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ANOMALOUS DISPERSION AND GROUP DELAY OF METAMATERIAL CELLS

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Аномальна дисперсія і груповий час затримки структур метаматеріалів

У даній роботі метаматеріальні структури розглядаються як два резонансних ланцюга (паралельний і послідовний), які з'єднані у вигляді паралельних і перехрещених входів 4-полюсного моста. Такий підхід дозволяє поширити деякі властивості мостових схем, що широко використовуються у метрології на метаматеріальні датчики. Наведено експериментальні та розрахункові характеристики метаматеріальних структур у мікрохвильовому діапазоні.

Bridge 4-poles for the first time began to be used in electrical engineering as precisely measuring chains [1,2]. In [2] it is noted that the Wheatstone bridge is used to accurately measure very low resistance values. At the beginning of the 20th century, bridge 4-poles began to be used as filters in high-frequency telephone communication networks [3]. In [4], the properties of a 4-pole bridge, which equivalent circuit is shown in Fig. 1, are examined in detail.

In particular, it is noted that due to the resonators finite Q factors (Q_1 and Q_2), the 4-pole may have characteristics with properties, that inherent to the Fano resonance. Figure 2 shows a microstrip bandstop filter photograph [5], where the dielectric sample is a plate 0.5 mm thick and the dielectric constant is $\varepsilon = 10$. A change in the position of the plate relative to the resonator leads to a change in its resonant frequency. In this case, the filter transfer coefficient changes, as well as its shape and the maximum achievable attenuation [6].

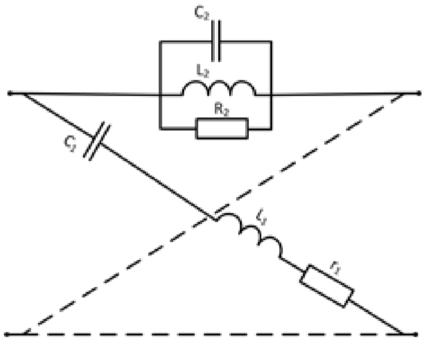


Figure 1. Bridge bandstop filter equivalent circuit.

