

A Compact Microstrip Lowpass Filter Possessing Sharp Roll-off and Ultra Wide Stopband

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Abstract—A novel microstrip lowpass filter possessing sharp roll-off rate and attaining ultra wide stopband is demonstrated in this article. An interdigital structure placed between the symmetric double stepped high-low impedance resonators offers enhanced transition characteristics along with the creation of finite attenuation poles in high frequency region. With the inclusion of symmetric series combination of coupled inductive stubs and tapered patch capacitors in the proposed design, miniaturized size, sharp transition characteristics from passband to stopband, minimal insertion loss in the passband and suppression of undesired harmonics. The filter has been designed, fabricated and measured successfully.

Index Terms— microstrip, lowpass filter, interdigital structure, ultra wide stopband, transmission zero.

I. INTRODUCTION

Planar compact lowpass filters are often utilized in several wireless communication applications for suppression of high frequency harmonics which usually takes place in nonlinear devices. High selectivity of the filter is attained by the creation of an attenuation pole close to the cutoff frequency and the broad stopband is achieved because of the generation of multiple transmission zeros in the region of the stopband. The design of planar lowpass filters in the conventional procedure utilizes high-low impedance resonators and open stubs [1]. However these filters suffer from two main disadvantages which are low roll-off rate and low stopband bandwidth. Increment of the number of resonators leads to enhanced stopband bandwidth of the filter, but it increases the physical dimensions of the filter.

Several methods have been proposed in the literature for design of a lowpass filter possessing compact size, minimal insertion loss in the passband, broad stopband and high selectivity [2]-[7]. A lowpass filter developed utilizing hexangular shaped resonators to attain high selectivity, compact physical size and broad stopband is demonstrated in [2]. Lowpass filter possessing compact physical size designed utilizing modified stepped impedance hairpin resonator is demonstrated in [3]. Compact lowpass filter designed utilizing coupled rhombic stubs to achieve high selectivity is presented in [4]. A lowpass filter designed utilizing symmetric dual rectangular capacitors along with coupling because of inclusion of interdigital structure to achieve miniaturization and broad stopband is presented in [5]. Symmetric loading of patch resonators and open stubs [6], cascading arrangement of triangular and funnel shaped resonant patches [7] are utilized to achieve a lowpass filter possessing high selectivity and wide suppression characteristics.

In this work, a basic lowpass filter is developed utilizing symmetric loading of double high-low stepped

impedance resonators coupled by an embedded interdigital structure. The inclusion of symmetrically paired structures in between high impedance stubs along with series combination of coupled inductive stubs and tapered patch capacitors result in a wide stopband bandwidth with compact physical dimensions. The filter is designed and fabricated utilizing FR4 substrate possessing relative permittivity of 4.4, thickness h of 0.8 mm and dielectric loss tangent of 0.02. The substrate is very cost effective. The various simulations are performed utilizing EM simulation software Advanced Design System (ADS).

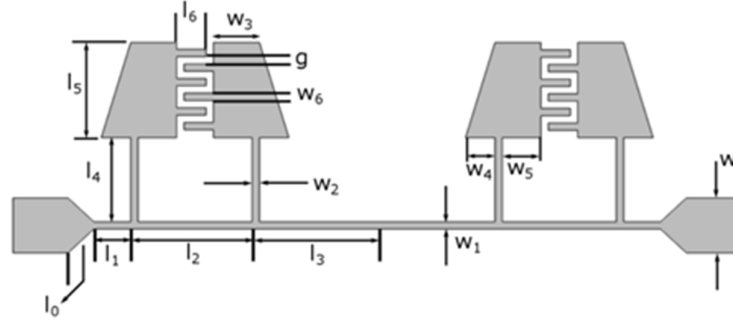


Figure 1. The structure of the basic lowpass filter design

II. FILTER DESIGN AND SIMULATED RESULTS

Fig. 1 displays the layout of the basic lowpass filter, which comprises of a symmetrical arrangement of double branch structure loaded on the primary high impedance transmission line. The symmetric branch structure comprises of a high impedance stub of length l_4 loaded with a low impedance tapered patch. The high impedance stub acts as an inductor and the low impedance patch acts as a capacitor. These symmetric tapered patches are coupled by an embedded interdigital structure. The interdigital structure is capable of providing higher capacitance and the value is dependent on the number of fingers possessing length l_6 , width w_6 and spacing g between them.

