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AN IMPROVED CRLH WIDE-BAND FILTER USING CSRRS WITH HIGH STOP BAND REJECTION

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Abstract—In this paper, a filter based on Composite Right/Left Handed (CRLH) structures is presented, wide pass band is obtained due to the balanced CRLH properties. Besides, it has Complementary Split-Ring Resonator (CSRR) units etched on ground plane, which improves signal rejection in its upper stop band. The CSRRs work as a stop band filter in a band near the main pass band of the filter and bring in equivalent negative permittivity. CSRRs and CRLH units occupy the two sides of substrate respectively and have little mutual affection in the pass band, so either structure can be designed independently, without considering the effect from the other. The improvement occupy no additional space, the size is as large as the original filter. Detailed design procedure is illustrated. Good agreements among simulation and measurement results are achieved. In addition, the filter has a semi-enclosed structure and compact size, and the performance is greatly improved.

1. INTRODUCTION

A balanced CRLH has wider pass band due to the connection of its right and left-handed bands [1]. In our previous research, a compact balanced CRLH unit and its relative characteristics are discussed [2]. Two metal via-walls connected to the ground reduce power leak sidewise, and weaken interference.

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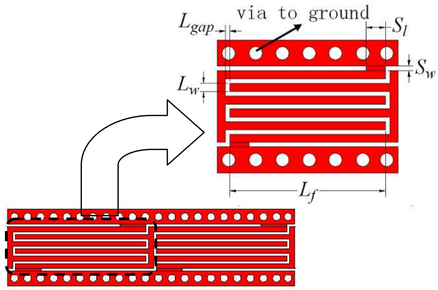


Figure 1. Structures of band pass filter and CRLH unit.

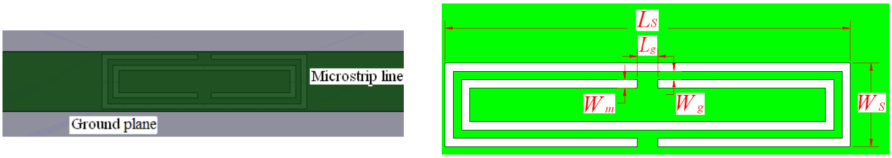
Wide band-pass filters are designed by the structure in [2]. The structures of the filter and CRLH unit are shown in Fig. 1. Its relative band width is larger than 70%. Good signal transmission is achieved, and the insertion loss is low. However, the filters do not perform well in the upper stop band, with low signal rejection and narrow stop band width. Additional passband exists near the main one, and electromagnetic waves in that band could not be well suppressed. Interference and noise are brought in, which deeply affect and deteriorate system function.

In this paper, an improved filter is designed using CSRRs. CSRR is the complementary forms of SRR, first proposed by Falcone et al. [3, 4]. Babinet principle is used to analyze this structure. Equivalent negative permittivity ε is achieved near the resonant frequency, and phase constant is imaginary, which indicates that electromagnetic wave will attenuate rapidly and stop band emerges.

CSRR is etched on the ground plane and does not occupy additional space. Small physical size is needed at resonant frequency using CSRR (typically one tenth of the free space wavelength [5]). It is possible to apply this configuration to design compact components. Little power leaks from the defected ground structure, so interference can be effectively restrained without deteriorating signal transmission. In this paper, CSRR property is analyzed in Section 2, where an empirical formula to describe the relationship between resonant frequency and CSRR size is extracted. Then, an improved wide-band filter with high stop band rejection is proposed using CSRRs in Section 3. Expanded upper stop band is achieved, and higher rejection in this band is observed. Some conclusions are presented in Section 4.

2. CSRR DESIGN

Detailed analysis and design of CSRR have been studied [3, 4] and are used to obtain equivalent negative permittivity [6], or improve rejection



(a) Microstrip with CSRR (b) CSRR structure etched in ground plane

Figure 2. CSRR designed in microstrip line circuit.

level [7, 8]. However, in their circuits the CSRR size is larger and the ring diameter larger than microstrip width, which leads to insufficient coupling because electromagnetic field concentrates near microstrip line. Here we carefully design the CSRR, and a rectangle CSRR is applied other than a round one, because by fixing suitable width, rectangle structure can be all located under the microstrip line. The whole structure has sufficient coupling with microstrip, which results in stronger resonance and higher rejection. The detailed structure is shown in Fig. 2(a). Gray color indicates the ground plane, and deep green indicates microstrip line on the top. The structure is fabricated on F4B dielectric substrate, and relative permittivity is 2.65 and height 0.8 mm. The width of microstrip line is 2.2 mm with characteristic impedance 50 Ω. Detailed size of CSRR is shown in Fig. 2(b), where the split ring gap L_g is 0.5 mm, the line width W_m and distance between two split rings W_g both 0.2 mm, and the width of external ring W_S 2 mm.

