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Rapid Viral Detection Using Microwave Sensors

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***Abstract*—The electromagnetic field (EMF) of biomolecules can be utilized for detection and identification purposes. This paper is presenting a preliminary proof-of-concept experiment for rapid virus detection using an improved complementary split-ring resonator of mutually-coupled cells. Spectral responses of the sensor prototype have reliably indicated the presence of an Adeno-Associated Virus (AAV) in the hosting medium. Besides, two isolates of a fish virus were differentiated when tested in the near-field of the sensor. Promising results would revolutionize the space to develop an inexpensive, reusable, rapid EM testing technology for lab-on-chip virus detection to help combatting future pandemics.**

***Keywords*—COVID, dielectric resonators, microwave sensing, non-invasive, viruses.**

I. Introduction

One of the most crucial components in navigating a pandemic is rapid testing. Without it, the main course of action without a viable vaccine is strict lockdown. However, as the COVID19 pandemic has demonstrated, the consequence of a lockdown can also be devastating on local/global economies, the healthcare system, and overall wellbeing of individuals and families. Furthermore, pandemic recoveries without rapid testing will be more drawn out having greater economic and personal tolls on society. As we have seen over the last two years with SARS-CoV-2, trillions of dollars have evaporated, job security has been decimated, mental health issues and substance abuse has rapidly increased, and we are now seeing the emergence of COVID variants (e.g., Delta, Omicron, etc.). Such viral outbreaks highlight the need for reliable, inexpensive, reusable, and rapid testing technologies of the presence of viruses and other pathogens which could be realized by exploiting current theoretical work on electromagnetic signal resonance [1]–[3]. In addition, such EMF sensing devices could be particularly useful for differentiating or resolving viral samples and perhaps even nucleic acid sequence information non-invasively.

Most biological processes occur in aqueous environments; for this reason, several theoretical, experimental, and numerical studies have been published examining the vibrational and structural dynamics of water. The frequency of vibrational resonances of biological molecules are typically within the 0.5–2 THz range. However, there are still significant challenges when using THz sensing systems. Firstly, resonance-based sensors are material and case specific as each biomolecule has its own resonance. This means that a general THz sensing system for biomolecule identification would be very expensive. Moreover, current technology does not have optimal capabilities to deal with the noise floor of such systems, which typically are on the order of -50 dBm. If lower frequency measurement systems could instead be used for distinguishing various biomolecules, this would be ideal since they are less expensive, and have much more accuracy and precision because the noise floor is on the order of -150 dBm.

For biomolecule solutions where the physical attributes are correlated to specific electromagnetic (EM) properties (e.g., dielectric permittivity and conductivity), micro/millimeter-wave sensing could be effectively used for sample identification [4]–[6]. Among the different EM sensing devices, dielectric resonators of small electrical size (in terms of wavelength) such as complementary split-ring resonators (CSRRs) are more favourable for highly sensitive applications. Their general working principle is based on detecting the dielectric contrast of tested materials present in the near-field region of the sensor. Particularly, changes in the sample's dielectric constant and loss tangent are perceived and interpreted through the sensing parameters (i.e., resonance frequency, phase, and/or amplitude) of the sensor on a readout device [6]. In this paper, an improved CSRR of three coupled cells is experimented for non-invasive virus detection in the low GHz spectrum as will be explained next.

II. Methodology and Measurements

A preliminary characterization was first performed across the spectrum 200 MHz – 67 GHz using the open-ended coaxial probe of the advanced dielectric assessment kit (DAK-TL) to determine and compare the permittivity and the loss tangent of the phosphate buffered saline (PBS) aqueous solution when a virus (Adeno-Associated Virus Serotype 8 (AAV8)) was and was not present in the solution. A pure PBS was first measured in a clean petri-dish at 9.51 mL then the AAV8 sample was mixed and measured accordingly in terms of ϵ' and $tan\delta$ at incrementing concentrations. The DAK-TL system was not able to capture any dielectric changes due the presence of small amounts of viral particles in the PBS solution. That would entail the need for more sensitive microwave instruments to detect the presence of viruses in the samples.

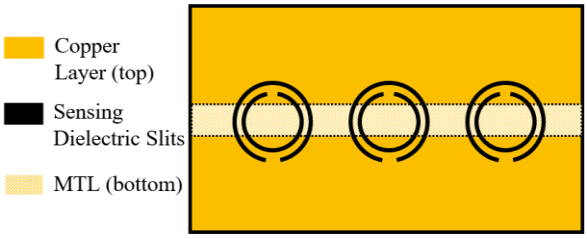

Fig. 1. Configuration of the TC-CSRR sensing structure.

To acquire more sensitive measurements on the viral samples, a planar CSRR sensing structure was used. The device is a triple-cell CSRR (TC-CSRR) that comprises a microstrip-line loaded with three similar cells of circular CSRRs cascaded horizontally on the top layer of a dielectric substrate as shown in Fig. 1. Each CSRR cell is composed of two concentric split-rings of dielectric slits nested inside each other with a gap t = 0.5 mm between each as engraved in the top copper layer. The detailed design and sensing principle of

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the microstrip structure can be found in [5], where been used for detecting delicate changes in blood glucose levels related to the diabetes conditions. When this CSRR structure is at resonance state, its stored electric energy (spreading over a larger region due to mutual coupling between unit cells) strongly interacts with the biological sample placed onto the sensing surface. Therefore, its modified resonance profile would be directly correlated to the EM identification of the loaded bio-sample.

