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Research Article

Compact Microstrip Lowpass Filter with Low Insertion Loss for UWB Medical Applications

Mohammed A. Aseeri, Meshaal A. Alyahya, Hatim A. Bukhari, and Hussein N. Shaman

National Centre for Sensors and Defense Systems Technologies (NCSDST), King Abdulaziz City for Science and Technology (KACST), Riyadh 11442, Saudi Arabia

Correspondence should be addressed to Mohammed A. Aseeri; masseri@kacst.edu.sa

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A microstrip lowpass filter based on transmission line elements for UWB medical applications is proposed in this paper. The filter is constructed of two symmetric shunt open-circuited stubs and three series unit elements. The filter is designed to exhibit an elliptic function response with equal ripple in the passband and the rejection band. A prototype is successfully designed, fabricated, and measured, where a good agreement is attained. The filter shows a high filtering selectivity and an ultra-wide stopband up to 20 GHz with an attenuation level of more than 20-dB. The filter is compact and has a low insertion loss and an ultra-wideband (UWB) rejection which makes it attractive for many technologies such as UWB medical applications.

1. Introduction

Ultra-wideband (UWB) technology has several features which makes it suitable for the application of medical monitoring such as penetrating through obstacles, high precision ranging at the centimeter level, low electromagnetic radiation, and low processing energy consumed. These monitoring applications could be patient motion monitoring, wireless vital signs monitoring of human body, and the medicine storage monitoring. One of the primary passive components of the UWB systems is lowpass filter which is necessary for blocking unwanted signals and suppressing spurious harmonics.

Lowpass planer filters with sharp roll-off, wide stopband, compact circuit size, and low insertion loss are in high demand in modern wireless communication systems and military radar receiver systems for blocking unwanted signals and suppressing spurious harmonics. A general common microstrip structure of lowpass filter is using high and low impedance (stepped-impedance) transmission lines which is known as stepped-impedance lowpass filter [1]. This type of filter has simple design methodology but it exhibits a poor skirt selectivity and a very low attenuation level at the rejection band. In order to improve the filter performance at the stopband, the low-impedance line can be replaced with a quarter guided wavelength open-circuited stub [2]. The open-circuited stub shorts can out the transmission at the resonant frequency and therefore a wider rejection band with a transmission zero can be obtained. Alternatively, a longitudinal slot can be implemented in the ground plane of a stepped-impedance filter to enhance its performance [3]. Due to the slow-wave effect of the slot-back microstrip line, the filter can exhibit a wider stopband and a sharper cut-off compared with the conventional filter. Other techniques can also be used to enhance the performance of the stepped-impedance filters such as stepped-impendence hairpin resonators [4, 5], folded stepped-impedance resonators [6], defected ground-plane structures (DGS) slot [7–12], and interdigital or semicircle defected ground-plane structures (DGS) [13, 14]. In addition, various methods and structure have been developed to enhance the performance of microstrip lowpass filters such as using circular-shaped patches and open stubs [15], rat-race directional couplers [16], stepped-impedance spiral resonator [17], combination of DGSs and a transformed radial stub (TRS) [18], T-shaped microstrip resonator cells [19], and coupled-line stub-loaded hairpin unit [20] and triangular and radial patch resonators [21].

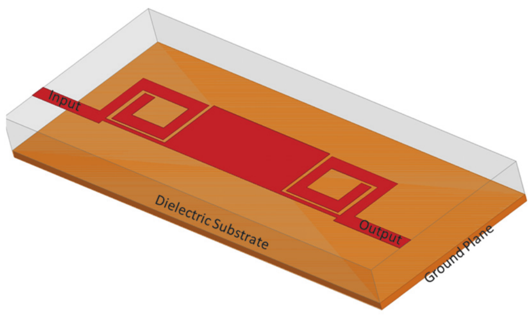

FIGURE 1: 3D view of the proposed microstrip lowpass filter.

Lowpass filter can also be designed using distributed elements such as open-circuited stubs and unit elements [2]. This type of filter has spurious harmonics and therefore, it requires more elements to enhance its performance. Alternatively, a cross-coupling can be introduced between the input/output feed lines to allow the filter to exhibit additional transmission zeros at the rejection band [22]. This proposed filter can be used in many technologies such as UWB medical applications [23].

