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Design of BPF for FR-I band for 5G technology

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ABSTRACT: The fifth generation of mobile communication (5G) technology is expected to provide higher data rates, lower latency, and improved reliability compared to previous generations. In order to achieve these goals, it is necessary to use a wide range of frequencies, including the FR-1 frequency range (30 MHz to 300 MHz). However, the use of a wide frequency range also increases the likelihood of interference from unwanted signals. In this paper, we present the design and implementation of band pass filters (BPF) for 5G communication in the FR-1 frequency range. We discuss various filter design methods and their performance in terms of attenuation, insertion loss, and return loss. We also present the results of simulations and measurements of the BPF performance in a 5G communication system. Our results show that the BPF can effectively reduce the interference from unwanted signals and improve the signal-to-noise ratio in the FR-1 frequency range.

I. INTRODUCTION

Radio frequency (RF) noise is an increasingly critical issue in 5G and wideband radar systems [1]. 5G communications is being implemented widely in 700 Megahertz (MHz), 3.6 Gigahertz (GHz), and 26 GHz bands, respectively. Due to effective rejection of spurious frequencies, microstrip bandpass filter (BPF) is regularly used to filter the RF noise signals and unwanted harmonics [2] whilst defining the operating bandwidth in wireless communication applications [3]. Moreover, BPF with compact size, low loss, and wide passbands becomes highly potential techniques to fulfil the 5G mobile communications requirements [4–5], which includes the massive multiple-input multiple-output (MIMO) system [6]. A BPF consists of several coupled resonators where the dimensions of the distributed lumped elements and number of resonators characterize the BPF [7]. Many miniaturization methods seek to minimize one or other of these quantities.r, BPF with compact size, low loss, and wide passbands becomes highly potential techniques to fulfil the 5G mobile communications requirements [4–5], which includes the massive multiple-input multiple-output (MIMO) system [6]. A BPF consists of several coupled resonators where the dimensions of the distributed lumped elements and number of resonators characterize the BPF [7]. Many miniaturization methods seek to minimize one or other of these quantities.An ideal BPF design would have zero insertion loss (S21), return loss voltage standing wave ratio (VSWR) of one, impedance matching at the desired value (e.g., 50 Ω), and linear phase response in the passband as well as infinite attenuation in the stopband, respectively

II. DESIGN OF FILTER

Parallel coupled line of microstrip are widely used in microwave component designs, such as microstrip filters including BPF [11], delay lines, impedance matching networks, and directional couplers due to its low-cost fabrication, easy integration [12], more stability [13], and simple design procedure [14]. Figure 1 shows the flowchart of the parallel-coupled line microstrip BPF design. In this paper, a proposed microstrip BPF based on the Butterworth filter response operating frequency between 3.40 and 3.80 GHz is designed and optimized using the Advanced Design System (ADS) software for sub-6 GHz 5G applications. The ADS software has built-in controllers that can optimize design key parameters for optimum simulated results [15]. The Butterworth filter will generate a maximally flat amplitude response in the passband. The use of maximally flat filter raises contradiction concerns between stability, response time and test precision. Maximally flat filter with low order *N* has characteristics, such as small filter overshoot, rapid response and bad test precision. High-order maximally flat low-pass filter (LPF) has a good test precision, large overshoot, poor stability, and slow response [16]. In this paper, the BPF design is based on the fourth order (N = 4) maximally flat response.

