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► **To cite this version:**

Lila Mouffok, Lana Damaj, Xavier Begaud, Anne Claire Lepage, Hubert Diez. Mutual coupling reduction between dual polarized microstrip patch antennas using compact spiral artificial magnetic conductor. EuCap, Apr 2011, Rome, Italy. pp.4. <hal-00614428>

HAL Id: hal-00614428

<https://hal.science/hal-00614428v1>

Submitted on 11 Aug 2011

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Mutual coupling reduction between dual polarized microstrip patch antennas using compact spiral artificial magnetic conductor

L. Mouffok¹, L. Damaj¹, X. Begaud¹, A.C Lepage¹, H. Diez²

¹Institut Telecom - Telecom ParisTech - LTCI - CNRS - UMR 5141 - 46 Rue Barrault, 75634 Paris France

²Centre National d'Etudes Spatiales, 18, Avenue Edouard Belin, 31401 Toulouse Cedex 9 France

Abstract—In this paper, we present a dual polarized microstrip antenna above an Artificial Magnetic Conductor (AMC). It is printed on a high permittivity substrate ($\epsilon_r=9.82$). The AMC is used in order to reduce the mutual coupling between two radiating elements. Two experimental prototypes are realized in order to validate the analysis. First, the performances of a patch antenna above AMC are analyzed. The return loss is less than -15 dB at 1.62 GHz. The measured radiation pattern shows that the antenna has a broadside gain of 7 dB and a cross-polar level about -15 dB. Then, the mutual coupling between two antennas above AMC is studied. 3 dB enhancement of mutual coupling compared to the array without AMC is observed at the operating frequency 1.62 GHz in H plane configuration. A good agreement between measurements and simulations results is observed.

I. INTRODUCTION

Microstrip antenna arrays are commonly used for their low profile and light weight. A key requirement for the arrays design is to reduce the coupling between each element. This mutual coupling is due to the excitation of space and surface waves. These surface waves can create very critical problem known as scan blindness [1].

In the recent years, new solutions to suppress surface waves have been proposed using an Artificial Magnetic Conductor (AMC) or Electromagnetic Band Gap (EBG) materials. These AMC, also known as High Impedance Surfaces (HIS), consist of periodic metallic or dielectric arrangements [2]. These structures can be used to reduce the mutual coupling between the radiating elements [3].

Objective of this paper is to demonstrate that thanks to these artificial structures, two dual polarized microstrip antennas can be placed very close to each other with a low mutual coupling and also low insertion loss between two polarization ports.

II. ANTENNA DESIGN

The final objective of this work is relative to spatial applications. So in order to realize a compact structure operating at 1.62 GHz, a dual polarized square microstrip patch antenna is printed on a Rogers TMM 100 substrate with a thickness of 0.762 mm and a dielectric permittivity ϵ_r of 9.82. This antenna has to be compact (maximum authorized

surface of 115x115 mm²) and must retain a directivity no lower than 6 dBi to be compliant with our specifications.

The mutual coupling between two microstrip antennas printed on a high permittivity substrate is high [3], so in order to improve isolation between antennas, we replace the ground plane of the microstrip antenna by the following designed AMC.

III. AMC DESIGN

To design AMC structures, it is essential to define their operational frequency band, into which the phase of the reflection coefficient varies from -90° to 90° [2], in order to have constructive interference. To determine the reflection coefficient phase, a unit cell of the AMC structure is simulated with CST microwave Studio ®.

The AMC structure studied in this paper is a periodic arrangement structure of a four arms spiral shaped unit cells [4] printed on dielectric substrate with ground plane. It allows designing a compact AMC, because the use of four long arms provides a high inductance value and the gap between them a high capacitance value.

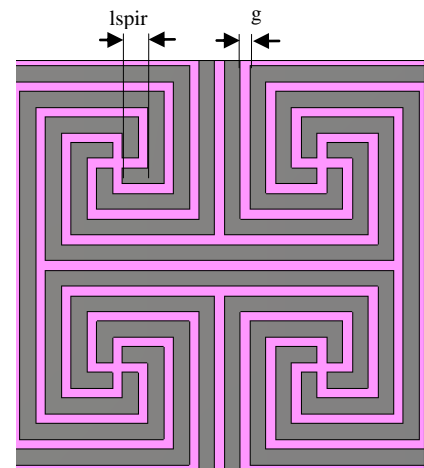


Fig. 1 AMC unit cell

The AMC structure has been realized on a Rogers TMM 100 substrate ($\epsilon_r=9.82$) with a total size of 115x115 mm² (the maximal size allowed by specifications) and a thickness of

0.762 mm. Dimensions of the unit cell are $l_{spir} = 0.8$ mm and $g = 0.3$ mm as shown in fig.1. At the operating frequency ($f = 1.62$ GHz), the AMC is characterized by a null reflection phase as shown in the phase diagram (Fig.2).

