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CONTACTLESS IDENTIFICATION OF ILLICIT LIQUIDS IN SEALED PLASTIC CONTAINERS USING A PLANAR SPLIT-RING RESONATOR

Subject and Purpose. *In this paper, the use of a planar split-ring resonator for contactless identification of liquids inside sealed thin-walled plastic containers is demonstrated numerically and experimentally. The motivation behind this study is to determine the split-ring resonator type most suitable for distinguishing among liquids.*

Methods and Methodology. *A planar split-ring resonator serves as a high-frequency sensor operating at 2.3 GHz. Different liquids are identified by comparing the transmission spectra of a planar feeding strip line that is loaded with the resonator. Plastic containers filled with various liquids are positioned at different distances from the resonator. The changes in the resonator spectrum are evaluated using its two key parameters: the resonant frequency and the inverse Q-factor. Additionally, the developed spectral-analysis software reduces errors in the determination of Q-factor.*

Results. *The ability of the planar split-ring resonator to distinguish among liquids has been demonstrated for three liquids with different compositions. In particular, mineral water, ethyl alcohol, and refined gasoline were identified. The differences among the liquids are tracked in the changes of inverse Q-factor and resonant peak frequency of the planar split-ring resonator. In this regard, the dependences of the inverse Q-factor and the resonant peak frequency on the distance between the liquid container and the planar split-ring resonator plane were analyzed. Furthermore, it has been shown that with the proposed planar split-ring resonator as a sensor, parameters of the liquid containers affect liquid-identification accuracy much less than they do when a photonic crystal with a defect is employed.*

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Conclusions. *A real advantage of the proposed planar split-ring resonator is its low sensitivity to the container parameters. This was experimentally verified while moving a 0.5-liter (16.9 FL oz) liquid-filled polyethylene terephthalate bottle along a straight line 2 mm away from the resonator plane.*

Keywords: *contactless liquid identification, split-ring resonator, microwave frequencies, inverse Q-factor, permittivity.*

Introduction

Precise determination of liquid composition is currently a tedious, time-consuming, and labor-intensive process that often delegates to laboratory methods, such as X-ray spectroscopy [1], gas chromatography (GC) [2], high-performance liquid chromatography (HPLC) [2, 3], and mass spectrometry (MS) [4], calling for long-term sample preparation, a skilled hand, and specialized instrumentation. At the same time, in-depth research, detailed liquid composition, complex methods, and expensive equipment are not always necessary. Instead, fast, contactless, and cost-effective assessments for *in-situ* applications are welcome to determine liquid quality or differentiate between food and non-food liquids in sealed containers. Of particular relevance is distinguishing between bottled water-containing liquids and flammable liquids categorized as hazardous sources in safety management for public areas. At airports or checkpoints, the Liquid Under Test (LUT) volume may be required to begin with 0.5 liters; relative identification (without opening the LUT container) should take no longer than one minute. These criteria readily designate limitations and disadvantages of optical [5], electrical [6], acoustic [7], ultrasonic [8], mass-spectrometric, and chromatographic research methods [2—4]. One of the few that meet the application criteria is the radiospectroscopy method. A range of liquid identification techniques use the radiospectroscopy method [9—12]. Some of them consider the real and imaginary parts of permittivity. However, the resonance method stands out due to its accuracy [9, 10].

According to recent publications, LUT containers were mainly laboratory cuvettes of a small capacity of up to 0.5 liters [15—18]. The focus was shifted to examining adulterations in aqueous solutions. Liquids in food containers were studied and reported well [9, 10]. However, the implementation of these methods is constrained by technological limitations. For example, with its complexity, the cavity resonator design discussed in [9] presents significant technological challenges. The liquid identification approach in [10] applies a sensor analogous to a photonic crystal. It consists of alternating, variable-impedance microstrip-line sections with a defective section in the middle. The drawback of the latter is that the transmission spectrum of the photonic crystal with a defect depends on the size of the liquid container.