A microstrip line having width w is included to attain impedance matching with the 50 Ω SMA connector. A tapered structure having length l_0 is added between these lines possessing width w and the primary high impedance transmission line. The various dimensions of the basic lowpass filter are $l_0 = 0.955$, $l_1 = 1$, $l_2 = 3.3$, $l_3 = 3.4$, $l_4 = 2.3$, $l_5 = 2.6$, $l_6 = 0.8$, $w = 1.5$, $w_1 = 0.2$, $w_2 = 0.2$, $w_3 = 1.25$, $w_4 = 0.8$, $w_5 = 1.05$, $w_6 = 0.2$ and $g = 0.2$ (all dimensions in mm).

Fig. 2(a) displays the LC equivalent circuit of the basic lowpass filter by assuming it as a lossless circuit. In this case, Y_{01} and Y_{02} denote the characteristic admittance of the high impedance transmission line and the quadrilateral patch respectively. C_i denotes the capacitance of the interdigital structure placed in between the adjacent quadrilateral patches and C represents the capacitance of the quadrilateral patch and the ground plane. In this case of the symmetric circuit, the transmission characteristics has been derived utilizing even and odd mode analysis as demonstrated by [5] as,

$$S_{21} = \frac{Y_o - Y_e}{(1 + Y_o)(1 + Y_e)} \quad (1)$$

$$Y_o = \frac{1}{Z_o} = -jY_{01} \tan(\beta_{01}l_2) + 2jY_{01} \frac{\omega(C+2C_i) + Y_{01} \tan(\beta_{01}l_4)}{Y_{01} - \omega(C+2C_i) \tan(\beta_{01}l_4)} \quad (2)$$

$$Y_e = \frac{1}{Z_e} = jY_{01} \tan(\beta_{01}l_2) + 2jY_{01} \frac{\omega C + Y_{01} \tan(\beta_{01}l_4)}{Y_{01} - \omega C \tan(\beta_{01}l_4)} \quad (3)$$

The capacitance C is evaluated using the equation (4) as,

$$C = \frac{Y_{02} \tan(\beta_{02}l_5)}{2\pi f} \quad (4)$$

The inductance values of the narrow microstrip lines are evaluated utilizing the equation (4) for the respective values of l as,

$$L_{2,3,4} = \frac{l_{2,3,4} \beta_{01}}{2\pi f Y_{01}} \quad (5)$$

where f represents the cutoff frequency of the basic lowpass filter. β_{01} and β_{02} denote the propagation constants of the high impedance microstrip line and the low impedance quadrilateral patch respectively.

It can be noticed from (1) that when the even mode admittance and the odd mode admittance are same finite attenuation poles will be produced. The simulated reflection and transmission characteristics of the basic lowpass filter are displayed in Fig. 2(b). The basic lowpass filter has a 3 dB cutoff frequency at 3.75 GHz as per the EM simulation. The existence of the interdigital structure leads to the formation of a finite attenuation pole at 4.1 GHz, which is quite close to the cutoff frequency and therefore the selectivity of the filter is increased. The stopband bandwidth extends from 4.0 GHz to 8.6 GHz at 20 dB rejection level. The filter possesses a compact physical size of 15.4 mm×5.1 mm.