CSRR property is related to size parameters. We keep W_S as a suitable constant and make all CSRR structure under main transmission line, to get sufficient coupling. Then we are interested in L_S, which determines both CSRR size and resonant frequency. First we would like to educe an empirical formula to describe the relationship between the resonant frequency f_0 and L_S. Ansoft HFSS is used. Models with different L_S are simulated, from 2.5 mm to 19.5 mm. Parts of the results (S_{21} curves) are shown in Fig. 3, where we can see that f_0 changes significantly with CSRR length L_S. In the stop band near resonant frequency, CSRR and microstrip have great mutual coupling and good inhibition achieved. The rejection level is 15 dB, while on the other band, they have weak coupling. We use interpolation method to extract the relationship between center frequency f_0 (in GHz) and CSRR length L_S (in mm) as

$$L_S = -0.0084 \times f_0^3 + 0.3470 \times f_0^2 - 4.8258 \times f_0 + 25.0725 \quad (1)$$

Smaller CSRR size results in higher resonatant frequency, but when L_S is too small, coupling between CSRR and transmission line

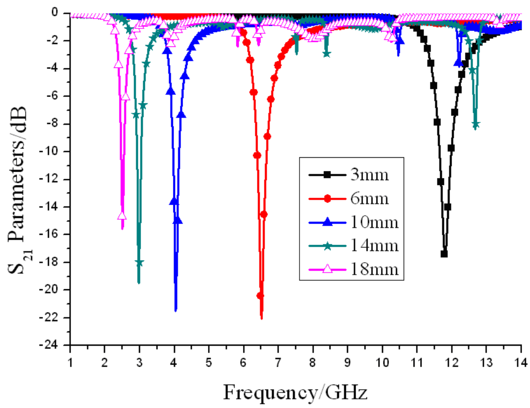
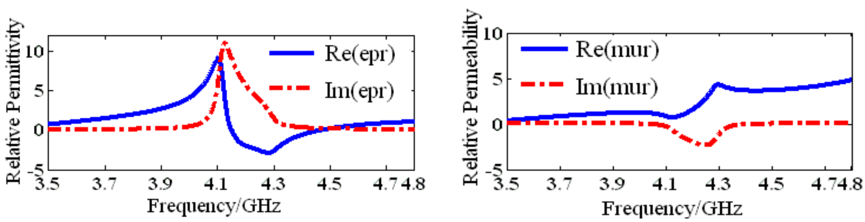


Figure 3. Simulation S_{21} curves with different L_S length.

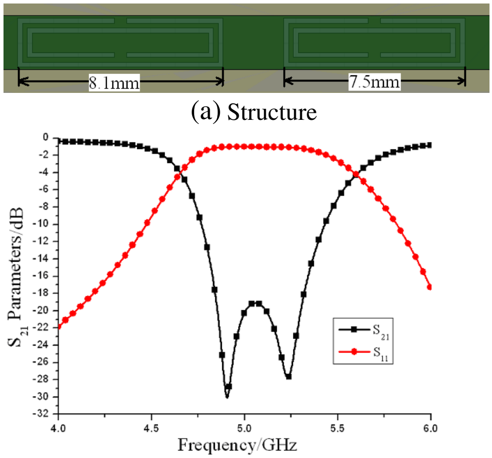


(a) Equivalent relative permittivity (b) Equivalent relative permeability

Figure 4. Equivalent medium parameters of CSRR.

is weaker, which leads to low rejection level, so L_S could not be discretionally small, which means that there is an upper frequency limit. At the same time, when L_S is too large, the stop band frequency is lower, but the result brought out by CSRR structure compares unfavorably with lumped circuit, which means that there is also a lower frequency limit. Considering a tradeoff between preciseness and designable level, we select L_S in the range [2.5, 19.5] mm. The formula is valid from 2 GHz to 15 GHz, and L_S is from 2.5 mm to 19.5 mm. Using the formula, we can calculate the CSRR size at any frequency where we need.

In a narrow band near resonant frequency, the equivalent permittivity is negative, which results in stop band. Taking CSRR with $L_S = 9.5$ mm as an example, we extract equivalent ε_r and μ_r, as shown in Fig. 4. From the two figures we can see that in the resonant frequency band (from 4.15 GHz to 4.50 GHz), the equivalent ε_r is negative, while in the frequency band beyond the resonance, it is



(a) Structure

(b) Simulated S parameters

Figure 5. Two CSRR units with different L_S.

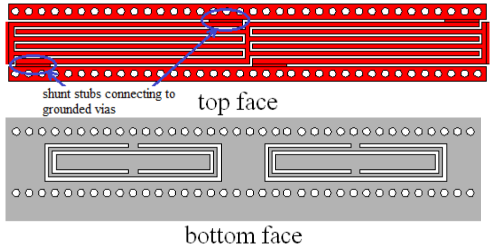
positive. However, μ_r is positive in the whole band. A single negative medium is achieved in that band, so signal rejection is obtained.

More resonant frequencies could be obtained if more CSRR units with different sizes are applied in circuit. Designing suitable sizes to make resonant frequencies close to each other, the stop bands connect together, which forms a wider band. As a sample, two CSRR units are simulated in HFSS, with different $L_S = 7.5$ mm and 8.1 mm, respectively. A wider stop band is achieved with its -10 dB relative bandwidth 13.7% and the largest signal rejection 30.5 dB. The relative structure and simulation results are shown in Fig. 5.

