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Design of a dual-band bandpass filter with shunt stubs for wireless local area network and satellite communication system

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ABSTRACT

High-performance radio frequency (RF) modules are required in transmitter and reception devices due to the recent expansion of wireless technology. The power amplifier, low-noise amplifier, filter, and mixer are the most crucial components in the RF transmitter/receiver chain. This work presents the design and analysis of a dual-band bandpass filter (BPF) for wireless local area network (WLAN) and C-band satellite applications. Stubs of the proper electrical length that are open and short-circuited are used to implement the filter. The low pass performance is generated by the open-circuited stubs. Short-circuited stubs achieve high-pass performance, while the combination of open and short-circuited stubs achieves bandpass performance. We confirm the filter's behaviour using the advanced design system 2022 simulation tool. The findings of return loss and insertion loss confirm the simulation-level performance analysis of the filter. The result demonstrates the suggested BPF's dual-band behaviour at 4 GHz and 6 GHz.

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1. INTRODUCTION

An essential component of wireless communication receivers is the radio frequency (RF) bandpass filter (BPF) module. Unintentional bands or interferences may be present in the signal that the antenna has picked up. Allowing the required channels for receiver signal processing is thus desirable. Similarly, we must use the BPF to appropriately filter out the higher-order frequencies produced by power amplifiers, mixers, and low noise amplifiers (LNAs) [1]–[4]. The bulk of the literature [5]–[8] concentrated on the compact character of the planar filter architectures. The selection of parameters for the prototype filters is the first step in the basic filter design. We chose stepped impedance-based filter designs due to their compact nature. Shorting the stepped impedance resonator produces a bandpass response [9]. Open and short-circuited stubs generate the bandpass response [10]–[12]. The study of linked transmission lines for the synthesis of BPFs begins at [13]. The examination of even and odd modes makes the mathematical modelling of these filters considerably more difficult. Researchers favour adding a coupled line with quasi-absorptive stub loading [14]. The quasi-absorptive character of the filter structure prevents the reflections from being optimally zero. A complementary-duplexer design best realises absorptive-type filters. The main and auxiliary channels of the duplexer have inverse transfer functions [15]–[21]. BPFs based on split ring resonators are a highly practical way to achieve high-frequency selectivity [22]. Many RF application modules make extensive use of the SRR structure's compact characteristics [23]–[25]. Adding complementary split ring resonators to linked line sections also achieves better bandpass response [26].

2. PROPOSED FILTER DESIGN

A cascade connection of high-pass and low-pass filters makes up the suggested BPF. High-pass filters make up the first stage of the two-stage BPF design process, while low-pass filters make up the second stage. Thus, the design of the high-pass and low-pass filter sections is where the BPF structure development starts. The cutoff response of the low-pass filter is intended to be 6 GHz. The low-pass filter is designed using third-order equiripple filter coefficients. The filter's shunt stubs and series gearbox lines are chosen with an electrical length of 450. Figure 1 depicts the low-pass filter section's transmission line equivalent.

