Microstrip Low-Pass Filter with Sharp Roll-Off Using Transformed Radial Stubs

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Abstract **─** A novel microstrip low-pass filter with good characteristics, such as sharp roll-off, wide stop-band, low insertion loss and good return loss is presented. The proposed filter with a 3 dB cut off frequency at 1.19 GHz, roll-off rate equal to 218 dB/GHz and a relative stop-band bandwidth of 163.5% (referred to a suppression level of -20 dB) is designed, fabricated and measured, achieving a highest figure of meritequal to 77228. There is good agreement between the simulation and measurement results.

Index Terms - Figure of merit, insertion loss, microstrip low-pass filter, return loss and roll-off rate.

I. INTRODUCTION

High performance and compact size low-pass filters are in high demand for many wireless applications, to eliminate spurious signals. Printed circuit board filters are most popular because of their easy realization, low cost and simple integration with other microwave circuits. Conventional low-pass filters using shunt stubs or high-low impedance transmission lines [1], have been widely used in microwave systems for their excellent characteristics. However, compact size and good performance are hard to achieve simultaneously. Thus, many techniques to achieve both size reduction and the other performance enhancements have been studied [2-12]. A microstrip low-pass filter symmetrically loaded with triangular and high-low impedance [2] and a low-pass filter, based on the main transmission line with radial patches [3] have been achieved to have sharp roll-off and a wide stop-band, but the size is large. In [4], both radial-shape patches and interdigital construction have been used to obtain compact size and wide stop-band, but the skirt characteristic was not sharp enough. Transformed radial stub cells have enhanced the compactness and enabled controllable transmission zeros in [5], but its frequency response has gradual transition band. In [6], a sharp rejection band using a Slit-Loaded Tapered Compact Microstrip Resonator Cell (SLTCMRC) has been presented. Disadvantages of the mentioned resonator are large size and low return loss. A microstrip low-pass filter using resonant patches and a meander transmission line has been presented in [7]; which results in a good pass-band performance, but the stop-band performance is not good. A microstrip low-pass filter with wide stop-band using an embedded band-stop structure has been presented in [8], but this filter suffers from a gradual transition band. A compact microstrip low-pass filter with compact size and simple structure based on the coupled-line hairpin unit has been designed in [9], but it doesn't have a sharp roll off. In [10] and [11] the Defected Ground Structure (DGS) has been designed, which results in a wide stop-band. In [12], a compact microstrip low-pass filter with wide stop-band using Open Stubs-Loaded Spiral Compact Microstrip Resonant Cell (OSLSCMRC) has been presented, but it has gradual response.

In this paper, a novel microstrip low-pass filter with good features such as compact size, sharp roll-off and wide stop-band is proposed as follows: design of a resonator using transformed radial stubs to obtain a sharp roll-off, design of a suppressing cell consisting of semicircles and open stubs to obtain a wide stop-band and the suppressing cell is added to the proposed resonator to have both wide stop-band and sharp roll-off.

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The proposed filter is designed, fabricated and measured. The results indicate the 3 dB cut off frequency at 1.19 GHz, the 20 dB stop-band bandwidth equal to 11.8 GHz (from 1.325 GHz to 13.125 GHz), low insertion loss and good return loss.

II. PROPOSED RESONATOR AND ITS CHARACTERISTICS

Figure 1 shows the proposed resonator, which consists of 8 transformed radial stubs and high impedance strip lines as a connector between the transformed radial stubs. The dimensions of the proposed resonator are: W_i=0.6, W_1=0.1, d_1=4, d_2=1.36, d_3=1.2, d_4=1.5, d_5=2.5, d_6=5.2, d_7=5.5, d_8=5.8 and d_9=11.3; all in mm and θ=70 in degree.

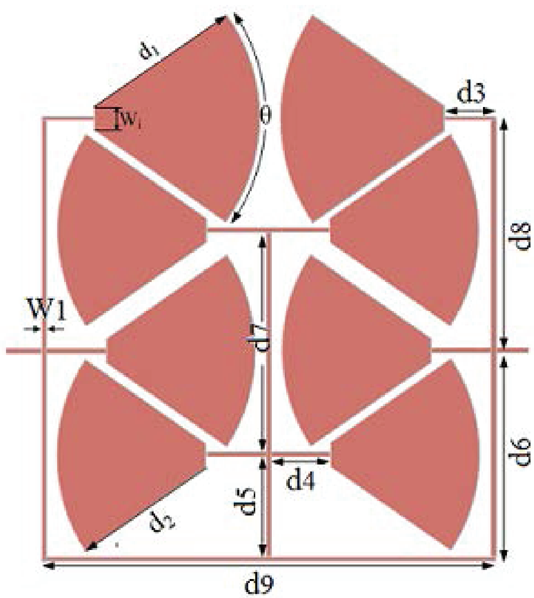

Fig. 1. The proposed resonator.