Finite attenuation poles are required to be generated at high frequency region to enhance the stopband bandwidth. The inclusion of symmetrical arrangement of paired digital stubs positioned at a distance of l_4' and l_4'' from the primary high impedance transmission line results in increment of the equivalent capacitance value. Fig. 3(a) displays the structure and Fig. 3(b) shows the enhanced roll-off rate of the modified basic lowpass filter along with the production of two transmission zeros at 14.70 GHz and 20.01 GHz.

For extension of the stopband bandwidth of the filter, mirrored coupled inductive stubs loaded with tapered quadrilateral patches are included at a distance l from the terminal of the primary high impedance transmission line.

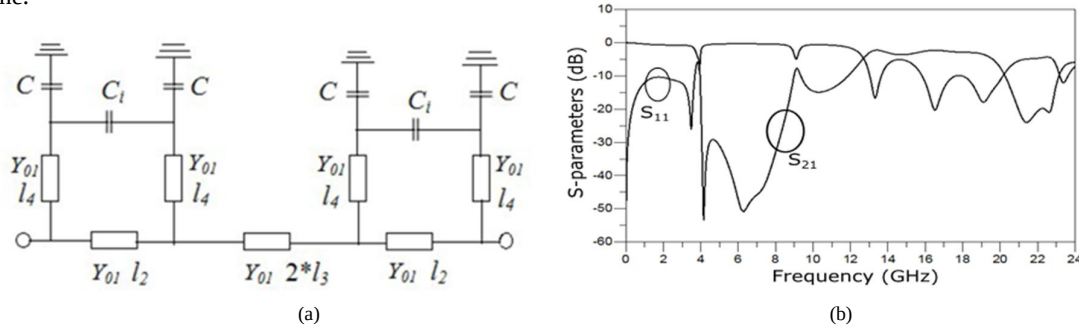


Figure 2. The basic lowpass filter: (a) Equivalent circuit model and (b) Simulated S-parameters vs. frequency response characteristics

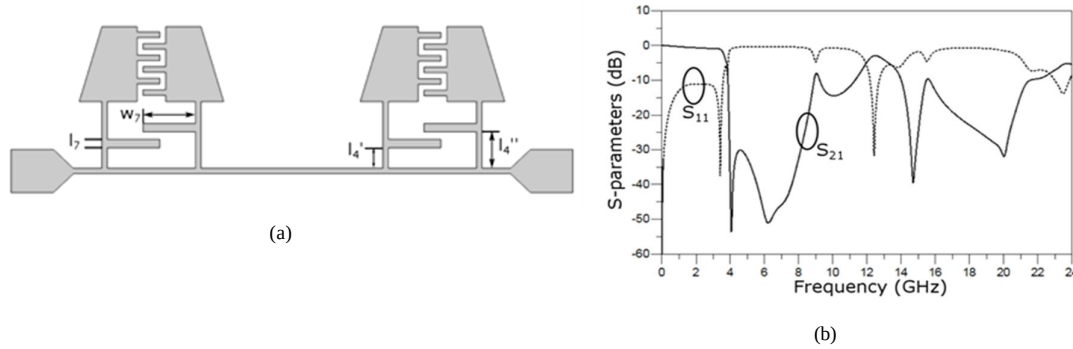


Figure 3. The modified basic lowpass filter design: (a) Structure and (b) Simulated S-parameters vs. frequency response characteristics

The incorporation of this structure slightly increases the physical dimension of the filter. The spacing between the coupled inductive stubs is denoted by g' ; the minimal value of g' results in increment of the coupling between the inductive stubs and ultimately leads to wide stopband bandwidth.

