The Eurasia Proceedings of Science, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2018

Volume 2, Pages 186-191

ICRES 2018: International Conference on Research in Education and Science

Compact Wideband Lowpass Filter Based on Inverted Cascading Stubs

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Abstract: In this study, a new compact wideband lowpass filter was introduced. The proposed filter is developed by cascading two shapes of ‘4’ open stubs back to back embedded on a microstrip line. This structure results in wide cutoff frequency and rejection band with improved scattering parameters. The filter utilized operating bands up to 4 GHz. Many useful wireless communication bands were allocated within this band, global system for mobile communications (GSM) bands (1.8, 1.9 and 2.1 GHz) and 2.4 GHz which is used for industrial, scientific and medical (ISM) band and wireless local area networks (WLANs) applications.The designed filter also covers the band 3.5 GHz widely used for worldwide interoperability for microwave access (WiMAX) applications. The frequency response of the filter shows good stopband characteristic and provides -3 dB cutoff frequency at 3.85 GHz. The return loss of the designed filter is -50.8 dB at 3GHz and the insertion loss is less than -0.18 dB along the passband. The proposed filter has been designed, analyzed, and optimized on a substrate with 10.8 dielectric constant and thickness of 1.27 mm using full wave Electromagnetic Simulator. The proposed filter is a compact size and the final optimized dimension of the simulated filter with the above features is only 20 mm ×15mm.

Keywords: Microstrip, Lowpass filter, WLAN applications, WiMAX, Wideband filter

Introduction

Microstrip filters are highly used in microwave systems due to their small size, easy of fabrication, low cost and light weight. Miniaturization in industry of mobile communication systems, motivate the researchers in continuing their filter design contributions with compact size that can be fitted easily inside the mobile phone. They try to design a simple microstrip miniaturized filter with sharp cut-off frequency and good attenuation characteristics that’s needed in modern communication systems applications (Hong and Lancaster, 2001; Solanki and Sharma, 2015).

Mixers and oscillators are commonly use lowpass filters to suppress harmonics, noise and other undesired signals that exist in their operations. A novel small size microstrip LPF with a sharp edge passband and high attenuation within stop-band are proposed and presented in literature. In (Mohsen, Zahra F, and Mozhgan, 2014), LPF was designed by combining the star-shaped resonator with the half ring-shaped stubs, this leads to a compact circuit size with sharp edge transition band. (Challal, Azrar and Vanhoenacker, 2012) proposed a wide stopband microstrip LPF based on quasi-triangular defected ground structure (DGS). This structure enhance the rejection of higher spurious and harmonics that is used in wideband applications. (Kim and Yun, 2005) use asymmetrical stepped microstrip structures to design LPF with good harmonic suppression. (Zakaria, Mutalib, Mohamad and Zainuddin, 2013) proposed a defected stripline structure to demonstrate a notch in bandpass filter constructed from the integration of lowpass and highpass filter. This notch was used to remove the undesired signals in the filter characteristics. (Seghier, Benabdallah, Benahmed, and Nouri, 2016) designed a composite microstrip bandpass filter with new techniques. The design utilized high-pass and low-pass structure embedding individually into each other. This technique was proposed to be used for ultra-wideband wireless communications. Optimization was used for tuning the passband performance of the proposed filter. The filter

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shows UWB characteristics with a good s-parameters in the range of 3GHz to 10GHz as well as sharpness rejection characteristics performance. A compact and wide stopband lowpass filter is presented in (Karthikeyan and Kshetrimayum, 2015). Two cascaded stages of open complementary split ring resonator (OCSRR) were used in the constructing of the LPF. DGS section using a shape of tapered dumbbell was placed under the resonators for the purpose of bandwidth enhancement. The rejection bandwidth covers the entire UWB spectrum.