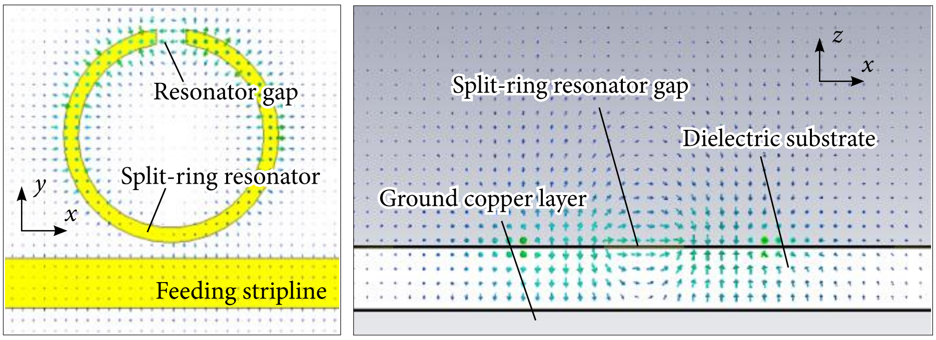
Nevertheless, the application potential of the planar structures has proven their effectiveness and economic feasibility [20, 21]. To eliminate the influence of container size, high-frequency elements with improved electromagnetic (EM) field localization, exceeding that of a photonic crystal with a defect, can be used. In this context, the search for an optimal planar structure with high EM field localization is an actual task in contactless technology of liquid identification.

In our recent studies [22, 23], we proposed improving EM field localization by changing the planar resonator topology. Building on our previous experience, the present work employs planar resonators as sensors for liquid identification through sealed plastic containers and forms a novelty in contactless liquid identification technology. The aim here is to demonstrate a planar circular split-ring resonator approach as the most suitable for contactless identification of liquids.

1. Numerical simulation

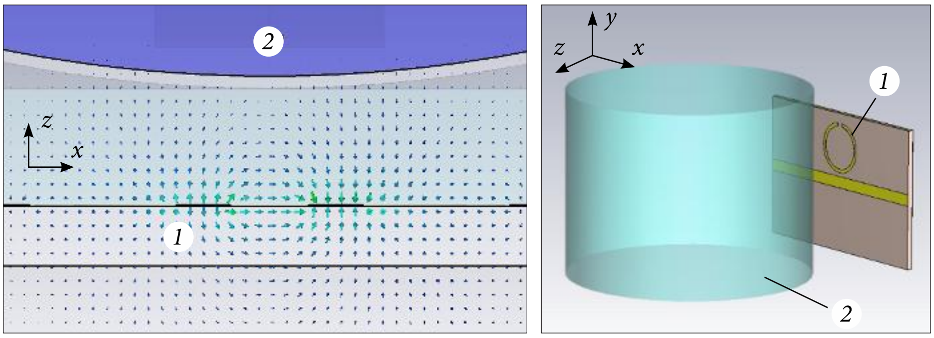
The current study features a Circular Split-Ring Resonator (CSRR), with the ring of radius 6.75 mm, width 1.0 mm, gap 2.0 mm wide, and metallization (copper) 35 μm thick. The feeding strip line is 3.3 mm wide and 1.1 mm spaced from the ring. The substrate is made of a 1.524 mm-thick dielectric material FR-4 (dielectric constant $\varepsilon = 4.3$ and loss tangent $\mathrm{tg}\delta = 0.025$). The resonant frequency of the unloaded CSRR is 2.1 GHz.

For split-ring resonators [22] at the resonant frequency, the electric components of the EM field are mainly concentrated in the resonator gap and decay exponentially with distance from the localization region at the resonator surface. In our previous studies [22], attention was paid to the spatial localization of the magnetic component of the EM field. However,



a *b*

Fig. 1. Spatial distribution of the electric component of the EM field: out-of-plane top view of the CSRR (*a*) and in-plane cross-sectional view near the CSRR gap (*b*)



a *b*

Fig. 2. Cross-sectional view (*a*, *1*) of the spatial distribution of the EM-field electric component near the CSRR surface when a cylindrical water-filled PET container (*a*, *2*) is 3 mm away from the CSRR surface. The simulation structure (*b*)

for liquid identification, the focus is shifted to the electric component due to its sensitivity to the changes in the dielectric constant of the medium [19, 20]. Figure 1 displays numerical simulation results obtained by the full-wave electromagnetic simulation method (finite difference time domain in COMSOL Multiphysics) and presents the spatial distribution of the electric component of the EM field in the immediate vicinity of the resonator gap.

Following Fig. 1, *a, b*, the electric component is localized in the region above the CSRR gap, forming a sensing zone whose extent and shape determine the CSRR sensitivity to changes in dielectric properties of an object located at a distance away from the CSRR surface. Thus, bringing a liquid-filled container to an area of maximum electric-component localization alters the CSRR resonant frequency and quality factor because the liquid-filled container permittivity differs from that of air.

