A Comparative Study between Half-Wavelength and Stepped Impedance Resonator based Microstrip Band-Pass Filters

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Abstract: In this paper an attempt is made to compare the electrical performance of two microstrip band-pass filters (BPF) designed using half-wavelength (λ/2) resonator and stepped impedance resonator (SIR). Coupled resonator based design methodology is adopted to design the two BPFs. The BPFs have a fractional bandwidth of around 1.9 % at 4.195 GHz. The comparative study from simulated results show that the BPF based on λ/2 resonator provides better insertion loss than the one based on SIR. On the other hand SIR based BPF provides better spurious signal rejection and in-addition to miniaturization.

Keywords: Band-pass filter, half-wavelength resonator, stepped impedance resonator, HFSS, CST.

Introduction

The rapidly advancing technology has resulted in increased dependency on wireless communication for various applications like cellular communication, radio and television broadcast and navigation. Furthermore, microstrip technology has played a significant role in realizing the wireless communication components accessible to wider spectrum of users especially for short range communication applications like Wi-Fi, Bluetooth.

As is well known microwave band-pass filters (BPF) are vital components both at transmitter as well as at receiver. At transmitter one of their primary functions is to reject spurious at harmonics following modulation or amplification. While at receiver pre-select filters rejecting image frequency become a vital component. Fig. 1 shows a typical block diagram of a wireless transmitter depicting utility of BPFs. The primary requirement of such a BPF is that it should have low insertion loss (IL) and high selectivity. To fulfill these requirements and to minimize the form factor, microstrip BPFs using Chebyshev approximation are designed in this paper using references [1-7].

Two microstrip BPFs are designed, one with half-wavelength (λ/2) resonator and the other with stepped impedance resonator (SIR). Both the filters are designed using well known parallel edge coupling using reference [2]. The BPFs are designed at 4.195 GHz with a fractional bandwidth of 1.9 % using Rogers RT/Duroid 5880 substrate (dielectric constant of 2.2, loss tangent of 0.0009, 20 mils thick). The BPFs are designed and simulated using HFSS and CST EM tools [8, 9].

The paper is organized as follows. Section II describes the design of BPFs. Comparison between the two BPFs is presented in Section III with conclusion in section IV.

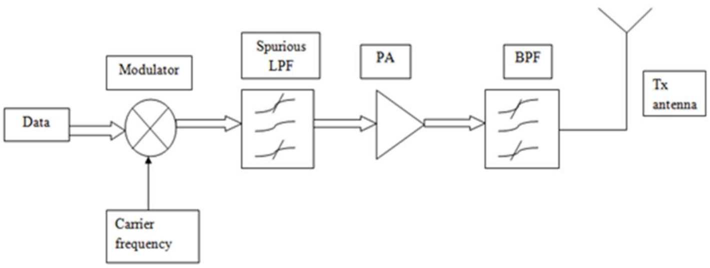
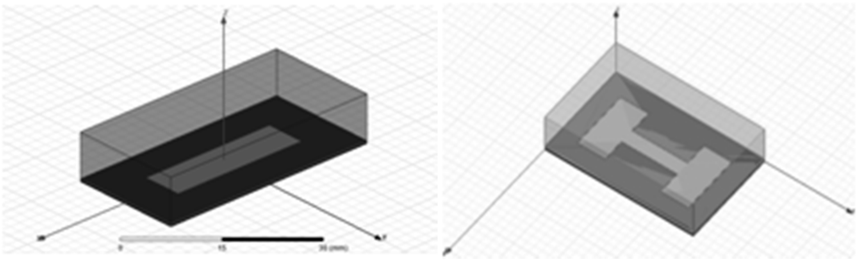


Figure 1. Block diagram of typical transmitter

Microstrip BPF

Coupled resonator based design methodology is adopted to design the two BPFs as used in reference [2]. Fig. 2 depicts the resonator types used in the designing the BPFs. Inter-resonator coupling is realized using inter-resonator gap along the resonators. This results in relatively strong coupling for a given inter-resonator spacing thus minimizing the effect of fabrication tolerance (and cost). In-addition it also results in compactness. Whereas tap feeding is used to realize the input-output coupling.