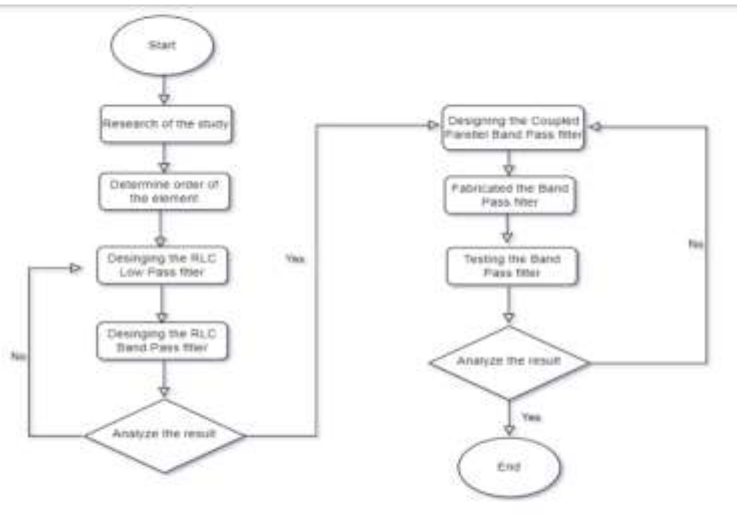
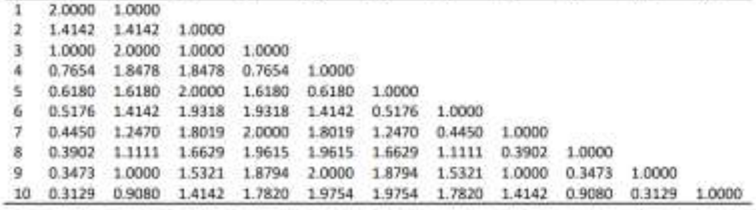


Fig. 1. Flowchart of the BPF design

Based on Figure 1, the flowchart starts with the design of a Butterworth LPF then transforms to its respective Butterworth BPF design. In this case, the fourth order (N = 4) LPF is initially designed based on ILM element values as enlisted in Table 1. The LPF has a maximally flat amplitude response in the passband region. Based on Table 1, the 4th order Butterworth maximally flat LPF has elements of g1 = 0.7654, g2 = 1.8478, g3 = 1.8478, and g4 = 0.7654, respectively. Figure 2 shows the lumped element circuit design for the LPF using the ADS software.

Table 1
Element values for maximally flat LPF prototype [8]



N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

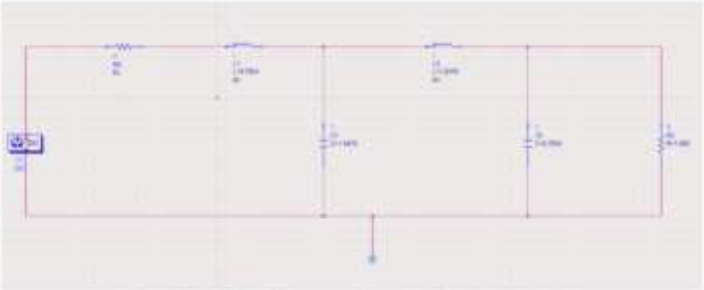


Fig. 2. The 4th order butterworth maximally Flat LPF circuit

conversion of the LPF to the BPF is done systematically based on Figure 3. Basically, each capacitor in the LPF circuit is replaced by parallel inductor and capacitor whereas each inductor in the LPF circuit is replaced by series inductor and capacitor to generate the respective BPF lumped element circuit**.**

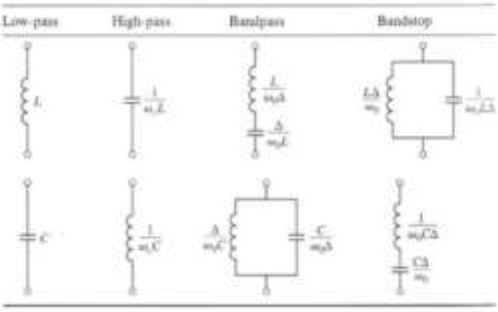


Fig. 3. Microwave filter conversion [8]