The CSRR-based sensor results were numerically simulated for a water-filled PET (polyethylene terephthalate) container, a hollow cylinder with outer diameter $d = 70$ mm, 0.3 mm thick walls, and permittivity 2.4. Simulation results presented in Fig. 2, *a* illustrate a cross-sectional view of the spatial distribution of the electric component of the EM field near the CSRR surface when the container is 3 mm from the CSRR surface. Figure 2, *b* shows the simulation structure.

Comparing the in-plane electric-component spatial distributions (Figs. 1, *b* and 2, *a*) in both unloaded and loaded CSRR cases, respectively, confirms the electric-component intensity decrease when the container approaches the CSRR surface. For a deeper analysis, refer to the transmission coefficient spectra $|S_{21}|$ numerically obtained for the cases depicted in Figs. 1 and 2 and plotted in Fig. 3, *a*.

Figure 3, *a* clearly illustrates two main effects arising as the container-to-CSRR distance decreases. The first is a resonant frequency shift towards lower values because the resonator effective capacitance is growing as the dielectric body enters the sensing

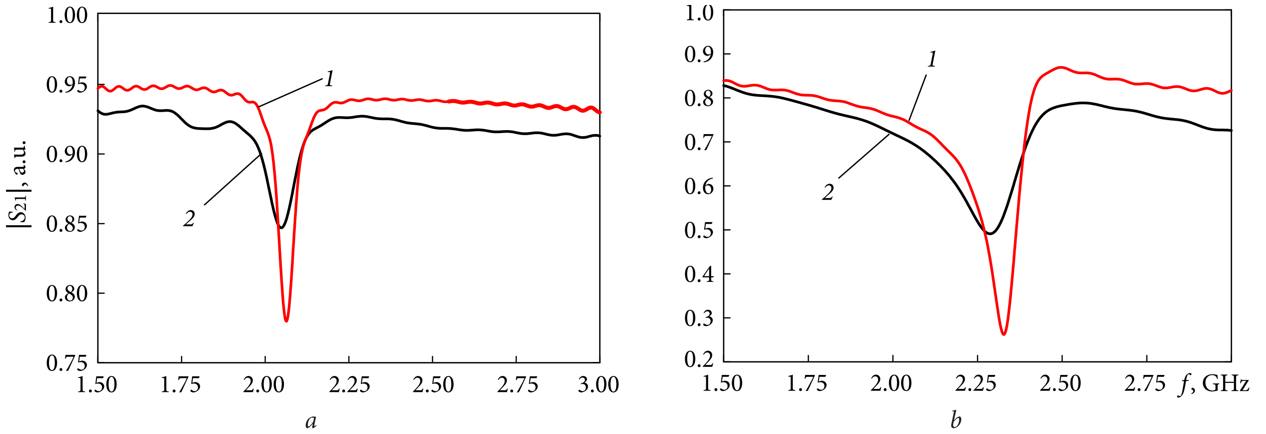


Fig. 3. Numerically obtained transmission spectra for the CSRR with a water-filled container 20 mm from the CSRR surface (curve *1*) and 3 mm from the CSRR surface (curve *2*): the CSRR is on the same side as the feeding line (*a*) and the CSRR and the feeding line are on opposite sides of the feeding line (*b*)

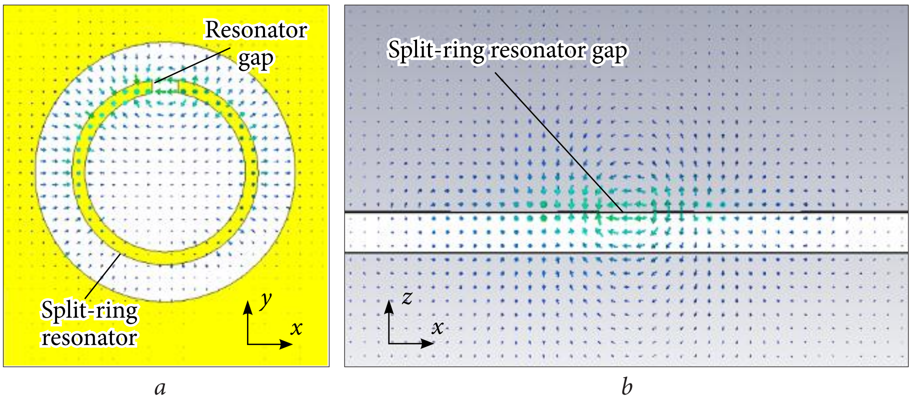


Fig. 4. Spatial distribution of the electric component of the EM field: out-of-plane top view of the CSRR surface (*a*) and in-plane cross-sectional view of the CSRR top surface (*b*)

