Mutual Coupling Reduction in CBS Antenna Arrays by Utilizing Tuned EM-EBG and Non-planar Ground Plane

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Abstract ─ Radiation surface wave (surface current) on ground plane has a destructive effect on the characteristics of antennas which benefits from a common ground plane, especially Cavity Backed Slot (CBS) antennas. Surface current increases mutual coupling in an antenna array. This in turn causes unwanted characteristics in array applications. The main goal of this work is to design a new modified antenna array achieving less mutual coupling by reshaping ground plane and using tuned Elongated Mushroom Electromagnetic Band Gap (EM-EBG). Moreover, in this study, we focus on the influence of changing depth of EM-EBG holes. In this regard, four different designs for CBS antenna arrays are investigated. The results reveals that by using two new methods, namely stepped ground plane and tuned EM-EBG, mutual coupling will be decreased by more than 9 dB. Decrement of mutual coupling improve radiation characteristic of array such as Front to Back Ratio (FBR) by 8 dB. The effectiveness of our design is confirmed by experimental results.

Index Terms ─ CBS antennas array, EM-EBG, High Impedance Surface (HIS), mutual coupling, phase center of antennas.

I. INTRODUCTION

Cavity backed slot antennas, because of their structures, are the most popular antennas for satellite application, aerospace and aircraft structures. In the two recent decades, extensive research on CBS arrays regarding influence of surface currents on this antenna has been performed [1]-[2]. Surface currents have destructive effects on antennas which have common ground plane specially cavity backed slot antennas. Surface currents increase mutual coupling of these antennas which in-turn causes unwanted characteristics in array applications such as grazing SLL [1]-[2].

To minimize the effects of surface currents, several methods have been introduced which mostly include the application of absorbers and lossy materials having the negative effects of being bulky and costly [1]-[4]. Using slits and utilizing High Impedance Surface (HIS) such as EBG structures have been proposed recently [2]-[7]. Recent investigations about HIS have showed that these methods are capable of confining mutual coupling [5], [6], [8] and [11]. EBG structures in specific frequency band suppress travelling surface waves [3]. Recently several types of EBGs have been introduced and investigated [8].

This study focuses on the S21 parameter and mutual coupling in a CBS antenna array, [5] and [12]. Two new methods for reduction in mutual coupling using non-planar ground plane, and tuning EM-EBG are suggested.

In the following sections, four designs are introduced which are dedicated to work at Ku band. Influence of ground plane shape on distribution and mutual coupling are fully investigated. First three designs are described in Section II and the last one is described in Section III and IV.

In Section II, planar (common) ground plane and non-planar (stepped) ground plane are compared. In Section III, EM-EBG having a band gap frequency similar to resonance-frequency CBS antennas is introduced.

In Section IV, effect of HIS is investigated for the proposed designs. Effect of the EM-EBG hole depth on mutual coupling is also studied; whereas, effect of non-equal depth of the holes has not been considered in previous works [8]-[9]. Depths of EM-EBG holes are tuned to achieve the highest isolation between antennas. All simulations are conducted for full wave condition by Ansoft HFSS 14 software [13]. In Section V, experimental results for confirmation of our simulation are written.

