A Novel Miniaturized Polarization Independent Artificial Magnetic Conductor using Patch Array Loading

V A Libi Mol[1] Dr. C. K. Aanandan[2]
[1]Research Scholar [2]Professor
[1,2]Department of Electronics Engineering
[1,2]Microwave Propagation Research Lab Cochin University of Science and Technology, Kerala

Abstract— The design of a novel miniaturized polarization independent artificial magnetic conductor is presented in this paper. A 2*2 patch array loading is used here for miniaturization of square patch AMC unit cell. This proposed structure can provide lower resonance frequency compared to an unloaded AMC with same periodicity and thickness and polarization independent reflection characteristics for normal incidence. A prototype is fabricated and tested to validate the characteristic. The performance of structure for different polarization and angle of incidence is also studied.

Key words: Artificial Magnetic Conductor, Patch array loading, miniaturization, Polarization

I. INTRODUCTION

Artificial magnetic conductor has found a lot of application in antenna engineering and radar cross section reduction due to its in-phase reflection and surface wave suppression characteristics [1]. It consists of a frequency selective surface (FSS) backed by grounded dielectric. The rapid advancements in communication system demands the design of compact and low profile antennas. Due to the in phase reflection property of AMC, it can be considered as a good candidate for ground plane in low profile antennas. Also, the surface wave suppression property of AMC can be utilized in antenna array applications to reduce the mutual coupling effects. The miniaturization of AMC is very challenging at low frequencies as the unit cell dimension is of the order of half wavelength [2]. Based on effective medium model with lumped LC elements, the resonance frequency of AMC is inversely proportional to square root of the product of inductance and capacitance of the unit cell. So to overcome the size limitation, researchers have proposed different techniques to reduce the resonance frequency of the structure by increasing the effective capacitance [3]–[7] or inductance of structure. AMC structures with interdigital capacitors [3], [4] or lumped capacitors [5] are reported for size reduction. In [6], AMC with split ring resonator loading is proposed to obtain an increase in capacitance and thus a reduction in resonance frequency. Further miniaturization [6] is achieved by using interdigital structures to the patches and wide SRR loading [7]. In this paper, miniaturization of AMC with 2*2 patch array loading is proposed. This patch loading results in an increase in the effective capacitance and thus a decrease in the resonance frequency. The simulated and measured performance of the proposed structure is also presented in this paper. It is easy to fabricate the proposed structure as compared to other multilayered structures [6], [7] since no via holes are needed.

II. PROPOSED STRUCTURE

Since the AMC unit cell size is fractionally smaller than the operating wavelength, the structure can be described using an effective medium model in which AMC unit cell is represented by LC resonance circuit. Based on this, the resonance frequency (frequency at which the reflection coefficient is +1) is given by $\omega=1/\sqrt{LC}$. The bandwidth of operation is taken as the frequency range in which the reflection phase varies from +900 to -900 and it is proportional to $\sqrt{(L/C)}$.

The proposed AMC unit cell with 2*2 patch array loading is shown in Figure. 1. It consist of two dielectric layers. The square patches are arranged on the top layer and 2*2 array of patches are placed on the grounded dielectric layer below it. The dielectric is FR4 with dielectric constant 4.4 and thickness 0.8 mm.

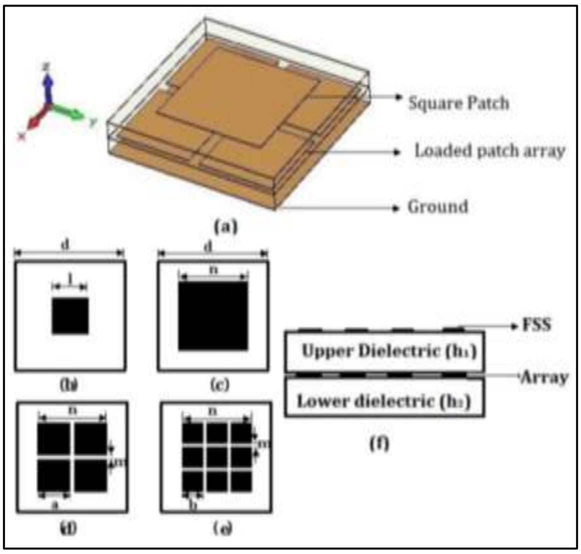

Fig. 1: (a)full view of the unit cell (b) Top layer Considered middle layer geometries [c-e] (c) single patch (d) 2*2 array (e) 3*3 array (f) Cross sectional view of the structure

