2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

A Polarization-Independent Switchable Absorber with Independently Controllable Absorption Frequencies

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Abstract

In this paper, a polarization-insensitive reconfigurable microwave absorber has been presented for switching applications. The proposed design is comprised of a rotated cross-dipole geometry, where the active components (PIN diodes) are mounted across the gaps symmetrically. The novelty of the structure exists in its independent control of the absorption frequencies in two different biasing conditions (ON and OFF states) by tailoring the physical parameters. Moreover, the diodes in the structure are loaded in parallel combination, which results in high accuracy and low operating voltage. Due to axial symmetry, the proposed design also exhibits switching response for both (horizontal and vertical) polarizations of incident wave. Experimental verification of the fabricated prototype has also confirmed the possibility of employing the proposed structure in various practical applications.

1. Introduction

Frequency selective surfaces (FSSs) are extensively used in a variety of applications, such as spatial filters, radomes, antennas, absorbers, shielding, and so forth [1, 2]. In recent years, increasing numbers of multifunctional and multi-application communication systems have paved the way to the development of reconfigurable FSS structures [3], [4]. Consequently, different tunable and switchable FSSs have been designed exhibiting various characteristics. A tunable absorber regulates the absorption frequency within a certain range [5], whereas switchable absorbers shift the frequency response between two different frequencies of interest [6]. These structures offer several promising applications in imaging, stealth technique, wireless communication, and security.

Several techniques have been implemented to obtain different types of switchable absorber designs; they can be controlled either electronically (using PIN diodes), mechanically (using spring resonators), or magnetically (using ferrites). However, active component (diode) enabled structures offer high speed, low cost, and compact size compared to the other sets of reconfigurable absorbers [7]. In the last few years, a few diode-controlled switchable absorbers have been presented in the literature, but most of them operate for single polarization only [8, 9]. Recently, a polarization-insensitive switchable absorber has been reported [10], however, it requires large operating voltage as the diodes are connected in series circuit. Besides, the design can't be controlled independently in two different biasing states. Therefore, a dual-polarized switchable absorber with independently controllable absorption frequencies is much needed in the current scenario.

In this paper, a narrow-band switchable microwave absorber has been presented based on rotated cross-dipole geometry. The proposed structure has two noteworthy advantages compared to the existing switchable absorbers – first, the absorption frequencies in two different states can be controlled independently through varying the physical parameters. Second, the active components are connected in parallel combination, thereby requiring minimal operating voltage and resulting in high accuracy. The proposed structure is axially symmetrical as well as angularly stable. Surface current distributions has also been studied to explain the switching mechanism of the proposed structure. Finally, an innovative biasing circuit has been incorporated to realize the prototype, which shows reasonable agreement between the measured and simulated responses under normal incidence.

2. Layout

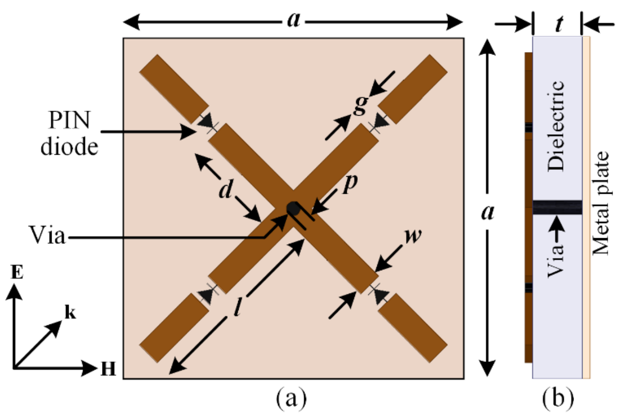


Figure 1. Unit cell layout of the proposed switchable absorber. (a) Top view, and (b) side view.

Figure 1 shows unit cell layout of the proposed switchable absorber, whose top layer consists of a rotated cross-dipole geometry and it is connected with the ground plane through metallic via at the centre. The semiconductor switches are mounted symmetrically across the slots present in the cross-dipole. The whole pattern is periodically imprinted on the grounded FR4 substrate (*tanδ* = 0.02 and ε_r = 4.4). BAP 70-03 PIN diodes are used in the design as the active components, which provide small resistance (R_{ON} = 1.5 ohm) and large capacitance (C_{OFF} = 0.1 pF) under ON and OFF states, respectively. The geometrical dimensions of the structure are optimized as follows: a = 24 mm, l = 13.6 mm, d = 6.74 mm, w = 1.8 mm, g = 1.7 mm, p = 0.8 mm, and t = 1.6 mm.

