	6.7812
$(Z_{0o})_{0,1} = (Z_{0o})_{5,6}$	37.5981 ohm	$(\varepsilon_{ro})_1 = (\varepsilon_{ro})_6$	5.7431
$(Z_{0o})_{1,2} = (Z_{0o})_{4,6}$	42.3804 ohm	$(\varepsilon_{ro})_2 = (\varepsilon_{ro})_5$	6.0281
$(Z_{0o})_{2,3} = (Z_{0o})_{3,4}$	43.8567 ohm	$(\varepsilon_{ro})_3 = (\varepsilon_{ro})_4$	6.1259
$w_1 = w_6$	0.386 mm	$l_1 = l_6$	2.852 mm
$w_2 = w_5$	0.577 mm	$l_2 = l_5$	2.772 mm
$w_3 = w_4$	0.596 mm	$l_3 = l_4$	2.756 mm

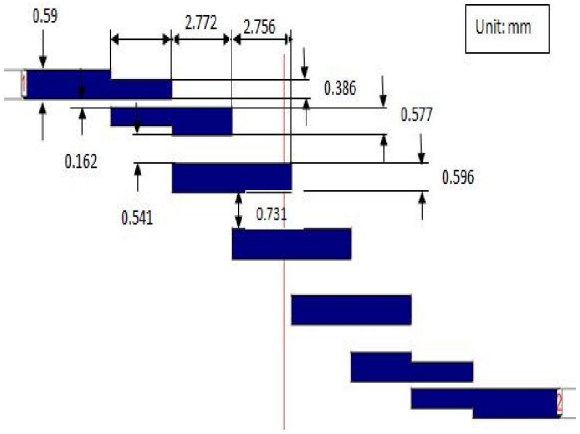

Fig. 7 Simulated layout of parallel coupled half wavelength microstrip bandpass filter.

VII. SIMULATION AND ANALYSIS

Fig. 7 represents the proposed layout of parallel coupled BPF. Fig.8 shows the performance of parallel coupled bandpass filter in terms of S-parameters. The centre frequency of the proposed parallel coupled filter is 9.7 GHz which is slightly deviated from theoretical or calculated value 10 GHz. Return loss is -45 dB which is good. Insertion loss is 0.8 dB. The bandwidth of the filter at – 3 dB is from 8.8 GHz to 10.2 GHz. FBW is 14% which is good agreement with the proposed value. No spurious bands occurred.

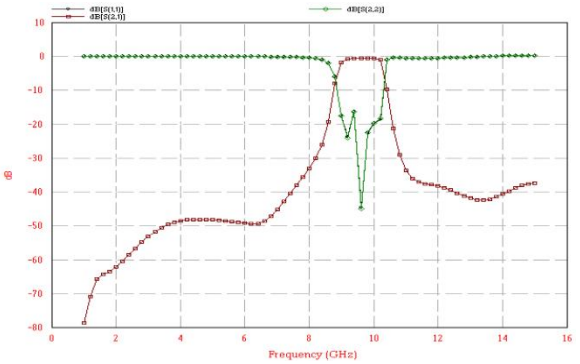

Fig.8 S-parameter simulated at centre frequency 10 GHz of parallel coupled half wavelength bandpass microstrip filter

TABLE III
COMPARISON OF FILTER RESPONSE

	End coupled BPF at 6GHz	End coupled BPF at 10GHz	Parallel coupled BPF at 10GHz
Transfer function	Chebyshev	Chebyshev	Chebyshev
Return loss	-19 dB	-6 dB	-45 dB
Insertion loss	-2 dB	-7 dB	-0.8 dB
Band width	5.5GHz-6.2 GHz	8.9GHz-9.2 GHz	8.8GHz-10.2 GHz
FBW	6%	5%	14%
Length of filter	55 mm	40.18 mm	32.621 mm

CONCLUSION

Firstly we compare the end coupled BPF at 6 GHz and end coupled BPF at 10 GHz. It looks response at 6GHz are good but the size of the filter is more. Length wise it is 14.82 mm longer than the end coupled filter designed at frequency 10 GHz. Introducing the defected ground structure (DGS) the length of the strip line length of the filter can be reduced [10]. If centre frequency is increased the size of the filter is reduced but the performance of the filter is deteriorated. If no. of resonator is increased then slightly the performance of the filter could be improved. Overall end coupled filter at 6 GHz and 10 GHz has narrow band width. FBW of end coupled microstrip filter is only limited to 10% (Theoretical) but practically it is not more than 8% but here we achieved only FBW 6% at 6 GHz and FBW 5% at 10 GHz. Due to bad coupling FBW is less. This is the disadvantage of end coupled bandpass filter. Secondly if we compare the parallel coupled BPF designed at 10 GHz with end coupled BPF designed at 10 GHz. The performance of parallel coupled filter is much better. Losses are very less. Band width is more due its good coupling factor. It is a wide band filter. FBW is higher. We achieved to miniaturize the filter also. Parallel coupled filter is 7.55 mm shorter than end coupled filter. We don't have the fabrication facility of these filters so our analysis is entirely simulated.

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