Parameter	Value in mm
Periodicity (d)	8
Width of square patch on top layer (l)	5
Width of square patch on middle layer (n)	7.5
Width of square patch on 2*2 array on middle layer (a)	3.5
Width of square patch on 3*3 array on middle layer (b)	2.167
Gap between patches on middle layer(m)	0.5
Thickness of top dielectric layer (h_1)	0.8
Thickness of bottom dielectric layer (h_2)	0.8

Table 1: Dimensions of Proposed AMC Structure

The square patch FSS on the top layer can be represented by a series LC circuit, or more precisely by capacitive component C since the effect of inductance is low. The loaded middle layer can be modelled as capacitive component C' and grounded dielectric as inductance L' as shown in Figure. 2.

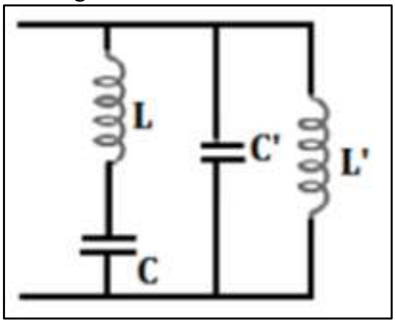

Fig. 2: equivalent Circuit model of the Structure

To understand the impact of 2*2 patch array loading, AMC structures without loading, with single patch and 3*3 patch array loading are also considered. The Geometry and dimensions of these AMC structures are shown in Figure. 1 and table 1 respectively. By the single patch loading of the square patch unit cell, the effective capacitance of the structure is increased resulting in reduced resonance frequency. This capacitance depends on the thickness of dielectric over which the array is loaded. Since the bandwidth is inversely proportional to square root of capacitance, the bandwidth of operation obtained will be less by this configuration. To avoid this drawback and to obtain reduction in resonance frequency, an array of patch loading can be employed. The 2*2 array configuration has less capacitance compared to the single patch loaded structure. Thus reduction in resonance frequency without much degradation in bandwidth as compared to unloaded structure can be obtained. Further improvement in bandwidth can be obtained by increasing the periodicity of array. But it will result in increase in resonance frequency as compared to lower periodic array loaded configuration, i.e., there is a tradeoff between increases in bandwidth and reduction in resonance frequency. So proper care should be taken to select the periodicity of array. The simulated resonance characteristic of the square patch AMC structure with single patch, 2*2 and 3*3 patch array loading is shown in Figure. 3 along with AMC without loading. Simulations are carried out using frequency domain solver in CST Microwave Studio. The comparison of simulated result is given in table.2. The results indicates that resonance frequency and bandwidth of structure can be controlled by loading the arrays with suitable periodicity.

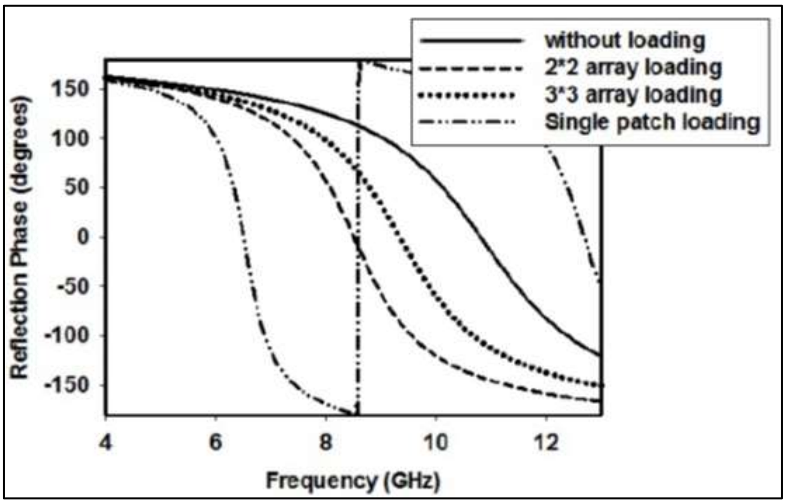

Fig. 3: Simulation studies on the effect of loaded structure on resonance frequency

