Triband and Quad band Filter Design using Resonators

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Abstract— Filter plays very important role in developments of such devices. In this paper, two types of multiband filters are designed using resonators. In former one, two sets of resonators i.e., stub loaded resonator and uniform half wavelength resonator are used. In latter one, a series capacitively coupled series resonator is modified by initially widening the inner section and then adding several rectangular slots on it so that they operate at quadruple band. The resonators are arranged in such way that both the filters become compact in size. Comparison of both filters is done in the end. This paper consists of mathematical analysis & partial implementation of capacitively coupled multiband filters. The simulation is done by using IE3D electromagnetic simulator for wireless applications.

Keywords— Multiband, Miniaturization, Tri-band , Quad band , Stub loaded resonator.

I. INTRODUCTION

Now days, modern wireless communication systems needs microstrip filters having much more features such as low cost, compact size, high selectivity and low loss. Miniaturization of the filter is popular research topic now a day due to expansion of wireless communication systems. Microstrip filters operating at multiple frequencies are admired in its place of single band filters due to having several advantages such as compactness, allocations of multiple band operations.

Various techniques have been considered by authors to designing triple and quadruple band microstrip bandpass filters utilizing stepped impedance resonators, multiple resonators, open circuited stubs, short circuited stubs, ring resonator, etc [1-12]. Depending on the rapid progress in communication technologies, more than one passbands are essential, so quadruple band bandpass filters have an ever-increasing demand in recent years.

Quasi lumped stub resonator is utilized to design dual band filter with the avail of folded stub loaded stepped impedance resonators [1]. In [2], for designing of triple band filter with compressed size, meandered-line SIR is utilized in WIMAX applications with good selectivity. In [4], to design dual band filter, spur line is utilized in the structure of the filter with stub loaded resonator. Spur line fortifies to engender transmission zeros in the vicinity to the pass band edges which increases sharp roll-off rate. Several designers withal use multimode resonators for designing of multiband filters. In [5], stub loaded quad mode resonator is recommended to design dual band filter. Quad mode resonator is studied by even and eccentric mode analysis.

In this paper, two types of filters are designed, analyzed and simulated. Both filters uses resonator, former uses rectangular resonator with slots added into it and latter one consist of two sets resonators i.e., stub loaded resonator and uniform half wavelength resonator. Both the circuits are compact in size. The design methodology and simulated results is presented. Simulated and calculated results are in fine agreement.

II. TYPES OF FILTERS

A. TYPE 1

Tri band filter operating at 1.84, 2.45 and 3.05 GHz is designed. Five transmission zeros are created which results in high selectivity. The experimental filter is simulated on a substrate with a relative dielectric constant of 2.94, thickness of 0.762 mm and loss tangent of 0.0012.

1) Geometry of Filter

The triband filter shown in figure1 consists of 4 resonators. Outer resonators are stub loaded resonators while inner ones are half wavelength resonators. Interdigital structure is used for the coupling of the RF signals from resonator 2 to resonator 3 which makes circuit compact. Filter consists of T-shaped stub loaded resonator. Frequencies of operation depend upon the dimensions of the lengths of stub.

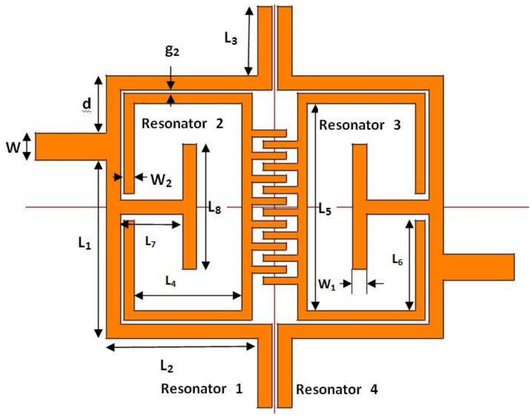

Fig 1. Geometry of triband filter

The length of the stub loaded resonator 1 and resonator 4 controls first and third resonant frequency whereas second pass band frequency depends upon resonator 2 and resonator 3. Dimensions of the filter in mm are provided in Table I.

TABLE I: DIMENSIONS OF THE DESIGNED TRIBAND BAND PASS FILTER.

Parameters	L_1	L_2	L_3	L_4	L_5	L_6
value	12.55	10.65	4.9	7.6	14.6	6.35
Parameters	L_7	L_8	L	d	W	W_1
value	4.35	8.8	49.6	4.05	1.9	1
Parameters	W_2	g_1	g_2	L_c	W_c	g_c
value	0.7	0.4	0.25	2.4	0.5	0.3

2) DESIGN METHODOLOGY

- Analysis of stub loaded resonator

The T-shaped stub loaded resonator configuration is symmetrical in nature so even and odd mode study of the filter is done. Plane A-A' splits the resonator in an equipollent way. The configuration of T-shaped stub loaded resonator is shown in Fig. 2(a).

