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Frequency Tunable Transmission Lines based on composite Metamaterial unit Cells

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Abstract

In this work; a frequency tunable transmission lines are designed using metamaterial split ring resonator unit cell. We prove that the tuning principle in metamaterial transmission lines is based on the variation of the resonance frequency of the permeability. The frequency-tuning, arises by changing the values of two gaps in the inner and outer rings of unit cell (g_1 and g_2). The branches of a disconnected gaps type conductor of each unit cell can be joined by switches (PIN diodes, MEMs, etc.). According to switch states ON or OFF, the unit cell has four different commutable behaviors which are 00, 01, 11 and 10. The results show that the resonance frequency of our metamaterial transmission line is strongly shifted by about 2.5 GHz between the cases (01) and (11).

Key-words: *Tunable Metamaterial, composite Metamaterials, Transmission line, RF-MEMS.*

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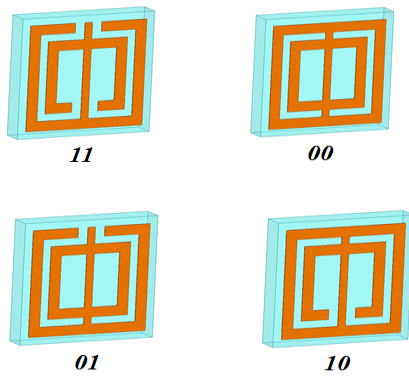
1. Introduction

The technologies to implement reconfigurable and tunable metamaterial transmission lines has seen significant progress in recent years [1]. The tuning is achieved through electronic actuation where, typically, changes in a capacitance, or local changes in the permittivity of a dielectric layer, are generated by the actuated voltage or applied field. These tunable or reconfigurable structures operate in the lineal regime[2]. Micro-electromechanical systems for radio-frequency applications (RF and MEMS) constitute a key enabling technology for telecommunication systems [3]. The successful integration of RF and MEMS switches in electrically small metamaterial resonators is expected to be an enabling technology for many microwave applications. The tuning principle in most metamaterial transmission lines is based on the variation of the resonance frequency of the resonant elements through electronic actuation. This tuning can be achieved by loading the split rings (SRRs, OCSRRs, etc.,) with varactor diodes or RF-MEMS. The goal of this work is to tune the frequency of metamaterial transmission line by changing the resonance frequency of the effective permeability in the SRR unit cell. It can be controlled by an external command system (PIN diodes, MEMs, etc).

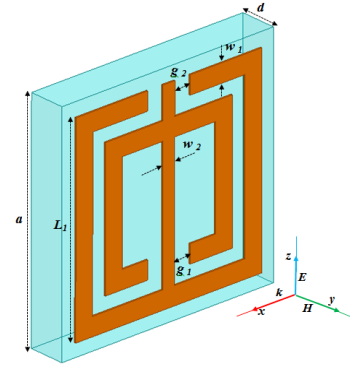
2. Method

2.1 Design of tunable metamaterial unit cell

Our tunable elementary unit cell is composed of split-ring resonator made of disconnected conducting with two gaps (g_1 , and g_2) in the inner and outer rings on opposite sides. Each gap can be joined by switches that enables to control over individual metamaterial elements. According to switch states (ON or OFF), the unit cell has four different behaviors that are (00, 01, 11, 10) as shown in Figure 1-(a). The actionable behavior of our unit cell allows us to introduce the tuning of metamaterial transmission line. The representation of the unit cell with all the geometrical parameters is shown in Figure 1-(b). The incident wave in Figure 1-(b), is a plane wave with its wave vector k in the x -direction and the E-field polarized in the z -direction, while the magnetic field vector H oriented along the y -direction.



(a)



(b)

Fig 1. (a)- All different cases of the gaps (g_1 and g_2), (b)- Tunable metamaterial unit cell ($w_1=0.2$ mm, $w_2=0.14$ mm, $d=0.8$ mm, $a=2.5$ mm, $L_1=2.2$ mm).

