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Modified Split-Ring Resonator with Electromagnetically Induced Transparency

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Introduction

Structures using the Electromagnetically Induced Transparency (EIT) effect were initially interesting for optics and optoelectronics due to the observation of "fast" light, "slow" light, and "left-handed" light (Fast light, slow light, and left-handed light) [1], specialized cells for memory elements of optical computers [2]. From such structures, metamaterials can be formed - a material whose properties are mainly due to the presence of an additional artificial periodic structure. For metamaterials, it is possible to modify the dielectric and magnetic permeability, which allows controlling the laws of dispersion, refraction, the reflection of electromagnetic waves [3], and the creation of left-handed environments.

In sufficiently strongly connected oscillatory contours at two closes but not coinciding frequencies (when degeneracy is absent), there are two so-called normal oscillations - in-phase and anti-phase [4]. The influence of an external harmonic signal on in-phase or anti-phase oscillation leads to EIT-type effects (or Fano resonance) if it is the interference of a different type of oscillation (in-phase-anti-phase), or to the interference of the Autler-Townes Splitting (ATS) type [5] if it is interference one type oscillating. With this effect, it is possible to create special types of blocking filters based on a transmission line of the resonant type in the form of "meta devices". For example, these can be modifications of Split-Ring Resonators (SRR) using a combination of microstrip and bulk dielectric resonators. A blocking filter is a device that is used to remove certain harmonics from signal spectra, when eliminating electromagnetic interference from industrial alternating current power networks, in high-quality audio equipment, to prevent self-excitation in power amplifiers [6].

The implementation of a blocking filter based on parallel pairs of SRRs etched on a substrate with a defective grounding structure (DGS) is known [1,7]. The DGS is on the ground plane of the microstrip line substrate, the SRRs are created on the inside of the circular etch planes of the DGS. The delay band and the attenuation in the delay band of such a filter increase when additional pairs of SRRs are created. Such a filter has small dimensions and is easily integrated into other metamaterial structures due to a similar design. The disadvantage of the resulting filter is low (up to 20dB) attenuation in the delay band when using a small number (1-2) of paired SRRs, which is comparable to solutions available on the market. To achieve higher attenuation values, it is necessary to introduce additional SSRs, which partially negates the advantage of compactness and makes it difficult to modify the filter.

Usually, DGS is etched on the ground plate; the planar SRR is introduced into the DGS gap; the transmission line and the ground plate are separated by a dielectric [8]. Due to resonant effects, two delay bands are generated between the DGS and the SRR, so the device described is a double-delay band microstrip filter: 3.62GHz to 5.19GHz and 6.13GHz to 8.37GHz. The design size is small compared to traditional dual-delay bandpass filters. Also, due to the relationship between SRR and DGS, the center frequency of the delay bands decreases as the DGS gap increases. However, the general appearance of the spectrum of the S21 transmission coefficient of such a structure cannot be changed, the parameters of the SSR and the filter as a whole are rigidly tied to the geometry of the DGS.

The useful model is based on the task of obtaining microwave filters, in particular, for the possibility of inducing a window of transparency in the delay band of the filter. Ref [9] demonstrated that bridge circuits, in the arms of which resonators of different types are included - parallel and series, which generally have different resonance frequencies and Q-factors, provide two independent paths of energy propagation and ideally model processes similar to Fano resonance. Such an approach makes it possible to carry out simplified modeling of processes during the practical creation of cells with EIT.

The purpose of this work is to create a cell that implements EIT in practice in the X band frequency range, based on a modified split-ring resonator, which, on the one hand, will be able to provide high attenuation at certain (resonant) frequencies, and on the other hand, will enable control transmission characteristics. Cell parameters were pre-calculated based on Fano resonance modeling using simplified numerical calculation when using bridge circuits.

Split-ring resonator

In this work, an ultra-high-pass filter with an induced transparency window, which contains DGS in the form of at least one planar SRR, which is formed by wrap elements, as well as a dielectric-separated transmission line and the ground plate was created. The wrapping element has the form of an outer open ring, and the wrapped element has the form of a high-quality dielectric resonator.

The geometry and properties of the SRR and the volume resonator are selected so that the second harmonic of the microstrip resonator, which has the form of a covering ring, coincides with the lowest type of oscillations of the dielectric resonator, which has the form of the covered bulk dielectric resonator.

Traditionally the quality factor (Q) of the resonator depends on the material from which it is made. A high-quality factor of the resonator is considered to be a quality factor with values greater than 2000. To obtain an induced transparency window in the filter delay band, the quality factor of the volume resonator must exceed the quality of the microstrip resonator several times. Adjusting the frequency of the combined resonator and changing the nature of the spectrum of the transmission coefficient of the filter is possible by changing the effective length of the microstrip resonator and the height of the dielectric resonator. Figure 1 shows the amplitude-frequency response of the filter.

