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***Abstract*—Metamaterials are commonly associated to antennas and other microwave devices due to their unique ability to manipulate electromagnetic waves. In general, the approach used to select metamaterials for a given application is based on a classical approach by extracting the scattering parameters to evaluate the material effective properties. In this paper, we address the problem of evaluation and analysis of a specific metamaterial, a chiral helix metamaterial through the use of two modal analysis Expansion Eigenmode Method and the Characteristic Mode Theory. An interaction of the chiral helix with Circular Polarized electromagnetic plane waves is studied. The modal net stored energy of the metamaterial is also calculated. A good agreement is obtained between the net stored energy calculated by the two methods for the chiral metamaterial. The effect of polarisation on the metamaterial is also highlighted by the modal analysis. These modal approaches applied to chiral metamaterials can be of interest for the design of circularly polarised metamaterial antennas.**

I. Introduction

Nowadays, the study of electrically small antennas with high performances in terms of gain, bandwidth and radiation pattern is an appealing research topic. Metamaterials (MTMs) and more particularly their potential to improve antenna performances [1] are also extensively studied at microwave frequencies. Generally, the methodology used to analyse MTMs while associating them to antennas, is based on their effective permittivity and permeability. The major disadvantage of this approach is that it does not give a full physical insight on the radiation properties and near-field coupling. Modal methods such as Eigenmode Expansion Method (EEM) [2] and Characteristic Mode Analysis (CMA) [3] can however provide a better physical insight on the radiating phenomena and based on the modal currents. Indeed, metamaterials can thus be classified into magnetic or electric structures in terms of stored energy, before their association to a given antenna. The main advantage of EEM and CMA is that they are independent of excitation and they are applicable to arbitrarily-shaped structures. The net and modal stored energies of MTMs can further be calculated thus providing insight on the antenna radiation efficiency. In this paper, our objective is to analyze the properties of chiral metamaterials which could be an interesting element for circularly polarized antennas with two modal approaches: EEM and CMA. To this end, after performing a modal analysis on the metamaterial, the net stored energy of a chiral metamaterial is calculated and compared for the two modal approaches. A single-turn helix metamaterial [4] is considered. The specificity of this metamaterial is that it interacts only with waves of one of the two orthogonal circular polarizations (CPs). This type of MTM is used for wide types of application from antennas and microwave to optics.

II. Stored Energy of Helix metamaterial: comparison between EEM and CMA

In this section, our aim is to calculate the net stored energy of a chiral metamaterial helix using the two modal analysis EEM and CMA. The design of the structure consists in a single turn metallic strip helix the dimensions of R = 7.75 mm, h = 12 mm, $2r$ = 1.55 mm and with a pitch angle of $\alpha = 13.65\,^\circ$ [4] as depicted in Fig. 1(b). For the design and

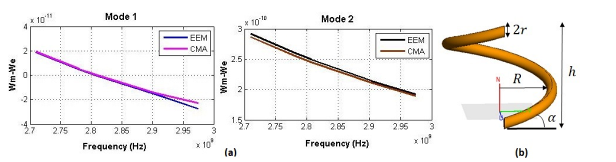

Fig. 1. (a) Net Stored Energy against frequency by CMA and EEM. (b) the chiral metamaterial structure

the evaluation of the impedance matrix, the commercial tool FEKO is used to design and to evaluate the impedance matrix of the structure. The frequency range varies from 2.6 GHz to 2.9 GHz. The Z matrix is then extracted and the stored energy is computed based on the evaluation of the eigenvalues of both of CMA and EEM. The net stored energy $\mathrm{W_m - W_e}$ is computed based on the net stored energy formulation defined in [5]. The first two modes for each modal analysis method are calculated and presented in Fig. 1. It is assumed that two modes are sufficient to analyze electrically small structures [6]. For CMA, the characteristic currents are real vectors, whereas the eigencurrents are complex vectors for EEM. Therefore we sorted the eigencurrents according to the ratio between imaginary and real parts of the complex eigenvalues of EEM. The $W_\mathrm{m} - W_\mathrm{e}$ is plotted against frequency. When this quantity $W_\mathrm{m} - W_\mathrm{e}$ vanishes, it indicates the resonance. The helix metamaterial resonates at 2.82 GHz for CMA. The net stored energy of mode 1 is negative and then positive after the resonance, this indicates that the energy switches from electric to magnetic at resonance. For mode 2, Fig. 1 shows that the stored electric energy is greater than the magnetic one in the whole frequency band of interest. It should be noted that the stored energy presented by EEM are complex quantities, since the eigencurrents are complex vectors [2]. Fig. 1, shows the real part of the $W_{\mathrm{m}} - W_{\mathrm{e}}$ (the imaginary parts are not shown). The $W_{\mathrm{m}} - W_{\mathrm{e}}$ vanishes at 2.82 GHz, which indicates the resonance. The net stored energy of mode 1 goes from electric to magnetic energy at resonance. For mode 2 the net stored energy is mostly electrical. Current distributions, at 2.82 GHz for TCM, of mode 1 switches from capacitive to inductive modes and mode 2 is a purely capacitive mode as shown in Fig. 3 (b).

