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PHASE FREQUENCY CHARACTERISTICS OF METAMATERIAL CELLS

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Фазочастотные характеристики ячеек метаматериалов

В докладе рассмотрены методики расчета фазочастотных характеристик ячеек метаматериалов. Приведены рекомендации по выбору параметров ячеек для достижения максимально возможного группового времени задерживания ячеек.

This article considers methods of calculation phase-frequency characteristics metamaterial cell. The recommendations for the selection of filter parameters to ensure their optimal selectivity beyond the bandwidth are given.

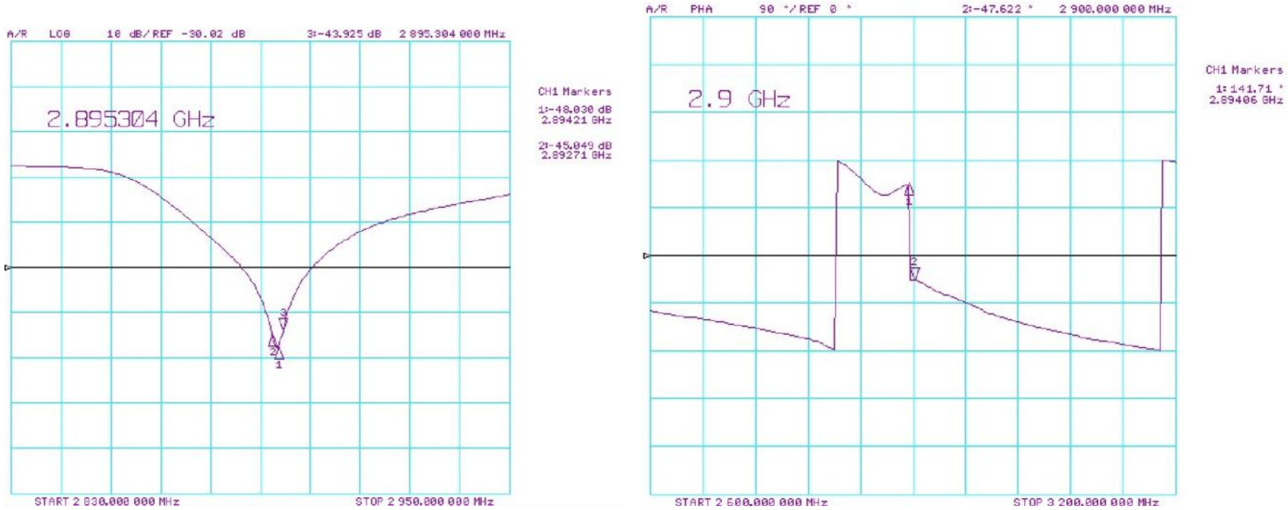
The article [1] presented and analyzed in detail the amplitude-frequency characteristics (AFC) of metamaterial cells. At the same time, the frequency response (FR) of such structures are studied completely insufficiently, although they help to analyze such important properties of metamaterials, as the anomalously high group delay time. For the analysis of the frequency response of the bandstop filter [2], taking into account the phase shift between its input and output, we will present the transmission coefficient of such a filter in the form:

$$T=e^{-j\varphi}-\frac{\mathrm{K}_1}{1+\mathrm{K}_1}-\frac{\mathrm{K}_2}{1+\mathrm{K}_2} \quad (1)$$

Here $\mathrm{K}_1, \mathrm{K}_2$ – are the complex coupling coefficients of the resonators with the load, defined as:

$$\mathrm{K}_1=\frac{K_1}{1+j(\varepsilon+\alpha)},\ \mathrm{K}_2=\frac{K_2}{1+j(\varepsilon-\alpha)} \quad (2)$$