When the plane electromagnetic (EM) wave is impinged on the structure, the cross-dipole geometry realizes an equivalent inductance along the incident electric field direction. During forward bias voltage, the diodes exhibit low resistance, and the entire length of the cross-dipole (*l*) provides and effective inductance, thus giving rise to a narrow-band absorption at a particular frequency. On the contrary, the diode has an equivalent capacitance during OFF state, and the equivalent inductance is resulted from the length starting from the centre up to the diode position (*d*). Therefore, the structure resonates at higher frequency due to smaller value of inductance, thus resulting in switching characteristic between the biasing conditions.

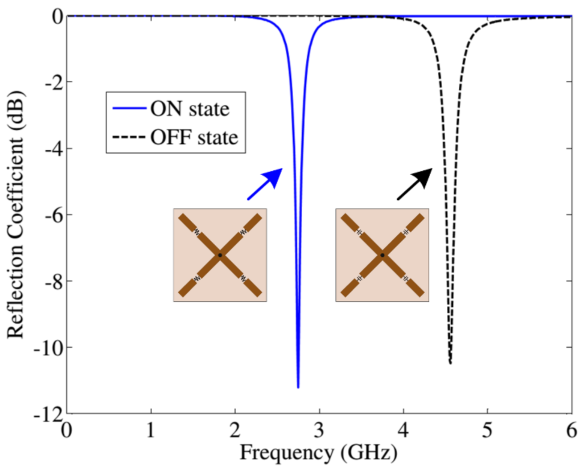


Figure 2. Simulated reflection coefficients of the proposed switchable absorber under normal incidence for both ON and OFF states.

Figure 2 exhibits the simulated reflectance of the proposed absorber under normal incidence. During ON state, the reflection dip is observed at 2.75 GHz having reflectivity of -11.21 dB, while the reflection dip is shifted to 4.56 GHz (with reflection coefficient of -10.48 dB) under OFF state. The resonance frequency thus switches from S-band (ON state) to C-band (OFF state), and can be used in any of these two microwave frequency spectra as required.

The surface current distributions of the proposed structure are also illustrated in Figure 3 to explain the switching mechanism. Under ON state, the current flows through the entire cross-dipole length (*l*), which gives rise to a narrow-band absorption at 2.75 GHz as observed from Figures 3(a) and 3(b). However, the diode exhibits an equivalent capacitance during OFF state, and the surface current is unable to flow beyond the gaps (*d*) as depicted in Figures 3(c) and 3(d). Therefore, the effective inductance of the structure is reduced, and the absorption is shifted to higher frequency (4.56 GHz).

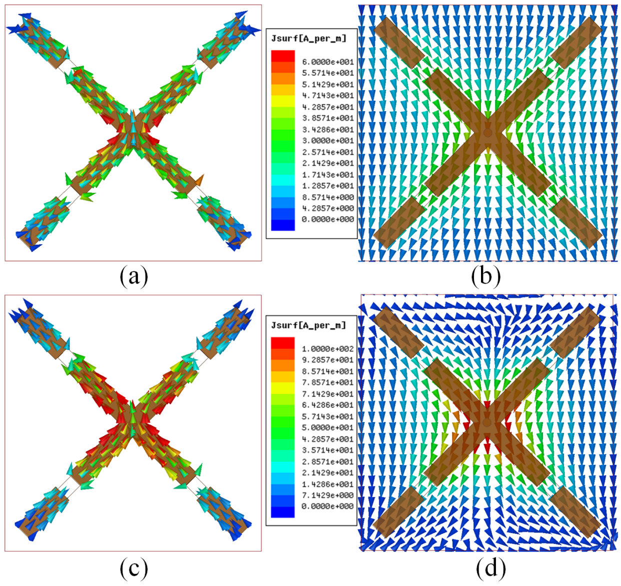
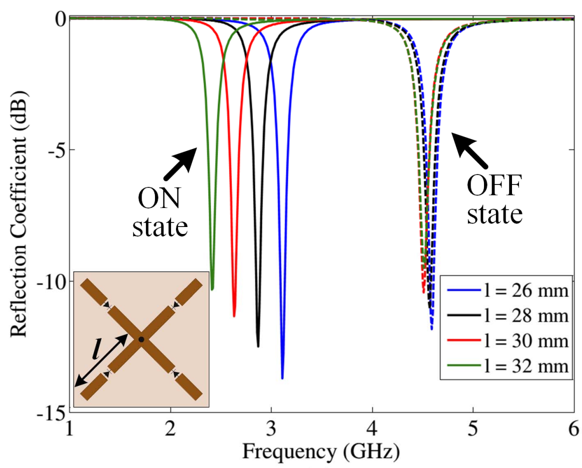
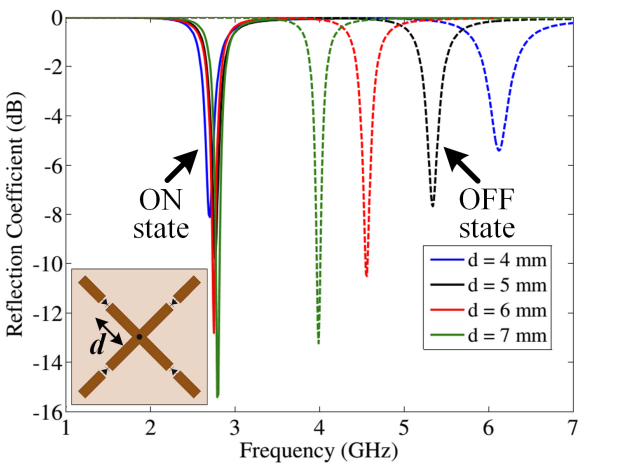


