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Development of split ring resonator for pineapple moisture content detection

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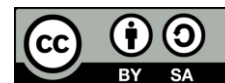Department of Electronic Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia

Article Info

ABSTRACT

Microwave resonant is one of the sensors used in characterizing the material and is also one of the most sensitive sensors for measuring dielectric properties. This project proposed the resonant method due to its accuracy and sensitivity. The split ring resonators were mounted on the fruit sample surface to observe the resonant frequency behavior, and to measure the fruit freshness. The resonator was set at 6 GHz using the FR4 lossy substrate. The findings show that the coupling distance and the ring radius have the greatest impact on preserving the resonant behavior. The fundamental of the obtained resonant frequencies was observed based on the different moisture content of the test material. The moisture level was observed at 38.2%, 54%, 69%, and 86.7%. At 86.7%, the resonant frequency has the highest shifting by shifting to the left. This shows that the larger resonant frequency change occurs when the water content is higher.

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1. INTRODUCTION

The microwave sensor is a microstrip-based device designed to calculate the permittivity of constant dielectric materials. Dielectric is a natural insulator with infinite resistivity. The sensor is created from modern microwave and radiofrequency engineering, as well as based on state-of-the-art electronic device technology. The creation of this sensor is according to the current demands for communication and data radar experimentation.

The research and development of senses such as taste, smell, and touch in the fruit technology field have helped drive consumers to purchase fruit products. However, the consumers cannot assess nutritional value, wholesomeness, and protection levels of fruits as these assessments require measurement. Pliquett [1] stated that the electrical measurement is one of the tools for material characterization using the electrical properties to determine the fruit quality. The measurement device is based on a microstrip ring resonator developed with a ring and ground plane. The resonant approach is based on the dielectric resonator frequency, and the dimensions are defined by its permittivity. The measurement of materials is performed between the separate ring resonator and the ground plane. Similar measurement devices are widely used in construction and manufacturing facilities. The implementation of these measurement devices has reduced the cost of modern and effective wireless, wired RF, and microwave services. Moreover, microwave technology is highly involved in the communication and sensing applications. In addition, the high operating frequencies of microwave technology permit large numbers of independent channels and for a wide variety of uses.

Many studies have been carried out on measurement of dielectric properties using split ring resonators as a sensor for various applications [2]-[15]. A portable ring-resonator permittivity measurement system has been proposed [16]. It measures the complex permittivity by using ring resonator. The measurement used is suitable for ultra-wideband ground-penetrating radar frequency. Microwave resonators can be design for sensing gas for humidity and ammonia [17]. A microstrip ring resonator for the meat quality detection is proposed [18] due to it simple design. However, it's difficult to obtain precise results. A complementary split ring resonator (CSRR) based sensor is explored for a sub millimeter crack [19].

Recently, resonators as biomedical sensors attract researcher attention. A capacitively fed split single circular ring (CSSCR) resonator with two layers has been designed [20]; a resonator layer and a matching layer. This technique allows more energy to be radiated into the human tissues and to obtain enhanced and stable resonance characteristics while illuminating the targets. The split-ring resonator (SRR) sensor can be used to detect glaucoma by integrating contact lens on flexible substrates [21].

A single feed resonator was introduced to enhance the return loss of the resonators [22]. Besides that, the SRR proves to be an alternative to the commonly used half-wave dipole to reduce the antenna dimension while maintaining a similar value of the radiation resistance. Therefore, no additional matching network is needed [23]. SRR produced a multiband characteristic when embedded with a single band antenna [24].

2. RESONATOR DESIGN AND DEVELOPMENT

The split ring resonator was designed using a CST microwave software simulator based on the analysis method. The simulation was carried out with or without materials, and the resulted graph's behavior was observed. The first resonant frequency was confirmed by observing the split ring resonator configuration changes that occur through the resonant frequency structure influences. Next, a suitable geometry for the ring resonator was determined, based on the specific dielectric constant, dielectric loss factor, and the tangent loss of the pineapple moisture point. Then, the ring resonator was simulated with the CST. Figure 1 shows the structure of a SRR.
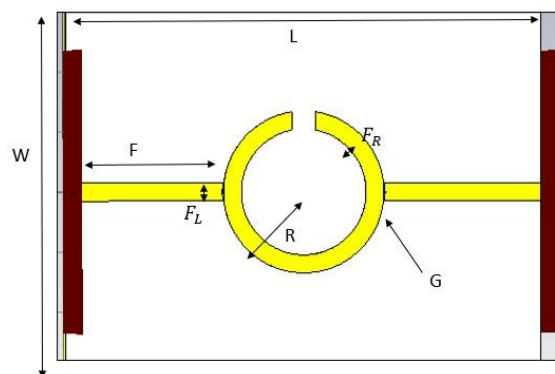