(a) (b)

Figure 2. Resonators used in designing BPF (a) λ/2 resonator (b) SIR

λ/2 resonator based BPF

The resonator width is chosen as 5 mm to maximize the Quality (Q) factor, which is found to be 275 at 4.195 GHz using HFSS [8]. A 3rd order BPF is realized using three such resonators which are gap coupled and a 50 Ω transmission line is tap-fed to the resonators at the input and output (I/O). The BPF is optimized using CST MWS whose schematic is depicted in Fig. 3. The optimized BPF design based on λ/2 resonators has the dimensions as shown in Table 1.

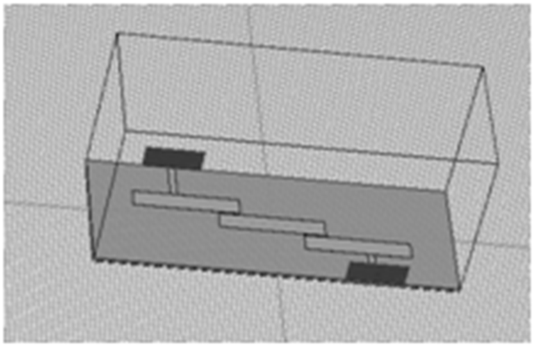


Figure 3. Edge-coupled BPF design based on λ/2 resonators in CST MWS

Table 1: Optimized BPF design based on λ/2 resonators

Dimension	Value (mm)
Substrate Length	83.1
Substrate Width	35.84
Substrate Height	0.508
Copper Thickness	0.036
Resonator Width	5
Resonator-1 Length	24.38
Resonator-2 Length	24.26
Resonator-3 Length	24.38
Inter-Resonator Spacing	0.42
Inter-Resonator Overlap	4.96
50 Ω line Width	1.56
50 Ω line Length	10
Tap feed position	8.56

SIR based BPF

SIR being a symmetric structure can be analyzed with half the structure as depicted in Fig. 4.

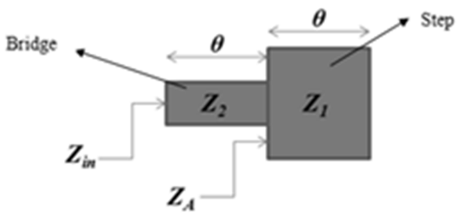


Figure 4. Symmetric Structure of SIR

The impedances Z_A and Z_{in} are given by equations (1) and (2).

$$Z_A = -jZ_1\cot\theta \quad (1)$$

$$Z_{in} = Z_2 *(Z_A + jZ_2\tan\theta) / (Z_2 + jZ_A\tan\theta) \quad (2)$$

where θ is the electrical length, Z_A and Z_{in} are input impedances and Z_1 and Z_2 are the characteristic impedances of step and bridge of SIR. The solutions are obtained for the electrical length (θ) by considering the cases of $Z_{in} = 0$ (short) and $Z_{in} = \infty$ (open) at the center of resonator.

$$k*f_1 = \theta_1 = \tan^{-1} (\mathrm{sqrt}(Z_1/Z_2)) \quad (3)$$

$$k*f_2 = \theta_2 = \pi / 2 \quad (4)$$

$$k*f_3 = \theta_3 = \pi - \tan^{-1}(\mathrm{sqrt}(Z_1/Z_2)) \quad (5)$$

where k is a constant given by equation (6).

$$k = ((2*\pi*l)/v_p) \quad (6)$$

It is observed from equation (3) that by varying the ratio between Z_1 and Z_2, required f_2/f_1 ratio can be obtained. This variation is shown is Fig. 5.