II. ANTENNA DESIGN

As mentioned in the previous section, one of the

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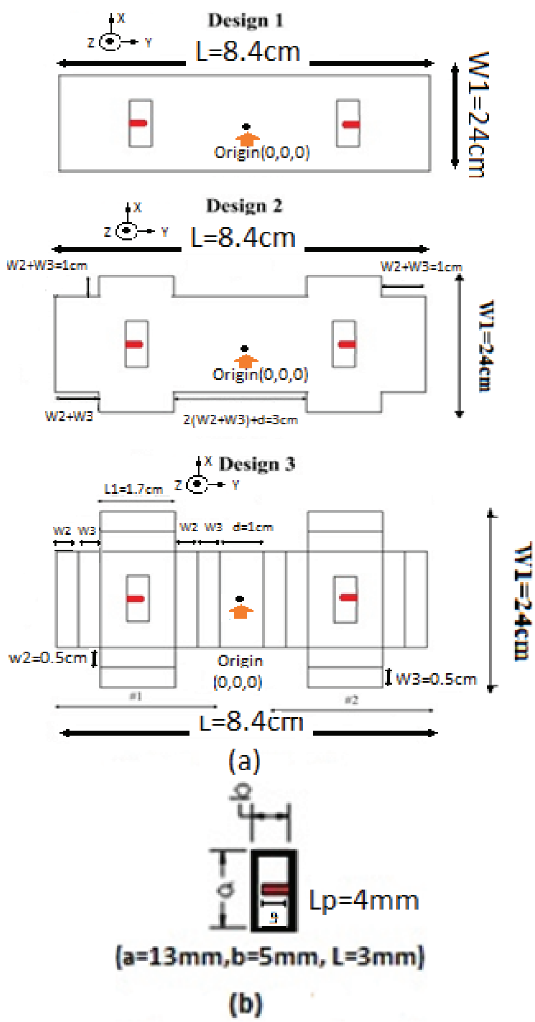
destructive effects of surface waves on CBS antennas is increasing mutual coupling [8]. In this section, at first, CBS array antenna similar to antenna which was introduced by Georgakopoulos [2], [11] is designed for working at 15 GHz.

The CBS antenna comprises of three parts: excitation probe, waveguide, and ground plane with slot. In Fig. 1 (a), three designs of CBS antenna array are presented. Main dimensions of the ground plane, aperture size and feed waveguide as well as aperture spacing in all three designs are the same. The only different aspect of these designs is the shape of ground plane. Slot size and excitation probe length inside the waveguide are depicted in Fig. 1 (b).

TE10 mode is excited in the feed waveguide, whose characteristic impedance for dominant mode is as below [14]:

$$Z_0 = \frac{\eta_0}{\sqrt{1-(\frac{f_c}{f})^2}} \times \frac{b}{a}, \quad (1)$$

where its value at 15 GHz, is 328 Ω, which could provide good impedance matching to free space.



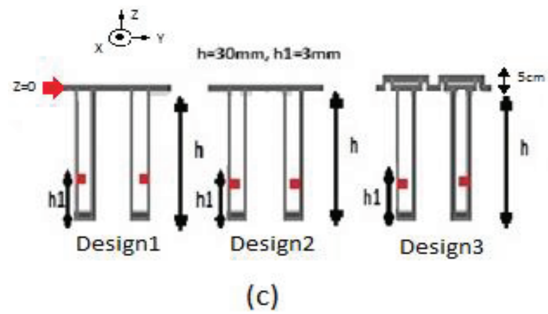


Fig. 1. The employed designs: (a) top view, (b) slot dimension and excitation probe length, and (c) side view (Lp is length of excitation probe, h is height of backed cavity and h1 is place of probe from the back of structure).

The CBS antenna with rectangular planar ground plane is named design 1. Next, the corner notched ground plane is introduced as design 2. The third design composes of two non-planar CBS antenna which has a distance of 0.5λ0 from each other. These three structures are designed to work at 15 GHz [9]-[10]. In Fig. 2, current distribution of all the three designs at 15 GHz are shown. The current surface distributed on the ground plane reaches together and thus causing mutual coupling.