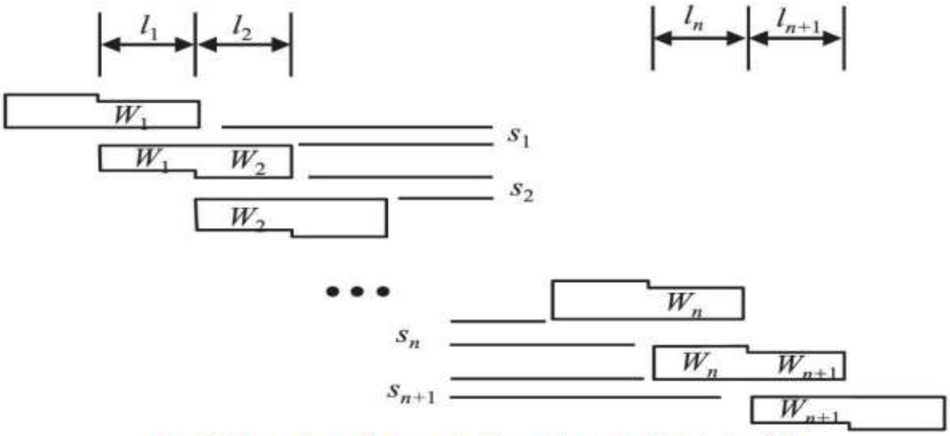
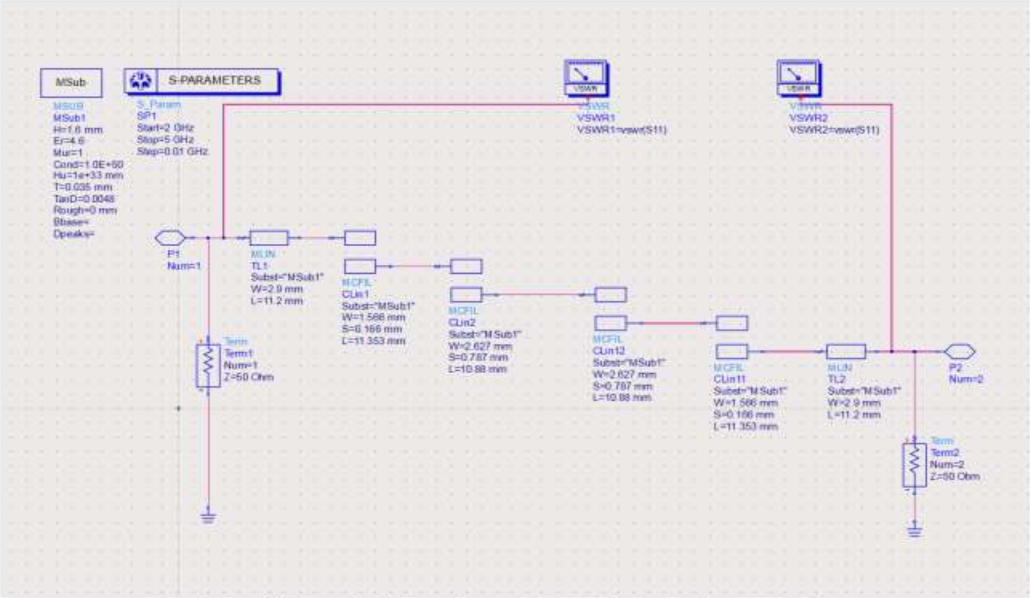


Fig. 5. General parallel coupled line microstrip BPF design [2]



MSUB
MSub1
H=1.6 mm
Er=4.6
Mur=1
Cond=1.0E+50
Hu=1e+33 mm
T=0.035 mm
TanD=0.0048
Rough=0 mm
Bbase=
Dpeaks=

S_Param
SP1
Start=2 GHz
Stop=5 GHz
Step=0.01 GHz

VSWR
VSWR1
VSWR1=vswr(S11)

VSWR
VSWR2
VSWR2=vswr(S11)