The simulated result of the proposed resonator is illustrated in Fig. 2. The obtained 3 dB cut off frequency is 1.19 GHz, the transition band from 3 to 20 dB is 0.15 GHz and the insertion loss from DC to 1.12 GHz is less than 1 dB. Transmission zeros are located at 1.39, 2.07, 2.98, 3.75 and 5.4 GHz with the attenuation level of -40.3, -49.32, -49.45, -59.56 and -60.43 dB, respectively. It is obvious that the sharp roll-off (equal to187.71%) is achieved, but the stop-band characteristics are not good.

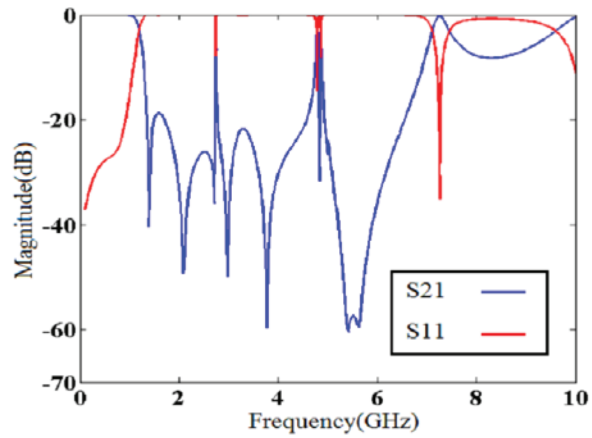

Fig. 2. The simulated S-parameters of the proposed resonator.

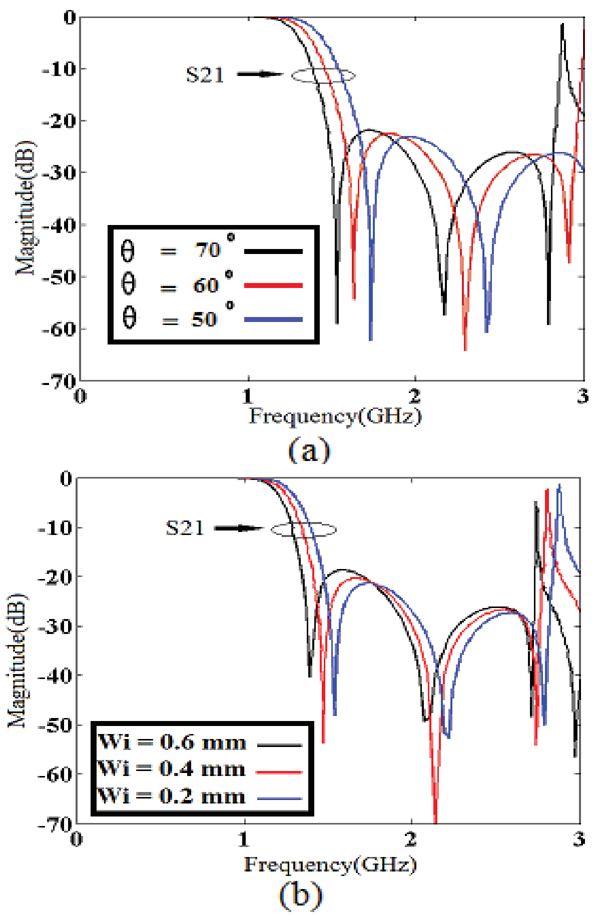

Fig. 3. (a) Simulated S-parameter of the proposed resonator as a function of θ and (b) simulated S-parameter of the proposed resonator as a function of W_i.

The simulated S-parameters of the proposed resonator as functions of θ and W_i are shown in Figs. 3 (a) and (b), respectively. Figure 3 (a) shows when θ increases from 50° to 70°, transmission zeros move to lower frequencies. Similarly, in Fig. 3 (b), by decreasing W_i from 0.6 mm to 0.2 mm, the transmission zeros move away from lower frequencies. Hence, the location of the transmission zeros can be controlled by these parameters.

III. SUPPRESSING CELL

To obtain both wide stop-band and sharp roll-off, a semicircular structure is added to the proposed resonator. Also, to achieve better suppression, an open stub is added to the semicircular structure that creates an attenuation pole at 0.9 GHz. Figure 4 shows the proposed suppressing cell consists of the semicircular structure and the open stub. Dimensions of the proposed suppressing cell are: W_2=0.4, d_{10}=2, R=3.4, d_{11}=8.4, d_{12}=9 and W_3=0.75; all in mm.