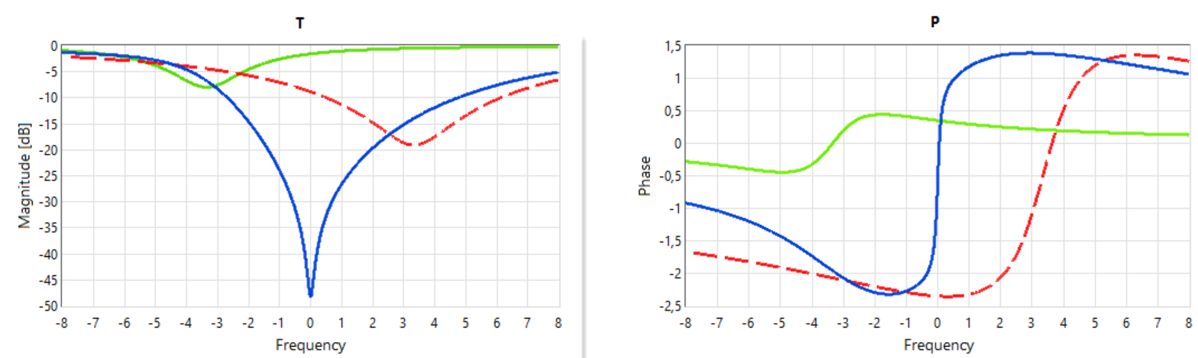
where *K1*, *K2* - coupling coefficients of loading resonators, defined as the ratio of the gained and loaded Q-factors of the first and second resonators, respectively [3], φ - parameter that characterize the phase shift between the input and output. In fig. 1 a) and b) experimental amplitude frequency response and phase response of bandstop filter [2] are presented.



a) b)

Fig. 1 a) the experimental AFC of the bandstop filter; b) the experimental FR of the bandstop filter.

Attenuation at a frequency of 2894.2 MHz is 48 dB (mark 1 in Fig. a)), and the phase shift between frequencies 2894.06 MHz and 2900 MHz (marks 1 and 2 in Fig. b)) is 188°.



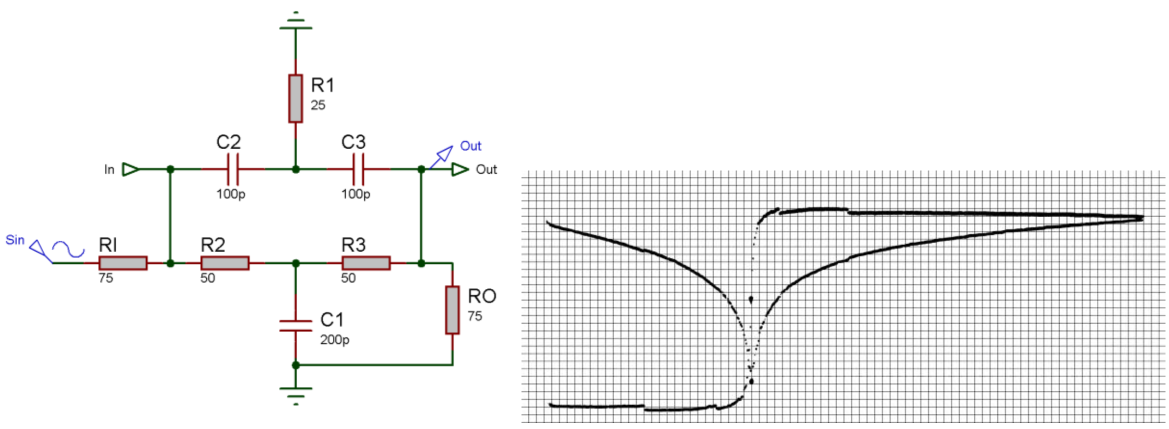
a) b)

Fig. 2 a) theoretical AFC of the bandstop filter; b) the theoretical FR of the bandstop filter.

In fig. 2 a) and b) amplitude-frequency response and phase response of the bandstop filter, calculated in accordance with formula (1). The green and red curves correspond to the characteristics of individual resonators (the green is a “half-wave” resonator, the red is a “wave” resonator according to [1]), and the blue curves correspond to the characteristics of the filter as a whole. Comparison of experimental and calculated characteristics (frequency response up to the sign) indicates the adequacy of the selected model. The criterion of adequacy is the asymmetry of the resonance characteristics inherent in such a phenomenon as “Fano resonance” [4].

As is known, the time derivative of the phase response is the group delay - GD. The large slope of the phase response of the filter in the region of the resonant frequency indicates that in the region of resonance such a filter is characterized by an anomalously high group delay time. Similar properties of metamaterials are associated with electromagnetically induced transparency and Fano resonance, but a detailed consideration of these issues is beyond the scope of this work.

In [1], it was noted that many “unique” properties (for example, extremely high Q) of the so-called Split Ring Resonators (SRR) can be easily explained if we take their lumped elements equivalent circuit in the form of a “bridge". This is suitable for the frequency response of such structures. In fig. 3 a) a diagram of the so-called Twin T bandstop filter [5] is presented, and in fig. 3 b) - its experimental phase response, which at some frequency undergoes a jump of 180°



a) b)

Fig. 3 a) Twin T bandstop filter; b) experimental phase response of the Twin T bandstop filter.

References

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