Reduction of EMI and Mutual Coupling in Array Antennas by Using DGS and AMC Structures

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Abstract — Considering the difficulty of via construction in EBG structures and the cost of lossy materials and absorbers, in this paper, we look for implementing DGS and Artificial Magnetic Conductor to reduce mutual coupling in enclosures and array antennas particularly in CBS antennas. Circular ring defected ground structure and capacitive loaded AMC strips are designed and optimized to have electromagnetic band gaps and incident wave reflection features, respectively, in the resonant frequency band of cavity backed slot (CBS) antenna. The complete structure consists of CBS antenna with circular ring DGS and CLS-AMC. These structures are investigated and enhancement in EMI and the radiation patterns of this antenna is observed.

1. INTRODUCTION
Performance limitations in electronic devices and electromagnetic structures due to mutual coupling between elements is an important aspect which has received much attention. Mutual coupling between different hardware stages such as devices or transmission lines in printed circuit boards is one type of electromagnetic interference (EMI). Moreover, excitation of the surface wave which causes EMI in the printed circuit antenna is another problem of mutual coupling that limits compactness of the structure.

So far, to reduce the effect of mutual coupling various methods have been proposed based on reducing surface waves. Utilizing the lossy material is one of these ways [1]. Using electromagnetic band gap structures (EBG) which reduce surface waves in all directions and in specific frequency bands have been increased in recent years. Decreasing of parallel plate waveguide noise [2] and enhancing antenna characteristics [3, 4] are some application of EBG structures.

In this paper we are focusing on improving the efficiency of cavity backed slot (CBS) antennas by reducing mutual coupling between two cavities through the common plane surface wave. In prior works diverse methods have been suggested for developing EMI in these structures such as implementing lossymaterials [1] or EBG structures constructed from metal patches and vias [5]. In this work, considering the absence of vias, which eases the fabrication process, we are using defected ground structures (DGS) and artificial magnetic conductors (AMC) to achieve this purpose. In addition to the difficulty of via construction, for reducing EMI, two EBG structures is required since each EBG structure with certain dimensions reduces surface waves just in one resonant frequency [5]. The CBS antenna without DGS and AMC structures is first simulated and its working frequencies are derived, then DGS and AMC are designed for this frequency band. Assuming the same dimensions as [5] for CBS antennas, the resonant frequencies of antennas are found to be 7.5 and 12 GHz. Dispersion diagram and the frequency band gap for circular ring DGS is obtained. Next, the transmission coefficient of capacitive loaded AMC strips will be considered and the dimensions of this structure are optimized to act in the operating frequency band of the CBS antenna. Finally, we examine CBS antenna with a circular ring defected ground structure and capacitive loaded strips, and subsequently enhancement in characteristics of the antenna has been observed.

2. CIRCULAR RING DEFECTED GROUND STRUCTURE
Electromagnetic band gap feature of DGS is introduced in [6]. In this paper, we use a circular ring defected ground structure with an internal radius of 2 mm and an external radius of 3 mm with a unit cell length of 8 mm. The circular DGS is constructed below a substrate with thicknesses of 1.575 mm and a permittivity of 10.2. The unit cell of this structure is shown in Fig. 1.

The dispersion or $\beta$-$f$ diagram can be calculated from the unit cell. Two dimensional Eigenmode solutions for Maxwell’s equations are obtained for the restricted unit cell (or Brillouin zone) under
periodic boundary conditions. Algorithms for solving Maxwell’s equations under periodic boundary conditions have been implemented using both the Green’s function, based on method of moments and the finite element method. In this work we have used a commercially available simulation tool based on finite element method (HFSS).

![Figure 1: Circular ring DGS showing the unit cell dimensions and the dielectric constant of the structure.](image1)

The dispersion diagram for this structure is shown in Fig. 2. It is observed that the circular ring DGS with the mentioned dimensions, possesses an omnidirectional surface wave band gap in the range of 10 to 13 GHz.

