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Compact Wide Stopband Lowpass Filter with High Suppression Using Corrugated Transmission Line

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Abstract. Compact and wide stopband lowpass filter with high suppression level using corrugated high impedance transmission line with symmetrically loaded multiple patch resonators is designed and demonstrated. The measured results validate the simulated characteristics and exhibit a roll-off of 60 dB/GHz and a wide stopband with suppression level better than 31 dB from 2.65 GHz to 13.4 GHz. The 3 dB cut-off frequency of the filter is at 2.04 GHz with passband insertion loss of 0.7 dB. The normalized circuit size of the developed filter is 0.21824 λ_g x 0.1314 λ_g, where λ_g is the guided wavelength of 80.646 mm at cutoff frequency for 50 Ω impedance.

1. Introduction

Compact lowpass filters with wide stopband bandwidth and high suppression level are in great demand for modern communication systems to suppress harmonics and spurious signals. Planar filters exhibit good electrical and mechanical characteristics together with the ease of fabrication, which makes it suitable for radio frequency and wireless applications [1]. Various methods have been proposed to exploit a lowpass filter with sharp roll-off and wide stopband by utilizing different dielectric material properties. The technique of etching defects in the ground plane supports sharp switching characteristics by suffering additional radiation due to the defected ground [2]. V. K. Velidi *et al*. reported the method of stub-loaded coupled-line hairpin unit to develop sharp roll-off lowpass filter with wide stopband [3]. Though size reduction was achieved by the proposed design, applications of the filter are limited in the S-band. Design of sharp roll-off lowpass filter with ultra wide stopband by creating multiple transmission nulls was proposed in [4]. M. Hayathi *et al*. developed a compact lowpass filter with wide stopband using modified semi-elliptic and semi-circular microstrip patch resonators [5]. To develop lowpass filters with good frequency characteristics the method of loading multiple patch resonators on high impedance transmission line has been reported recently by the authors in [6−7]. Although these reported filters are good choice for modern communication systems, they suffer deficiencies such as limited stopband suppression level and large circuit size.

In this paper, a compact microstrip lowpass filter with wide stopband and high suppression level is designed by loading resonator1 as centre resonator, and resonator2 and resonator3 as side resonators on corrugated high impedance transmission line. Each resonator is designed with high impedance short circuited stub and low impedance open circuited patch. The 3 dB cut-off frequency of the filter is at 2.04 GHz with a roll-off of 60 dB/GHz. The filter achieves a high stopband suppression level better

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than 31 dB from 2.65 GHz to 13.4 GHz. The wide stopband characteristics with high suppression level has simultaneously obtained by applying a narrow band design for the resonator1 and wideband design for resonator2 and resonator3.

2. Proposed filter design

Sharp switching characteristics of a lowpass filter from passband to stopband can be realized by generating infinite attenuation poles at finite frequencies. By cascading multiple resonators on a high impedance transmission line we can execute such characteristics [1]. As shown in figure 1, the proposed filter consists of a centre resonator, resonator1 and two side resonators, resonator2 and resonator3 respectively. Resonator1 is designed with high impedance short circuited stub and modified funnel patches. U-shaped high impedance stubs and modified triangular patches are used for the design of resonator2. These patch resonators are loaded as λg/2 stepped impedance resonators on a high impedance corrugated main transmission line with characteristic impedance of 120 Ω.

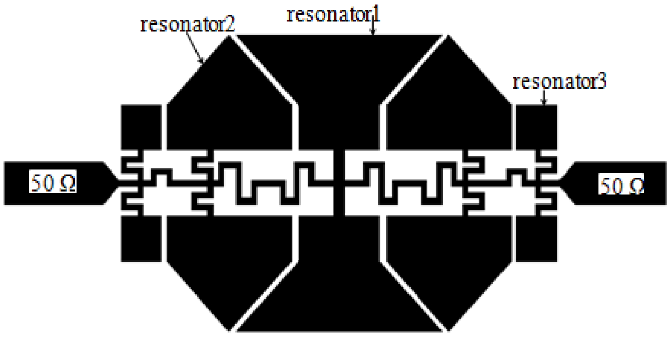

Figure 1. Schematic structure of the proposed filter.