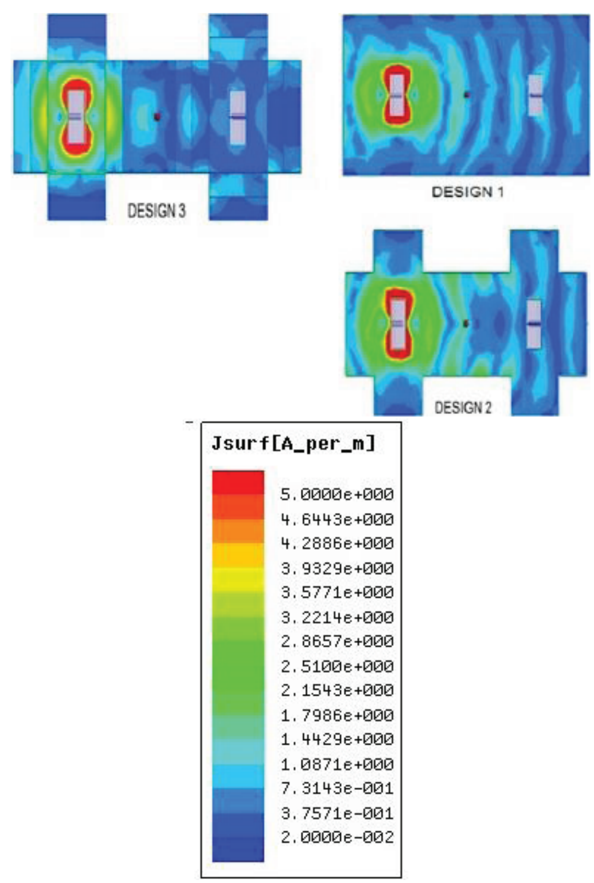


Fig. 2. Current distribution on the three designs.

Results of simulation for scattering parameters of the designs reveal that design 3 has the minimum reflection (Fig. 3), and the best mutual (Fig. 4). One can see that for non-planar structure, mutual coupling is improved by 2.5 dB. It is evident that non-planar structure suppresses current distribution more than the others and has the best isolation.

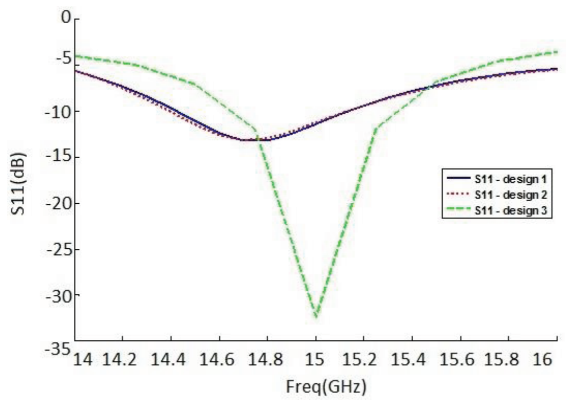


Fig. 3. Reflection coefficient, S_{11} for designs 1, 2 and 3.

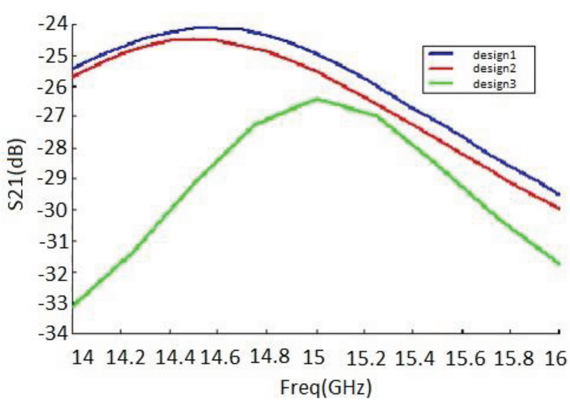


Fig. 4. Mutual coupling extracted by HFSS simulator for the three designs.

III. UTILIZING EBG STRUCTURE

One important feature of high impedance surface is its ability to compensate surface current in band gap [3]. A new type of this structure has been recently introduced as an EM-EBG [8]-[9], which confines the surface current more than the common mushroom EBG. Compactness of EM-EBG is its advantage in comparison to common EBG. Fabrication of EM-EBG is straightforward. To fabricate EM-EBG in order to work at 15 GHz, lumped circuit model as mentioned in [8] is utilized. Side view of EM-EBG is illustrated in Fig. 5. It consists of two parts, top part has more capacitive effect. As a result, it is named capacitance part while the bottom part, named inductive part, has inductive effect. In a normal EM-EBG cell, the depth of two parts are the same.

