Parallel-Coupled Line Bandpass Filter Design Using Different Substrates for Fifth Generation Wireless Communication Applications

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Abstract—**The aim of this paper is to propose characterization of a compact microstrip bandpass filter (BPF) design for fifth generation (5G) wireless communication applications concerning the design frequency of 15 GHz. The BPF design consists of quarter wave parallel-coupled line resonators and additional small resonator attached between the first/last coupled-line section and the ports' 50 ohm transmission line. The characterization is based on the analysis of different substrates with the selected relative permittivity of 2.2 (RT/Duroid 5880), 3.55 (RO4003C), 4.70 (TMM4), 10.7 (RO6010) and 11.20 (RO3010). The proposed design with RO6010 substrate exhibits an improvement in the bandwidth performance. The design and analysis are performed via the use of Keysight's Advanced Design System (ADS) 2015 simulator.**

Keywords—bandpass filter; coupled-line; fifth generation; microstrip; resonator.

I. INTRODUCTION

Currently, there is an increasing demand for bandpass filter (BPF) as it has been considered as an important component in designing any modern front-end of the wireless communication systems such for the future fifth generation (5G) communication. 15 GHz band is one of the candidates to be considered for use in 5G cellular technology, besides other bands in the spectrum above 6 GHz. Thus, in order to keep the wireless communications up-to-date, various researches on the BPF have been conducted [1, 2]. As a matter of fact in very high frequency applications, lumped components are not practically to be implemented, therefore; the lumped element BPF circuit is transformed to the planar transmission line circuit [3]. In this study, insertion loss method, which uses network synthesis technique with a completely specified frequency response, has been applied to design the BPF filter.

Moreover, there are different types of microstrip line filters such as hairpin, coupled-line, step impedance, and stub impedance [1, 3-9]. At microwave frequencies, the design of BPF often uses the parallel-coupled line technique due to the simple structure, good performance and the easy fabrication process. Authors in [4] and [3] presented the design of coupled-line BPF that optimized using flame retardant 4 (FR-4) substrate with a center frequency of 1.42 GHz and 2.44 GHz, respectively. In [4], the designed BPF demonstrated a well bandwidth performance of 300 MHz with return loss greater 10 dB and insertion loss of 2.806 dB. On the contrary, the designed BPF in [3] offered narrower bandwidth of 80 MHz with return loss better than 16.1 dB and insertion loss of 3.1 dB. In [5], a parallel-coupled BPF design for S-band application was proposed using higher relative permittivity substrate of RT/Duriod 6010. The simulation results showed significantly better bandwidth of 66% for 2 to 4 GHz frequency range with return loss of 11 dB and insertion loss of 1 dB. While, [1] proposed BPF design implementing stub-inserted interdigital coupled-lines using FR-4 substrate with design frequency of 4 GHz. This BPF has displayed overall improved results of insertion loss and return loss, but slightly narrower fractional bandwidth performance than [5]. The proposed BPF achieved bandwidth up to 40% for frequency range of 3.2 GHz to 4.8 GHz with very well insertion loss of 0.92 dB and with return loss better than 15 dB. In addition, Saad et. al. [6] proposed a BPF design at the design frequency of 5 GHz using Ferro Tape as the substrate with thickness of 0.635 mm. However, performance of this BPF showed quite high insertion loss of 4.9 dB for bandwidth of 180 MHz with return loss of 7 dB. Authors in [7] took a different approach using Teflon substrate with thickness of 0.504 mm. The design by using T-feeder coupling lines and hairpin resonator at the center frequency of 5.205 GHz. Simulation analysis showed that bandwidth of 10.34% with return loss of 23 dB and insertion loss of 1.4 dB at resonant frequency of 5.13 GHz. The reviewed previous works above have been designed with frequencies less than 6 GHz. Currently, 5G cellular technology is being researched with consideration of a higher spectrum than 6 GHz band.

