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A review of the Design and Development of Microstrip Multiband Bandpass Filter for 5G Systems

Anitha George
Division of Electronics
School of Engineering, CUSAT
Cochin, Kerala, India
anithageorge@cusat.ac.in

Anju Iqubal
Division of Electronics
School of Engineering, CUSAT
Cochin, Kerala, India
anjuiqubal.soe.cusat@gmail.com

Abdulla P
Division of Electronics
School of Engineering, CUSAT
Cochin, Kerala, India
abdulla@cusat.ac.in

***Abstract*— Microstrip bandpass filters have been the subject of research for a long time to suit the needs of contemporary multiservice wireless communication systems. Multiband bandpass filters, or BPFs, are necessary for the receiver front end to work as a single unit that can serve many bands simultaneously. Particularly promising are the compact design, low integration cost, and simplicity of manufacture using printed circuit technology of planar bandpass filters. The design and implementation of filters for fifth-generation (5G) mobile communication systems is complicated due to the necessity for high integration, low cost, and high-speed data transfer. This paper offers and discusses a comprehensive assessment of existing research on microstrip single multiband bandpass filter designs for fifth-generation applications, with an emphasis on the most recent advances.**

Keywords- 5G; Bandpass Filter; Microstrip; Microwave; Multiband.

I. INTRODUCTION

Microwave filters are an essential component of receivers. In order to control the frequency response at a specific location in a microwave system, a microwave filter is a two-port network that transmits at frequencies inside the filter's passband and attenuates at frequencies inside the filter's stopband. Since lumped element inductors and capacitors are not appropriate for use at microwave frequencies, transmission line sections that function as inductors and capacitors are used instead [1]. Reducing filter passband losses is essential since, when utilized with a receiver, it improves the noise figure in addition to reducing total transistor losses.

There are two conductors used to transport microwave energy. At each of its endpoints, a conductor's characteristic impedance should be matched to maximize efficiency. All impedance components are taken to be lumped constants. This is not the case for long transmission lines covering a large frequency range, though. Short conductor lengths' inductances and capacitances are taken into consideration due to the high operating frequency [2].

The bandpass filter is preferred over other types of filters in microwave systems due to its small size and adaptability. The bandpass filtering method is stable and long-lasting in addition to increasing receiver sensitivity [3]. The size of the distributed components and the number of suggested resonators define the filter properties in a BPF, which consists of several connected resonators. For this reason, the majority of microstrip filter minimization techniques aim to reduce one or both of these values. The number of components used and the kind of resonators determine the properties and responsiveness of a bandpass filter [4,5]. In general, bandpass can be improved by adding finite transmission zeros (TZs) at particular frequencies or by increasing the number of filter orders [6].

For microstrip line filters, a variety of topologies and techniques have been described, including combline, hairpin, parallel-coupled-line, step impedance, and stub impedance [7-14]. created a tiny planar BPF utilizing a state-of-the-art microstrip coupled-line technique. A 3 GHz filter was constructed with two λg/4 lines of three lines that were parallelly linked. The filter area is 152.57 mm^2, and the lines are separated by non-uniform line elements. Low-temperature co-fired ceramic is another approach [10], whose implementation is becoming more and more feasible as a result of precise electromagnetic analysis and which permits the creation of filter structures with tiny physical dimensions. Planar hairpin resonators can be used to build a physically tiny BPF. The hairpin form with T-feeders described in [11] is used in the construction of the hairpin filter to create a changeable coupling effect. About 0.2 is the operating frequency that is noticed.

The simulated 5.80 GHz centre frequency required by RFID applications is around 0.2 GHz lower than the observed operation frequency. The size of the resonator is 320.76 mm^2. Combination filter designs are currently widely used in many different applications due to their small size and low loss [12,13]. A new improved combined BPF with two poles, numerous TZs, and a size of about 138 mm2 is described in [12]. The filter has a transmission coefficient of around 2.681 dB, a reflection coefficient of roughly 18.2 dB, a centre frequency of 1.45 GHz, and 11.41% of fractional bandwidth (Δf) [13] designs and explains an upgraded combined bandpass with stepped impedance with an array of SIRs. The design has the benefit of having no lumped parts and minimal via-hole grounds, making [33].

