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3.4-3.9GHz Parallel Coupled Bandpass Filter with High Stopband Rejection and High Return Loss

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ABSTRACT

This paper presents the design, fabrication, and measurement of 3.4-3.9 GHz parallel coupled microstrip bandpass filter. The EM simulation results indicate that the insertion loss varies between -1dB and -0.795dB at the desired frequency band. Both input and output *VSWRs* show the maximum value of 1.28. More than 40dB rejections out of band are witnessed at the stopbands of DC-2.7GHz and 4.85-7.45GHz. In contrast, the measured insertion loss is a little poorer, changing from -1.87dB to -2.59dB, and above 40dB suppression is also recorded at the same stopbands. A little higher input and output *VSWRs*, 1.415 and 1.404 are achieved in the fabricated filter. These results demonstrate that the developed filter can be applied in 3.4-3.9GHz communication systems.

***Keywords* -** Stopband Rejection, Parallel Coupled Filter, Insertion Loss

I. INTRODUCTION

Bandpass filter (BPF) is a passive component capable of selecting a signal inside a specific bandwidth with a certain centre frequency known as passband and reject signals in another frequency region known as stopband. BPF can reduce the harmonic and spurious emissions for transmitters and may improve the rejection of interferences for receivers. Parallel coupled resonator filter plays an important role in bandpass filter configuration for application requiring narrow to moderate bandwidth (up to about 20%) [1, 2]. Up to now, it has been applied in RF/microwave circuit due to its advantages of planar structure, light weight, ease of synthesis method, low cost, and easy matching to RF circuit [3, 4]. However, this kind of filter has a large size and suffers from the spurious responses at the second harmonic. The resolution to miniature of size and elimination of spurious passband based on parallel coupled lines has been reported in our previous works [5].

There have been papers based on parallel coupled lines and aiming at 2.4GHz [6，7], 3GHz [8], 4.5GHz [9], and 5.8GHz [10]. In this work we would like to give a way to conceive, design, and fabricate traditional parallel coupled bandpass filter within 3.4-3.9GHz frequency range, but with 5mm width and having low insertion loss (*IL*) and high selectivity. The initial physical dimensions of filter are calculated and optimized using ADS, and then the optimized sizes are tuned slightly using the fullwave electromagnetic simulator HFSS. The performance of the fabricated BPF is characterized using R&S Vector Network Analyzer.

II. INDENTATIONS AND EQUATIONS

Fig. 1 illustrates a general structure of parallel coupled microstrip BPF that uses half-wavelength line resonators. When the length l of parallel coupled microstrip line equals to $\lambda/4$, the filter has bandpass characteristic. The strips are arranged parallel close to each other, so that they are coupled with certain coupling factors for a given spacing between resonators, and thus, this filter structure is particularly convenient for constructing filters having a wider bandwidth [11]. However, the parallel coupled BPF can not operate at high frequencies due to its spurious passband, and can not provide a steep rejection out of band. If several parallel coupled microstrip lines are cascaded, good filtering characteristic will be achieved.

A perfect filter would have zero *IL* at the passband and infinite attenuation in the stop band but practically these characteristics are not feasible. Chebyshev type filters are popular for their high selectivity, i.e., they have a relatively fast signal cutoff between pass and stop band. Filters operating in gigaherz frequency ranges rely on distributed transmission line structures to obtain the desired frequency response [12]. The Chebyshev approach

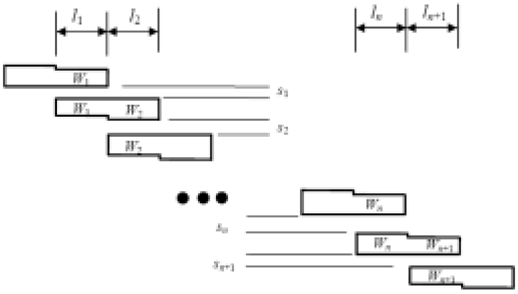

Fig. 1 General structure of parallel coupled microstrip BPF.

shows certain ripples in the pass region, such as 0.01 dB, or 0.1 dB, or even higher values, this can lead to better slope in the stop region [13]. We use the following equations [11] for designing the parallel coupled filter.

$$\frac{J_{01}}{Y_0}=\sqrt{\frac{\pi FBW}{2g_0g_1}} \qquad (1)$$

$$\frac{J_{j,j+1}}{Y_0}=\frac{\pi FBW}{2}\frac{1}{\sqrt{g_jg_{j+1}}} \qquad (2)$$

for j=1 to n=1

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

FBW is the relative bandwidth, $J_{j,j+1}$ is the characteristic admittance of *J* inverter and *Yo* is the characteristic admittance of the connecting transmission line, g_0, g_1, .., g_n can be derived from:

