Efficient electrically small apertures and their applications in microwave components

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Abstract

In this paper, we present the design of efficient electrically small apertures loaded with metamaterial-inspired sub-wavelength resonators. The employment of the proposed resonators, whose resonant frequency is independent from the surrounding environment, enables efficient radiation and automatic impedance matching, without increasing the physical dimensions of the aperture. This interesting phenomenon is applied to design a new family of microwave components, including electrically small aperture antennas, self-filtering horn radiators, waveguide microwave diplexers, waveguide filters, waveguide (un)balanced and switchable power splitters, etc.

1. Introduction

One of the major advantage of employing metamaterial concepts in microwave antennas resides in the possibility of miniaturizing the dimensions of the radiators. Typical applications concern dipole and microstrip antennas, whose electrical dimensions can be squeezed by loading electrically short radiators with a single or a few metamaterial-inspired resonators [1]-[3]. In this case, what happens is that a short antenna, which is a highly inefficient and mismatched radiator by itself, is brought to a resonance condition by the presence of the electrically small resonator(s) and is matched to its feeding line through the reactive impedance matching enabled by the same resonator(s). This approach, valid for linear and patch antennas, can be extended also to electrically small *aperture antennas*, which are inefficient radiators by themselves. Typically, in order to efficiently extract power from an electrically small aperture, one can place a conventional resonating element across the aperture. However, this solution results in a quite bulky setup, which is in conflict with the final goal of having a miniaturized efficient aperture. In other words, in order to make a sub-wavelength aperture radiating efficiently, the additional resonator should have a resonant length (typically half wavelength). As it was the case in the miniaturization of linear antennas, metamaterial concepts can play a significant role also in this application field. Miniaturized resonators as the ones used for metamaterial inclusions (e.g. split-ring resonators, etc.), in fact, can be successfully used for this purpose. For instance, it has been demonstrated that one or two split-ring resonators placed across an electrically small aperture allow extracting power efficiently from the aperture, without altering the compactness of the entire setup [4].

In this contribution, we propose to employ a new inclusion – the connected bi-omega particle – to efficiently extract power from a sub-wavelength aperture. We show that the resonant frequency of such a particle is independent from the surrounding environment and can be predicted by using a simple analytical model. In this way, the design of the particle is straightforward, as well as its employment in a new family of microwave components, including electrically small aperture antennas, self-filtering horn radiators, waveguide microwave diplexers, waveguide filters, waveguide (un)balanced and switchable power splitters, etc.

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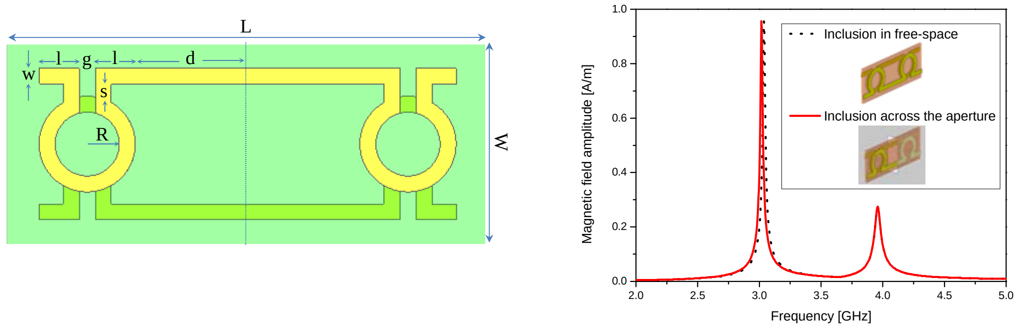
2. Connected bi-omega particle: operation and design

