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DESIGN AND IMPLEMENTATION OF BAND-PASS FILTERS FOR THE 5TH GENERATION WIRELESS SYSTEM

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ABSTRACT

This paper proposes a band-pass filter with a center frequency of 4.2 GHz, which can be applied in fifth - generation (5G) mobile communication. Currently, 5G networks are experiencing rapid development and are highly regarded as the primary network technology. Currently, 5G technology can be divided into two major frequency ranges. The first range is defined by 3GPP and operates below 6 GHz, known as the sub-6 GHz frequency range. The second range falls approximately between 30 GHz and 100 GHz. This paper aims to design a microstrip band-pass filter with a center frequency of 4.2 GHz. By modifying the line width, shape, and the number of couplings in the filter, we can achieve the desired frequency range and increase the bandwidth. A 4.2 GHz bandpass filter was fabricated on an FR4 substrate with a relative dielectric constant of 4.4, and the overall dimensions is 17×5×1.55 mm3.and measured. T Through simulation analysis, it can be understood that adding the inner ring with a gap can improve the overall performance of the filter.

Keywords: Open-Loop Resonator, Band-Pass Filter, Sub-6G

1. INTRODUCTION

Sub-6G systems refer to wireless communication systems that operate in the frequency range below 6 GHz. It is a subset of the fifth generation (5G) mobile communication technology, while 5G operates in higher frequency bands, including the millimetre-wave range. In comparison, Sub-6G communication systems have lower frequencies but offer certain advantages in terms of coverage and penetration capabilities. Sub-6G systems play a vital role in the development of 5G technology. They have unique advantages in providing wide-ranging coverage and penetration capabilities, making them suitable for different environments such as urban, suburban, and rural areas. Additionally, Sub-6G technology can be combined with higher frequency bands in 5G to achieve comprehensive communication capabilities Dahlman et al. (2018).

RF noise refers to unwanted electromagnetic signals or interference that can degrade the performance of radio frequency (RF) systems. A planar band pass filter (BPF) is an RF filter that selectively allows signals within a specific frequency range to pass while suppressing others. They are designed to suppress noise and provide better signal quality for RF systems. Planar BPFs have compact planar structures, making them suitable for integration on printed circuit boards (PCBs) and other planar substrates. These filters find wide application in various RF applications, including wireless communication systems, radar systems, and RF front-end modules Hussaini et al. (2015), Rodriguez et al. (2017), Al-Yasir et al. (2019), Abdulraheem et al. (2014). Some papers on filter design like Nieto and Sauleau (2006), Mallahzadeh et al. (2012), Al-Yasir et al. (2019) provide numerous filter design methods and structures, such as stepped impedance resonators (SIR), combline filters, ring resonators, and so on. In references Gil et al. (2008), Hsu et al. (2010), Al-Nuaimi et al. (2010), Al-Yasir et al. (2019), several designs are mentioned that involve increasing the number of resonators or modifying the resonator configuration. For example, in Gil et al. (2008), a complementary spiral rectangular resonator is utilized in conjunction with coupled finger capacitors to achieve selectivity in the low-frequency range and passband of a band-pass filter. A series LC resonator is then employed to create transmission zeros, and a combination of the band-pass filter and series LC resonator is integrated to improve selectivity in the high-frequency range. In Hsu et al. (2010), a wideband band-pass filter is designed to simultaneously meet the requirements of differential mode response and common mode suppression. The design involves using a pair of structures similar to SIRs and embedding a pair of defected ground structures (DGSs) on the ground plane. The wideband response is primarily achieved through a strong coupling mechanism, which further splits the already divided modes into four poles to support the wideband characteristic. Additionally, a band rejection effect generated by a set of DGSs is utilized to create zero locations. The design is implemented at the common mode resonance point, reducing the signal passage, and achieving the desired suppression effect. In Al-Nuaimi et al. (2010), a structure composed of metal rings with a small gap, or a split-ring resonator (SRR) is employed. Through its unique geometric shape and structural parameters, the SRR structure is capable of blocking signals within a specific frequency range. In Al-Yasir et al. (2019), a novel asymmetric open-loop resonators band pass filter is proposed. It is composed of four different-sized open-loop resonators combined to form a band pass filter. The design achieves its desired characteristics by adjusting the quantity and impedance values of asymmetric stepped impedance resonators (ASIRs).

