

Microwave Switch based on Tunable Single Negative Metamaterials

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Abstract—The microwave switch based on tunable single negative (SNG) metamaterials was presented. Firstly, the tunable SNG metamaterial was fabricated and its electromagnetic properties were investigated. It was found that the gap properties of the SNG metamaterial can be tuned conveniently and the epsilon-negative (ENG) gap can change to mu-negative (MNG) gap by increasing external voltage. Then, the microwave switch based on the tunable SNG metamaterial was designed through exploring the transmission properties of the heterostructure constructed by the tunable SNG metamaterial and an ENG metamaterial.

Keywords—metamaterial; tunable; single negative; microwave switch

I. INTRODUCTION

Single negative (SNG) metamaterials, as one kind of metamaterials, have attracted intensive studies in the past few years, due to their unique electromagnetic properties and potential applications[1-26]. There are two kinds of SNG metamaterials: one is the epsilon-negative (ENG) metamaterial, in which the permittivity is negative but the permeability is positive; the other is the mu-negative (MNG) metamaterial, whose permeability is negative but permittivity is positive. In order to implement SNG metamaterials, many structures have been presented, such as the array of split ring resonators, thin metal wires, metallic S-like ring array, transmission lines with series capacitors and shunt inductors loading, and so on [2-8]. Nevertheless, all these metamaterials have fixed operating frequencies and their working band can't be tuned, which limits their practical applications greatly.

In recent years, tunable metamaterials have attracted recently intensive attentions and different kinds of tunable metamaterials have been proposed [13-21]. For example, in Ref. [9-15] ferroelectric materials, ferromagnetic materials, and liquid crystals are hired. These metamaterials can be controlled by dynamic magnetic fields, high voltages or temperature. In order to make up a metamaterial that is more convenient to control, the varactor diodes, which can be tuned just by low direct current voltages, are also considered. For instance, in Ref. [16-19] different kind of active tunable metamaterials based on varactor diodes have been studied.

In this paper, the tunable SNG metamaterial is fabricated and its electromagnetic properties are investigated detailly. The results show that by tuning the external voltage, the SNG gap of our structure can alter from ENG gap to MNG gap and in the meantime, the width and depth of the ENG or MNG gap can be

controlled conveniently. Moreover, the transmission properties of the heterostructure constructed by the tunable SNG metamaterial and an ENG metamaterial are also investigated. It is found that the tunneling phenomenon will conditionally emerge by tuning the external voltages. With these features, the tunable SNG metamaterial heterostructure can be utilized in designing the microwave switch.

II. TUNABLE SNG METAMATERIAL

As we all know, the SNG metamaterials can be realized by periodically loading series capacitors and shunt inductors on transmission line as shown in Refs. [2, 8]. For the microstrip metamaterial, the effective permittivity and permeability can be determined by the following approximate expressions [22]:

$$\epsilon_{eff} \approx (C_0 - 1/\omega^2 Ld)/p, \quad (1)$$

$$\mu_{eff} \approx p(L_0 - 1/\omega^2 Cd), \quad (2)$$

where p is the structure constant of the microstrip line, L and C are the values of the loaded inductors and capacitors respectively and L_0 and C_0 are the distributed parameters of the microstrip line. The tunable SNG metamaterial can be realized by loading varactor diodes in stead of series capacitors on the microstrip, as shown in Fig. 1. Here, each unit cell consists of one inductor and two varactor diodes. All varactor diodes are connected end to end or head to head. Direct current (DC) electric power is applied on the varactor diodes through restricting circuit resistors. The wire denoted by V_+ is connected to the positive electrode of DC power supply and the cathode of DC power supply is connected to the ground plane of microstrip through wire V_- . In addition, series radio frequency chokes (RFC) are used to separate the alternating current (AC) signal network and the coupling capacitors are used to avoid the diode reverse saturation current flowing into the measurement equipment of network analyzer. For our sample, the microstrip transmission line is designed with strip width 2.73 mm to match the characteristic impedances 50 Ω . The substrate is F4B with thickness $h = 1$ mm and relative permittivity $\epsilon_r = 2.65$. Under these parameters, the distributed inductor and capacitor values are $L_0 = 248$ nH/m and $C_0 = 99$ pF/m respectively and the structure constant is 5.04.