The Keysight Technologies PNA N5227A was calibrated and used to acquire the scattering measurements from these two CSRR sensors at 1600 frequency points from 1 to 6 GHz at 22ºC room temperature. The experiment setup of the VNA connection to the CSRR sensors using coaxial cables is shown in Fig. 2. Before loading any sample, the TC-CSRR exhibits a transmission resonance around f = 2.3 GHz. A rectangular plexiglass container was integrated on top of the TC-CSRR across the sensing region to hold the tested samples. The holder has bases with minimal thickness of about 0.15 mm to expand the sample interaction with the coupled fields.

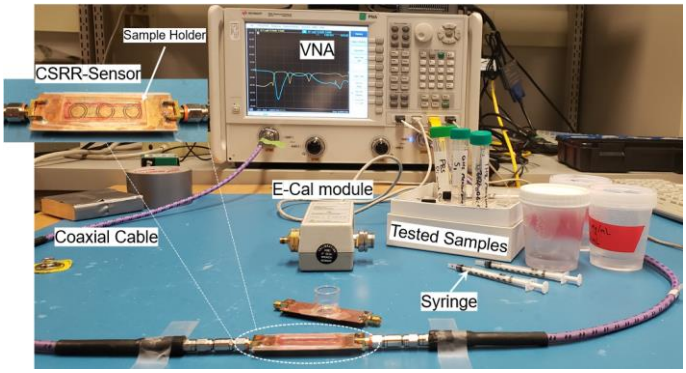

Fig. 2. Complete experimental setup comprises VNA connected to the fabricated microwave sensors via coaxial cables.

Two samples, pure PBS and PBS/AAV8, were measured to investigate the existence of an EM signature associated with AAV8 presence. However, this does not show the uniqueness of such a signature (if found). Therefore, we further investigated uniqueness by comparing two similar genetic samples. In particular, to test against the probability of uniqueness of waveform characteristics associated with a pathogen sample, two isolates of the fish virus, viral hemorrhagic septicemia virus (VHSV), specifically isolate samples containing IVa and IVb, were measured and compared. Testing the last two samples would also show the feasibility of detecting two similar viruses that only differ by a single gene when obtaining a difference in their resonance signatures in the sensor's responses.

The reflection $|S_{11}|$ and transmission $|S_{21}|$ coefficients of the sensor were measured for the four samples when loaded precisely at 600 μL. All the measurements were repeated five times for repeatability verifications and the average is reported in Fig. 3 and 4. In the reflection readings depicted in Fig. 3, noticeable differences were observed in the resonant amplitudes and frequencies near 2.0 GHz and 3.0 GHz. Similarly, the two resonances captured in the transmission coefficient (Fig. 4) around 1.5 GHz and 3.9 GHz, change their depths and shift the resonant frequencies differently with respect to the four samples. A noticeable deviation was observed between the PBS and PBS/AAV8 and between IVa and IVb, indicating the existence of the AAV8 in the PBS and the possibility to detect the single gene difference between the two VHSV viral samples.

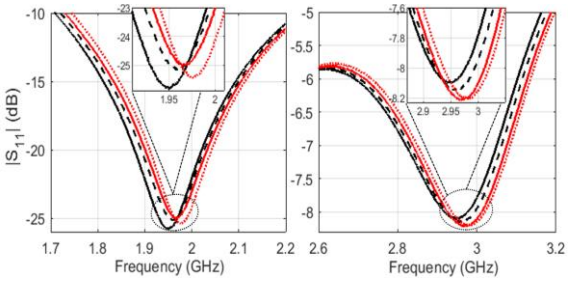

Fig. 3. Measured reflection $|S_{11}|$ coefficients for the different samples.

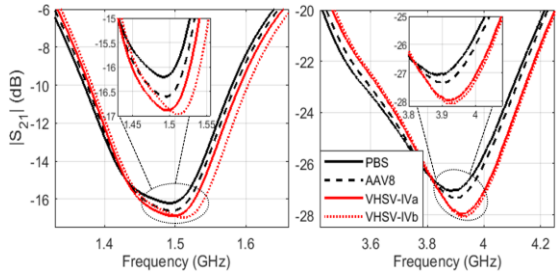

Fig. 4. Measured transmission $|S_{21}|$ coefficients for the different samples.

III. Conclusion

The hypothesis from reviewing the collected data is that the obtained scattering results demonstrate that there exists an electromagnetic signature associated with AAV8. Additionally, two similar fish viruses (VHSV) that only differ by a single gene were differentiated when tested onto the sensitive CSRR unit. With sufficiently precise and accurate measurements of EM signatures of biomolecules being performed, the underlying sensing technology could potentially be developed as a novel lab-on-chip that utilizes electromagnetic waves and artificial intelligence for rapid non-invasive testing of viral detection and identification.

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