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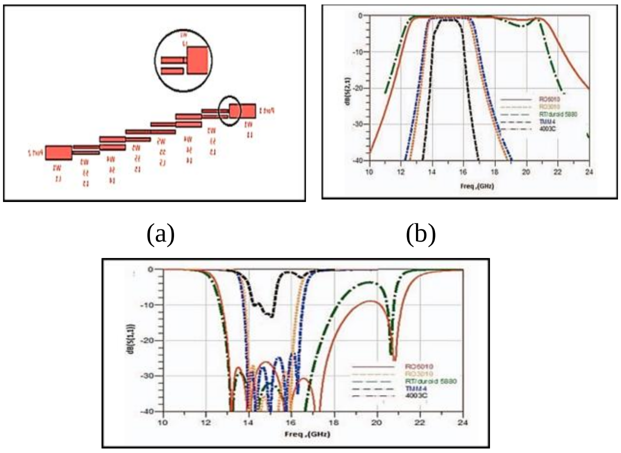
Due to the growing demand for high data rates, Fifth Generation (5G) mobile communication is becoming more and more popular [15]. Recent years have seen a rapid development in mobile communications technologies. The next wireless industry standard is the 5G mobile network, which comes after the previous generations [16,17]. The goal of 5G's flexible use is to cover a wide range of radio bands, which have frequencies between 400 MHz and 90 GHz [18]. With this wide range spectrum, 5G applications might not require the entire sub-6 GHz bandwidth, just the necessary channel bandwidth.

II. SINGLE-BAND MICROSTRIP BPFS FOR 5G USES

Microstrip BPF with a small size was presented by Al-Areqi, et al. [21] for 5G wireless communication applications. The resonance frequency of the suggested design is intended to be 6.1 GHz. The BPF consists of a tiny resonator coupled between the 50 transmission line ports and the first and last coupled-line ports, as well as quarter-wave parallel-coupled line resonators. Based on the investigation of many substrates with relative permittivity (εr) values of 2.21, 3.55, 4.71, 10.69, and 11.19, the analysis was conducted [2].

The recommended configuration, which makes use of a substrate with $€_r$ of 11.20, enhances bandwidth performance. Design and analysis are done with ADS software. The suggested parallel-coupled line BPF arrangement is shown in Figure 1(a), and the outcome is shown in Figure 1(b).



(a) (b)

(c)

Figure 1: (a)Single-band BPF layout, (b) Simulation S_{21} results, (c) Simulation S_{11} results using different substrates [21]

A compact BPF was proposed by Al-Yasir et al. (2018) for 5G wireless communications [22]. The proposed architecture includes proposals for a resonance frequency of 3.6 GHz. Three resonators make up the planar filter, and each one is terminated by an input and output terminal capacitor with a 50Ω transmission line impedance at one end and a via-to-hole ground at the other. The suggested combline filter is only 54 mm3 in size and is constructed on an alumina substrate with a €r of 9.8. CST programme simulates the proposed filter. Figure 2(a) below displays the suggested combline BPF structure, while Figure 2(b) displays the simulation results.

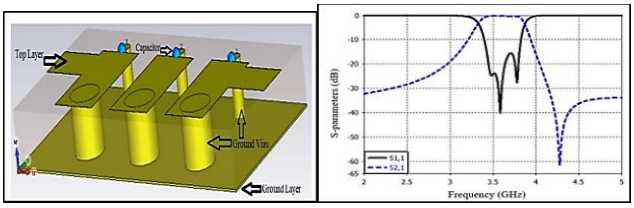


Figure 2: (a) The suggested layout, (b) Simulation results

Al-Yasir et al. [23] developed a highly tiny microstrip open-loop BPF for 5G communication. The resonance frequency of the suggested design is 3.55 GHz. The planar BPF is made up of 50 °C transmission line ports and three trisection open-loop ring resonators. An attenuation zero of finite frequency is successfully generated on the upper edge of the passband, resulting in a tighter cut-off frequency for the passband. Applying the recommended design results in a reduction of the design size as well as the introduction of positive or negative cross-coupling (Mij). To operate in the sub-6 GHz 5G band, Mij between the poles has been modified. The suggested structure is simulated using CST software and built on a substrate with a $€_r$ of 10.2 and a little 72.39 mm3 area. The measured and simulated results agree well. The recommended BPF design is shown in Figure 3(a), and the measured results are displayed in Figure 3(b).

