IRAQI Academic Scientific Journals

University of Mosul - Iraq College of Engineering AREJ Al-Rafidain Engineering Journal 1993

Al-Rafidain Engineering Journal (AREJ) Vol. 30, No. 2, September 2025, pp. 176-182

High-Selectivity Performance Dual-Mode Folded Half-Wavelength Resonator Band Pass Filter for 5G Networks

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Received: April 26th, 2025 Received in revised form: July 31th, 2025 Accepted: August 25th, 2025

ABSTRACT

This paper presents the new dual-mode half-wavelength folded microstrip resonator. The capacitance effect achieves the external coupling by changing the gap distance, while stub loading achieves the internal coupling. The second-order Chebyshev bandpass (BPF) filter was simulated by HFSS software on a thin Rogers substrate. The BPF is operated at a center frequency of 1.980 GHz, which results in a return loss of 16.97 dB, while the insertion loss is equal to 1.2185 dB. The BPF measures its bandwidth at 3 dB, which is equivalent to 50 MHz. The spurious frequency occurs at 4.27 GHz. The resonator offers a size of about (0.726λg× 0.278λg) which is smaller than a single mode. Moving the feeding line close to the center of the resonator has significantly enhanced the spurious window by about 2.75, and two Tzs appear on both band sides. The results show a satisfactory agreement with the requirement for 5G applications.

Keywords:

Dual-mode resonator; Bandpass filter; High selectivity; Half-wavelength folded resonator; 5G.

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1. INTRODUCTION

These days, sophisticated wireless communication systems are developing quickly because of advancements in microwave and radio frequency (RF) technology [1, 2]. the vital role of band-pass filters (BPF) in communication systems, which are necessary for minimizing interference in high-frequency applications and preserving signal integrity. This is particularly crucial for the 5G technology, which requires effective filtering to control frequency bands [3]. Several methods for designing bandpass filters have been developed during the past few decades, such as lumped-element (LC circuit), dielectric filters, cavity resonators, microstrip arrangements, coaxial arrangements, and high-temperature superconductors [4, 5]. Microstrip filters are small size, inexpensive, lightweight, and simple to manufacture; nonetheless, it might be challenging to build a high-performance device for a microwave system [6, 7]. A dual-mode resonator is suggested because it offers half the size of the filter compared with a single resonator.

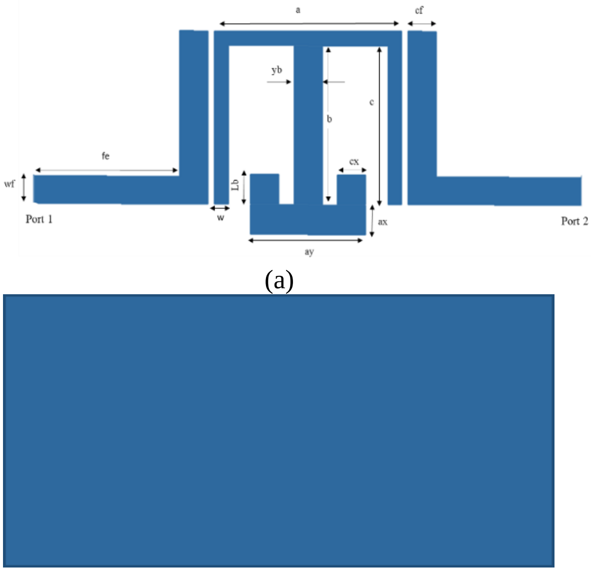
There are a number of previous studies on dual-mode microstrip filters. In [7], a fractionally slotted daul-mode octagonal shape has been proposed to operate at wireless LAN applications. It offers a high selectivity on both sides of passband by inserting TZ. The varying shape of the fractional can control the insertion loss and return loss with a 22% size reduction. A folded half-wavelength dual-mode resonator is suggested by [8] for applying at millimeter wave. The size reduction in this paper was low, there was a high loss in the insertion band compared with studies close to the operation frequency. In [9], the design of a dual-mode, compact microstrip bandpass filter (BPF) is delineated, featuring square ring and cross-loop slots on a square patch resonator. Two transmission zeros (TZs) are employed to facilitate the filter's dual-mode response; these TZs, positioned near the edges of the passband, enhance selectivity. Compared to the conventional square patch resonator, the proposed slotted design achieves a size reduction of 61%.

