Miniaturised microstrip lowpass filter with broad stopband and sharp roll-off

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Miniaturised microstrip lowpass filter with broad stopband and sharp roll-off

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A novel miniaturised microstrip lowpass filter has been studied. With triangular and high–low impedance resonators symmetrically loaded, the proposed filter has successfully achieved size reduction and performance enhancement simultaneously. A demonstrator filter with 3 dB cutoff frequency at 1.5 GHz has been designed, fabricated and measured. Results show that a roll-off of 257 dB/GHz together with a relative stopband bandwidth of 157.4% can be obtained while achieving a high figure-of-merit of 38747.

Introduction: Miniature lowpass filters with high performance are in great demand for communication systems to suppress harmonics and spurious signals. Filters fabricated by printed circuit board (PCB) technology are generally preferable for their easy realisation and low cost as well as easy integration with other microwave circuits. Thus, PCB lowpass filters with small size and enhanced performance have been studied continually in recent years [1–5].

In [2], a lowpass filter based on cascading multi-resonators was studied. Investigations indicated that sharp roll-off and wide stopband were achieved while the size was relatively large. Using symmetric rectangular coupled capacitors [3], a compact resonator with high stopband suppression was obtained. But this structure can only suppress the fourth-harmonic waves. In [4], a simple compact structure was reported by using a stepped impedance hairpin resonator with a pair of coupled stepped impedance resonators (SIRs) inside. The primary disadvantage of this configuration is that the skirt characteristics are not sharp enough. Introducing complementary split-ring resonators can also achieve small size as well as sharp roll-off [5]. However, this method always results in a 3D or multiplayer structure that increases circuit complexity.

In this Letter, a novel microstirp lowpass filter symmetrically loaded with triangular and high–low impedance resonators is proposed and implemented. Measured results indicate that the designed filter has a better than 15 dB stopband rejection from 1.55 to 13 GHz, together with a sharp roll-off of 257 dB/GHz, which agree well with simulation results. The size of the filter is only 14.2 × 19 mm, which corresponds to an electric size of $0.108\lambda_g \times 0.145\lambda_g$ (λ_g is the waveguide length at 1.5 GHz). Performance of the demonstrator is presented and compared with other work.

Proposed filter: Fig. 1 shows the layout of the proposed lowpass filter. It consists mainly of a high–low impedance main transmission line loaded by three types of resonators, i.e. resonators 1, 2, 3. To illustrate the design theory of the proposed filter, frequency responses caused by the loading of these different resonators are studied.

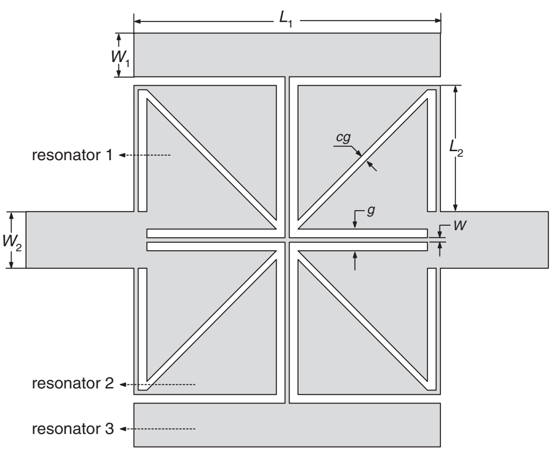

Fig. 1 *Layout of proposed lowpass filter*

Figs. 2*a* and *b* illustrate the frequency responses of the filter with resonators 1 and 2, respectively. We find that the two filters exhibit the same fundamental resonant frequency but different stopband performance. It can be seen that the filter with resonator 1 has a wide stopband with one transmission zero, i.e. TZ_1, at about 7.5 GHz. However, the roll-off is not ideal. As for the filter with resonator 2, it exhibits a sharp roll-off and a relatively narrow stopband. Two transmission zeros, i.e. TZ_2 and TZ_3, are located at about 2.1 and 3.1 GHz, respectively. Based on the investigation mentioned above, if we can properly combine the two resonators in a filter, the mutual suppression of spurious passbands and thereby a better stopband performance is expected to be achieved. Fig. 2*c* shows the frequency response of the filter with both resonators 1 and 2. As can be observed from the Figure, the locations of the transmission zeros are just around those in Figs. 2*a* and *b*. Both a sharp roll-off and a wide stopband are obtained, but an undesired response appears at f_s. Thus, the high–low impedance resonator 3 is introduced to suppress this undesired response. As can be seen from Fig. 2*d*, enhanced stopband performance is finally achieved under the combined effect of the three resonators.