This paper focuses on the research of a sub-6G compatible band-pass filter. A compact fifth order microstrip open loop resonator BPF is introduced in this paper, covering the frequency range of 3.9 to 4.4 GHz for 5G applications. The filter is simulated using Ansoft HFSS v.14 software. We will follow the following steps for simulation: 1. Adjust a single open-loop resonator to the target frequency. 2. Increase the number of coupled resonators and modify the spacing between them to achieve better characteristics. 3. Add an inner loop to obtain optimal filter parameters. 4. Implement and measure the band-pass filter at 4.2 GHz. It is fabricated on an FR4 substrate with a relative dielectric constant of 4.4, and the overall dimensions of the filter are 17×5×1.55 $mm^{3.}$

2. FILTER DESIGN

2.1. OPEN-LOOP RESONATOR FILTER DESIGN

The geometric of the proposed band-pass filter in this paper is shown in Figure 1 (a). The filter consists of 5 sets of open-loop resonators and is powered through two 50Ω input impedance transmission lines. The filter utilizes an FR4 substrate with dimensions h=1.55 mm, ε_r=4.4, and a loss tangent of 0.02. The resonant frequency is chosen to be 4.2GHz, suitable for 5G applications. The initial stage of the filter design involves creating a band-pass filter using open-loop resonators. The design steps for the BPF, as described in the paper, can be summarized as follows:

Step1.esigning a prototype of a low-pass filter (LPF) with standardized characteristic impedance (g_0) and cutoff frequency (ω_c).

Step2. Using certain transformation techniques, the designed prototype of a low-pass filter can be converted into a band-pass filter that operates at the desired resonant frequency. This step will result in an integrated component circuit of capacitors and inductors, forming a band-pass filter.

Step3. The Richard's transformation is used to convert the band-pass filter into a microstrip planar band-pass filter Hong and Lancaster (2004). The physical parameters of the open-loop resonator filter without inner rings can be calculated using the same design steps described in Hong and Lancaster (1997). The configuration and optimized parameters of the BPF filter are shown in Figure 1(b) and Table 1, respectively.

Figure 1

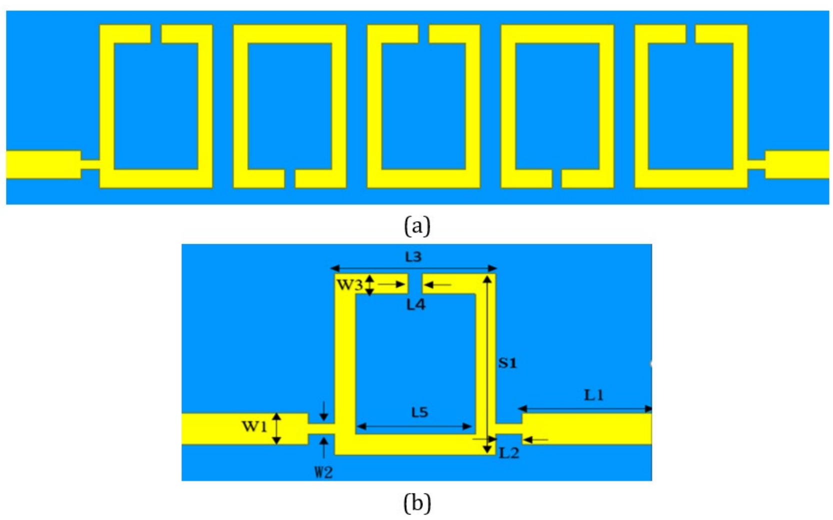


Figure 1 (a) Five Order Open-Loop Resonator Band-Pass Filter Without Inner Rings
(b) Open-Loop Resonator