Fig. 4(a) displays the structure of the proposed filter. The various parameters of the designed filter are $l = 5.0$, $l_4' = 0.7$, $l_4'' = 1.25$, $l_7 = 0.3$, $l_8 = 0.65$, $l_9 = 1.8$, $w_7 = 1.85$, $w_8 = 0.2$, $w_9 = 2.2$, $w_{10} = 3.6$ and $g' = 0.1$ (all in mm). Fig. 4(b) displays the simulated frequency response characteristics of the designed filter. The lowpass filter has a 3 dB cutoff frequency at 3.683 GHz. The frequency corresponding to first attenuation peak is at 4.07 GHz and the respective suppression level is 58.76 dB; therefore the transition band between the 3 dB and the 58.76 dB is 0.387 GHz. The roll-off rate of the designed filter is 144.08 dB/GHz. The proposed filter has a wide stopband bandwidth from 3.8 GHz to 23.8 GHz with a suppression level of 20 dB.

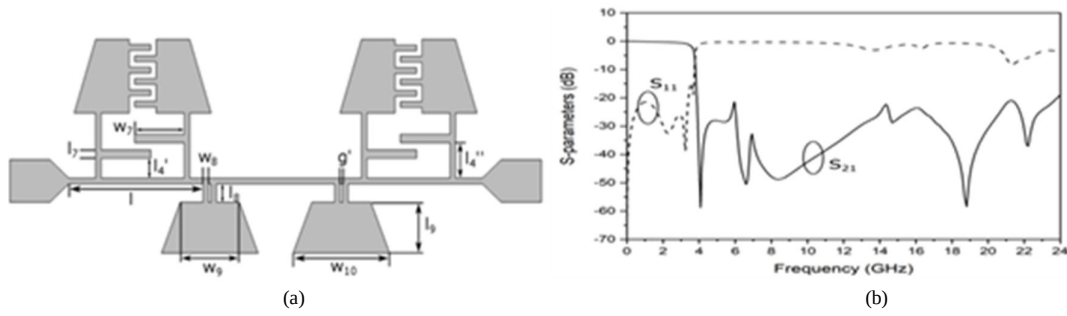


Figure 4. The proposed lowpass filter design: (a) Structure and (b) Simulated S-parameters vs. frequency response characteristics

III. SURFACE CURRENT DISTRIBUTION ALONG THE PROPOSED STRUCTURE

In order to investigate the functioning of the filter in the passband and stopband, the surface current distribution is studied at two different frequencies, at 1.5 GHz which lies in the passband and at first attenuation pole frequency of 4.07 GHz. Fig. 5(a) portrays the simulated surface current distribution at passband frequency of 1.5 GHz. It can be noticed from the figure that the RF energy at this frequency is transmitted from the input port to output port easily through the primary high impedance transmission line. The amount of RF energy concentrated around the patch resonators of the design is negligible and this proves that the passband operation of the filter at this frequency. At the first attenuation pole frequency of 4.07 GHz,

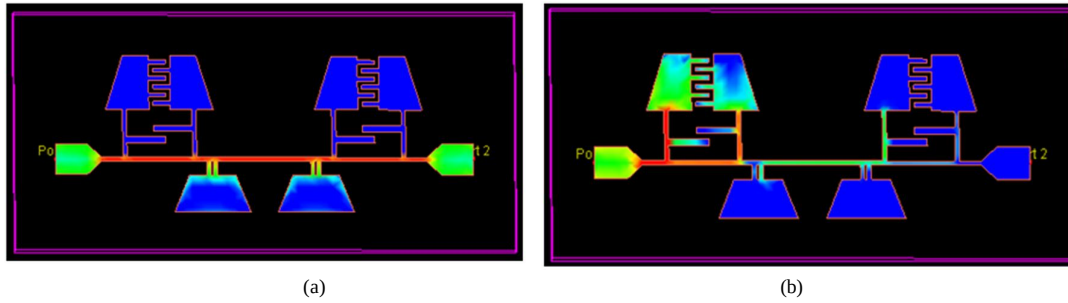


Figure 5. Surface current distribution of the proposed lowpass filter design at: (a) 1.5 GHz frequency and (b) 4.07 GHz frequency

