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Physics

MICROWAVE RESONANCE IN A SYSTEM OF INTERACTING CONDUCTING RINGS AND ITS APPLICATIONS

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The interaction between standing Sommerfeld microwaves within a system comprising two closely spaced conducting rings gives rise to pronounced resonance phenomena. The behavior of this system depends on the relative arrangement of the receiving and transmitting points. Specifically, it leads to a sharp reduction or enhancement of signal output within a narrow frequency range. Remarkably, this structure can serve dual roles: acting as both a band-stop filter and a band-pass filter, all within the same restricted frequency band.

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Introduction. The recent surge in demand for contemporary high-frequency communication systems, characterized by minimal dispersion and extensive bandwidth, has led to a renewed interest in various types of surface electromagnetic waves [1–4]. The elimination of undesired interband frequencies and the prevention of noise are critical aspects in microwave and wireless communication systems. To utilize the GHz–THz frequency range, it is necessary to minimize dielectric and ohmic losses and to mitigate the dispersion of the signal in transit. One potential solution to these challenges is the use of surface waves on wires with a circular cross-section, a phenomenon first observed by Sommerfeld. However, the broad radial extension of Sommerfeld surface waves limits their practicality, as a substantial isolated region around the conductor is required to prevent significant field distortion. The potential applications of these waves broadened when Goubau discovered that by coating wires with a dielectric layer or corrugating the wire surface, the lateral confinement of these surface waves could be significantly improved – configurations known as a Goubau line [5–8]. These communication elements, along with enhanced field confinement,

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offer several benefits such as low losses and dispersion, and a straightforward fabrication process, making them suitable for ultra-wideband applications.

The demand for low-loss and ultra-wideband wave-guiding systems in the GHz and THz regions has sparked a resurgence of interest in various forms of the Goubau line. The associated challenges have been extensively revisited over the past decade [9–13], coinciding with the rapid advancement of high-speed broadband communication technologies like $5G$ and $6G$ networks [14]. It's worth noting that in current data transfer applications, wave-guiding distances have been significantly reduced to the dimensions of a single board or integrated circuit. Planar analogs of corrugated Goubau lines, combined with traditional microstrip transmission line design, have been widely used in low-loss transmission lines in the THz, super-, and extremely-high frequency spectra [12, 13, 15, 16]. Several electronic devices have been proposed based on the Goubau line concept, including wideband transmission lines [8, 17], passive components [18], leaky-wave antennas [19], frequency-selective configurations [15, 16], sensors [20], and more.

RF filters have been widely used in various wireless systems and circuits. One of the challenges in science since time immemorial is to create as simple and affordable a filter as possible, which will be compatible with many devices. Along with the development of the telecommunication sector, there is also a need to pay great attention to the filter energy saving problems, because most of the modern equipment works with a battery, which in itself means energy limitation. That's why low energy consumption is one of the most important parameters characterizing current clearing. To achieve the above goals, several methods have been studied over the years, using everything from the simplest materials to metamaterials [21]. Due to its simplicity, the model with ring resonators studied within the framework of this article can be used in many systems/environments. Despite the simple structure and, therefore the low price, the model still does not have enough practical use, which will contribute to the modernization of the model.

Materials and Methods. In this study, we fabricated annular copper resonators and investigated the system comprising these resonators using the Rohde & Schwarz ZNB20 vector network analyzer (VNA). The objective of the system analysis was to ascertain the quantitative proportion of radiated, non-reflected, and received waves across various cells. The system is constituted by one or more copper rings, all of which share identical parametric properties. Throughout the investigation, we examined multiple system configurations, including a single ring and dual rings separated by varying distances (2.5 *mm* and 5 *mm*).

In this experimental setup, two rings within the system are positioned in planes that are parallel to each other, with the line joining the centers of the rings oriented perpendicularly to these planes (Fig. 1). Affixed to the frame of the VNA ports are metallic rods that are parallel to the plane of the rings. These rods, situated on opposing sides of the ring/rings plane, possess the capability to traverse the length of the ring. A specific system was employed to quantify port rotations: a hypothetical line is drawn from the center of the ring/rings to the extremities of the rods, and the