In order to investigate the transmission property of the tunable SNG metamaterial, The S₂₁ parameters of the tunable SNG metamaterial with different bias voltages are measured by Angilent 8722ES vector network analyzer, as shown in Figs. 2(a) and 2(b). In the meantime, the effective permittivity and permeability of the metamaterial under the bias voltages of 2 V and 20 V are calculated using Eqs. (1) and (2), and depicted in Figs. 3(a) and 3(b). According to Figs. 3(a) and 3(b), it can be seen that, in Fig. 2(a), the stopband is ENG in nature, while in Fig. 2(b) the MNG gap is obtained. Therefore, for the metamaterial shown in Fig. 1, the electromagnetic property of bandgap can be alternated by tuning the external voltage applied on the varactor diodes. In addition, for the ENG gap shown in Fig. 2(a), its lower edge frequency is sensitive to the external bias, while the higher one is not, resulting in the change of gap width and depth. For MNG gap, the situation is similar, except that its higher edge frequency of MNG gap is sensitive to the external bias, while the lower one is not, as shown in Fig. 2(b).

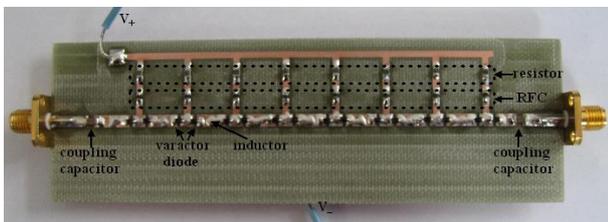


Figure 1. The photograph of the tunable SNG metamaterial based on microstrip line.

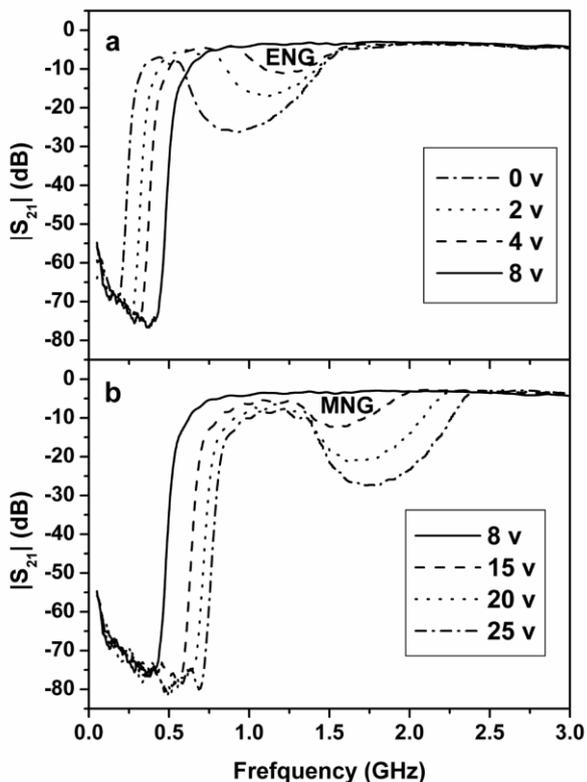


Figure 2. The measured S₂₁ parameters of the tunable SNG metamaterial with different bias voltages.

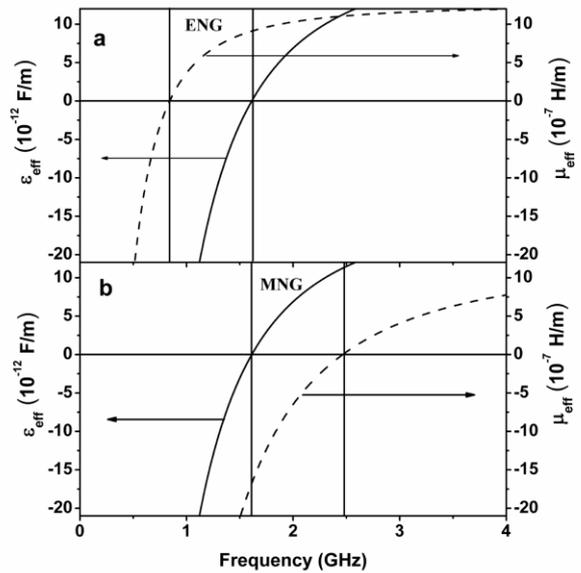


Figure 3. The calculated effective permittivity and permeability of the tunable microstrip metamaterial. (a) The bias voltage is 2 V; (b) The bias voltage is 20 V.

