Indian Journal of Science and Technology, Vol 7(5), 566–570, May 2014
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Determination of Sucrose in Raw Sugarcane Juice by Microwave Method

Beulah Jackson[1*] and T. Jayanthy[2]

[1]Sathyabama University, Chennai, Tamil Nadu, India; beulah_jack@yahoo.com
[2]Panimalar Institute of Technology, Chennai, Tamil Nadu, India.

Abstract

A more accurate and less time consuming method to determine sugar content in a sugarcane juice is proposed in this paper. The increasing use of microwaves for industrial testing is a growing demand for permittivity measurement as a function of frequency. Determination of sugar in sugarcane is an important task in sugar refineries as well as food industries. Early estimation of sugar content in cane juice also enables fixing the price for canes for procurement from the fields. The various methods to measure sugar content are IR method and chemical analysis method which consumes time. Hence we propose a microstrip resonator sensor designed at 1 GHz fundamental frequency using ADS tool which has passed experimental validation by means of Vector Network analyser. The sensor is implemented using planar technology and is more compact and is well suited for permittivity measurement. The technique adopted for the sensor is shift in resonant frequency as a function of density of sucrose content in sugarcane juice.

Keywords: Frequency Shift, Microstrip, Moisture Content, Permittivity, Resonator Sensor

1. Introduction

Around the world, sugarcane is one of the important commercial crops used to manufacture several types of sweetener such as white and brown sugar[1]. Measuring sugarcane quality in the field is also important to improve the current payment system. At present, sugarcane quality is only randomly sampled and measured at the mills using sophisticated laboratory equipment. Hence, it is difficult to ensure growers are appropriately paid for the quality of their product. The current practice does not strongly motivate growers to pay more attention to improve the quality of their product.

India ranks first in the international scenario in sugar cane cultivation as well as in sugar production, yet the cost of production of sugar is higher in India. This is due to relatively lower recoveries of sugar per ton of cane crushed,more energy consumption and higher losses of sugar in bagasse, filter cake,and molasses. Sugar production technologies has undergone aphenomenal change throughout the world replacing human skills and conventional or traditional processing methods by automation . The conventional methods to measure sugar content in sugar cane are IR method, chemical analysis and optical methods[2–5].These methods are time consuming and it takes 2–3 hours. Several Research have shown that spectroscopic methods can be successfully used to predict quality of sugarcane based on juice samples, but inadequate sample preparation and mixing with reagents causes major errors in this method[6].

An alternate to the above stated methods is microwave method which is fast, accurate and non-destructive. Microwave dielectric measurement methods generally fall into two categories: non resonant and resonant methods. Resonant methods including resonator perturbation methods have relatively high accuracy than non-resonant ones. Microwave free space method was adopted for the measurement of sugar content in sugarcane juice in which the concentration of sugarcane juice was determined based on change in the dielectric constant. But the accuracy was limited because of the formation of air bubbles in dielectric liquid cell[7]. The most common type

*Author for correspondence

of sensor used for permittivity measurement is using microstripline.

In comparison with other structures used for permittivity measurement such as waveguide cells, resonant cavities or coaxial probes, the advantages of the micostrip are small size, simple fabrication and low cost. The material under test is usually placed on top of the microstripline and its properties are calculated from the attenuation and the relative shift in resonant frequency[8]. Microstrip ring resonators are frequently employed in microwave integrated circuit design. Resonant structures such as rectangular, square, and circular ring resonators have been widely studied in oscillators, filters and antennas[9]. Microstrip Ring Resonator (MRR) has been reported as a moisture sensor and for permittivity measurement of dielectric materials[10–12]. It exhibits a periodic frequency response with many well-defined resonance frequencies, which can be exploited to determine material properties.

In this paper a square ring resonator implemented as sensor is proposed which occupies comparatively lesser area than the conventional ring resonator of same electrical length[12]. The mechanism adopted for the determination of permittivity is the relative shift in resonant frequency which takes place when microwave interacts with the sample. From the measured shift in resonant frequency for different modes, the dielectric constant for various quantity of sugar in a cane juice has been established.