Figure 1. Design of split-ring resonator without MUT

The arrangement of the split-ring resonator consisted of circular rings made with the complete electric conductor. The structure was perpendicularly excited to the split ring plane by using a time-varying electric field. The current flowed along with the rings and produced the solenoid. Therefore, a resonant magnetic dipole was created from a resonator with a split ring. The ring content is made with copper, while the ring resonator substratum is made with loss FR-4. The analyses were done using the CST software and were based on the parameters in Table 1:

Table 1. The parameters in designing the split-ring resonator

Parameter	Dimension (mm)
Feedline length, F	40
Width of the feedline, F_l	3
Width of the feedline of the ring, F	1.5
Coupling gap, g	0.1
The total length of the substrate, L	40
The total width of the substrate, W	30
The radius of the ring, r	6

The pineapple sample or material under test (MUT) is placed on the resonator. The MUT is the objects used to fill the gap and the dimension that are smaller as compared to the ring resonator. The different moisture levels of pineapple were used to observe the resonant frequency.

Table 2 shows the value of relative permittivity and tangent loss of different pineapple moisture levels from previous paper [25]. The freshness of the pineapple is described by the dielectric permittivity of the material, as shown in (1)-(3)

Table 2. The moisture contents, dielectric and tangent loss of pineapple

Moisture (%)	Dielectric constant (ε')	Dielectric loss (ε'')	Tangent loss
86.7	60.758	12.7592	0.21
69.0	45.890	14.2259	0.31
54.0	33.290	12.3173	0.37
38.2	20.018	9.2083	0.46

The ε_0 in (1) is referring to free space permittivity, while the ε_r is referring to complex permittivity. Meanwhile, the real part of the complex permittivity is shown in (2), where the ε_r' is referring to a dielectric constant that corresponds to the energy stored in a material when an electric field is applied, while the ε_r'' is referring to the imaginary part that is converted energy into heat. Tangent loss is the ratio between the imaginary and real parts, as shown in (3) as $tan\delta$. In (3) measures the ability of the material to absorb microwave energy and dissipate heat for the efficiency of microwave heating.

$$\varepsilon = \varepsilon_0 + \varepsilon_r \tag{1}$$

$$\varepsilon_r = \varepsilon_r' + j\varepsilon_r'' \tag{2}$$

$$tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} \tag{3}$$

3. RESULTS AND DISCUSSIONS

Based on the mathematical analysis, the ring resonator was designed based on the observation of resonant frequent by using a CST software simulation. The design of the ring resonator was compared with other collected simulation data sets that have different parameter changes, in order to check the validity of the split-ring resonator model generated by the CST software. Furthermore, the split ring resonator was attached to the substrate to confirm that the model is resonating at the tuned frequency.

After determining the proper geometry and excitations with sufficient calculation, the resonant frequency simulation was performed from 0 to 6 GHz, in order to investigate the influences of the changes of SRR structures to the resonant frequency structures. The pineapple samples were inserted between the gap, while the simulation was done by using the CST software to observe the resonant frequency. The geometry without MUT was used as a reference and control.

Figure 2 shows the changes that occur in the resonant frequency, after the material is placed on the resonator sensor. The frequency shifted, as shown by the simulation using the CST software. It can be seen the resonant frequency with MUT shifted to the left, as compared to the resonant frequency without MUT. The simulation was done between 2 GHz to 6 GHz, as this is the acceptable range of the fundamental resonant frequency. The change in resonant frequency can be achieved if the MUT dimension is smaller than the ring resonator and the difference is filled in. These shifting demonstrate that the presence of material on the SRR induces the increase of the capacitance while causing the reduction of the resonant frequency, as the capacitance is inversely proportional to the resonant frequency.

