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Study and Design of A Dual Mode Resonant Band-Pass Filter Suspended Substrate Stripline for 5G Communications

***Abstract**. In this paper, a compact dual-mode bandpass filter suspended stripline is presented. A square-shape resonator with four shorted ground posts was lied on substrate (Roger 5880, Er=2.2) in the middle of metallic cavity to operate at 5G mobile communications. The internal coupling was achieved by notching the resonator at the place 450 with respect to input and output ports, where the external capacitive coupling was realized by changing the length of input feeder. A 2nd and 4th order bandpass Chebyshev filter are designed and simulated to operate at resonant frequency is 4.8GHz and bandwidth is 100MHz. The simulation results show, the spurious window is about 1.844, the unloaded Q-factor was 1024, the insertion loss was 0.1 dB and the return loss is 17.6 dB.*

***Streszczenie**. W artykule przedstawiono zwartą linię paskową zawieszonego filtra pasmowego o dwóch trybach pracy. Na podłożu (Roger 5880, Er=2,2) w środku metalowej wnęki położono kwadratowy rezonator z czterema zwartymi słupkami uziemienia, aby działał w komunikacji mobilnej 5G. Sprzężenie wewnętrzne uzyskano poprzez nacięcie rezonatora w miejscu 450 względem portów wejściowych i wyjściowych, gdzie zewnętrzne sprzężenie pojemnościowe zrealizowano poprzez zmianę długości podajnika wejściowego. Filtr Czebyszewa pasmowoprzepustowy drugiego i czwartego rzędu zaprojektowano i zasymulowano do pracy przy częstotliwości rezonansowej 4,8 GHz i szerokości pasma 100 MHz. Wyniki symulacji pokazują, że fałszywe okno wynosi około 1,844, nieobciążony współczynnik dobroci wynosił 1024, tłumienność wtrąceniowa wynosiła 0,1 dB, a tłumienność odbiciowa 17,6 dB. (**Badanie i projekt podwójnego trybu rezonansowego filtra środkowoprzepustowego z zawieszoną linią paskową podłoża dla komunikacji 5G**)*

Keywords: Microwave filter, dual-mode BPF, suspended microstrip filter, 5G applications.
Słowa kluczowe: Filtr mikrofalowy, dwutrybowy BPF, zawieszony filtr mikropaskowy, aplikacje 5G

Introduction

The microwave pass filter (BPF) is the main component in wireless communication systems, the band pass filters have small attenuation in desirable pass band and high attenuation for undesirable band to reject un wanted band access to other stage in communication system, there are many kinds of micro wave filter such as micro stripe filter [1]–[3] ,Tunable Microwave Filters [4]–[6], Waveguide Filter [7], [8],[9] and cavity resonator[10], [11] .

In [12], wideband band pass filter in suspended substrate stripline realized at band (1 GHz to 12.7 GHz) and maintain rejection hump better than 100 dB at both the side of the BPF. A dual-band dual-mode bandpass filter using series coupled ring resonators designed using EM simulator and fabricated on 1.63mm thick tachonic substrate achieved resonant frequencies of the two passbands at 1.73 GHz and 2.37 GHz while the centre transmission zero at 2.04 GHz [13]. In [14], a dual-mode suspended-substrate stripline filter designed by CST simulation software and fabricated at centre frequency 2.07 GHz with two ring resonators packaged in a metallic cavity and achieved return loss was 16.42 dB and insertion loss was 0.926 dB. In [15], a miniaturized suspended stripline resonator with high unloaded quality factor realized at resonator consists of a thin substrate with double-layer strips on both sides connected by a metallic via hole, the filter simulated by HFSS software and fabricated at centre frequency 670 MHz with a bandwidth of 160 MHz and insertion loss of approximately 0.38 dB. In [16] a millimetres-wave dual-band bandpass filter using substrate integrated waveguide (SIW) dual-mode cavities is designed, a dual-band bandpass filter is designed, and the centre frequencies of the two passbands are 26.73GHz and 31.52GHz, respectively. The 3dB-passbands are 26.24-27.21GHz (3.6%) and 31.2-31.84GHz (2%), respectively, with maximum insertion loss of 0.48dB and 0.67dB, respectively, and return loss larger than 12dB in both pass-bands.