2. Sensor Configuration

The proposed resonator is shown in Figure 1. The microstrip line square ring resonator includes the feed lines, a closed conductor loop and coupling gaps. The resonator is one guide wavelength long which is designed for fundamental frequency of 1 GHz. The proposed sensor has been fabricated on a FR4 substrate (εr=4.6) with the dielectric thickness of 0.762 mm. The design parameters used are strip width is 1.6 mm, feed length is 40mm and the coupling gaps are 0.35 mm and resonator length is 170mm. Each side of the square resonator is 4.25cm. Resonator length is found out by the equations (1) and (2)

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\left(1 + 12\left(\frac{h}{w}\right)\right)^{\frac{1}{2}} + 0.04\left(\left(1 - \frac{w}{h}\right)\right)^2\right] \tag{2}$$

The coupling gaps have an influence to the resonance frequencies of the ring resonator structure. Normally coupling between the feed lines and the ring resonator are tried to implement with loose coupling. The loose coupling produces negligible effects to the resonance frequencies. Suitable length for the coupling gaps has to be chosen by using prototypes or modern electromagnetic simulation tools. The effects of the different lengths of coupling gaps are minor to determined values of dielectric constant and dissipation factor, if the coupling is implemented loose.

3. Measurement Setup

The measurement setup is shown in the Figure 2. The experimental setup consists of the resonator, liquid sample and Vector Network Analyzer (VNA). The VNA is used to measure the transmission parameter of the sensor with and without the sample in the frequency range between 0.91 GHz to 3 GHz. The calibration procedure is performed to establish a 50 ohm impedance between the sensor and the coaxial cable.A sample of cane juice is taken in a beaker and placed over the sensor. The frequency response of the reflected signal is displayed in the network analyzer. The shift in the resonant frequency for different concentration of sucrose is recorded by connecting the sensor with a vector network analyzer.

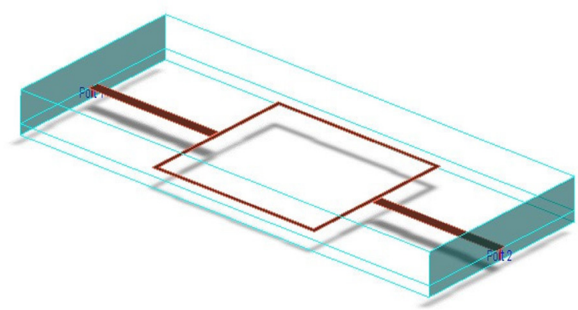

Figure 1. Square ring resonator.

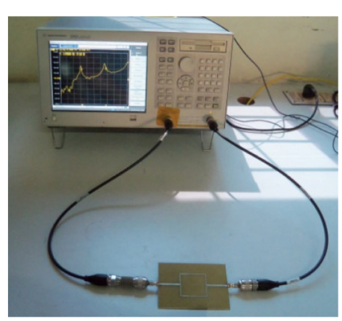

Figure 2. Measurement setup.

The shift in resonant frequency is calibrated to measure the dielectric constant of the material under test.

4. Permittivity Measurement

The microstrip ring resonator method is based on the fact that the effective permittivity will change if the boundary of the substrate, with known dielectric constant is modified by placing a dielectric material above it, thereby changing the resonant frequency of the ring resonator. 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/ concentration of sugar content in cane juice. The relationship between polarization of a material and the electric field that induces it is given by,

$$P(\omega)=\varepsilon_0\,\chi(\omega).E(\omega) \qquad (3)$$

In the above formula χ represents the susceptibility. It is given by the formula,

$$\chi=(\varepsilon_r-1) \qquad (4)$$

This frequency dependence of the susceptibility leads to frequency dependence of the permittivity. The relationship between the frequency and the effective dielectric constant is given by,

$$f_0=\frac{C}{\sqrt{\varepsilon_{eff}}}\frac{1}{L_{eff}} \qquad (5)$$

where L_{eff} is an effective length of the resonator which is equal to one guide wavelength and ε_{eff} is the effective dielectric constant.