Based on Solyom, *et al*. [25], the pineapple was conducted to determine the effects of moisture levels. The samples were prepared by placing the samples in a hot-air drying oven at 80°C to obtain different moisture content levels. The article states that the dielectric properties were calculated by using the process of cavity disturbance. The results obtained are as shown in Figure 3. The resonant frequency is shifted to the left when the sample with higher moisture is placed on the resonator.
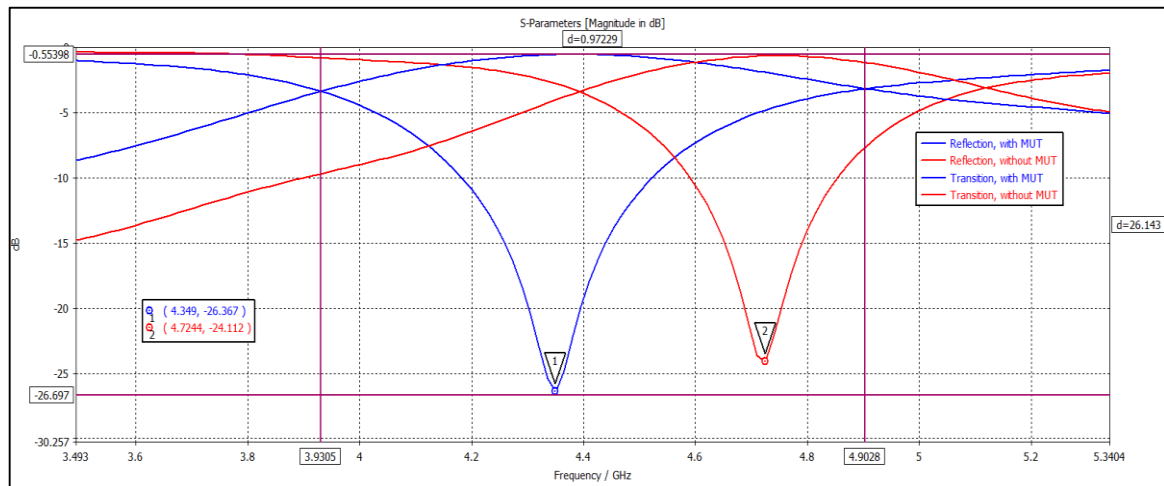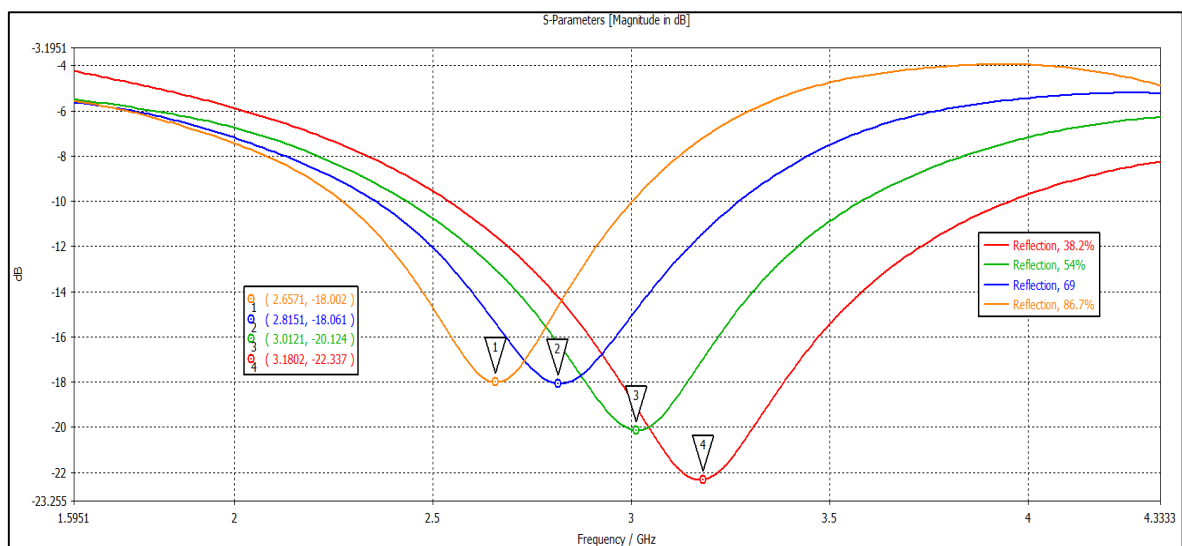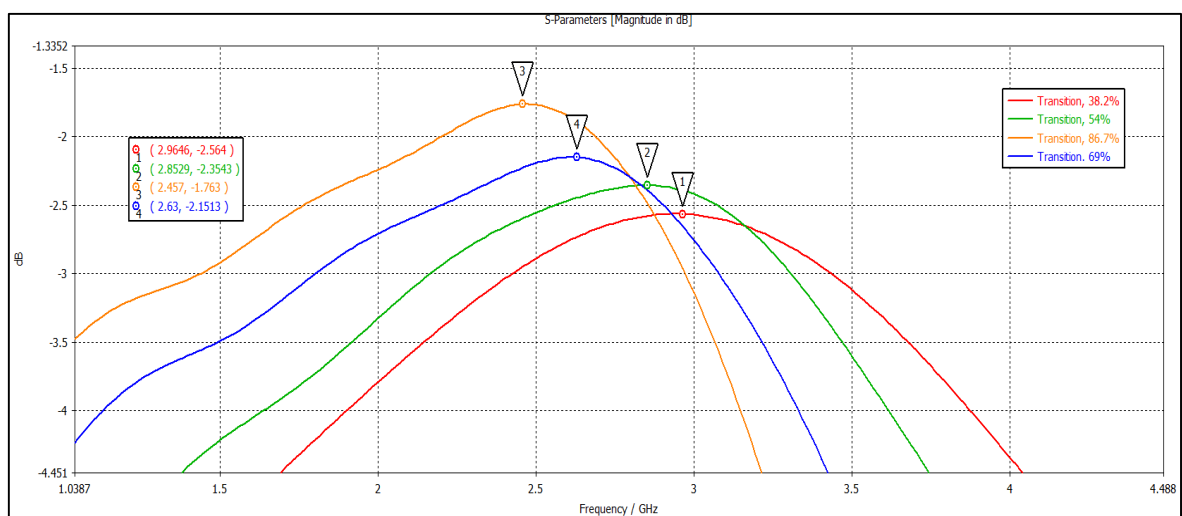
Figure 2. Comparison with and without MUT