$$g_0=1 \qquad (4)$$

$$g_1=\frac{2}{\gamma}\sin(\frac{\pi}{2n}) \qquad (5)$$

$$g_i=\frac{1}{g_{i-1}}\frac{4\sin\left[\frac{(2i-1)\pi}{2n}\right]\cdot\sin\left[\frac{(2i-3)\pi}{2n}\right]}{\gamma^2+\sin^2\left[\frac{(i-1)\pi}{n}\right]} \quad \text{for i=2,3,…n} \qquad (6)$$

$$g_{n+1}=1.0 \quad \text{for n odd} \qquad (7\text{-}1)$$

$$g_{n+1}=\coth^2(\frac{\beta}{4}) \quad \text{for n even} \qquad (7\text{-}2)$$

Where

$$\beta=\ln\left[\coth(\frac{L_{AR}}{17.37})\right] \qquad (8)$$

$$\gamma=\sinh(\frac{\beta}{2n}) \qquad (9)$$

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

for j=0 to n, and

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

for j=0 to n

Fig. 2 shows the designed filter with fractional bandwidth *FBW*=(3.9-3.4)/3.65=13.69%. The filter design presented uses three sections of six coupled microstrip lines with narrow gap, hence resulting in a reduced size. From the equations above, the component values of forth-order Chebyshev filter with passband ripple L_{AR}=0.5dB are g_0=1, g_1=1.6703, g_2=1.1926, g_3=2.3661, g_4=0.8419, and g_5=1.9841. Calculated even and odd impedances are listed in Table 1.

Fig.2 The designed parallel coupled filter.

Table 1. Z_{0e} and Z_{0o} of each microstrip line.

i	$J_{i,i+1}$	$Z_{0e}(\Omega)$	$Z_{0o}(\Omega)$
0	0.007178	74.3874	38.4951
1	0.003049	58.7848	43.5394
2	0.002562	57.2249	44.4158
3	0.003049	58.7848	43.5394
4	0.007178	74.3863	38.4953

The chosen substrate is Rogers 6010, which has a permittivity ε_r =10.2, thickness *h*=0.635mm, and dielectric loss tan δ =0.0023. The reason for choosing this relative high substrate ε_r is to have a circuit of a smaller size, compared with those on substrates with lower ε_r. The width *W* and length *L* of each strip and the space *S* of each coupled line can be obtained using ADS Line-Calc, as shown in Table 2.

Table 2. Calculated dimensions of width, space, and length.

section	W/mm	S/mm	L/mm
1	0.378660	0.257866	8.290670
2	0.507470	0.659342	8.023750
3	0.517503	0.773598	7.999280
4	0.507470	0.659342	8.023750
5	0.378669	0.257877	8.290650

III. FIGURES AND TABLES

Based on the above values and taking standard input and output port impedances as Z_0=50Ω, the design was simulated. For balancing the different specifications, the proposed filter structure has been optimized and simulated in the frequency range from DC to 7.2 GHz. Fig. 3 shows the frequency response of the circuit simulation using ADS Software. We see a resonant at the central frequency of 3.65GHz. The circuit simulated *IL* is excellent, below 1.05, and input and output *VSWRs* are better than 1.12 at the desired frequency range. These results are much better than those in Ref.[3], where *IL*=2.5dB and return loss>10dB at 3.6GHz. Therefore, the EM simulation can be performed using HFSS based on the initial results.

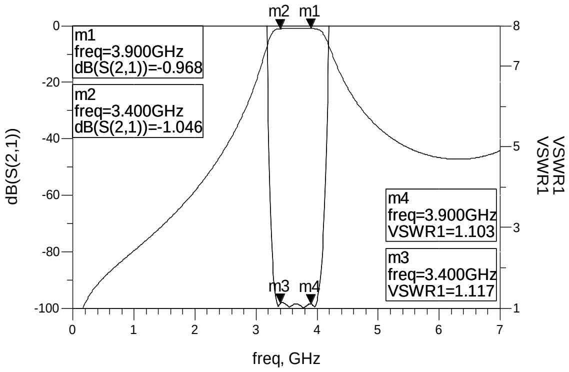

Fig.3 Frequency response of the circuit simulation.

Fig. 4 compares the EM simulated and measured frequency responses, which are represented by the solid and dash lines, respectively. The *IL* and *VSWRs* are measured with R&S ZVK Vector Network Analyzer, and the test configuration is present in Fig. 5.

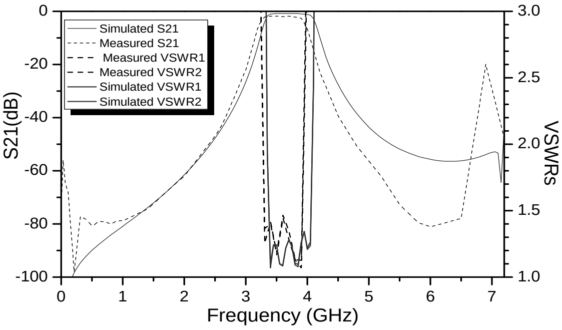

Fig. 4 EM simulated and measured results of filter.