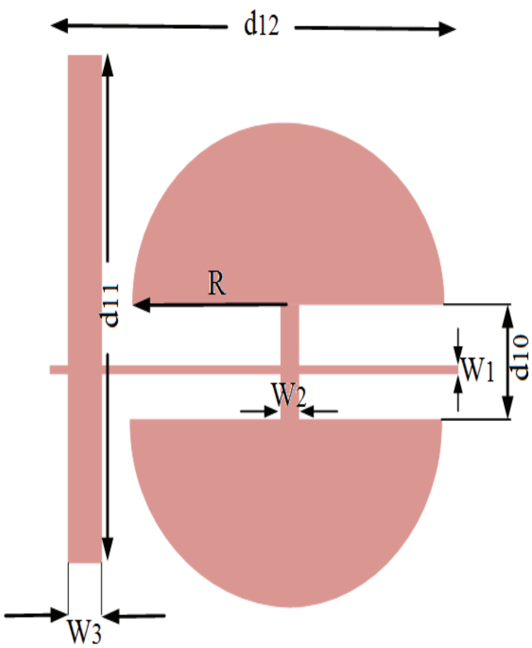

Fig. 4. The proposed suppressing cell.

Figure 5 shows the simulated S-parameters of the proposed suppressing cell. As can be seen, the suppressing cell has a cut off frequency at 1.9 GHz and a wide stop-band from 5.35 GHz to 21.5 GHz.

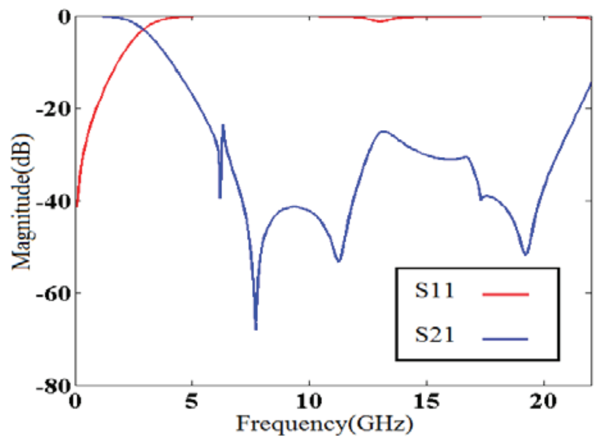

Fig. 5. Simulated S-parameters of the suppressing cell.

IV. FILTER DESIGN AND DISCUSSION

To obtain a filter with sharp rejection band and wide stop-band, the suppressing cell is added to the proposed resonator. The layout of the proposed filter is shown in Fig. 6. The width and length of the feeding line for 50Ω matching are W=1.16 mm and L=2 mm, respectively. The proposed filter has been fabricated on the RT/Duroid 5880 substrate with dielectric constant of ε_r=2.2, thickness of 15 mil and a loss tangent of 0.0009. Simulation is accomplished using an EM-simulator ADS and measurement is carried out using a HP8757A vector network analyzer.

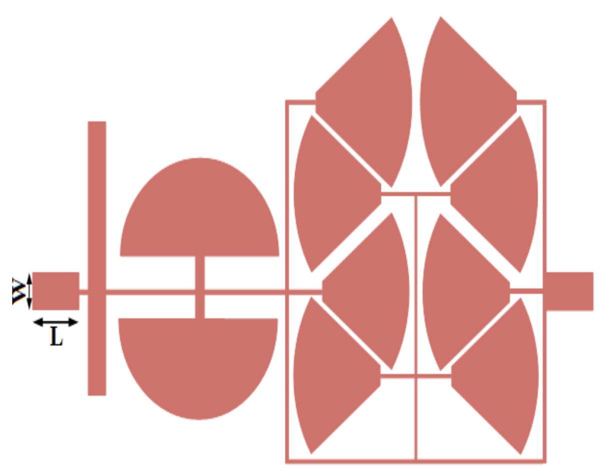

Fig. 6. The proposed filter.

Figure 7 illustrates the simulated and measured S-parameters, which are in good agreement. The measured specifications of the proposed filter are sharp roll-off, low insertion loss, good return loss, compact size and wide stop-band up to 10.8 *fc*, with size of about 20.3×13.2 mm^2 (0.118λg×0.078λg, where λg is the guided wavelength at 3 dB cut off frequency).