3. CAPACITIVE LOADED AMC STRIPS

The usage of metallic arrays printed on dielectric substrate in the absence of vias (AMC) has attracted a lot of interest in recent years. Due to reflecting incident waves with a zero degree reflection phase, this surface performs as equivalent artificial magnetic conductors. In this part, we analyze and design a CLS structure. The incident wave reflection properties of this structure has been assessed by using the commercial finite element full wave solver HFSS and the transmission coefficient and reflection phase is obtained. The strip width and length are optimized to attain 7–13 GHz frequency band for reflecting the incident waves. For analyzing this structure with HFSS software, a two port waveguide with two perfect electric conductors is used [7]. The CLS surface is perpendicular to the PEC walls. The size of capacitor gaps are 0.3 mm and every line width is 0.4826 mm. As shown in Fig. 3, every CLS length is 4.3688 mm and the length of one CLS unit cell which consists of three capacitive loaded strips along the axis is 14.605 mm. This structure is constructed on a substrate with 0.254 mm thickness and a permittivity of 2.2. The HFSS calculated magnitudes of $S_{11}$ and $S_{21}$ for a unit cell of CLS in the two ported waveguide is shown in Fig. 3. The strong reflectivity is turning on near 7.6 GHz and lasts up to 13.5 GHz.

![Figure 3: The CLS-AMC geometry.](image3)

![Figure 4: Magnitudes of the HFSS-predicted S parameters for a CLS unit cell.](image4)
4. CBS ANTENNA WITH DGS AND AMC

In this part, we combine the cavity backed slot antenna with circular ring DGS and capacitive loaded AMC strips. Dimensions of cavities, coaxial feed and space between the two cavities are the same as [5]. The top and side view of CBS antenna with DGS and AMC is shown in Figs. 5(a) and (b), respectively. The array of circular ring DGS consists of 28 microstrip circular rings forming an array of $4 \times 7$ elements. The array period is 8 mm and equals the dimension of the unit cell. This array is placed below the common ground plane between two cavities. Array of $2 \times 12$ CLS unit cells is located over the common ground plane. The separation between two CLS unit cells in the $x$ and $y$ directions are 3.175 mm and 4 mm respectively.

Figure 5: Side (a) and top (b) views of the CBS antennas demonstrate the placement of the DGS and AMC structures.

The $S_{21}$ (where one antenna is acting as a source and the other as a receiver) of the CBS antennas with and without circular ring DGS and CLS artificial magnetic conductor structures is shown in Fig. 6. These simulations show that significant coupling reduction is achieved, reaching around 40 dB at 11.5–13 GHz frequency band. In the view of the fact that starting frequency of incident waves reflection in the CLS structure was around 7.8 GHz; and the best reduction in mutual coupling occurred over 7.8–8.5 GHz band which has a shift of 0.3 GHz from the resonant frequency.

In view of the reduction of surface waves on the common ground plane and also mutual coupling

Figure 6: Magnitude of the $S_{21}$ parameter for CBS antenna with and without circular ring DGS and CLS structure.
between the two cavities, we expect the radiation patterns become directive in comparison with CBS antenna without DGS and AMC. The radiation pattern of CBS antenna with and without DGS and AMC is shown in Figs. 7(a) and (b) for $f = 12\, \text{GHz}$. It is clear that the radiation pattern rotates in the direction opposite to the side in which the DGS and AMC structures are located and the gain of the antenna is also increased. The radiation pattern for $f = 7.5\, \text{GHz}$ is shown in Figs. 8(a) and (b) for both CBS antennas with and without DGS and AMC. The same result in this frequency is preserved as well. We should mention that enhancement of radiation pattern for both 7.5 GHz and 12 GHz are achieved in one structure while in [5] two EBG structures were implemented for enhancing EMI in each resonant frequency and improving of radiation pattern for both 7.5 GHz and 12 GHz was not accessible at the same time.

![Radiation Pattern at 12 GHz](image1.png)

Figure 7: Radiated field patterns at 12 GHz (a) without and (b) with DGS and AMC structures. The pattern is plotted in the $y$-$z$ plane (E-plane).

![Radiation Pattern at 7.5 GHz](image2.png)

Figure 8: Radiated field patterns at 7.5 GHz (a) without and (b) with DGS and AMC structures. The pattern is plotted in the $y$-$z$ plane (E-plane).
5. CONCLUSION

It is demonstrated that DGS and AMC structures can be designed and implemented to reduce the mutual coupling between elements in array structures instead of using two EBG structures with vias that complicate the manufacturing. To derive the dispersion diagram of circular ring DGS and reflection and transmission data for normally incident plane wave illumination in CLS metamaterial HFSS software is used. A set of effective enhancement in decreasing EMI and radiation pattern of the antenna and in the resonant frequency band is observed and discussed.

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REFERENCES