Figure 1b shows the window of induced transparency in the form of a wavy region in the center of the graph. Due to the different qualities of the resonators, it is possible to obtain a several times narrower resection band with complete signal suppression and better filter matching.

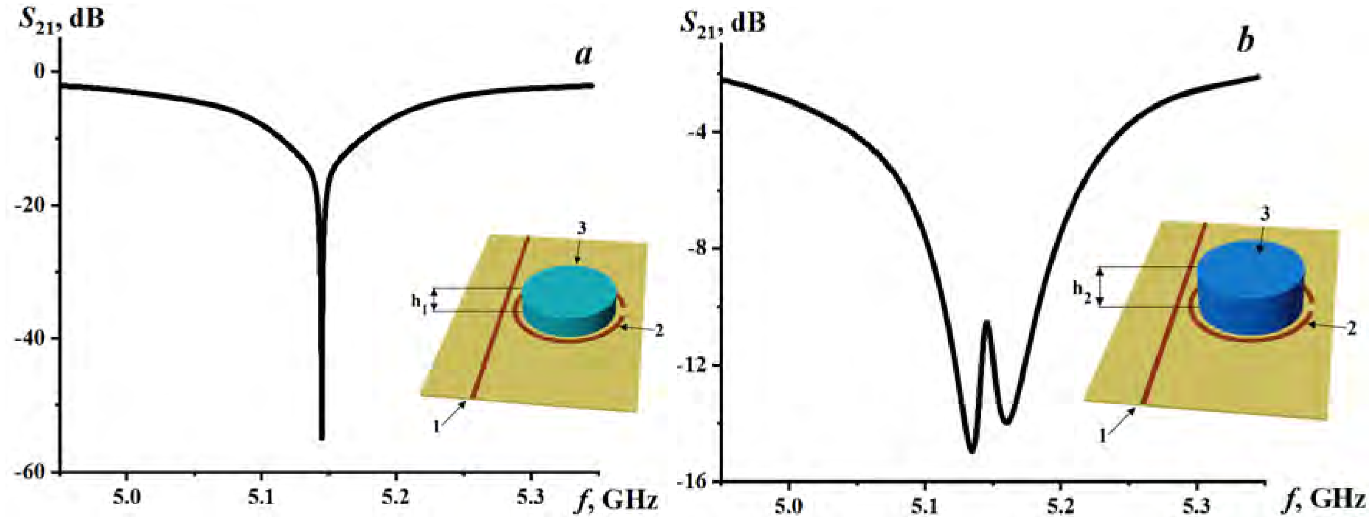

Figure 1: Transmission spectra of the claimed barrier filter upon reaching Fano resonance (a) and barrier filter with induced transparency window (b). Insets: view of the claimed filter, containing transmission line (1), microstrip resonator (2), and three-dimensional cylindrical dielectric resonator (3) with height h_1 (a) and h_2 (b).

A barrier filter was connected to the Agilent N5230A microwave vector analyzer. The copper outer ring (Inset in Figure 1) is made of microstrip with a width of w=1mm and the earthing plate is separated by a substrate made of multilayered microwave material based on polyphenylene oxide (FLAN) dielectric material.

The bulk cylindrical dielectric resonator (Inset in Figure 1) had the following parameters: diameter D=13.1 mm, height h=1.74mm, dielectric constant ε=78, resonance frequency f=5.14GHz, quality factor Q=2350. Spectra of scattering matrix coefficients of the obtained filter were measured in the frequency range 4.95-5.35GHz, in particular, the transmission coefficient S21. The results are consistent with analytical expressions in [9].

As a result of the measurements, it was determined that it is possible to obtain a filter with high attenuation in the delay band (not less than 40dB) and a window of transparency in the delay band due to the frequency consistency of bulk cylindrical dielectric and microstrip resonators.

Conclusion

A cell consisting of a microstrip and a cylindrical dielectric resonator is proposed. The obtained cell made it possible to realize in practice the phenomena described by Fano and derivative resonances (Fano, Stark resonance, electromagnetically induced transparency). Named phenomena were modeled and calculated using bridge circuits. Then electrical parameters of the experimental cell were studied in the microwave range and compared with the results of theoretical calculations, the results match qualitatively. The presented cell allows changing easily the parameters of the circuit components, which allows modeling of various resonance phenomena in the microwave range. A transparency window of about 4GHz was achieved.

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