area. The second is a rise of the inverse *Q*-factor, which reflects an increase in dielectric loss in the liquid. When interpreting these alterations, attention should also be taken of the feeding strip line effect. When placed near the strip line, a water-filled container influences strip-line coupling to the resonator (a portion of the strip-line field penetrates the dielectric body of the container), as well as alters the characteristic wave impedance of the strip line. This can distort the broadband end of the spectrum (Fig. 3, *a*, curve *2*), change the depth of the resonance dip, and, in some cases, cause an impedance mismatch. Depending on the container shape and volume, these effects are quite difficult to account for.

A solution to this problem is the following CSRR modification. The resonator is placed in a metallization hole on the substrate side opposite the feeding strip line. The spatial distributions of the electric component of the EM field near it are shown in Fig. 4, *a*, *b*. With this topology, the influence of the aforesaid undesirable effect is minimized because the feeding strip line is on the bottom side of the substrate, while the resonator is on the top (ground plane) (Fig. 4, *b*). A spatial separation between the excitation and sensing components reduces the mutual influence between the LUT and the excited structure, significantly enhancing measurement accuracy. It is evident from Fig. 3, *b* that the loaded resonator spectrum looks like a single minimum (curve *2*), in contrast to the case the CSRR and the strip line are on the same side of the substrate (Fig. 3, *a*).

Bringing the container closer to the CSRR also changes its resonant frequency and quality factor (Fig. 3, *b*). As viewed in Fig. 4, the field localization occurs in the gap region because the resonator's electric component is the most intense near the

CSRR gap. This region is the most sensitive to spectral changes as the LUT-filled container approaches the resonator. By consistently moving the container closer to or farther from the resonator and examining the transmission spectra, one observes distance-dependent alterations in the CSRR resonant frequency and inverse *Q*-factor [9, 10]. For different liquids in the container, these two parameters vary differently with distance from the resonator, allowing one to distinguish one liquid from another. The influence of the container's characteristic size and wall thickness is well described in [19, 24].

The transmission coefficient spectra obtained by simulation or experiment are approximated by a Lorentzian curve to evaluate the resonant frequency and inverse *Q*-factor using the complex transmission coefficient derivation in [25]. For this purpose, a specially developed program helps reduce errors in the resonant frequency and inverse *Q*-factor without approximation.

2. Experiment and discussion

The experimental setup for the verification of liquid identification using a planar CSRR is illustrated in Fig. 5, *a*. The CSRR was fabricated on an FR-4 material substrate by chemical etching. The measurement system consists of a CSRR etched in the ground metallization and used as a sensing element, and a feeding strip line etched on the opposite side of the substrate. Coaxial-to-microstrip adapters and coaxial cables connect the CSRR to the vector network analyzer P9374A to measure the electromagnetic transmission coefficient within the frequency bandwidth 3 to 7 GHz.

A two-dimensional scanning device [22] was used to precisely (within 0.1 mm) position a container with LUT relative to the CSRR. A 0.5-liter PET bottle, 70 mm in diameter, with a 0.3-mm-thick wall (Fig. 5, *a*) represented the container with LUT. The theoretically and experimentally obtained norma-