In this paper designed dual-mode bandpass filter suspended stripline to be operated for 5th generation for mobile applications at centre frequency 4.8 GHz with band width 100 MHz, utilizing close rectangular loop resonators topic on substrate Rogers RT/Duroid 5880 with dielectric constant $\varepsilon r = 2.2$ with thickness 0.1 mm in side metallic cavity having a conductivity of 5.8×107 S⁄m and shorting ground posts via cavity. Four cases was studded with difference position of posts to choose which case achieve a good quality factor with higher value of spurious window for designed. The Chebyshev Low pass Prototype Filters used to designed 2nd order dual-mode band pass filter and 4th order band pass filter and simulation by (HFSS) software to find various results such as passband width, stopband attenuation, Input and Output Impedances, Return loss, Insertion loss and group delay are considered while designing the filter where these filter parameters play an integral role in the assessment of frequency dispersion over the given frequency band.

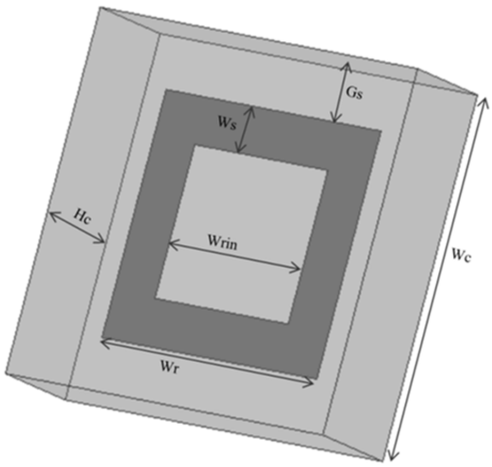

Fig.1. square stripe line in the middle of cavity.

Filter design

Fig.(2), show the purpose of dual-mode resonator, it consist of square stripe line with side length (λg /4) is Wr= 21mm and notching in the middle by square notch with side length Wrin= 13mm which is the width of stripe line Ws= 8mm, this square stripe line topic on Rogers RT/Duroid 5880 with dielectric constant εr = 2.2 with thickness 0.1 mm and existing in the middle of metal cavity having conductivity of 5.8×107 S⁄m with dimensions (Wc=31mm ,Wc= 31mm, Hc= 10mm), a stripe line away from inner sides of cavity is Gs=10mm and 5mm from inner base.

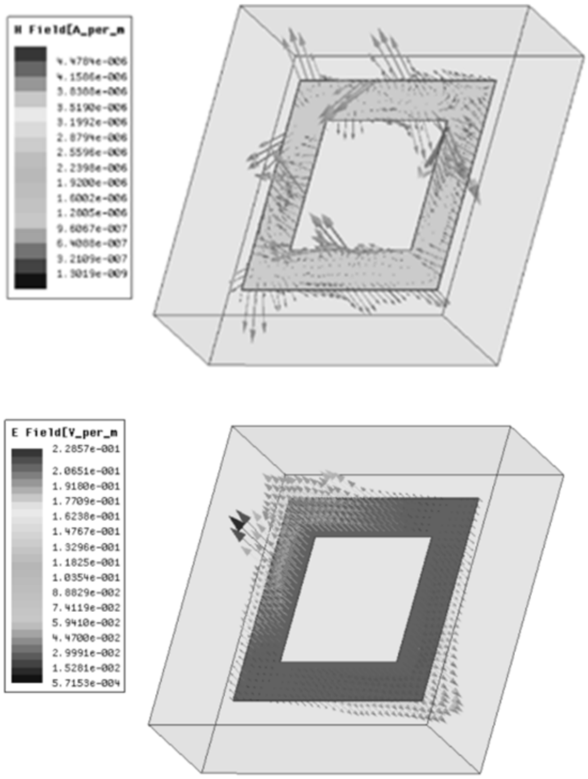

Fig.2. Distributions of H-field and E-field in the cavity.