The design based on an ultra-thin liquid-crystal polymer substrate at higher design frequency of 9.4 GHz was proposed in [8] showing the insertion loss of 2.1 dB and the return loss better than 20 dB with 5.7% bandwidth. Another design at millimeter-wave band concerning design frequency of 25 GHz was reported in [9] achieving 20% bandwidth along with return loss better than 15 dB and insertion loss of 2 dB. Meanwhile, Tsai et al. in [10] proposed a higher millimeter-wave band design using coupled microstrip resonators concerning the design frequency of 77 GHz. Where, the performance of this BPF demonstrated the return loss better than 15 dB and insertion loss of 1.3 dB in the pass band with

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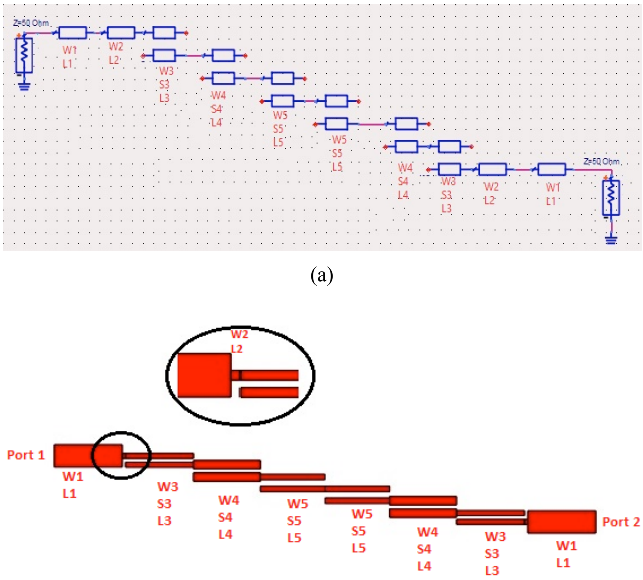
the bandwidth of 9.5%.

Thus in this paper, a compact BPF consisting of quarter wave parallel-coupled line resonators is proposed by studying the effect of different substrates of RT/Duroid 5880, RO4003C, TMM4, RO6010 and RO3010 that having the dielectric constant in the range of 2 to 11.5. To enhance passband and bandwidth performance, small resonator is added to the first and end section of coupled-line. The design concerns a center frequency of 15 GHz, which simulated and analyzed using Keysight's Advanced Design System (ADS) 2015 simulator.

II. PARALLEL-COUPLED LINE BANDPASS FILTER DESIGN

Chebyshev type filter with the number of order, N set to be five is chosen for this design. Whilst, the passband ripple is 0.5 dB. Then, the conversion to the parallel-coupled BPF structure that having schematic and layout as shown in the following Fig. 1 can be performed by computing the even and odd characteristic impedances of coupled-line as expressed in (1) and (2). Small resonators have been added to the first and end section of coupled line to improve the bandwidth and passband response.



(a)

(b)

Fig. 1. (a) Schematic and (b) layout of the proposed parallel-coupled line BPF

$$Z_{0e_{k,k+1}} = Z_0\left[1 + J'_{k,k+1} + {J'_{k,k+1}}^2\right] \qquad (1)$$

$$Z_{0o_{k,k+1}} = Z_0\left[1 - J'_{k,k+1} + {J'_{k,k+1}}^2\right] \qquad (2)$$

where, k varies from 0 to N. While, $J'_{k,k+1}$ and Z_0 represent the admittance inverter and the characteristic impedance that has a typical value of 50Ω. The admittance interver for first and last stage can be given by (3), while the other stages are computed using (4).

$$J'_{0,1} = J'_{k,k+1} = \left\{\frac{\pi\Delta}{2g_0g_1}\right\}^{\frac{1}{2}} \qquad (3)$$

$$J'_{k,k+1} = \frac{\pi\Delta}{2\sqrt{g_k g_{k+1}}} \qquad (4)$$

where, g_k and Δ are the normalized elements obtained from the Chebyshev table and the fractional bandwidth, accordingly. The fractional bandwidth, Δ can be given by (5):

$$\Delta = \frac{w_2 - w_1}{w_0} \qquad (5)$$

where, w_0, w_1 and w_2 are the design, lower and upper end of angular frequency, respectively. The calculated parameters obtained by using (1) to (5) are tabulated in Table I.

