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Energy Harvesting using loaded Metamaterial Absorber Unit-cell with polarization independent Capability

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***Abstract*—In this paper, we demonstrate the feasibility of harvesting electromagnetic waves by using a metamaterial absorber unit-cell with a high absorption rate of 98.86 %, that operates at 5.8 GHz. The numerical results show that the prosed unit-cell has nearly constant performances regardless the polarization angle of the incoming waves. Then four resistive loads were embedded in the unit-cell to compute the radiation to RF conversion efficiency. An equivalent circuit model was also proposed and comparison was made to the simulation results.**

I. Introduction

Nowadays, the demand for energy autonomy for portable systems becomes more and more substantial particularly in 5G communication technology [1], Radio Frequency Identification (RFID) [2], electric vehicles [3], Internet Of Things (IoT) and Wireless Sensor Nodes (WSN) [4]. RF and microwave rectennas, containing rectification circuit, have been investigated for powering low consumption devices using RF and microwave sources [5]. Energy harvesting using several microstrip antennas, as collectors, has also been investigated [6]. However, with conventional microstrip antennas we still have some limitations like: low RF-to-AC conversion efficiency, polarization mismatch, narrow beam-width etc.. In recent decade, research on metamaterials is of great interest, especially tunable, intelligent and reconfigurable metasurfaces [7]. Planar metasurfaces have been used for RF energy harvesting, due to their high efficiency [8] compared with conventional patch antennas.

This work presents a new design for a metamaterial absorber unit-cell, that can be used to harvest energy from surrounding environment which is transported by randomly polarized waves. The grounded unit-cell was designed to operate at 5.8 GHz and the numerical results show that the characteristics of the metamaterial particle are stable and less sensitive to the polarization of incoming waves.

II. Simulation Results

A. Unit cell Design

The proposed unit cell is depicted in Fig.1 with its geometrical parameters values. The structure was designed on 0.8-mm FR4 epoxy substrate with dielectric constant of 4.3 and dielectric loss tangent of 0.025.

B. Unit Cell Response

The unit cell was characterized using floquet modal analysis on the commercial software CST Microwave Studio. In order to calculate the absorption coefficient, given by Eq.(1), of the unit cell, the scattering parameters were estimated using TE, TM, LHCP and RHCP polarized waves as input excitations.