III. MICROWAVE SWITCH BASED ON TUNABLE SNG METAMATERIAL

In order to explore the application of the tunable SNG metamaterial, a heterostructure constructed by the tunable SNG metamaterial and ENG metamaterial is designed, shown in Fig. 4. The left part is the tunable SNG metamaterial and the right part is a nontunable ENG metamaterial fabricated by loading lumped-element series capacitors (3.0 pF) and shunt inductors (3.9 nH) on microstrip. The measured S₂₁ parameters of the heterostructure with different bias voltages are illustrated

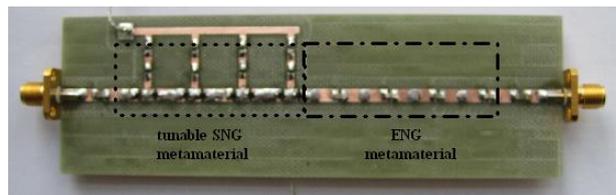


Figure 4. The photograph of heterostructure constructed by the tunable SNG metamaterial and the ENG metamaterial.

in Fig. 5. Obviously, the bias voltage also has a great effect on the transmission properties of the heterostructure. As we know, EM tunneling only occurs in the MNG-ENG heterostructure and when the average permittivity and average permeability is simultaneously zero, a complete tunneling can just be obtained [1,2,8]. In Fig. 5, when the bias voltage is small, e.g. 6 v, there is no EM tunneling as the tunable SNG metamaterial is ENG here and the tunneling condition isn't met. However, when the bias voltage is enhanced and the tunable SNG metamaterial changes to a MNG metamaterial, EM tunneling begins to emerge in the heterostructure. When the bias voltage is increased to a certain value (for our sample, about 18 v), the tunneling condition is best

satisfied and a highest transmittance is obtained. Therefore, the heterostructure containing the tunable SNG metamaterial can be utilized as a microwave switching, due to that a good electromagnetic tunneling will happen under a certain voltage value (about 18 v for our sample) while there is no tunneling phenomenon under some voltage values (e.g. 6 v or smaller for our sample).

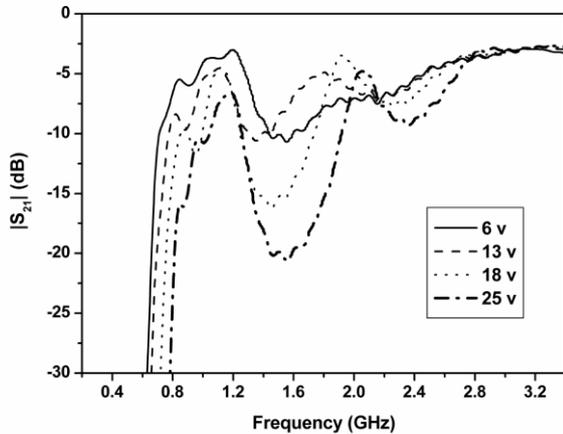


Figure 5. The measured S_{21} parameters of the heterostructure shown in Fig. 4 with different bias voltages.

IV. CONCLUSION

To sum up, we investigated detailedly the transmission properties of the tunable SNG metamaterials based on the microstrip line. We found that by tuning the external voltage, our structure can provide either an epsilon-negative or a mu-negative band gap, with varying gap width and depth. Moreover, the heterostructure constructed by the tunable SNG metamaterial and an ENG metamaterial was also investigated. It was found that the tunneling phenomenon will conditionally emerge by tuning the external voltages. Therefore, a microwave switching can be designed based on the heterostructure constructed by the tunable SNG metamaterial and an ENG metamaterial.

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