

## Research Article

### Moisture Content Determination Using Microstrip Fractal Resonator Sensor

<sup>1</sup>Beulah Jackson and <sup>2</sup>T. Jayanthy

<sup>1</sup>Sathyabama University,

<sup>2</sup>Panimalar Institute of Technology, Chennai, India

**Abstract:** This study presents a novel method for determining the moisture content in spices by means of compact microstrip fractal resonator. The proposed resonator is designed at 1 GHz using FR4 substrate with dielectric constant of 4.6. A resonator sensor in the shape of fractal designed using the tool ADS and working at 0.9 GHz to 3 GHz band is demonstrated. The relative shift in frequency and attenuation was observed to vary with respect to the moisture content/permittivity of the test material independent of its density.

**Keywords:** Attenuation, microstrip sensor, minkowski resonator, moisture content, permittivity, shift in frequency

#### INTRODUCTION

Moisture content is a measure of the quantity of water in a product. It provides valuable information about yield and quantity making it important from a financial stand point. In addition moisture content provides information about texture since increasing levels of moisture provide water mobility. The determination of moisture constitutes one of most important and most widely used analytical measurements both in processing and testing of foods including spices since it is frequently an index of stability and quality. The moisture content in materials like grains, seeds, food products, rubber, foams influences storage and shelf life and quality control. It is also an important factor in determining the market price because the dry matter of spices has more value than the water it contains.

In this study, a novel method to measure the moisture content of cardamom has been proposed. Cardamom is the queen of spices generally used as food item. The aroma and therapeutic properties of cardamom are due to its volatile oil. Microwave moisture sensors operate non-destructively and hence are well suited for applications in industry. The commonly used sensor is a resonator where the introduction of moist material lowers the resonant frequency and attenuates the resonance curve. We have proposed a fractal resonator sensor which is designed to determine the moisture content in cardamom and the sensor has been implemented for a density independent calibration.

#### MOISTURE MEASUREMENT METHODS

Several methods are currently in practice. Notable ones include evaporation method, distillation method,

chemical reaction method (based on Karl Fischer method), Gas production method and also physical methods. Even though the above said methods are cheap and easy to use, they are time and energy consuming and also destructive. Spectroscopic methods which include microwave techniques are capable of determining the moisture content rapidly.

Microwave techniques have been considered for a long time for moisture sensing in many food processing and agriculture related industries. They are suitable for on-line real time monitoring and control (Kupfer *et al.*, 2000). In microwave frequency measurement, transmission line using wave guides or coaxial lines and resonant cavity are employed. The disadvantages of these methods are the requirement for precise fabrication of sample holder and confinement of the samples (Kraszewski *et al.*, 1996; Nyfors and Vainikainen, 1989).

An approach is presented in Jayanthy and Sankaranarayanan (2006) where moisture content of spices such as cardamom and pepper are determined directly from microwave dielectric properties by using free space technique. Moisture content in wheat is determined using free space technique (Kraszewski *et al.*, 1996). Free-space method (Trabelsi and Nelson, 2003) is used to measure the dielectric properties of moist granular materials at microwave frequencies. The free- space microwave measurement method is very useful for non-destructive and non contact measurement of the moisture content of spices but the drawback is microwave components used in this method are bulky. To overcome this drawback compact planar resonators using ring structure are proposed for permittivity measurement in wheat and grain (Joshi *et al.*, 1997; Somporn and Prayoot, 2009). Microstrip antenna and open ended coaxial probe are also used as moisture sensors (Khalid *et al.*, 2006; Yeow *et al.*, 2010). We

propose a miniature microwave sensor which is based on microstrip technology to determine the moisture content in cardamom. The uniqueness of this sensor is reduced area when compared to ring resonator.