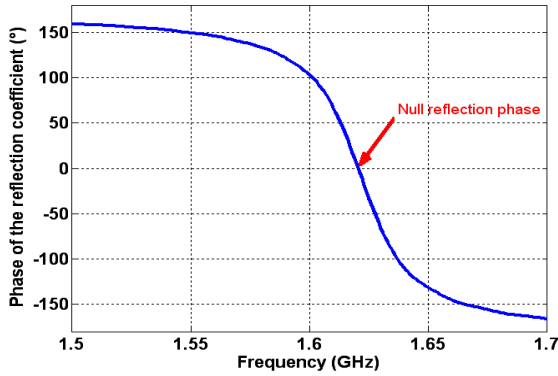


Fig. 2 Phase of the reflection coefficient of the AMC

IV. PATCH ANTENNA PERFORMANCE IMPROVEMENT

The dimensions of the patch antenna are optimized with an added air layer to improve the isolation between the two ports and keep directive gain higher than 6 dB (Fig.3). The square patch width is 52 mm. It is fed by two orthogonal probes located at 9 mm from its center. The feed location is optimized to provide a good impedance matching. The AMC is composed by 18 x 18 unit cells and the air layer thickness is 0.762 mm.

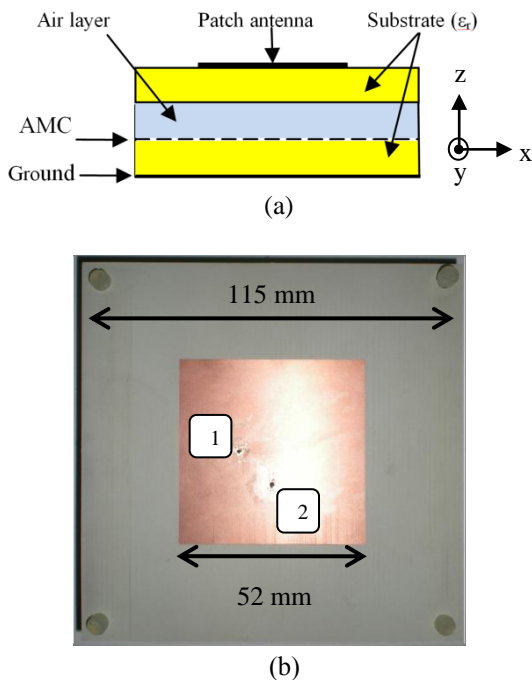


Fig. 3 Side view (a) and front view (b) of the realized structure

Simulations have been performed with CST Microwave Studio[®]. Measured and simulated return losses are compared in Fig.4. Satisfying agreements between simulations and measurements are observed. The frequency shift (around 20 MHz) is due to small variations of the air layer thickness over the realized structure. Despite this shift, the antenna remains matched at 1.62 GHz. The feeding ports of this single patch antenna element have -15 dB of return loss and -15 dB of isolation loss between them.

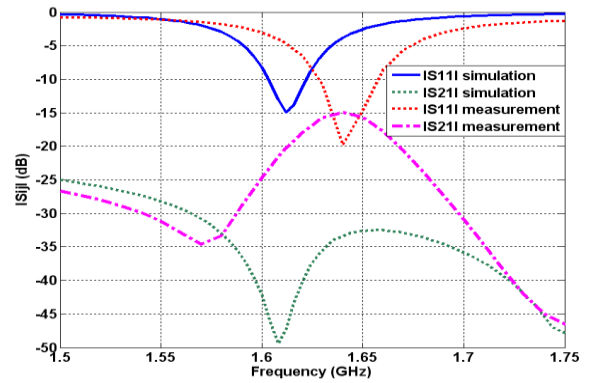


Fig. 4 Simulated and measured results (return loss and insertion loss) of the dual polarized antenna

Because both ports are symmetrical, we only represent one radiation pattern in E and H planes.

Fig. 5 and Fig.6 compare the simulated and measured co-polar and cross-polar radiation patterns in the E and H planes respectively. For both planes, it is found that the simulated and the measured co-polar radiation patterns are in good agreement. The broadside realized gain is about 7dB at 1.62 GHz and the HPBW is 90°. The measured cross-polar level is about 15 dB lower than the co-polar level. The simulation cross-polar level is very low and is not represented on this graph. This measured cross-polar level is probably due to some technical problems during the fabrication process of the structure. This antenna shows a rotational symmetry of the radiation pattern which is an interesting feature of AMC based antennas.