Step impedance method with linear alternative too high or too low part characteristic impedance was used to design less complexity LPF. Good filter response characteristics can be achieved by changing length or width of the designed impedances. The lowpass filter is usually implemented either by series connected high-low stepped-impedance sections or by series-shunt stubs microstrip line sections. Microstrip is an easy method to design LPFs by alternating high impedance and low impedance sections of microstrip lines. Stepped impedance LPFs filters are popular because they are easier to design and take up less space than a similar lowpass filter using stubs (Omid and Arman, 2012; Garvansh and Arun, 2014; Shilpi. Pooja and Prasad, 2014; Abdel-Rahman, Verma, Boutejdar and Omar, 2004; Mathaei, Young and Jones, 1980; Niharika and Pankaj, 2012; Liew, Syed, Mohd, Yufridin and Lee, 2015; Packiaraja, Vinoyb, Ramesha and Kalghatgi, 2011).

In this paper, a wideband LPF using two inverted "4" shapes resonators of microstrip stubs of high-low impedances is presented. The resonators designed using high-low impedance sections transformed from lumped elements ladder LPF. A review of design technique to convert a lumped element LPF prototype into microstrip line circuits is presented. The design and synthesis of the proposed LPF has been presented. Substrate with dielectric constant 10.8 and thickness of 1.27 mm at 3.85GHz cut-off frequency have been used. The results of the optimized filter were obtained through full wave Electromagnetic Simulator.

Lumped Elements Lpf Design Review

The proposed LPF filter specifications are to pass 4 GHz frequency band with attenuation not less than -15 dB at 6 GHz and 3.85 GHz cut-off frequency. According to tables given in (Pozar, 2012), fourth order filter with maximally flat response will achieves the desired requirements of prototype LPF. The forth order values of these elements are: go= g5=1, g1=g4=0.7654, g2=g3=1.8478.

The lumped values of the LPF can be calculated from:

$$C_i = \frac{g_i}{Z_o \omega_c} \qquad (1)$$

$$L_i = \frac{Z_o g_i}{\omega_c} \qquad (2)$$

The circuit of maximally flat fourth order LPF is given in Fig.1 and the Lumped values after frequency and impedance scaling are given as: C_1=0.63281 PF, L_2=3.81972 nH, C_3=1.52789 PF, L_4=1.58204 nH.

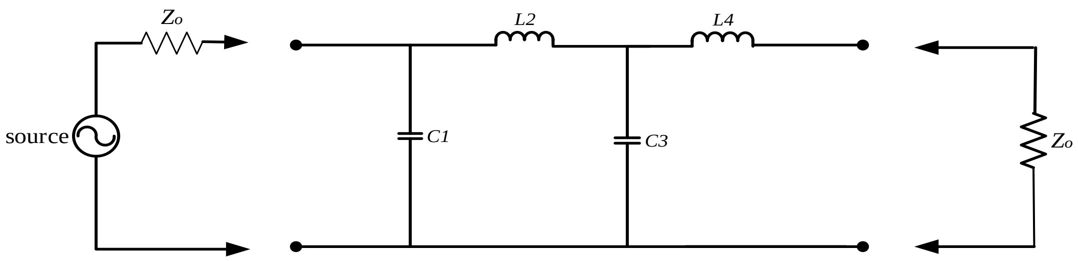

Figure 1. Maximally flat fourth order LPF equivalent circuit

The corresponding frequency and phase response are shown in Fig.2. It is clearly shown that the response is maximally flat with cut-off frequency at 3.85 GHz and stop frequency at 6 GHz with (-15) dB attenuation.