III. Scattering Parameters and Modal Weighting coefficients (MWC)

The scattering parameters of a periodic array of spiral helix is computed by the numerical simulator CST Microwave Studio. Periodic boundary conditions are applied to simulate the periodic structure. Three configurations are investigated. In the first case, the electric field $\vec{E}$ is polarized along the axis of the helix and the magnetic field $\vec{H}$ are along the $\vec{y}$ direction. In the second case, the $\vec{H}$ is polarized along the axis of the helix and the $\vec{E}$ is polarized along the $\vec{x}$ direction and in the third case the $\vec{E}$ is along the helix axis and $\vec{H}$ along $\vec{y}$ direction as shown in Fig. 2. The reflection and the transmission coefficients are computed with CST. The results are depicted in Fig.2. The resonance frequency is found around 2.82 GHz for all the configurations which agree with the results of the stored energy. It is important to note that around the resonance, the components of the reflected fields have the same magnitude with a 90° shift between the components. This is to confirm the CP of the reflected field by the helix. In order to analyze the chirality and the interaction of the helix with different excitation, the MWCs are computed for the three configurations mentioned above. As illustrated in Fig. 3. mode 1 presents a coefficient peak at the resonance frequency for all the configurations except for mode 2 which is a purely reactive mode over all the frequency band. This is can be predicted from Fig. 1. It is obvious from Fig.3 that the helix has a maximum interaction for case 2. It is important to note that the optimal helix has ”maximum chirality” at the resonance and highly affected when it is excited with axial magnetic field and electric field polarized along the ends of the helix, this chiral material has different response and this agrees with the results that the spiral helix emit circularly polarized wave.

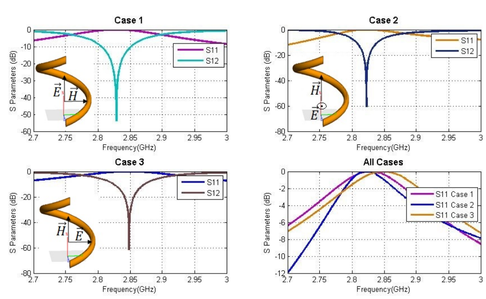

Fig. 2. Scattering parameters of all the configurations

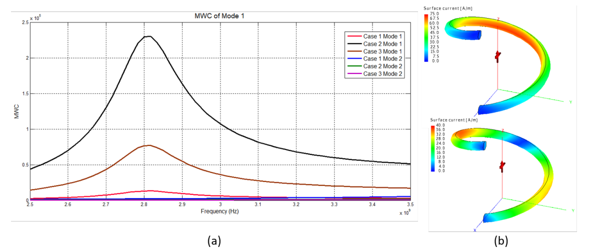

Fig. 3. (a) Modal Weighting Coefficients for different configurations (b) Modal currents of the helix metamaterial by CMA

IV. Conclusion

The properties of chiral helix metamaterial is demonstrated using two modal analysis CMA and EEM. FEKO was used to evaluate the impedance matrix and a mathematical formulation was implemented to evaluate the stored energies. The analysis of the chiral metamaterial by modal approaches shows a strong dependence on the polarization of the fields. The stored energies were also calculated for these metamaterial. It should be noted that the stored energies are independent of excitation. Further studies will be presented where the excitation can be accounted for to determine the net stored energy for a given application. The comparison between EEM and CMA are in good agreement also for chiral metamaterials, not only in terms of modal significance but also currents distributions, far fields and stored energies.

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