

## RF Sensor for Food Adulteration Detection

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**Abstract**—Microwave testing is an area of research where material characterization is done using interrogating microwaves over a frequency band, and this technique can provide excellent diagnostic engineering, geophysical prospecting. Every material has a unique set of electrical characteristics that are dependent on its dielectric properties. Accurate measurements of these properties can provide valuable information about the material. This work presents a non-destructive technique for the detection of adulterants in food using the proposed RF sensor. The proposed RF sensor is operational at C-band with its resonant frequency at 5.7 GHz. The structure is designed using Ansys HFSS, and a predicted model of the proposed sensor is developed and fabricated. Some common food samples are tested using the fabricated sensor, and a shift in resonant frequency is obtained, which indicates the rate of adulteration. From the obtained results, a general conclusion is obtained on the dependency of the rate of adulteration and permittivity of the food sample. A precise correlation of permittivity of common food samples and its resonant frequency is obtained. The predicted model and the experimental results harmonize, which indicates that the model is proficient in real time testing.

### 1. INTRODUCTION

Food adulteration has a long history in human society, and it still occurs in modern times. Food safety is a condition that ensures that food will not cause harm to the consumer when being prepared and consumed according to its intended use. It entails the handling, preparation, and storage of food in ways that prevent food-borne illnesses. Quality and safety remain a major challenge in the production of food items [1, 4, 5].

When conventional destructive testing and non-destructive testing are compared, destructive testing in some ways is the most reliable method. However, non-destructive testing (NDT) retains a significant advantage over destructive testing because it covers more ground and saves food material while reducing time and manpower. NDT fosters a single technique for the detection of adulterants in different food items while destructive testing requires non-identical methods for testing each food item. The fundamental principle of the proposed sensor is to sense the variation in resonance frequency and notch depth due to volume or permittivity perturbation of material under test (MUT) as and when adulterants are added. When adulterants are added in a controlled manner to pure MUT, the permittivity of MUT changes which alters the equivalent capacitance value of the sensor and beget a left shift (blue shift) in its resonant frequency. This change in resonance frequency infers added adulterants, from which permittivity can be calculated. Permittivity is calculated using an empirical formula developed using linear regression analysis of simulated data modeled. The sensor works at a resonance frequency of 5.7 GHz (ISM-band) under the C-band of the microwave electromagnetic spectrum. The real time test results were found to be agreeable to the modeled solution.

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*Received 1 September 2020, Accepted 26 September 2020, Scheduled 12 October 2020*

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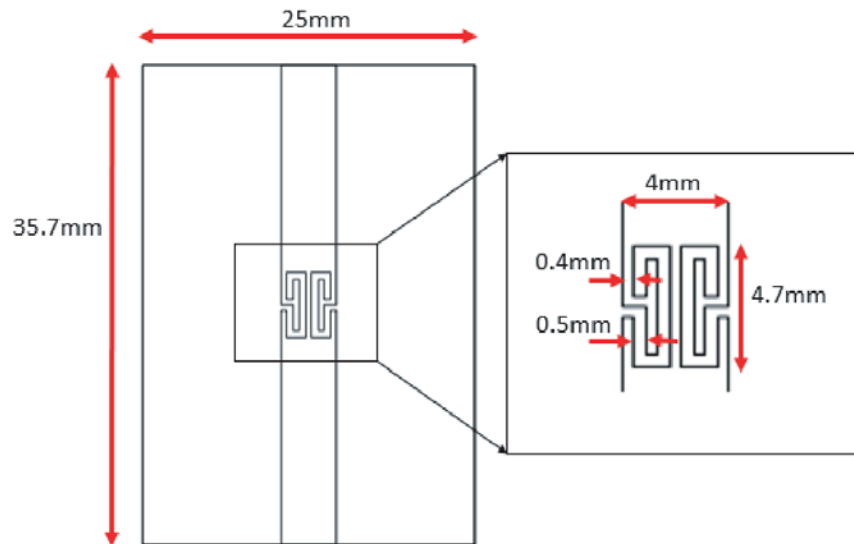
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## 2. GEOMETRY AND DESIGN

The structure is designed using the Ansys HFSS. The sensor is a uniplanar inter-digitated capacitor structure (IDC). The principle of the sensor is based on the interactions between electromagnetic field from the sensor and the MUT, placed above IDC structure. The loaded resonator is characterized by parameters such as resonant frequency, permittivity, and volume of MUT.