2.2 Effective Parameters Extraction

Several reports have been published for the extraction of the constitutive parameters by using scattering parameters S . They deal with the isotropic parameters of metamaterials. However, it has already been demonstrated [4] that most metamaterials are intrinsically bianisotropic due to the asymmetry of the composite components such as split-ring resonators.

For a bianisotropic metamaterial, the propagation wave vector is related not only to permittivity and permeability but also to the magneto-electric coupling coefficient. Figure 2 shows the schematics of a homogeneous bianisotropic material slab. The metamaterial effective parameters extraction requires two steps [5]:

- Computation of the homogenized metamaterial forward and backward wave impedance (z^+ , z^-) and complex refractive index (n) which are expressed in terms of reflection and transmission coefficients S_{ij} .

- Retrieval of the electromagnetic constitutive parameters (permittivity, permeability and magneto-electric coupling coefficient) from the S_{ij} parameters.

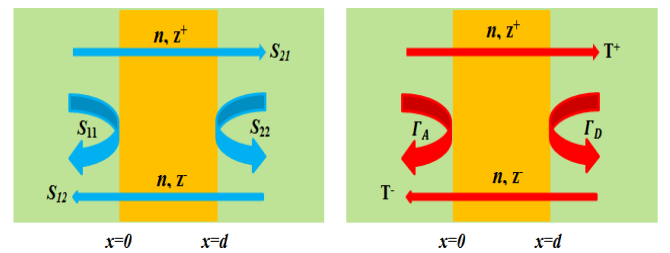


Fig 2. Transmission and reflection coefficients in bianisotropic metamaterial

The effective parameters expressions (magnetolectric coupling coefficient and effective permeability) are:

$$\zeta_0 = \frac{(2 - \Gamma_C)^2 - (4\Gamma_A^2 + \Gamma_C^2)}{4i\Gamma_A\Gamma_C / n} \quad (1)$$

$$\mu_{yy} = \frac{\Gamma_C(n^2 + \zeta_0^2)}{n(2 - \Gamma_C) - 2n\Gamma_A - i\Gamma_C\zeta_0} \quad (2)$$

3. Results

3.1 Characterization of tunable metamaterial unit cell

In this section, we study the influence of the gaps g_1 and g_2 on the electromagnetic properties of metamaterials. We use the effective permeability and the transmitter powers as an essential two parameters to appreciate the efficiency of the tunable metamaterial unit cell.

The simulation results of effective permeability and transmitted power for different values of the gap g_2 (case 01) where $g_1=0$ are shown in Figure 3.