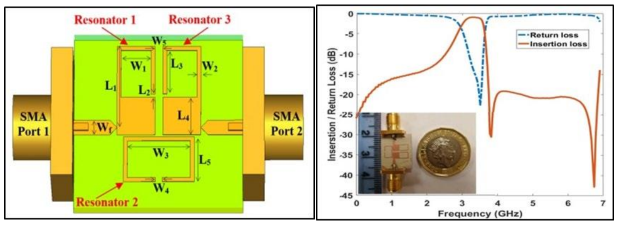
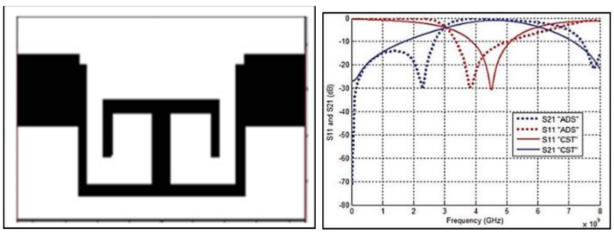


Figure 3: (a) The presented layout, (b) Measured results

Haddi et al. [17] suggested a tiny wideband microstrip BPF with exceptional performance for the 5G mobile communications systems in 2020. It uses a rectangular T-shaped resonator. The WLAN and WIMAX application frequencies are also included in this frequency range. The intended design is intended to have a transmission coefficient of less than 1 dB, a reflection coefficient of more than 30 dB, and a 4.75 GHz resonance frequency with 70% of Δf. The FR4 substrate with an $€_r$ of 4.3, a thickness of 0.8 mm, and a tangent loss of 0.025 was used to design the small 45 mm2 microstrip BPF utilizing CST software. The outcomes show good agreement with the ADS software's output. Figure 4(a) illustrates the recommended BPF structure, and Figure 4(b) compares the simulation results. The results are quite promising and the suggested filter is simple to make.



(a) (b)

Figure 4: (a) The suggested layout, (b) Simulation results

For 5G wireless communication applications, Saleh et al. [24] proposed hairpin BPF (HPBF) and Interdigital BPF (IBF). Resonance frequencies of 3.94 GHz and 6.65 GHz are intended for the suggested architecture. Across the frequency bands of 3.96 GHz and 6.45 GHz, respectively. Transmission coefficients of HPBF are 10.43 dB and 0.64 dB and 14.48 dB and 0.47 dB. Through the frequency spectrum of 3.96 GHz, the simulated reflection coefficient and transmission coefficient are 11.25 dB and 0.64 dB, respectively, with out-of-band rejection up to 11.22 GHz. Furthermore, IBF is constructed at the second frequency band with two different groundings via hole radii (r Via), where r = 0.7 mm in state 2 and 0.4 mm in state 1.

Alnahwi et al. [25] discussed the design and development of a single-band BPF for 5G applications in 2021, utilizing the SL-MMR approach. Using a mathematical analysis of SLRs as a foundation, this paper aims to provide an affordable microstrip filter featuring improved stopband and passband characteristics.

For 5G systems, Abdullah et al. [26] presented a multilayer (ML) hairpin BPF and parallel-coupled line (PCL) BPF. The planned four-pole resonator has a bandwidth of 130 MHz and a centre frequency of 2.58 GHz, respectively. The filters have a 0.1 dB passband ripple and a Chebyshev response. The hairpin line offers small filter design structures. In principle, "U" bending λg/2-line resonators with parallel couplings can be used to create them. The parallel-coupled line resonator construction is used to generate the ML BPF. FR4 was the substrate used, and it had a thickness of 1.6 mm and a 4.3 relative permittivity ($€_r$). A comparison between the return loss of substrates RO3003 and FR4 and the simulated transmission coefficient was performed to confirm the efficacy of the proposed filter design. To simulate the PCL filter, programs such as CST and ADS are utilized. A complete concordance between simulation results and actual findings was achieved during the experimental validation of the PCL Bandpass filter, showing an accurately measured return loss. According to the simulation results, the hairpin ML BPF reduces the filter size greatly and performs well in terms of S-parameter characteristics [33].