The particle under study is sketched in Fig. 1a. It consists of two reversed metallic omega pairs printed on the two sides of a dielectric board. From geometrical considerations, it results that this symmetrical structure supports two fundamental modes characterized by odd and even electric field distributions, respectively. The odd mode is quite interesting because it is characterized by a strong excitation of the two strips connecting the omegas at each board side. Due to the balanced configuration of the particle and to the localization of the field within the particle shape, the resonant frequency of the modes are expected to be independent from the surrounding environment and depend only on the geometrical parameters of the particle and the geometrical/electrical parameters of the board. Since the particle size is a small fraction of the wavelength at the resonant frequency, it is possible to model its electromagnetic behaviour through a quasi-static model that can be easily obtained by exploiting the earlier results on individual helical and omega particles and on the helical particle pair. The full details about the analytical model will be presented at the congress. Here we would like to remark only that the agreement between the analytical model and the full-wave simulations is excellent and that the expected independence of the resonant frequencies of the particle with respect to the surrounding environment is verified, as shown in Fig. 1b. As an example, in the figure we report the cases of the particle in free-space and placed across an electrically small slit drilled in a metallic plate.



a) b)

Fig. 1: a) Geometrical sketch of the connected bi-omega particle. b) Amplitude of the magnetic field recorded by the probes at the centres of the loops in the cases of a slab in free-space and across a slit in a metallic screen.

3. Connected bi-omega particle: applications

The proposed structure can be successfully used to conceive a new family of microwave components that can find application in satellite applications. Typical components for satellite communications are realized in waveguide technology and, thus, operate over a broad frequency band.

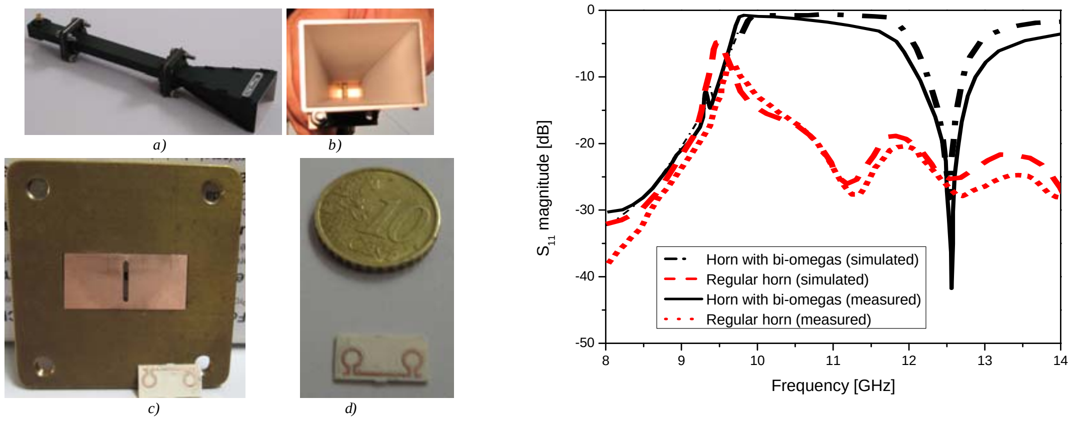


Fig. 2: (left) Self-filtering horn antennas fabricated and tested. (right) Reflection coefficient of the horn antenna with and without the connected bi-omega particle placed at its throat.

However, while for other applications broadband operation is desired, this is not the case in satellite systems, where narrowband signals are used and noise must be filtered out efficiently. Usually, noise reduction is accomplished by using bulky and expensive additional filters, that can be easily replaced by the structure reported in the previous section. This solution is cheap, light, and does not require additional space. The connected bi-omega particle, in fact, can be easily integrated inside any component. In Fig. 2, we show a new self-filtering horn antenna for satellite applications we have tested and fabricated. In Fig. 3, we show the design of a waveguide diplexer, employing two particles with slightly different dimensions in order to resonate at different frequencies. In Fig. 4, we show an unbalanced tunable power splitter obtained by placing proper switches at proper locations on the omega particles. More details on the design procedures and operation of the components of Figs. 2-4 and further applications will be presented at the congress.