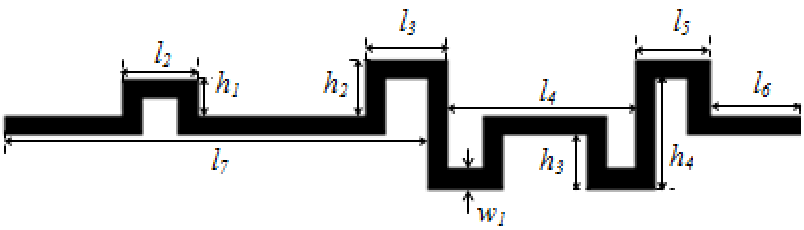

Figure 2. Layout of the corrugated high impedance transmission line.

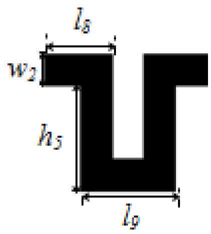

Figure 3. Layout of U-shaped high impedance stub of resonator2.

Figure 2 demonstrates the layout of the corrugated transmission line symmetrical about longitudinal axis. The optimum dimensions selected for the transmission line are: l_1 = 0.75 mm, l_2 = 0.8 mm, l_3 = 0.9 mm, l_4 = 2.1 mm, l_5 = 0.8 mm, l_6 = 1 mm, w_1 = 0.2 mm, h_1 = 0.4 mm, h_2 = 0.65 mm, h_3 = 0.65 mm and h_4 = 1.3 mm. As illustrated in figure 3, the layout of U-shaped high impedance stub of resonator2 increases the effective inductance that enhances the stopband bandwidth of the filter. The optimized structure dimensions are: h_5 = 0.65 mm, l_7 = 4.7 mm, l_8 = 0.45 mm, l_9 = 0.6 mm and w_2 = 0.2 mm. Figures 4 and 5 show the geometry of resonator1 and resonator2 respectively. The open circuited capacitive patches of the resonators are short circuited to the ground at its transmission zero, and so produce a high attenuation level in the stopband. The selected dimensions for patch resonators are: l_{10} = 1.4 mm, l_{11} = 8.2 mm, l_{12} = 1.65 mm, l_{13} = 3.35 mm, h_6 = 1.1 mm, h_7 = 1.6 mm and w_3 = 0.4 mm. The filter analysis is carried out using FR4 material with t = 0.8 mm. The lumped element values of the high impedance stubs as inductance, L and low impedance patches as capacitance, C can be determined by the circuit analysis demonstrated in [8]. Each patch resonator acts as shunt connected series L-C circuits and produces their own transmission zeroes correspond to the resonant frequency f_Z, which can be extracted using (1) as:

$$f_Z = \frac{1}{2\pi\sqrt{LC}}. \quad (1)$$

To enhance the stopband bandwidth, resonator3 is introduced with U-shaped high impedance stub and square patches, which serve as suppressing cells at high frequencies.

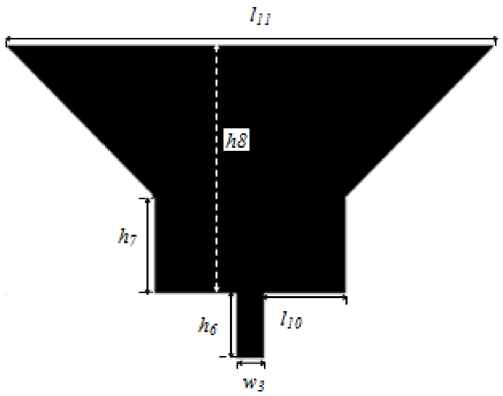

Figure 4. Geometry of modified funnel patch resonator.

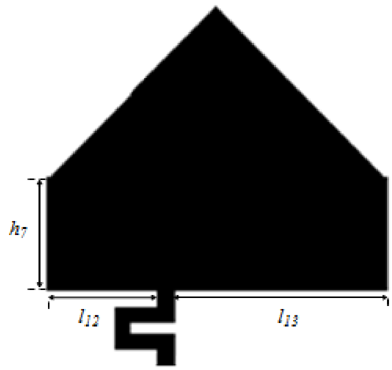

Figure 5. Geometry of modified triangular patch resonator.