5. Results and Discussion

The relationship between the permittivity and the relative shift-in frequency for various modes (given in Table 1) is the result of simulation of the designed sensor. For the fundamental mode the frequency for air as dielectric is 997.4 MHz is near approximation to the designed resonant frequency of 1 GHz. When the sample is placed over the resonator the frequency is shifted from the resonant frequency (Figure 3). For different values of permittivity the simulated result shows dielectric constant is inversely proportional to the change in resonant frequency according to equation (5). A graph is drawn for the mode 1 simulated values as shown in Figure 4.

Table 1. Dielectric constant vs. frequency

Dielectric Constant	Mode 1 (GHz)	Mode 2 (GHz)	Mode 3 (GHz)
1	0.997	2.011	2.977
2	0.939	1.891	2.814
3	0.890	1.794	2.676
4	0.852	1.721	2.554
5	0.818	1.646	2.461
6	0.789	1.591	2.365
7	0.761	1.532	2.283
8	0.740	1.492	2.213
9	0.717	1.448	2.151
10	0.699	1.396	2.098

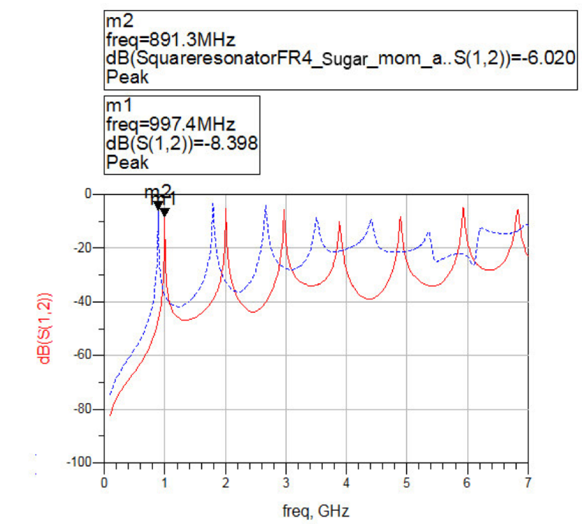

Figure 3. Simulated Output.

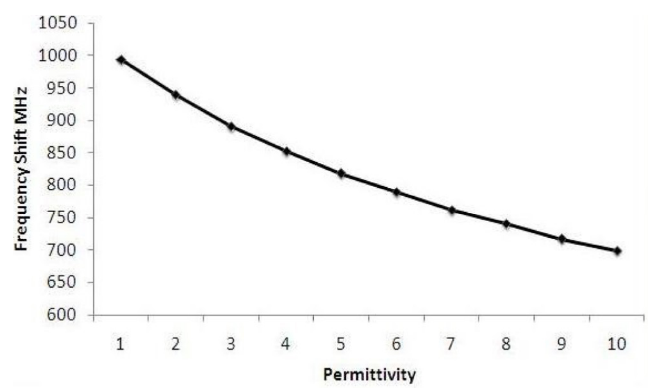

Figure 4. Dielectric constant vs frequency.

The dielectric sample cane juice diluted for various proportion and sugar mixed with water when placed on the resonator connected to network analyser gives the inference of shift in frequency (mode 1) which occurred due to the presence of water content. The presence of water in the sample leads to decrease in effective dielectric constant and increase in the frequency shift. The effective dielectric constant was found out using equation (5) and given in Table 2 and Table 3. A graph is drawn between effective dielectric constant and concentration of sugar in water and cane juice which is given in Figure 5 and Figure 6. When the cane juice is diluted and the water content in sugar increases the permittivity decreases as the moisture content increases. Accordingly the frequency also get shifted from the resonant frequency. From the relative shift in the frequency the sucrose content in cane juice can be determined.

Table 2. Frequency shift vs dielectric constant for sugar concentration

Sugar with Water	Frequency shift (MHz)	Effective dielectric constant
1:1	930	1.8975
1:2	945.5	1.8664
1:3	960.4	1.8374
1:4	972	1.8155
1:5	986	1.7897
1:6	997.3	1.7694

Table 3. Frequency shift vs. dielectric constant for cane juice concentration

Cane Juice with Water	Shift in Frequency	Effective dielectric constant
1:0	955	1.8478
1:1	968	1.8230
1:2	970	1.8192
1:3	977.55	1.8052