A compact lowpass filter with an elliptic function response and a very wide rejection band is introduced in this paper. The filter is constructed of three series unit elements and two shunt open-circuited stubs. The filter is designed to provide an equal ripple in the passband and the rejection band. It is designed to have a passband with a sharp selectivity and an ultra-wide stopband. The proposed designed is implemented on a microstrip substrate and fabricated using printed-circuited-board (PCB). The filter design, analysis, and measurement results are demonstrated in detail.

2. Filter Design

The 3-dimensional view of the microstrip design of the proposed filter is shown in Figure 1 and Figure 2 illustrates its transmission line equivalent circuit model. The filter is comprised of two symmetric shunt open-circuited stubs, with a characteristic impedance of Z_s, separated by three series unit elements or connecting lines with characteristic impedances of Z_1 and Z_2. The open-circuited stub has an electrical length of θ_s while the electrical lengths of the unit elements are described by θ_1 and θ_2.

The *ABCD* matrix (M_t) of the equivalent circuit model can be written as

$$M_t = \begin{bmatrix} A_t & B_t \\ C_t & D_t \end{bmatrix} = M_s M_1 M_2 M_1 M_s, \quad (1)$$

where M_s is the *ABCD* matrix of the open-circuited stub and M_n is the *ABCD* matrix for the unit elements (for $n = 1, 2$) which can be defined by

$$M_s = \begin{bmatrix} 1 & 0 \\ \dfrac{j \tan \theta_s}{Z_s} & 1 \end{bmatrix}$$

TABLE 1: Circuit parameters for the proposed filter at 4.0 GHz.

Parameter	Z_o	Z_s	Z_1	Z_2	θ_s	θ_1	θ_2
Value	50 Ω	96 Ω	170 Ω	20.2 Ω	90°	30°	60°

$$M_n = \begin{bmatrix} \cos \theta_n & j Z_n \sin \theta_n \\ \dfrac{j \sin \theta_n}{Z_n} & \cos \theta_n \end{bmatrix} \quad (2)$$

For a feed line impedance of Z_o, the insertion loss (S_{21}) and return loss (S_{11}) responses can be computed as follows:

$$S_{21} = \frac{2 \left(A_t D_t - B_t C_t \right)}{A_t + B_t / Z_o + C_t Z_o + D_t}$$
$$S_{11} = \frac{A_t + B_t / Z_o - C_t Z_o - D_t}{A_t + B_t / Z_o + C_t Z_o + D_t} \quad (3)$$

In general, a transmission line filter with quarter-wavelength elements ($\theta_s = \theta_1 = \theta_2 = \lambda/4$ at f_o) has all of its transmission zeros at a single frequency, e.g., midstopband frequency (f_o). Therefore, it requires more elements to enhance the selectivity and to increase the bandwidth of the rejection band. Alternatively, the circuit elements are designed to have different or unequal electrical lengths to allow the filter to exhibit three transmission zeros inside the rejection band, at $f_o/3$, f_o, and $5f_o/3$. In this case, the electrical lengths are chosen to be $\theta_s = 3\theta_1 = 2\theta_2$ at the midstopband (f_o). In order to show the performance of this new structure, the filter is designed to have a cut-off frequency at about 3.0 GHz. The filter is also designed to have a return loss of more than 24-dB within the desired passband and an insertion loss of more than 20-dB over the whole rejection band. Furthermore, the filter is designed to generate three transmission zeros at the rejection band at 4.0 GHz, 12 GHz, and 20 GHz. In order to achieve this, the circuit model is optimized based on the above formulations and the calculated parameters are displayed in Table 1. The calculated magnitude response, of the circuit model using the parameters values in Table 1, is demonstrated in Figure 3. As can be noticed, the filter exhibits three transmission zeros which are widely separated from each other providing a very ultra-wide rejection band with high selectivity. These transmission zeros are generated by the two open-circuited stubs. This is because the length of each open-circuited stub (θ_s) is a quarter-wavelength at 4.0 GHz and therefore, its fundamental resonant frequency is generated at 4.0 GHz and it has spurious resonant frequencies occur at odd multiples of the fundamental one. Hence, the first and second spurious resonant frequencies are located at 12 GHz and 20 GHz as shown in Figure 4. Since the first three resonant frequencies of the open-circuited stubs are located inside the rejection band, the filter exhibits vey wide stopband. The filter exhibits an equal ripple for the return loss at the passband and for the insertion loss at the rejection band. Furthermore, addition, the first resonant frequency of the stub is located close to the cut-off frequency of the lowpass filter leading to a sharp rate of cut-off.