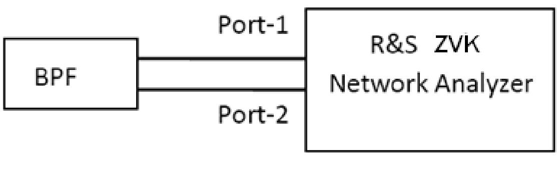

Fig. 5 Test set up for microstrip parallel coupled BPF.

From Fig.4, the EM simulation results indicate the *IL* of about -0.83 dB and *VSWRs* of no more than 1.22. The simulated BPF has a sharp skirt and out-of-band rejection levels above 40 dB at the stopbands of DC-2.7GHz and 4.85-7.45GHz. The measured results show better out-of-band rejection at 4.85-7.45GHz, but a little poorer *IL* and *VSWRs* performances. *IL* ranging from -1.87dB to -2.59dB and *VSWRs* below 1.4 are achieved. In addition, the measured passband shifts to lower frequency by 100Hz, and the achieved structure suffers from the existence of second spurious response around -20dB at 6.9GHz.

IV. CONCLUSION

In this paper, a parallel coupled microstrip bandpass filter with a narrow width of 5mm is designed for 3.4-3.9GHz wireless communications. At the center frequency, the EM simulated insertion loss and *VSWRs* have the values of about -0.83 dB and better than 1.22, respectively. Besides, in the simulation results, sharp attenuations above 40 dB are obtained at DC-2.7GHz and 4.85-7.45GHz. The measurement gives also very good out-of-band rejection characteristic, however, with larger insertion loss of about -1.9dB with 1dB ripple and greater *VSWRs* less than 1.4 in the frequency range of 3.4-3.9GHz. This larger loss originates likely from losses of the coaxial connectors and their poor contacts to the microstrip line. These results demonstrate that the developed filter has very good filtering characteristics and can be applied in 3.4-3.9GHz communication systems.

REFERENCES

[1] L Chen, M.Q. Wu, Y. Xiao, and S.R. Zhang, Design of parallel coupled band-pass based on ADS, *Piezoei. Ectrics&Acoustooptics, 34(3)*, 2012, 483-485.

[2] A. Bhattacharjee and N. Kumar Singh. Design, fabrication and analysis of parallel-coupled line bandpass microstrip filter for C-band application, *International Journal of Electrical, Electronics and Computer Engineering, 1(2)*, 2012, 51-54.

[3] A. Renu Goyal, B. E. Manpreet S. Manna, and C. E. Sushil Kakkar, Design and analysis of microstrips coupled line band-pass filter, *International Journal of Advanced Technology & Engineering Research (IJATER), 4(2)*, 2014, 24-27.

[4] J.T. Kuo, M. Jiang, and H.J. Chang, Design of parallel-coupled microstrip filters with suppression of spurious resonances using substrate suspension, *IEEE Transactions on Microwave Theory and Techniques, 52(1)*, 2004, 83.

[5] Y.H. Yao and T.X. Fan, 2.9-8.4GHz filter bank using stub-loaded multi-mode resonators, *Journal of Electromagnetic Analysis and Applications, 6*, 2014, 397-403.

[6] S. Srivastava, R.K. Manjunath, and P. Shanthi, Design, simulation and fabrication of a microstrip bandpass filter, *International Journal of Science and Engineering Applications, 3(5)*, 2014, 154-15.

[7] P. Mondal, A. Ro, T. Moyra，S.K. Parui, and S. Das, New concept for designing of compact parallel coupled bandpass filter, Proc. *International Conference on Communication, Circuits and Systems(iC3S-2012),* Bhubaneswar, Odisha, India, 2012, 19 -21.

[8] M. Jaldi and M. Tayarni, Improvement of stopband property of parallel coupled microstrip bandpass filters by use of open stubs, *International Journal of Information and Electronics Engineering, 3(1),* 2013, 68-71.

[9] M.L. Roy, A. Perennec, Spurious responses suppression of parallel coupled-lines microstrip bandpass filters: comparison and improvements of planar approaches. I*nternational Journal of Microwave Computer-Aided Engineering, 17(1),* 2007, 104-109.

[10] M.A. Othman, M. Sinnappa, M.N. Hussain, M.Z.A. Abd. Aziz, and M.M. Ismail, Development of 5.8GHz microstrip parallel coupled line bandpass filter for wireless communication system, *International Journal of Engineering and Technology, 5(4)*, 2013, 3227-3234.

[11] J.S. Hong and M.J. Lancaster, *Microstrip Filters for RF/Microwave Applications* (John Wiley & Sons Ltd., 2011).

[12] S.Srinath, Design of 4th order parallel coupled microstrip bandpass filter at dual frequencies of 1.8 GHz and 2.4 GHz for wireless application, *International Journal of Innovative Research in Computer and Communication Engineering, 2(6),* 2014, 4744-4747.

[13] M. Alaydrus, Designing microstrip bandpass filter at 3.2 GHz, *International Journal on Electrical Engineering and Informatics, 2(2),* 2010, 71.