Miniaturization of Microstrip Hexagonal Open-Loop Resonator Bandpass Filter Using Capacitive Loading

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Abstract: - A compact fifth-order quasi-elliptic band-pass filter (BPF) based on Hexagonal Open-Loop Resonators (HOLRs) with capacitive loading is presented in this paper. A capacitive loading is used to reduce size and to obtain more compactness and sharp rejection, as well as spurious shift towards higher frequencies. The filter has been designed to operate at a center frequency of 2.45 GHz for wireless applications and Network systems operating in ISM band. The stopband rejection of the upper band extends to 6.62 GHz with a value greater than 32 dB. Furthermore, there are two transmission zeros at 2.02 and 2.62 GHz for a sharp cutoff response. The roll-off rates are 346 dB/GHz and 323 dB/GHz at lower and upper stopbands, respectively. The miniaturization technique using capacitive loading has led to 27% reduction in filter dimensions.

Key-Words: - Open-loop hexagonal resonator; band-pass filter; capacitive coupling; miniaturization

1 Introduction

High-performing microstrip BPF with compact size, high rejection, steep skirt and harmonic suppression is very desirable in wireless communication systems. Although a wide varieties of topologies have been proposed to fulfill these requirements, quasi-elliptic cross-coupled open-loop resonator filters have always drawn much attention. Therefore, many researchers have proposed various configurations for those filters [1]-[5] where most of them rely on the Square Open-Loop Resonator (SOLR) topology, because the coupled SOLRs are more flexible to construct a variety of cross-coupled planar filters, which have the similar coupling configurations as those of waveguide cavity cross-coupled filters [6]. Some papers have used different shapes like triangular and circular geometries [7]-[8]. Hexagonal geometry is also introduced with a new topology [9]; This type has a higher degree of coupling when compared to rectangle and square counterparts. Here, we tried to pay this topology more attentions and thorough study to achieve more compactness.

To reduce the circuit size and shift the first spurious response to a higher frequency band, many methods have been proposed using varactors as in [10], ferroelectric Barium-Strontium-Titanate capacitors [11]; or capacitors such as miniaturized hairpin resonator filters [12]. In this article, a fifth-order HOLR quasi-elliptic BPF is studied, then the filter is redesigned using capacitive loading maintaining the same center frequency to exhibit compact size, wide stopband and good selectivity. The unloaded and loaded filters have been fabricated and characterized.

2 The Proposed HOLR Filter

The filter shown in Fig.1 consists of 5 capacitively loaded HOLR resonators. The tapped-lines used in [9] don't retain the required performance. So, a relocation has been done with an optimized value $S_t = 0.78$ mm using a full-wave simulator.

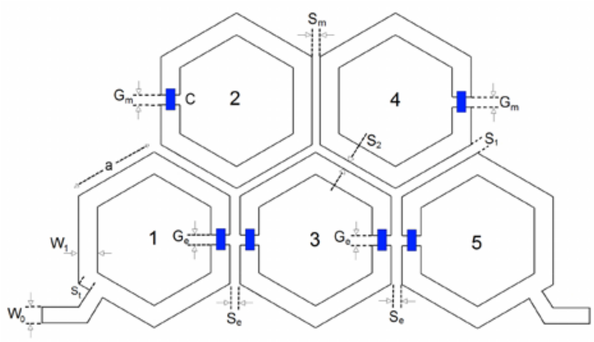


Fig.1. Configuration of the fifth-order HOLR quasi-elliptic BPF with capacitive loading.

Furthermore, all filters are assumed to be designed using a copper Microstrip on an Arlon/25N substrate with a relative dielectric constant of 3.25 and a thickness of 0.8mm. The dimensions of the filter without the loaded capacitor are as follows:

$W_0 = 1.8\,mm,\ W_1 = 1.8\,mm,\ a = 7.44\,mm,$

$S_t = 0.78\,mm,\ G_m = 0.36\,mm,\ G_e = 0.56\,mm,$

$S_m = 1.02\,mm,\ S_e = 0.58\,mm,$

$S_1 = 0.66\,mm,\ S_2 = 1.14\,mm.$

Observing the simulation results in Fig.2, the attenuation pole pair is perfectly located at 2.46 and 2.53 GHz with a return loss of 21.87 dB and 27.2 dB respectively. The passband is located at 2.49 GHz with an insertion loss of about 2.1 dB. The 3 dB bandwidth ranges between 2.42 and 2.56 GHz giving a 6% Fractional Bandwidth (FBW).
Transmission zeros are clear on Fig.2(b) at frequencies 2, 2.64, and 3.5 GHz.