This study [10] used a multi-mode design for wideband applications and used various filter feeds, such as microstrip/CPW. Furthermore, transmission zeros were inserted on each side of the filter passband. The design was complex and required fabrication on both sides of the microstrip, and the resulting size was larger than previous studies. For millimeter wave systems, dual-mode BPF integrated substrate gap waveguide (ISGW) filters are suggested in [11]. Two TZs are produced for a single resonator on either side of the passband, resulting in increased selectivity. Compared to the various dual-mode filters, it has a smaller size and few perturbed structures. A compact microstrip low-pass filter for millimeter-wave applications is introduced in [12], employing the input/output coupling structure to provide a high roll-off rate and an extensive stopband. The filter's input/output coupling lines generate additional TZs beyond the passband, enabling precise control over their positioning and significantly enhancing stopband performance. The filter demonstrates a -3 dB cutoff at 42 GHz and an 81 GHz stopband, representing an eightfold improvement over similar filters in this frequency range.

In this paper, a dual-mode microstrip half-wavelength folded resonator BPF will be designed that operates at fifth-generation frequencies. A novel feeding topology has been suggested to enhance the separation of the filter and the spurious window. It consists of a thin substrate Roger (RT/duroid) type with $\varepsilon r = 6.15$, a loss tangent (tan δ) of 0.0019, a thickness of h = 1.27 mm, and a microstrip line width of W = 1.87 mm. The lower part of the chip is a complete ground, while the upper part is the filter to be designed. Capacitive feeding is used to control the gap between the input and output and the resonato. The bandwidth is controlled by stub loading. The operating frequency (fo) is 1.98 GHz, the bandwidth (BW) is 50MHz.

2. PROPOSED DUAL MODE BPF FOLDED HALF-WAVELENGTH

A coupled-feed dual-mode microstrip resonator filter can simulate a bandpass filter. The figure (1) shows a proposal of a new dual-mode folded microstrip half-wavelength resonator filter. The input and output coupled-feed lines, with their coupling spacing (g) and line width (cf), couple the signal to the dual-mode resonator. The dual-mode resonator sets the length of the U-shaped resonator to create the right resonant frequencies (a and c); the bandwidth can be changed by modifying the length of the open circuit's loaded part (b and Lb). The proposed dual-mode resonator is connected to two microstrip lines that have an open-stub-loaded resonator and a characteristic impedance of 50 Ω. The resonator has been simulated on Roger RT substrate with $\varepsilon_r = 6.15$, loss tangent (tan δ) is 0.0019, and a thickness of h = 1.27 mm.



(a)

(b)

Fig. 1 A schematic structure of a coupled-feed dual-mode microstrip resonator filter (a) Top. (b) Bottom.

To systematically design a microwave filter, the external (Qex) and internal coupling should be studied. The Qex has been realized by modifying the gap distance between the resonator and the feed line. The connection between the Q_{ex} and the gap (0.2-1.0 mm) is shown in Figure 2, where Q_{ex} peaks at about 450 when the gap is 1 mm, showing that as the gap size increases, the coupling strength also increases. The Q_{ex} reaches peak values of approximately 450 at 1 mm, demonstrating the expected direct proportional relationship between coupling strength and gap dimension. The range (0.2–0.4 mm) has more stable Q_{ex} values between 25 and 75, which is the useful design range for high bandwidth. The curve demonstrates that a wide range of bandwidths can utilize this type of coupling.