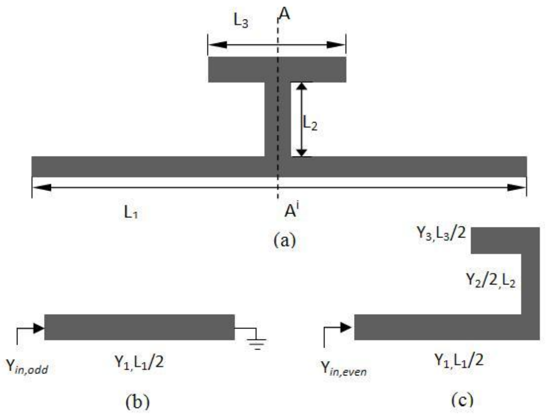

Fig. 2. (a)Configuration of stub loaded resonator. (b) Odd mode equivalent circuit. (c) Even mode equivalent circuit

- **Odd mode analysis**

Form odd mode equipollent circuit of stub loaded resonator shown in Fig 3(b), the input admittance is given by equation (1),

$$Y_{in,odd} = \frac{Y_1}{j\tan(\theta_1/2)} \qquad (1)$$

Where, $\theta = \beta L$, electric length of resonator

The resonance condition is, $Y_{in,odd} = 0$. Hence the fundamental frequency for odd mode resonance is given by equation (2),

$$f_{odd} = \frac{(2n-1)c}{2L_1\sqrt{\varepsilon_{eff}}} \qquad (2)$$

- Even mode analysis

Form even mode equivalent circuit of stub loaded resonator shown in figure 3(c), the input admittance is given by equation (3),

$$Y_{in,even} = \frac{jY_1\left(\frac{2Y_1\tan(\theta_1/2)+Y_2\tan\theta_2}{2Y_1-Y_2\tan(\theta_1/2)\tan\theta_2}\right) + Y_3\tan(\theta_3/2)}{1 - j\left(\frac{2Y_1\tan(\theta_1/2)+Y_2\tan\theta_2}{2Y_1-Y_2\tan(\theta_2/2)\tan\theta_2}\right)Y_1Y_3\tan(\theta_3/2)}$$

Where, $\theta = \beta L$, electric length of resonator

The resonance condition is, $Y_{in,even} = 0$. Hence the fundamental resonant frequency for odd mode resonance is given by equation (4),

$$f_{even} = \frac{nc}{(L_1 + 2L_2 + L_3)\sqrt{\varepsilon_{eff}}} \qquad (4)$$

Equation no.1 and 2 represents fundamental resonant frequencies for even and odd mode respectively. The odd mode frequency does not depend upon length of the stub.

B. Type2

1) Geometry of filter

A series capacitively coupled resonator is modified by initially widening the inner section and then adding several rectangular slots on it so that they operate at triple and quadruple bands. For the control of resonant frequencies of the filter and for miniaturization of size of the filter, slots are added to it. Dimensions of the slots control the resonant frequencies

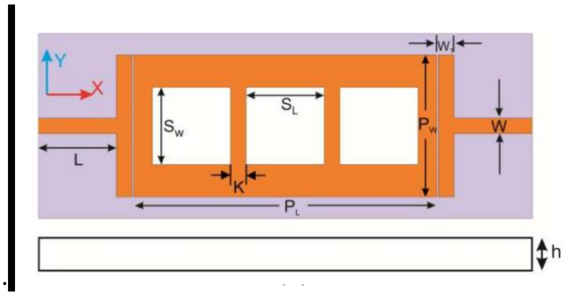

Fig 3.Geometry of designed 3 slot quad band filter

The filter is planner in structure shown in Fig. 3. P_l and P_w Signifies the length and width of the rectangular resonator and length and width of the rectangular slots added into it is given by S_l and S_w. A slight capacitive slit is kept between the feed line and resonator section for coupling of RF signals. T-shaped configuration is used for providing electromagnetic energy to the inner resonator section. The dimensions of the filter in mm are given in following Table II.

TABLE II : DIMENSIONS OF THE DESIGNED FOUR SLOT BAND PASS FILTER.

Parameter	P_l	P_w	**L**	**W**	**K**	S_l, S_w
3 Slot filter	19.2	9.2	5	1	1	5.0,5.0

Adding of slots leads to miniaturization of the filter. The filter having dielectric constant of, ε_r = 10.5 and thickness 1.25 mm is used. High dielectric constant is chosen so that filters does not radiate.