Configuration	Resonance Frequency	Bandwidth
Without loading	10.81	2.83
Single patch loading	6.5	0.74
2*2 patch array	8.5	1.82
3*3 patch array	9.33	2.3

Table 2: Analysis of the result

The simulation study on the effect of dielectric thickness (h2) over which 2*2 array is loaded, with the total dielectric thickness kept same (h1+h2=1.6 mm) is shown in Figure. 4. It shows that as the h2 decreases from 1.2 mm to 0.2 mm, the resonance frequency increases from 7.1 GHz to 10.4 GHz.

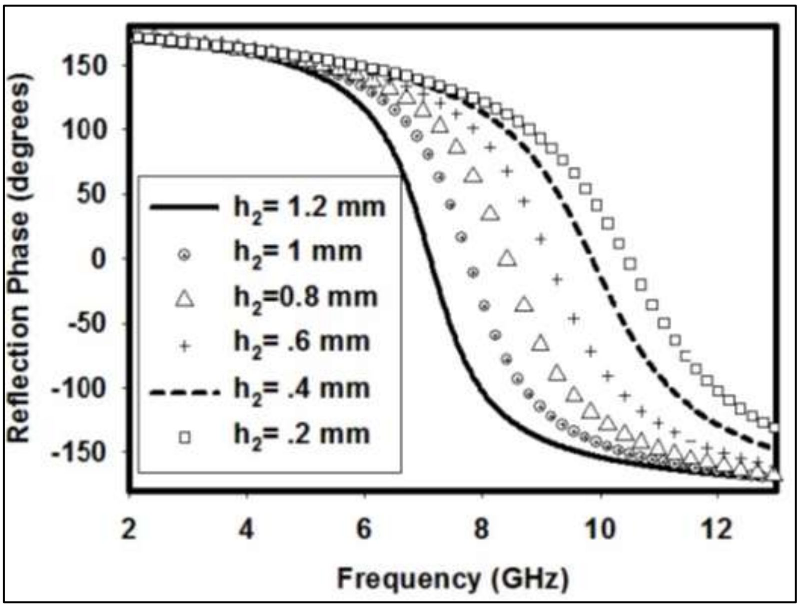

Fig. 4: Simulation result showing the effect of dielectric thickness h2 on resonance frequency (h1= 1.6 mm- h2)

A study on the effect of angle of incidence and polarization on the resonance is also conducted. As the proposed unit cell is symmetrical, its reflection characteristics will be same when the structure is illuminated with TE or TM polarized waves. The polarization angle ϕ = 00 and ϕ = 900 corresponds to TE and TM polarized wave respectively. The simulation result depicted in Figure. 5 indicates that the resonance characteristic of structure is independent of polarization angle of incident wave for normal incidence.

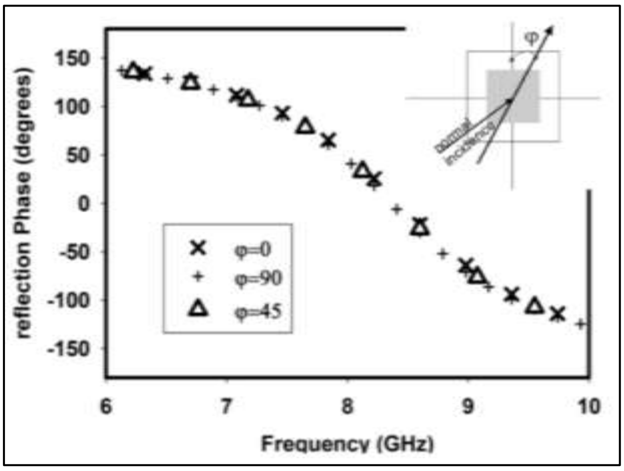

Fig. 5: Simulation results showing the effect of polarization angle on resonance frequency for normal incidence

