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COMPACT LOWPASS FILTER WITH WIDE STOPBAND USING NOVEL DOUBLE-FOLDED SCMRC STRUCTURE WITH PARALLEL OPEN-ENDED STUB

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Abstract—Nowadays, there is expanding interest in planar compact microstrip filters applied to microwave wireless system. The compact microstrip resonant cell (CMRC) and spiral compact microstrip resonant cell (SCMRC) are more and more popular in filter design due to their slow-wave and band-stop effects. In this paper, a novel double-folded SCMRC (DSCMRC) is proposed, analyzed and measured, which turns out to have more compact dimensions and distinctly broader stopband than CMRC and SCMRC. Furthermore, an improved DSCMRC circuit with two parallel open-ended stubs that are added into the DSCMRC structure is presented, which could introduce more transmission zeros in the stopband for better out-of-band rejection than the original DSCMRC. The measured results show the excellent performance of the improved DSCMRC circuit structure. Finally, a novel low-pass filter incorporating two improved DSCMRC in series is simulated and measured, which proves to have an excellent performance of out-of-band rejection up to 25 GHz with a really compact circuit size.

1. INTRODUCTION

Various kinds of microwave low-pass filters have been extensively applied to modern wireless systems as a necessary and important module, among which planar microstrip filters are most popular

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because of the ease of fabrication and integration. Traditional microstrip low-pass filters, however, require large size to achieve high performance [1]. There has been much effort to develop compact filters [2]. The general method to reduce the circuit size of filters is reducing the phase velocity or obtaining slow-wave propagation by enhancing the inductance and the capacitance of the transmission line, since the size of microwave filter is proportional to the guided wavelength which is proportional to the phase velocity [2].

Microstrip transmission lines incorporating electromagnetic bandgap (EBG) structures present slow-wave and band-stop characteristics, which have been widely employed to reject unwanted frequency similar to filters and to reduce the size of microstrip structures in various circuits [3–8, 25, 26]. However, the EBG structure, which is in the form of a periodic array of dielectric inclusions or a two-dimensional periodic array of perforations in the ground plane of the microstrip line, has an uncertain propagation constant and has much difficulty in fabrication [9, 10].

To solve this problem, a much simpler structure, the one-dimensional microstrip EBG cells alternately named compact microstrip resonant cell (CMRC), is proposed in [9] by etching specific patterns on transmission line itself. The CMRC turns out to exhibit good slow-wave and band-stop characteristics due to the significant increase of the series inductance and the shunt capacitance of the line [9, 10]. These characteristics of CMRC as well as its much easier fabrication make it particularly suitable for application in a growing number of circuits and systems as a low-pass filter structure [11–14].

To further enhance the slow-wave effect for circuit size reduction and prompt the performance of stop-band, a novel spiral compact microstrip resonant cell (SCMRC) has been introduced in [15, 16]. It consists of four folded lines instead of four triangular pattern in [9, 10], which results in advance of the inductance and the capacitance of the line without increasing the size and then achieves better performance in both slow-wave and wide band-stop effect compared with the former one.

However, both CMRC and SCMRC with slow-wave and wide band-stop characteristics still cannot meet the requirement of some low-filter applications that demand highly wide out of band rejection and compact structure, which indicates that the inductance and the capacitance of the line should be further improved without any distinct performance deterioration. To solve this difficulty, a novel double-folded SCMRC (DSCMRC) has been proposed, simulated and measured, which turns out to have more compact circuit dimension and broader stopband than SCMRC with low insertion loss in the passband. Furthermore, two parallel open-ended stubs are added into the original DSCMRC structure to introduce more transmission zeros in the stopband without increasing the circuit size obviously.