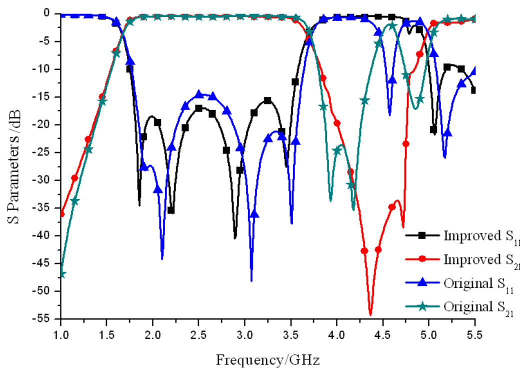
3. IMPROVED CRLH FILTER WITH CSRRS

The filter made up of two CRLH units is shown in Fig. 6(a). Interdigital capacitor has three pairs of fingers with the finger length $L_f = 12$ mm (refer to Fig. 1), width $L_w = 0.25$ mm and the gap between fingers $L_{gap} = 0.14$ mm. Microstrip line width is 2.2 mm. Length of shunt stub S_l is 1.8 mm, and width S_w is 0.14 mm. Simulated S parameters are presented in Fig. 6(b). The 3 dB passband of original filter is from 1.69 GHz to 3.69 GHz, with the smallest insertion loss 0.2 dB. However, the upper stop band is narrow, and its -10 dB band is from 3.80 GHz to 4.37 GHz. There is a parasitic passband with the center frequency 4.57 GHz.

Two CSRRs with different sizes are etched on the ground plane.



(a)



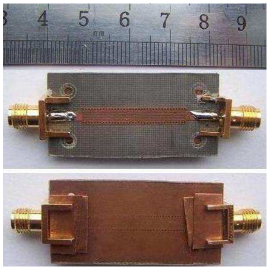
(b)

Figure 6. Simulated results of improved and original filters. (a) Structure of improved filter with CSRRs loaded. (b) Simulated S parameters of improved and original filters.

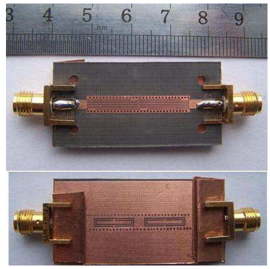
According to Eq. (1), we can calculate the needed value of L_S to generate wider stop band. After simple optimization in HFSS, finally we choose two CSRR units with $L_S = 9.5$ mm and 9.8 mm. Simulated S parameter curves are shown in Fig. 6(b). A high signal rejection is achieved at desired frequency band. The upper -10 dB stop band of improved filter is from 3.83 GHz to 4.84 GHz, with band width of 1.01 GHz, almost twice as large as the original one. From the comparison we can see that CSRRs enhance high rejection level but have little influence on the main pass band and that the filter function is greatly improved as we expect.

Photographs of the fabricated original and CSRR improved filters are presented in Figs. 7(a) and 7(b). Comparison of measured S parameters between them is shown in Fig. 7(c) and Table 1.

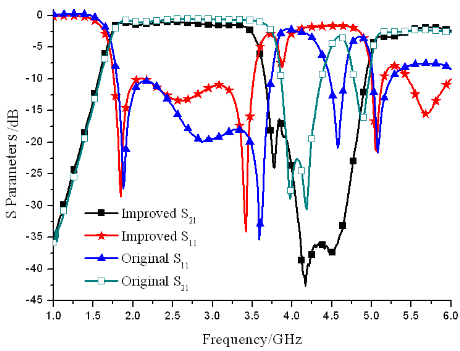
From the measured S curves we can see that the upper stop band expands to its twice, consistent with the simulation result. At the



(a)



(b)



(c)

Figure 7. Comparison of improved and original filters. (a) Top and bottom appearance of original filter. (b) Top and bottom appearance of improved filter. (c) Measured S parameter of improved and original filter.

Table 1. Comparison of original and improved filters.

	3 dB pass band (GHz)	−10 dB upper stop band (GHz)
Original filter	1.73 to 3.76	3.86 to 4.36
Improved filter	1.72 to 3.52	3.65 to 4.93

same time, the rejection level of improved filter in the upper stop band reaches 40 dB, much higher than 25 dB of the original one. The smallest insertion losses of improved and original filters are 0.5 dB and 0.4 dB, respectively. The original parasitical passband is restrained effectively. We also remark that a small offset of S_{21} curve at the high frequency is caused mainly by some uncertainties in reality such as inaccurate relative permittivity of dielectric substrate and fabrication errors, which can be further improved by carefully tuning the size of CSRRs.

4. CONCLUSION

An improved CRLH filter is presented, using CSRRs to expand the stop band and increase rejection level. The feature of CSRRs with different ring sizes is analyzed, and good signal rejection in the stop band is observed. It is a convenient way to improve the inhibition at any desired band (due to the equivalent single negative permittivity), without deteriorating signal transmission in other band. We also remark that wider stop band and higher rejection could be effectively and easily achieved if more CSRR units are applied in circuit.

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