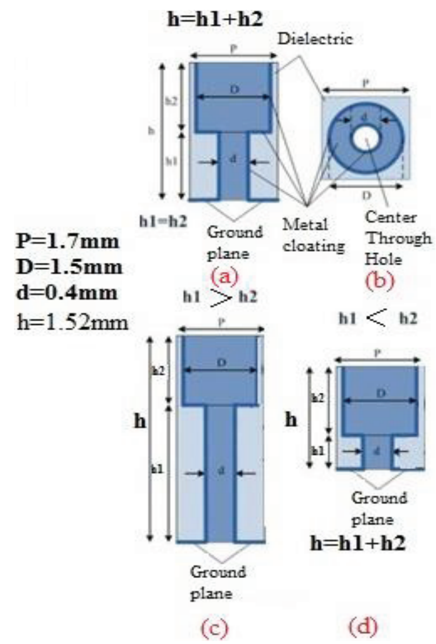


Fig. 5. An EM-EBG cell is composed by two metalized holes (vias) with two different diameters. Diameter of the top hole is (D) and the other hole is (d). (a) Side view of normal EM-EBG (h_1=h_2=h/2), (b) top view, and (c) tuned EM-EBG, the first case (h_1<h_2) tuned EM-EBG, the second case (h_1>h_2).

IV. TUNING EM-EBG HOLES DEPTH

As mentioned in a normal EM-EBG cell, the depth of the two parts is similar. For more suppression of the current distribution on ground plane, tuned EM-EBG which is designed on Taconic RF35 (60 mil) is applied on the ground plane of design 3, this new design is named design 4. Width, length and height of tuned EM-EBG structure are selected as 10 mm, 24 mm and 1.52 mm, respectively, which fills the distance between the two slots on non-planar ground plane. This EM-EBG structure has 14 rows and 6 columns.

Depth of holes (h_1, h_2) as mentioned above, referring to capacitive part and inductive parts of EM-EBG, are changed to achieve the best isolation. Depth of the holes influences the bandwidth and parameters of EBG. For achieving more isolation, EM-EBG holes depth is tuned. Top holes depth (h_1) and that of bottom holes (h_2) influence the capacitive and inductive parts, respectively [8]. The result of mutual coupling simulation between two antennas are extracted by numerical methods using Ansoft HFSS Designer.

In Fig 6, mutual coupling for different depths are presented. The best mutual couplings at 14.6-15.5 GHz bandwidth is obtained for h_1=0.9h, h_2=0.1h.

By tuning h_1, h_2, i.e., by changing capacitive and inductive parts of EM-EBGs, mutual coupling is decreased by 9 dB in comparison to design 3.

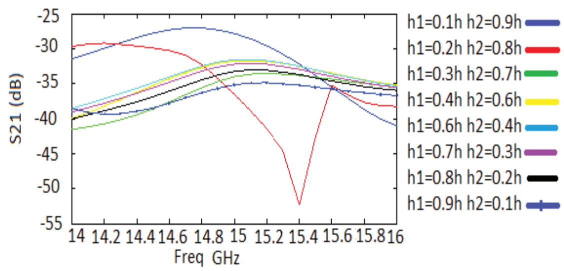


Fig. 6. Simulation result of mutual coupling for different capacitive and inductive parts.

Using numerical methods, the dispersion diagram can be extracted. In Fig. 7, the dispersion diagram of the tuned EM-EBG in periodic condition for the first three modes (TM_0, TE_1, and TE_2) are illustrated. The band gap of 15-17 GHz between the two first modes is seen. Also, between TM_0 and TE_1 modes, a band gap is observed where none of surface modes are supported.

Result of current distribution on design 4 is depicted in Fig. 8. By comparing Figs. 2 and 8, it is obvious that by inserting EM-EBG, the surface current on second antenna has been decreased. Phase center is one of most important characteristics of aperture antennas such as cavity backed slot antennas for interferometer applications. Result of calculation of place of phase center of two antennas for design 3 and design 4 are presented in Tables 1 and 2. For design 3 and 4, place of phase centers in Y direction are symmetric and in Z direction are similar. By inserting EM-EBGs (reduction of mutual coupling) phase center of antennas of design 4 move forward in Z direction. These results are calculated by CST Microwave Studio Software.