This paper is presented as follows. Firstly, the circuit structures of the SCMRC and the DSCMRC are analyzed in Section 2, and the performance of them are measured, compared and discussed with their corresponding scattering parameters. Secondly, the theory and design of an improved DSCMRC with two parallel stubs is introduced in Section 3. Good performance of this structure is demonstrated and discussed. Thirdly, a novel low-pass filter consisting of two improved DSCMRC connected in series is designed, simulated and measured in Section 4, which presents compact circuit size and excellent out-of-band rejection characteristics. Finally, conclusions and discussions are made in Section 5.

2. THE CIRCUIT STRUCTURES OF SCMRC AND DSCMRC

SCMRC has been introduced in [15] as an improved derivative of the original CMRC structure and it turns out to be with more compact size and better out-of-band performance due to the increase of the

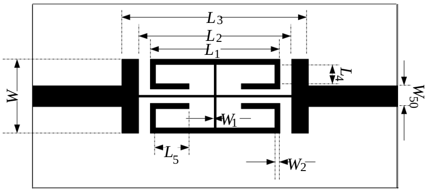


Figure 1. The circuit structure of SCMRC.

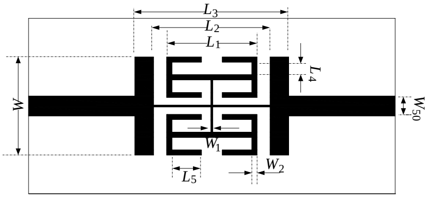


Figure 2. The circuit structure of DSCMRC.

Table 1. Circuit dimensional parameters of SCMRC.

Variable	Value (mm)	Variable	Value (mm)
L_1	7.17	W	4.60
L_2	8.46	W_1	0.10
L_3	10.32	W_2	0.29
L_4	1.00	W_{50}	1.14
L_5	1.85		

Table 2. Circuit dimensional parameters of DSCMRC.

Variable	Value (mm)	Variable	Value (mm)
L_1	4.98	W	5.06
L_2	6.43	W_1	0.10
L_3	8.48	W_2	0.29
L_4	0.73	W_{50}	1.14
L_5	1.63		

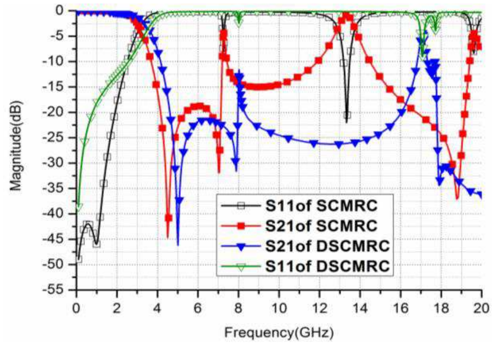
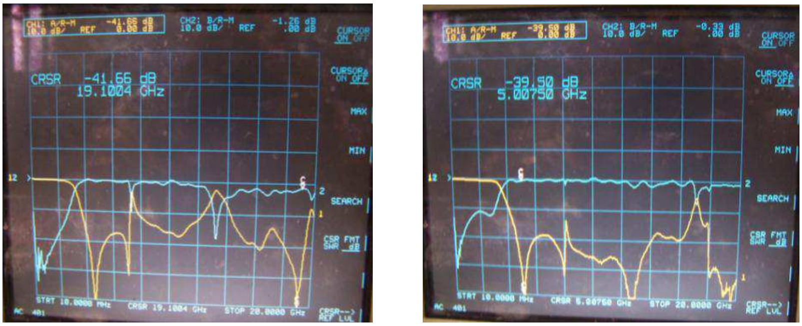


Figure 3. The simulated results of SCMRC and DSCMRC.



(a)

(b)

Figure 4. The measured results of SCMRC and DSCMRC. (a) SCMRC. (b) DSCMRC.