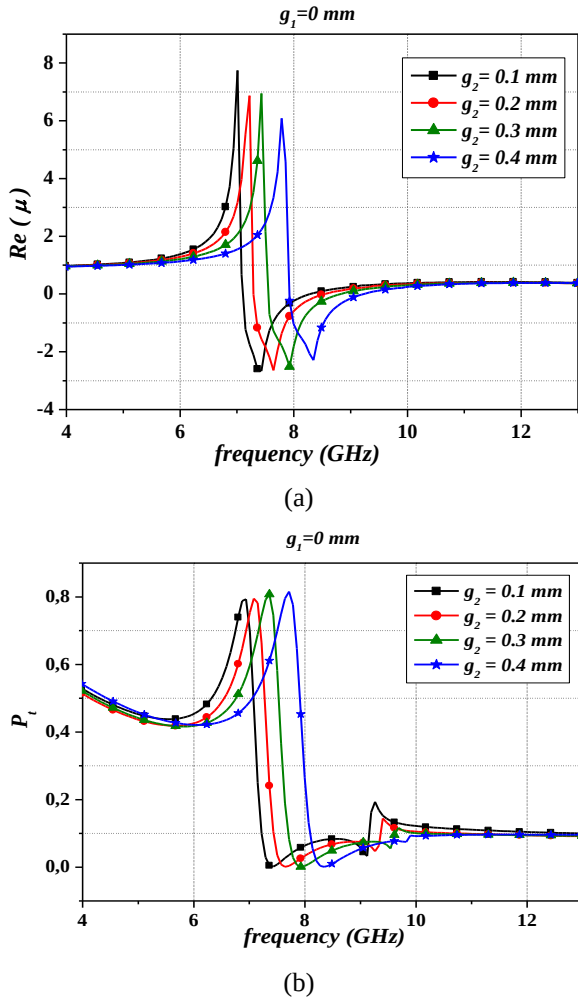


Fig 3. (a) Real part of permeability (b) transmitted power for different values of the gap g_2 .

It is clear from the plot that the metamaterials shows the normal resonant behavior in the frequency band (6-9 GHz).

The resonance frequency shift to the higher frequency when the gap g_2 increases as shown in figure 3-(a). The transmitted power is normalized to incident power and calculated over the 4 to 13 GHz frequency band, it is about 80 % at 7.3 GHz for $g_2=0.1$ mm as shown in Figure 3-(b).

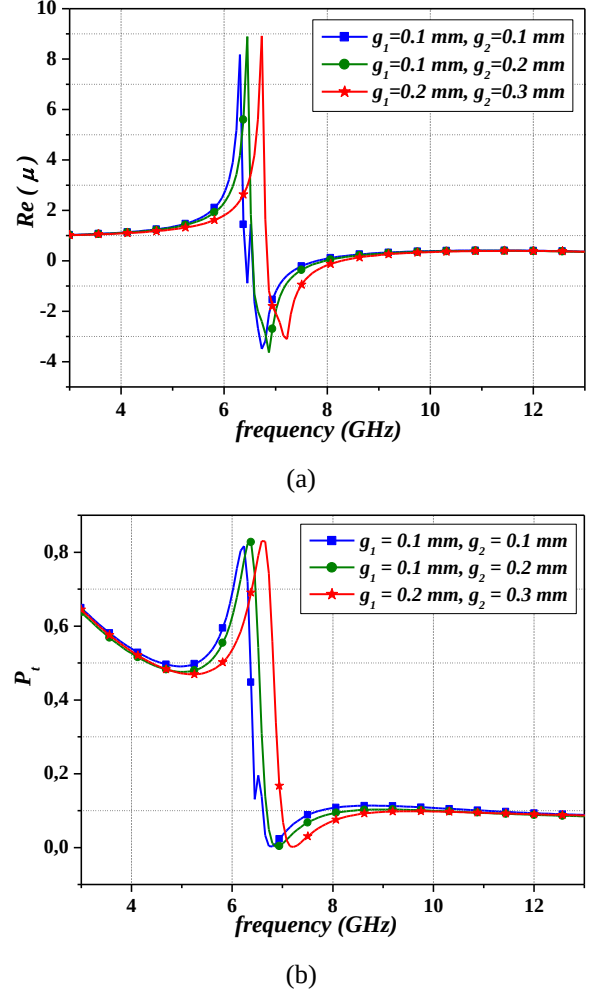
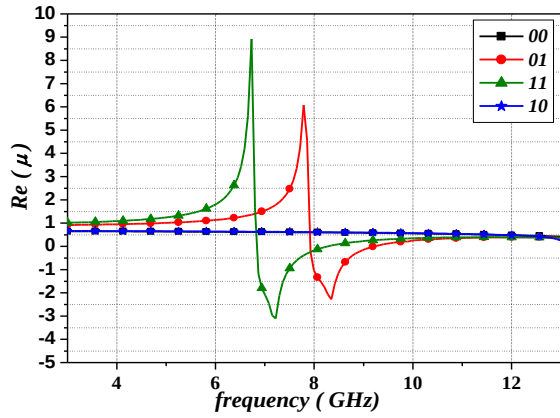