To improve the Spurious window, insertion grounded post was suggested. Four cases study were used to show highly behaviour of resonator, the first case as shown in Fig.(3) the location of post in centre of resonator and radius of post (Ri) change from 1 mm to 6 mm, as shown a Spurious window (fs/f0) relatively increased but quality factor will be decreasing with increasing Ri.

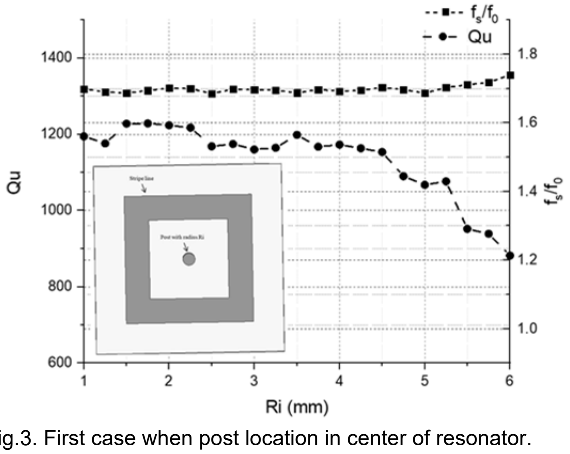

Fig.3. First case when post location in center of resonator.

The second case proposed was four grounded posts it locations in side of square notch of stripe line as shown in Fig.(4), each post have radius 1 mm. in this case calculate Spurious window (fs/f0) and quality factor when positions of posts change by moving from center of resonator to the interior angle of the square a diagonal movement with distance from center of resonator to center of each posts is Rd.

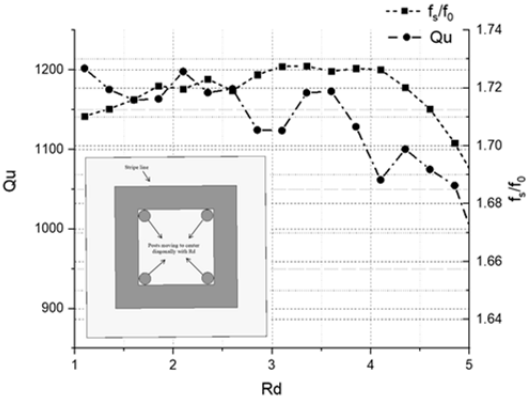

Fig.4. second case illustrate posts locations and its movement.

In Fig.(4) notice a Spurious window (fs/f0) is increasing to some extent but quality factor (Qu) was decreasing.

The third case was the grounded posts with radius 0.25mm pass through at aperture in stripe line with radius Rh as shown in Fig.(5), the calculations of Spurious window (fs/f0) and quality factor (Qu) at posts position was fixed and radius of aperture in stripe line was change from 1mm to 5mm.

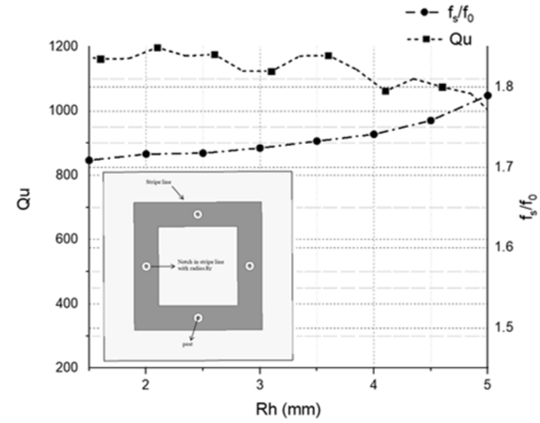

Fig.5. third case illustrate posts locations and its movement.

