Design of a Low-Cost Portable Microwave Sensing System for Organic Tissue Analysis

Anja Kovačević, Nikola Basta

Abstract— **In this research project, we have created a low-cost portable microwave sensing system capable of spatially differentiating two types of tissues in two operating modes. By enhancing the calibration procedure for NanoVNA, we obtained measurements that are on par with measurements obtained by professional measurement equipment, having up to three orders of magnitude higher price.**

Index Terms— **microwave measurements, sensors, tissue analysis.**

I. INTRODUCTION

In recent years, there is a significant growth in research employing technological innovations to improve the quality of medical diagnostics and treatment while, simultaneously, reducing their cost. Medical systems which are considered to be a gold standard for medical diagnostics, such as magnetic resonance imaging (MRI), tend to be very expensive, which limits their accessibility to the general population. On the other hand, the development of consumer electronics at higher frequencies has enabled the construction of relatively affordable microwave measurement systems. By pairing such measuring systems with printed circuits, it is possible to create low-cost microwave systems for medical purposes.

The main goal of this research project was to build an affordable, user-friendly and compact system for tissue analysis which can be utilized in laboratories and medical facilities. Presented system is capable of forming the spatially resolved dielectric image of the tissue under test (TUT).

II. SENSOR DESIGN

The sensing component of the built system is a printed circuit on FR4 substrate. To form a spatial image of TUT, the sensor is composed of a several mutually decoupled sensing cells (SCs) with split-ring resonators (SRRs). At its resonant frequency, the SRR is strongly coupled with the microstrip feeding line, introducing significant losses for waves traveling along the line, which manifests as a notch in the sensor's transfer function. Gaps in the SRR introduce capacitances which are increased by placing TUT, causing a frequency shift of the notch. The presence of tissue also introduces inherent losses, causing a change in the Q-factor of the resonator. Having different EM properties, different tissues introduce different changes to the response, which opens a possibility for their differentiation.

A. Kovačević and N. Basta are with the School of Electrical Engineering, University of Belgrade, Serbia (email: anja@etf.bg.ac.rs and nbasta@etf.bg.ac.rs)

The operating range was determined as explained in [1]. Due to the limited operating range, separation of resonant frequencies reduces the number of SCs in the sensor which leads to the decrease of the resolution of the TUT image. As the optimal selection of SCs from the bank is directly correlated with the properties of TUT, we have determined the frequency shift of each SC with a reference 7mm×7mm×7mm sample of muscle tissue placed on the left lateral gap.

In a real measurement scenario, the properties of the sample can differ from the reference sample. Additionally, for electrical and mechanical protection, an isolation layer is placed between the sensor and the sample, which weakens the sensor−sample interaction. To estimate the optimal spacing between the SCs, we have constructed three sensors with 4, 5 and 6 SCs from the bank, respectively.

III. MEASUREMENT SETUP

To measure the sensor's transfer function, we have used a low-cost portable vector network analyzer (VNA), NanoVNA V2 Plus4, operating at 50 kHz−4.4 GHz [2]. The complete measurement setup is shown in Fig. 1. The estimated price of the system is around 300$, excluding the price of the laptop which is used for data post-processing.
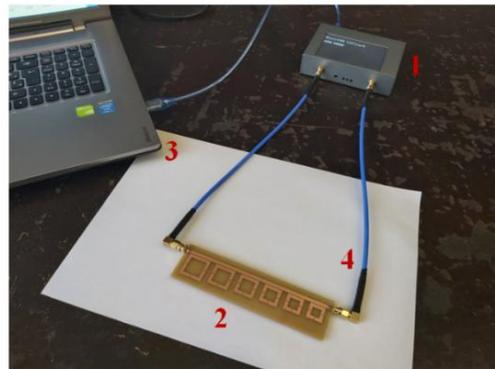

Fig. 1. Complete measurement setup contains (1) NanoVNA V2 Plus4, (2) sensor, (3) laptop, and (4) cables and assembly connectors.

The commonly used full 2-port SOLT calibration procedure cannot be applied since the second port of NanoVNA is equipped only with a receiver. Therefore, we have implemented enhanced response (ER) calibration procedure described in [1]. Definitions of calibration standards that come with NanoVNA are not supplied with the device. To avoid measurement errors caused by using ideal definitions, we have measured *s*-parameters of a NanoVNA's calibration kit on a professional VNA device Agilent N5227A. The results were stored and reused as standard definitions for further measurements.

Testing of the built system with pork muscle and fat tissue samples was conducted ex-vivo in two different operating

modes. In the discrete mode (DM), the sensor was covered with a very thin isolation layer (~10 μm), which makes it highly sensitive to the presence of a sample. Tissue samples used for testing in the DM occupy an area not much greater than the area of SC's lateral gap. On the other hand, the continuous mode (CM) is suited for larger TUT samples. The CM can simulate the process of tumor detection in the surrounding healthy tissue, as described in the next chapter. Due to the size of tissue samples, the sensitivity in CM must be decreased by placing an additional thick isolation layer (~1 mm) between the sensor and the TUT.