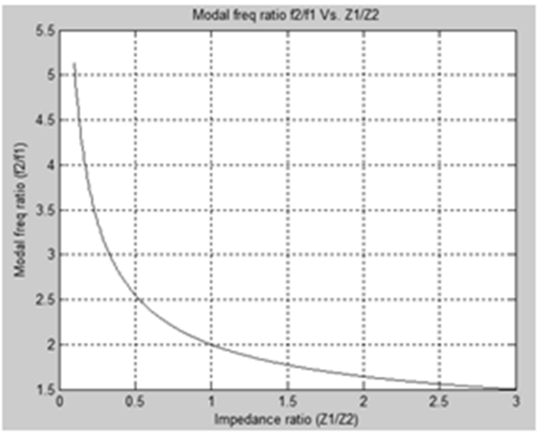


Figure 5. Modal Frequency ratio f_2/f_1 V/s Z_1/Z_2

For given f_1 of 4.195 GHz and f_2 of 12 GHz, the SIR is designed using HFSS and it has a step width of 7.74 mm and bridge width of 1.9 mm with lengths of 3.7 mm each. The microstrip BPF based on SIR is constructed using three gap coupled SIRs and its I/O has a tap-fed 50 Ω transmission line. The BPF is then iteratively optimized using CST MWS whose design is as shown in Fig. 6. The optimized BPF design based on SIRs has the dimensions as shown in Table 2.

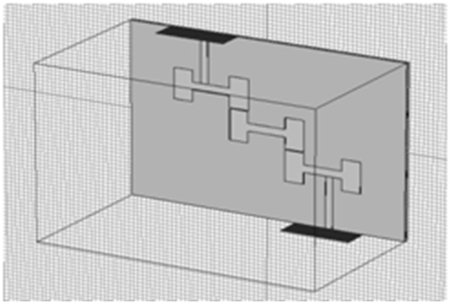


Figure 6. Edge-coupled BPF design based on SIR in CST MWS

Table 2: Optimized BPF design based on SIRs

Dimension	Value (mm)
Substrate Height	0.508
Copper Thickness	0.036
SIR Step Width	7.74
SIR Bridge Width	1.9
Resonator-1 Length	15.1
Resonator-2 Length	14.844
Resonator-3 Length	15.1
Inter-Resonator Spacing	0.202
Inter-Resonator Overlap	4.505
50 Ω line Width	1.56
50 Ω line Length	10
Tap feed position from bridge	1.598

Simulation Results with Comparison

To evaluate the efficiency of each of the two BPFs, they are compared based on electrical and physical parameters. The frequency responses obtained from the BPFs are compared using three frequency bands as shown in Fig.7 to Fig.12. The first frequency band ranges from 4.1 GHz to 4.3 GHz and is named narrow span. The second frequency band called the medium span ranges from 3.6 GHz to 4.7 GHz. The third frequency band called wider span ranges from 0 GHz to 12 GHz.