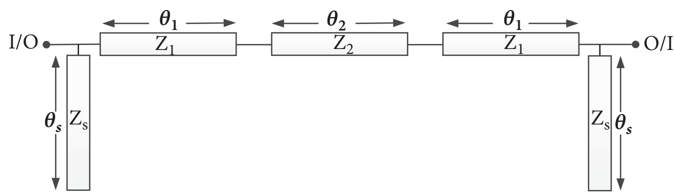

FIGURE 2: Equivalent circuit model of proposed lowpass filter.

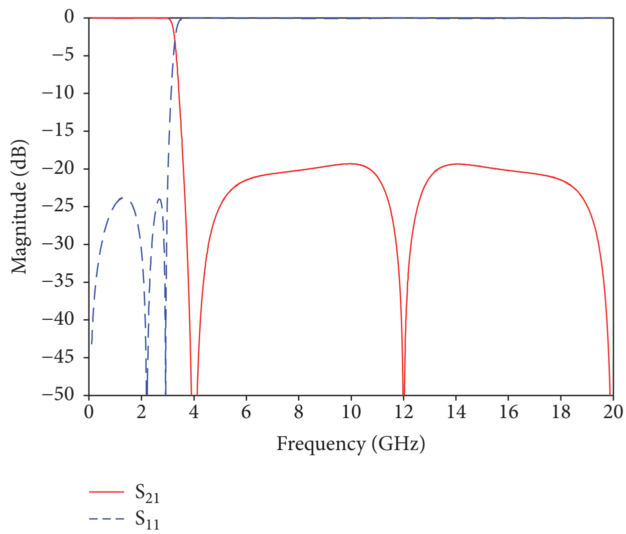

FIGURE 3: Calculated performance of the circuit model in Figure 2 with the parameters values in Table 1.

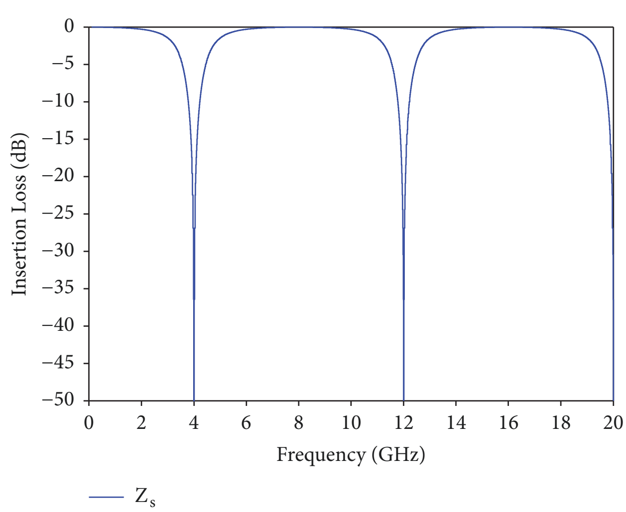

FIGURE 4: Calculated insertion loss of the open-circuited stub connected to 50 Ohm line.

3. Microstrip Design and Experiment Results

The proposed filter design is constructed on a RT Duroid 5880 substrate with $\varepsilon r = 2.2$ and thickness 0.254 mm and the microstrip layout is demonstrated in Figure 5. Based on the microstrip design equations in [2] with a slight tuning,

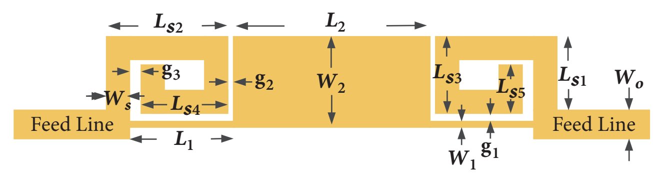

FIGURE 5: Microstrip layout of the proposed filter.