Electric field in the resonant structure is mainly responsible for the characterization of MUT. The electric field is confined to the resonant structure of the sensor that interacts with the MUT at resonant frequency. The loading of MUT on the sensor changes its effective capacitance, which causes a shift in resonant frequency. This shift in frequency is used to identify the permittivity of MUT from developed empirical formula. From the latter result, the percentage of adulterants in MUT can be predicted by comparing it with its standard permittivity [2].

The ports are modelled with n-type SMA connectors with  $50\ \Omega$  impedance, and they are attached with the microstrip line conductor. The sensor is designed on an FR4 substrate whose effective dielectric constant is 3.5 F/m at 5.7 GHz for  $50\ \Omega$  impedance. When the EM wave is launched from one port, most of the EM energy at the resonating frequency gets stored in the sensor structure. This remains available for interaction with the MUT resulting into a shift in the resonant frequency. Figure 1 shows the proposed sensor structure with optimized values of different dimensions and its enlarged view.



**Figure 1.** Geometry of sensor.

## 3. SIMULATION

A model is created by specifying copper as material for each sub-structure in the proposed sensor. An air box surrounding the antenna structure is created, which has about double the dimension of the antenna structure and extending in all directions. Figure 2(a) shows the resonant frequency of sensor in unloaded condition. The position of the MUT is decided by plotting the  $E$ -field intensity in the resonant structure shown in Figure 2(b). The ideal position of the MUT is centre of the antenna.

A significant change in resonant frequency is obtained when MUT is placed above the sensor in close contact. Materials of different permittivities are taken as MUT, and its corresponding resonant frequency is obtained as shown in Figure 3. The consolidated data are shown in Table 1, and its corresponding graph shows an inverse relation as illustrated in Figure 4.

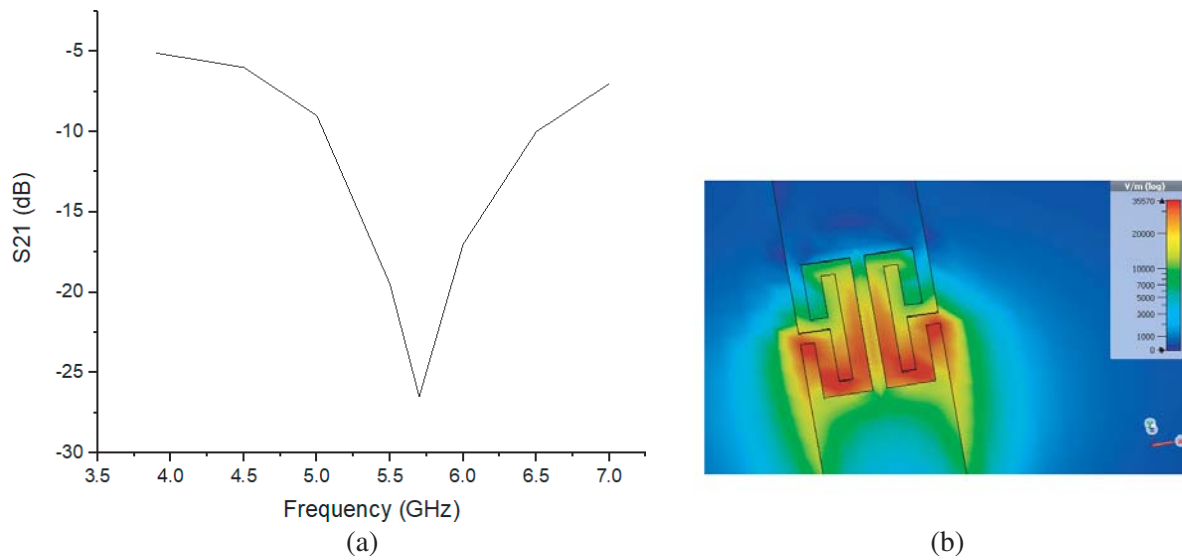


Figure 2. (a) Resonant frequency of unloaded sensor. (b) Electric field distribution of sensor.