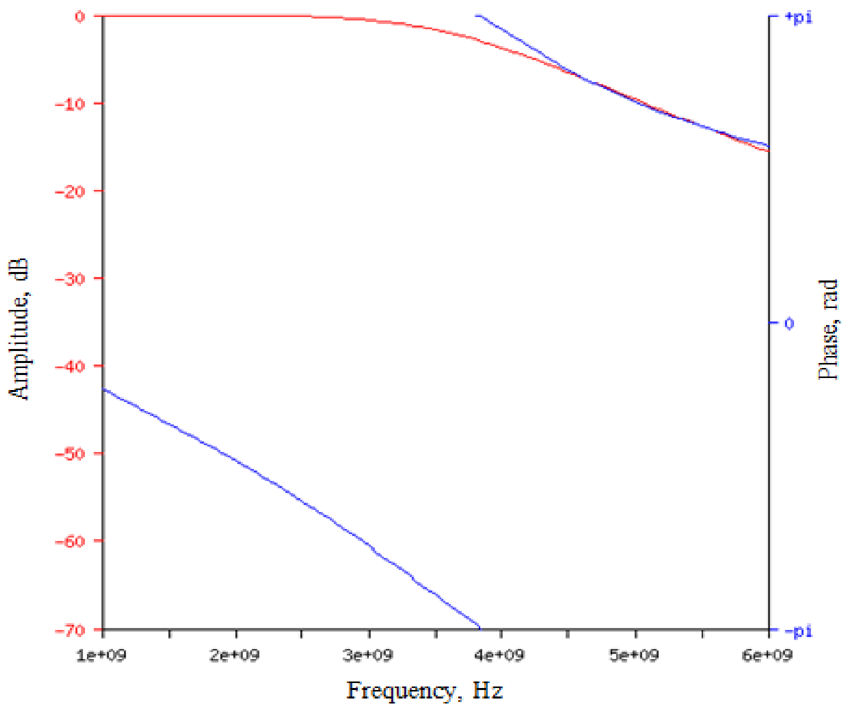

Figure 2. Frequency and phase responses of maximally flat of order N=4.

Distributed Model of the Proposed 4th Order LPF

The conversion of lumped element LPF to distributed microstrip model is done using low-high impedance transformation sections. The low impedance shunt stub will act as shunt capacitor and the high impedance series stub will act as series inductances. The source and load will terminated by 50 Ω impedances. The design and synthesis of the microstrip LPF with series-shunt stubs microstrip sections is achieved on substrate of 10.8 dielectric constant and 1.27 mm thickness. The highest characteristic impedance is assumed to be Z_{high}=70 Ω and the lowest impedance is Z_{low}=52.5 Ω. The corresponding width of the shunt and series stubs are W_C=1 mm and W_L=0.5 mm respectively and the width of the input/output of 50 ohm port sections is W_F=1.1 mm. The initial guess of electrical length of series and shunt stubs can be calculated by:

$$\ell_{ci} = \frac{\lambda_{gc}}{2\pi} \sin^{-1}(2\pi f_c Z_{low} C_i) \qquad for\, i = 1,3 \tag{3}$$

$$\ell_{li} = \frac{\lambda_{gl}}{2\pi} \tan^{-1}\left(2\pi f_c \frac{L_i}{Z_{high}}\right) \qquad for\, i = 2,4 \tag{4}$$

$$\lambda_g = \frac{c}{f_r \sqrt{\varepsilon_{eff}}} \tag{5}$$

Where c is the speed of light in free space, f_r is the resonance frequency and ε_{eff} is the effective dielectric constant given by:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\left(1 + 12\frac{h}{w}\right)^{-0.5} + 0.04\left(1 - \frac{w}{h}\right)^2\right] \tag{6}$$

Where h is the substrate thickness and w is the width of microstrip section. Using equations (3)-(6), and using f_r=f_c, then the initial guess of stubs length are:

$$\ell_{c1} = 3.7\,mm, \ell_{c3} = 4.9\ mm, \ell_{l2} = 4.2\,mm, \ell_{l4} = 2.4\,mm$$

Figure 3 shows the distributed microstrip LPF model transformed from fourth order maximally flat lumped elements LPF circuit.