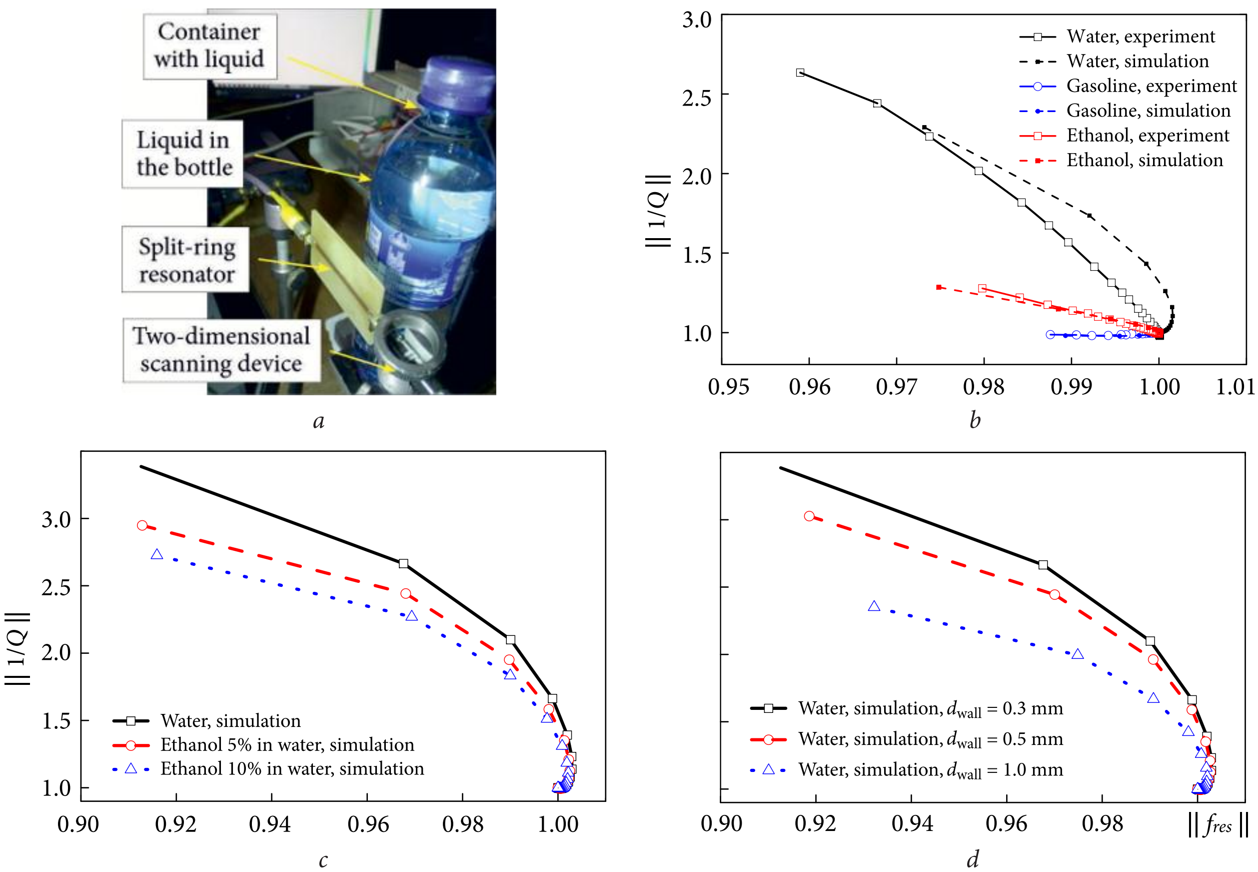


Fig. 5. A photograph of the experimental setup (*a*). Inverse *Q*-factor versus resonant frequency f_{res}: experimental and numerical simulation results for various liquids (*b*), numerical simulation results for different ethanol concentrations (*c*), and numerical simulation results for different wall thicknesses of water-filled containers (*d*)

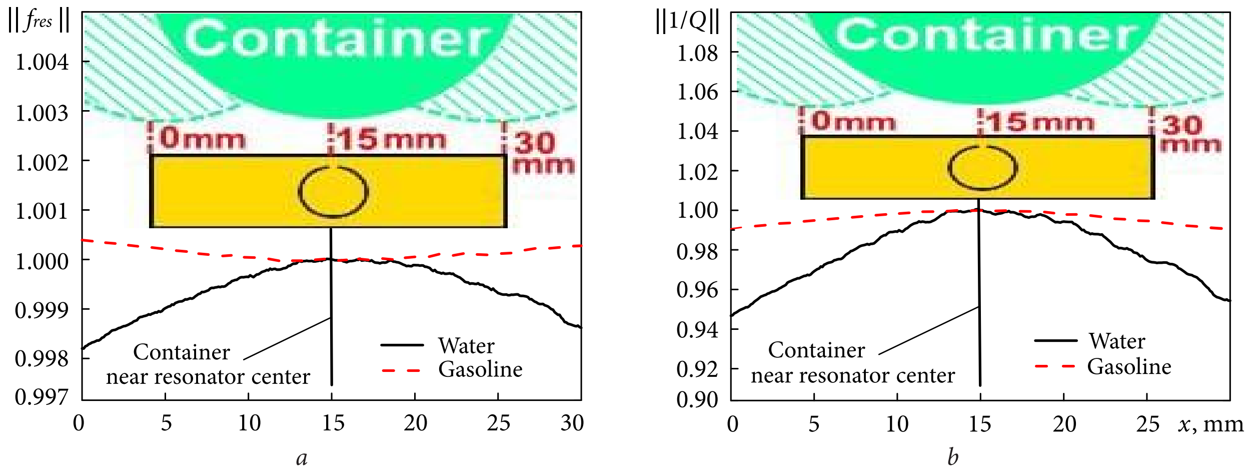


Fig. 6. The CSRR resonant frequency (*a*) and the CSRR inverse quality factor (*b*) while moving a LUT container (PET bottle) parallel to the resonator plane (along the *x*-axis) at 2 mm from the resonator surface

