A Dual-Band Metamaterial Design using Double SRR Structures

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Abstract **─** Based on a periodic array of interspaced conducting split ring resonators (SRRs) and continuous wires, a composite structure is proposed to hold a dual-band in the microwave regime. With simultaneously negative values of effective permeability and permittivity, the composite structure displays a negative refractive index characteristic in a dual-band. The location of the two resonant frequencies is investigated by adjusting the distance between the neighboring asymmetrical SRRs in a single array element. Numerical results show the impact of the distance on the resonant frequencies due to coupling effects. Different simulation softwares are adopted to verify the accuracy of our design.

Index Terms **─** Composite structure, mutual coupling effect, negative refractive index, SRRs.

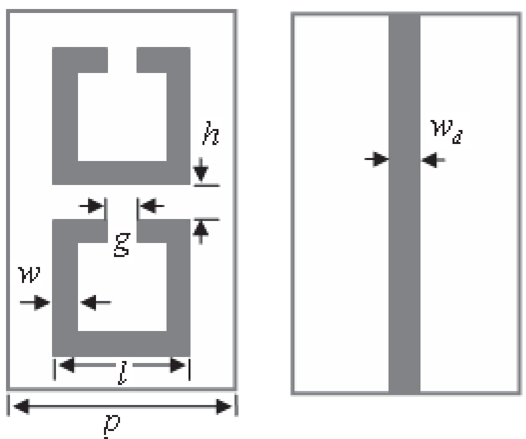
I. INTRODUCTION

Negative index materials (NIMs), hypothesized by Veselago in 1968, are media in which the electric permittivity (ε_{eff}) and the magnetic permeability (μ_{eff}) are simultaneously negative over a common frequency band [1]. The interesting properties of NIMs, such as the reversal of Snell's Law, the Doppler effect, and the Vavilov-Cerenkov effect, have unique abilities to control the electromagnetic wave propagation and revolutionize the microwave component design. Up to now, an important approach to obtain negative values of effective permittivity over wide frequency bands is to use periodic thin wire arrays [2]. Negative values of effective permeability can be obtained by using special magnetic resonator structures, such as split ring resonators (SRRs) and spiral resonators [3]. Many studies have been made on NIM simulations, optimizations, and designs after the first NIM was demonstrated at microwave frequencies in 2000 [4]. For example, dual-band and multi-band metamaterials are developed for engineering applications [5-9]. Metamaterial studies on dual-band operations are reported in THz and near-infrared regions [5-6]. Those structures are composed of two individual resonators with different physical dimensions, which lead to different resonance frequencies. A metamaterial is proposed to possess three pass bands by utilizing the interactions between the ferrimagnetic host and wire array [7]. Multi-band metamaterials are obtained using micro-split SRR structures and multi-layer structures [8]. Those designs mentioned above almost ignore the effects of the mutual coupling between neighboring SRRs. In [9], two distinct resonances are achieved by using the effects of coupling between neighboring SRRs. The design chooses symmetrical structures and does not analyze the influence of the distance between neighboring SRRs.

In this paper, the effects of mutual couplings between two neighboring SRRs are utilized to obtain a dual-band characteristic. Each SRR in the asymmetrical structure responds to a resonant frequency band. How the distance between the two SRRs affecting the coupling effects is simulated and analyzed. Some parameter studies give design insights for practical applications. Finally, results with two different softwares for the dual-band structure calculation are in a good agreement.

II. CONFIGURATION AND ANALYSIS

The schematic view of the composite structure and its design parameters are given in Fig. 1. In this model, two copper SRRs and a wire are positioned on opposite sides of a substrate which has a relative dielectric constant of $\varepsilon_r = 3.5$, a dielectric loss tangent of $\tan\delta_c = 0.003$ and a thickness of $d = 0.5$ mm. The thickness and conductivity of the copper are 0.017mm and 5.8×10^7 S/m, respectively. In Fig. 1(a), the distance h between the neighboring SRRs is a variable parameter.



(a) Top view. (b) Bottom view.

Fig. 1. Schematic view of the composite structure. The geometry parameters are $p = 5$mm, $l = 4$mm, $w = 0.5$mm, and $g = 0.2$mm and $w_d = 0.2$mm.

It is noted that the two SRRs form two different resonant circuits (Loop1 and Loop2) are due to the asymmetry along the horizontal line. When changing the distance h between the two SRRs, the resonant frequencies will shift. Because of the existence of the slit where the electromagnetic fields concentrate, the effect of couplings between the two SRRs has a greater impact on Loop2 than Loop1. Thus, the resonance of Loop2 changes greatly when changing h. So, it is particularly important to understand the coupling between neighboring SRRs for the dual-band design of the structures. This prediction will be verified in the following section.