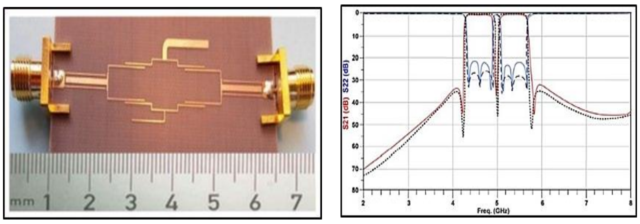
A third-order microstrip single-band BPF based on fractal linked lines and two slotted lines was proposed by Basheer et al. [27] for 5G applications. The proposed structure exhibits strong selectivity qualities and a broadband rejection response. The suggested design is simulated using HFSS software. The filter is designed to have a resonance frequency of 6.1 GHz and is constructed on a substrate with a thickness of 0.508 mm and an $€_r$ of 3.55. The results of the simulation show a broadband rejection, high selectivity, and an 8.1% Δf. Table 1 lists the performance comparisons for the most recent microstrip single-band BPFs for 5G applications.

TABLE 1: A COMPARISON OF MICROSTRIP SINGLE-BAND BPFS FOR 5G IN TERMS OF PERFORMANCE.

Ref.	Technology	Substrate	Freq. (GHz)	FBW (%)	$\|S_{21}\|$ (dB)	$\|S_{11}\|$ (dB)	Size ($λg^2$) or (mm^2)	Applications
[21]	Quarter wave parallel-coupled line	RT/Duroid 5880	15.38	37	0.8	10	139.7 mm^2	5G Wireless Communication
		RO4003C	15.15	4.43	1.8	10.1	276.4 mm^2	
		TMM4	15.2	18.67	1.52	10.23	151.42 mm^2	
		RO6010	16.4	43.7	1.2	10.4	15.78 mm^2	
		RO3010	15.16	21.63	2.2	10.3	94.08 mm^2	
[22]	Combline	Alumina	3.64	10.9	0.11	15.2	-	5G communications
[23]	Open-loop	RO3010	3.45	7.91	0.9	22	0.0458 $λg^2$	5G Communications
[17]	Rectangular-shaped	FR4	4.69	3-62	0.92	31.3	46 mm^2	5G mobile communications
[24]	Hairpin	RO4003C	3.96	18.99	0.79	10	-	5G RF front-end wireless
			6.62	22.38	0.5	19		
			6.32	Case1: 39.92	10.32	6.31		
			6.23	Case2: 29.91	1.09	11.05		
[25]	SIR/SLR	FR4	3.94	14.1	2.4	19	1251 mm^2	5G Mid-Band Applications
[26]	Hairpin	FR4	2.85	-	5.72	38.94	2756.4 mm^2	5G Applications

III. DUAL-BAND MICROSTRIP BPFS FOR 5G USES

Riaz et al. [28] presented a unique dual-band BPF structure with robust isolation, broadband rejection, and improved selectivity for 5G communications systems. For the proposed architecture, resonance frequencies of 4.6 GHz and 5.4 GHz with Δf of 13.5% and 11.5%, respectively, are anticipated. The visa-free dual-band filter's open-loop resonators are shunt-loaded using the λg/2-line open-circuit stub. After being inter-digitally coupled to the input/output feed lines, the SIRs are electromagnetically coupled to the resonators. The two stubs' diameters can be changed to change the TZ frequencies and resonant mode. The filter's performance is confirmed by the measurement results. The coefficients of transmission and reflection are higher than 20 dB, at 1.03 and 0.82 dB, respectively. and exceed 20 dB. More than 290 dB/GHz of skirt steepness and more than 35 dB of band isolation characterize the filter. Figure 5(a) depicts the proposed design prototype, and Figure 5(b) compares the results of the measurements and simulations.

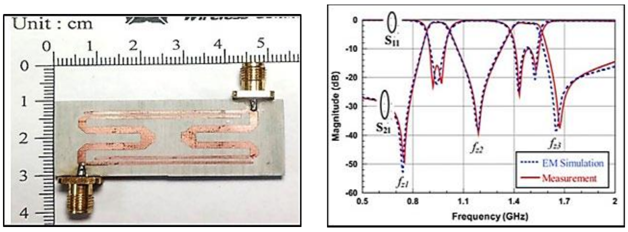


(a) (b)

Figure 5: The prototype of the suggested design, (b) Measured and simulated frequency responses comparison

In 2020, Hsu et al. [29] also introduced a small dual-band BPF with interlocking SIRs in support of 5G New Radio Access Technology. With resonance frequencies, the proposed architecture aims to cover six distinct ranges in the 5G mid-band spectrum of 1.48 GHz and 0.946 GHz, respectively, and Δf of 9.8% and 9.5%. At 500–850 MHz, 1050–1350 MHz, and 1600–2000 MHz, respectively, three stopbands are required. Two SIRs are given in a linked configuration to achieve the highest level of quality.

