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Electromagnetic Coupling Reduction between Millimeter Microstrip Antennas using High Impedance Surface

Cuong Tran Manh *

Abstract— Recently, a widely use of High Impedance Surface (HIS) structures in several applications such as in radar and telecommunication systems have been described in the literature. An interesting characteristic of the High Impedance Surface (HIS) is that it can be used to reduce the mutual coupling between microstrip antennas. In this paper, firstly the band-gap features of three types of high impedance surface structure have been studied by using CST Microwave Studio. Secondly, those HIS structures are integrated into an antennas array system to improve the low mutual coupling. The investigation included both E and H coupling direction, and antenna system is analyzed using HFSS. A significant value of -12 dB mutual coupling reduction is reached at resonant frequency.

Index Terms— Microstrip antennas, mutual coupling effect, surface waves, HIS.

1 Introduction

Mutual coupling between the antenna elements is a phenomenon which is due to an exchange of energy between antennas [1]. As a consequent, mutual coupling may influence the efficiency of antenna by generating side-lobes or blind angles. In the current development of telecommunication technology, particularly in satellites communications or high rate millimeter range. This leads to a request for new types of antennas, more compact, low profile and with a low mutual coupling.

For millimeter microstrip antennas, the size of the antenna is very small. Therefore the mutual coupling is important. At the distance of $\lambda/2$ between two antennas, mutual coupling is very important due to the propagation of surface waves. Also, it is observed that both increasing the substrate thickness and the permittivity will increase the mutual coupling; even so the bandwidth is slightly increased [2]. Therefore in the case of high permittivity, it is more necessary to minimize mutual coupling using new techniques.

High Impedance Surface is a structure formed of periodic metallic electromagnetic unit cells. The first of its characteristic is that it possess a 0° reflection coefficient within the band-gap (which is opposed to the case of a perfect conducting surface), this characteristic was applied for the low-profile antenna structure application. The second, in his forbidden frequency band, the effective impedance surface of HIS is very high, therefore, it does not support surface wave. Then, the use of the HIS structure for microstrip antennas, by integrating them into the ground plane of the antenna, can eliminate the surface waves, thereby reduce significantly mutual coupling between antennas. Up to the moment, there have been several studies related to the problems of application HIS structure on mutual coupling reduction, as in Yang studies [2], as well as a number of other studies are undertaken for the same purpose to reduce the effects of surface waves [3]-[6]. Researches also showed that the application of HIS structure, have a signification mutual coupling reduction. The added structure to eliminate surface wave is usually placed between the two antenna elements. However, to the best of our knowledge, there is no research up to now about application of HIS for reduction of mutual coupling in the millimeter wave domain nor systematic studies of how to reduce the coupling between antennas

This study compared three different HIS: square patch, Jerusalem cross and 2LC patch or unit cell. They have been used in electromagnetic structures and have being integrated the useful one into a millimetric patch antennas which permit us to have a low mutual coupling between two antennas. We use CST Microwave Studio solvers [7] for study.

2 HIS Simulation

The HIS concept was presented for the first time by Sievenpiper in 1999 [4]. In the frequency range where the surface impedance is very high, the tangential magnetic field is small. These types of structure are called, also Artificial Magnetic Conductor (AMC). In general, it consists of a ground plane, a dielectric substrate, periodic metallic patche or unit cell surface and/or connecting vias. The structure was arranged in two dimensional lattices and connected to the ground plane by the vias. This type of structure is fabricated easily by using printed-circuit-board technology

We have used three HIS structures, which were named “square cells”, “Jerusalem cross cells”, and “2LC unit cells”, the last one concerned with his equivalent circuit proposed by Schurig et al. in [8].

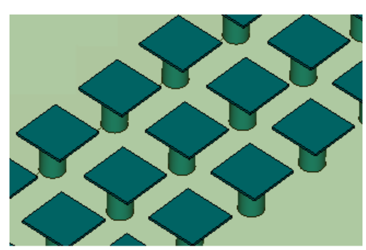

Fig. 1. Perspective view of a High Impedance Surface

* *Department of Physics, Hanoi National University of Education, Vietnam.*
E-mail: tmcuong0279@gmail.com

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Those unit cells are presented in Fig. 2, with descriptions of shapes and dimensions. These types of structure behave as parallel L-C resonant circuits, which act as electronic filters to block the flow of currents along the sheet. The inductor L created by the current through the vias, and the capacitor C generated by the gap effects between the neighbouring elements. These values could be calculated by the research in [9]-[11] and bandgap of structure (BW) could be calculated as follow [4]:

$$BW = \frac{\Delta\omega}{\omega} = \frac{1}{\eta}\sqrt{\frac{L}{C}} \quad (1)$$

$$\omega = \frac{1}{\sqrt{LC}} \quad (2)$$

$\eta = 120\pi$ is the free space impedance.