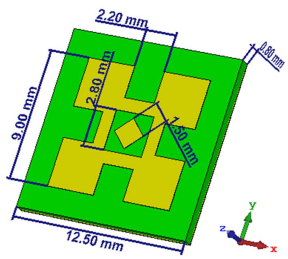

FIGURE 1. 3D DIMENSIONAL GEOMETRY OF THE UNIT-CELL

$$A(\omega) = 1 - |S_{11}|^2 - |S_{21}|^2 \quad (1)$$

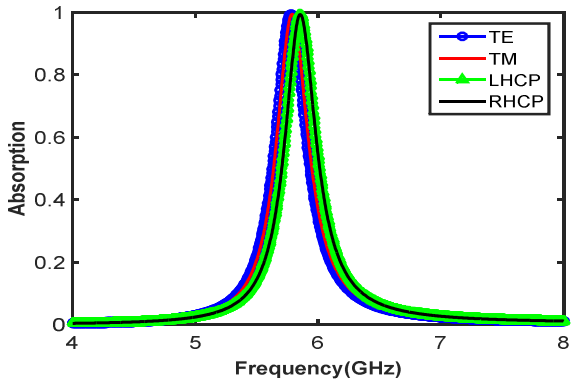

FIGURE 2. ABSORPTION OF THE UNIT CELL AS A FUNCTION OF FREQUENCY, FOR MODES : TE, TM, LHCP, AND RHCP

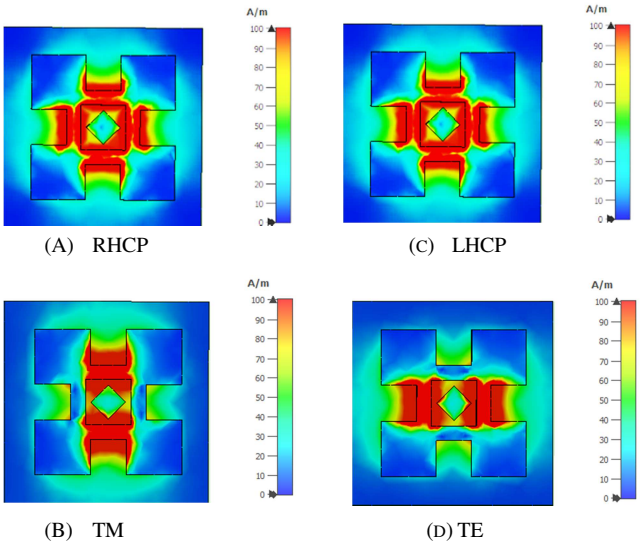

FIGURE 3. SURFACE CURRENT DISTRIBUTION AT 5.8 GHZ, FOT RHCP, TM, LHCP AND TE MODES

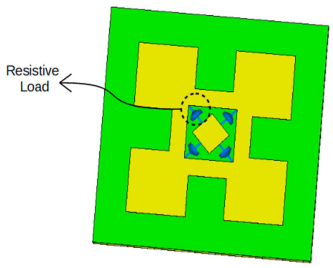

FIGURE 4. 3D DIMENSIONAN UNIT-CELL WITH EMBEDDED RESISTIVE LOADS

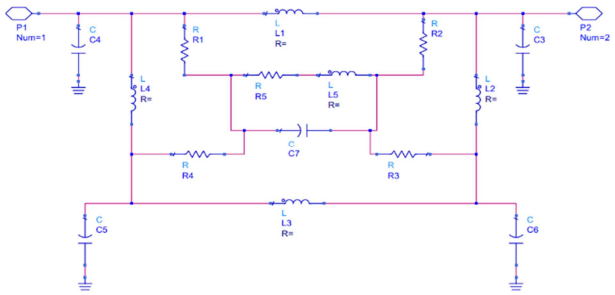

FIGURE 5. EQUIVALENT CIRCUIT MODEL

From Fig.2, it is clearly shown that the response of the unit-cell is very less sensitive to the polarization of incident waves and absorption peaks reach 98.86 % at the operating frequency.

Fig.3 shows the numerical results of the magnitude of the surface current across the upper copper sheet of the unit-cell at the resonance frequency. The highest magnitude (red color) appears at the strips located in the right and left sides and in the upper and lower sides, for TE and TM modes respectively, and at all the four strips for RHCP and LHCP polarizations. This means that the maximum amount of energy is located in these regions.

C. Energy Harvesting Trough resistive loads

In order to demonstrate, the ability of the unit-cell to harvest the ambient EM energy, and according to the results of the current distribution, four resistive loads have been embedded in the unit cell as shown in Fig.4

An equivalent circuit model for the whole structure is shown in Fig.5. Fig.6 illustrates the reflection coefficient for EM and circuit model simulations.

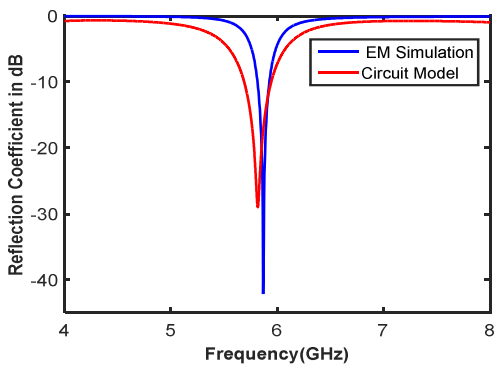

FIGURE 6. S-PARAMETERS RESPONSE (EM SIMULATION VS CIRCUIT MODEL)

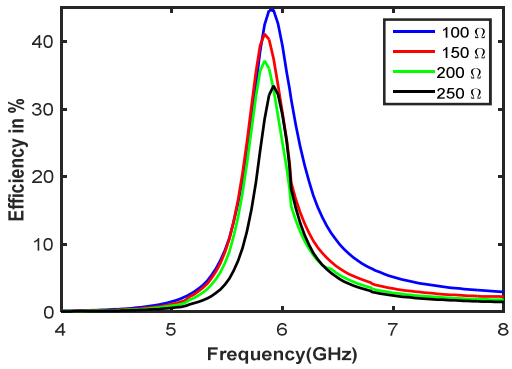

FIGURE 7. EFFICIENCY AS A FUNCTION OF FREQUENCY

III. UNIT-CELL EFFICIENCY

The radiation to RF conversion efficiency of the unit-cell is computed by Eq.(2), where the incident power, P_{In} , is the real power available on the footprint of the unit-cell in Watts. This power can be obtained by multiplying the physical area of the unit-cell by the Pointing vector, while P_L, is the time-average active power dissipated in all resistive loads. Fig.7 shows the efficiency as a function of frequency for different loads values.

$$\eta = \frac{P_L}{P_{In}} \tag{2}$$

IV. CONCLUSION

In this work, we showed numerically that the proposed unit-cell can potentially be used for electromagnetic energy harvesting regardless of the polarization of incident waves with high absorption rate at 5.8 GHz. The experimental validation of the structure is planned. Also, an RF-to-dc conversion circuit will be integrated to complete the rectenna.

ACKNOWLEDGMENT

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