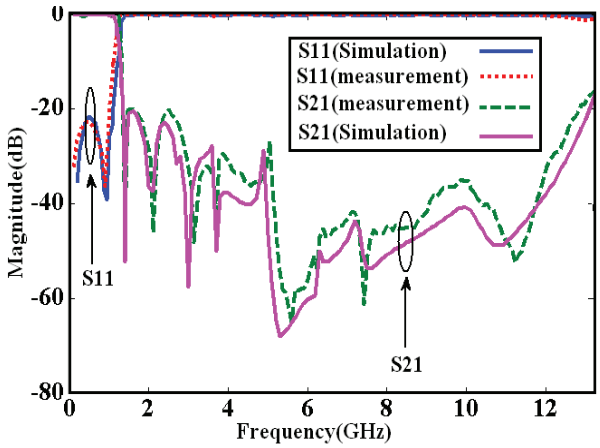

Fig. 7. The simulated and measured S-parameters of the proposed LPF.

The photograph of the fabricated filter is shown in Fig. 8.

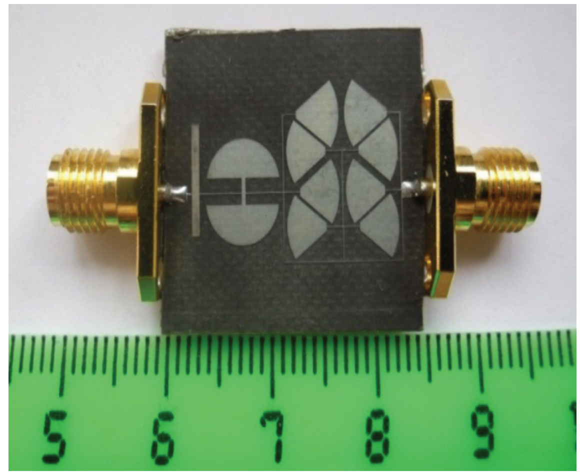

Fig. 8. Photograph of the fabricated filter.

A comparison with other LPFs is given in Table 1, which shows that the proposed filter has good characteristics with compact size.

Table 1: Comparisons between the proposed filter and other works

Reference	f_c	RSB	SF	NCS	AF	ζ	FOM
[2]	1.5	1.57	1.5	0.108×0.145	1	257	38747
[3]	2.4	1.36	3	0.351×0.106	1	93	10106
[4]	1.18	1.32	1.5	0.079×0.079	1	36	11543
[5]	3.2	1.66	2	0.12×0.063	1	10	4391
[6]	1.78	1.41	1	0.25×0.19	1	168	4985
[7]	1.3	1.52	1.7	0.12×0.071	1	37	11221
[10]	2.95	1.46	2	0.43×0.27	2	25	315
[11]	3.4	1.4	2	0.25×0.16	2	37	350
This work	1.19	1.63	2	0.118×0.078	1	218	77228

In Table 1, the roll-off rate ζ is given by:

$$\zeta = \frac{\alpha max - \alpha min}{f_s - f_c} (dB / GHz), \qquad (1)$$

where α_{max} is the 40 dB attenuation point, α_{min} is the 3 dB attenuation point, f_s is the 40 dB stop-band frequency and f_c is the 3 dB cut off frequency.

The Relative Stop-Band Bandwidth (RSB) is defined as:

$$RSB = \frac{Stopband\ \ bandwidth\ (\text{-}20\ dB)}{Stopband\ \ center\ \ frequency}. \qquad (2)$$

The Suppression Factor (SF) is based on the stop-band suppression. A higher suppression leads to a greater SF.

$$SF = \frac{Attenuation\ \ level}{10}. \qquad (3)$$

The Normalized Circuit Size (NCS) is given by:

$$NCS = \frac{Physical\ \ size\,(length \times width)}{\lambda g^{2}}, \qquad (4)$$

where λ_g is the guided wavelength at 3 dB cut off frequency.

The Architecture Factor (AF) can be recognised as the circuit complexity factor, which is defined as 1 and 2 when the design is 2D or 3D, respectively.

Finally, the Figure-of-Merit (FOM), which is the overall index of a proposed filter, is defined as:

$$FOM = \frac{\zeta \times RSB \times SF}{NCS \times AF}. \qquad (5)$$

It can be seen from Table 1 that the proposed filter exhibits the highest figure of merit equal to 77228, among the quoted filters.

V. CONCLUSION

A novel microstrip low-pass filter consisting of the transformed radial stubs, semicircular units and open stubs has been presented. The proposed filter has 3 dB cut off frequency at 1.19 GHz and roll-off rate equal to 218 dB/GHz. The insertion loss from DC to 1.15 GHz is less than 0.3 dB, the relative stop-band bandwidth with 20 dB attenuation level is 1.63 GHz (from 1.32 GHz to 13.12 GHz) and the return loss in the stop-band region is close to 0 dB, indicating negligible radiation loss.

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