### MINKOWSKI FRACTAL RESONATOR

Applying fractals to resonator elements allows for smaller resonators. A miniaturization of loop resonator using the fractal technique is known as Minkowski square loop resonator (John and Yahya, 2002). The fractal resonator was created by using the initial Square Pulse (SP) to iterate at each side of the loop. The starting geometry of the fractal, called the initiator, is a square. Each of the four straight segments of the starting structure is replaced with the generator. The iterative generating procedure continues for an infinite number of times (Elkamchouchi and El-Salam, 2003). The proposed resonator is Minkowski square first iteration resonator.

The generation of the resonator for the first iteration is given in Fig. 1. The Minkowski Fractal Algorithm (MFA) can be implemented through the three parameters shown in Fig. 1a. Here, 'a' is the length of the generator, 'Fig. 1b' is the indentation width and 'h' is the indentation depth. For the first iteration, 'a' is set equal to the length of the initiator, 'b' is chosen as a fraction of 'a' and 'h' is related to 'a' through the indentation factor 'ρ' where:

$$\rho = \frac{h}{a/3} \quad (1)$$

### SENSOR CONFIGURATION

The proposed sensor is shown in Fig. 2.

The sensor has been designed for permittivity measurement at design frequency of 1 GHz. The resonator is etched using the substrate FR-4 with the dielectric constant  $\epsilon_r = 4.6$ . The other parameters are Feed length = 40 mm, Coupling gap = 0.35 mm, Substrate thickness (h) = 1.6 mm, width of the Microstrip line (w) = 1 mm and total resonator length = 170 mm. Resonator length is one guide wavelength and is found out by the following equations:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{eff}}} \quad (2)$$

where,

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ \left( 1 + 12 \left( \frac{h}{w} \right)^2 + 0.04 \left( \left( 1 - \frac{w}{h} \right)^2 \right) \right)^{-1/2} \right] \quad (3)$$

$\lambda_0 = \frac{c}{f}$  is the free space wavelength.

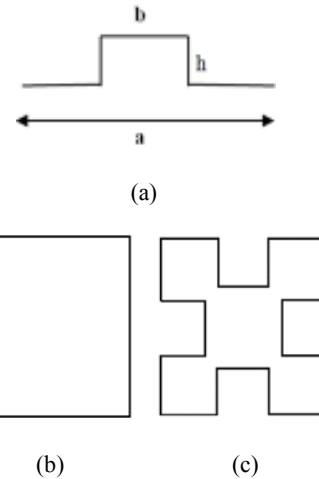


Fig. 1: Generation of a Minkowski fractal resonator, (a) generator, (b) initiator and (c) iteration

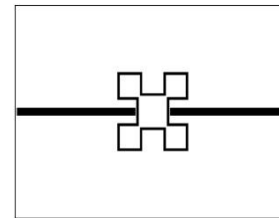


Fig. 2: Minkowski fractal resonator sensor



Fig. 3: Measurement setup

The side length of the square ring resonator L has to be calculated as  $L = \frac{\lambda_g}{4}$  where  $\lambda_g$  is the guide wavelength.

**Measurement setup:** The experimental setup consists of the resonator, sample dry and wet cardamom and Vector Network Analyzer (VNA) (Fig. 3). The VNA was used to measure the transmission parameter  $S_{12}$  of the sensor with and without the sample in the frequency range between 0.91 GHz to 3 GHz. The calibration procedure was performed using Agilent's open, short and load standard from 0.91 GHz to 3 GHz to establish a 50 ohm calibration plane between the sensor and the coaxial cable.

Ten grams of cardamom is taken and water is added in steps of 5 mL. Five such samples were prepared and the moisture content is measured as a percentage (Nelson *et al.*, 2000) as:

$$\text{Moisture Content (\%)} = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{wet}}} \times 100\% \quad (4)$$