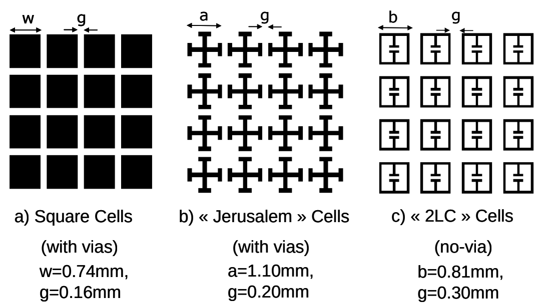

Fig. 2. Top-view of the designed HIS structures and their lateral dimensions.

We have simulated and designed millimeter microstrip antennas in the frequency band 38GHz-45GHz. The resonant frequency of the antenna application is located at 42GHz (see Fig. 3), so the HIS structures and antennas are all optimized at 42GHz.

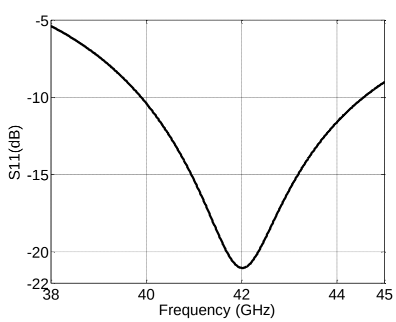

Fig 3. Return loss of conventional antenna

We evaluate the band-gap of the HIS structure, as well as to understand the characteristics of them, we use CST Microwave Studio simulator. The simulation is performed by using the Eigen-mode solver. The dispersions of each three single unit cell selected are shown in the inset of Fig. 4, with periodic boundary conditions in the propagation direction. The dimensions of all unit cells are shown in the Fig. 2. The dispersion diagram was calculated by varying the phase, shifts in the propagation direction between 0° and 180° [12]. Results show that the square cell and Jerusalem cross cell structures possess a forbidden band-gap of 28.8% (31.2-43.3GHz) and 24% (32.0-42.5GHz) respectively, while 2LC cell structure shows have no band-gap because the propagating modes exist simultaneously in this structure, this result agrees with the prediction of Sievenpiper in [4].

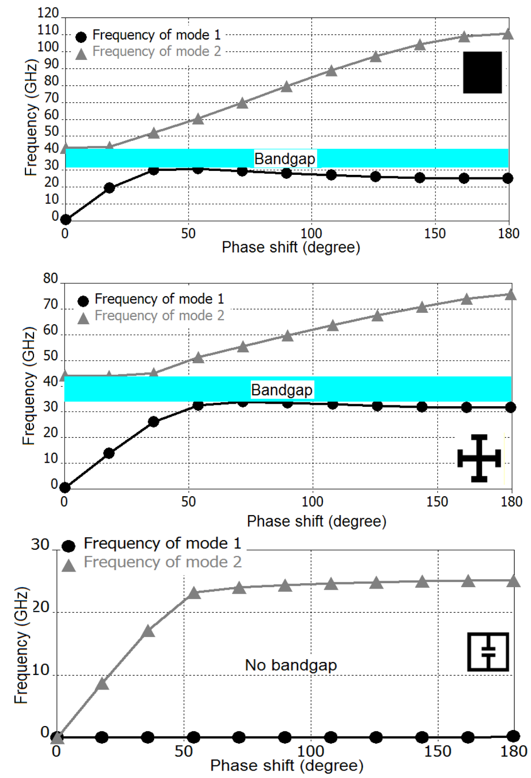

Fig. 4. Dispersion diagram of three structures: Square cell, Jerusalem cross cell and 2LC unit cell.

From these dispersion diagrams it is shown that the forbidden band-gap of the square cell structure possesses 4.8% larger bandwidth than that of Jerusalem cross cell structure. We shall expect a better coupling reduction by square patch unit cells HIS.

3 Mutual Coupling of Conventional Microstrip Antenna Array

For two rectangular microstrip patch antennas the coupling for two side-by-side elements is a function of the relative alignment [1]. When the elements are positioned collinearly along the E-plane, this arrangement is referred to as the E-plane; when the elements are positioned collinearly along the H-plane, this arrangement is referred to as the H-plane, as shown in Fig. 5.

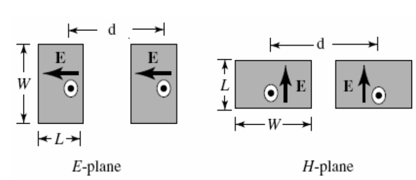

Fig 5. E plane and H plane coupling

We have simulated the coupling between two patch antennas, by using a three dimensional full-wave solver based on the finite element method (HFSS). In simulation, one antenna is activated and the mutual coupling is measured at the feeding port of the other. We normalized the field power in all case to 1W. The separation of the two antennas is d=0.5λ_{42} (λ_{42} is the free space wavelength at 42GHz), the size of the ground plane is about three wavelength. The thickness of microstrip substrate is 0.51mm and the relative permittivity is 3.58. Two antennas have the same patch size of 1.60mm×1.68mm (W×L=0,22λ_{42}×0.23λ_{42}), and were excited by coaxial probe feed method, which have low spurious radiation [1]. The resonant frequency of the patch antennas is 42GHz. In the simulation, only port one is activated and port two is matched to 50Ω. We see a strong mutual coupling level of -19dB(E plane) and -16dB (H plane) in Fig. 6.