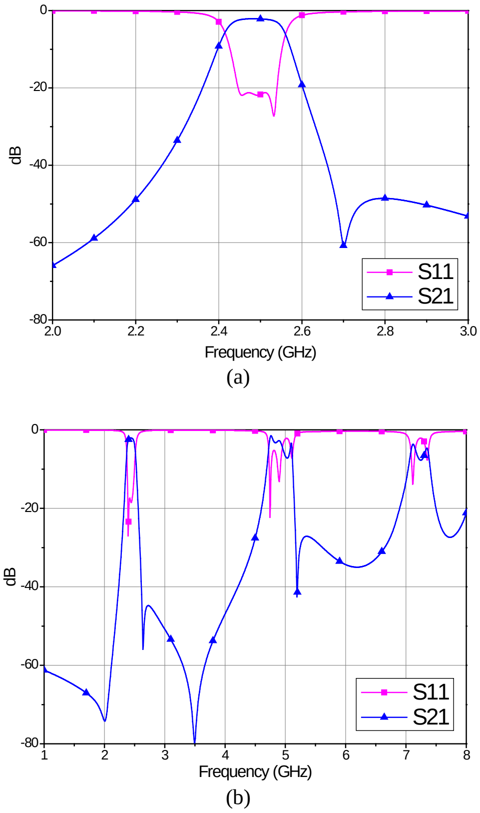


Fig.2. Simulation results of the transfer responses of the HOLR microstrip filter (a) Passband (b) Broadband response.

3 Miniaturization Using Capacitive Loading

Fig.3(a) illustrates the frequency responses of a single HOLR when it is fed under weak coupling case. If a capacitor is connected between the two open ends of the resonator, then the resonant frequencies will shift down. The shift in frequency of the first resonance can be translated into miniaturization by decreasing the total size of the resonator.

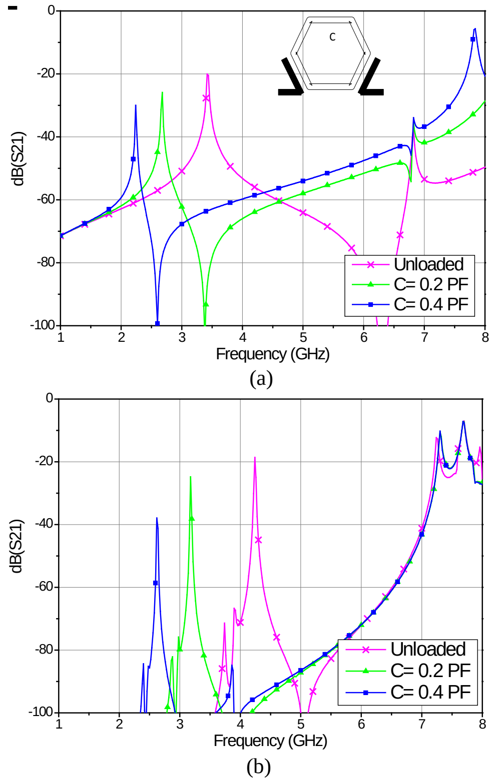


Fig.3. Transfer responses of (a) a single resonator (b) 5 HOLR filter with weak coupling for unloaded and loaded resonator with two capacitance values.

Increasing the value of the capacitance will increase the frequency shift of the first resonance and thus increase the degree of miniaturization. Applying the same method to the HOLR filter, a plot of the transfer response for different value of capacitances is shown in Fig.3(b).
Table 1 summarizes comparison results for these single resonators, and for different values of capacitance, where "a" is the rib's length of the resonator, A_0 is its area, A_m is the area of the loaded resonator, f_1/f_0 is the ratio of the second resonant

Table 1

Comparison results of transfer response for unloaded and loaded resonators with different capacitance values of the capacitors.

C(pF)	*a(mm)*	*$A_m(mm^2)$*	*$A_m/A0$*	*f_1/f_0*
0	6.3	80	1	2
0.2	4.9	48	0.6	2.5
0.4	4.0	32	0.4	3

frequency to the first one. For a capacitance of 0.4 PF, a reduction in size of 40% is achieved and a shift in the spurious frequency reaches three times the fundamental one.