The internal coupling is demonstrated by changing the length of two loaded stubs (b and Lb). Figure (3) shows the effect of the length of stubs on the S-parameter response at different frequencies. The bandwidth is directly proportional to the length of stubs. The range of bandwidth that can be achieved this way is wide. The transmission zero (TZ) is already inserted in the lower band side to improve the suppression of the filter response.

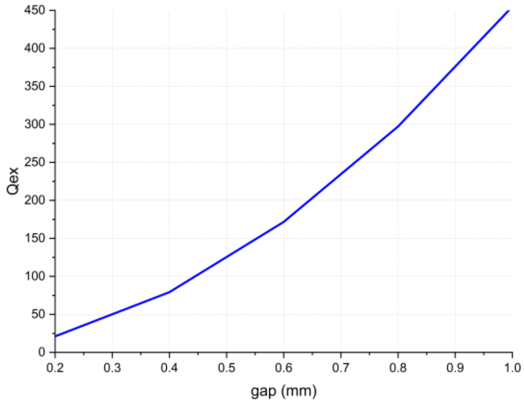


Fig. 2 The external coupling vs gap distance between feed line and resonator.

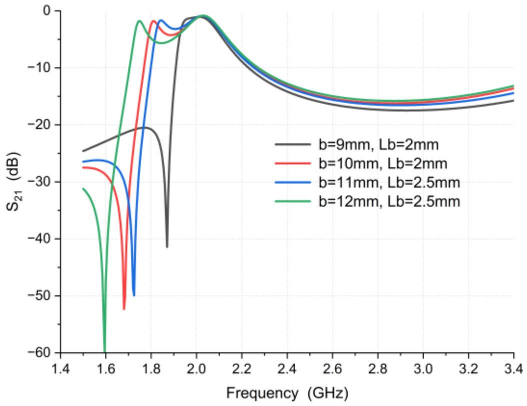


Fig. 3 Internal coupling of a dual-mode resonator vs lengths of open-loaded stub (b, Lb).

3. DESIGN METHOLODOGY

The formula can be used to determine the band-pass filter's design parameters, including the coupling coefficients and external quality factors, in relation to the general coupling structure. A coupling feed connects the resonator's externally loaded Q to the input/output port. By modifying the gap (g) between the coupled-feed and open-loop resonators, the Qex values can be obtained. Then, the second-order Chebyshev low-pass prototype filter element (g) values at insertion loss 0.1 dB are as follows [13]:

g_0=1, g_1 =0.8431 , g_2 =0.622

The external quality factor (Qex) extraction computation can be found as formula (1)[14, 15].

$$Q_{ex} = \frac{g_0 g_1}{FBW} \qquad (1)$$

$$FBW = \frac{Bw}{f_0} \qquad (2)$$

Where FBW is the fractional bandwidth and fo is the resonant frequency.

At a center frequency of about 1.98 GHz, the Qex will be equal to 33.39. Figure 2 reveals a gap of 0.3 mm.

The coupling coefficient ($K_{i,i+1}$) measures how strongly connected elements (like resonators) interact with each other and is very important for how well the filter works (like its bandwidth, selectivity, and insertion loss). Formula (3) provides the extraction computation [14, 15].

$$K_{(i,i+1)} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \quad for\ i = 1 to\ n-1 \quad (3)$$

At a center frequency of about 1.98 GHz and a BW of 50 MHz, the $K_{1,2}$ will be equal to 0.03487. Figure 3 reveals b=10mm and Lb=2mm.

Equations 1-3 can determine certain physical dimensions, as previously mentioned. The optimization values have been obtained by using HFSS software to simulate the BPF. Table (1) displays the dimensions of the coupled-feed dual-mode microstrip resonator filter.

Table 1: Optimum dimensions of coupled-feed dual-mode microstrip resonator filter.