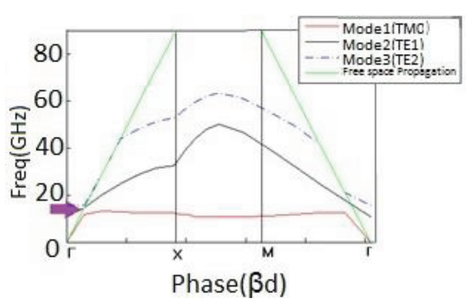


Fig. 7. Dispersion diagram of the tuned EM-EBG cell.

Table 1: Place of phase centers of antennas design 3

Frequency (GHz)	Left Antenna (X,Y,Z) mm	Right Antenna (X,Y,Z) mm
14.6	(0,-23.8,-1.77)	(0,23.8,-1.65)
14.8	(0,-24,0.38)	(0,24.04,0.56)
15	(0,-23.89,0.56)	(0,23.95,1.65)
15.2	(0,-23.82,1.3)	(0,23.86,0.89)
15.4	(0,-23.97,-1.47)	(0,24,-1.13)
15.6	(0,-24.44,-2.6)	(0,24.45,-2.53)

Table 2: Place of phase centers of antennas design 4

Frequency (GHz)	Left Antenna (X,Y,Z) mm	Right Antenna (X,Y,Z) mm
14.6	(0,-23.59,8.7)	(0,23.61,8.83)
14.8	(0,-23.52,9.45)	(0,23.57,9.56)
15	(0,-23.33,9.28)	(0,23.42,9.4)
15.2	(0,-23.17,7.98)	(0,23.26,8.09)
15.4	(0,-23.14,5.7)	(0,23.24,5.77)
15.6	(0,-23.3,3.78)	(0,23.4,3.58)

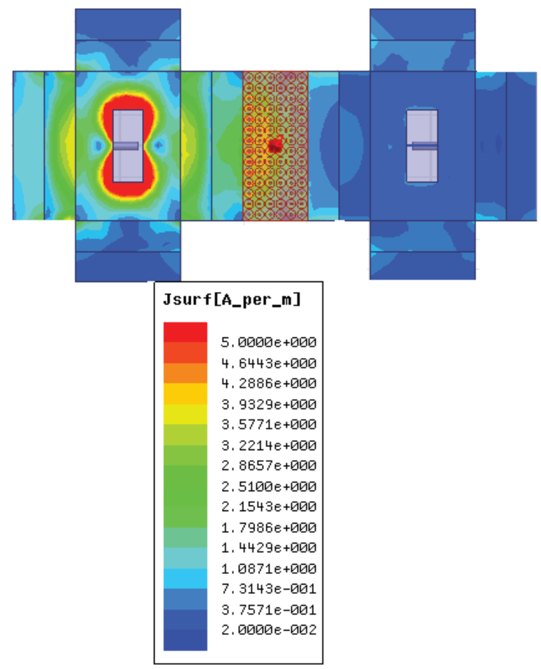
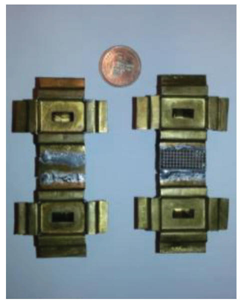


Fig. 8. EM-EBG effect on current distribution for design 4.

V. MEASUREMENT RESULTS

To validate the results of simulation for different designs of isolation antennas in array, especially effect of applying a tuned EM-EBG structure, based on designs 3 and 4, two non-planar CBS antenna arrays (2×1) were fabricated. In one array, between the two antennas a tuned EM-EBG is inserted as shown in Fig. 9. The results of measurement of S parameters for designs 3 and 4 are extracted by Agilent 8720ES network analyzer. And also result of pattern and gain measurements have been extracted in Antenna Chamber of KN Toosi Technical Universty. The fabricated antennas have 5% return loss bandwidth and 26 dB isolation for design 3 comparing to 33 dB for design 4 as shown in Figs. 10 to 13. The measurement results reveal that by inserting tuned EM-EBG mutual coupling is decreased by 7 dB, FBR is decreased by 7.5 dB and total gain is improved by 0.5 dB. On the whole, from both simulation and measurement, it could be understood that design 4 has a better performance compared with design 3.