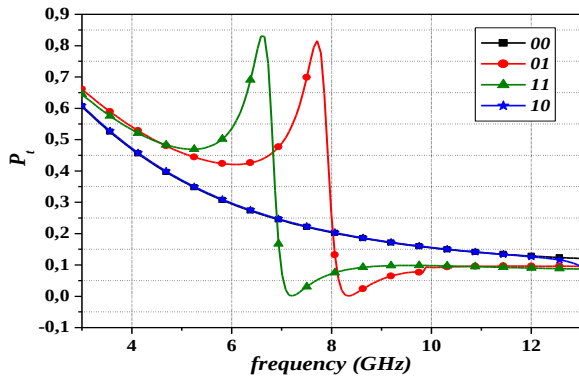
Fig 4. Real part of permeability (b) transmitted power for different values of the gaps (g_1 , and g_2).

Figure 4-(a, and b), illustrate the effect of the gaps g_1 and g_2 on the transmitted power and real permeability (case 11). It can be seen that we also have a normal resonant behavior in this case. The resonance frequency is slightly shifted to the higher frequency band.

Figure 5, illustrates all previous results (cases 00, 01, 11 and 10). We note that the behavior of metamaterial can be tuned by opening the gap g_2 or each gap (g_1 and g_2) in the same time (case 01 and 11). The case 01 acts strongly on the metamaterial frequency resonance which shifts to higher frequencies when g_2 is increased.



(a)



(b)

Fig 5. (a)-Real part of permeability (b)-transmitted power for all different cases (00, 01, 11, 10).

3.2 Conception of tunable transmission line

We use the tunable metamaterial unit cells (Figure.1) to design a tunable metamaterial transmission line. The proposed metamaterial transmission line consists of 8 SRR unit cells as shown in Figure 6.

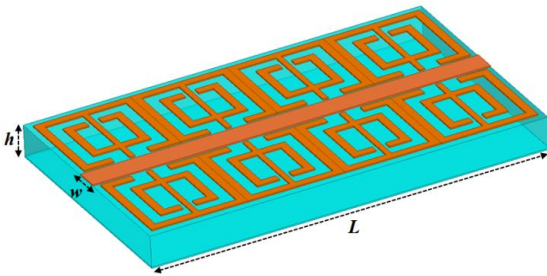


Fig 6. Tunable metamaterial transmission line ($w=0.6$ mm, $L=10$ mm, $h=0.8$ mm).

The simulation was done for different values of the gaps (g_1 and g_2).

Figure 7, illustrates all previous cases (cases 00, 01, 11, and 10). The resonance has shifted in the case 11 to around 7 GHz from the 9.5 GHz obtained in the case 01. The results

support the hypothesis that the tuning can only be achieved if we have a variation on the resonance frequency in the permeability.

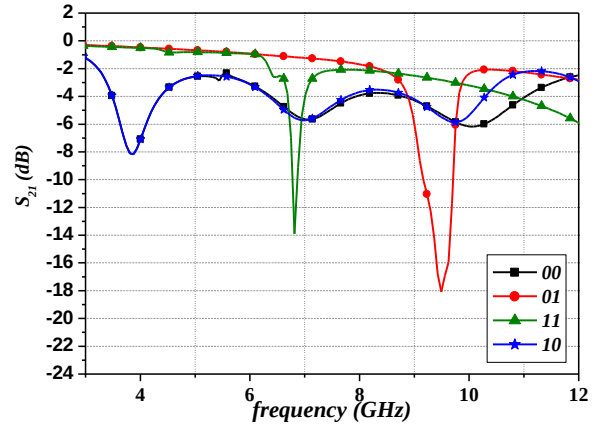


Fig 7. Transmission parameter S_{21} for all cases.

4. Conclusion

We have design and investigate a tunable metamaterial transmission line for the microwave applications. Metamaterial transmission lines can be useful as tunable and reconfigurable filters. It is possible to tune the filter central frequency by changing the resonance frequency of the effective permeability in the unit cell.

The obtained results show that the resonance frequency of our metamaterial transmission line can be shifted by about 2.5 GHz between the cases (01) and (11).

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