Using a 2D electromagnetic simulator, Fig.4 shows the simulation results of the HOLR unloaded and loaded filters. As we can see, the first spurious frequency of the loaded filter is shifted towards the second spurious frequency of the HOLR filter, while maintaining the same passband for both filters.
Using a full-wave electromagnetic simulator, Fig.5 shows the broadband response of the loaded filter.
The dimensions of the filter's geometry shown in Fig.1 are as follow:

$$W_0 = 1.8\,mm, W_1 = 1.8\,mm,\ a = 5.14\,mm$$

$$S_t = 0.78\,mm, G_m = 0.38\,mm, G_e = 0.5\,mm$$

$$S_m = 0.42\,mm, S_e = 0.42\,mm$$

$$S_1 = 0.4\,mm, S_2 = 0.51\,mm.$$

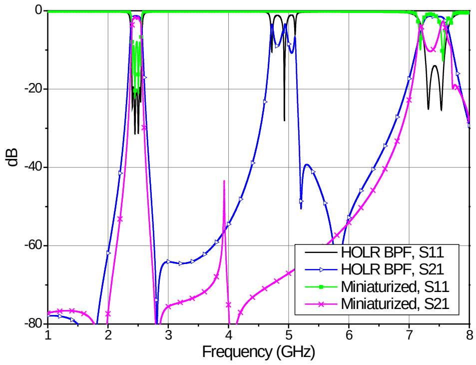


Fig.4. Responses of the HOLR filter with and without capacitive loading.

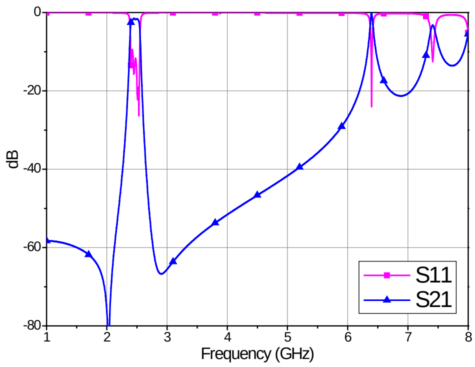


Fig.5. Broadband responses of the loaded filter.

Table 2 shows a comparison between the hexagonal open loop resonator filter and the loaded one based on the dimension, the attenuation poles location, insertion loss and FBW. The size of the HOLR filter is about 0.59λg x 0.40λg, where λg is the guided wavelength at the midband frequency of 2.49 GHz. The size of the loaded filter is only 0.41λg x 0.27λg. There is 27% reduction in filter dimensions when compared to those of the conventional one.

Table 2

COMPARISON BETWEEN THE UNLOADED FILTER AND THE LOADED ONE.

Filter Configuration	HOLR Filter	Loaded HOLR Filter
Dimension	0.59λg × 0.40λg	0.41λg × 0.27λg
Attenuation Poles Locations	2.00GHz, 2.64GHz, 3.50GHz	2.03GHz, 2.90GHz, 3.83GHz
Insertion Loss (dB)	2.11	1.78
FBW	5.9%	6.9%

Fig.6 depicts the effect of the capacitances on the loaded filter. As can be seen, adding the capacitors has shifted the passband towards very lower frequencies leaving spurious frequencies unchanged. Also note that the bandwidth shrinks to about 40% of its initial value. This can be referred to the concentrated electrical fields inside the capacitors enhancing and shifting the transmission zero towards the passband.

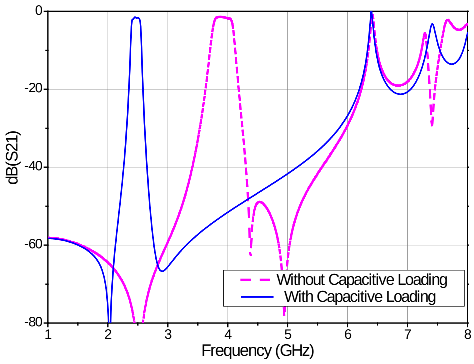


Fig.6. Simulated Results of the miniaturized filter with and without capacitive loading.

Fig.7 shows a comparison between the two filters. Maintaining the same passband's bandwidth, frequency and the steep skirt, the 20 dB stopband rejections of the loaded filter extends to 6.2 GHz.