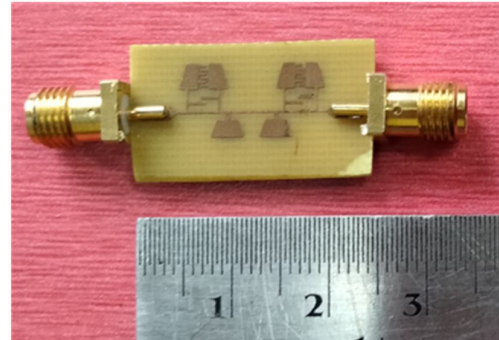
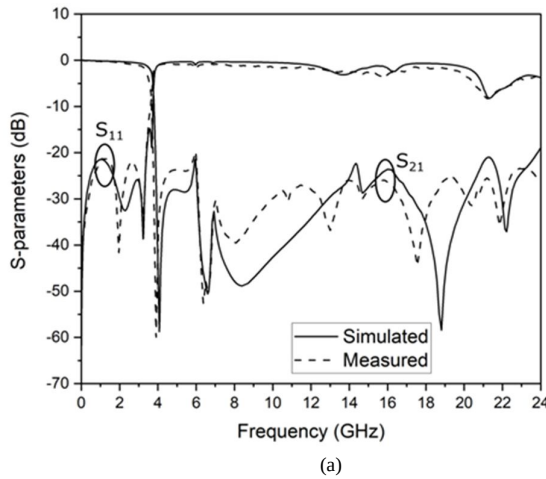


Figure 6. Proposed lowpass filter design: (a) Comparison of measured and simulated results and (b) Fabricated prototype

maximum portion of the RF energy is concentrated around the first patch resonator and transmission of the RF energy to the output port is not seen which states the stopband behavior of the designed filter as can be noticed from Fig. 5(b).

IV. MEASURED AND SIMULATED RESULTS

The proposed filter is fabricated utilizing low cost FR4 substrate and the performance characteristics of the filter are measured employing the available R & S ZVB 20 Vector Network Analyzer. The fabricated prototype of the designed structure and the comparison of the measured and simulated results up to a frequency of 20 GHz are displayed in Fig. 6. The measured 3 dB cutoff frequency of the proposed structure is 3.67 GHz. The insertion loss in the passband is less than 0.5 dB up to a frequency of 3 GHz and the value of return loss is more than 21 dB in the entire passband.

The measured frequency at first attenuation pole having suppression level of 59 dB is 4.06 GHz; therefore the transition band between passband and stopband at 3 dB and 59 dB suppression level is 0.39 GHz and therefore the evaluated roll-off rate of the filter is 143.5 dB/GHz. The return loss value in the stopband is negligible up to 15 GHz and beyond 15 GHz it increase up to 5 dB. The cause for this increase in the value of return loss at high frequency range is the inherent dielectric losses related with the FR4 substrate. The fabricated filter possesses wide stopband bandwidth and it extends from 3.72 GHz to 24 GHz at 20 dB suppression level. The value of RSB (Relative Stopband width) of the fabricated filter evaluated at 20 dB rejection level is 146.32 %.

A comparison of the proposed design with other relevant designs existing in the literature is depicted in Table I. The roll-off rate, ξ is evaluated employing [7]. From Table I it can be observed that the proposed filter possesses satisfactory characteristics such as high roll-off rate and wide stopband bandwidth.