The resonance characteristic of the structure also depends on the incident angle. The oblique incident angle up to which the resonance characteristic of the structure remains unchanged for TE or TM polarized wave measures the angular stability of structure. Simulated reflection phase for TE polarized wave under different oblique incidence is depicted in Figure. 6 and it reveals an angular stability up to 400. TM polarized wave incidence also shows an angular stability up to 400 (Fig.7). For higher angle of incidence the structure loses the AMC property for both TE and TM polarized wave. It is also noted that up to 400 reflection characteristics of structure is independent of polarization angle (ϕ).

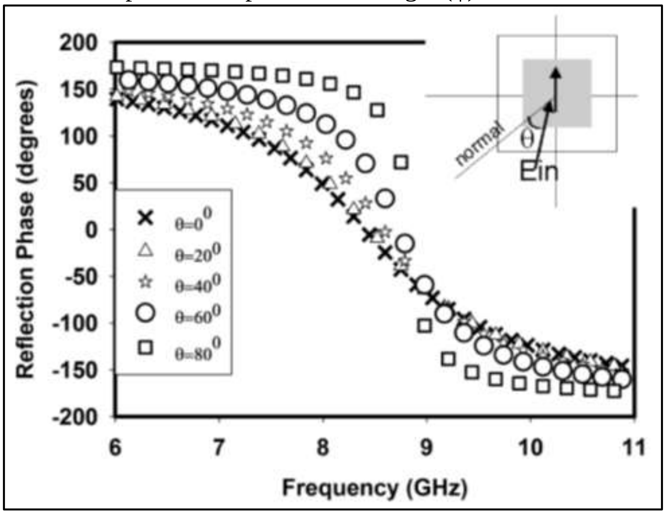

Fig. 6: Simulated reflection phase for different incident angle for TE polarized wave

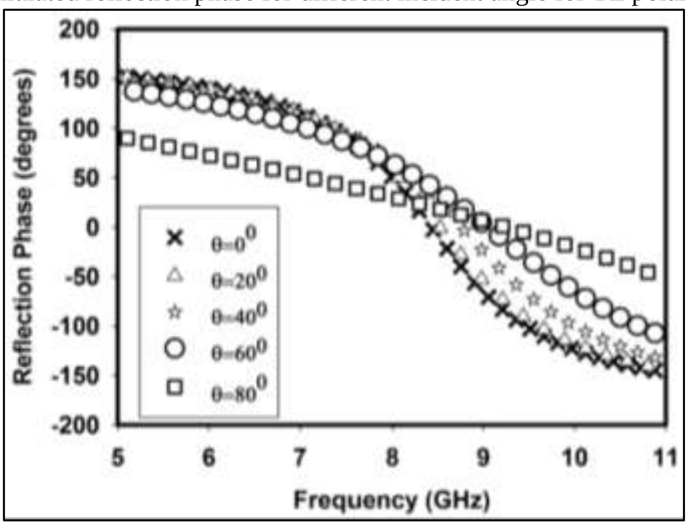

Fig. 7: Simulated reflection phase for different incident angle for TM polarized wave

III. RESULTS AND DISCUSSION

To validate the performance, a 30 cm * 30 cm AMC structure composed of 37 * 37 unit cell is fabricated. The photograph of fabricated prototype is given in Figure. 8.

