EIT-like response in asymmetrically coupled split ring resonators

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Abstract

In this paper we investigate EIT-like effects in coupled split ring resonators, excited with guided waves. We will demonstrate existence of following effects: transmission peak at certain frequency, extreme values of group index of refraction and group delay, and pair of resonators which act as bright and dark element. We also provide method to tune the frequency where EIT-like effects occur.

1. Introduction

Electromagnetically induced transparency (EIT) is the effect which renders narrow transparency window in otherwise opaque medium [1, 2]. It has been explained by destructive interference of transitions between quantum states which prevents the absorption. EIT is associated with extreme dispersion, leading to very high group index of refraction (i.e. low group delay).

Similar effects to EIT can be observed in systems which are entirely classical, under certain conditions, when coupling between two oscillators is present [1, 2]. In particular, by proper coupling of meta-atoms in metamaterial EIT-like absorption can be achieved.

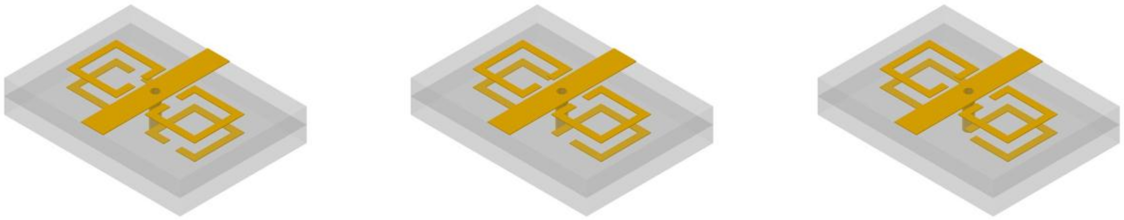
In this paper, we investigate variations in spatial arrangement and geometry of split ring resonators coupled with transmission line (i.e. excited by guided wave). We will demonstrate that these variations affect coupling, and can lead to EIT-like effect, with accompanying high group index of refraction. This type of guiding structure can find application as a delay line, whenever high values of group delay for short electrical lengths are required.

2. Proposed structure

Structures that we investigated are depicted on Fig. 1, where relevant dimensions and substrate parameters can be found in [3]. It consists of microstrip line loaded with via hole, and coupled with four split rings, two in the top layer and two in the middle layer. Bottom layer is metalized. Length of the unit cell is 3.65 mm.

First variation is obtained by twisting the rings in the middle layer by 90 degrees (Fig. 1a). Then two more variations are obtained by moving position of the gap in those rings closer to the corner (Fig. 1b) and in the corner (Fig. 1c). Note that, due to opposite orientation of the rings on each side of transmission line; symmetry is preserved for all three structures. This opposite orientation also causes phase difference between rings on each side, which is necessary to observe EIT-like phenomenon.

Changing position of the gap changes the orientation of the induced electrical dipole in the ring. Consequently it changes the coupling strength between the rings in top and middle layer. The separation between resonant frequencies of coupled oscillator is proportional to the coupling strength; therefore we expect that changing gap position will allow us to tune the resonant frequency of split ring pair.



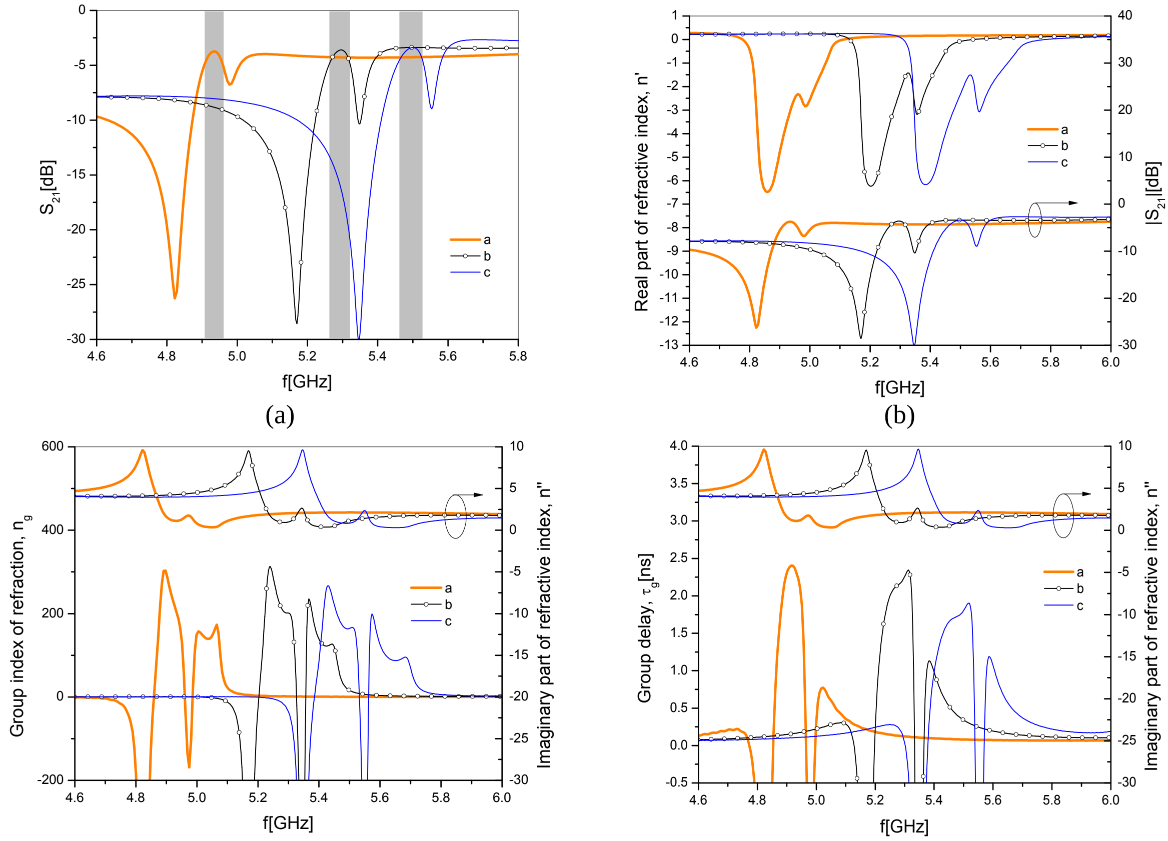
(a) (b) (c)