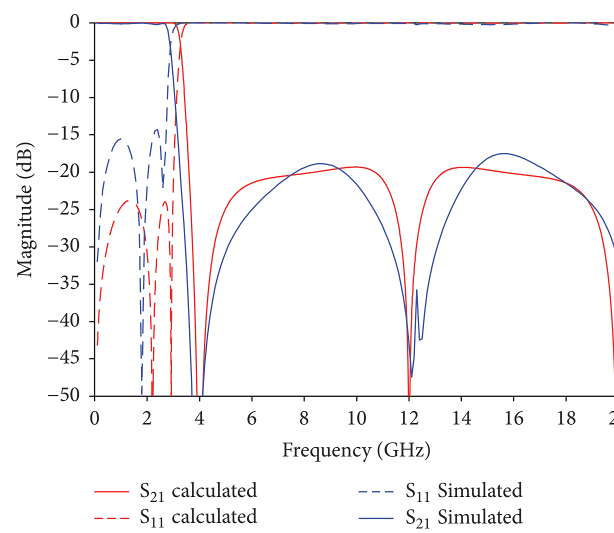

FIGURE 6: Calculated and simulated responses of the proposed filter.

the parameters of the microstrip layout are as follows: W_o = 0.75 mm, W_s = 0.7 mm, W_1 = 0.05 mm, W_2 = 3.4 mm, L_{s1} = 3.0 mm, L_{s2} = 4.65 mm, L_{s3} = 3.15 mm, L_{s4} = 3.65 mm, L_{s5} = 2.3 mm, L_1 = 4.2 mm, L_2 = 8.2 mm, $g_1 = g_2$ = 0.25 mm, and g_3 = 0.3 mm. The open-circuited stubs are folded in a rectangular spiral shape to reduce the filter size. The distance g_2 is optimized to have no effect on the filter performance. The microstrip layout is simulated using a commercially available tool [24] and the simulated performance is compared with the calculated results as depicted in Figure 6. Good agreement between the theoretical and simulated responses is obtained. However, there is a slight difference between the simulated and the theoretical passband. The microstrip layout can be further tuned to reduce the effect of discontinuity and to obtain a better agreement. A prototype of this filter is successfully fabricated and measured and Figure 7 shows a photograph of the fabricated filter. The fabricated filter is very small with an overall size of about 18.0 mm by 3.75 mm. The measured

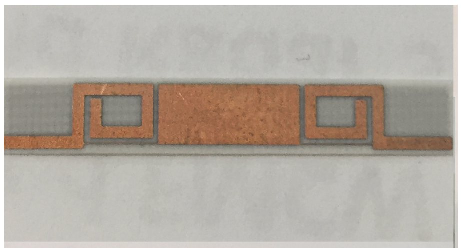

Figure 7: Photograph of fabricated filter.

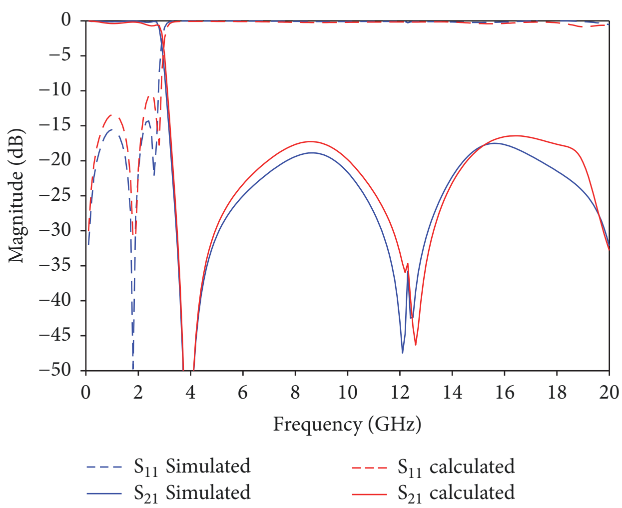

Figure 8: Simulated and measured insertion and return losses of the fabricated filter.