Dimensions	at f_o =1.98GHz
Distance between the dual-mode resonator and the coupling feed (g)	0.3 mm
Resonator length (a)	14.15 mm
Resonator length (c)	11.52mm
Resonator length (b)	9.96mm
Resonator width (w)	0.89 mm
Feed width (w_f)	1.87 mm
Coupling feed width (c_f)	1.89 mm
Feed length (f_e)	17.55mm
C_x	2 mm
y_b	2 mm
a_x	2 mm
a_y	8 mm
L_b	1.72 mm
W_s	19.92 mm
L_s	53.65 mm

4. SIMULATION RESULTS

Figure 4 shows the simulation frequency response of the second-order Chebyshev dual-mode BPF. The operation center frequency of the filter (f_o) is 1.98 GHz, which gives a 16.97 dB return loss, and the insertion loss is equal to 1.2185 dB while the minimum IL value is about 1 dB occurs at 2 GHz. The bandwidth of the BPF is measured at 3 dB, which is equal to 50 MHz. There is a TZ that appears at 1.87 GHz with an isolation level of 41.19 dB. The minimum isolation in the lower sideband is 20.5 dB, and it gradually increases as the frequency decreases. The maximum isolation in the upper sideband is 17.47 dB, occurring at 2.945 GHz. The results show a good agreement with the requirement for 5G applications.

Figure (5) depicts the broad frequency response of the second-order Chebyshev dual-mode bandpass filter. The isolation gradually decreases after the frequency reaches approximately 2.8 GHz. The spurious frequency is at 4.27 GHz, exhibiting a return loss of about 17.07 dB. The total spurious window (fs/fo) in this filter is around 2.15.

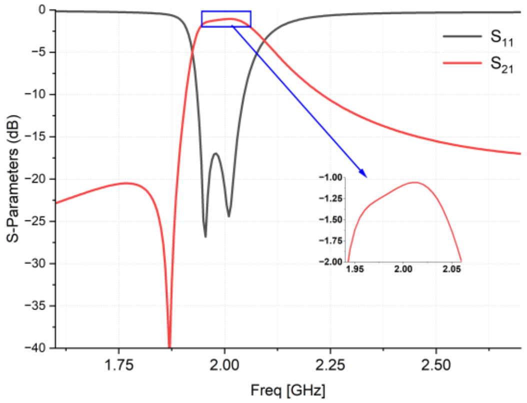


Fig. 4 Simulated results of the second-order Chebyshev dual-mode BPF.

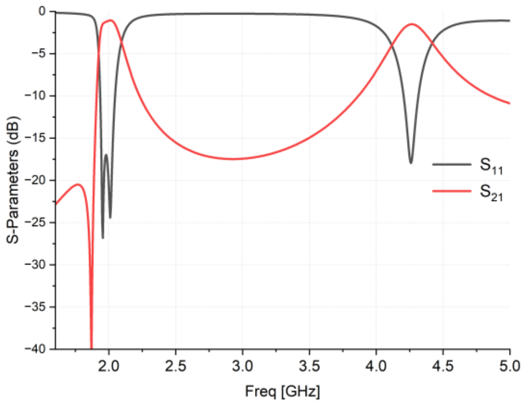


Fig. 5 Simulated results of broad frequency of the second-order Chebyshev dual-mode BPF.

5. EFFECTIVE OF LOCATION FEEDING LINE

Three feeding topologies (direct, offset and asymmetric) have been presented to examine their impact on the behavior of the microwave BPF dual-mode resonator. Figure 6 displays the frequency response of a second-order Chebyshev BPF with a direct feed coupling type. The TZ is at 3 GHz, so the BPF's upper selectivity has increased. The isolation becomes 45 dB on the upper side, which is greater than three times the opposite coupling topology in Figure 3. The result shows there is no effect on the spurious frequency. The coupling technique offers double TZs on each side.