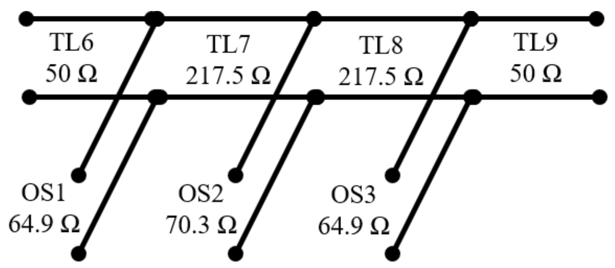

Figure 1. Transmission line equivalent of low pass filter

The capacitive reactance comes from the shunt open-circuited stubs (OS1, OS2, and OS3), and the inductive reactance comes from the series transmission lines (TL7 and TL8). For the low pass filter component, the transmission lines TL6 and TL9 function as a 50 feed line at 6 GHz. Table 1 shows the measurements of the open-circuited stubs and transmission wires. The BPF's initial stage is called a high-pass filter. Generally speaking, switching between an inductor and a capacitor may change a low-pass response into a high-pass response and vice versa. High-pass filters use short-circuited stubs with an electrical length of 450. The high-pass filter uses 4 GHz as its cutoff frequency. Figure 2 depicts the high-pass filter section's construction. Capacitive reactance is provided by the series transmission lines (TL2, TL3, and TL8), while inductive reactance is provided by the shunt short-circuited stubs (SS1 and OS2). For the high-pass filter portion, the transmission lines TL1 and TL5 function as a 50-ohm feed line at 4 GHz. Table 1 shows the measurements of the transmission lines, open-circuited stubs, and short-circuited stubs. As shown in Figure 3, the high-pass filter serves as the first step and the low-pass filter as the second stage in the implementation of the suggested BPF. We choose the low-pass and high-pass cutoff frequencies to achieve dual-band performance in a BPF. We implement the low-pass and high-pass filters using stubs of the proper length, either open or short-circuited. We implement the lowpass and highpass filter portions using third-order 3 dB equiripple filter coefficients. We chose the coefficients 3.3487, 0.7117, and 3.3487. The transmission line's microstrip characteristics are achieved on an FR4 substrate with a thickness of 1.6 mm.

Table 1. Proposed band pass filter dimensions

Low pass section			High pass section		
Transmission line	Length (mm)	Width (mm)	Transmission line	Length (mm)	Width (mm)
TL6, TL9	6.6056	3.0271	TL1, TL5	10.005	2.9633
TL7, TL8	1.8772	3.3848	TL2, TL4	5.1582	1.5537
OS1, OS3	3.8237	0.11	TL3	5.1211	1.8327
OS2	3.3848	1.8772	SS1, SS2	5.757	0.12

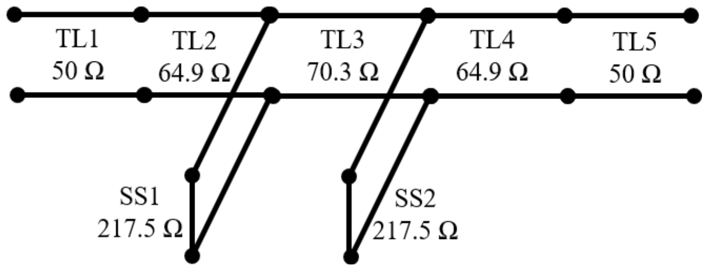

Figure 2. Transmission line equivalent of high pass filter

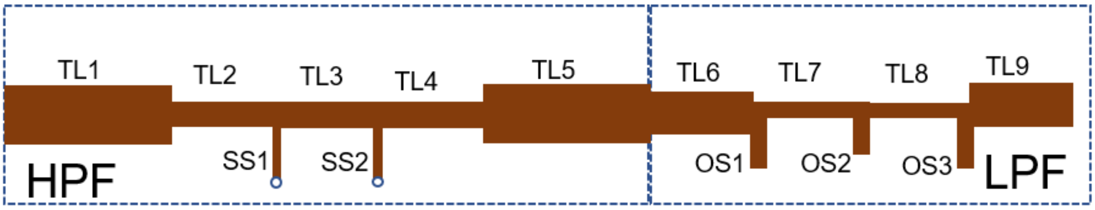

Figure 3. Structure of the proposed band pass filter

3. RESULTS AND DISCUSSION

The advanced design system software's layout option creates transmission lines with the proper length and width specified in Table 1. The layout option generates the structure, which the schematic option then imports as an EM model. The co-simulation process takes place in the schematic design. We use the co-simulation option to confirm the performance of the low-pass filter. The lowpass filter's co-simulation parameters are shown in Figure 4. We set the low-pass filter's cutoff frequency at 6 GHz. Figure 5 displays the lowpass filter's co-simulation S parameter outcome. We implement the low-pass filter layout via simulation after importing the EM model to the schematic. We achieve an insertion loss of 3 dB at 5.947 GHz and the highest return loss in the passband is 28.59 dB.