One advantage is that two passbands at the necessary frequencies can be achieved by adjusting the impedance ratio of the inter-locked SIR. Second, three TZs are assigned to each stopband by the coupling portion of the interlocked SIR, greatly enhancing stopband suppression. The estimated transmission and reflection coefficients for the given design are 2.16 dB and 1.33 dB, respectively, while the reflection coefficient is greater than 10 dB. At transmission zeros, stopband suppression exceeds 38 dB. The circuit has a relatively tiny size—0.03 μg2. The design prototype that is being given is shown in Figure 6(a), and the contrast between the simulation and measured results is shown in Figure 6(b).

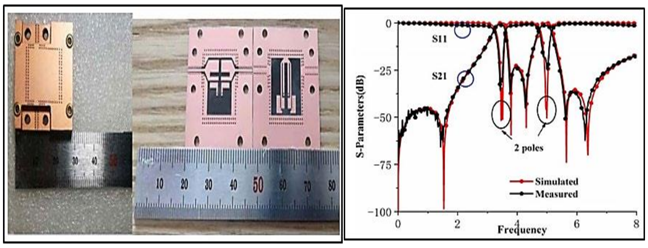


(a) (b)

Figure 6: (a) The proposed design prototype, (b) Comparison of measured and simulated results.

For 5G mid-band applications, Zhang et al. [30] introduced a cross-coupled dual-band BPF with separate electric and magnetic coupling paths in the same year. This configuration also incorporates source-to-load connections to improve the flexibility of various feed lines. The dual-band BPF generates five adjustable gearbox zeros (TZs) in total. Two pairs of λg/4 SIRs are used to produce high overall performance of the filter.

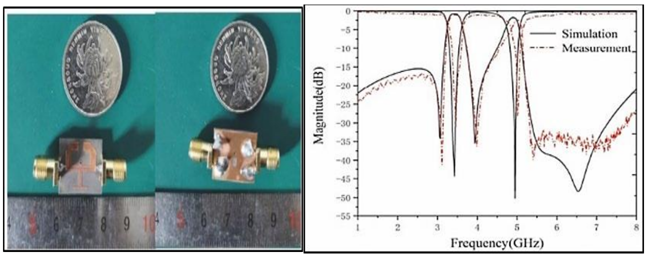
The stepped-impedance resonators that comprise the passband are folded onto two different layers, increasing the controlled range of the second passband while decreasing the size of the filter. The design prototype is shown in Figure 7(a), and Figure 7(b) shows a comparison between the measurements and the simulation's output. With transmission coefficients of 1.45 and 1.43 dB, respectively, the resonance frequencies are 3.46 GHz and 4.87 GHz, and the measured result indicates that 7.72% and 4.06% of Δf are attained.



(a) (b)

Figure 7: (a) The proposed design model, (b) Comparison of measured and computed frequency responses.

Peng et al. [31] suggested in 2020, a uniform impedance resonator (UIR) and a folding short-circuited stub-loaded SIR to create a small dual-band BPF for 5G communication. Resonance frequencies of 3.45 GHz and 4.9 GHz are intended for the suggested architecture. The suggested filter has a hybrid feed method, which makes it tiny and very independent. The suppression of the filter is increased when the source load is connected to produce TZs simultaneously. Moreover, the design can be made more versatile by utilizing the loaded rectangular defective ground structure (DGS) to alter the impedance matching. The test demonstrated good agreement between the simulated and measured findings and confirmed the efficacy of the provided filter. Figure 8(a) depicts the proposed design prototype, and Figure 8(b) compares the results.