As shown in Fig.(5), a Spurious window (fs/f0) is reverse relationship with quality factor (Qu).

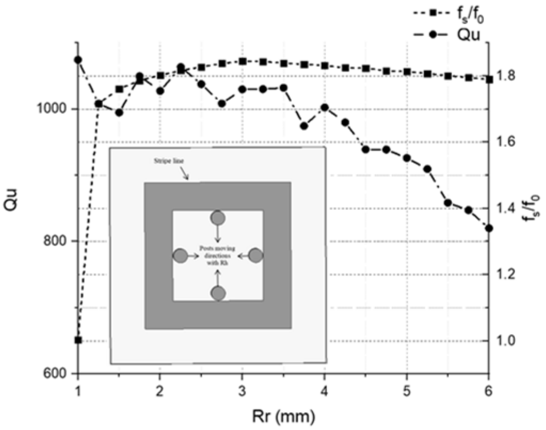

Fig.6. fourth case illustrate posts and apertures.

In fourth case, was four grounded posts in side square notch and its locations vertical and horizontal to centre of resonator as shown in Fig.(6), each post have radius 1mm , calculate Spurious window (fs/f0) and quality factor (Qu) where posts movements horizontal for posts at position left and right and vertical for posts top and bottom of centre of resonator with distance Rr. In Fig.(5) notice at Rr= 3mm, Spurious window (fs/f0) above 1.8 and quality factor (Qu) above 1000, and these values are considered the best values obtained in the four cases.

The summary of four cases studied illustrated in Table (1), which contents the changes values of Spurious window and quality factor.

Table 1. all four cases results for posts locations change.

Case study	fs/f0	Qu
Case one	1.01 to 1.77	717.8 to 1284.1
Case two	1.63 to 1.72	877.2 to 1201.8
Case three	1.7 to 1.78	969.7 to 1201
Case four	1 to 1.844	820 to 1074.3

To design a filter, several steps should be taken. Firstly the specifications of band pass filter in Table (2), the specifications that are suitable for 5G .

Table 2. specifications of filter.

Centre frequency	4.8 GHz
20 dB Bandwidth (BW)	100 MHz
Return Loss (S11)	<-16 dB
Insertion Loss (S21)	< 0.1 dB

Secondly find the values of internal and external coupling, these values found by using the Chebyshev Low pass Prototype Filters used to synthesizing the filter coupling matrix [m] according to the filter specifications in Table (1). The coupling matrix [m] and external quality factor Qu for a band pass filter with standard directly can be synthesized according to Eq. (1 to 3) [17] [18], and by using the low pass prototype filter g-values [19] [20].

(1) $$Qu_1 = \frac{g_0 g_1}{FBW}$$

(2) $$Qu_n = \frac{g_n g_{n+1}}{FBW}$$

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

These g-element values are determined according to the filter order and pass band ripple (LAr).The g-element values of the common used low pass prototype filters such as Chebyshev can be directly obtained from tables [19].

The internal coupling between resonators is realized using a notch, which is perturbed on the square resonator filter as shown in Fig.(7).

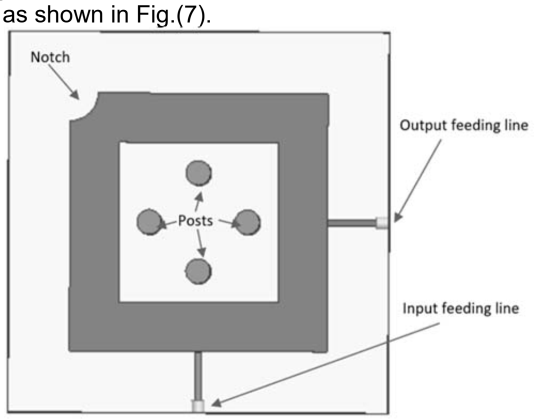

Fig.7. The design chosen show internal and external coupling.