IV. MEASUREMENT RESULTS

Uncalibrated and ER-calibrated s_{21} measurements without TUT for sensor with 6 SCs are shown in Fig. 2. To test the accuracy of the built measurement setup, we have repeated the measurement with Agilent N5227A and plotted these results as "Reference" in Fig. 2. The "ER-calibrated" and "Reference" results match well with a maximum deviation of less than 1 dB, even though NanoVNA is up to three orders of magnitude less expensive than professional VNA. Further measurements were performed by using NanoVNA with ER calibration procedure.
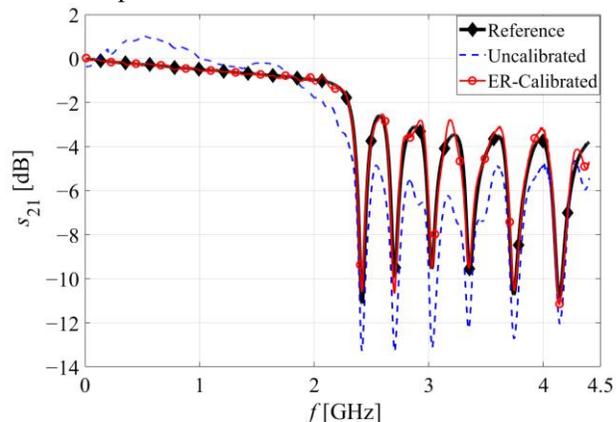

Fig. 2. Measurement results for sensor with 6 SCs without a sample.

The measurement results in the DM showed that all three sensors can reconstruct the spatial distribution of TUT pieces. The optimal choice for the DM is the sensor with 6 SCs, since it achieves the highest image resolution. Measurement results and scenario for the DM are presented in Fig. 3. By interpreting the results from Fig. 3, the TUT image can be unambiguously reconstructed. An unchanged notch signifies that there is no sample on top of the corresponding SC. An almost disappeared notch with large frequency shift is interpreted as a SC with muscle tissue, while a small frequency shift translates into the SC with fat tissue.

Degradation of the response in the CM is larger with sensors with more SCs, due to the proximity of the resonant frequencies. Therefore, the reconstruction is the easiest when using a sensor with 4 SCs, but thus formed image has the fewest pixels. To simulate the tumor detection, we have covered the sensor with 4 SCs with a layer of fat (healthy) tissue and measured the response. Then, the fat tissue was punctured on the second and the fourth SC, the pieces of muscle tissue (tumors) were inserted into the holes, after which the measurement was performed. The measurement results for the described scenario are presented in Fig. 4. By

comparing the results for healthy tissue and sample with tumors, we can determine the position of tumors by identifying the notches that have experienced frequency shift. A sensor with 5 SCs is a compromise solution for use in both modes.
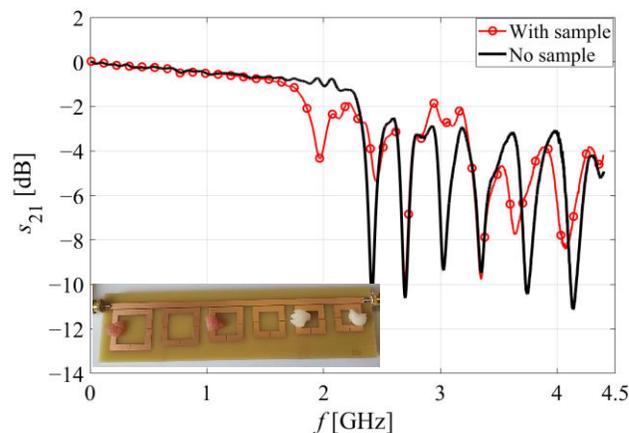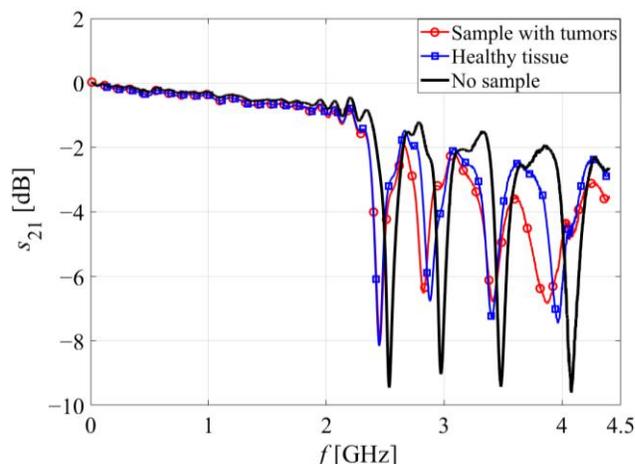

Fig. 3. Measurement results in the DM.

Fig. 4. Measurement results in the CM.

SCHOLARSHIP IMPACT

Anja Kovačević has presented a part of the presented project at IMBIOC 2023 where she had an opportunity to discuss her work, as well as emerging topics, with attending coleagues. Scholarship has inspired her to pursue a PhD degree and a scientific and academic career in the field.

REFERENCES

[1] A. Kovačević, N. Basta, S. Savić, "Low-cost Portable Sensing System for Organic Tissue Detection and Differentiation", 2023 IEEE MTT-S International Microwave Biomedical Conference (IMBioC), pp. 1−3, IEEE, Leuven, Belgium, Sep, 2023
[2] About NanoVNA V2 NanoRFE. Available at: https://nanorfe.com/nanovna-v2.html (Accessed: December 4, 2023).