Table 1

Table 1 The Optimized Parameters of the Proposed Flat Filter (Units in Mm)

W1	W2	W3	L1	L2	L3	L4	L5	S1
1.19	0.4	0.8	4	0.8	5	0.43	3.7	6.98

Based on the literature, after calculating the coupling coefficients, the next step is to determine the distance between the resonators that matches the calculated coupling coefficients. To find this distance, simulation results, particularly the S21 graph, need to be observed. The spacing between coupled resonators affects the characteristics of the filter. By varying the distance (L6) between the resonators and the number (N) of hairpin resonators (N), the optimal design parameters for this study can be determined. Figure 2 shows the simulation results for five resonators with different L6 parameters (0.5~0.9mm). The results indicate that as L6 increases, the center frequency also increases, but the insertion loss increases as well, resulting in poorer filter characteristics. At L6=0.5mm and N=5, the minimum insertion loss is -3.21 dB at a resonant frequency of 4.21 GHz; however, the return loss is (20 dB), and there is still room for further improvement.

Figure 2

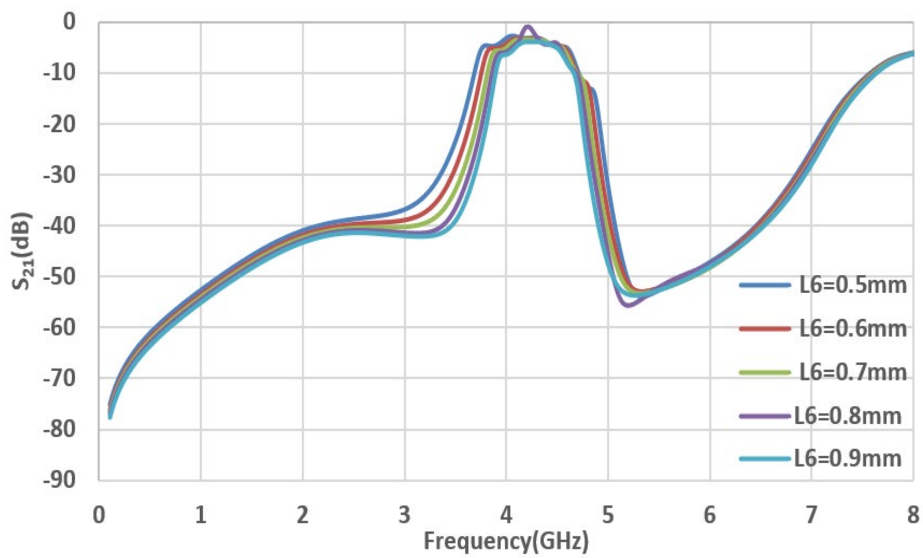


Figure 2 Simulation Results for Different L6 Parameters (N=5)

Table 2

Table 2 The Simulated Data for the Characteristics of the Five-Order Filter with Different Coupling Distances (L6)

number of hairpin resonators (N)	coupling distances L6	resonant frequency (GHz)	Insertion loss (dB)
	0.5 mm	4.195	-3.21
N=5	0.9 mm	4.265	-3.90
	1.3 mm	4.353	-5.31

2.2. DESIGN OF OPEN-LOOP RESONATOR FILTER WITH INNER LOOP

The addition of an inner loop improves the performance of the filter, especially in terms of frequency response and selectivity. The inner loop introduces additional resonant modes into the filter structure, which increases the degrees of freedom and allows for better adaptation to specific frequency requirements. By adjusting the geometry and dimensions of the inner loop, the resonant frequency, bandwidth, and transmission characteristics of the filter can be modified. The inner loop also provides additional coupling paths, which can alter the coupling effects and transmission characteristics of the filter, further adjusting its performance. Therefore, the addition of an inner loop enhances the performance and design flexibility of the filter, making it more suitable for specific application needs.