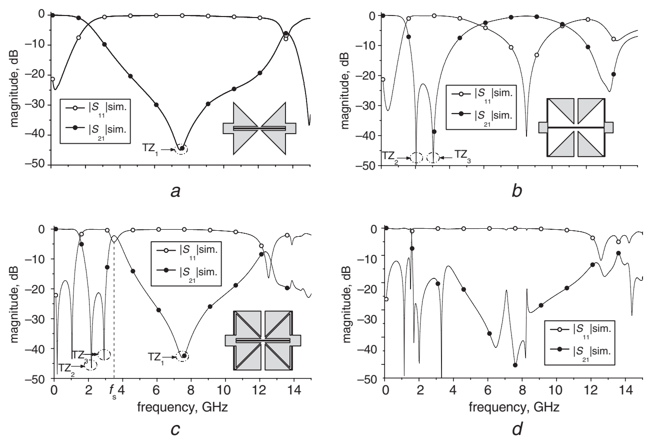

Fig. 2 *Simulated S-parameter of studied resonator*

a Filter with only resonator 1
b Filter with only resonator 2
c Filter with resonators 1 and 2
d Filter with resonators 1, 2 and 3

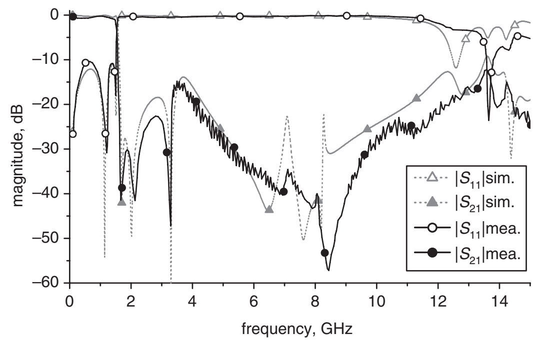

Fig. 3 *Measured and simulated S-parameter of proposed lowpass filter*

Table 1: Performance comparisons among published filters and proposed one

Ref.	Roll-off rate ξ	Relative stopband bandwidth (*RSB*)	Suppression factor (*SF*)	Normalised circuit size (*NCS*)	Architecture factor (*AF*)	*FOM*
[2]	92.5	1.355	3	0.351 × 0.106	1	10106
[3]	40.7	1.078	2	0.159 × 0.128	1	4312
[4]	30.8	1.636	1	0.037 × 0.093	1	14644
[5]	130	0.933	2	0.227 × 0.089	2	6004
This work	257	1.574	1.5	0.108 × 0.145	1	38747

Results: A prototype of the lowpass filter has been fabricated on a Duroid 5870 substrate ($\varepsilon_r = 2.33$, thickness = 0.7874 mm). The structure parameters of the LPF are: W = 0.2 mm, W_1 = 2 mm, W_2 = 2.6 mm, L_1 = 14.2 mm, L_2 = 5.8 mm, g = 1 mm, cg = 0.3 mm. Simulation was accomplished using EM simulation software Ansoft HFSS. Measurement was carried out on an Agilent 8510C network analyser. Fig. 3 shows the simulated and measured results, which agree well. As can be observed from the Figure, the proposed filter features low insertion loss, very sharp roll-off and high suppression in a wide stopband. For comparison, Table 1 summarises the performance of some published lowpass filters. In this Table, the roll-off rate ξ is given by:

$$\xi = \frac{\alpha_{\max} - \alpha_{\min}}{f_s - f_c} \quad \text{(dB/GHz)}$$

where $\alpha_{\max}$ is the 40 dB attenuation point and $\alpha_{\min}$ is the 3 dB attenuation point; f_s is the 40 dB stopband frequency and f_c is the 3 dB cutoff frequency. The relative stopband bandwidth (RSB) is defined as:

$$RSB = \frac{\text{stopband bandwidth}}{\text{stopband centre frequency}}$$

The suppression factor (SF) is based on the stopband suppression. For example, if the stopband suppression is under 15 dB, then SF is considered as 1.5. A higher suppression leads to a greater SF. The normalised circuit size (NCS) is given by:

$$NCS = \frac{\text{physical size(length} \times \text{width)}}{\lambda_g^2}$$

where λ_g is the guided wavelength at 3 dB cutoff frequency. The architecture factor (AF) can be recognised as the circuit complexity factor, which is defined as 1 when the design is 2D and as 2 when the design is 3D. Finally, the figure-of-merit (FOM), which is the overall index of a proposed filter, is defined as:

$$FOM = \frac{\xi \times RSB \times SF}{NCS \times AF}$$

As can be seen from the Table, the proposed filter exhibits the highest figure-of-merit (38747) among the quoted filters.

Conclusions: A novel microstrip lowpass filter symmetrically loaded with triangular and high–low impedance resonators has been studied. Using this structure, a prototype filter with 3 dB cutoff frequency f_c = 1.5 GHz has been designed, fabricated and measured. Results indicate that the proposed filter demonstrates many attractive features with compact size, low passband insertion loss, wide stopband, and sharp skirt characteristic. Compared with other published filters, the proposed filter features a very high figure-of-merit of 38747.

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