2) Design methodology

- **Effective dielectric constant**

Effective dielectric constant's frequency dependant expression can be given by equation (8),

$$\varepsilon_{reff}(f)\ \ \varepsilon r - \left[\frac{\varepsilon_r - \varepsilon_{reff}(0)}{1+P(f)}\right] \quad (8)$$

$$\varepsilon_{reff}(0) = \left\{\frac{\varepsilon_r+1}{2}\left[1-\frac{1}{2H}\left(\frac{\varepsilon_r-1}{\varepsilon_r+1}\right)\left(\left(\ln\frac{\pi}{2}+\frac{1}{\varepsilon_r}\ln\frac{4}{\pi}\right)\right)\right]-\right.$$

^{2} , wh< *1.3*

$$H = \ln\left(\frac{4h}{w} + \sqrt{16\left(\frac{h}{w}\right)^2 + 2}\right)$$

$$P(f) = P1P2[(0.1844 + P3P4)10f\,h]^{1.5763}$$

$$P1 = 0.27488 + \left[0.6315 + \frac{0.525}{(1+0.157\,fh)^{20}}\right]\frac{w}{h} - 0.065683\exp\left(-8.7513\frac{w}{h}\right)$$

$$P2 = 0.33622[1-\exp(-0.0344\,\varepsilon_r)]$$

$$P3 = 0.0363\exp\left(-4.6\frac{w}{h}\right)\left\{1-\exp\left[-\left(\frac{fh}{3.87}\right)^{4.97}\right]\right\}$$

$$P4 = 1 + 2.751\left\{1-\exp\left[-\left(\frac{\varepsilon_r}{15.916}\right)^{8}\right]\right\}$$

- **Width of microstrip patch**

Using above terms, Examination of deviation of width of microstrip patch is done. For 9mm width of the microstrip line, it is noticed that as the value of ε_{reff} varies from 10 to 10.5 which is equals toε_r frequency changes from 1 GHz to 10 GHz. Calculated values are given in following Table III,

TABLE III : ANALYSIS OF VARIATION OF WIDTH OF MICROSTRIP PATCH..

W=1, f=10GHz	**W=1mm,f=1GHz**
ε_{reff} =8	ε_{reff} =10.2
W=9mm,f=10GHz	**W=9mm,f=1GHz**
ε_{reff} = 10	ε_{reff} = 10.5

From analysis, the width of the microstrip patch is selected as 9 mm so that the calculations become easier.

- **Length and width calculations**

Rogers RT/Duroid 6010.5 substrate is used having ε_r= 10.5 and thickness 1.25 mm (h=1.25 mm) to design and fabricate the filters and f_r = 2.41GHz.

Width of the microstrip patch can be given by,

$$W = \frac{1}{2f_{r\sqrt{\mu_0\epsilon_0}}}\sqrt{\frac{2}{\varepsilon_r+1}} = 26\text{ mm} \quad (9)$$

Extended incremental length of patch,

$$\frac{\Delta L}{h} = \frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.3\right)} = 0.5295\text{ mm.} \quad (10)$$

Actual length of the patch,

$$L = \lambda/2 - 2\Delta L \quad (11)$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L = 19.2\text{ mm.}$$

- **Frequencies calculations**

A generalized expression for the normalized frequency in terms of normalized length of the slot can thus be given by Equation (12),

$$\left(\frac{f}{f_0}\right)_n = \psi_n + \sum_{n,m}\zeta_{n,m}\sin\left(\theta_n.n\pi\frac{S_L}{P_L}\right) + \sum_{n,m}\xi_{n,m}\cos\left(\theta_n.n\pi\frac{S_L}{P_L}\right) \quad (12)$$

From the generalized equation, the first resonant frequencies of 4 slot filter can be given by,

$$\left(\frac{f}{f_0}\right)_1 = \psi_1 + \zeta_{1,1}\sin\left(\pi\frac{S_L}{P_L}\right) \quad (13)$$

$$\mathbf{f_1 = 2.34\ GHz}$$

Where,

$$\psi_1 = 0.00196(1-\exp(S_w/2)) + 1$$

$$\zeta_{1,1} = -0.02146(S_w)^{1.5}$$

From the generalized equation, the second resonant frequencies of 4 slot filter can be given by,

$$\left(\frac{f}{f_0}\right)_2 = \psi_2 + \zeta_{2,1}\sin\left(2\pi\frac{S_L}{P_L}\right) + \xi_{2,1}\cos\left(2\pi\frac{S_L}{P_L}\right) \quad (14)$$