When the sample is placed over the resonator, the fringing fields interact with the dielectric and energy is coupled into it causing a shift in the resonant frequency. This shift depends on the moisture content. The relationship between polarization of a material and the electric field that induces it is given by:

$$P(\omega) = \epsilon_0 \chi(\omega) \cdot E(\omega) \quad (5)$$

In the above formula  $\chi$  represents the susceptibility. It is given by the formula:

$$\chi = (\epsilon_r - 1) \quad (6)$$

This frequency dependence of the susceptibility leads to frequency dependence of the permittivity. The shape of the susceptibility with respect to frequency characterizes the dispersion properties of the material. The relationship between the frequency and the permittivity is given by:

$$f_0 = \frac{c}{\sqrt{\epsilon_r} L_{eff}} \quad (7)$$

The relative permittivity of the dry and moist spice can be found out with the aid of the following curve fitting Eq. (8):

$$f_r = 1073.5 - 68.7314 \epsilon_r + 5.2022 \epsilon_r^2 - 0.1876 \epsilon_r^3 \quad (8)$$

## RESULTS AND DISCUSSION

Moisture content calculated using Eq. (4), shift in resonant frequency due to permittivity of the dielectric material, dielectric constant calculated using Eq. (8) and the insertion loss are tabulated in Table 1.

Upon placing the dry sample on the sensor the frequency shown in the VNA is 1.003 GHz. For the moist sample the resonant frequency is decreased with the increase in the moisture level in the spice since the interaction of the applied electromagnetic field with moist spice depends upon the dielectric permittivity. Figure 4a shows the frequency response of the sensor for different percentage of moisture content. Since microwave is attenuated due to the presence of moisture the insertion loss increases with the increase of moisture content Fig. 4b. The dielectric constant of the MUT increases as the water content in the cardamom increases Fig. 4c.

Table 1: Measured result

Moisture content (%)	Frequency shift (MHz)	Dielectric constant	Attenuation (dB)
0	1003	1.1162	0
33.3	999	1.1858	-21
50	984.5	1.4446	-22
60	970	1.7146	-24
66.6	955.5	1.9969	-26
71.4	941.2	2.2886	-27

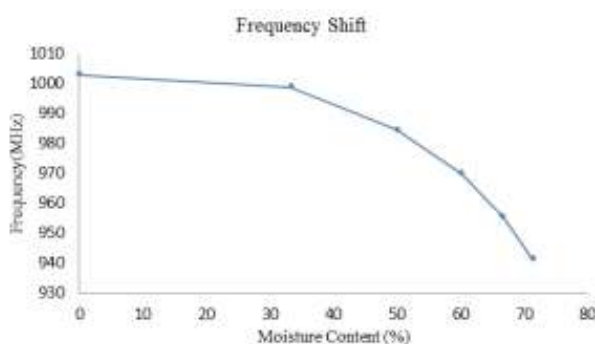


Fig. 4a: Moisture content Vs frequency



Fig. 4b: Moisture content Vs attenuation

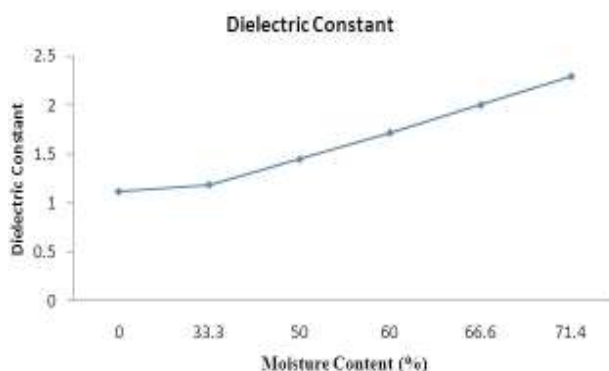


Fig. 4c: Moisture content Vs dielectric constant

## CONCLUSION

A fast and accurate method of measurement of moisture content was performed using a fractal resonator sensor which is designed at 1 GHz resonant frequency. A shift in the resonant frequency due to the moisture content in spice and also the attenuation for various moisture levels were studied. A vector network analyzer (E5062A) is used to get the frequency response and the attenuation in dB. The sensor designed, fabricated and tested is compact and can be used to perform highly sensitive moisture measurements independent of the density of the test material.

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