(a)

(b)

Figure 3. Comparison of; (a) reflection, (b) transmission with a different water content of pineapple

The results tabulated in Table 3 show the data in resonance frequency compared with the resonator without and with MUT for different moisture content levels.

Table 3. Difference between the resonance frequency

Moisture level, %	Frequency, GHz	Difference between resonance frequency (Without MUT – with MUT), GHz
Original	-	4.7244
38.2	3.1802	1.5442
54	3.0121	1.7123
69	2.8151	1.9093
86.7	2.6571	2.0673

The resonant frequency sensor changed significantly with different moisture levels. The MUT for 38.2%, 54%, 69%, and 86.7% moisture level shift to the left when the pineapple material was inserted on the SRR. The largest difference in the frequency shift occurs between 4.7244 GHz to 2.6571 GHz and at 86.7 percent of moisture content, as shown in Table 3. As the behavior of the MUT electromagnetic field is dependent on the dielectric permittivity, the resonant frequency decreases with the increase of the pineapple moisture levels. The moisture content in MUT attenuates the microwave sensor. Thus, the MUT dielectric constant increases with increasing pineapple water contents.

The resonant frequency is shifting when the material is placed on the resonator, possibly due to the interaction between the electric field with dielectric and energy [26]. The polarization between the material and electric field induces is demonstrated by (4):

$$P(\omega) = \varepsilon_0 x(\omega).E(\omega) \tag{4}$$

where; $P(\omega)$ represents polarization, $E(\omega)$ is the electric field, and $x(\omega)$ is dielectric susceptibility.
From (4), the dielectric susceptibility is shown to be a proportionality constant that indicates the polarization of dielectric material in response to an electric field.

$$x = (\varepsilon_r - 1) \tag{5}$$

where; ε_r represent the permittivity. The equation shows that the frequency of susceptibility leads to the frequency of permittivity. The relationship between frequency and permittivity is as shown in (6):

$$f_0 = \frac{c}{\sqrt{\varepsilon_r}} \frac{1}{L_{eff}} \tag{6}$$

It can be observed that when the moisture content increases, the dielectric material also increases, while the resonant frequency decreases. In (6) also shows that the dielectric material is inversely proportional to the resonance frequency. Thus, as the moisture level increases, the resonance frequency decreases.

4. CONCLUSION

Sensing food quality by measuring the dielectric constant method shows some amazing results, and can lead to better fruit quality consumption, as quality is the key to the food sector and market. This research paper aims to validate the importance of this technique in examining the fruits' freshness levels. The moisture content from the pineapple was used to observe the behavior of resonant frequency. This research showed that the split ring resonator could work with a frequency of up to 6 GHz on the substratum. The analysis was performed to confirm the SSR geometry that can alter, modify and maintain the resonance frequency, even as the substrate's electromagnetic loss increases. The resonance activity was observed by changing the SRR's coupling gap, radius, and moisture levels of pineapple. The findings show that the increase in the coupling gap width between the ring and feedline positively impacts the resonance frequency. As the coupling gap width increases, the resonance frequency also increases. Another parameter observed is the radius of the ring. As the radius of the ring increases, the inductance also increases. Hence, from the formula, the inductance is inversely proportional to the resonance frequency. Thus, as the inductance decrease, the resonance frequency increases, as the inductance is inversely proportional to the frequency. The variation between the resonance frequency shift with the different pineapple moisture levels was also observed and compared. The results showed that the higher the moisture content, the lower the resonance frequency, as the dielectric material is inversely proportional to the resonance frequency.

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