On the orientation of split-ring resonators excited by guided waves

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Abstract

In this paper we investigate how different positions of a gap influence the characteristics of split-ring resonators coupled to microstrip line. We show that split-ring resonator (SRR) with a gap perpendicular to microstrip line exhibits a strong electric response. Its magnetic response is a very weak despite of the external magnetic field that is perpendicular to the SRR plane. Influence of via that connects microstrip line to ground plane is also examined.

1. Introduction

Electric coupling to magnetic resonance of split-ring resonator and the influence of electric response of SRR to the electric response of the wire were studied in details in papers [1-4]. It was found both, theoretically and experimentally, that SRR in addition to the magnetic response has the electric response that is identical to the response of cut wires. But, this fact was not exploited much in the applications of SRRs when they are excited with guided waves. It is still considered an obvious that the incident EM wave excites the magnetic resonance only if the external H-field is perpendicular to the SRR plane. Experimental verification of existing electric and/or magnetic resonances depending on the orientation of SRRs is performed only in free space [3].

In this paper we investigate both, numerically and experimentally how different positions of the gap affect the characteristics of SRRs excited by microstrip line. We compared the conventional SRR with a gap that is parallel to microstrip line to the SRR with a gap that is normally placed. We found a considerably different influence of via to SRR with a different orientation of the gaps. Although the external H-field is perpendicular to the SRR plane in both cases we found that only a strong electric resonance is excited in the SRR with a gap perpendicular to the transmission line, while the strong magnetic resonance exists in the conventional SRR with parallel gap.

2. Split-ring resonators with different positions of the gap

We investigated the characteristics of split-ring resonators coupled to microstrip line whose gap has a different position in respect to the transmission line: when the gap is parallel to the line and when is perpendicular to it. Unit cells with two split-ring resonators whose gaps have a different position are shown in Figure 1. Each cell is realized on two-layer substrate (h_1=0.635mm, h_2=1.575mm, ε_{r1}=10.2, ε_{r2}=2.2). In the middle between SRRs there is a vertical via that connects microstrip line with ground plane. Except the position of the gaps all geometrical parameters of unit cells are identical.

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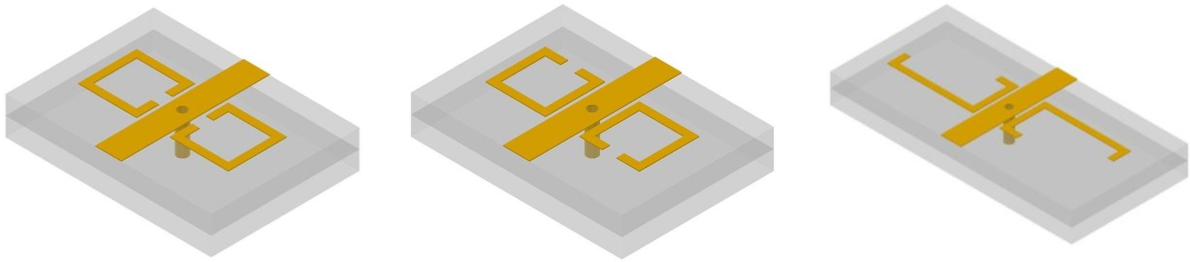
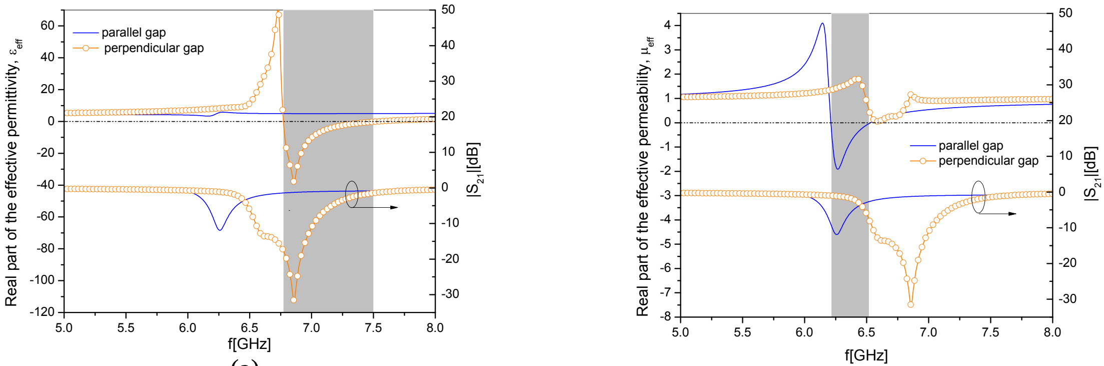


(a) gaps parallel to the line (b) gaps perpendicular to the line (c) J-resonator

Fig. 1: Different unit cells which consist of SRRs with the different positions of the gaps and J-resonator.