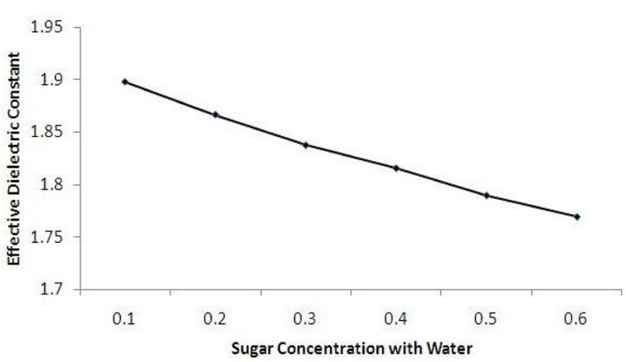

Figure 5. Sugar content vs effective dielectric constant.

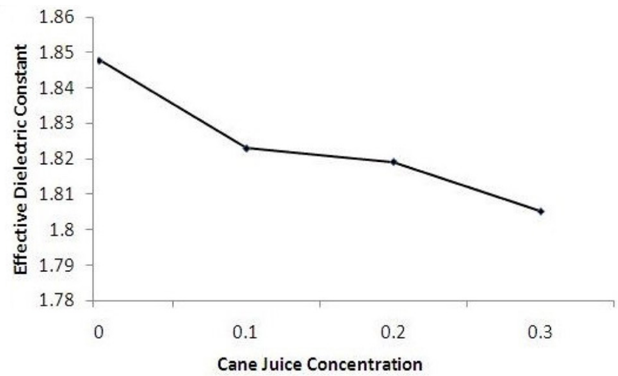

Figure 6. Cane juice concentration vs effective dielectric constant.

6. Conclusion

Determination of sugar content in sugarcane juice is an important task in sugar refineries as well as in food industries because of continuous evolution during the fermentation process. Early estimation of sugar content in cane juice also enables fixing the price of canes for procurement from the fields. The conventional methods like IR method and chemical analysis methods are time consuming for this application. Hence, we have introduced a fast and accurate microwave method using microstrip square ring resonator to determine the sugar content in the sugarcane juice by means of permittivity which varies with respect to the shift in frequency observed when the microwave interacts with the sample. The resonator was designed using ADS simulation tool and experimentally verified using network analyser E6062A.

7. References

1. Nayaka MAH, Sathisha UV, Manohar MP, Chandrashekar KB, Dharmesh SM. Cytoprotective and antioxidant activity studies of jaggery sugar. Food Chem. 2009;115(1): 113–18.
2. McCarthy SG. The integration of sensory control for a sugarcane harvester. [PhD Thesis]. Univ. of Southern Queensland, Australia; 2003.
3. Mehrotra R, Siesler HW. Application of mid infrared/near infrared spectroscopy in sugar industry. Appl Spectros Rev. 2003; 38:307–54.
4. Jagdish T et al. Direct near infrared analysis of sugar cane clear juice using a fiber-optic transmittance probe. J Near Infrared Spectros. 2003; 11:351–56.
5. Arora MG, Singh M. Industrial chemistry. New Delhi: Anmol Publications, Pvt Ltd; 2004.

6. Temma T, Hanamatsu K, Smnoki F. Measuring the sugar content of apples and apple juice by near infrared spectroscopy. Optical Review. 2002; 9:40–4.
7. Jayanthy T, Sankaranarayanan PE. Estimation of sugar content in sugarcane using microwaves INCON-2004 ISOI Pune; 2004 Dec 1–2.
8. Nyfors E, Vainikainen P. Industrial Microwave Sensors. Norwood, MA: Artech House, 1989.
9. Chang K. Microwave ring circuits and antennas. John Wiley &sons, Inc., 1996.
10. Abegaonkar MP, Karekar RN, Aiyer RC. Microwave microstrip ring resonator as a moisture sensor for biomaterials: application to wheat grains. Meas Sci Tech.1999; 10(3): 195–200.
11. Bernard PA, Gautray JM. Measurement of dielectric constant using a microstrip ring resonator. IEEE Trans Microw Theor Tech. 1991; 39(3):592–95.
12. Jackson B, Jayanthy T. Measurement of complex permittivity using planar resonator sensor. IOSR Journal of Electronics and Communication Engineering (IOSR-JECE). 2014 Jan; 9(1): 54–7.