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Design of miniaturized U-shaped parallel coupled bandpass filter

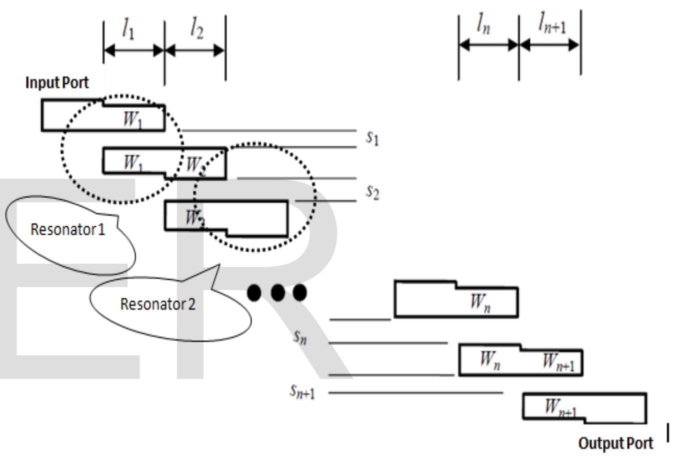
Inder Pal Singh, Praveen bhatt[1], Manish Gupta[2]
Shinas College of Technology, Shinas, P.O. Box 77, PC 324, Oman
[1]SGI Panipat, India, [2]Department of EECE, ITM University, Gurgaon, India
ipsingh201277@rediffmail.com praveen34592@gmail.com manish911989@gmail.com

Abstract— This paper proposed a synthesis of miniaturized U-shaped parallel coupled band pass filter. U-shaped BPF is originally a stair type parallel coupled BPF which is a modified structure realized by folding the arms of traditional stair type parallel coupled bandpass filter. U-shape filter consists of half wavelength long resonators and is designed using J-inverters. In this paper comparison has been made between the tradition stair type parallel coupled BPF and the U-shaped parallel coupled BPF on the basis of same parameters. Filter is designed for the centre frequency 10 GHz, dielectric constant 10.2 and dielectric height 0.635 mm. Proposed filter gained a FBW of 1% and reduction in size 40.7% compare to the tradition stair type parallel coupled BPF. Electromagnetic simulation software IE3D is implemented to design and optimize the filter.

Index Terms — even and odd modes, IE3D, insertion loss, return loss, stair type Parallel coupled BPF, U-shaped Parallel coupled BPF.

1. Introduction

Microstrip filter is vastly being used in modern wireless and mobile communication systems. Bandpass filter is widely used in any type of communication system. In this modern era, miniaturized and lightweight devices such as microstrip filter plays a very important role as being a component of the hand-held electronic communication devices. Merits of the microstrip filter is its small size, large bandwidth, frequency sharing capability, tunning capability, good reliability and high selectivity[1]. Various topologies are available for designing a parallel coupled BPF. Parallel coupled architecture is extensively employed in the designing of bandpass filter because parallel-coupled structures are simple in designing and fabrication. Variety of approaches are available to reduce the size of parallel-coupled structure[2]. Defected ground structure (DGS) is the good technique to reduce the size but limitation with this techniques is non-availability of exact form expressions for designing a DGS unit[4]. In parallel coupled structure coupling strength is a measure of the quality of filter. To achieve the minimum losses coupling should be tight. Due the tight coupling in stair type parallel-coupled BPF shows fewer losses. When stair type parallel-coupled structure is transformed into U-shape parallel-coupled BPF coupling strength is deteriorate. For the tight coupler and wideband filter design, strongly coupled microstrip lines are required. In some electronic circuits input-output of the microstrip filer is required in one straight line whether horizontal or vertical. The proposed filter here fulfils this requirement. To make input-output alignment of filter in one line, the arms of the stair type parallel coupled microstrip BPF is folded. Folding of arms of the filter reduces the coupling strength that has to be taken into account while designing a filter. Full wave analysis has been performed to strengthen the coupling strength.