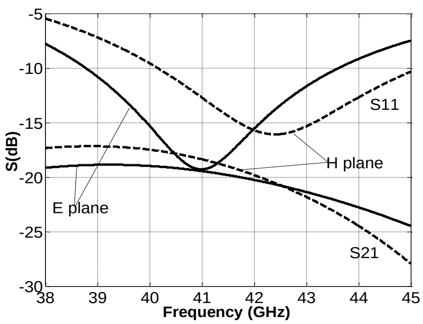

Fig. 6. Comparison of E and H plane mutual coupling effect (S21) of the antennas in Fig. 3 at d= 0.5λ_{42}.

4 Application of HIS for Reducing the Coupling

From the above discussion, it is found that the conventional microstrip antenna arrays exhibit a very strong mutual coupling due to the impact of surface waves. Two columns of HIS patches are inserted between the antennas to suppress surface waves. The thickness of microstrip substrate is the same with the conventional case: 0.51mm and the relative permittivity is 3.58. The antennas distance is 0.5λ42GHz. We used the three HIS structures mentioned above which have been designed using an effective model by CST MWS. The resonant frequency of the patch antennas is 42GHz, just within the band-gap of HIS. In each case, two columns of HIS have been inserted between two antennas. The HIS installation is presented in Fig. 7.

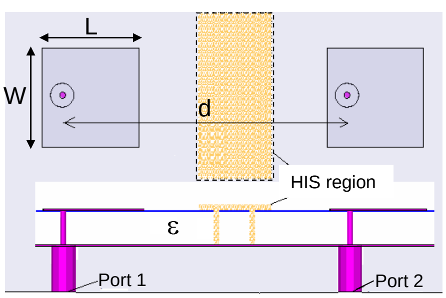

Fig. 7. Integration of HIS columns between the two antennas.

From those results, the mutual coupling level has changed. At the resonant frequency of 42GHz, for the case of E-plane (Fig. 8), the square cells structure shows the mutual coupling of only -32dB, which correspond to an appreciatively -12dB mutual coupling reduction.

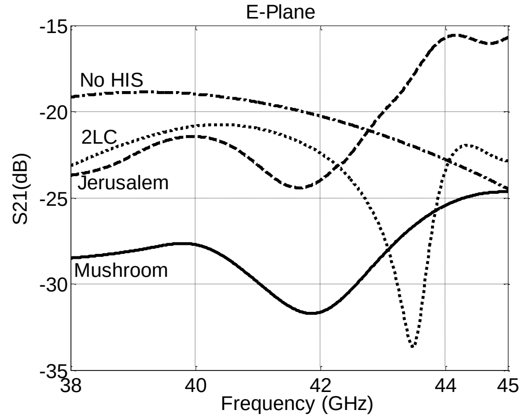

Fig. 8. Comparison of mutual coupling using three different HIS structures with conventional microstrip antennas in cases of E plane

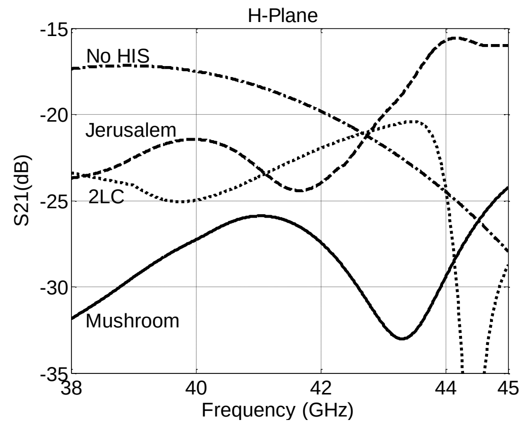

Fig. 9. Comparison of mutual coupling using three different HIS structures with conventional microstrip antennas in cases of H plane

We see that by using the HIS structures, it is possible to design a low-profile antenna arrays while maintaining a low mutual coupling. The Jerusalem cross structure shows the mutual coupling reduction of -4dB and -2dB for the 2LC structure.

For the case of H-plane (Fig. 9), the results are -7dB, -4dB, -2dB respectively. This was realized for the case of 2LC structure, mutual coupling reduction is very small causing by his "no-bandgap" characteristic. And as the expected, these results show that the integration of square HIS structure into an antennas array system could help to improve the efficiency of the shield with a significant -12dB mutual coupling reduction for the E-plane case and -7dB for the H-plane case at the resonant frequency (42 GHz).

5 Conclusion

In this paper, three high impedance surface structures have been applied to reduce the coupling effect between elements in the array antenna. The resonant frequency is optimized to fall inside the HIS band-gap. Dispersion diagram of three structures are analyzed based on the CST Microwave Studio

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calculations. In the region of forbidden band of HIS, surface waves are eliminated. The structure without the forbidden band could not help to reduce remarkably the coupling. The structure with the large forbidden band (square cells) could be used to reduce significantly the coupling between millimeter microstrip antennas, compared with conventional cases. The square cells HIS allows to reduce coupling between antennas to -32dB for the E-plane case, -27dB for H-plane case and we can reach to maximum of -12dB mutual coupling reduction at the resonant frequency. This technique can be used in many antenna system designs.

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