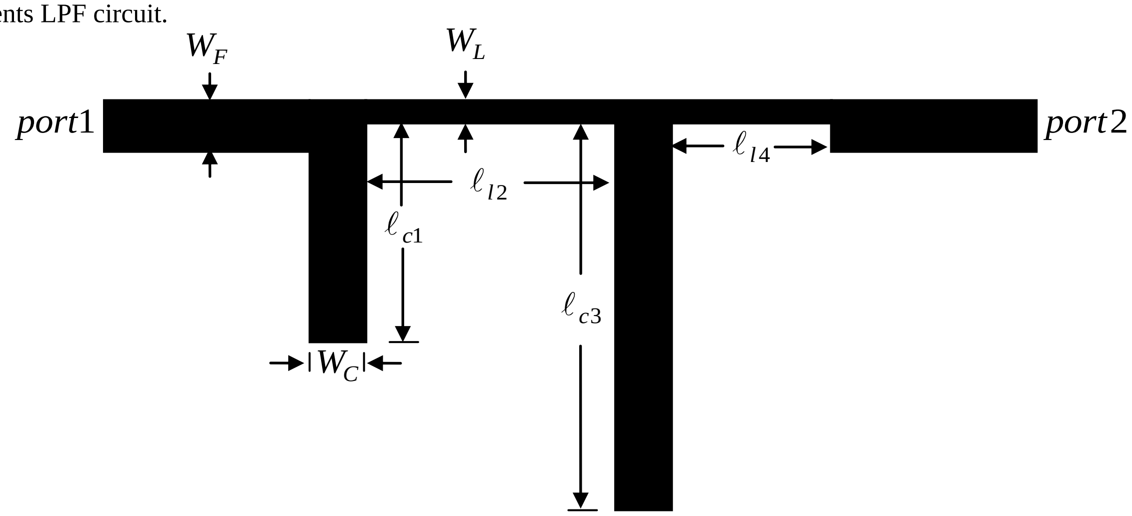

Figure 3. Filter configuration of transformed lumped elements of order N=4

The filter configuration shown in Fig.3 is analyzed using full wave Electromagnetic Simulator. Figure 4 shows the simulated frequency response of the distributed LPF model of Fig. 3. It is clearly shown that the cut-off and stop frequencies are 4.1 and 5.78 GHz respectively with 1.68 GHz transition band.

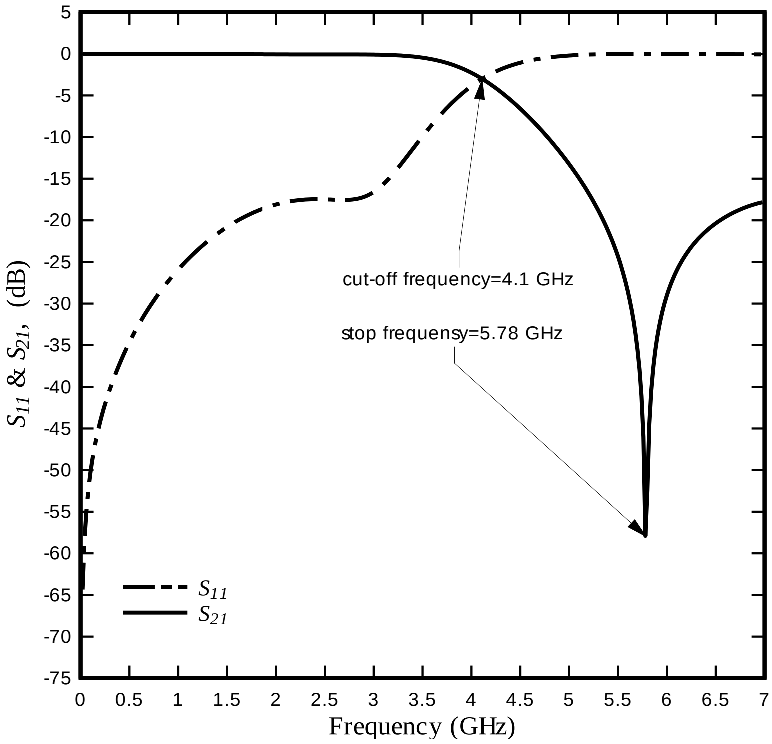

Figure 4. Frequency response of distributed microstrip LPF

Figure 4 show that the cut-off frequency of the distributed LPF transformed from lumped elements is shifted from the designed cut-off frequency 3.85 GHz to 4.1 GHz. The length of the series and shunt stubs can be optimized to tune the filter to the desired cut-off frequency.