In this study, two types of inner loops were attempted in the open-loop resonator: (1) an inner loop with a gap and an opening in the same direction as the outer loop, and (2) a closed inner loop. The geometry of the 5-order annular band-pass filter with an inner loop is shown in Figure 3

Figure 3

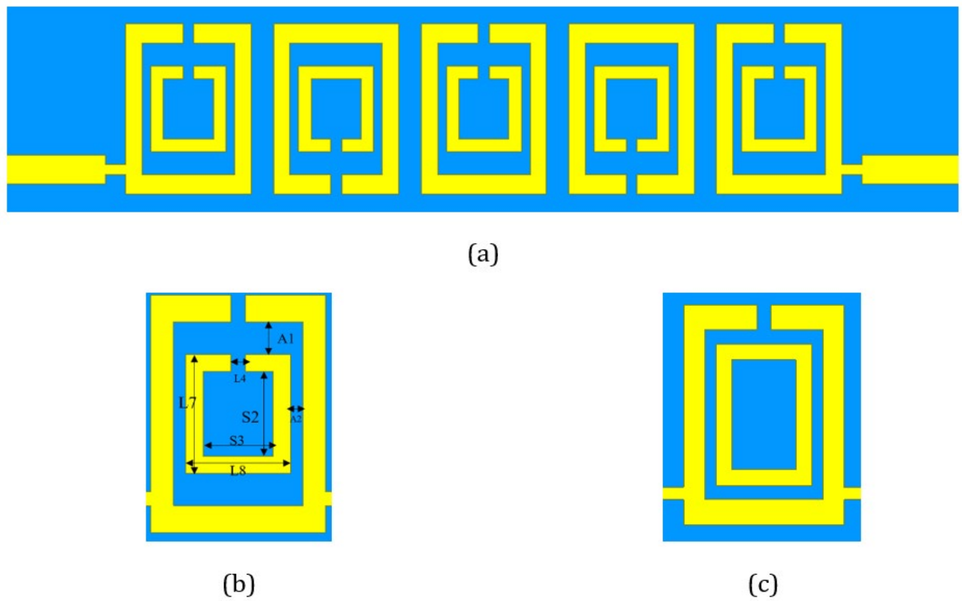


Figure 3 (a) 5 Order Band-Pass Filter with an Inner Loop
(b) Inner Loop with Gaps in the Same Direction as the Outer Ring
(c) Rectangular Inner Loop

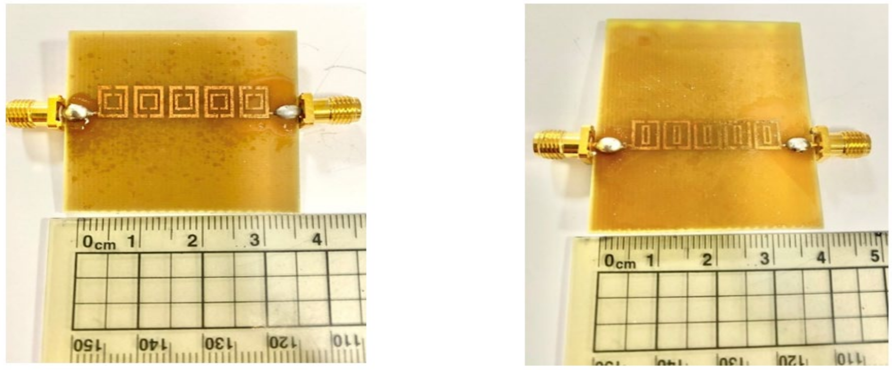
By modifying the line width, shape, and the number of couplings in the filter, we can achieve the desired frequency range and increase the bandwidth. The optimization parameters were obtained through simulations using the HFSS software, as described in Table 3. The S-parameter results from both simulation and measurement are shown in Figure 5 and Figure 6. The simulation results of the BPF with a co-directional gap loop show a -10dB bandwidth of 220MHz and an insertion loss of -3.05 dB at 4.195GHz. The simulation results of the BPF with a rectangular inner ring show a -10dB bandwidth of 180MHz and an insertion loss of -3.21 dB at 4.195GHz. In addition, compared to a 5-order filter without the added inner ring, the co-directional gap ring can improve the performance of the filter in the passband.

