Integrated network analyzer with resonant cavity for moisture content measurement in cork stoppers

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***Abstract*— This work introduces a novel system for measuring the moisture content of cork stoppers using a custom-designed Network Analyzer (NA)-based setup integrated with a resonant cavity. By using microwave techniques, the system measures perturbations in the resonant parameters of the cavity caused by the dielectric properties of moisture present in the cork. This approach addresses the limitations of traditional slow methods, offering a faster and more efficient alternative for moisture analysis in the wine industry.**

***Index Terms* — Network Analyzer, cork stoppers, moisture measurement, resonant cavity, S_{21} parameter.**

I. INTRODUCTION

The wine bottle-filling industry requires cork stoppers to have a low moisture content (3-8%) for optimal wine conservation, as higher moistures can allow the formation of TCA, an abbreviation for 2,4,6-trichloroanisole, which is an exceedingly potent chemical. Even in minuscule quantities, it can impart musty scents and tastes to wines. Therefore, careful moisture content analysis during cork drilling is critical to ensure wine quality.

To address this risk and monitor moisture content, the industry uses a standard method to estimate cork moisture. This involves measuring the cork's weight before and after drying it in a forced-air oven, as specified in the standard To mitigate this risk, the industry currently employs a method for estimating cork moisture, allowing accurate results by measuring the weight of the cork before and after being dried on a forced air oven, a procedure outlined in the standard [1]. Despite being well-established, this procedure is lengthy and time-consuming, and alternative faster methods [2] lack the accuracy of the forced-air oven approach. Given this fact, there is a need to develop an efficient and rapid method for measuring moisture content in corks.

In this project, we propose a novel method for measuring the moisture content in corks using microwave techniques. This approach is composed of a system comprising a resonant cavity and a custom-designed measurement setup, which primarily incorporates a Network Analyzer. The technique exploits the fact that the dielectric properties of materials cause perturbations in the resonant parameters of the cavity, enabling accurate moisture detection.

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THEORETICAL ASPECTS

It is well known that the resonant frequency and Q-factor depend on the dielectric properties of the materials inside of a cavity. This can be used as an advantage to determine the microwave properties of materials [3,4]. These measurements use the change in the resonant frequency, ΔF, and the change in the transmission factor (given by S_{21}), ΔT, that can be experimentally obtained using a standard network analyzer.

In the case of cork moisture measurements, it was observed that the most accurate correlations were achieved by fitting the inverse of the transmission magnitude to the mass of water in the cork. This relationship was found to follow a linear trend, making it a reliable metric for quantifying moisture content. The study demonstrated that this method offers a precise and efficient way to evaluate cork moisture.

II. SYSTEM DESCRIPTION

The system architecture is presented in Fig. 1. The setup features a custom-designed cavity for operation within the S-band frequency range, accompanied by a measurement system that evaluates the S_{21} parameter across the frequencies of interest. This configuration focused solely on measuring the magnitude of the transmitted power, which is the unique parameter needed for evaluating the moisture content, eliminating the need for phase measurement and thus simplifying the overall design.

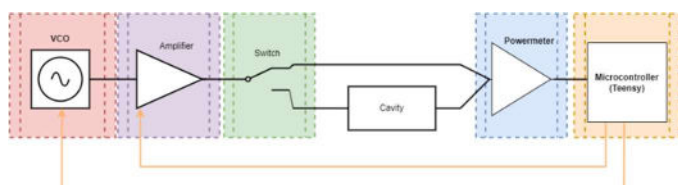

Figure 1 – Overall description of the resonant cavity and measurement system.

A commercially available Voltage-Controlled Oscillator (VCO) is utilized for frequency sweeping, and after the RF signal chain, a logarithmic power meter captures and translates this power into a voltage that is then sampled with an ADC. The RF and signal processing components were integrated into a Printed Circuit Board (PCB), shown in Fig. 2. The board also has a microcontroller for processing the data and future serialized communication with other devices in an industrial setting.

III. MEASUREMENTS

To test the effectiveness of the designed system, a set of cork stoppers were selected with a range of moisture content from 1 to 8%. For comparison, the same stoppers have been previously dried and weighted, allowing us to obtain the real moisture contents (reference measurement) by weighting them again when performing the measurement.