2. Half Wavelength Stair Type Parallel Coupled Bandpass Filter

Fig. 1 Layout of stair case type parallel coupled half wavelength microstrip bandpass filter.

Stair type parallel coupled resonator BPF is represented in the Fig. 1. Good resonance can be achieved in case of tight coupling along the half wavelength. The length of the parallel coupled microstrip, $l_1, l_2, l_3, \ldots l_n, l_{n+1}$, are of first, second and n[th] resonator respectively. $w_1, w_2, w_3, \ldots\ldots\ldots w_n, w_{n+1}$ 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 resonator, where n is the order of resonator. Even-mode and odd-mode characteristic impedances of the parallel coupled microstrip line resonators are given by the equations [3].

Even- Mode characteristic impedance, Z_{0e}:

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

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

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

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.

3. Design Specifications of Stair Type 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 1
Filter parameter values for stair type 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

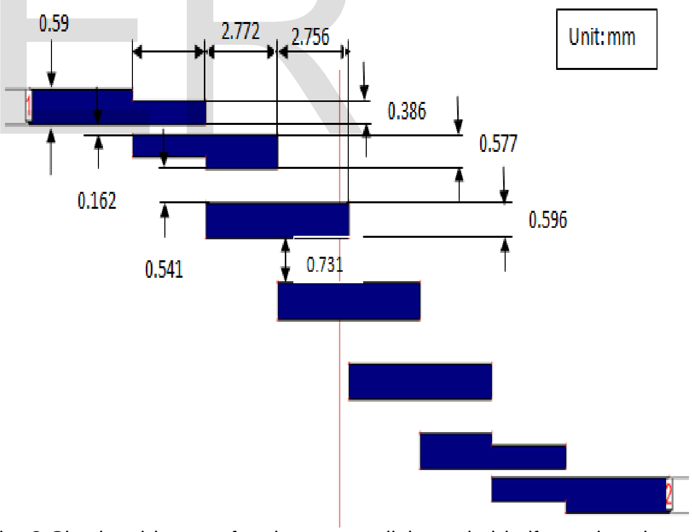


Fig. 2 Simulated layout of stair type parallel coupled half wavelength microstrip bandpass filter.

A stair type parallel coupled BPF uses a very good coupling strength and return and insertion losses are also optimum[5]. In the wireless communication systems this occupies a large area in the circuit of the system. Different approaches are presented in this paper to reduce the size of filter without compromising the quality of the filter. First approach utilizes the folding of arms, here we have given the name to this folding arm structure, U-shape parallel coupled BPF. The arms are folded from the center of the structure. This is two fold geometry. U-shape parallel coupled BPF is shown the Fig. 3. Primary structure is the stair type parallel coupled which is folded in U-shape and second coupled strip of the third resonator is shifted inside the structure to strengthen the coupling. It is clear that any coupling encountered in the miniaturized microstrip filters is that of the proximity coupling, which is basically through fringe fields [6]. The interactions of a couple-line can be found resulting to a resonant circuit therefore it can be employed as key parts of a bandpass filter [7].

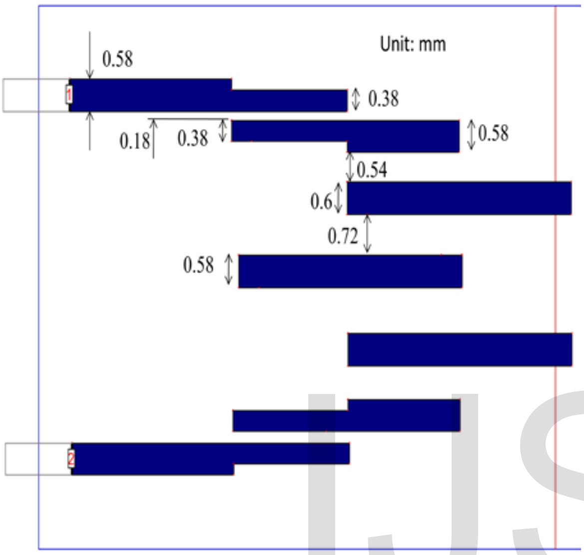


Fig. 3 U-shape parallel coupled bandpass filter.