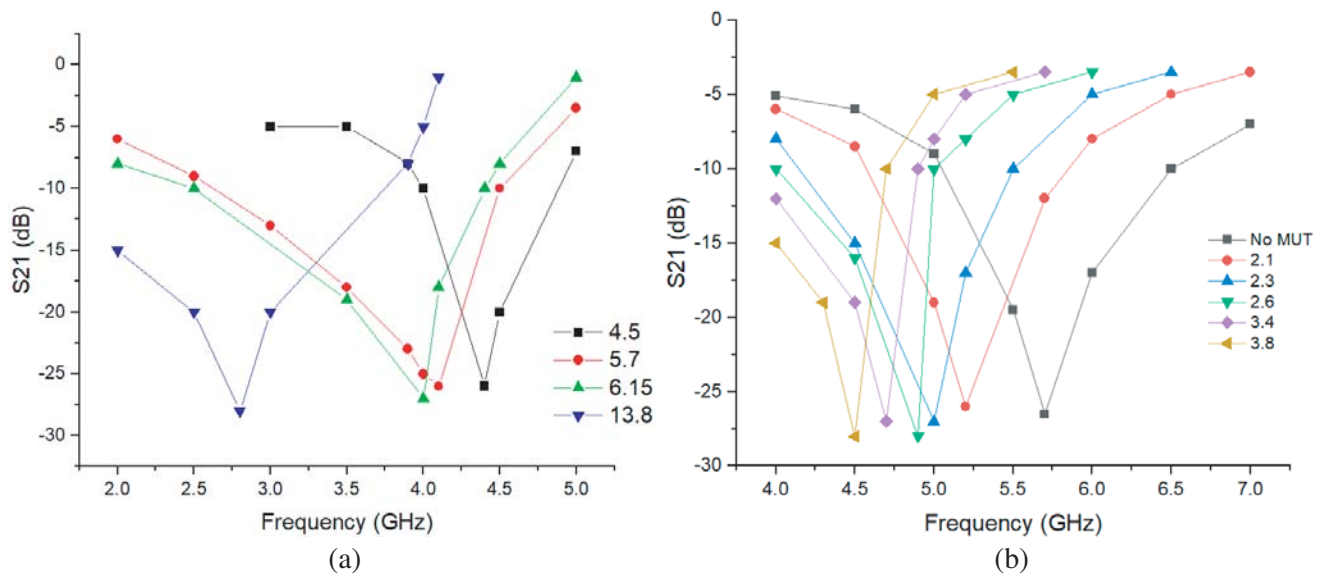
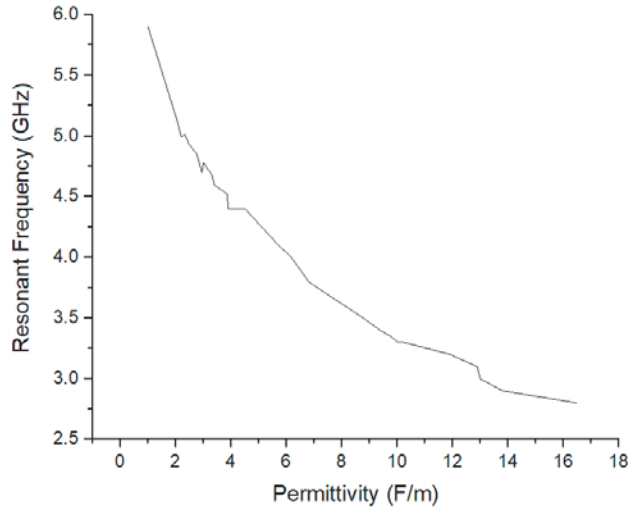


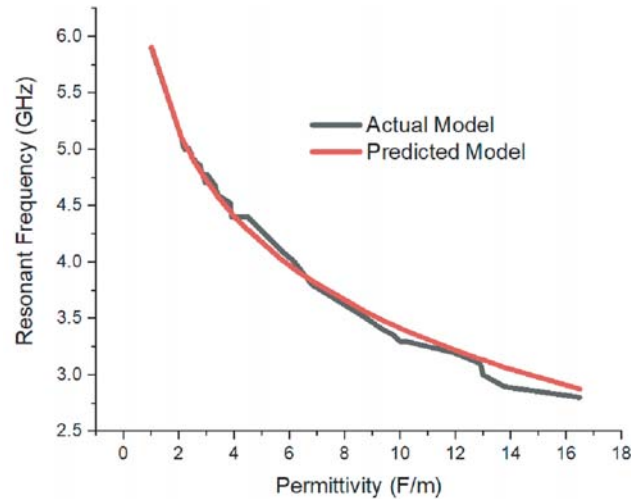
Figure 3. Simulated data. (a) Resonant frequency in range 2 GHz to 5 GHz. (b) Resonant frequency in range 4 GHz to 6 GHz.