Figure 3 - Designed PCB comprising the measurement and processing chain of the system.

In Fig. 3, a typical measurement of S_{21} of a sample of different stoppers is depicted. As it is possible to see, different corks with various moisture content exhibit different transmission frequency responses of the cavity; the blue curve corresponds to the empty response of the cavity. The inverse of the magnitude of the resonance of each curve is extracted and fitted to the reference moisture content.

IV. RESULTS

The performance of the proposed system is demonstrated in Fig. 4, which shows the relationship between the estimated and actual moisture content of cork stoppers. The data reveals a strong correlation, as evidenced by a coefficient of correlation $R^2 = 0.936$.

The 95% confidence interval in the plot is relatively tight, reflecting the system's precision. The computed standard error for the slope of the regression line is 0.0745, while the standard error for the intercept is 0.4086. These values suggest that the system provides a reliable linear fit, although minor deviations are present. 85% of the deviations are within 1% of moisture and the standard error for the estimated moisture percentage is less than 0.72%. While the method is not without its limitations, the results show effectiveness in accurately estimating moisture contents, better than the existent portable methods [2].

V. CONCLUSION

This paper presented a novel microwave-based system for measuring the moisture content of cork stoppers, which includes a network analyzer integrated with a resonant cavity. By using perturbations in the resonant parameters caused by moisture-induced changes in dielectric properties, the system demonstrated its ability to estimate moisture content accurately. Experimental results showed a high correlation (R² = 0.936) between the estimated and actual moisture levels, validating the

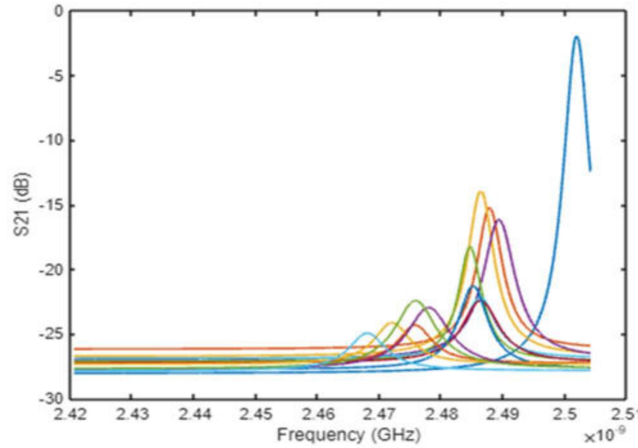

Figure 2- Measured and interpolated S_{21} results over the span of frequencies of interest.

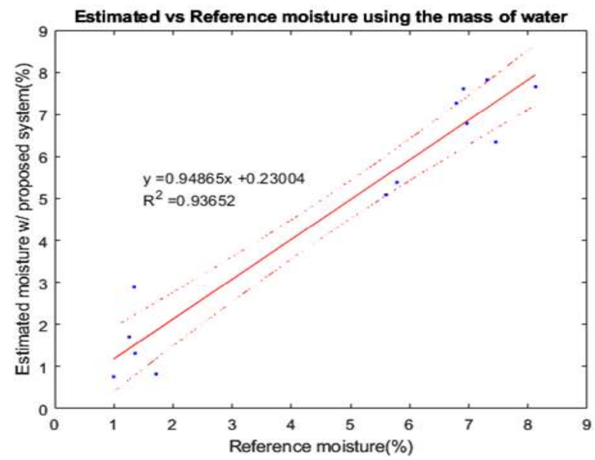

Figure 4- Estimated moisture content versus the reference moisture obtained with the oven method.

effectiveness of this method as long as the mass of the cork is also measured. Compared to traditional methods like the forced-air oven technique, which is time-consuming, this system offers a faster, more efficient, and reliable alternative.

ACKNOWLEDGMENT AND CAREER PLANS

The IEEE MTT-S scholarship has been a pivotal milestone in my career, supporting my project and providing invaluable insight into a career in microwaves. Since receiving the award, I began my Master's at FEUP in Electrical Engineering, specializing in Telecommunications, Electronics and Computers, which is allowing me to further deepen my knowledge about microwave engineering and expand my academic horizons. Attending the International Microwave Symposium enriched this journey, broadening my perspective on the field and sparking my interest in Quantum Systems, which I now consider for future research.

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