Cascaded LPF Design and Simulation Results

To enhance the passband and stopband characteristics of the converted prototype LPF shown in Fig.3, two modified stages have been cascaded. The positions of the shunt stubs in each of the modified stage are vertically changed to form a shape of "4". One of the "4" shapes is inverted and embedded back to back with the other as shown in Fig.5.

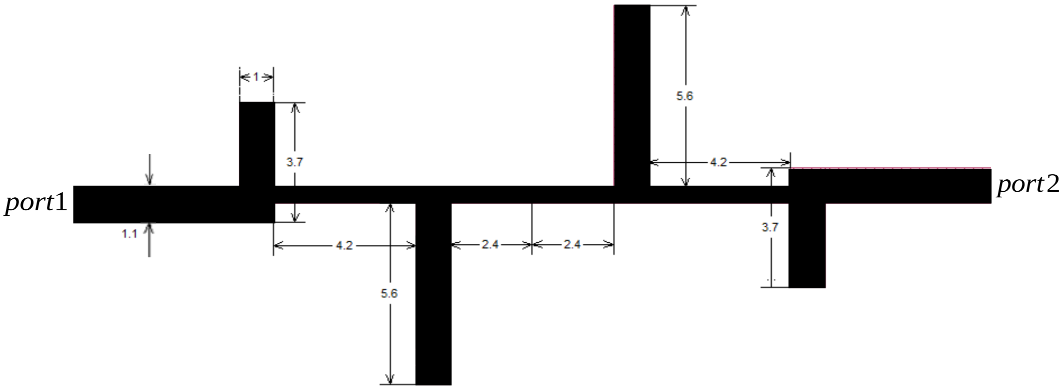

Figure 5. The proposed configuration of two stages of inverted "4" shapes LPF

The configuration of the proposed LPF presented in Fig.5 is built and simulated using full wave Electromagnetic Simulator. Figure 6 shows the simulated frequency response of the single stage and the modified two stages LPF. The proposed filter response has a Quasi-elliptical shape with sharp cut-off and small transition band. The cut-off frequency is 3.85 GHz and the stop frequency is at 4.78 GHz with attenuation -60.9dB followed by transmission zero of attenuation of -81.8 dB at 5.6 GHz.

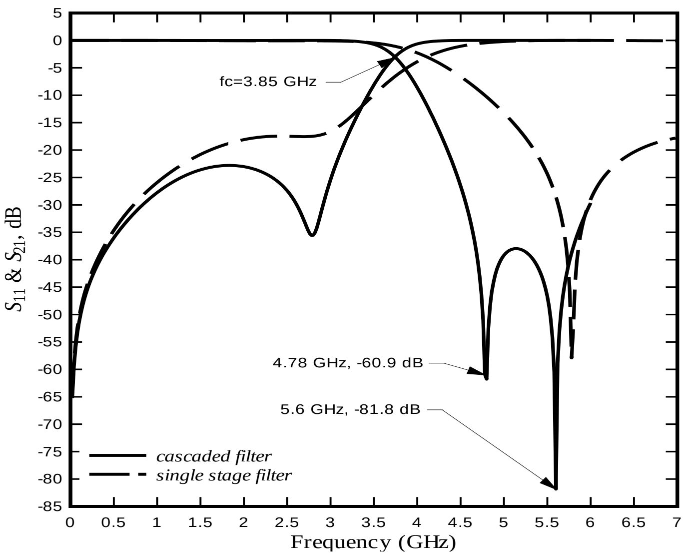

Figure 6. Frequency response of the designed LP filters: Single stage (dotted line), and cascaded two stages of inverted shapes of "4" (sold line)

Conclusion

In this paper a design procedures of fourth order lumped elements maximally flat LPF was presented. The order of the filter was selected according to the prototype LPF specifications. The transformed distributed microstrip LPF filter has small increment drift in the value of cut-off frequency, so the lengths of shunt stubs should be increased to overcome this drift. Quasi-elliptical frequency response can be achieved by cascading of two filter stages. With proper selection of shunt stubs vertical positions, optimal pass, transition, and attenuation bands characteristics can be achieved.

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