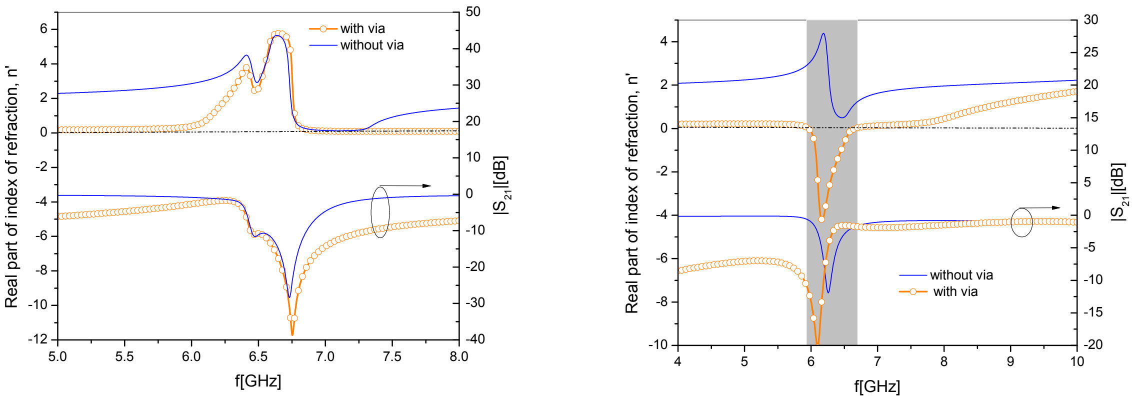
Extracted effective permittivity and permeability for the unit cell without via are shown in Figure 2. It can be seen that SRRs with parallel gaps exhibit negative values of the effective permeability due to their resonant magnetic response excited by magnetic field perpendicular to the SRR plane. It is interesting to note that the extracted effective permittivity for SRRs with gap perpendicular to microstrip line exhibits very clear range of negative values due to strong electric or cut-wire response. Almost the same effective parameters are extracted for the unit cells which consist of two J-resonators obtained by rectifying the upper horizontal segment of SRRs as it is shown in Fig.1c.



(a) (b)

Fig. 2: Extracted effective permittivity and permeability for the unit cells without via. Rectangular bars show the range of negative values of the effective parameters.

Influence of the via is also different for the SRRs with parallel and perpendicular gap: it adds negative permittivity to existing negative permeability forming left-handed band in the case of parallel gap, while in case of perpendicular gap, only the shape of effective parameters is a little bit changed. Influence of via to the index of refraction for two positions of the gap is shown in Fig. 3.

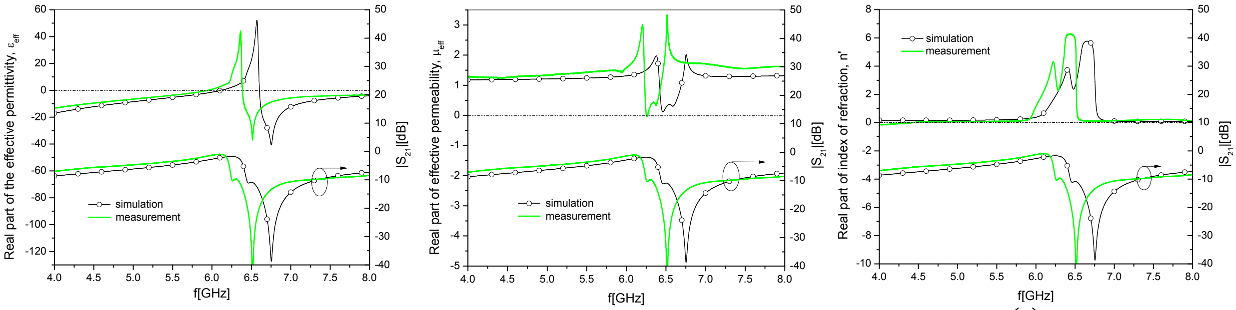


(a) perpendicular gaps (b) parallel gaps

Fig. 3: Influence of via to the extracted index of refraction for SRRs with: (a) perpendicular gaps and (b) parallel gap in respect to microstrip line. Rectangular bars show the left-handed band.

3. Measured results

We fabricated and measured the samples with SRRs that have two different positions of the gaps. Measurements are performed on Agilent PNA E8364A network analyzer using custom designed TRL calibration set to obtain *S*-parameters at the defined reference plane. Extracted effective parameters for the sample with via and perpendicular gaps are shown in Fig. 4. Measured results are very similar to the numerical simulations, except the small frequency shift of about 200MHz due to influence of the glue added between two substrate layers during fabrication that is not taken into account in simulations.



(a) (b) (c)

Fig. 4: Extracted effective parameters from simulated and measured results for unit cell with gaps perpendicular to microstrip line. Unit cell is with via.

4. Conclusion

In this paper we investigated the influence of the position of the gapes in split-ring resonators excited with microstrip line. We noticed a very strong electric response in the SRR with gap perpendicular to microstrip line, which gives the negative value of permittivity. At the same time the SRR with gap parallel to the line exhibits a strong magnetic resonance that is obvious, since it is excited with magnetic field perpendicular to SRR plane. It is interesting that SRR with perpendicular gap has almost the same characteristics as a J-resonator that is formed by rectifying the horizontal segment of the SRR.

Adding via to the SRR with perpendicular gap as well as to the J-resonator does not change considerably their characteristic. But, it has a great influence to the characteristics of the SRR with parallel gap, since via gives a negative permittivity in the range where the negative permittivity already exists and creates the left-handed pass band.

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