Some applications of MTMs based on non-Foster active loads

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Abstract

In this contribution, we propose a novel approach to dramatically improve the operation bandwidth of a Split Ring Resonator (SRR) by loading its external gap with an active non-Foster circuit. The theoretical aspects, as well as some applications in the field of electrically small microwave antennas, enhanced microwave transmission, and microwave absorbers are presented.

1. Introduction

In the last decade, metamaterials (MTMs) have received the attention of the scientific community for the innovative technology opportunities that they offer. Actually, the most common approaches used to obtain a MTM exhibiting a negative effective permeability are based on the use of resonant inclusions immersed in a host material. One of the main limitations of this approach is the intrinsic narrowband response due to the resonant behaviour of the metallic inclusions. In antenna theory, it is know that the bandwidth of a resonant component can be increased by using an external non-Foster matching network. This method, however, cannot be easily extended to the case of MTM inclusions, due to the different excitation mechanism.

In this contribution, following the pioneering works in the field [1]-[3], we propose a novel approach to use non-Foster active elements to enhance the operation bandwidth of a single SRR and apply it in different application fields, including electrically small antennas, enhanced transmission, absorbers.

2. SRR loaded with non-Foster active elements

As showed in [4], the magnetic response of an SRR can be modelled as an LC series circuit. Following this model, the angular resonance frequency ω_0 is given by:

$$\omega_0 = (LC)^{-1/2}. \tag{1}$$

The rapid grow of the reactance around the resonance frequency is responsible for the narrowband behaviour of the SRR. A way to broaden the operation bandwidth is to load the SRR with a circuit such that the reactance of the overall circuit is zero in a large frequency range. In order to satisfy such a condition, a circuit whose reactance exhibits a negative slope is required [1]. Such a circuit violates Foster’s theorem, so it cannot be realized with passive elements but only with an active circuit based on Negative Impedance Converter (NIC) [5]. Due to the geometrical structure of the SRR, it is straightforward to connect the load impedance between the opposite faces of the external gap. This configuration corresponds to a parallel connection of the active load to the gap capacitance and, therefore, to the total capacitance of the SRR [4]. In order to analytically determine the load impedance that compensates the intrinsic reactance of the SRR, it is useful to ideally load the SRR with a lumped impedance Z_L in parallel to the SRR capacitance. In this case, the overall impedance of the circuit is:

$$Z_{tot} = j\omega L + \left(j\omega C + \frac{1}{Z_L} \right)^{-1}. \tag{2}$$

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From this expression, by forcing the cancellation of the reactance, it is possible to obtain the required load impedance as:

$$Z_L = \frac{1}{C}\frac{j\omega}{\omega^2 - 1/LC}, \tag{3}$$

that coincides with the impedance of an LC parallel circuit with $L_p = -L$ and $C_p = -C$. This type of load, connected in parallel to the gap capacitance, allows to cancel the resonant LC series circuit effect, ensuring a broadband response.

3. Proposed applications

As a first application, we have considered the MTM-inspired antenna proposed in [6] and showed in the inset of Fig. 2. By loading the SRR in its external gap with the appropriate negative values of L and C elements, the reflection coefficient of the antenna shows a dramatic bandwidth enhancement, as can be seen from the full-wave simulation result reported in Fig. 2.

The second proposed application deals with the extraordinary transmission through a sub-wavelength aperture. The structure is described in [7] and showed in the inset of Fig. 3. In the same figure it is possible to note the improved transmission bandwidth obtained through our approach.

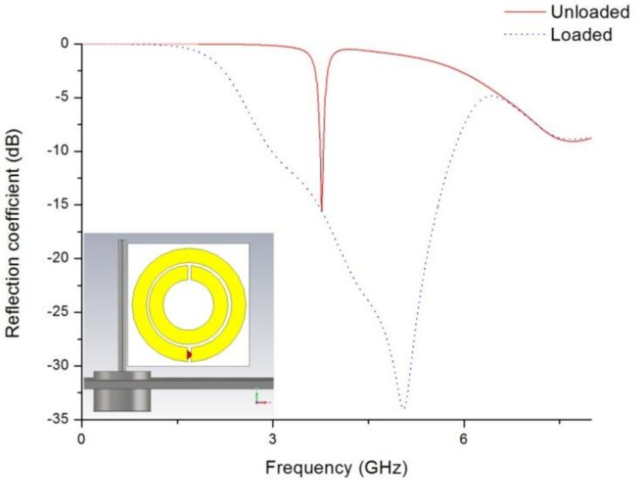

Fig. 2: Geometry and reflection coefficients of the antenna proposed in [6] and its loaded version.

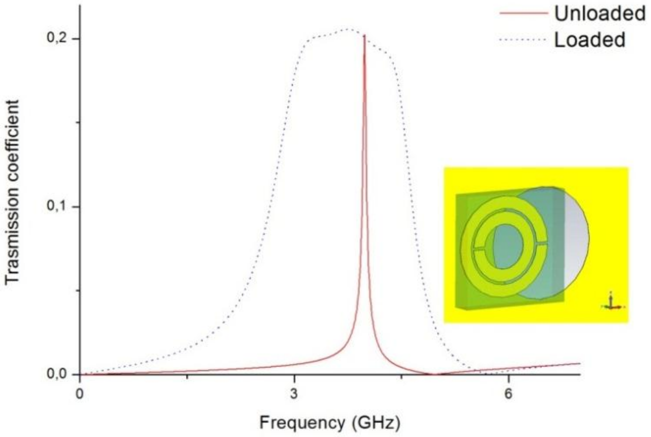

Fig. 3: Geometry and transmission coefficients of the structure proposed in [7] and its loaded version.

Finally, in Fig. 4 we show the absorbance of the absorber presented in [8] compared to the one of the same device loaded with non-Foster elements.

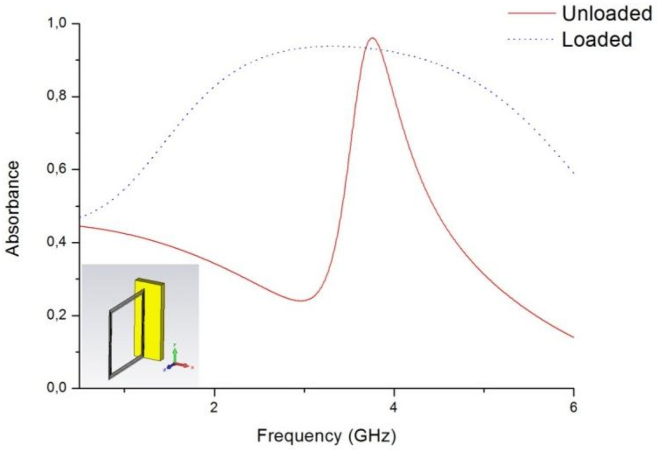

Fig. 4: Geometry and absorbance of the absorber proposed in [8] and its loaded version.

The practical implementation of the active non-Foster load through proper NIC configurations, as well as the definition of the stability conditions are currently under investigation and will be detailed presented at the conference.

4. Conclusion

In summary, we have shown that by loading an SRR through a proper active non-Foster load in its external gap it is possible to improve the operation bandwidth of such inclusion. The proposed approach has been successfully used in three different applications, including miniaturized MTM-inspired antennas, enhanced transmission, and microwave absorbers. Current developments of this research are focused on the actual implementation and the stability analysis of the presented solutions.

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