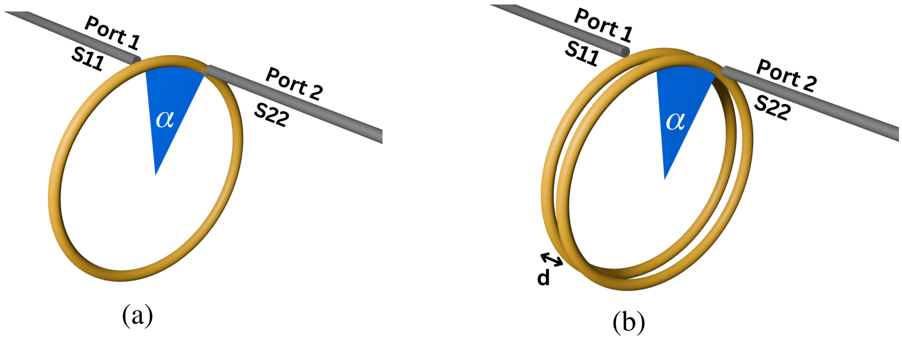

Fig. 1. The picture of microwave transition in cases with one ring (a) and two interacting rings (b), when the transmitting and receiving points are offset relative to each other.

projection degree formed on the plane of the rings is measured (α, indicated in blue in the Fig. 1). By varying this degree, the system' response is measured. During the study, the cases of α equal to $0°$, $90°$, $180°$ and $270°$ were investigated.

The selection of the research domains was predicated on the physical attributes of the ring, specifically the ring's length. The frequency range corresponding to the wavelength equivalent to the ring's length, as well as the frequency range corresponding to twice this wavelength, were examined. The S_{12} and S_{21} modes were investigated utilizing the Rohde & Schwarz ZNB20 vector network analyzer. Given the symmetry of the port model, identical patterns are observed in both cases, rendering the examination of one case sufficient. The research primarily employed the S_{21} mode.

The inner diameter of the ring: 36 *mm*, the thickness of the ring walls is 1.7 *mm*. The length of the ring is 124.72 *mm*, which corresponds to the wavelength of the frequency of 2.403 GHz. For this reason, the 1.8–2.8 GHz range was chosen for study.

Results and Discussion. The transition factor's dependence on frequency is investigated for both single and double rings. These rings are positioned at relative degrees of $0°$, $90°$, $180°$ and $270°$ with respect to the transmitting and receiving points (Fig. 2). Notably, when considering an isolated ring, the received signal exhibits a smooth frequency-dependent behavior without pronounced resonances. This behavior arises due to the half-wavelength standing Sommerfeld wave formed within the ring. However, as a half-wave dipole antenna, the ring also experiences significant radiation losses. Specifically, surface charges oscillate between the conduction point and its opposite position, resulting in the observed behavior.

In the case of double rings, the interaction between the Sommerfeld waves formed within the rings becomes pivotal. Sommerfeldian waves are characterized by the movement of charges along the surface of conductive rings. Under interaction conditions, the radiation from charges oscillating in opposite phase within the rings exhibits a quadrupole character. Importantly, the small size of this quadrupole ensures a significant accumulation of wave fields near the rings at the resonance frequency.

Notably, the resonance frequency value of 2.2 GHz, obtained from experimental results, corresponds to a Sommerfeld wavelength of approximately 138 *mm*. The slight