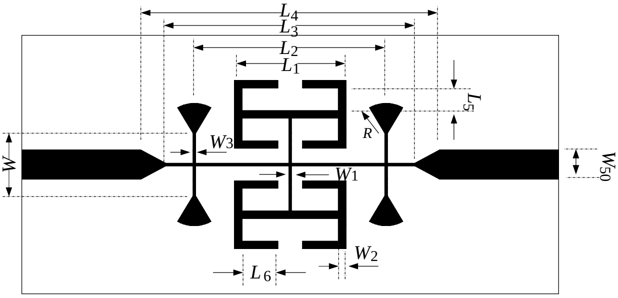


Figure 5. The circuit structure of DSCMRC with stubs.

line series inductance and shunt capacitance compared to the original CMRC. The circuit structure of SCMRC is presented in Figure 1, of which the circuit parameters are shown in Table 1. The width of the cell (W) is carefully adjusted to the standard 50 ohm line for matching purpose [15]. As an improved SCMRC, the double-folded SCMRC (DSCMRC) is shown in Figure 2 with four double-folded lines instead of four triangular pattern in [9] and four folded lines in [15]. More folded lines result in enhancement of the line inductance and more coupling gaps between the lines cause increase of the line capacitance, which enable DSCMRC to exhibit remarkable slow-wave and bandstop characteristics even only one cell is applied. The circuit parameters of the DSCMRC are shown in Table 2. Both the SCMRC and the DSCMRC are simulated and optimized under ADS Momentum environment and fabricated on Taconic RF-35 substrate with a relative permittivity of 3.5, a height of 0.508 mm and the loss tangent of 0.0018. The simulated results are shown in Figure 3, while the measured results obtained by Agilent scalar network analyzer are shown in Figure 4, which indicate apparently better out of band rejection of DSCMRC without circuit size increasing.

3. IMPROVED DSCMRC WITH PARALLEL OPEN-ENDED STUB

Given that dual behavior resonators (DBRs) could provide transmission zeros in the stop-band and obtain good out-of-band rejection performance [17, 18], an improved CMRC is proposed and implemented in [5] to achieve excellent wide out-of-band rejection by adding two unsymmetrical stubs in the original CMRC and the measured results have demonstrated the validity of this method. Based on the same con-

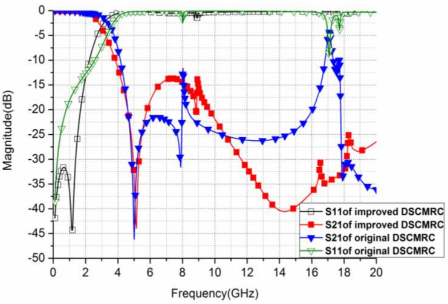


Figure 6. The simulated result of DSCMRC and improved DSCMRC.

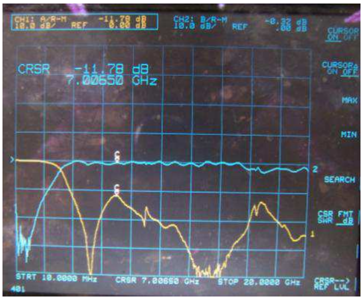


Figure 7. The measured result of improved DSCMRC.

sideration, an improved DSCMRC structure incorporating two parallel open-ended stubs is introduced, simulated and measured in this section. It could be seen that the stopband of the DSCMRC are obviously further extended without size increasing as a result of extra transmission zeros introduced by the stubs. The DSCMRC with stubs is shown in Figure 5, which includes two 60-degree sector open-ended stubs and which is built on the same substrate of Taconic RF-35. The circuit dimensions of the improved DSCMRC are shown in Table 3 and the simulation results in ADS Momentum are illustrated in Figure 6, which show that the added stubs really introduce a transmission zero near 15 GHz and then further extend the stopband compared to the original DSCMRC. For further investigation, the location of the transmission zero could be shifted by changing the length of the stubs and the radius of sectors [18].

The measured results obtained by Agilent scalar network analyzer are shown in Figure 7, from which we can see that the results are almost consistent to the simulation data and we can make sure excellent performance of this the improved DSCMRC structure with parallel stubs.