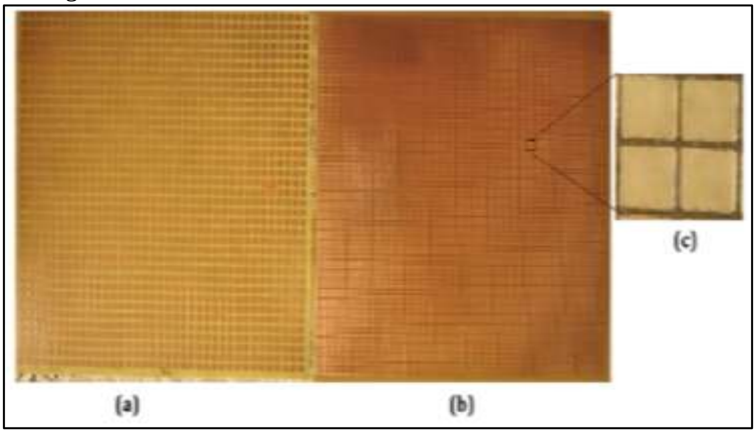

Fig. 8: Photograph of fabricated prototype a) Top layer b) loaded 2*2 array Structure c) Enlarged view of array unit cell

Its reflection phase is measured using two horn antennas. Both this antennas were placed very near to each other, facing the target. The reflectivity from a metal plate with same dimension as of the structure is taken for normalization. The phase of transmission coefficient S21 of structure is noted. Both the simulated and measured results of AMC without loading and AMC with 2*2 array patch loading are shown in Figure. 9. The measured resonance frequencies are 10.72 GHz and 8.83 GHz. The small difference in measured results as compared to simulations can be accounted for variation in permittivity, fabrication error etc. Polarization independent behaviour of the structure for normal incidence is also verified by measurement. The measured result depicted in Figure. 10 indicates the resonance characteristics of structure is not varying with polarization angle (ϕ).

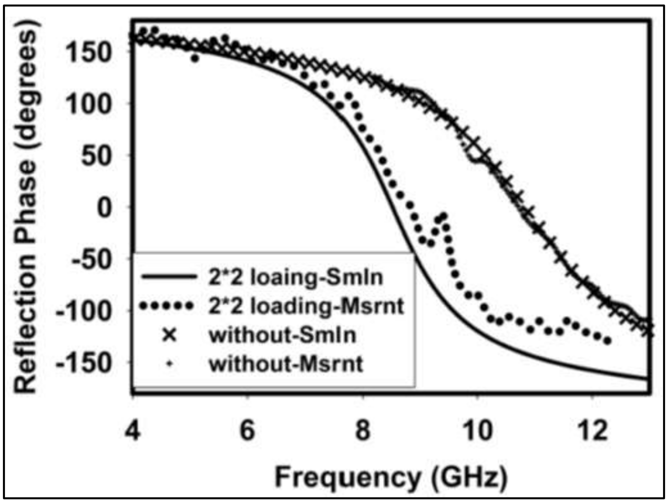

Fig. 9: Comparison of results

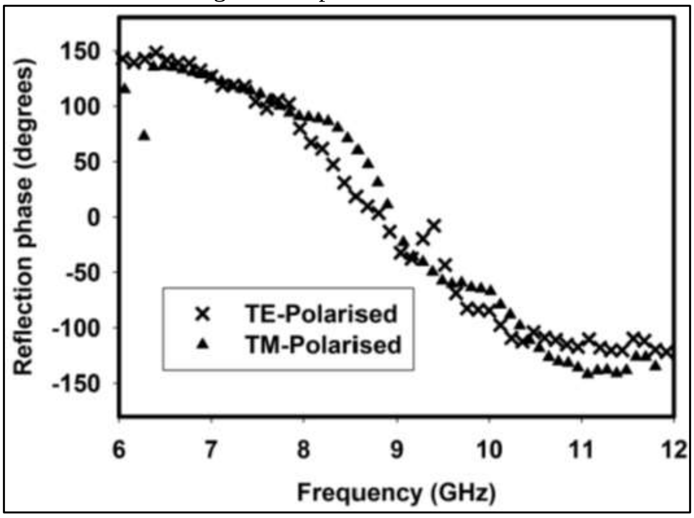

Fig. 10: Measured reflection phase for TE and TM polarized incident wave for normal incidence

IV. CONCLUSION

A new miniaturized AMC using square patch array loading is proposed. A prototype is fabricated and its reflection phase is measured. It is in good agreement with simulated result. The proposed structure is easy to fabricate as no via holes are needed.

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