Figure 3. Surface current distributions of the proposed switchable absorber. (a) Top surface, and (b) bottom surface at 2.75 GHz during ON state. (c) Top surface, and (d) bottom surface at 4.56 GHz during OFF state.

Thus, the absorption frequencies of the proposed structure are regulated in different ways under different biasing conditions. They can also be individually controlled, while the other absorption frequency remains almost constant. When the cross-dipole length (*l*) is varied keeping the diode position (*d*) constant, the effective inductance also changes under ON state. This shifts the resonance in lower range of resonance as observed from Figure 4(a). However, there is insignificant variation in the OFF state frequency, since the positions of the diodes (*d*) are constant.



(a)



(b)

Figure 4. Simulated reflectances of the proposed structure for different values of physical paramters. (a) Variation in corss-dipole length (*l*), and (b) variation in the position of the diodes from the centre of the geometry (*d*).

In the similar way, the OFF state absorption frequency can be altered independently while keeping the ON state resonance constant. Figure 4(b) shows the reflection coefficient responses for different values of the positions of the diodes (*d*) while maintaining the other parameters fixed. The ON state resonance remains unchanged due to no variation in the length of the cross-dipole (*l*). But, the OFF state frequency gradually shifts to lower range as depicted in the figure. Thus, the frequency of the proposed switchable absorber structure can be controlled independently by varying the geometric dimensions.

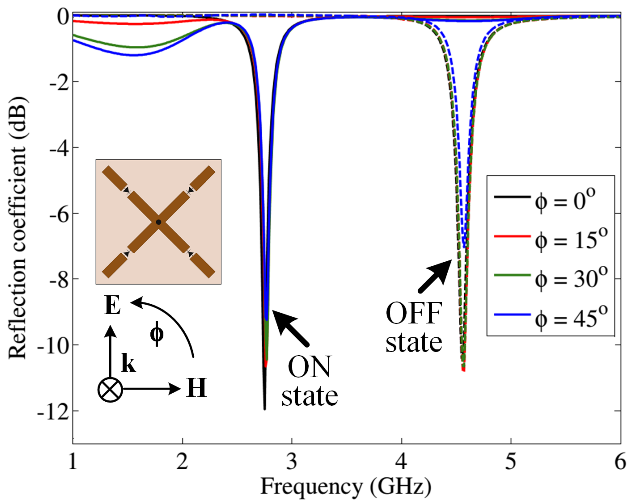


Figure 5. Simulated reflection coefficients of the proposed switchable absorber for different polarization angles under normal incidence. The solid lines represent ON state responses, while the dotted lines exhibit OFF state responses.

While varying the angle of polarization of the incident EM wave, the structure exhibits similar reflection characteristics for both the ON and OFF states as observed from Figure 5. Therefore, the design can be regarded as a polarization-insensitive switchable absorber. The biasing circuitry implemented across the fabricated sample would not affect the original structure resonance as discussed in the measurement section.

3. Experimental Verification

To experimentally validate the proposed switchable absorber, the structure has been fabricated on a FR4 substrate using conventional printed circuit board technique. 49 unit cells are printed on the sample having an overall size of 168 mm × 168 mm, as shown in Figure 6. BAP 70-03 PIN diodes are then soldered on the fabricated prototype using surface-mount technology.