Table 3

Table 3 The Optimized Parameters of the Proposed Flat Filter (Units in Mm)

L7	L8	A1	A2	S2	S3	L4
5	3	0.7	0.4	4	2	0.43

Figure 4



(a) (b)

Figure 4 A Prototype of The Fabricated Filter:
(a) The Inner Loop with the Same Opening Direction as the Outer Loop,
(b) Rectangular Inner Loop Without Gap

Figure 5

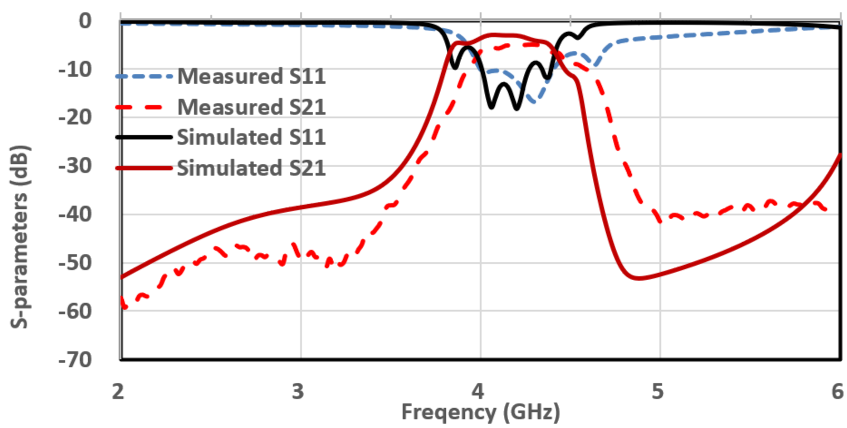


Figure 5 Simulation and Measurement Results of A 4.2ghz Bandpass Filter with a Co-Directional Gap Loop

Figure 6

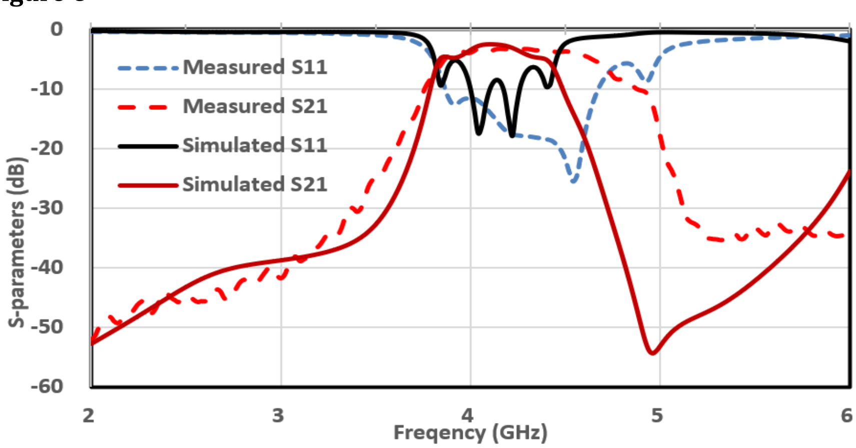


Figure 6 Simulated and Measured Frequency Response of the Proposed 4.2ghz Bandpass Filter with a Rectangular Inner Loop

3. CONCLUSION

This paper presents a systematic approach for designing bandpass filters by optimizing the filter characteristics through the addition of inner loops. The simulation results closely match the implemented results. In terms of implementation, the best results were achieved using a rectangular inner loop with five coupled resonators. The center frequency was 4.195 GHz, and the S_{21} value was -3.05 dB.

CONFLICT OF INTERESTS

None.

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