Wideband RCS Reduction of Microstrip Antenna by Frequency Reconfigurable Electromagnetic Band Gap

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Abstract— In this paper, a novel frequency configurable electromagnetic band-gap (EBG) structure is designed to achieve microstrip antenna's RCS reduction in a wide frequency range. The compact frequency configurable EBG element is comprised of spiral inductors and two diodes. By turning the diodes on or off, the frequency configurable EBG element can operate at different frequency. And then it can work in a wide frequency band. Based on the cancellation of the reflection from the EBG structure and the perfect conductor of the antennas, RCS reduction can be realized over the frequency range of 6 GHz–12 GHz.

1. INTRODUCTION

With the development of stealth technique, more and more attention has been paid to radar cross section (RCS) reduction. And antenna's scattering makes the main contribution to the total RCS of low-observable platform [1]. In recent years, many methods have been proposed to reduce the antenna's RCS. For example, the structural modification [2] and the use of frequency select surface (FSS) are both effective solutions to achieve RCS reduction. However, FSS can only reduce out-band RCS reduction. Based on passive cancellation theory, the EBG structure is applied to RCS reduction. The mushroom-like EBG structure is a classical EBG structure proposed by Sievenpiper [3]. In reference [4], RCS reduction is realized in a narrowband. However, a wideband RCS reduction is usually required in modern battleground environment.

Reconfigurable antennas have a unique advantage in modern wireless communication system, because it can be applied to multiple systems and has a multifunctional role. In reference [5], a frequency reconfigurable EBG structure is designed and used for a microstrip antenna to shift the resonance frequency of the antenna. Moreover, a novel reconfigurable EBG structure is proposed to switch its own resonance frequency in reference [6]. The above researches prove the significance of reconfigurable EBG structure. However, almost no research on loading reconfigurable EBG structures to accomplish RCS reduction has been done.

In this paper, 40 EBG elements are used to cover the partial substrate around the patch of the antenna. And each element is comprised of spiral inductors and two diodes. The dimensions of the EBG element and antennas are optimized by using Ansoft's HFSS software. As a result, RCS can be reduced over the frequency range of 6 GHz–12 GHz by turning the diodes on or off.

2. DESIGN OF THE ANTENNA AND THE RECONFIGURABLE EBG STRUCTURE

In order to load more reconfigurable EBG elements, each cell should be miniaturized. Figure 1 shows the geometry of the miniaturized EBG element, which is comprised of spiral inductors. And the resonance frequency of each element is able to shift by changing the length of the spiral. Furthermore, the principle of its operation is based on the cancellation of the reflection from the EBG structure and the perfect conductor of antennas. When the reflection phase of the EBG is less than $\pm 90^\circ$, the effect of RCS reduction can be achieved.

Figure 2 shows a novel reconfigurable EBG element based the element in Figure 1. And the dimension is 4.6 mm × 4.6 mm. Besides, each element covers the partial FR-4 substrate with the thickness of 2.5 mm and relative permittivity of 4.4. In order to change the length of the spiral, two diodes are added to each element.

In theory, there are four kinds of state for each EBG element. However, significant RCS reduction can be realized in only three states.As shown in Table 1, these three states are defined as three modes.

Based on the above analysis, the antenna with reconfigurable EBG elements is able to operate in three different modes. And the geometry of the antenna operating in different modes is shown in Figure 3. The reference antenna consists of one metal ground with the dimension of 36 mm × 36 mm and one metal patch with the dimension of 10 mm × 10 mm. Furthermore,the distance between the coaxial probe and the center of the patch is 2 mm.

Table 1: States of two switches in different modes.

mode switch	mode1	mode2	mode3
switch1	on-state	off-state	off-state
switch2	on-state	off-state	on-state

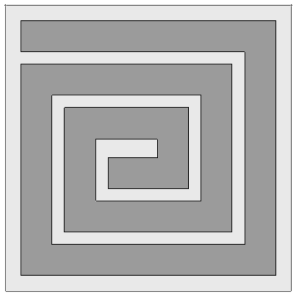


Figure 1: Simulative demonstration and geometry of the EBG element.

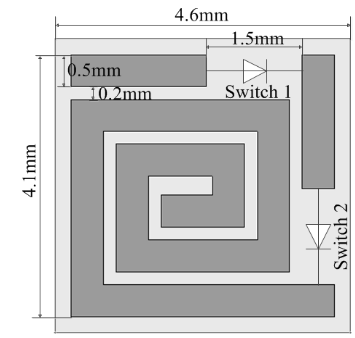


Figure 2: Simulative demonstration and geometry of the reconfigurable EBG element with two diodes.