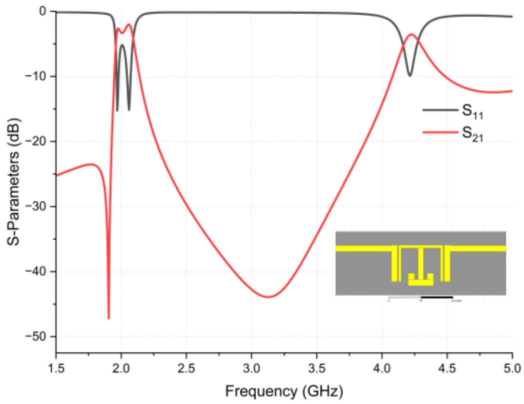


Fig. 6 Simulated results of the second-order Chebyshev dual-mode BPF with direct feed topology.

Figure 7 shows the frequency response of a second-order Chebyshev dual-mode BPF with a small offset in the position of the feeding line. The topology offers a slight enhancement in isolation and spurious windows, which are 19 dB and 2.2, respectively. A single TZ appears at 1.9 GHz on lower side band, providing an isolation level of 34.4 dB.

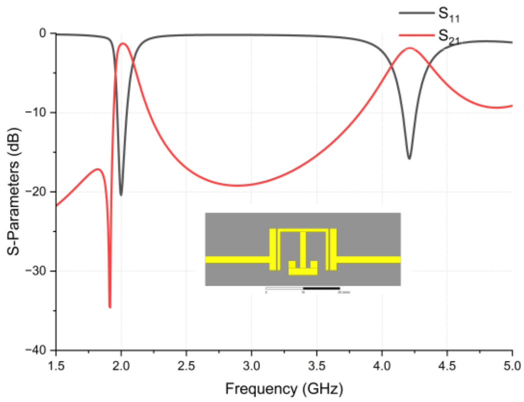


Fig. 7 Simulated results of the second-order Chebyshev dual-mode BPF with offset feed topology.

Moving the feeding line further away from the center of the resonator (a) greatly impacts how the BPF works, as illustrated in Figure 8. Two Tzs have appeared on both band sides. The upper Tz achieves a high isolation of 55 dB at 4.4 GHz, which improves the roll-off of the BPF. The lower TZ appears at 1.86 GHz, providing an isolation level of 43.47 dB. This topology offers a significant enhancement in the spurious window, increasing it from 2.1 to 2.75.

Figure 9 shows the frequency response of a second-order Chebyshev dual-mode BPF with an asymmetric feed topology. Two transmission zeros (Tzs) appear on both sides of the band. The upper TZ provides strong isolation of over 70 dB at 2.9

GHz, greatly improving the BPF's ability to filter compared to other designs. The spurious window remains at the same value of the fundamental design, which is 2.1.

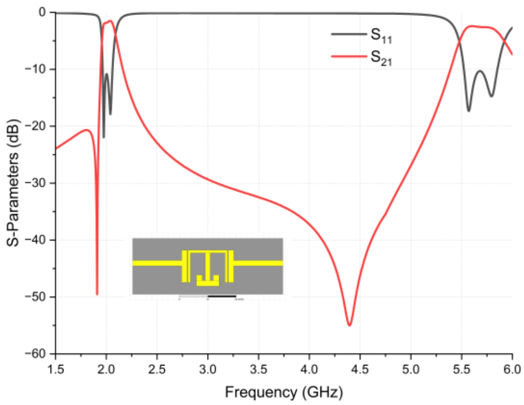


Fig. 8 Simulated results of the second-order Chebyshev dual-mode BPF with offset1 feed topology.

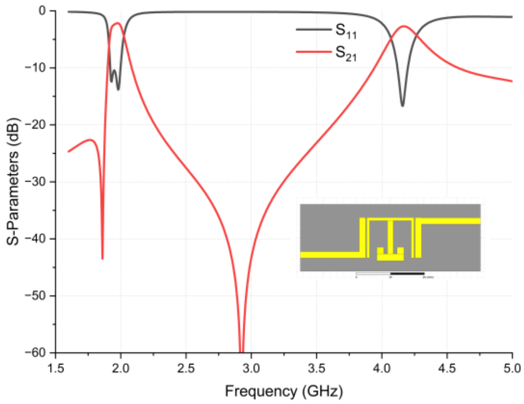


Fig. 9 Simulated results of the second order Chebyshev dual mode BPF with asymmetric feed topology.