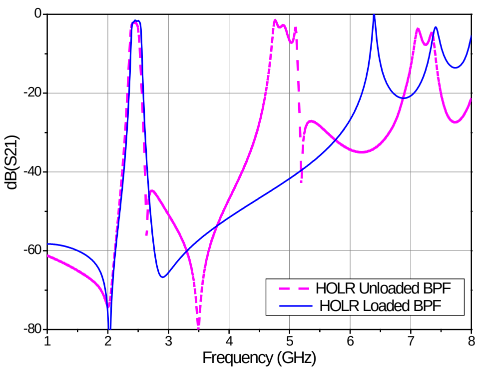
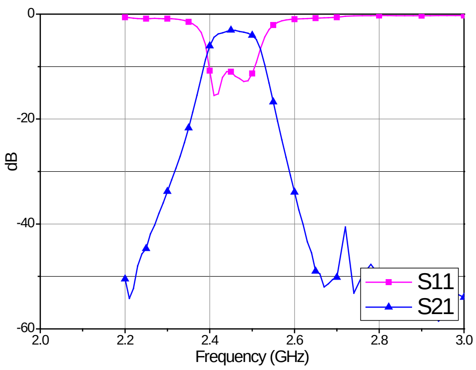


Fig. 7. Response comparison between the unloaded and loaded filters.

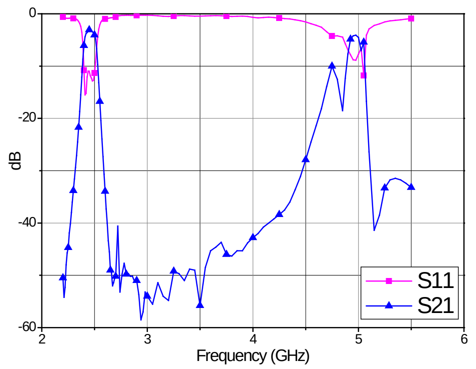
4 Measurement Results

The two proposed filters are fabricated using Arlon 25N substrate with a thickness of 0.8 mm, a relative dielectric constant of 3.25, and a loss tangent of 0.0025. The circuit size of the HOLR unloaded filter is relatively small, but compared to the loaded one it shrinks to about 50% with an area equal to (28×18.8 mm^2). Capacitors of 0.4 PF capacitance belong to muRata have been used. Note that the first spurious resonance remains unchanged at twice the fundamental of the unloaded resonator as shown in Fig.8.

Observing the measurement results in Fig.8, the attenuation pole pair is located at 2.41 and 2.48 GHz with a return loss of 15.52 dB and 12.83 dB respectively. The passband is centered at 2.46 GHz with an insertion loss of about 3.1 dB.



(a)

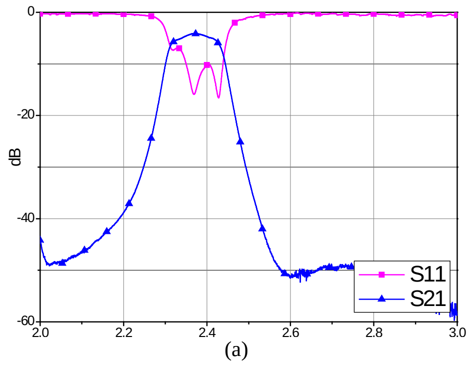


(b)

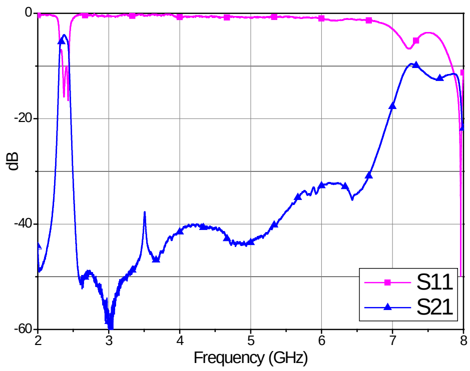
Fig.8. Measured (a) passband and (b) broadband responses of the HOLR unloaded filter.

The 3 dB bandwidth ranges between 2.4 and 2.52 GHz giving a 5.1% FBW. Transmission zeros are at frequencies 2.21 GHz and 2.67 GHz.

Fig.9 shows the measured responses of the loaded filter. The shift in frequency is mainly due to the tolerance of the capacitors, which can be considered as a disadvantage of this method. Note that the spurious frequencies shift more than three times the center frequency of the passband, which means that



(a)



(b)

Fig.9. Measured (a) passband and (b) broadband responses of the HOLR loaded filter.

the values of the capacitance are a little bit higher than its nominal values. Also, these values and their positions between the gaps are not fully identical leading to non-accurate results. Further miniaturization could be done by increasing the values of the capacitances.