The notch not only controls the coupling between resonators, but also controls the bandwidth of the filter response, the relationship between coupling bandwidth M12 and notch radius show in Fig.(8). it can be seen that the coupling bandwidth is increased as the notch radius increases.

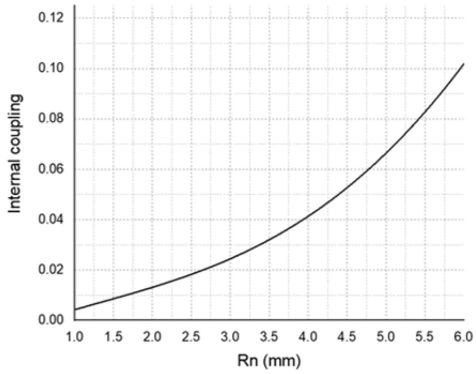

Fig.8. Relationship between internal coupling and notch radius.

External coupling is connection between input and output of filter to resonator as shown in fig.(7), connects the filter to the outside is expressed as external (Qu), the value of Qu is determined by the overlap between the input transmission line and the square resonator filter, the value of Qu can be calculated from value of group delay[19]. The Fig.(9) show the relationship between Qu and length of feeding line (Lf).

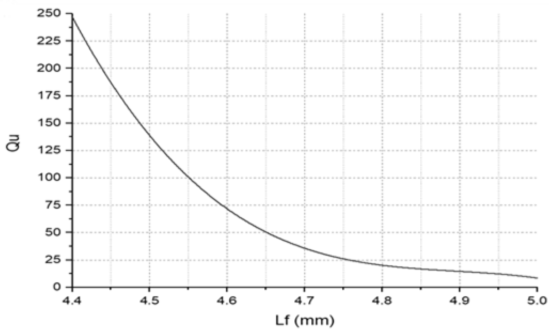

Fig.9. Relationship between (Qu) and length of feed line.

Fourth-order filter design

a fourth order filter can be designed by using and developing two pieces of dual-mode second-order band pass filter as shown in figure (10).

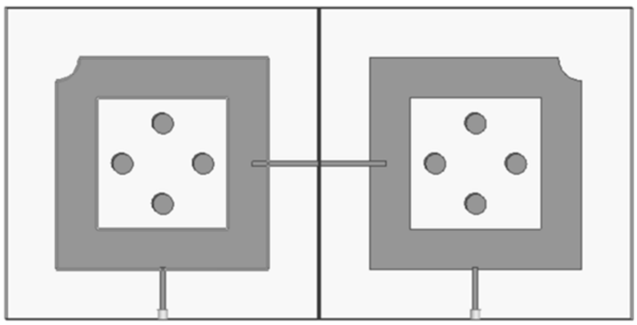

Fig.10. dual-mode fourth-order band pass filter.

The development is according to Chebyshev low pass prototype filters. Based on these filter specifications the g-values of the low pass prototype filter are g1= 1.1088, g2= 1.3062, g3= 1.7704, g4= 0.8181 and g5= 1.3554 [19], [21]. The normalized synthesized coupling matrix [m] and Qu according to Eq. (1 to 3) are given in Table(3).

Table 3. The normalized coupling matrix for fourth-order.

	s	1	2	3	4	L
s	0	0.9392	0	0	0	0
1	0.9392	0	0.8221	0	0	0
2	0	0.8221	0	0.653	0	0
3	0	0	0.653	0	0.8221	0
4	0	0	0	0.8221	0	0.9392

At implementation the design of dual-mode square resonator fourth order filter by HFSS software as shown in fig.(10) after calculated physical dimensions, using Table (3) found the external coupling Qu equal to 53.22 and by using the sketch in Fig.(9) found the length of feeding line is (5.46 mm), and using Table (3) with sketch in Fig.(8) found the radius of notch (2.24 mm), after that using optimization in HFSS software then calculations the return loss (S11) and insertion loss (S21) of filter as shown in Fig.(11).