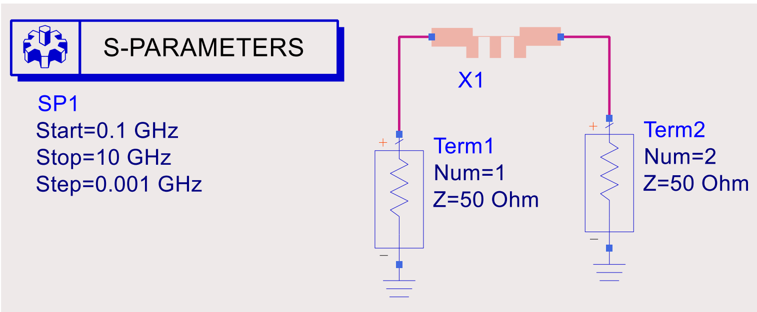

Figure 4. Co-simulation structure of the low pass filter

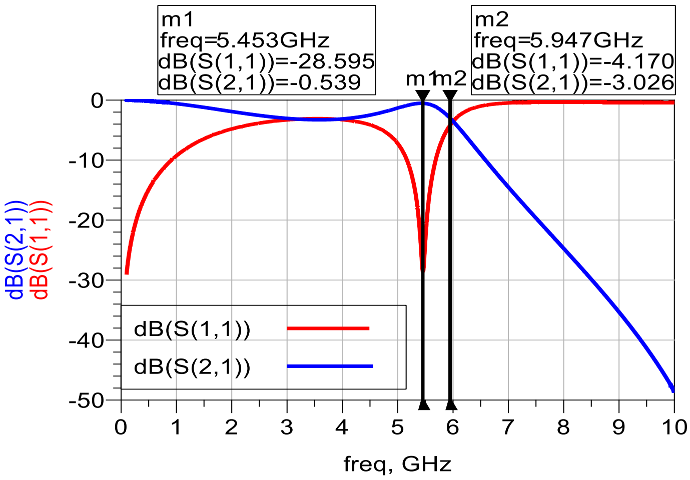

Figure 5. S-parameter simulation result of the low pass filter

The co-simulation option is used to confirm the high-pass filter's performance. The high-pass filter's co-simulation structure is seen in Figure 6. In a high-pass filter, short-circuited stubs are favoured. The 4 GHz cutoff frequency is the result of the high-pass filter's design. Figure 7 displays the high-pass filter's co-simulation S parameter outcome. With a return loss in the passband of up to 50 dB, an insertion loss of 3 dB is attained at 3.88 GHz.