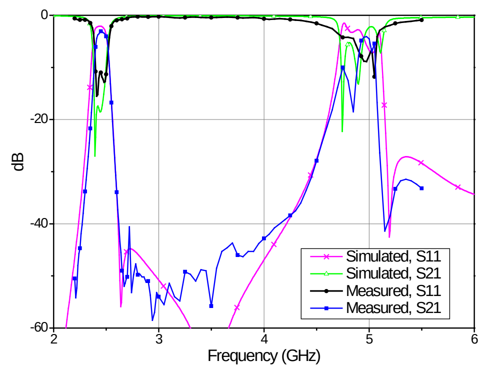
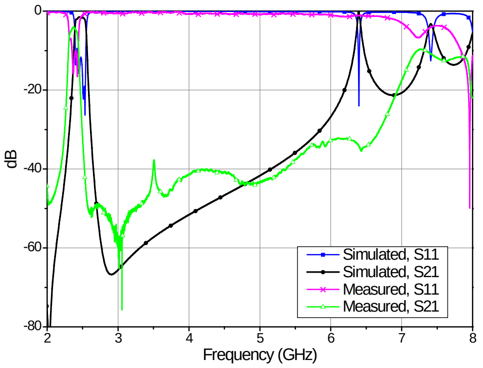
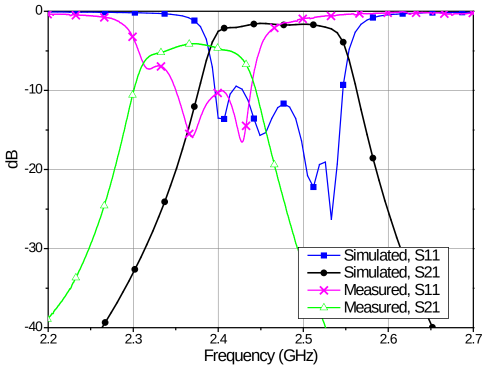


Fig.10. Comparison between the Simulated and the Measured Responses of the unloaded HOLR BPF.

A comparison between the simulated and the measured responses of the unloaded HOLR BPF are shown in Fig.10. Also a comparison between the simulated and the measured responses of the loaded HOLR BPF are shown in Fig.11. The insertion loss is larger due to conductor, dielectric and connectors' losses. In addition, the shift in frequency is very clear as discussed above, and the band pass is narrower.



(a)



(b)

Fig.11. Comparison between the simulated and the measured (a) passband and (b) broadband responses of the loaded HOLR BPF.

Fig.12 shows the comparison between the measured results of the two filters. As can be seen, the spurious frequencies are shifted toward very high frequencies, but the passband shift is also very clear. This can be also referred to the inaccurate values of the capacitors. The fabricated HOLR BPF and the loaded one are depicted in Fig.13.

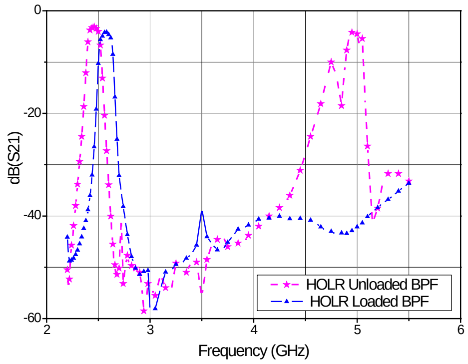


Fig.12. Measured broadband responses of the unloaded and loaded filters.

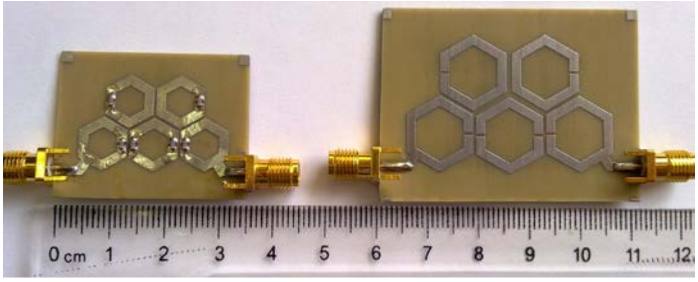


Fig.13. A photograph of the two fabricated filters.

5 Conclusion

A compact fifth-order HOLR quasi-elliptic BPF with capacitive loading is presented in this paper. The filter topology is based on HOLRs offering additional electric coupling, compact size and sharp rejection compared to a conventional SOLR filter. At a center frequency of 2.45 GHz, two Filters with and without capacitive loading have been designed and fabricated. The loaded filter has an extra 27% reduction in filter dimensions. A wide stopband reaches 6.62 GHz with rejection value greater than 32 dB. Moreover, a shift in measured frequency against the simulation result has been observed due to capacitance tolerances and available fabrication technology.

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