Spurious Response Suppression in Waveguide Filters using E-Shaped Chiral Resonators#

(Short Paper)

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Abstract: In this paper, chiral E-shaped resonators are used in a waveguide. Direction of EM wave and position of resonators for effective excitation is studied and various resonances of E-shaped resonators are determined. As a consequence an analytical equivalent circuit model is proposed. Finally, an array of these resonators is used to realize a wide reject band. The resulted band stop filter performance is simulated and a rejection level of almost 40 dB is achieved to confirm the effectiveness of the idea. This stopband filter is used in cascade with a bandpass filter to suppress its spurious response.

Keywords: Chiral, E-Shaped Resonator, Spurious Response, Waveguide Filter.

1 Introduction

Spurious bands and their rejection as a common problem for all transmission line type filters are increasingly notified recently. These undesired frequency bands degrade filter rejection performance specially, for wide band cases. In waveguide filters the first spurious band is relatively close to the desired frequency band because of dispersive behavior of waveguides.

Using low pass or band reject structures can be considered as a solution for this reason. In this paper, we use chiral structures to realize a wide reject band in a waveguide and improve stop band response of a waveguide BPF for the first time. These new resonators have been introduced in various shapes such as E-shaped, F-shaped, Y-shaped, etc. They have an electric resonant frequency within the same frequency range of their magnetic resonant frequency [15].

The resonant frequencies of these chiral structures can be controlled and tuned to provide a wide rejection bandwidth. In the next section, we describe how E-shaped resonators can reject an undesired frequency band. We will extract magnetic resonant frequencies via analyzing their quasi static equivalent circuit. In section 3 the simulated frequency response will be presented.

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2 E-shaped resonator responses

The sub-wave length resonators considered in this paper, are introduced by Wongkasem [14, 15]. These structures perform a double negative pass band (DNG) which can easily be tuned in both the frequency of operation and bandwidth. In other word, in spite of SRR and CSRR, those are magnetic resonators (they can generate negative permittivity but in a frequency of almost two or three times of the frequency which negative permeability occurs and do not overlap [17, 18]) the new structures can generate both negative permittivity and negative permeability in the same frequency range. The basic topology of these chiral structures (E-shaped, F-shaped, Y-shaped resonators) are depicted in Fig. 1.

To study the electromagnetic behavior of an E-shaped resonator that is excited with an EM wave, we consider an array of resonators illuminated with magnetic field perpendicular to resonator plane. Current loops will be induced in the resonator and at resonance, these current loops are closed through capacitance between two consecutive resonators and introduce a ring [1, 19]. E-shaped resonators can also be excited by a properly polarized time-varying electric field. The incident electric field should be parallel to the longest arm of E-shaped resonator [20].

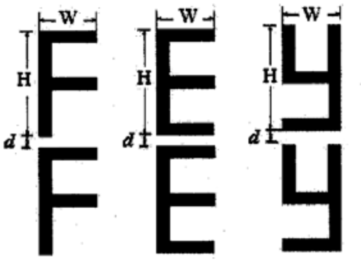
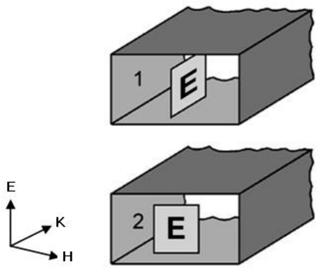


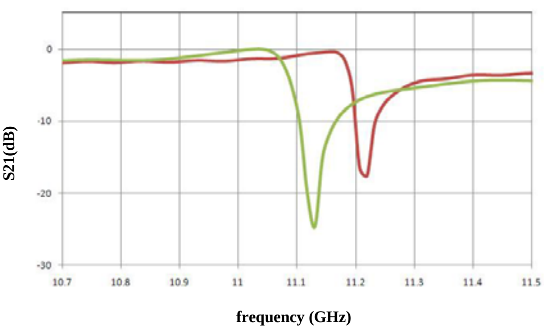
Fig. 1 “F, E, Y” -shaped resonators

However, it can be verified that magnetic coupling is the dominant coupling mechanism as it is shown in Fig. 2. Therefore, here we chose the orientation of Fig. (2-a-1) in order to be excited magnetically. The rejection level depends on the number of resonators. Increasing the number of resonators, results in more suppression level [21] and the amount of rejection can be achieved by each resonator depends on the magnetic coupling between line and resonators. Therefore, the distance between resonators and waveguide walls is also a key parameter [21].

Another important parameter is the distance between resonators that affects the rejection bandwidth strongly. Besides, to widen the rejection bandwidth, several resonators with different sizes and thus different resonances can be used.



(a)



(b)

Fig. 2 (a). Position 1: only magnetic excitation. Position 2: only electric excitation (b). Behavior of E-shaped resonator related to position 1 and 2

To analyze the magnetic responses of resonators to this excitation, an equivalent circuit is presented. Since the dimensions of resonators are chosen much smaller than the wavelength of an incident electromagnetic wave, resonators can be modeled by a lumped element equivalent circuit [6, 9, 14]. The proposed equivalent circuit is depicted in Fig. 3.