3. Simulated and measured results

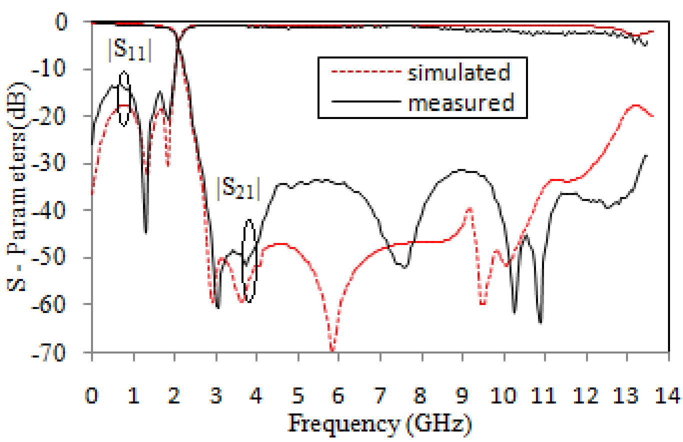

Figure 6. Simulated and measured results of the proposed filter.

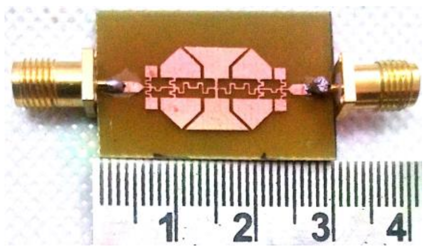

Figure 7. Photograph of prototype filter.

The filter analysis is carried out using FR4 material having permittivity 4.4, thickness 0.8 mm with loss tangent of 0.02. The simulation was accomplished with EM simulation software Zeland IE3D and the measurements are carried out using R&S ZVL 13 Vector Network Analyzer. The simulated results are validated with experimental results as shown in figure 6. The measured 3 dB cut-off frequency of the filter is at 2.04 GHz with a roll off rate of 60 dB/GHz. The filter exhibits high suppression level better than 31 dB with a wide stopband bandwidth from 2.65 GHz to 13.4 GHz. The measured insertion loss of the filter is less than 0.7 dB in the passband at 1.5 GHz. The maximum return loss in the passband of the filter is 13 dB and in the stopband is less than 1.2 dB up to 8.5 GHz and 3 dB in the upper end of the stopband. Excluding the tapered feed line the filter has a compact size of 17.6 mm x 10.6 mm, which corresponds to the normalized circuit size of 0.21824 λ_g x 0.1314 λ_g, where λ_g is the guided wavelength of 80.646 mm at cut-off frequency for 50 Ω impedance. Figure 7 shows the photograph of the fabricated filter. Table 1 presents the performance comparison of the proposed filter with some similar works reported in the literature. As shown in table 1, the proposed filter exhibits compact size and wide stopband with high suppression level among the quoted filters.

Table 1. Comparison between Proposed Filter and Some reported Work.

Ref	$f c^a$ (GHz)	SBW[b] (GHz)	SSL[c] (dB)	NCS[d] (λg^2)	ε_r & t [e] (mm)
[3]	0.5	0.8−4.6	20	0.022	4.4, 1.58
[4]	1.26	1.37−16	20	0.036	3.38, 0.508
[5]	3.12	3.68−19	20	0.056	2.2, 0.787
[6]	5.55	5.58−11.8	15	0.085	4,4, 1.6
[7]	2.5	2.72−10	23	0.052	4.4, 1.6
This work	2.04	2.65−13.4	31	0.029	4.4, 0.8

[a] cut-off frequency
[b] stopband bandwidth
[c] stopband suppression level
[d] normalized circuit size
[e] permittivity and thickness of the substrate material used

4. Conclusion

A compact and wide stopband lowpass filter with high suppression level is designed and demonstrated by loading multiple patch resonators on high impedance corrugated transmission line. The measured results of the proposed filter demonstrate very good electrical characteristics together with compact size, which makes it suitable for practical applications in modern communication systems.

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