lized inverse Q-factors versus the resonant frequency f_{res} for different container-to-planar-resonator distances are plotted in Fig. 5, *b*. The calibration was carried out on the feeding strip line with the resonator being absent. The f_{res} and $1/Q$ values were normalized to their respective values obtained for the resonator without the container. Figure 5, *b* plots normalized $1/Q$ values, experimental and simulated, as a function of f_{res} for mineral water (safe and reference liquid), ethyl alcohol (relatively nonhazardous liquid), and refined gasoline (flammable and explosive, i.e., hazardous and illicit for transportation in luggage).

Figure 5, *b* demonstrates a good agreement between the numerically simulated and experimentally obtained results. The measurement error is influenced by various factors [19, 24]. But the most impactful factors are container geometry and material properties, including shape, wall thickness, material permittivity, and air gaps. Even minor alterations in these parameters can lead to noticeable shifts in the resonant frequency and Q-factor fluctuations since they disrupt the effective localization of the electric field above the resonator and affect the dielectric constant distribution in the sensing region.

With the proposed sensor design, not only can various liquid compositions be identified, but also their solutions. Thus, an alcohol in water was identified with an accuracy no worse than 1% by measuring the transmission coefficient of the feeding strip line with a loaded resonator (Fig. 5, *c*). The impact of container wall thickness on liquid identification accuracy is illustrated in Fig. 5, *d*. According to the numerical simulation, the container material when identifying liquids (water, ethanol, gasoline) is essential if the container wall is thicker than 1 mm.

The claimed advantage of the planar resonator — low effect of the container parameters — was experimentally verified by moving a container in the form of a 0.5-liter LUT-filled PET bottle along a straight line parallel to the plane of the resonator and 2 mm away from its surface (Fig. 6). The bottle central position relative to the resonator is marked with the vertical line (the axis through the normal to the resonator plane from its center (Fig. 6)).

The resonant-frequency alteration caused by container deviations from the central position is within 0.2%. It is comparable to that of the microstrip analog of the photonic crystal structure described in [10, 19]. Thus, the electric-field component localization in the CSRR allows one to neglect the container parameters, in particular, the container's position relative to the CSRR center.

Conclusions

An innovative contribution to contactless liquid identification has been made. The application of a circular planar resonator in the split-ring form (circular split-ring resonator, CSRR) as a liquid sensor has demonstrated the effectiveness of this sensor type. The capability to accurately identify liquids with different compositions, including ethyl alcohol and refined gasoline, is confirmed by analyzing the dependences of the inverse quality factor and resonant frequency on the distance between the liquid container and the resonator plane.

It has been shown that when a planar CSRR is used as a sensor, the influence of container parameters on liquid identification accuracy is significantly smaller than that observed for the photonic-crystal sensor with imperfection. Furthermore, the resonant frequency shift obtained with the CSRR is approximately four times greater than that of a previously studied planar photonic crystal with a microstrip defect at the same separation distance.