Where,

$$\psi_2 = 0.0002137\exp(S_w/2) + 1$$

$$\zeta_{2,1} = 0.001523(S_w)^2$$

$$\xi_{2,1} = -0.0003646S_W{}^{2.5}$$

$$\mathbf{f_2 = 3.85\ GHz}$$

From the generalized equation, the third resonant frequencies of 4 slot filter can be given by,

$$\left(\frac{f}{f_0}\right)_3 = \psi_3 + \zeta_{3,1}\sin\left(\theta_3 3\pi\frac{S_L}{P_L}\right) + \xi_{3,1}\cos\left(\theta_3 3\pi\frac{S_L}{P_L}\right) \quad (15)$$

Where,

$$\psi_3 = 0.0006119(1-\exp(S_w/2)) + 1$$

$$\zeta_{3,1} = 0.003115(S_w)^{1.45}$$

$$\xi_{3,1} = -0.001151S_W{}^{2.17}$$

$$\theta_3 = -0.03354(S_W/P_W)^{-1} + 0.6816$$

$$f_3 = 6.9\ \mathrm{GHz}$$

Similarly,

$$f_3 = 9.32\ \mathrm{GHz}$$

III. SIMULATION RESULTS

The simulated results of both the design are given in following Fig 4 and Fig 5. From the results of type 1 filter shown in Fig 4, the tri band filter's (Type1) pass band frequencies are centered at 1.84, 2.45 and 3.05 GHz having 3dB bandwidths of 131.06, 136.04 and 254.26 MHz respectively. Return loss of the filter is greater than 20 dB each frequencies and insertion loss for three frequencies are -1, -1.3 and -0.64 dB respectively. In addition to this five transmission zeroes are created at 1.63, 2.02, 2.34, 2.62 and 3.4 GHz which are close to the pass band edges which improves selectivity of the filter.

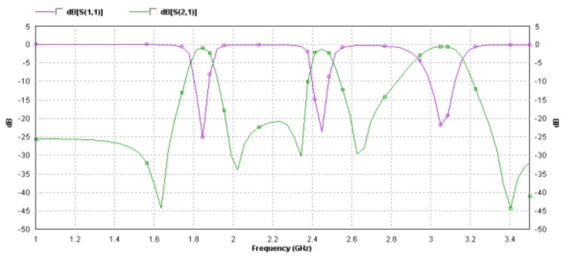

Figure 4.Simulation results of designed triband filter (Type 1)

From the results of type 2 filter shown in Fig 4, the quad band filter has a good pass band performance at 2.34, 3.85, 6.9 and 9.32GHz having 3dB bandwidths of 167.1, 251.63, 285.71 and 296.1 MHz respectively. Return loss of the filter is nearby 10dB at each frequency.

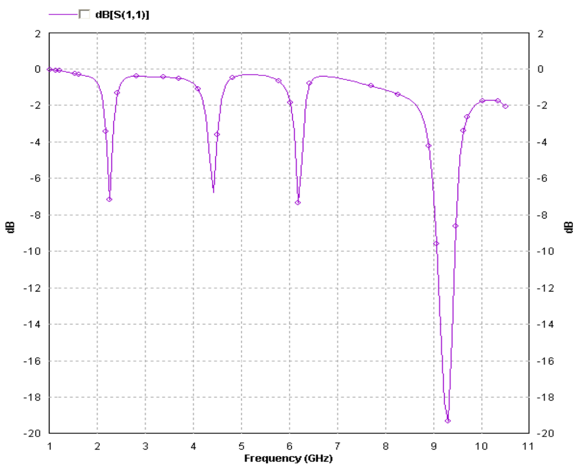

Fig 5. Simulation results of designed quadband filter (Type 2)

From analysis, Simulation results and theoretical results are in good agreement. In consideration with the return and insertion losses, type 1 filter gives better results. The results of the type 1 filter also provide transmission zeroes owing to high selectivity. Hence can be applicable in WIMAX and DCS systems.

IV. CONCLUSION

In this paper, two techniques are discussed for designing triband and quad band filters using resonators. Type 1 is a tri band filter is designed to provide three passbands centered at 1.84, 2.45 and 3.05 GHz. Five transmission zeros are created which results in high selectivity. Type 2 is a four slot quad band filter operating at 2.34, 3.85, 6.9 and 9.32GHz. From simulation results, type 1 filter is superior than type 2 filter since it includes five transmission zeroes at 1.63, 2.02, 4.65, 6.82 and 8.59 GHz near the pass band edges. Both the filters are having compact size, planner in structure, high selectivity, sufficient out of band rejection and multiband operation applicable for WIMAX system. Theoretical predictions are demonstrated by the experimental results of two multiband filters.

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