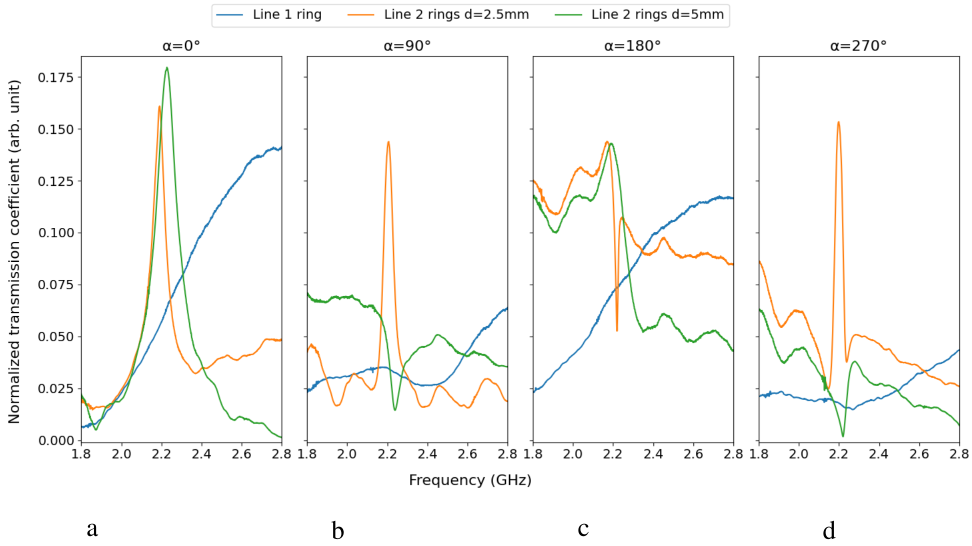

Fig. 2. The figure shows the frequency dependence of the transmission coefficient of the microwave in the rings system, when the transmitting and receiving ports are $\alpha = 0^\circ$ (a), $\alpha = 90^\circ$ (b), $\alpha = 180^\circ$ (c), and $\alpha = 270^\circ$ (d). Measurements were made in the case of one ring (blue), in the case of two rings, 2.5 *mm* (yellow) and 5 *mm* (green) removed from each other.

deviation from the ring length (which is 120 *mm*) can be attributed to the intricate interaction between the rings.

Two cases of a microwave signal passing through a double-ring system were observed, with the surfaces of the rings separated by 2.5 *mm* and 5 *mm*, respectively. Although both cases exhibit a sharp change in the transition factor depending on frequency, the distribution of wave fields differs significantly. The primary factor driving this difference is the interaction between the rings. From a practical standpoint, the case with the sharpest dispersion of the transition coefficient which occurs when the rings are 2.5 *mm* apart is particularly interesting. When the transmitting and receiving points form degrees (α) of 0°, 90°, and 270°, a narrow frequency range (approximately 50 MHz) shows a sharp increase in the passing frequency. However, at α=180° case between the transmitting and receiving points, the situation changes dramatically, resulting in a sharp drop in the transition factor within a frequency range of about 10 MHz. These results provide compelling evidence that the system consisting of two rings, due to the formation of Sommerfeld standing waves, indeed functions as a resonator.

The proposed structure exhibits a remarkable dual functionality: it can simultaneously serve as both a gate filter and an output filter within the same narrow frequency range. Importantly, the universality of the investigated physical phenomenon suggests that similar results may be observed not only in the microwave frequency range but also in the terahertz and infrared domains.

Conclusion. The system comprising two interacting conductor rings functions as a resonator, primarily due to the formation of Sommerfeldian standing waves. Notably, this resonator exhibits transverse dimensions significantly smaller than the resonant wavelength. By exploiting this geometry, the system facilitates microwave signal transmission and reception from distinct points along the rings. Consequently, it supports diverse modes of resonant dispersion during transitions. Remarkably, the same structure can serve as both a gate filter and an output filter within a narrow frequency range.

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Ն. Գ. ՄԱՐԳԱՐՅԱՆ

ՄԻԿՐՈԱԼԻՔԱՅԻՆ ՌԵԶՈՆԱՆՍԸ ՓՈԽԱԶԴՎՈՂ, ՀԱՂՈՐԴԻՉ ՕՂԱԿՆԵՐԻ ՀԱՄԱԿԱՐԳՈՒՄ ԵՎ ԴՐԱ ԿԻՐԱՌՈՒԹՅՈՒՆՆԵՐԸ

Կանգուն զոմերֆելդյան միկրոալիքների միջև փոխազդեցությանը ապահովում է արտահայտված ռեզոնանսային իրավիճակ: Համակարգի ընդունող և հաղորդող կետերի փոխադարձ դասավորությունից կախված, այն կտրուկ նվազեցնում կամ ավելացնում է ազդանշանի թողարկումը, հաճախությունների նեղ տիրույթում: Այնպես որ, կառուցվածքը միաժամանակ կարող է ծառայել ինչպես փականցային, այնպես էլ թողարկող ֆիլտր, միևնույն հաճախային նեղ տիրույթում:

Н. Г. МАРГАРЯН

МИКРОВОЛНОВЫЙ РЕЗОНАНС В СИСТЕМЕ ВЗАИМОДЕЙСТВУЮЩИХ ПРОВОДЯЩИХ КОЛЕЦ И ЕГО ПРИМЕНЕНИЯ

Взаимодействие между стоячими микроволнами Зоммерфельда в системе, состоящей из двух близко расположенных проводящих колец, приводит к выраженным резонансным явлениям. Поведение этой системы зависит от относительного расположения точек приема и передачи. В частности, оно приводит к резкому уменьшению или усилению сигнального выхода в узком диапазоне частот. Примечательно, что эта структура может играть двойную роль, действуя и как фильтр полосного подавления, и как фильтр полосного пропускания, все в одном ограниченном диапазоне частот.