performance of the prototype is compared with the simulated results and demonstrated in Figure 8. The experimental filter shows excellent results with an insertion loss of about 0.4 dB at the passband centre frequency. It also exhibits an ultra-wide rejection band up to 20 GHz with three transmission zeros and an attenuation level of more than 20-dB. The filter shows an equal ripple for the return loss at the passband and for the insertion loss at the stopband. A performance comparison between published works and proposed filter is demonstrated in Table 2. It can be noticed that the proposed filter shows wider stopband bandwidth.

4. Conclusion

In this paper, a microstrip lowpass filter based on transmission line elements is proposed. The filter has been constructed of three series unit elements between two symmetric shunt open-circuited stubs. The filter has been designed to have a cut-off frequency at about 3.0 GHz. In order to allow the filter to exhibit an equal ripple in both passband and rejection band, the open-circuited stub has been designed to have its first three resonant frequencies inside the stopband. A prototype has been successfully designed, fabricated, and measured, where excellent agreement between the expected and measured performances is obtained. The filter exhibits a quasielliptic function response leading to a high filtering selectivity and an extended stopband up to 20 GHz with an attenuation level of more than 20-dB. Due to the small size, low insertion loss, and wide rejection band, the proposed filter looks attractive for making it attractive for many technologies such as UWB medical applications.

Table 2: Performance comparisons between published works and proposed filter.

Ref	Relative stopband bandwidth	Rejection level (dB)	Up to
[3]	0.92	20	6.8 GHz
[4]	1.54	14	17 GHz
[5]	1.52	10	12 GHz
[7]	0.85	15	5 GHz
[8]	1.45	20	20 GHz
[9]	1.07	10	10 GHz
[11]	0.58	15	10 GHz
[12]	1.2	30	10 GHz
[13]	1.36	10	16 GHz
[16]	1.42	10	6 GHz
[17]	1.14	15	11 GHz
[18]	1.2	10	20 GHz
[19]	1.2	10	8 GHz
[20]	1.407	20	4.5 GHz
[21]	1.3	20	19 GHz
[22]	0.8	30	5 GHz
This work	*1.5*	*20*	*20 GHz*

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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References

[1] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Network, and Coupling Structures*, Artech House, Norwood, Mass, USA, 1980.

[2] J. Hong and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, John Wiley & Sons, New York, NY, USA, 2001.

[3] S. Y. Huang and Y. H. Lee, "Compact stepped-impedance low-pass filter with a slot-back microstrip line," *Microwave and Optical Technology Letters*, vol. 50, no. 4, pp. 1058–1061, 2008.

[4] F. Zhang, S. Liu, P. Zhao, M. Du, X. Zhang, and J. Xu, "Compact ultra-wide stopband lowpass filter using transformed

stepped impedance hairpin resonator," in *Proceedings of the 2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, pp. 2227-2228, 2017.

[5] M. H. Yang and J. Xu, "Design of compact, broad-stopband lowpass filter using modified stepped impedance hairpin resonators," *IEEE Electronics Letters*, vol. 44, no. 20, pp. 1198–1200, 2008.

[6] S. Pinel, R. Bairavasubramanian, J. Laskar, and J. Papapolymerou, "Compact planar and vialess composite low-pass filters using folded stepped-impedance resonator on liquid-crystal-polymer substrate," *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 5, pp. 1707–1712, 2005.

[7] A. B. Abdel-Rahman, A. K. Verma, A. Boutejdar, and A. S. Omar, "Control of bandstop response of Hi-Lo microstrip low-pass filter using slot in ground plane," *IEEE Transactions on Microwave Theory and Techniques*, vol. 52, no. 3, pp. 1008–1013, 2004.

[8] S. Sen and T. Moyra, "Design of a Chebyshev stripline based lowpass filter using open stubs and Defected Ground Structure (DGS)," in *Proceedings of the 2016 IEEE International Conference on Wireless Communications, Signal Processing and Networking, WiSPNET 2016*, pp. 936–939, Chennai, India, March 2016.