Table 1. Resonant frequency vs permittivity.

Permittivity	1	2.1	2.2	2.45	2.6	2.94	3.3	3.87	4.5	5.7	6.5	8.8	10	11.9	12.9	13	16.5
Resonant frequency	5.7	5.1	5	4.94	4.9	4.7	4.68	4.52	4.2	4.1	3.9	3.5	3.3	3.2	3.1	3	2.8



**Figure 4.** Simulated model obtained from Table 1.



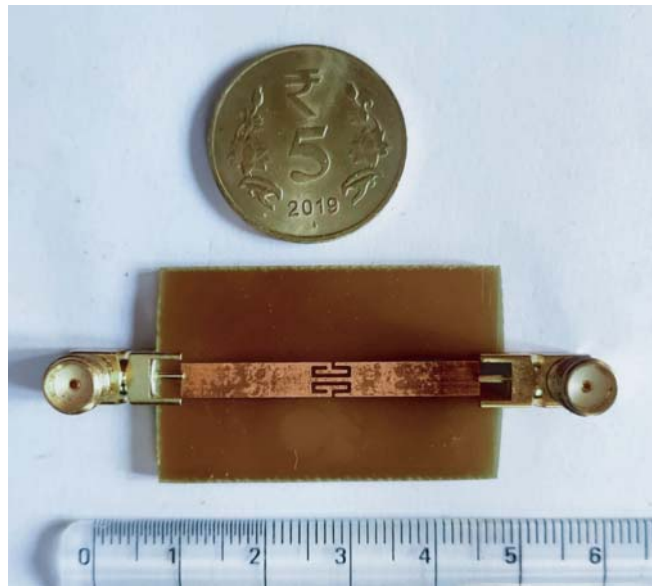
**Figure 5.** Predicted model.

#### 4. MODELLING

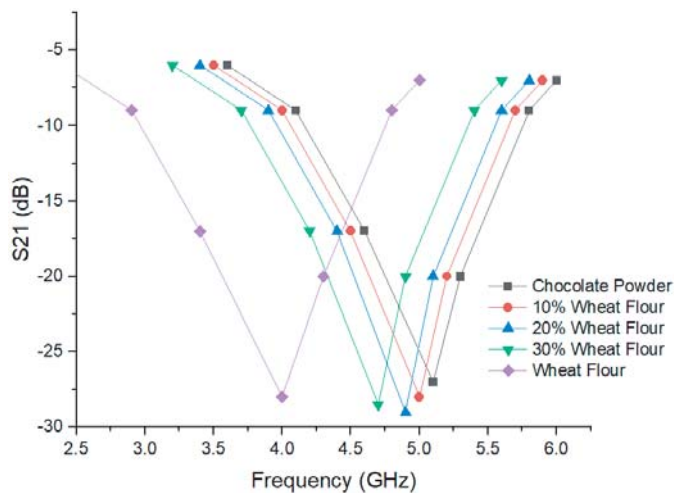
After simulation, the data set obtained is converted to a numerical model which relates permittivity and resonant frequency. The simulated model is approximated using regression analysis to obtain a predicted model and its corresponding empirical formula. The actual model and corresponding predicted model is shown in Figure 5. The predicted model traces actual model with an accuracy of 98%. The empirical formula of predicted model obtained using regression analysis is given by,

$$\varepsilon = e^{5.457 - 0.923F_r} \quad (1)$$

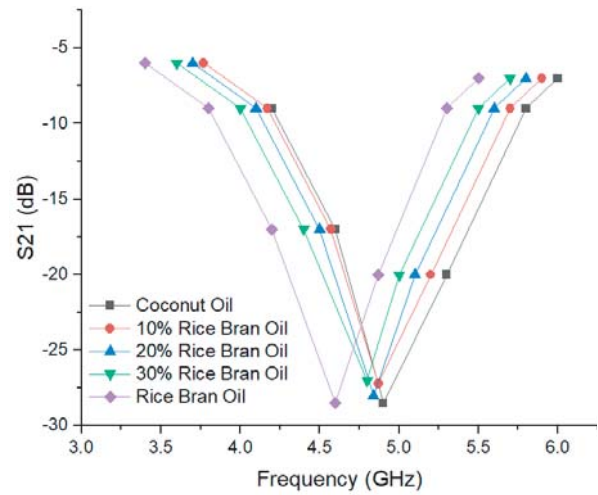
where  $F_r$  is the resonant frequency, and  $\varepsilon$  is the permittivity of MUT.