III. RESULTS AND DISCUSSION

The simulations are performed by using two commercial electromagnetic softwares: Ansoft HFSS and CST Microwave Studio. The investigated array composed of the composite structures shown in Fig. 1 is plotted in Fig. 2. Only an element is needed to be extracted for analysis due to the periodicity. The unit structure under investigation is excited by a plane wave from $-y$ direction with z polarization. The walls perpendicular to the z-axis are modeled to be perfect electrical conductors (PECs) while the walls perpendicular to x-axis are modeled to be perfect magnetic conductors (PMCs). The remaining walls, which are perpendicular to the y-axis, are modeled to be the input/output ports.

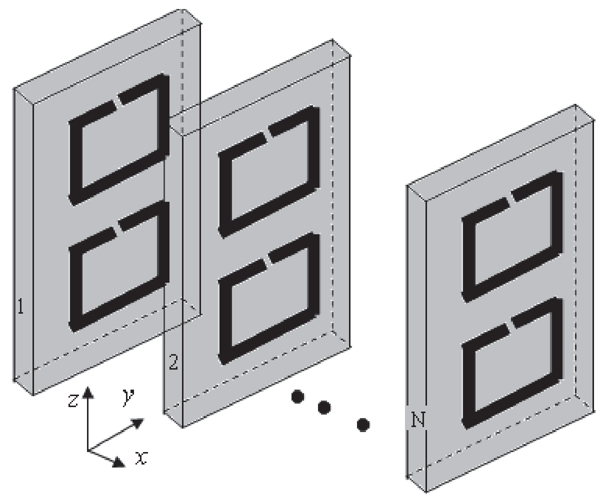
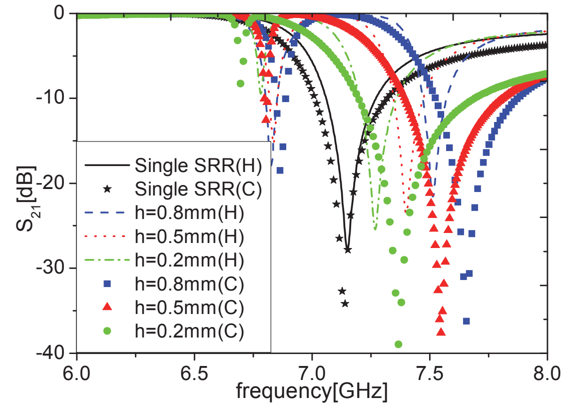


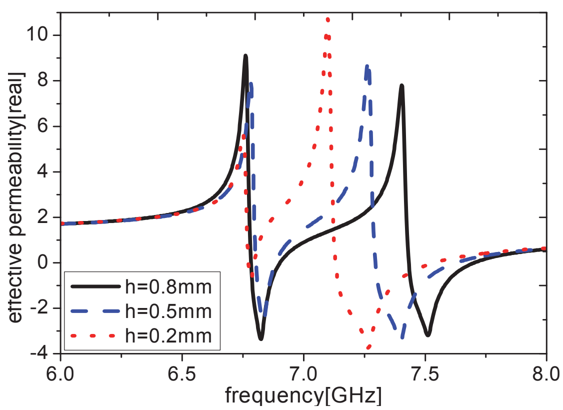
Fig. 2. Schematic three-dimensional simulation of array.

In this section, the effective medium parameters (μ_{eff}, ε_{eff} and n_{eff}) as well as the transmission characteristics are investigated for the proposed structure. Herein, the effective medium parameters of a given structure can be found by a standard retrieval algorithm [10]. In order to verify the identity of views between the artificial magnetism from electromagnetics and the negative refractive index from optics, the resonance responses of the composite structure without the wire are plotted in Fig. 3.

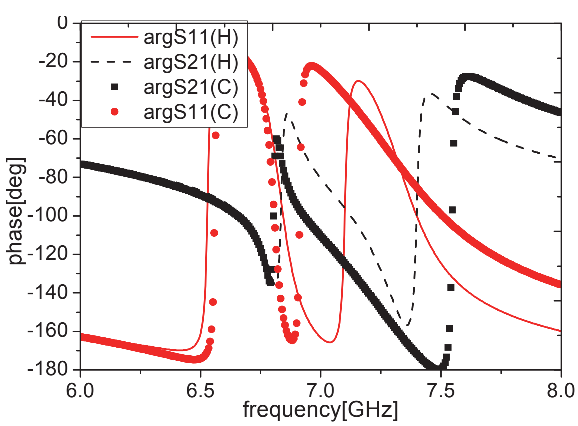
Compared to a single SRR structure with the same size, the interaction of the two SRRs splits the magnetic resonance into two resonances, as shown in Fig. 3(a) where the location of resonance will shift when changing the distance h between the two neighboring SRRs. When h is less than 0.2 mm, the lower resonance becomes weak and the upper resonance is closer to that of the single SRR structure. Figure 3(b) shows that there are two regions with negative permeability near the resonance frequencies. It is also found that the regions shift when changing the distance *h*, similar to the results in Fig. 3(a). The dips in the phase curve of S_{21} in Fig. 3(c) indicate the presence of two negative permeability bands.



(a) S_{21} versus frequency（H-HFSS, C-CST).