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REFERENCES

1. Zhong, Yu, Sun, B., Yu, D., Li, W., Zhang, Yu, Li, M., Liu, J., 2010. Identification of Liquid Materials Using Energy Dispersive X-ray Scattering. *Procedia Eng.*, **7**, pp. 135—142. DOI: 10.1016/j.proeng.2010.11.020
2. Eiceman, G.A., Gardea-Torresdey, J., Overton, E., Carney K., Dorman, F., 2004. Gas Cchromatography. *Anal. Chem.*, **76**(12), pp. 3387—3394. DOI: 10.1021/ac0400663
3. Snyder, L.R., Kirkland, J.J., & Dolan, J.W., 2010. *Introduction to Modern Liquid Chromatography.* 3rd ed., Wiley.
4. Rouessac, F., Rouessac, A., 2007. *Chemical Analysis: Modern Instrumentation Methods and Techniques.* 2nd ed., Wiley.
5. Obeidat, Yu., Mousa, E.A., Mushaljy, R., 2023. Contactless optical liquid identifier. *ACS Omega,* **8**(38), pp. 34787—34794. DOI: 10.1021/acsomega.3c03856
6. Goossens, J., Bormans, S., Oudebrouckx, G., Vandenryt, T., El Habti, S., Mahdavinasab, S., Thoelen, R., 2022. Liquid identification in a microplate format based on thermal and electrical sensor data fusion. *IEEE Sens. J.*, **22**(20), pp. 19809—19817. DOI: 10.1109/JSEN.2022.3202691
7. Zhang, J., Zhou, K., 2023. Identification of Solid and Liquid Materials Using Acoustic Signals and Frequency-Graph Features. *Entropy*, **25**(8), 1170. DOI: 10.3390/e25081170
8. Pappas, R.A., Bamberger, J.A., Bond, L.J., Greenwood, M.S., Panetta, P.D., Pfund, D.M., 2001. Ultrasonic methods for characterization of liquids and slurries. In: *2001 IEEE Ultrasonics Symp.* (*Proc.*): Cat. No.01CH37263. Atlanta, GA, USA, **1**, pp. 563—566. DOI: 10.1109/ULTSYM.2001.991685
9. Klein, N., Krause, H.-J., Vitusevich, S., Rongen, H., Kurakin, A., Shaforost, O. N., 2011. Dual-mode microwave cavity for fast identification of liquids in bottles. In: *2011 IEEE MTT-S Int. Microwave Symp.* Baltimore, USA, pp. 1—4. DOI: 10.1109/MWSYM.2011.5972696
10. Polevoy, S.Y., Vakula, A.S., Nedukh, S.V., Tarapov, S.I., 2017. Fast Identification of Liquids Using Planar Metamaterial. *Telecom. Rad. Eng.*, **76**(3), pp. 237—243. DOI: 10.1615/TelecomRadEng.v76.i3.40
11. Jiang, Y., Ju, Y., Yang, L., 2016. Nondestructive In-situ Permittivity Measurement of Liquid within a Bottle Using an Open-Ended Microwave Waveguide. *Nondestruct. Eval.*, **35**(7). DOI: 10.1007/s10921-015-0322-8
12. Dubey, S., Ta, K., Chiao, J.-C., 2017. Liquid interrogator for security applications. In: *2017 IEEE Sensors Conf.* Glasgow, UK, pp. 1—3. DOI: 10.1109/ICSENS.2017.8234305
13. Jose, K.A., Varadan, V.K., Varadan, V.V., 2001. Wideband and noncontact characterization of the complex permittivity of liquids. *Microw. Opt. Technol. Lett.*, **30**(2), pp. 75—79. DOI: 10.1002/mop.1225
14. Kim, J.W., Pasupathy, P., Zhang, S., Neikirk, D.P., 2009. Measurement of liquid complex dielectric constants using non-contact sensors. In: *Proc. of IEEE Sensors.* Christchurch, New Zealand, pp. 2017—2020. DOI: 10.1109/ICSENS.2009.5398291
15. Shafi, K.T., Jha, A.K., Akhtar, M.J., 2016. Nondestructive technique for detection of adulteration in edible oils using planar RF sensor. In: *2016 IEEE MTT-S Int. Microwave and RF Conf. (IMaRC)*. New Delhi, India, 05—09 Dec. 2016, pp. 1—4. DOI: 10.1109/IMaRC.2016.7939636
16. Liu, Ch., Liao, Ch., Peng, Y., Zhang, W., Wu, B., Yang, P., 2024. Microwave Sensors and Their Applications in Permittivity Measurement. *Sensors*, **24**, 7696. DOI: 10.3390/s24237696
17. Vélez P., Su L., Grenier K., Mata-Contreras J., Dubuc D., Martín F., 2017. Microwave Microfluidic Sensor Based on a Microstrip Splitter/Combiner Configuration and Split Ring Resonators (SRRs) for Dielectric Characterization of Liquids. *IEEE Sens. J.*, **17**(20), pp. 6589—6598. DOI: 10.1109/JSEN.2017.2747764
18. Lim, H., Lee, D.-H., Kim, J., Hong, S., 2022. Spectroscopic Sensing Method of Liquid Permittivity with On-Chip Capacitor. *J. Electromagn. Eng. Sci.*, **22**, pp. 28—33. DOI: 10.26866/jees.2022.1.r.57
19. Polevoy, S.Yu., Vakula, A.S., Nedukh, S.V., Tarapov, S.I., 2019. A technique for non-contact identification of liquids in closed containers using microwave planar metamaterial. *URSI Radio Sci. Bull.*, **2019**(371), pp. 53—62. DOI: 10.23919/URSIRSB.2019.9117244
20. Vakula, A.S., Polevoy, S.Yu., Nedukh, S.V., Tarapov, S.I., 2019. Portable 2.0—2.5 GHz oscillator-detector unit for liquids identification by planar photonic crystal technique. *Telecommunications and Radio Engineering*, **78**(9), pp. 813—819. DOI: 10.1615/TelecomRadEng.v78.i9.70