(a)

(b)

Fig. 9. Fabricated cavity backed slot antenna non-planar array: (a) top view and (b) side view (left) design 3, (right) design 4.

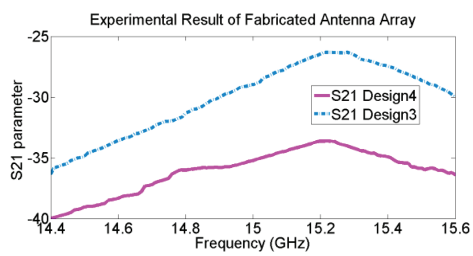
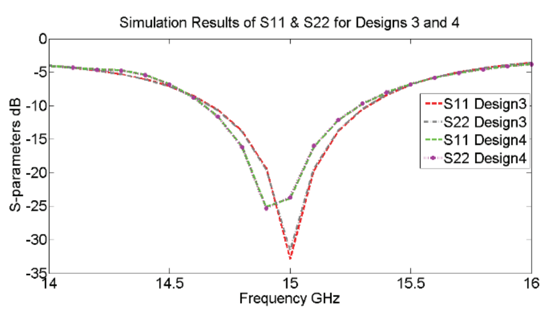
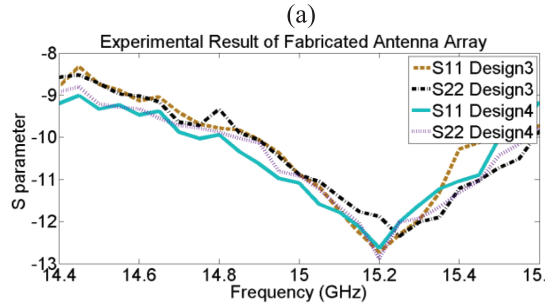


Fig. 10. Mutual coupling improvement by applying tuned EM-EBG.



(a)



(b)

Fig. 11. (a) Simulated and (b) measured S_{11} and S_{22} for designs 3 and 4.

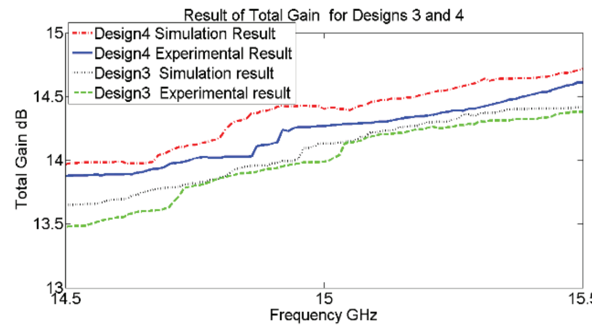


Fig. 12. Gain of designs 3 and 4.

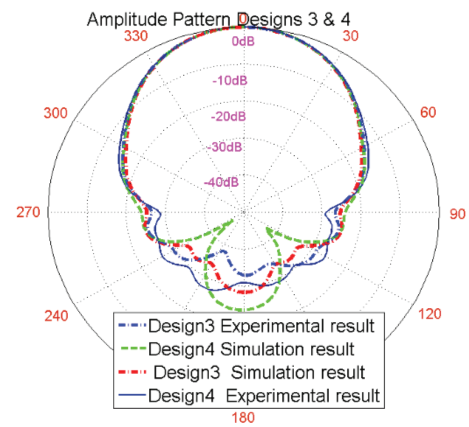


Fig. 13. Amplitude pattern of simulation and experimental results.

VI. CONCLUSION

In this paper, two new methods have been presented for reduction of mutual coupling in CBS antennas, including non-planar ground plane and tuned EM-EBG. Simulations reveal that by utilizing non planar ground plane mutual coupling is decreased by 2.5 dB comparing to planar ground plane. Results show that the depth of holes have a great impact on the surface current suppression.

Two prototypes of non-planar antenna were fabricated. For one of them, tuned EM-EBG had been used. The performance of the fabricated antennas were compared with each other. The measurements confirmed that a tuned-EM-EBG improves the mutual coupling and FBR by about 7 dB and 8 dB respectively.

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