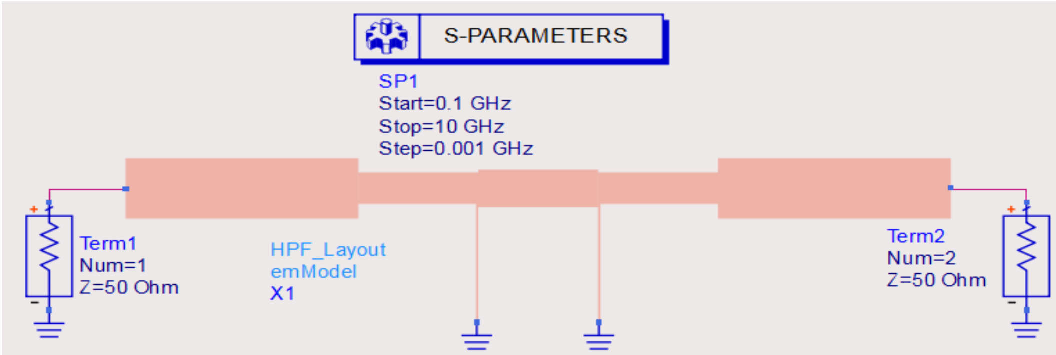

Figure 6. Co-simulation structure of the high pass filter

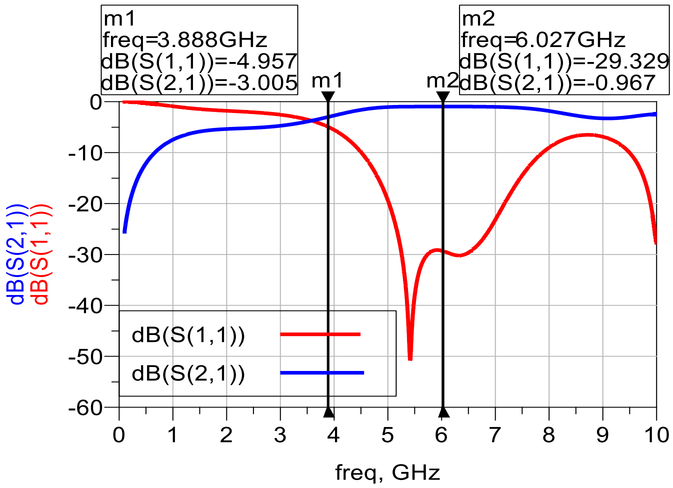

Figure 7. S-parameter simulation result of the high pass filter

We merge the low-pass and high-pass filter layout designs into a single layout and load it as an EM model into the schematic. Figure 8 displays the suggested BPF's co-simulation structure. A ground pin links the shorted-out transmission lines. Figure 9 displays the suggested BPF's S-parameter simulation performance. The dual-band bandpass performance of the BPF is centred at 4 GHz and 6 GHz. Band 1 has a bandwidth of 806 MHz and operates from 3.725 GHz to 4.531 GHz. In the pass band 1, a minimal insertion loss value of 1.26 dB is attained. Band 2 has a bandwidth value of 1.779 GHz and operates from 5.053 GHz to 6.832 GHz. Band 2 has a minimal insertion loss value of 1.45 dB.

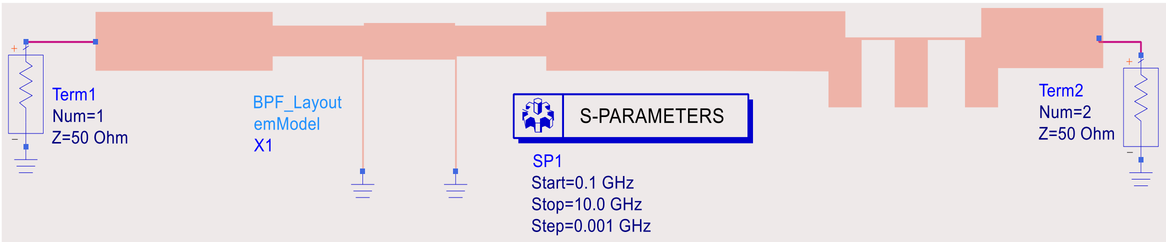

Figure 8. Co-simulation structure of the proposed band pass filter

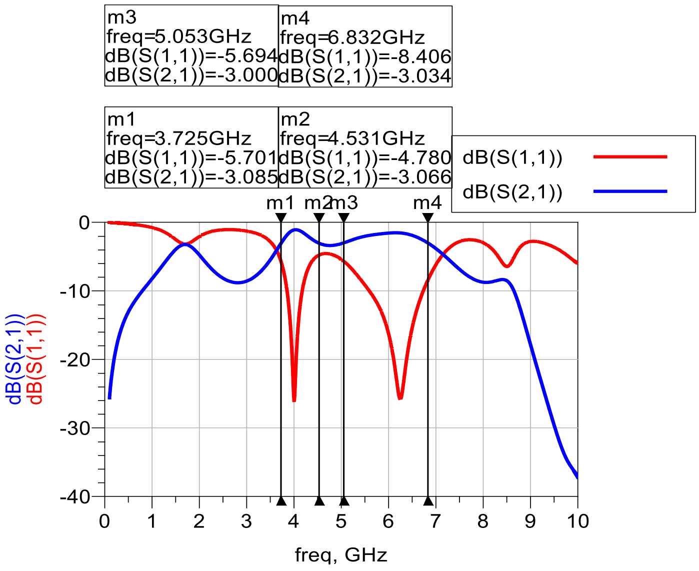

Figure 9. S-parameter simulation result of the proposed band pass filter

4. CONCLUSION

This study proposes a dual-band BPF for C-band and wireless local area network (WLAN) applications. The suggested approach uses the cascading realisation of a high-pass filter and a low-pass filter. The high-pass and low-pass filters' cutoff frequencies provide the bandpass response from 4 GHz to 6 GHz. We create low-pass and high-pass filters using the third-order Chebyshev coefficients. We assess the filter's performance using the advanced design system 2022 simulation. In the passband, the filter has excellent insertion loss and return loss performance. To achieve the BPF in microstrip form, FR4 substrates with a dielectric constant of 4.6 are recommended. C band satellite applications are supported by frequency band 1, which spans from 3.725 GHz to 4.531 GHz with a bandwidth value of 806 MHz. Applications for WLAN and 5G mobile communication are supported by the frequency band, which spans from 5.053 GHz to 6.832 GHz with a bandwidth value of 1.779 GHz.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Jacob Abraham	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Kannadhasan Suriyan	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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