P1
Num=1

Term
Term1
Num=1
Z=50 Ohm

MLIN
TL1
Subst="MSub1"
W=2.9 mm
L=11.2 mm

MCFIL
CLin1
Subst="MSub1"
W=1.566 mm
S=0.166 mm
L=11.353 mm

MCFIL
CLin2
Subst="M Sub1"
W=2.627 mm
S=0.787 mm
L=10.88 mm

MCFIL
CLin12
Subst="MSub1"
W=2.627 mm
S=0.787 mm
L=10.88 mm

MCFIL
CLin11
Subst="M Sub1"
W=1.566 mm
S=0.166 mm
L=11.353 mm

MLIN
TL2
Subst="M Sub1"
W=2.9 mm
L=11.2 mm

P2
Num=2

Term
Term2
Num=2
Z=50 Ohm

Fig. 6. Parallel coupled line microstrip BPF design in the ADS software

Figure 7 shows the respective layout design of the BPF in the ADS software whereas Figure 8 shows the fabricated BPF using the FR-4 substrate with two Sub-Miniature A (SMA) coaxial cable connectors.

IV. RESULTS AND DISCUSSION

The simulation result of the return loss (S11) and insertion loss (S21) show that the BPF design operates between 3.423 and 3.766 GHz band edge frequencies as in Figure 9. In this case, the S11 is nearly -30 dB at 3.53 GHz whereas S21 is -2.007 dB at 3.423 GHz and -2.108 dB at 3.766 GHz, respectively. In this study, the Keysight FieldFox radio frequency (RF) analyzer model N9913A is used to measure the performance of the fabricated BPF. Figure 10 shows the S11 of the fabricated BPF is -28.41 dB at 3.53 GHz whereas Figure 11 shows the S21 of the fabricated BPF is -13.15 dB at 3.423 GHz and -6.419 dB at 3.766 GHz, respectively.

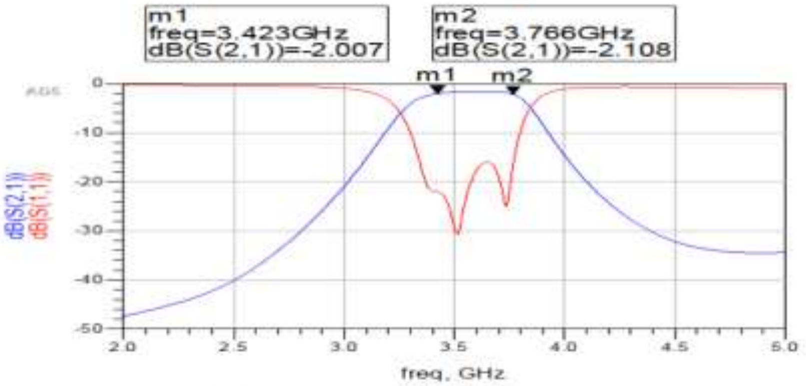


Fig. 9. Simulations of return and insertion losses

Fig. 10. Measurement of return loss

Fig. 11. Measurement of insertion loss

Moreover, Figure 12 indicates that return losses (S11 and S22) have matching impedance nearby 50 Ω within the band edge frequencies. Figure 13 shows the Smith chart plot in which the fabricated BPF has matching impedance close to 50 Ω at the operating frequency of 3.53 GHz. Furthermore, the fabricated BPF has the return loss VSWR of 1.073 as in Figure 14 and return loss phase of 66.88o as in Figure 15 at 3.53 GHz, respectively.

V. CONCLUSIONS

In this study, the design of bandpass filter (BPF) using parallel coupled microstrip resonator has been designed and simulated using the ADS software operating at the edge frequencies between 3.40 and 3.80 GHz. The design applies the insertion loss method (ILM) initially based on the 4th order Butterworth maximally flat low-pass filter (LPF) then converted to the respective BPF with the FR4 substrate. The BPF design successfully generates acceptable performance in terms of a good matching impedance of 50 Ω, adequate far field radiation pattern, return loss (S11) of below -10 decibel (dB), voltage standing wave ratio (VSWR) near to 1, maximum gain of 1.75 decibel relative to isotropic (dBi), maximum directivity of 10.32 dBi, and maximum radiated efficiency of 13.91 %, respectively. In sum, this parallel coupled line microstrip BPF design can be potentially applied for sub-6 GHz 5G applications.

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