Table 3. Circuit dimensional parameters of DSCMRC with stub.

Variable	Value (mm)	Variable	Value (mm)
L_1	4.20	W	2.44
L_2	3.71	W_1	0.10
L_3	5.87	W_2	2.89
L_4	7.74	W_3	0.10
L_5	1.35	R	1.15
L_6	0.89	W_{50}	1.14

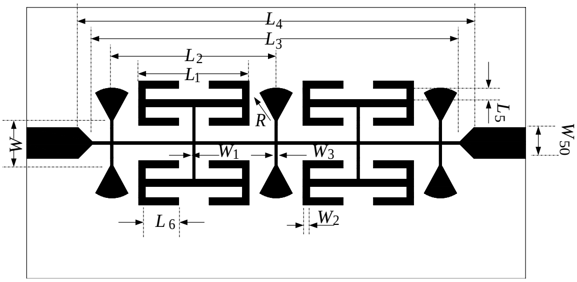


Figure 8. The circuit structure of the LPF.

4. LOW-PASS FILTER INCORPORATING IMPROVED DSCMRC

Variety of low-pass filters have been developed rapidly recently as they are extensively applied in modern wireless systems [19–24]. In this section, a novel low-pass filter consisting of two improved DSCMRCs connected in series is simulated and measured, as shown in Figure 8. Its circuit size parameters are shown in Table 4 and its simulation result under ADS Momentum and measured result based on the Taconic RF-35 substrate are illustrated in Figure 9, from which we can see that the measurement result is largely in accordance with the simulation result and the divergence above about 12 GHz may result from the dimension tolerance of circuit fabrication and cavity assemble and also the test tolerance caused by testing cable. The LPF is measured by Agilent vector network analyzer, the actual circuit photo of the LPF is shown in Figure 10, which illustrates that the low-pass filter has an

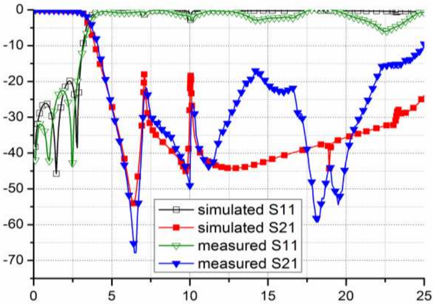


Figure 9. The simulated and measured result of LPF with improved DSCMRC.

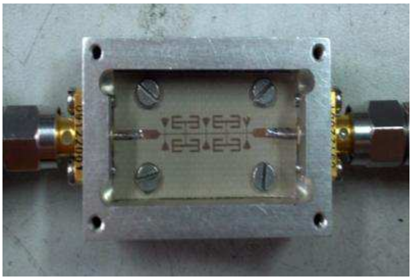


Figure 10. The circuit photo of the LPF.

Table 4. Circuit dimensional parameters of LPF with improved DSCMRC.

Variable	Value (mm)	Variable	Value (mm)
L_1	4.48	W	1.69
L_2	6.66	W_1	0.10
L_3	14.89	W_2	0.27
L_4	16.00	W_3	0.10
L_5	0.42	R	1.19
L_6	1.35	W_{50}	1.14

extraordinarily superb performance of stopband rejection from about 4 GHz up to 25 GHz (below −10 dB) with really compact circuit size.

5. CONCLUSION

In this paper, a novel double-folded SCMRC (DSCMRC) is presented, which proves to be more compact and have better stopband performance than CMRC and SCMRC. Then, two parallel open-ended sector stubs are introduced into the DSCMRC structure to further extend out-of-band rejection by adding extra transmission zeros in the stopband, which prove to be valid through measurement results. Finally, a novel low-pass filter incorporating two improved DSCMRCs connected in series is proposed with an excellent performance of stopband rejection from about 4 GHz up to 25 GHz. These novel DSCMRC structure and low-pass filter could be utilized in many microwave wireless system applications.

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