21. Bhatti, M.H., Jabbar, M.A., Khan, M.A., Massoud, Y., 2022. Low-Cost Microwave Sensor for Characterization and Adulteration Detection in Edible Oil. *Appl. Sci.*, **12**, 8665. DOI: 10.3390/app12178665
22. Girich, A., Nedukh, S., Polevoy, S., Sova, K., Tarapov, S., Vakula, A., 2023. Enhancement of the microwave photon-magnon coupling strength for a planar fabricated resonator. *Sci. Rep.*, **13**(924). DOI: 10.1038/s41598-022-27285-6
23. Girich, A., Nedukh, S., Polevoy, S., Sova, K., Tarapov, S., Vakula, A., 2024. Enhancement of photon-magnon coupling strength by inverted split-ring resonator at GHz. *AIP Adv.*, **14**(2), 025138. DOI: 10.1063/5.0187796
24. Isakov, D., Stevens, C. J., Castles, F., Grant P. S., 2017. A Split Ring Resonator Dielectric Probe for Near-Field Dielectric Imaging. *Sci. Rep.,* **7**, 2038. DOI: 10.1038/s41598-017-02176-3
25. Skresanov, V.N., Glamazdin, V.V., Shubny, A.I., Eremenko, Z.Ye., 2011. Hardware computing system for measurement of low and high quality resonators characteristics within the bandwidth from 26 GHz to 37.5 GHz. *Telecommunications and Radio Engineering*, **70**(7), pp. 625—647. DOI: 10.1615/TelecomRadEng.v70.i7.70

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БЕЗКОНТАКТНА ІДЕНТИФІКАЦІЯ РІЗНИХ РІДИН У ГЕРМЕТИЧНИХ ПЛАСТИКОВИХ КОНТЕЙНЕРАХ З ВИКОРИСТАННЯМ ПЛАНАРНОГО РОЗІМКНЕНОГО КІЛЬЦЕВОГО РЕЗОНАТОРА

Предмет і мета роботи. У цій статті чисельно та експериментально описане використання планарного розімкненого кільцевого резонатора для безконтактної ідентифікації рідин усередині герметичних тонкостінних контейнерів з поліетилентерефталату (ПЕТ). Метою роботи було визначення типу розімкненого кільцевого резонатора, який найбільше підходить для розрізнення рідин.

Методи та методологія. Планарний розімкнений кільцевий резонатор використовували як високочастотний сенсор, що працює на частоті 2.3 ГГц. Рідини ідентифікували шляхом порівняння спектрів пропускання плоскої мікросмужкової лінії живлення, на яку був установлений резонатор. Для цього пластикові контейнери, заповнені різними рідинами, розташовували на різних відстанях від резонатора. Зміни спектра резонатора оцінювали за двома ключовими параметрами — резонансною частотою та оберненою добротністю. Крім того, розроблене програмне забезпечення для спектрального аналізу зменшувало похибки у визначенні добротності резонатора.

Результати. Здатність планарного кільцевого резонатора розрізняти рідини була продемонстрована для трьох рідин різного складу: мінеральної води, етилового спирту та очищеного бензину. Відмінності між рідинами відстежували, порівнюючи графіки залежності оберненої добротності та резонансної пікової частоти від відстані між контейнером з рідиною та площиною планарного резонатора з розімкненим кільцем. Крім того, було показано, що при використанні планарного розімкненого кільцевого резонатора як сенсора параметри контейнерів значно менше впливають на точність ідентифікації рідини, ніж при використанні фотонного кристала з дефектом.

Висновки. Перевагою запропонованого планарного резонатора є його низька чутливість до параметрів контейнера. Це було експериментально підтверджено під час переміщення заповненого рідиною контейнера у вигляді ПЕТ-пляшки об᾽ємом 0.5 л (16.9 fl. oz.) уздовж прямої лінії на відстані 2 мм від площини резонатора.

Ключові слова: *безконтактна ідентифікація рідини, резонатор з розімкненим кільцем, мікрохвильові частоти, обернена добротність, діелектрична проникність.*