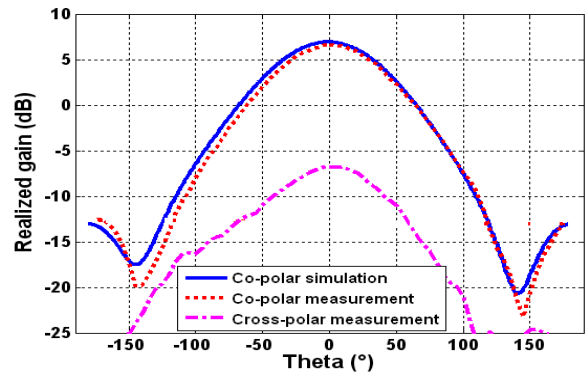


Fig.5 Simulated and measured radiation pattern in the E plane

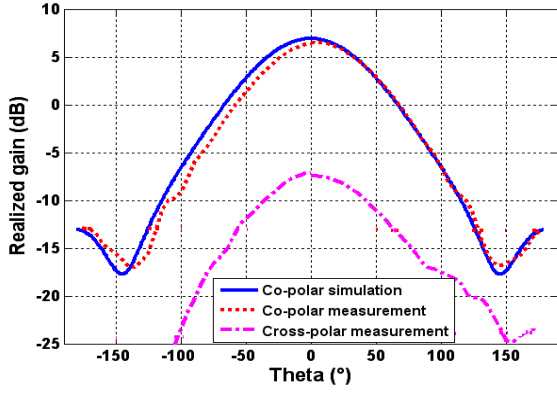


Fig.6 Simulated and measured radiation pattern in the H plane

V. MUTUAL COUPLING REDUCTION

The use of high dielectric substrate increases the coupling levels, due to the surface waves which propagate into the substrate from one antenna to another. In this part, we want to study the coupling between two antennas over AMC. The dimensions of the AMC are the same than previously, but the thickness of air layer is reduced to 0.3 mm, in order to decrease the width of the square patch from 52 to 43 mm [5]. It is important to note that this size remains suitable to obtain directive gain close to 6 dB. The distance between the centers of the two elements is 69 mm ($\approx \lambda_0/3$ where λ_0 is the wavelength in free space at 1.62 GHz). These two antennas have been simulated, realized, and then measured. The ports numbers are indicated in Fig.7.

Return loss, insertion loss and mutual coupling simulations and measurements are given in Tables I and II respectively. There is a good agreement between the simulations and the measurements. The feeding ports have a return loss below -10 dB and a mutual coupling between the different ports less than -15dB.

To show the effect of AMC, we compare the performances of the structure with the AMC and without it at 1.62 GHz. Table III represents the return loss, insertion loss and mutual coupling of the two antennas without AMC. The size of the dielectric substrate is the same, only the size and location of feeding ports of antennas have been changed to operate at 1.62 GHz. AMC has been replaced by a perfect metallic ground plane.

The proposed structure with AMC has about 3 dB enhancement of decoupling in H-plane configuration (ports 2 and 4), but there is no effect at the E-plane configuration (ports 1 and 3). This is probably due to the asymmetry of the spiral unit cell, which can reduce the surface currents only in H-plane configuration.

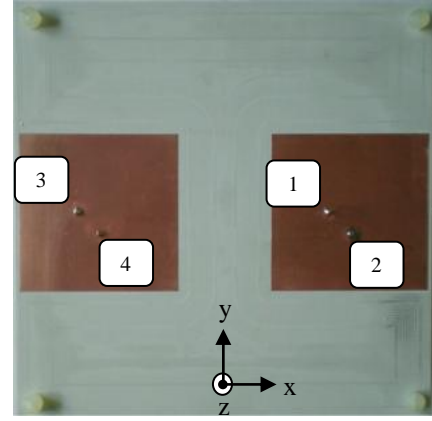


Fig. 7 The two realized antennas

TABLE I
RETURN LOSS, INSERTION LOSS AND MUTUAL COUPLING SIMULATIONS FOR THE ANTENNA ARRAY WITH AMC AT 1.62GHZ

$ S_{ij} $ (dB)	i=1	i=2	i=3	i=4
j=1	-10.1	-17.3	-14.0	-43.2
j=2	-17.3	-18.1	-35.6	-17.2
j=3	-14.0	-35.6	-7.7	-25.0
j=4	-43.2	-17.2	-25.0	-18.6