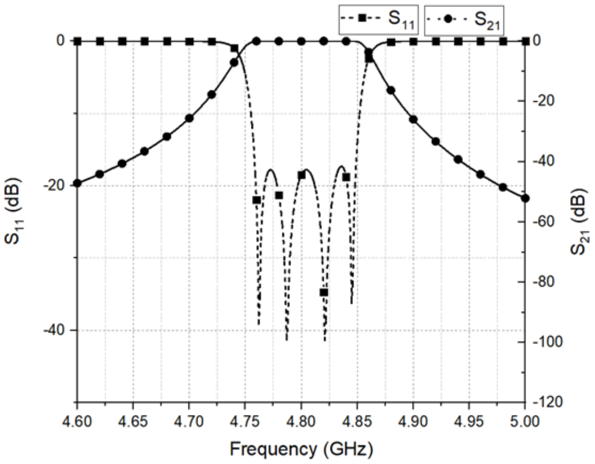

Fig.11. Frequency response for band pass filter.

As shown in Fig.(11), band width of filter is 94 MHz, insertion loss less than 0.1 dB and return loss is -17.86 dB. The design is achieve of specifications for 5G. Fig.(12) is show a change in Spurious window after implementation fourth order.

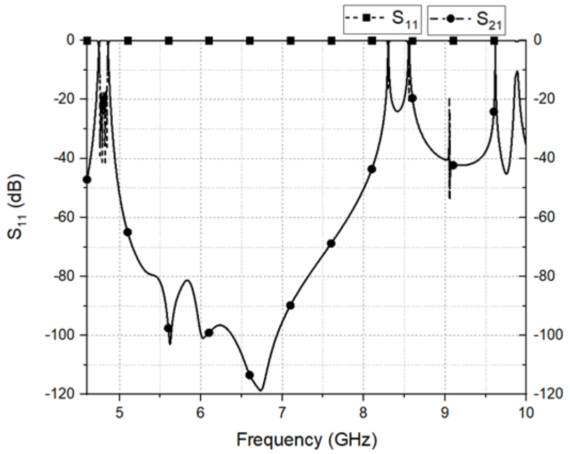

Fig.12. Frequency response for BPF illustrate Spurious window .

The Spurious window (fs/f0) as shown in fig.(12) is change from 1.844 to 1.729 after realized fourth order filter. The dual-mode fourth-order band pass filter is compared with other literatures as summarised in Table 4. It is shows that the proposed filter is competitive in terms of insertion loss and suppression.

Table 4. :Performance comparison with previous works.

Ref.	f0 (GHz)	FBW(%)	S12(dB)	order	fs/f0
[14]	2.07	2.415	0.926	4	1.8
[15]	0.67	23.8	0.38	5	2.388
[16]	26.73	3.6	0.48	2	1.188
[22]	31.7	4.5	0.9	2	2.36
[23]	6.6	16.666	0.3	2	1.89
[10]	28	1.7	0.1	3	1.5
[24]	4.1	19.75	0.7	2	1.49
[25]	4	105.17	1.8	6	2.25
[26]	6.4	4.6	1	2	1.25
[27]	2.45	4.37	0.37	2	1.79
[14]	2.07	2.415	0.926	4	1.8

Conclusions

Designing of Dual mode with centre frequency 4.8 GHz and band width 100 MHz, the design begin with Chebyshev Low pass Prototype Filter for fourth order. The posts position effect to Spurious window and quality factor of filter. The internal coupling in filter is realized by using notch at square resonator and coupling line for fourth order, and external coupling is realized by length of feeding line. For dual mode filter design a second harmonic band at frequency 8.85 GHz where this value is acceptable, and insertion loss for S11 at frequencies (4.75 GHz to 4.85 GHz) is 17.65 dB and for S21 is 0.1 dB which agreeable too.

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