TABLE I. THE CALCULATED PARALLEL-COUPLED BPF PARAMETERS

Stage	Normalized Element, g_k	Admittance Inverter, $J'_{k,k+1}$	Even Mode Impedance (Z_{0e})	Odd Mode Impedance (Z_{0o})
1	1.7058	0.3034	69.77	39.43
2	1.2296	0.1084	56.06	45.16
3	2.5408	0.0888	54.83	45.95
4	1.2296	0.0888	54.83	45.95
5	1.7058	0.1084	56.06	45.16
6	1	0.3034	69.77	39.43

TABLE II. THE USED SUBSTRATES IN THE STUDY WITH DIFFERENT THICKNESS AND RELATIVE PERMITTIVITY

Substrates	Dielectric Constant, ε_r	Thickness (mm)	Loss Tangent, tan δ
RT/Duroid 5880	2.2	0.508	0.0009
RO4003C	3.55	0.508	0.0027
TMM4	4.70	0.508	0.0020
RO6010	10.7	0.635	0.0023
RO3010	11.20	0.640	0.0022

TABLE III. THE OPTIMIZED DIMENSIONS IN MM OF THE DESIGNED BPFS

BPF Dimension	Substrates				
	RT/Duroid 5880	RO4003C	TMM4	RO3010	RO6010
W1	1.55	1.13	0.93	0.56	0.58
L1	3.62	2.96	2.61	1.77	1.80
W2	0.53	0.57	0.42	0.29	0.13
L2	0.09	0.09	0.09	0.09	0.09
W3	0.53	0.57	0.42	0.29	0.13
S3	0.02	0.13	0.08	0.16	0.10
L3	3.55	3.20	2.73	1.82	1.81
W4	0.45	1.09	0.46	0.25	0.22
S4	0.10	0.13	0.34	0.49	0.10
L4	3.69	2.92	2.70	1.83	1.78
W5	0.37	0.85	0.62	0.25	0.14
S5	0.10	0.40	0.40	0.58	0.17
L5	3.34	2.98	2.66	1.83	1.72

Afterward, by utilizing Rogers RT/Duroid 5880, RO4003C, TMM4, RO6010 and RO3010 substrates with specifications stated in Table II and the parameters in Table I, the dimensions of coupled-line width, W and gap spacing, S can be calculated. While, the length, L of each coupled-line resonator at each stage can be computed from (6). The respective calculated dimensions for BPFs operate at 15 GHz are designed, simulated and optimized using ADS software. The optimized dimensions are summarized in the Table III.

$$L = \frac{\lambda}{4} = \frac{3\times10^{8}}{4f\sqrt{\varepsilon_{e}}} \qquad (6)$$

III. RESULTS AND DISCUSSION

Referring to Fig. 2 and 3, the insertion loss of RO6010 BPF across the passband is 1 dB. While, the bandwidth is 44.7% across 12.85 to 19.56 GHz with return loss better than 10 dB. Meanwhile, RT/Duroid 5880 BPF has insertion loss of 0.8 dB as depicted by Fig 2. 37% of the bandwidth from 12.6 to 18.16 GHz is demonstrated by the BPF using this substrate. Furthermore, the RO3010 BPF has insertion loss of 2 dB and return loss that greater than 10 dB with 21.73% of the bandwidth from 13.5 to 16.8. In addition, the insertion loss of TMM4 BPF is 1.5 dB and the return loss more than 10 dB. Whereas, the bandwidth is 18%. Then, it can be noted that RO4003C BPF has the worse bandwidth of 4.33%. Its insertion loss and return loss are better than 1.7 dB and 10 dB, accordingly. The designed BPFs' performances are then summarized in Table IV.