Fig. 1: Proposed structures obtained by twisting the angle between rings by 90 degrees (a), and then moving gap position (b), (c).

3. Results

Results of full-wave electromagnetic simulations, for structures on Fig. 1, are given on Fig. 2. Transmission coefficient (S21 parameter) magnitude is shown on Fig. 2a. Shaded areas indicate EIT-like transmission peak for each structure. These peaks appear at 4.9, 5.3 and 5.5 GHz for structures on Fig. 1a-c respectively, thus corroborating our assumption about the possibility of tuning. Similar effect would be obtained by changing gap position of the rings in top layer.

Fig. 2b shows extracted effective index of refraction for these structures, which exhibit large bands of negative values. Fig. 2c shows effective group index of refraction, which has extreme values (260-300) at frequencies that correspond to transmission peaks, which further extends analogy with EIT. Finally, Fig. 2d shows group delay, calculated from phase of transmission coefficient, also shows extreme values at frequencies of interest (1.8-2.5 ns), which agrees well with group index of refraction.



(a) (b) (c) (d)

Fig. 2: Results for (a) transmission coefficient; (b) index of refraction; (c) group index and (d) group delay.

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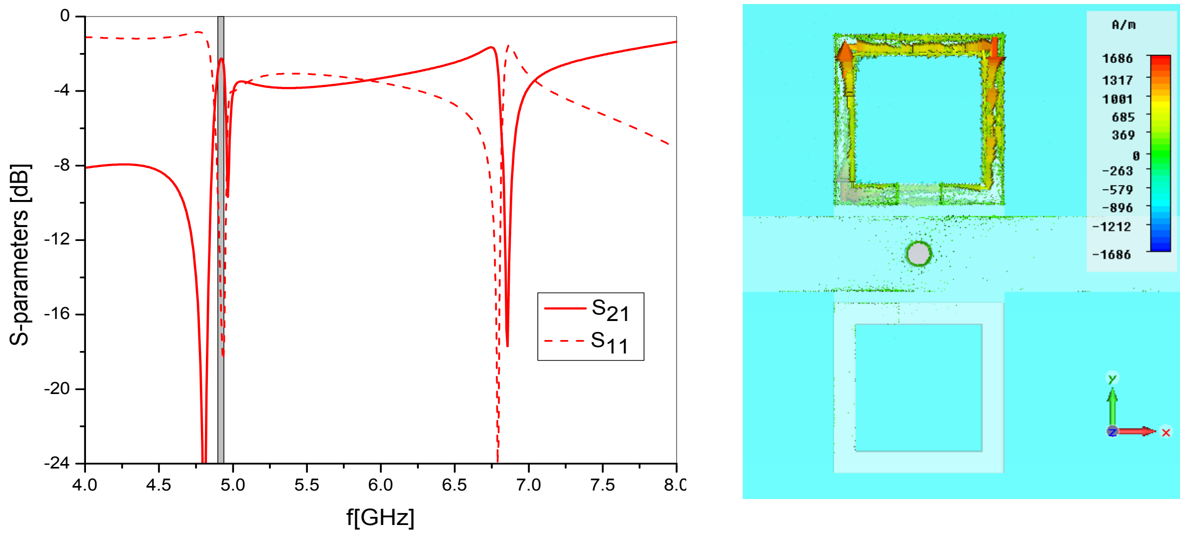
To get additional insight in this phenomenon, we examined current distribution in transmission peak. Fig. 3a shows transmission and reflection for structure 1a, and Fig. 3b shows current distribution along the rings, for the shaded frequency on Fig. 3a. Here we observe clearly that only one pair of rings is strongly excited, therefore acting as a bright element, while other is practically unexcited, acting as a dark element. This type of behaviour is characteristic for EIT-type phenomenon [1].



(a) (b)

Fig. 3: (a) Transmission and reflection coefficients and (b) current distribution along the rings for structure on Fig. 1a.

4. Conclusion

We have demonstrated an EIT-like effect for system of coupled split rings, excited by guided wave. Analogy with EIT can be seen in transmission peak at certain frequency, extreme values of group index of refraction (up to 300) and group delay (up to 2.5 ns). This analogy is further supported by examining current distribution along the rings, where we show that one pair of split rings acts as bright, and the other as dark element.

We also provide ability to tune EIT-like transmission peak by changing position of the gap in rings with perpendicular gap. Here we obtained three frequencies: 4.9, 5.3 and 5.5 GHz, but arbitrary frequency in this range could be obtained by optimizing gap position. Further study is required to find out maximal and minimal achievable frequencies.

References

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