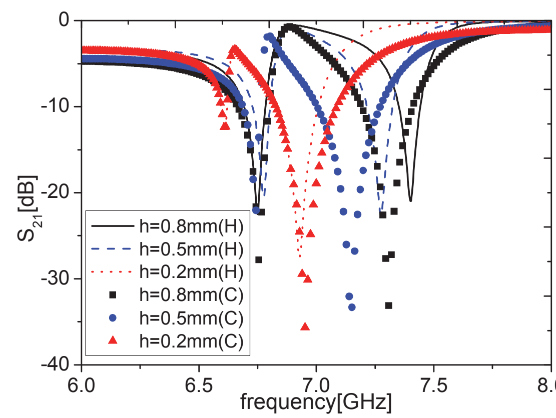
(b) Effective permeability versus frequency.



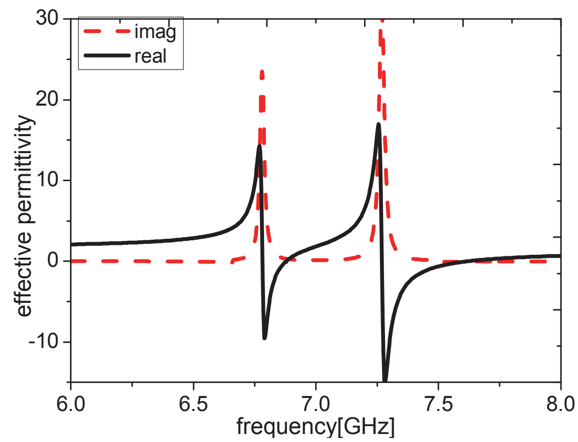
(c) T/R phase versus frequency ($h = 0.5$mm).

Fig. 3. Simulation results for the proposed structures without the wire.

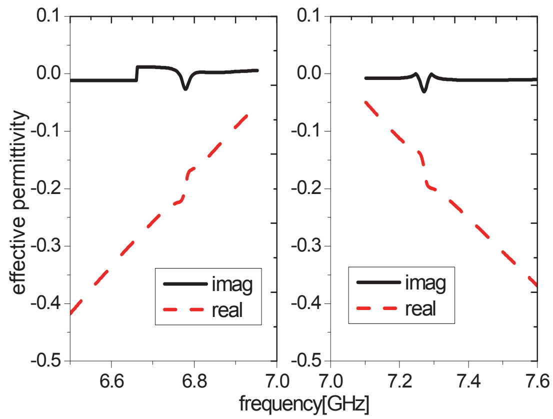
In the following, the response of the structure with a metal wire is investigated. Amplitudes of the S_{21} parameters with different distance *h* are plotted in Fig. 4(a). Also, the effective relative permeability, effective relative permittivity and effective refractive index are given in Figs. 4(b), (c), and (d), respectively. It is found that resonant frequencies in the structure with a wire have a down shift, but the regions with negative permeability are consistent. At the same time, the value of effective permittivity is negative in the region. It can be expected that the structure will exhibit a regime of negative refractive index when the negative permeability band in Fig. 4(c) and the negative permittivity band in Fig. 4(d) overlap. Figure 4(d) shows that there are two regions exhibiting the negative refractive index. It is also noted that when changing the distance *h*, the negative index regions will shift, same as the previous results.



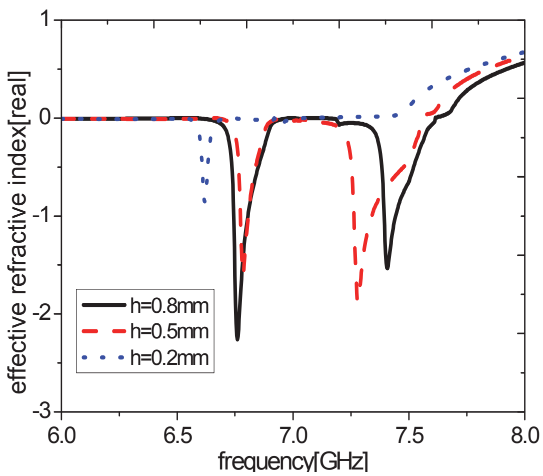
(a) S_{21} versus frequency (H-HFSS, C-CST).



(b) Effective permeability versus frequency.



(c) Effective permittivity versus frequency.



(d) Effective refractive index versus frequency.

Fig. 4. Simulation results for the proposed structures.

IV. CONCLUSION

In this paper, a composite structure composed of double SRRs is proposed to realize a dual-band characteristic. The effects of coupling between neighboring SRRs is considered as one of the major factors in this design. Numerical results show the impact of the distance between neighboring SRRs on the resonant frequencies. Our future works may be focused on how to obtain desired resonances in metamaterials by adjusting the coupling effects.

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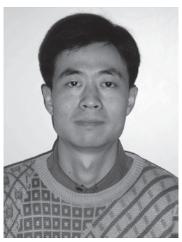

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