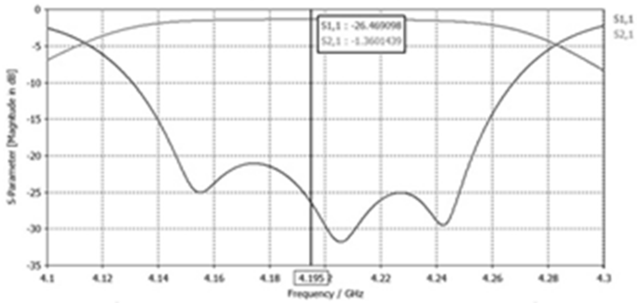


Figure 7. CST simulated result over narrow span of λ/2 resonator based BPF

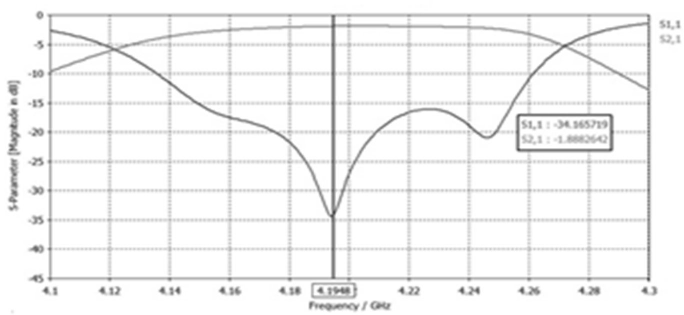


Figure 8. CST simulated result over narrow span of SIR based BPF

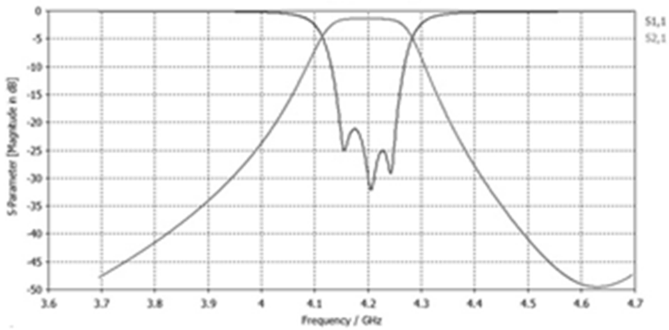


Figure 9. CST simulated result over medium span of λ/2 resonator based BPF

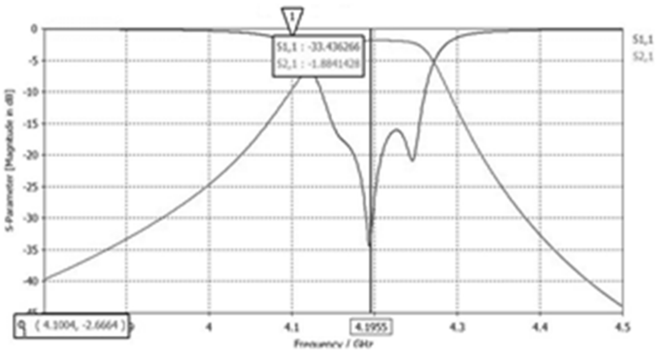


Figure 10. CST simulated result over medium span of SIR based BPF

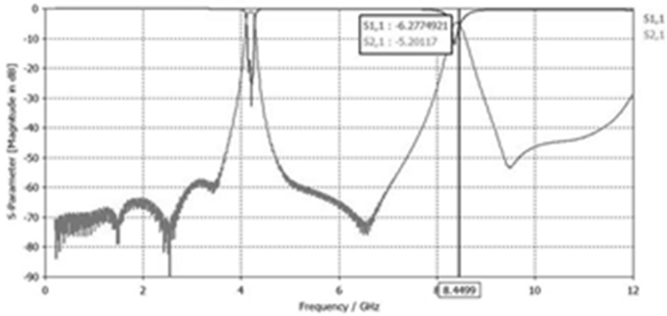


Figure 11. CST simulated result over wider span of λ/2 resonator based BPF

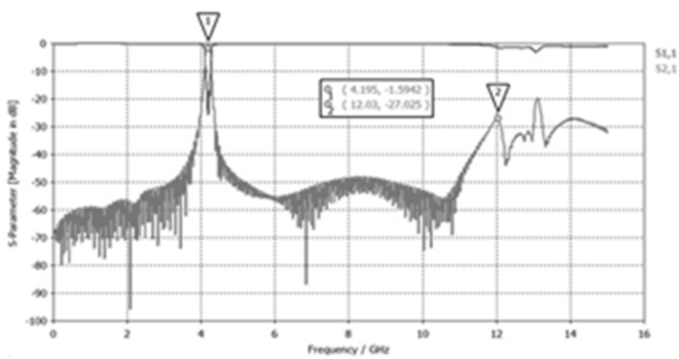


Figure 12. CST simulated result over wider span of SIR based BPF

Table 3 shows the comparative study between the microstrip BPFs using λ/2 resonator and SIR, based on electrical and physical parameters.

Table 3: BPFs Comparative Study

Parameter	BPF based on λ/2 resonators	BPF based on SIRs
Center frequency	4.198 GHz	4.202 GHz
Insertion Loss	-1.36 dB over 80 MHz BW	-2.188 dB over 80 MHz BW
Return Loss	21.05 dB over 80 MHz BW	15.933 dB over 80 MHz BW
Size	(83.1x35.84x0.58) mm^3	(83.1x35.84x0.58) mm^3
Resonator Q-factor	275.827	257.175
Stop-band Rejection level @ 3.845 GHz	-38.5714 dB	-37.45 dB
Stop-band Rejection level @ 4.545 GHz	-45.7692 dB	-45.68 dB
Spurious Signal Rejection	8.434 GHz	12.03 GHz

Conclusion

The two microstrip BPFs based on parallel edge-coupled resonator technique using λ/2 resonators and SIRs have been designed and simulated for a given filter specifications using HFSS and CST. It is observed that the BPF based on λ/2 resonator has better insertion losses rather than BPF based on SIR, which on the other hand yields better spurious signal rejection and smaller in size. The BPF using λ/2 resonator can be realized using hair-pin resonator to further minimize the size. Furthermore, the BPF using SIR can offer dual-band resonance by changing the SIR dimensions to match the dual-band frequencies.

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