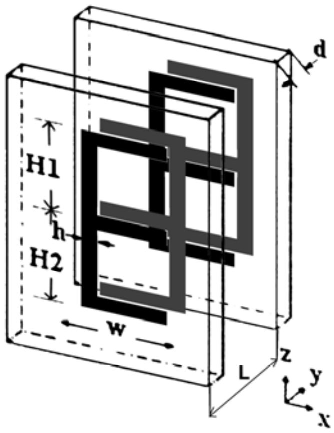
In this model, inductance L of each ring is directly proportional to the area enclosed by each ring, and is equal to:

$$L_i = \mu_0 F_i S / l \tag{1}$$

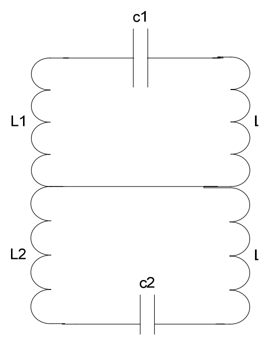
where F_i is fractional area of the cell occupied by the top and bottom loops (Fig. 3-a), S is total area of cell and l is the distance between consequence resonators. Also, C_1 and C_2 are the capacitances of the top and bottom metallic strips, respectively:

$$C_1 = C_2 = \frac{\varepsilon_0 \varepsilon_r wh}{d} \tag{2}$$

Because two currents flowing in second strips have the same magnitude and are in opposite direction, there is no capacitance between two middle strips.



(a)



(b)

Fig. 3 Equivalent circuit of E-shaped resonator

It is inferred from equivalent circuit that an E-shaped resonator have two magnetic resonances frequencies we use these resonances to design a band stop structure, in order to eliminate undesired responses of a band pass filter.

A stop band chiral structure in waveguide has been designed. We have used the CER-10 ($\varepsilon_r = 10$, thickness=0.635 mm) as the substrate for resonators. Resonator dimensions have been determined and different resonances are arranged to reject the band between 10 to 15 GHz. The Simulated performance is depicted in Fig. 4.

3 Waveguide Filter with Suppressed Spurious Response

A third order inductive post Tchebychef bandpass filter with a central frequency of 9 GHz and 9% fractional band width have been designed to evaluate the effectiveness of the presented idea. Seven E-shaped resonators are considered on the CER-10 substrate and are cascaded with the original filter in order to reject the first spurious band (H1=2.25 mm, H2=2.7 mm, w=1.1 mm, h=0.475 mm and the distance between resonators is 2.47 mm).

Fig. 5 shows the simulation results. It is seen that adding the E-shaped resonators results in a significant rejection of undesired band while the main passband remains almost unchanged. As it is seen a rejection of more than 30dB is achieved in a very wide frequency range and this causes a very good rejection slope in the upper side of the main passband.

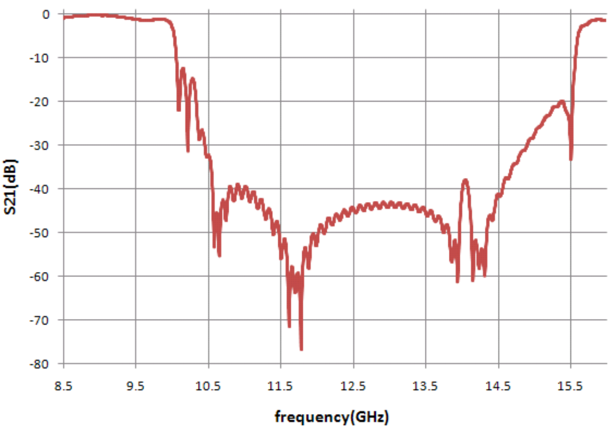
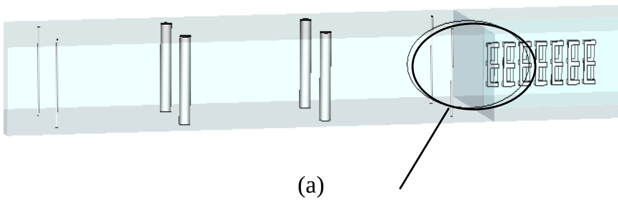


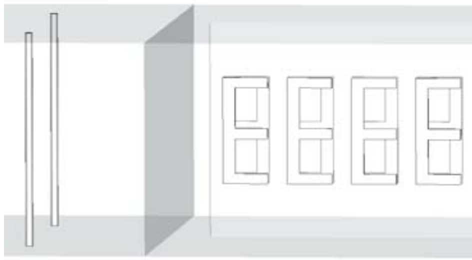
Fig. 4 Stopband response of E-shaped resonators in waveguide

4 Conclusion

E-shaped resonators were discussed and their response and equivalent circuit were obtained for analyzing purpose. Then, E-shaped resonators have been used to suppress the undesired passbands in waveguide filters for the first time. It is based on the stopband behavior of sub-wave length chiral E-shaped resonators. It was shown that they have some electric and magnetic resonant frequencies with negative permittivity and permeability respectively. Therefore, the phase constant is negative in these frequency regions and the propagation of signal is prevented. A waveguide bandpass filter with improved out of band performance, have been designed and simulated. Rejection level of first spurious band is greater than 30 dB, without any notable variation or loss in the main passband.



(a)



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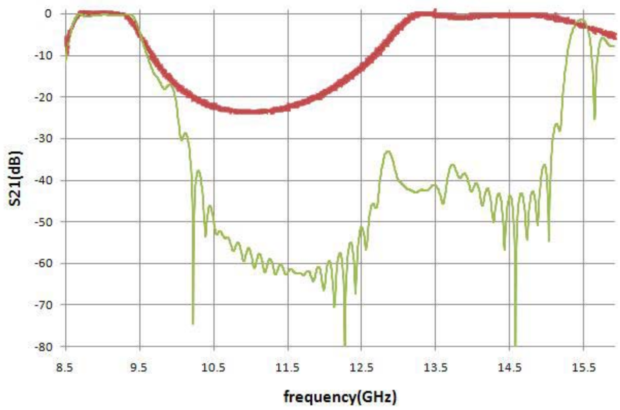

(c)

Fig. 5 (a), (b). The waveguide filter and the chiral array structure (c). The frequency response of the filter with improved out of band performance (green-thin line) compared to the original bandpass filter (red-thick line)

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