**Figure 6.** Fabricated sensor.



**Figure 7.** Resonant frequency of chocolate powder adulterated with wheat flour.



**Figure 8.** Resonant frequency of coconut oil adulterated with rice bran oil.

### 5. FABRICATION AND TESTING

The technique used for fabrication is photolithography. This is a chemical etching process by which the unwanted metal regions of the copper layer are removed. An FR4 substrate with  $\epsilon = 4.4$ F/m,  $\tan(\delta) = .02$  and  $h = 1.6$  mm is used for this implementation [6]. The final fabricated structure using photolithography and milling is shown in Figure 6.

The testing is performed using Anritsu VNA Master 2026C. The antenna is operational over the range of C band with unloaded resonant frequency 5.7 GHz. To detect adulteration, the food samples used are chocolate powder with adulterant wheat flour [3], and coconut oil with adulterant rice bran oil [2]. Chocolate powder with various concentrations (10%, 20% and 30%) of wheat flour added as adulterant is tested, and significant variation in resonant frequency is observed as shown in Figure 7. Coconut oil adulterated with various concentration levels of rice bran oil (10%, 20% and 30%) is tested, and it indicates satisfactory results as given in Figure 8. Using the predicted model given in Equation (1), permittivities for all cases are given in Table 2.

**Table 2.** Adulteration test results.

Material Under Test	Resonant Frequency	Predicted Permittivity using Model
Chocolate Powder	5.1	2.11
Wheat Flour	4	5.84
10% Wheat Flour in Chocolate Powder	5.02	2.28
20% Wheat Flour in Chocolate Powder	4.93	2.47
30% Wheat Flour in Chocolate Powder	4.74	2.94
Coconut Oil	4.9	2.54
Rice Bran Oil	4.63	3.26
10% Rice Bran Oil in Coconut Oil	4.87	2.61
20% Rice Bran Oil in Coconut Oil	4.84	2.69
30% Rice Bran Oil in Coconut Oil	4.8	2.79

## 6. CONCLUSION

In this paper, a non-destructive compact RF sensor for food adulteration detection is proposed, designed, and tested. The proposed sensor is found to be working in C-band with a resonant frequency of 5.7 GHz. A good agreement between simulated and measured results demonstrates the validity of sensor for food adulteration detection. The proposed sensor will be impactful in fast and efficient prediction of food quality in the future.

## REFERENCES

1. Banerjee, D., S. Chowdhary, S. Chakraborty, and R. Bhattacharyya, "Recent advances in detection of food adulteration," *Food Safety in the 21st Century*, 145–160, Elsevier, 2017.
2. K. T. Muhammed Shafi, A. K. Jha, and M. Jaleel Akhtar, "Nondestructive technique for detection of adulteration in edible oils using planar rf sensor," *2016 IEEE MTT-S International Microwave and RF Conference (IMaRC)*, 1–4, IEEE, 2016.
3. Lin, B. and S. Wang, "Dielectric properties, heating rate, and heating uniformity of wheat our with added bran associated with radio frequency treatments," *Innovative Food Science & Emerging Technologies*, Vol. 60, 102290, 2020.
4. Mohammad, Al-Mamun, T. Chowdhury, B. Biswas, and N. Absar, "Food poisoning and intoxication: A global leading concern for human health," *Food Safety and Preservation*, 307–352, Elsevier, 2018.
5. Posudin, Y., K. Peiris, and S. Kays, "Non-destructive detection of food adulteration to guarantee human health and safety," *Ukrainian Food J.*, Vol. 4, No. 2, 207–260, 2015.
6. Sebastian, M. T., *Dielectric Materials for Wireless Communication*, Elsevier, 2010.