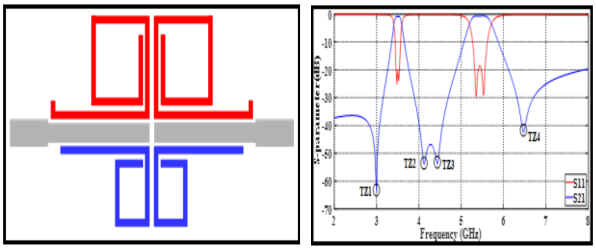
(a) (b)

Figure 8: (a) The prototype of the proposed design, (b) Measured and simulated frequency responses.

Khani and Ezzulddin (2022) [32] According to offer a dual-band BPF with independent bands for 5G mobile communications, a small size, strong selectivity, and a straightforward layout. According to offer a dual-band BPF with independent bands for 5G mobile communications, a small size, strong selectivity, and a straightforward layout. It is based on two folded λg/2-line resonators.

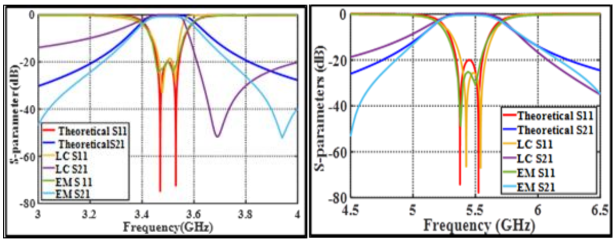
Resonance frequencies of 3.5 GHz and 5.45 GHz, with Δf of 4.8% and 8.9%, respectively, are envisaged for the suggested design. The resonance frequencies of the filter are designed and set up separately. The transmission and reflection coefficients of the suggested filter are -0.8 dB, -0.5 dB, -20 dB, and -18.4 dB, respectively, and it reaches four TZs. A RO4350B substrate with a thickness of 0.508 mm and an εr of 3.66 serves as the foundation for the suggested design. It has a tiny size of 0.039 μg^2.

Here are the suggested/2-line resonators shown in Figure 9(a). Figure 9(a) depicts the recommended dual-band BPF configuration, and Figure 10(b) shows the outcomes of the simulation. The way in which the simulation and LC circuit results seemed to align well with the theoretical conclusions is shown in Figure 10(a) for the first band and Figure 10(b) for the second band. Table 2 lists the performance comparisons of contemporary microstrip dual-band BPFs for 5G applications.



(a) (b)

Figure 9: (a) The suggested layout, (b) Simulation findings



(a) First band (b) Second band

Figure 10: Theoretical, EM simulation, and LC circuit findings comparison

TABLE 2: PERFORMANCE COMPARISONS FOR RECENT MICROSTRIP DUAL-BAND BPFS FOR 5G APPLICATIONS

Ref.	**Technology**	**Substrate**	**Freq. (GHz)**	**FBW (%)**	**$\|S_{21}\|$(dB)**	**$\|S_{11}\|$(dB)**	**Size (λg^2) or (mm^2)**	**IS (dB)**	**TZs**	**IBs**	**Applications**
[28]	coupled lines multimode	Arlon CuClad217LX	4.6\5.4	13.5\11.5	1.02\0.8	>20	-	>-40	3	NA	5G communications systems
[29]	SIR	RO4003C	0.945\1.47	9.89\9.7	2.18\1.36	>9.9\9.9	0.04 λg^2	>-40	3	NA	5G new radio access technology
[30]	SISL	RT/duroid5880	3.45\4.9	7.82\4.08	1.15\1.42	>25\<25	0.065 λg^2	>-50	5	yes	5G Sub-6 GHz Bands
[31]	Folded short-circuited stub-loaded SIR and Uniform impedance resonator (UIR)	RT5880	3.45\4.9	-	0.9\2.4	31\28	0.051 λg^2	>-35	3	yes	5G communication
[32]	Folded λg/2-Line	RO4350B	3.5\5.45	4.8\8.9	0.8\0.5	20\18.4	0.039 λg^2	>-50	4	yes	5G mobile communications

IV. CONCLUSION

This article provides thorough and current analyses on microstrip single/multi-band bandpass filter designs, methods, and problems for 5G applications. The study covers single and multiband microstrip BPFs with various design techniques for future and present 5G applications. This paper focuses on the important microstrip BPF elements and also presents and discusses a comparison of alternative design techniques and layouts. These reviews assisted us in determining the primary concerns, which were related to the dimensions, capabilities, and distinctiveness of microstrip BPF filters. Despite these limitations, we hope to see more creative, intriguing, and flexible BPFs in the years to come.

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