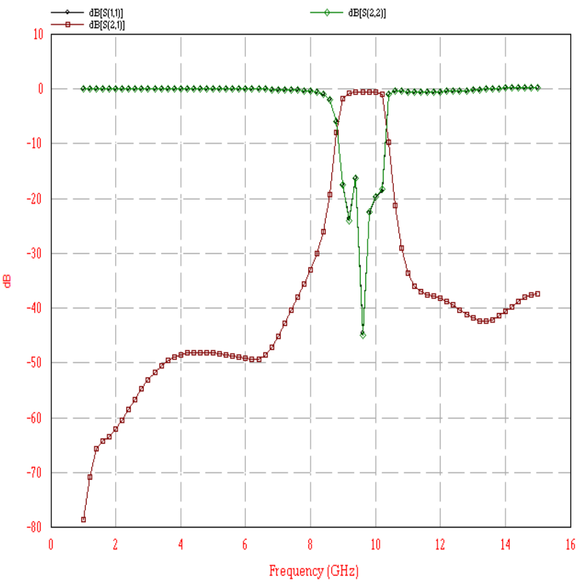


Fig. 4 S-parameter response of simulation at centre frequency 10 GHz of stair type parallel coupled half wavelength bandpass microstrip filter.

Simulated response of stair type parallel coupled BPF shown in Fig.4 gives a return loss of -45 dB at – 3 dB. Its pass band is entirely flat so it has very minimum insertion loss. Its band is from 8.8 GHz to 10.3 GHz.

Fig.3 shows U-shape parallel coupled BPF is simulated on the same design specification as stair type parallel coupled BPF. Its simulation is shown in Fig. 6 at the center frequency 10 GHz which is shifted by 1 GHz in this case. Band of the filter is from 8.2 GHz to 9.8 GHz. Return loss is -18 dB which is more in this case. Its bandwidth is 0.6 dB larger than stair type filter. Its insertion loss is -1 dB. Structure in Fig. 5 is improved version of design given in Fig.3 in which coupling strength is improved by incorporating one addition parallel strip in resonator 1 and resonator 6.

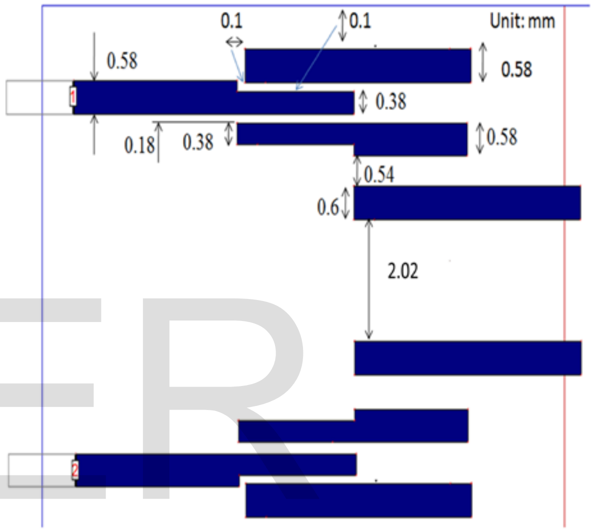


Fig. 5 U-shape parallel coupled bandpass filter with three coupled lines in resonator 1 and resonator 6.