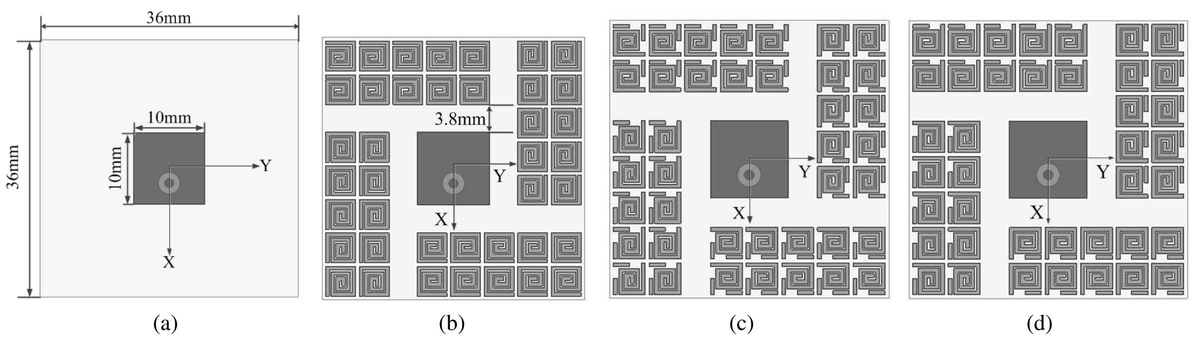


Figure 3: The geometry of the antenna operating in different modes, (a) reference, (b) mode1, (c) mode2, (d) mode3.

3. SIMULATION RESULTS

All radiation characteristics including S_{11} and radiation patterns are shown in Figure 4 and Figure 5. As shown in Figure 4, it can be seen that the antenna with and without reconfigurable EBG elements operate at same frequency. Moreover, EBG elements have almost no impact on radiation patterns, which can be seen in Figure 5. The simulated gain of the reference antenna is 5.67 dB in normal direction (z-axis). Besides, the gain of the antenna operating in mode1, mode2 and mode3 is 5.56 dB, 5.54 dB and 5.60 dB respectively. So, the max gain loss is less than 0.13 dB.

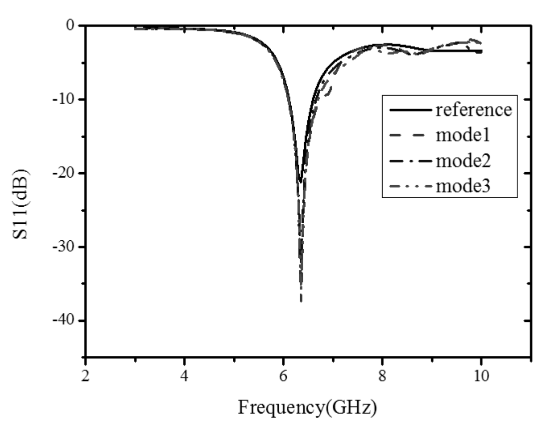
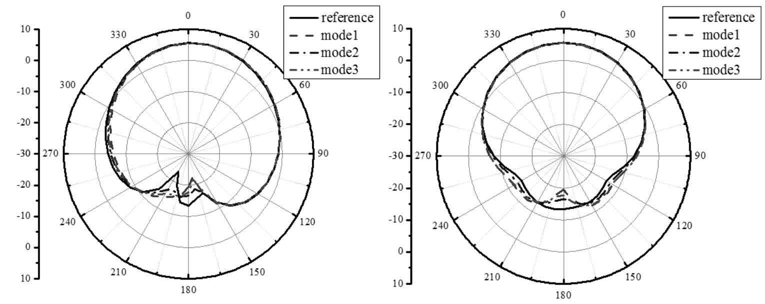
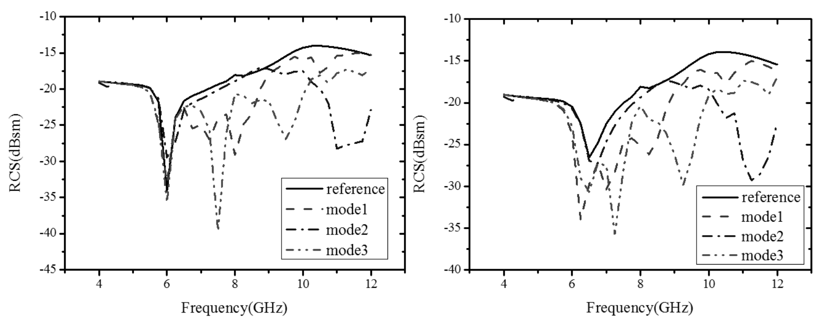


Figure 4: Comparison of S_{11} of antennas in different modes.



(a) *xoz*-plane (b) *yoz*-plane

Figure 5: Comparison of radiation patterns of antennas in different modes.



(a) *xoz*-plane (b) *yoz*-plane

Figure 6: Comparison of monostatic RCS of antennas in different modes.

As shown in Figure 6, RCS reduction is achieved in different range of frequency by controlling the operating mode of the antenna. As a result, the antenna is able to operate in a state of low RCS from 6 GHz to 12 GHz.

4. CONCLUSION

A frequency EBG structure is designed and simulated to apply to RCS reduction of the antenna. By using some PIN diodes to change the effective length of spirals, the resonance frequency of EBG elements can be shifted. As a result, the antenna with reconfigurable EBG structures can remain a state of low RCS over a wide frequency range.

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