Table 2 compares several previously published works based on key parameters like center frequency, bandwidth, permittivity, insertion loss, and electrical size. One of the standout points in this study is its compactness; it achieves an electrical size of just 0.201 λg^2, which is smaller than most of the other designs listed, especially when compared to [16] and [11]. The insertion loss is maintained at a comparatively low level of 1.2 dB, somewhat exceeding that of comparable devices utilizing similar materials.

Table 2: Comparative analysis of related published works

Ref.	***f_o*** **(GHz)**	**FBW (%)**	**ε_r**	**IL (dB)**	**Size (λ_g^2)**
[3]	2.5	4.8	4.4	1.1	0.211
[7]	2.4	5	10.2	0.91	0.173
[8]	40	15	2.2	2.5	0.483
[11]	26	3.71	3.48	1.1	2.463
[16]	1.95	2.56	6.15	1.1	0.782
This study	1.98	2.53	6.15	1.2	0.201

6. CONCLUSION

This dual-mode half-wavelength folded microstrip resonator shows strong potential, especially for compact 5G applications. The way external coupling is managed using capacitive effects is clever; as the space between the feed line and resonator becomes smaller, Qex decreases, allowing for adequate control. Internally, stub loading boosts coupling proportionally, while the resonator length directly tunes the center frequency, making fine adjustments intuitive and precise. The design, simulated using HFSS, demonstrates reliable performance. Even with a compact footprint (0.257 λg × 0.167 λg) and a spurious response around 4.27 GHz, the filter maintains solid efficiency. The changing of feeding topologies has a significant effect on the behavior of BPF. At the offset feeding near the center of the resonator, the best results were obtained.

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مرشح نطاق ترددي عالي الانتقائية ثنائي الوضع مطوي بنصف الطول الموجي لشبكات الجيل الخامس

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تاريخ الاستلام: 26 ابريل 2025   استلم بصيغته المنقحة: 31 يوليو 2025   تاريخ القبول: 25 أغسطس 2025

الملخص

تقدم هذه الورقة البحثية مرنانًا جديدًا ثنائي الوضع، ذو شريط مطوي نصف موجي. يُحقق تأثير السعة الاقتران الخارجي بتغيير مسافة الفجوة، بينما يُحقق التحميل المبدئي الاقتران الداخلي. يحاكي مرشح تمرير نطاق تشيبيشيف (BPF) من الدرجة الثانية ركيزة روجرز رقيقة. يعمل مرشح تمرير نطاق تشيبيشيف (BPF) عند تردد مركزي يبلغ 1.980 جيجاهرتز، مما يُنتج خسارة عودة قدرها 16.97 ديسيبل، بينما تُعادل خسارة الإدخال 1.2185 ديسيبل. يقيس مرشح تمرير نطاق تشيبيشيف عرض نطاقه عند 3 ديسيبل، أي ما يعادل 50 ميجاهرتز. يحدث التردد الهامشي عند 4.27 جيجاهرتز. يوفر المرنان حجمًا يبلغ حوالي (0.726 λg × 0.278 λg)، وهو أصغر من الوضع الأحادي. أدى تحريك خط التغذية بالقرب من مركز الرنان إلى زيادة نافذة الترددات الزائفة بشكل ملحوظ بنحو 2.75، وظهرت معاملتا Tz على جانبي النطاق. تُظهر النتائج توافقًا جيدًا مع متطلبات تطبيقات الجيل الخامس.

الكلمات الداله :

مرنان ثنائي الوضع؛ مرشح تمرير النطاق؛ انتقائية عالية؛ مرنان مطوي بنصف الطول الموجي؛ 5 G