[9] D. Ahn, J. Park, C. Kim, J. Kim, Y. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure," *IEEE Transactions on Microwave Theory and Techniques*, vol. 49, no. 1, pp. 86–93, 2001.

[10] T. Kim and C. Seo, "A novel photonic bandgap structure for low-pass filter of wide stopband," *IEEE Microwave and Guided Wave Letters*, vol. 10, no. 1, pp. 13–15, 2000.

[11] H. Fu and Y. Yu, "A novel lowpass filter based on multistage defected ground structure," in *Proceedings of the 16th IEEE International Conference on Ubiquitous Wireless Broadband, ICUWB 2016*, Nanjing, China, October 2016.

[12] L.-H. Hsieh and K. Chang, "Compact elliptic-function low-pass filters using microstrip stepped-impedance hairpin resonators," *IEEE Transactions on Microwave Theory and Techniques*, vol. 51, no. 1, pp. 193–199, 2003.

[13] F. Wei, L. Chen, X.-W. Shi, Q.-L. Huang, and X.-H. Wang, "Compact lowpass filter with wide stop-band using coupled-line hairpin unit," *IEEE Electronics Letters*, vol. 46, no. 1, pp. 88–90, 2010.

[14] A. Balalem, A. R. Ali, J. Machac, and A. Omar, "Quasi-elliptic microstrip low-pass filters using an interdigital DGS slot," *IEEE Microwave and Wireless Components Letters*, vol. 17, no. 8, pp. 586–588, 2007.

[15] G. Karimi, A. Lalbakhsh, and H. Siahkamari, "Design of sharp roll-off lowpass filter with ultra wide stopband," *IEEE Microwave and Wireless Components Letters*, vol. 23, no. 6, pp. 303–305, 2013.

[16] R. Gómez-García, M.-A. Sánchez-Soriano, M. Sánchez-Renedo, G. Torregrosa-Penalva, and E. Bronchalo, "Extended-stopband microstrip lowpass filter using rat-race directional couplers," *IEEE Electronics Letters*, vol. 49, no. 4, pp. 281-282, 2013.

[17] S. Majidifar, S. V. Makki, A. Ahmadi, and S. Alirezaee, "Compact microstrip lowpass filter using stepped impedance spiral resonator," in *Proceedings of the 2012 4th International Conference on Computational Intelligence and Communication Networks (CICN)*, pp. 23–26, Mathura, Uttar Pradesh, India, November 2012.

[18] S. Xu, K. Ma, F. Meng, and K. S. Yeo, "DGS embedded transformed radial stub for ultra-wide stopband lowpass filter," *IEEE Electronics Letters*, vol. 48, no. 23, pp. 1473–1475, 2012.

[19] K. Zhao, L. Li, and Y. Wang, "A Novel lowpass filter using three corner-cutting T-shaped compact microstrip resonator cells," in *Proceedings of the 2012 Spring Congress on Engineering and Technology (S-CET)*, pp. 1–3, Xi'an, China, May 2012.

[20] V. K. Velidi and S. Sanyal, "Sharp roll-off lowpass filter with wide stopband using stub-loaded coupled-line hairpin unit," *IEEE Microwave and Wireless Components Letters*, vol. 21, no. 6, pp. 301–303, 2011.

[21] M. Hayati, S. Naderi, and F. Jafari, "Compact microstrip lowpass filter with sharp roll-off using radial resonator," *IEEE Electronics Letters*, vol. 50, no. 10, pp. 761-762, 2014.

[22] H. Shaman and J.-S. Hong, "Wideband bandstop filter with cross-coupling," *IEEE Transactions on Microwave Theory and Techniques*, vol. 55, no. 8, pp. 1780–1785, 2007.

[23] E. Pancera, "Medical applications of the ultra wideband technology," in *Proceedings of the 6th Loughborough Antennas and Propagation Conference, LAPC 2010*, pp. 52–56, Loughborough, UK, November 2010.

[24] Sonnet Software Inc., EM User's Manual, Ver. 12, NY 2005.