TABLE I. COMPARISON OF PROPOSED FILTER WITH OTHER RELATED WORKS

Ref.	Substrate	ξ (dB/GHz)	Stopband (GHz @ dB)
[3]	FR4	61.7	1.44 – 12.35 @ 17
[4]	Taconic TLY-8	57.8	1.65 – 19 @ 35
[5]	F4B	25.75	2.8 – 9.35 @ 20
[6]	FR4	67.27	2.85 – 16 @ 22
[7]	FR4	84	5.88 -11.8 @ 15
[8]	FR4	100	2.6-20 @ 20
[9]	RT/Duroid 5880	123	1.76-17.6 @ 20
[10]	RT/Duroid 5880	92.5	1.6-25 @ 25
[11]	RO4003	28.8	8.05-12.9 @ 20
[12]	RT/Duroid 5880	84	1.84-21.39 @ 20
This work	FR4	143.5	3.72-24 @ 20

V. CONCLUSION

A microstrip lowpass filter having ultra wide stopband and high selectivity is presented in this paper. The filter also possesses low values of insertion loss and high values of return loss in the passband. The results illustrate that the proposed filter has advantages like compact size, adequate impedance matching in the passband and satisfactory level of harmonic suppression up to 6th order. Owing to the possession of all these features it can be concluded that the filter is a preferable component for several wireless communication applications.

REFERENCES

- [1] J.S. Hong and M.J. Lancaster, "Microstrip filters for RF/Microwave applications," New York: Wiley, 2001.
- [2] Hayati, M., M. Gholami, H. S. Vaziri, and T. Zaree, "Design of microstrip lowpass filter with wide stopband and sharp roll-off using hexangular shaped resonator," *Electronics Letters*, vol. 51, no. 1, pp. 69-71, January 2015.
- [3] Xu, L.-J. and Z. Duan, "Miniaturized lowpass filter with wide band rejection using modified stepped-impedance hairpin resonator," *Microwave and Optical Technology letters*, vol. 59, no. 6, pp. 1313-1317, June 2017.
- [4] Zhang, B., S. Li, and J. Huang, "Compact lowpass filter with wide stopband using coupled rhombic stubs," *Electronics Letters*, vol. 51, no. 3, pp. 264-266, February 2015.
- [5] Li, L. and Z.-F., Li, "Compact quasi-elliptic lowpass filter using symmetric rectangular coupled capacitors," *Electronics Letters*, vol. 44, no. 2, pp. 124-125, January 2008.
- [6] T. K. Rekha, P. Abdulla, P. M. Raphika, and P. M. Jasmine, "Compact microstrip lowpass filter with ultra-wide stopband using patch resonators and open stubs," *Progress in Electromagnetics Research C*, vol. 72, pp. 15-28, January 2017.
- [7] P. M. Raphika, P. Abdulla, and P. M. Jasmine, "Compact lowpass filter with a sharp roll-off using patch resonators," *Microwave and Optical Technology letters*, vol. 56, no. 11, pp. 2534-2536, November 2014.
- [8] T. K. Rekha, P. Abdulla, P. M. Jasmine, and A. R. Anu, "Compact microstrip lowpass filter with high harmonics suppression using defected structures," *AEU - International Journal of Electronics and Communications*, vol.115, February 2020.

- [9] M. H. Roshani and S. S. Roshani, "Design of a low pass filter using rhombus-shaped resonators with an analytical LC equivalent circuit," *Turkish journal of electrical engineering & computer sciences*, vol. 28, pp. 865-874, March 2020.
- [10] A. Lalbakhsh, M. Jamshidi, H. Siahkamari, A. Ghaderi, A. Golestanifar, R. Linhart, J. Talla, R. B. V. B. Simorangkir, K. Mandal, "A compact lowpass filter for satellite communication systems based on transfer function analysis," *AEU - International Journal of Electronics and Communications*, vol. 124, March 2020.
- [11] W. A. E. Ali and A. Boutejdar, "Compact tunable U-Hi-Lo low pass filter using quasi C-shaped stubs," *Journal of Instrumentation*, vol. 15, pp. P08010-P08010, August 2020.
- [12] M. Hayati, S. Lotfi, H. Siahkamari, T. Blecha, R. Linhart, and M. (B.) Jamshidi, "A compact simple microstrip lowpass filter based on elliptical analyzed resonator," *Frequenz*, vol. 76, no. 5-6, pp. 247-254, November 2021.