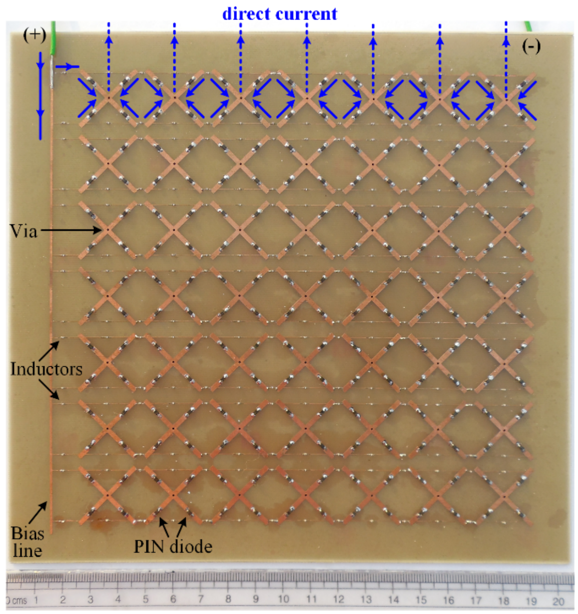


Figure 6. Picture of the fabricated prototype. Solid and dotted blue arrows indicate the direct current at the top surface and back ground plane, respectively.

In order to describe the biasing network, a schematic diagram, consisting of two unit cells arranged in single row, has been illustrated in Figure 7. A metal line is printed at the left side of the sample from which narrow-width biasing lines are drawn horizontally for connecting to the cross-dipole terminals. Then the diodes are loaded across the gaps in such a way that the cathodes and the anodes are connected with the centers and the terminals of the cross-dipoles, respectively. Since the centers of the cross-dipoles are joined with the ground plane through metallic vias, the cathodes are thus connected with the ground plane.

Therefore, when the ground plane and the left-side biasing line are connected to the negative and positive terminals of a supply voltage, respectively, direct current flows through the diodes, cross-dipole, and metallic vias uninterruptedly as illustrated in Figure 7. Inductors having value of 22 nH are mounted across the metal lines between the consecutive cross-dipoles, which isolate the biasing circuitry from EM wave. Since all the diodes are connected in parallel circuit, a nominal supply voltage is required to turn on the diodes simultaneously, unlike the existing single-band switchable absorbers.

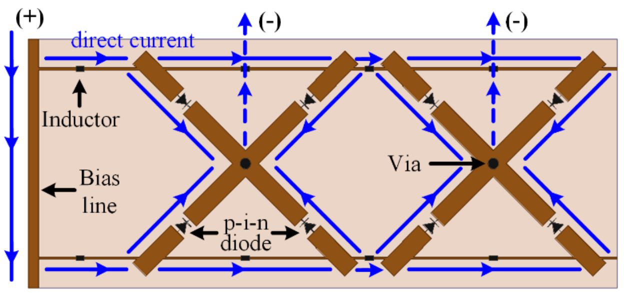


Figure 7. Schematic view of the biasing network in the fabricated prototype of the proposed structure.

After realizing the biasing network, the sample has been examined in anechoic chamber using free space technique. The prototype, while measured, exhibits a reflection dip at 2.69 GHz (with reflection coefficient of -12.24 dB) during ON state, whereas the resonance frequency shifts to 4.46 GHz having reflectivity of -10.80 dB under OFF state. The measured results have also been compared with the simulated responses as shown in Figure 8, which are in good agreement with each other. A small deviation is observed that can be accounted to diode parasitic values and fabrication tolerance.

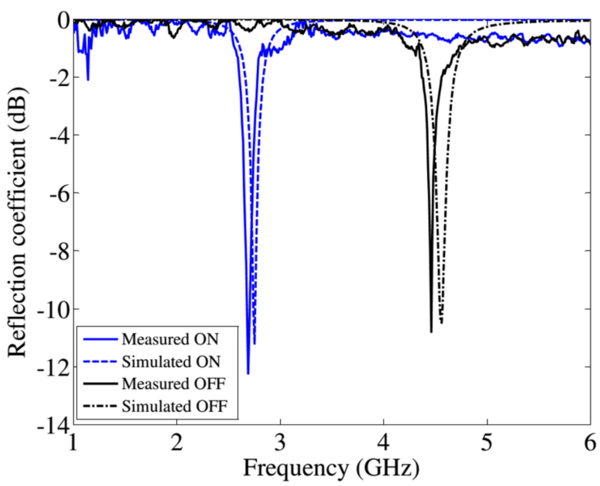


Figure 8. Comparison of simulated and measured reflectances of the switchable absorber.

4. Conclusion

In this paper, a polarization-insensitive switchable microwave absorber has been numerically simulated and experimentally demonstrated. The proposed structure exhibits the novelty of controlling the absorption frequencies independently over different biasing conditions. Since the diodes in the geometry are connected in parallel circuit, malfunction of single or a few diodes will not affect the overall structure performance, thus providing high accuracy over the earlier reported reconfigurable structures. The design has also been realized with the help of a novel biasing circuitry, which confirms the experimental verification of the proposed switchable absorber.

7. References

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