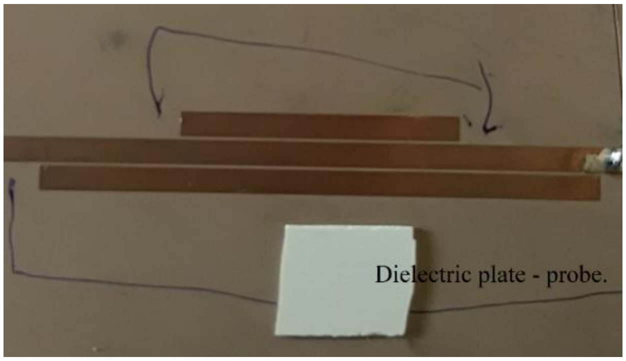
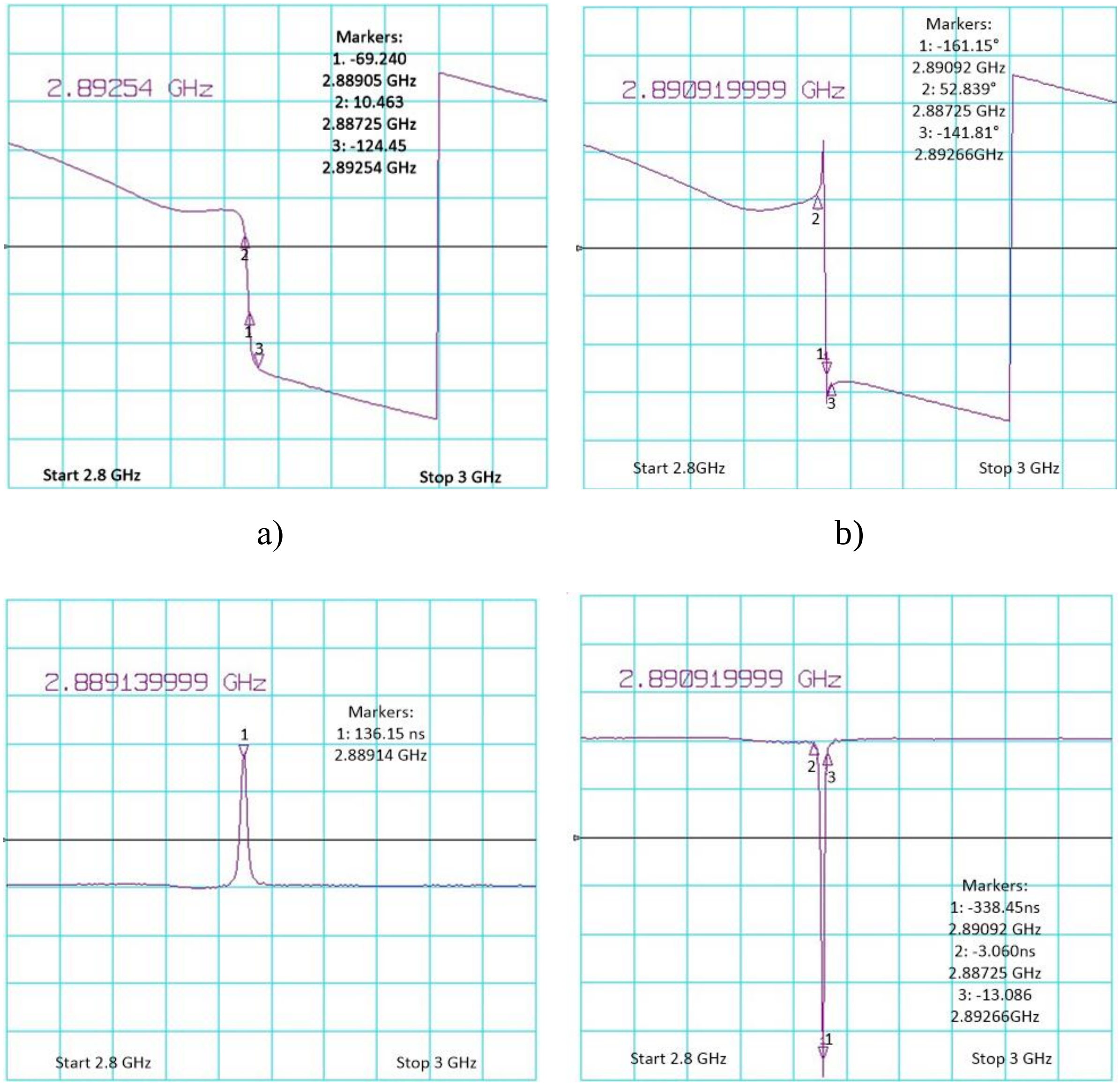


Figure 2. Microstrip bandstop filter with dielectric samples for frequency tuning.



a) b)

c) d)

Figure 3. Phase characteristics (a, b) and their corresponding group delay time characteristics (c, d).

In articles, reports, and reviews that consider structures based on metamaterial cells as sensors [7–11], the amplitude characteristics of the transmission and reflection coefficients of such structures are mainly studied. At the same time, both calculated and experimental the metamaterial cells phase characteristics can also be used in the measurement process, which was demonstrated in [12]. Indeed, in the above-mentioned bridge structures measurement applications [1,2] the 4-pole balanced properties are used, that is why there is a possibility of achieving “0” in the measurement process”. The 4-pole transfer coefficient zero value is achieved at the Fano resonance [4], but it is difficult to accurately detect it because of the high sensor sensitivity in the resonance region. It is known that when “crossing the zero value” the transmission coefficient changes sign, so that, its phase characteristic and phase derivative, which is the group delay time, change abruptly.

Conclusion: From the foregoing, it follows that in some cases, to increase the sensitivity of sensors based on metamaterials, it is necessary to analyze not only their amplitude, but also phase characteristics. It is also important to note that the large positive value of the group time delay does not mean that the causality principle is violated [13].

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