Based on this study, RO6010 substrate offers the best bandwidth performance of 44.7% compared to other substrates with agreeable well insertion loss and return loss. This can be due to its characteristic good thermal mechanical stability. While, RT/Duroid 5880 provides the best insertion loss of 0.8 dB that contributed by its low dissipation factor. However, it has a slightly narrower bandwidth than RO6010. In term of BPF size, the designs using RO6010 and RO3010 substrate depict quite similar size of 15.2. x 3.4 mm^2 and 14.7 x 6.4 mm^2 due to the close relative permittivity of 10.7 and 11.2, accordingly.

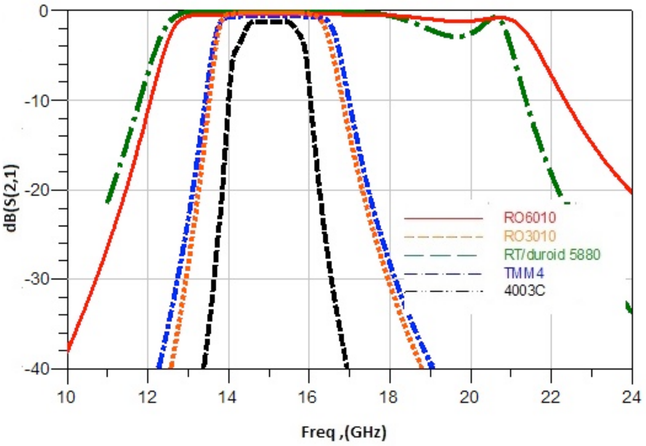


Fig. 2. S21 of 15 GHz parallel-coupled BPFs using different substrates

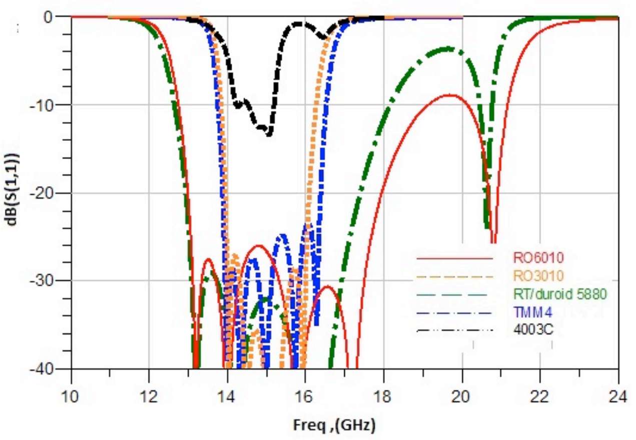


Fig. 3. S11 of 15 GHz parallel-coupled BPFs using different substrates

TABLE IV. SUMMARY AND COMPARISON OF THE BPF WITH DIFFERENT SUBSTRATES

Substrates	**S21 (dB)**	**S11 (dB)**	**Operating Frequency (GHz)**	**BW (%)**	**Size (mm^2)**
RT/Duroid 5880	≥ -0.8	≤ -10	12.6 – 18.16	37	25.4 x 5.5
RO4003C	≥ -1.7	≤ -10	14.48 – 15.62	4.33	25.5 x 10.8
TMM4	≥ -1.5	≤ -10.2	13.7 – 16.5	18.6	22.6 x 6.7
RO6010	≥ -1	≤ -10	12.85 – 19.56	44.7	15.2. x 3.4
RO3010	≥ -2	≤ -10	13.5 – 16.8	21.73	14.7 x 6.4

IV. CONCLUSION

In this study, the design of band pass filter using microstrip parallel-coupled resonator has been presented using Keysight's ADS software with the concern of operating frequency at 15 GHz. The design has been performed with implementation of different substrates of RT/Duroid 5880, RO4003C, TMM4, RO6010 and RO3010. These BPFs exhibit well insertion loss and return loss with significantly different bandwidth performance. The best performance with compact size can be observed from the design using substrate of RO6010.

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