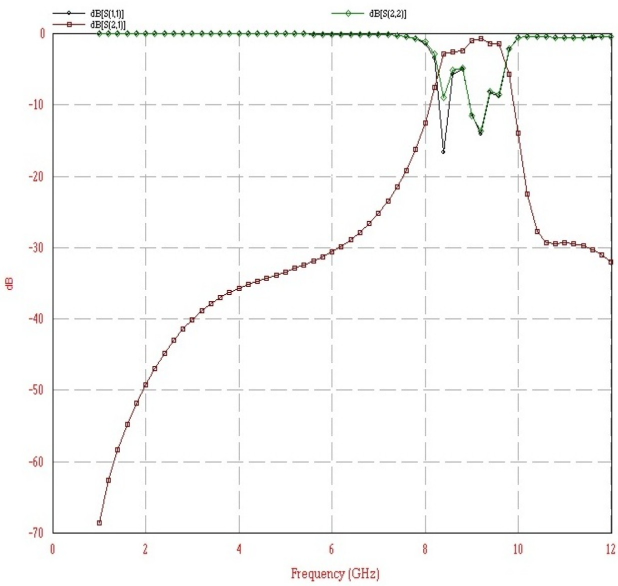


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Fig. 6 S-parameter response of U-shape parallel coupled bandpass filter.

Fig. 8 shows that inserting one parallel arm in resonator 1 and resonator 6 reduces the return loss which comes -22 dB which is good response. Bandwidth is 0.7 GHz. Its passband is almost flat with insertion loss of – 0.2 dB which is a great achievement of this structure over the previous structure given in Fig. 3. This structure is not good for wideband application but can be used for narrow band. In this paper our motive is to miniaturize the stair type parallel coupled BPF so yet our motive is not achieved. Structure given in Fig.5 shows the lossless response but not suitable for wideband systems.
In Fig. 7 design of U-shape miniaturized parallel coupled BPF is depicted. This structure is same as the structure given in Fig. 5 the only difference is that one additional one parallel strip is inserted between resonator 2 and resonator 4. Fig. 7 shows the miniaturized form of stair type parallel coupled bandpass filter, complete U-shape miniaturized parallel coupled bandpass filter which almost gives the same response as stair type parallel coupled BPF gives.

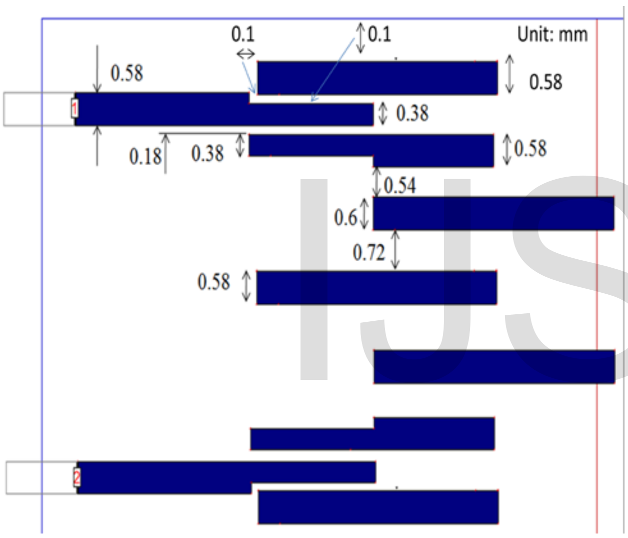

Fig. 7 U-shape miniaturized parallel coupled BPF.

In Fig. 7 resonator 3 and resonator 4 are tightly coupled which increases the bandwidth and finally the response of the filter is wideband.

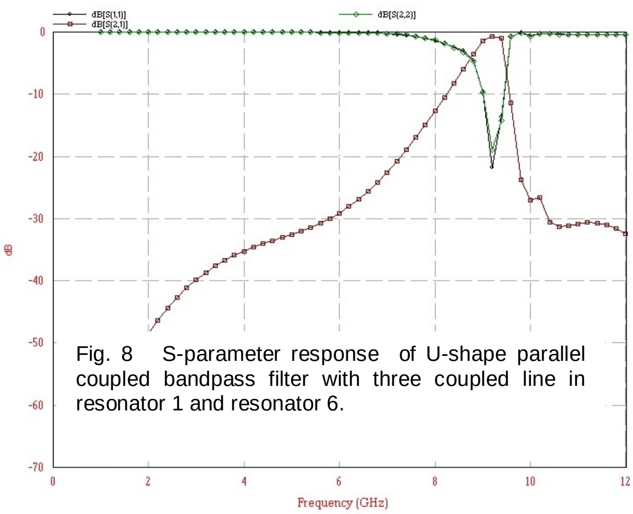

Fig. 8 S-parameter response of U-shape parallel coupled bandpass filter with three coupled line in resonator 1 and resonator 6.