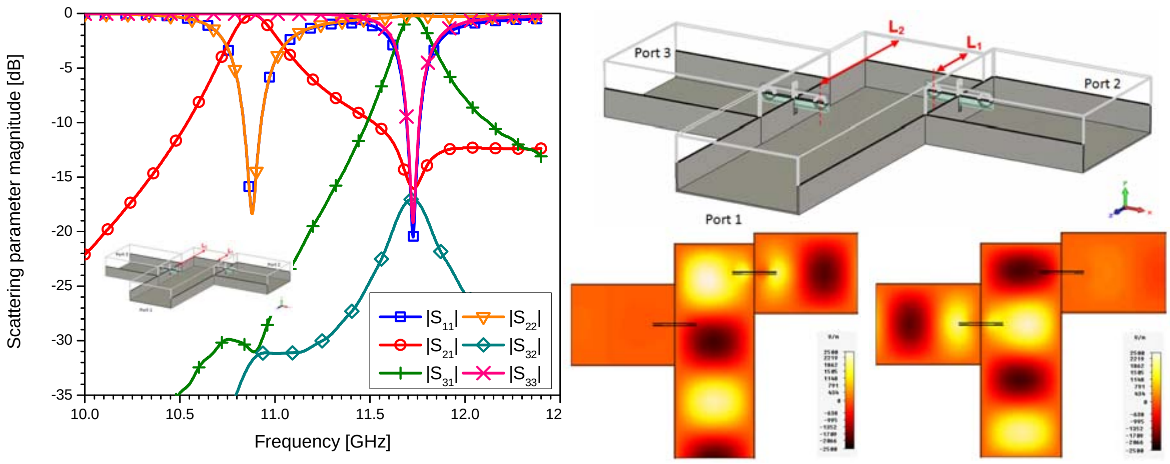


Fig. 3: (right-up) Diplexer sketch. (left) Magnitude of the S parameters of the diplexer. (right-down) Field distribution at the two different resonant frequencies of the connected bi-omegas at Ports 2 and 3, respectively.

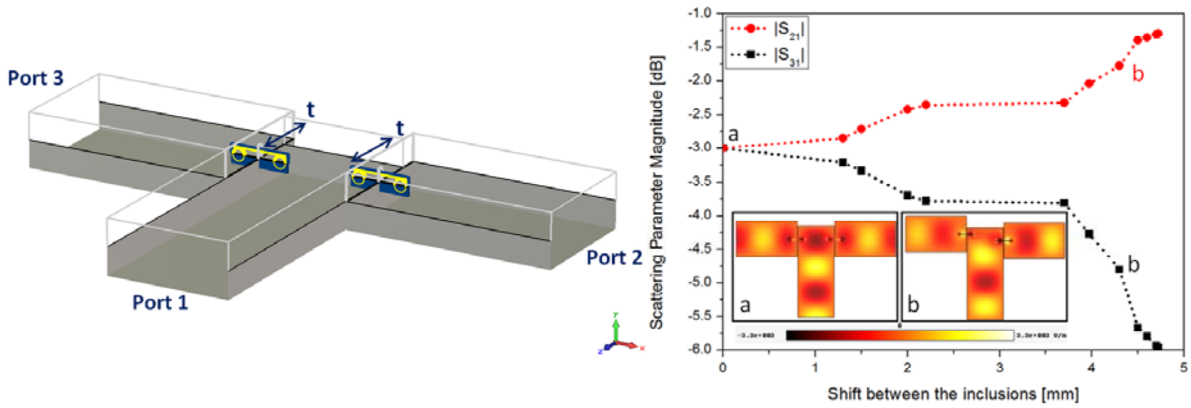


Fig. 4: (left) Power splitter sketch. (right) Magnitude of the simulated S21 and S31 parameters of the unbalanced power splitter varying the shift *d* between the two bi-omega particles. In the insets a) and b) we show the maps of the y-component of the electric field for the balanced (*d = 0 mm*) and one unbalanced (*d = 4.3 mm*) case.

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