TABLE II
RETURN LOSS, INSERTION LOSS AND MUTUAL COUPLING MEASUREMENTS FOR THE ANTENNA ARRAY WITH AMC AT 1.64 GHZ

$ S_{ij} $ (dB)	i=1	i=2	i=3	i=4
j=1	-15.4	-15	-16.8	-34.7
j=2	-14.6	-10.1	-30	-22.5
j=3	-16.8	-30.0	-16.8	-20
j=4	-34.7	-22.5	-20	-10

TABLE III
RETURN LOSS, INSERTION LOSS AND MUTUAL COUPLING SIMULATIONS FOR THE ANTENNA ARRAY WITHOUT AMC AT 1.62 GHZ

$ S_{ij} $ (dB)	i=1	i=2	i=3	i=4
j=1	-11.7	-40.0	-14.0	-46.0
j=2	-40.0	-18.3	-44.0	-14.2
j=3	-14.0	-44.0	-11.0	-43.0
j=4	-46.0	-14.2	-43.0	-18.3

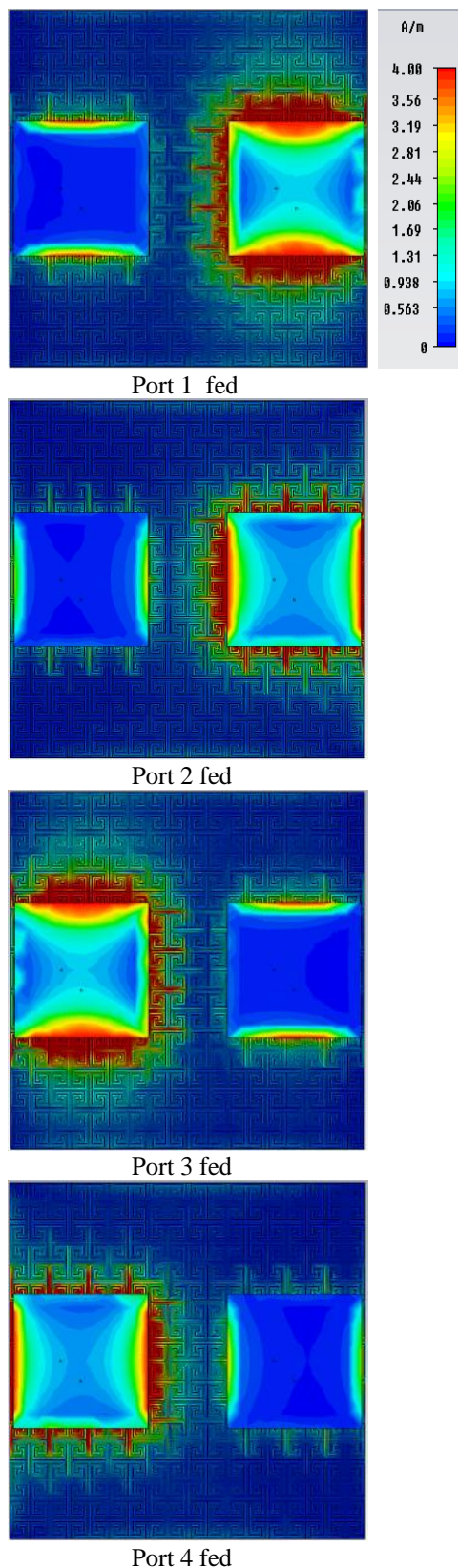


Fig. 8 Surface currents at 1.62 GHz for the four ports, one port is fed, the others loaded with 50 Ohms.

The figure 8 shows that the currents are localized around antenna and more important on passive antenna in E-plane configuration. As we can see, surface currents are present and it seems to be clear that the antenna has modified the behavior of AMC. It's necessary to remind that AMC has been characterized without antenna. To improve the efficiency of AMC, further work must be performed to take into account the antenna while characterizing the AMC.

The coupling reduction could be improved. Indeed, the two antennas are separated by only 2 unit cells in the proposed structure.

By decreasing the size of the unit cell, it will be possible to insert more unit cells between antennas, and thus to decrease the coupling.

VI. CONCLUSION

In this paper, a four arms spiral shaped AMC structure with an air layer is used to reduce the coupling between two dual polarized microstrip antennas. The parameters of the structure (spacing, width, number of the unit cells and the thickness of the air layer) were studied. First, a patch antenna over AMC has been designed. Then, two antennas over AMC and close to each other have been analyzed. It demonstrates good performances and a 3 dB mutual coupling reduction in H-plane configuration.

ACKNOWLEDGMENT

The authors would like to thank the French Space Agency (Centre National d'Etudes Spatiales, CNES) for proposing and sponsoring this work.

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