Simulation response of Fig. 7 is shown in Fig. 9 gives return loss at -3 dB is – 28 dB. Insertion loss is -1 dB. Passband is almost flat with some spurious response. Band of the filter is 8.2 GHz to 9.8 GHz.

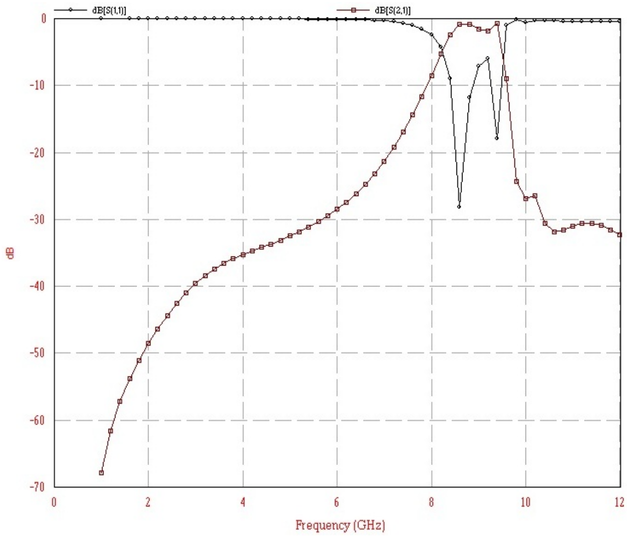

Fig. 9 S-parameter response of U-shape miniaturized parallel coupled BPF.

4. Simulation and Analysis

In this paper four parallel coupled bandpass filters are designed and simulated by electromagnetic Zealand simulator IE3D. Simulation results are given in the table below.

TABLE -2

COMPARISON OF FILTER RESPONSE

	Stair type parallel coupled BPF	U-shape Parallel coupled band-pass filter	U-shape BPF with three coupled lines in resonator1 and resonator 6.	U-shape parallel coupled miniaturi-zed BPF
Transfer Function	Cheby.	Cheby	Cheby.	Cheby.
Return Loss	-45 dB	-18 dB	-22 dB	– 28 dB
Insertion Loss	-0.1 dB	-1 dB	– 0.2 dB	-1 dB
Bandwidth (BW)	8.8 GHz to 10.3 GHz	8.2 GHz to 9.8 GHz	8.8 GHz to 9.5 GHz	8.2 GHz to 9.8 GHz
FBW	15%	16%	7%	16%
Area of Filter	171.5 mm^2	81.8 mm^2	101.6 mm^2	101.6 mm^2

5. Conclusion

Our aim in this paper is to design the miniaturized parallel coupled bandpass filter for wireless communication devices. U-shape miniaturized parallel coupled bandpass filter is designed and compared with the traditional stair type parallel coupled bandpass filter. From the Table 2 it is clear that proposed filter has 17 dB more return loss. Return loss of proposed filter is -28 dB which is more than -20 dB so there is no effective return loss. Proposed filter has nearly flat response. It has few spurious peaks in the band particularly at 9 GHz. These losses are due to sharp bending of the structure due to that it loses its coupling strength. This could be overcome by using the DGS structure [8]. The area of the stair type parallel coupled filter is 171.5 mm^2 and the area of U shape miniaturized parallel coupled is 101.6 mm^2. Here we achieved to miniaturize the stair type parallel coupled by 40.7 %.

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